ARCTEQ®
RELAYABLE POWER

# AQ-F255

## Feeder protection IED

# Instruction manual



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Please read these instructions carefully before using the equipment or taking any other actions with respect to the equipment. Only trained and qualified persons are allowed to perform installation, operation, service or maintenance of the equipment. Such qualified persons have the responsibility to take all appropriate measures, including e.g. use of authentication, encryption, anti-virus programs, safe switching programs etc. necessary to ensure a safe and secure environment and usability of the equipment. The warranty granted to the equipment remains in force only provided that the instructions contained in this document have been strictly complied with.

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# 1 Document information

## 1.1 Version 2 revision notes

Table. 1.1 - 1. Version 2 revision notes

| Revision | 2.00 |
|---|---|
| Date | 6.6.2019 |
| Changes | - New more consistent look.<br>- Improved descriptions generally in many chapters.<br>- Improved readability of a lot of drawings and images.<br>- Updated protection functions included in every IED manual.<br>- Every protection IED type now has connection drawing, application example drawing with function block diagram and application example with wiring.<br>- Added General-menu description. |
| Revision | 2.01 |
| Date | 6.11.2019 |
| Changes | - Added description for LED test and button test.<br>- Added display sleep timer description.<br>- Complete rewrite of every chapter.<br>- Improvements to many drawings and formula images.<br>- Order codes revised.<br>- Added double ST 100 Mbps Ethernet communication module and Double RJ45 10/100 Mbps Ethernet communication module descriptions |
| Revision | 2.02 |
| Date | 7.7.2020 |
| Changes | - A number of image descriptions improved. |
| Revision | 2.03 |
| Date | 27.8.2020 |

| | |
|---|---|
| Changes | - Terminology consistency improved (e.g. binary inputs are now always called digital inputs).<br><br>- Tech data modified to be more informative about what type of measurement inputs are used (phase currents/voltages, residual currents/voltages), what component of that measurement is available (RMS, TRMS, peak-to-peak) and possible calculated measurement values (powers, impedances, angles etc.).<br><br>- Tech data updated: non-directional overcurrent<br><br>- Tech data updated: non-directional earthfault<br><br>- Tech data updated: directional earthfault<br><br>- Tech data updated: current unbalance<br><br>- Tech data updated: overfrequency, underfrequency and rate-of-change-of-frequency.<br><br>- Improvements to many drawings and formula images.<br><br>- AQ-F255 Functions included list Added: Voltage memory, vector jump, indicator objects, U0 recloser and measurement recorder.<br><br>- Added "32N" ANSI code to directional earth fault protection modes "unearthed" and "petersen coil grounded".<br><br>- Added 6th harmonic to harmonic overcurrent protection function.<br><br>- Fixed reset ratio of under- and overfrequency protection function from 103 % / 97 % to +/- 20 mHz..<br><br>- Fixed reset ratio of rate-of-change-of-frequency protection function from 20 mHz/s to 100 mHz/s.<br><br>- Changed disturbance recorder maximum digital channel amount from 32 to 95.<br><br>- Added residual current coarse and fine measurement data to disturbance recorder description.<br><br>- Event read mode parameter added to Modbus description.<br><br>- HSO1 and HSO2 connection swapped in arc protection card (was way wrong before).<br><br>- Updated I01 and I02 rated current range.<br><br>- Added inches to Dimensions and installation chapter.<br><br>- Added raising frames, wall mounting bracket, combiflex frame to order code.<br><br>- Added logical input and logical output function descriptions.<br><br>- Additions to Abbreviations chapter.<br><br>- Added button test description to Local panel structure chapter.<br><br>- Added note to Configuring user levels and passwords chapter that AQ-250 frame units generate a time-stamped event from locking and unlocking user levels.<br><br>- Added note to Configuring user levels and passwords chapter that user level with a password automatically locks itself after 30 minutes of inactivity.<br><br>- Added more "Tripped stage" indications and fault types to Measurement value recorder function.<br><br>- Updated: Digital input activation and release threshold setting ranges and added drop-off delay setting.<br><br>- Added sample rate to voltage and current measurement tech data.<br><br>- Fixed overvoltage, undervoltage, neutral overvoltage and sequence voltage stage misspelled IDMT curve formula. |
| Revision | 2.04 |
| Date | 8.6.2021 |
| Changes | - Increased the consistency in terminology<br><br>- Various image upgrades<br><br>- Visual update to the order codes |



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| Revision | 2.05 |
|---|---|
| Date | 22.6.2021 |
| Changes | - Fixed phase current measurement continuous thermal withstand from 30A to 20A.<br><br>- Fixed lots of timing errors written to registers table. "Prefault" is -200 ms from Start event, "Pretrigger" is -20 ms from trip (or start if fault doensn't progress to trip), "Fault" is start (or trip if fault doesn't progress to trip).<br><br>- Added event history technical data |
| Revision | 2.06 |
| Date | 21.6.2022 |
| Changes | - AQ-F255 Functions included list added: Voltage-restrained overcurrent (Iv>)<br><br>- Connections image updated<br><br>- Improved descriptions generally in many chapters.<br><br>- Improved readability of a lot of drawings and images.<br><br>- Added synchronizer, single-pole object and single-pole overcurrent protection.<br><br>- Added functionality packages.<br><br>- Order codes have been revised.<br><br>- Added LN mode parameters to all functions (On, Blocked, Test, Test/Blocked, Off).<br><br>- Added color themes parameter description.<br><br>- Improved color sleep mode description.<br><br>- Improved alarm function color behavior description and images.<br><br>- Added operation time with different measurement values vs setting ratio in instant operation mode to non-directional overcurrent function description.<br><br>- Fixed bias calculation formula for restricted earth fault function. Was correctly in the code, just written wrong in the manual.<br><br>- Added synchrocheck start check parameter description.<br><br>- Added 30 s pretriggering time for disturbance recorder (AQ-250 devices only).<br><br>- Added new trip detections and fault types to measurement value recorder.<br><br>- Added user description parameter descriptions for digital inputs, digital outputs, logical inputs, logical outputs and GOOSE inputs.<br><br>- Arc point sensor HSO1 and HSO2 position fixed.<br><br>- Added spare part codes and compatibilities to option cards. |
| Revision | 2.07 |
| Date | 7.7.2022 |
| Changes | - Added voltage THD function description.<br><br>- Added THD voltage measurements.<br><br>- Fixed logical input amounts.<br><br>- Added common signals function description.<br><br>- Added PTP time synchronization description.<br><br>- Added Modbus Gateway description.<br><br>- Added zero sequence recloser description.<br><br>- Added more fault types to Measurement value recorder (VREC) function. |

| Revision | 2.08 |
|---|---|
| Date | 8.9.2022 |
| Changes | - Added stage forcing parameter to function descriptions.<br>- Fixes to "Real time signals to comm" description.<br>- Added "Ethernet port" parameter description to IEC61850, IEC104 and Modbus TCP descriptions.<br>- Removed "Measurement update interval" settings from Modbus description. No longer in use.<br>- Renamed "System integration" chapter to "Communication" and restructured the chapters to be closer to how they are in the menus.<br>- Added "Event logger" chapter.<br>- Added more descriptions to new IEC 61850 ed2 GOOSE parameters.<br>- Added "Condition monitoring / CB wear" description to object description.<br>- Added "User button" description.<br>- Added logical device and logical node mode descriptions. |

## 1.2 Version 1 revision notes

Table. 1.2 - 2. Version 1 revision notes

| Revision | 1.00 |
|---|---|
| Date | 8.4.2013 |
| Changes | - The first revision for AQ-F255 IED |
| Revision | 1.01 |
| Date | 9.2.2017 |
| Changes | - Order code upgraded<br>- Programmable stage description added |
| Revision | 1.02 |
| Date | 20.12.2017 |
| Changes | - Measurement value recorder description<br>- ZCT connection added to current measurement description<br>- Internal harmonics blocking to I>,I0>,Idir>,I0dir> function descriptions<br>- Non-standard delay curves added<br>- Event lists revised on several functions<br>- RTD&mA card description improvements<br>- Auto-recloser function readability improvements<br>- Ring-lug CT card option description added<br>- Fault view description added<br>- New U> and U< function measurement modes documented<br>- Order code revised |
| Revision | 1.03 |
| Date | 14.8.2018 |
| Changes | - Added mA output option card description and ordercode<br>- Added HMI display technical data |


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# 2 Abbreviations

AI – Analog input

AR – Auto-recloser

ASDU – Application service data unit

AVR – Automatic voltage regulator

BCD – Binary-coded decimal

CB – Circuit breaker

CBFP – Circuit breaker failure protection

CLPU – Cold load pick-up

CPU – Central processing unit

CT – Current transformer

CTM – Current transformer module

CTS – Current transformer supervision

DG – Distributed generation

DHCP – Dynamic Host Configuration Protocol

DI – Digital input

DO – Digital output

DOL – Direct-on-line

DR – Disturbance recorder

DT – Definite time

FF – Fundamental frequency

FFT – Fast Fourier transform

FTP – File Transfer Protocol

GI – General interrogation

HMI – Human-machine interface

HR – Holding register

HV – High voltage

HW – Hardware

IDMT– Inverse definite minimum time

IED – Intelligent electronic device

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IGBT – Insulated-gate bipolar transistor

I/O – Input and output

IRIG-B – Inter-range instruction group, timecode B

LCD – Liquid-crystal display

LED – Light emitting diode

LV – Low voltage

NC – Normally closed

NO – Normally open

NTP – Network Time Protocol

RMS – Root mean square

RSTP – Rapid Spanning Tree Protocol

RTD – Resistance temperature detector

RTU – Remote terminal unit

SCADA – Supervisory control and data acquisition

SG – Setting group

SOTF – Switch-on-to-fault

SW – Software

THD – Total harmonic distortion

TRMS – True root mean square

VT – Voltage transformer

VTM – Voltage transformer module

VTS – Voltage transformer supervision



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# 3 General

The AQ-F255 feeder protection IED is a member of the AQ-200 product line. The hardware and software are modular: the hardware modules are assembled and configured according to the application's I/O requirements and the software determines the available functions. This manual describes the specific application of the AQ-F255 feeder protection IED. For other AQ-200 series products please consult their respective device manuals.

AQ-F255 offers a modular feeder protection and control solution for applications that require a large I/O capacity. There are up to eleven (11) option card slots available for additional I/O or communication cards for more comprehensive monitoring and control applications. AQ-F255 communicates using various protocols including the IEC 61850 substation communication standard.

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# 4 IED user interface

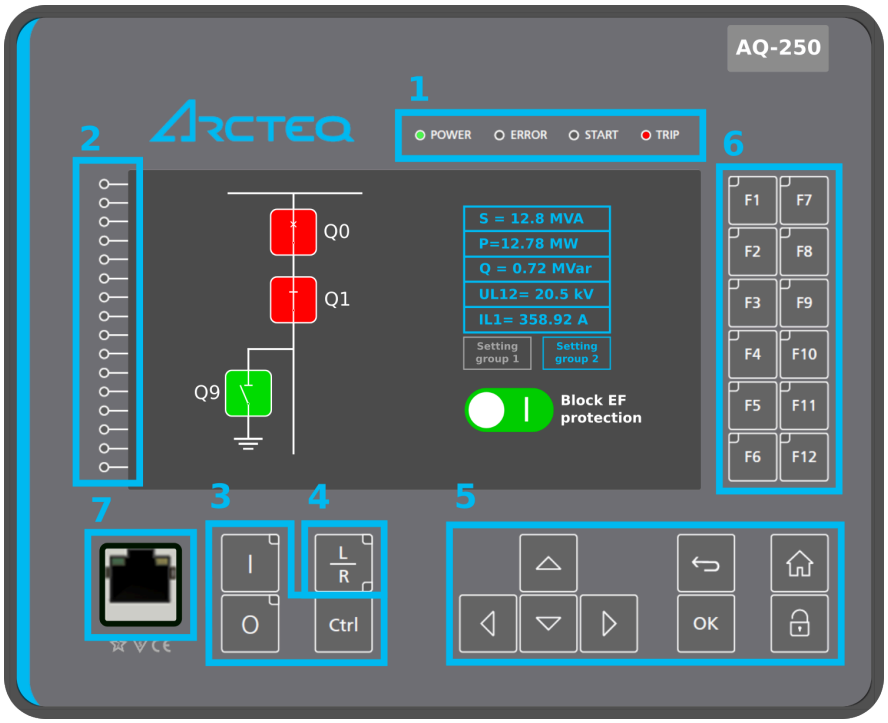
## 4.1 Panel structure

The user interface section of an AQ-200 series device is divided into two user interface sections: one for the hardware and the other for the software. You can access the software interface either through the front panel or through the AQtivate freeware software suite.

### 4.1.1 Local panel structure

The front panel of AQ-250 series devices have multiple LEDs, control buttons and a local RJ-45 Ethernet port for configuration. Each unit is also equipped with an RS-485 serial interface and an RJ-45 Ethernet interface on the back of the device. See the image and list below.

Figure. 4.1.1 - 1. Local panel structure.




1. Four (4) default LEDs: "Power", "Error", "Start" (configurable) and "Trip" (configurable).
2. Sixteen (16) freely configurable LEDs (red, orange, green) with programmable legend texts.
3. Three (3) object control buttons: Choose the controllable object with the Ctrl button and control the breaker or other object with the I and the O buttons.
4. The L/R button switches between the local and the remote control modes.
5. Eight (8) buttons for IED local programming: the four navigation arrows, the Back and the OK buttons, the Home and the password activation buttons).
6. Twelve (12) freely configurable function buttons (F1…F12). Each button has a freely configurable LED (red, orange, green).
7. One (1) RJ-45 Ethernet port for IED configuration.

When the unit is powered on, the green "Power" LED is lit. When the red "Error" LED is lit, the device has an internal (hardware or software) error that affects the operation of the unit. The activation of the yellow "Start" LED and the red "Trip" LED are based on the setting the user has put in place in the software.


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The sixteen freely configurable LEDs are located on the left side of the display. Their activation and color (green, orange, red) are based on the settings the user has put in place in the software.

The view in the screen is freely configurable. Virtual switches and buttons can be added which can be used to change the setting groups or control the device's general logic locally or remotely. The status of the object (circuit breaker, disconnector) can be displayed on the screen. All measured and calculated values regardless of the magnitude catecory (current, voltage, power, energy, frequency, etc.) can be shown on the screen.

Holding the I (object control) button down for five seconds brings up the button test menu. It displays all the physical buttons on the front panel. Pressing any of the listed buttons marks them as tested. When all buttons are marked as having been tested, the device will return back to the default view.

## 4.2 Configuring user levels and their passwords

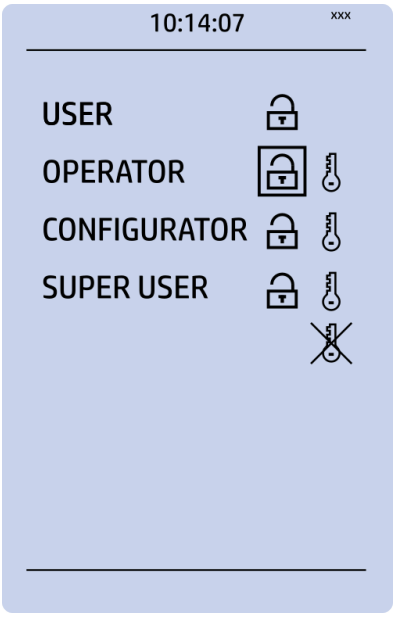
As a factory default, no user level is locked with a password in an IED. In order to activate the different user levels, click the Lock button in the device's HMI and set the desired passwords for the different user levels.

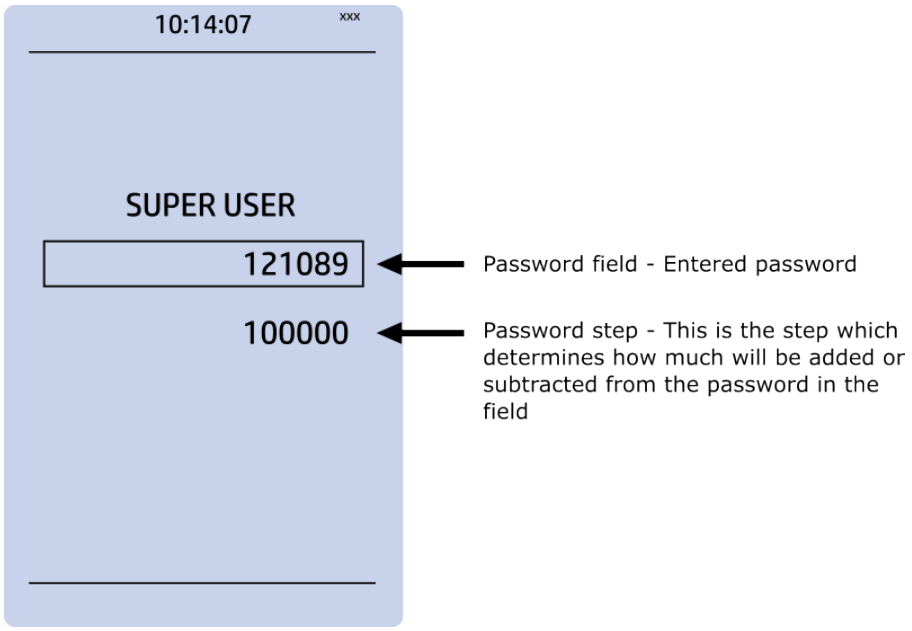
NOTE!

Passwords can only be set locally in an HMI.

A number of stars are displayed in the upper right corner of the HMI; these indicate the current user level. The different user levels and their star indicators are as follows (also, see the image below for the HMI view):

- Super user (***)
- Configurator (**)
- Operator (*)
- User ( - )






You can set a new password for a user level by selecting the key icon next to the user level's name. After this you can lock the user level by pressing the Return key while the lock is selected. If you need to change the password, you can select the key icon again and give a new password. Please note that in order to do this the user level whose password is being changed must be unlocked.

As mentioned above, the access level of the different user levels is indicated by the number of stars. The required access level to change a parameter is indicated with a star (*) symbol if such is required. As a general rule the access levels are divided as follows:

- *User:* Can view any menus and settings but cannot change any settings, nor operate breakers or other equipment.
- *Operator:* Can view any menus and settings but cannot change any settings BUT can operate breakers and other equipment.
- *Configurator:* Can change most settings such as basic protection pick-up levels or time delays, breaker control functions, signal descriptions etc. and can operate breakers and other equipment.
- *Super user:* Can change any setting and can operate breakers and other equipment.

NOTE!

In AQ-250 frame units unlocking and locking a user level generates a time-stamped event to the event log.

NOTE!

Any user level with a password automatically locks itself after half an hour (30 minutes) of inactivity.


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# 5 Functions

## 5.1 Functions included in AQ-F255

The AQ-F255 feeder protection relay includes the following functions as well as the number of stages for those functions.

Table. 5.1 - 3. Protection functions of AQ-F255.

| Name (number of stages) | IEC | ANSI | Description |
|---|---|---|---|
| NOC (4) | I><br>I>><br>I>>><br>I>>>> | 50/51 | Non-directional overcurrent protection |
| NOCS (2) | IPW><br>IPW>> | 50/51 | Single-pole non-directional overcurrent protection.<br>Included in function package "R". |
| DOC (4) | Idir><br>Idir>><br>Idir>>><br>Idir>>>> | 67 | Directional overcurrent protection |
| NEF (4) | I0><br>I0>><br>I0>>><br>I0>>>> | 50N/<br>51N | Non-directional earth fault protection |
| DEF (4) | I0dir><br>I0dir>><br>I0dir>>><br>I0dir>>>> | 67N/<br>32N | Directional earth fault protection |
| IEF (1) | I0int> | 67NT | Intermittent earth fault protection |
| OV (4) | U><br>U>><br>U>>><br>U>>>> | 59 | Overvoltage protection |
| UV (4) | U<<br>U<<<br>U<<<<br>U<<<< | 27 | Undervoltage protection |
| NOV (4) | U0><br>U0>><br>U0>>><br>U0>>>> | 59N | Neutral overvoltage protection |
| FRQV (8) | f><br>f>><br>f>>><br>f>>>><br><br>f<<br>f<<<br>f<<<<br>f<<<< | 81O/<br>81U | Overfrequency and underfrequency protection |
| ROCOF (1) | df/dt>/<<br>(1…8) | 81R | Rate-of-change of frequency |

| Name (number of stages) | IEC | ANSI | Description |
|---|---|---|---|
| CUB (4) | I2><br>I2>><br>I2>>><br>I2>>>> | 46/<br>46R/<br>46L | Negative sequence overcurrent/<br>phase current reversal/<br>current unbalance protection |
| VUB (4) | U1/U2>/<<br>U1/U2>>/<<<br>U1/<br>U2>>>/<<<<br>U1/<br>U2>>>>/<<<< | 47/<br>27P/<br>59PN | Sequence voltage protection |
| HOC (4) | Ih><br>Ih>><br>Ih>>><br>Ih>>>> | 50H/<br>51H/<br>68H | Harmonic overcurrent protection<br><br>The detection and blocking or tripping based on a selectable harmonic. The phase currents and the residual currents have separate stages. |
| CBFP (1) | CBFP | 50BF/<br>52BF | Circuit breaker failure protection |
| VOC (1) | Iv> | 51V | Voltage-restrained overcurrent protection |
| REF (1) | I0d> | 87N | Low-impedance or high-impedance restricted earth fault/ cable end differential protection |
| TOLF (1) | TF> | 49F | Line thermal overload protection |
| PGS (1) | PGx>/< | 99 | Programmable stage |
| OPW (1) | P> | 32O | Overpower protection |
| UPW (1) | P< | 32U | Underpower protection |
| RPW (1) | Pr | 32R | Reverse power protection |
| VMEM (1) | - | - | Voltage memory |
| ARC (1) | IArc>/I0Arc> | 50Arc/<br>50NArc | Arc fault protection (optional) |

Table. 5.1 - 4. Control functions of AQ-F255.

| Name | IEC | ANSI | Description |
|---|---|---|---|
| SGS | - | - | Setting group selection |
| OBJ | - | - | Object control and monitoring<br><br>(10 objects available) |
| OBJS | - | - | Single-pole object control and monitoring.<br><br>Included in function package "R". |
| CIN | - | - | Indicator object monitoring<br><br>(10 indicators available) |
| CLPU | CLPU | - | Cold load pick-up |
| NJK | - | 79N | Zero sequence recloser |
| SOTF | SOTF | - | Switch-on-to-fault |
| SYN | ΔV/Δa/Δf | 25 | Synchrocheck |
| GSYN | ΔV/Δa/Δf | 25 | Synchronizer.<br><br>Included in function package "S". |
| VJP | Δφ | 78 | Vector jump |


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| Name | IEC | ANSI | Description |
|---|---|---|---|
| AR | 0 → 1 | 79 | Auto-recloser |

Table. 5.1 - 5. Monitoring functions of AQ-F255.

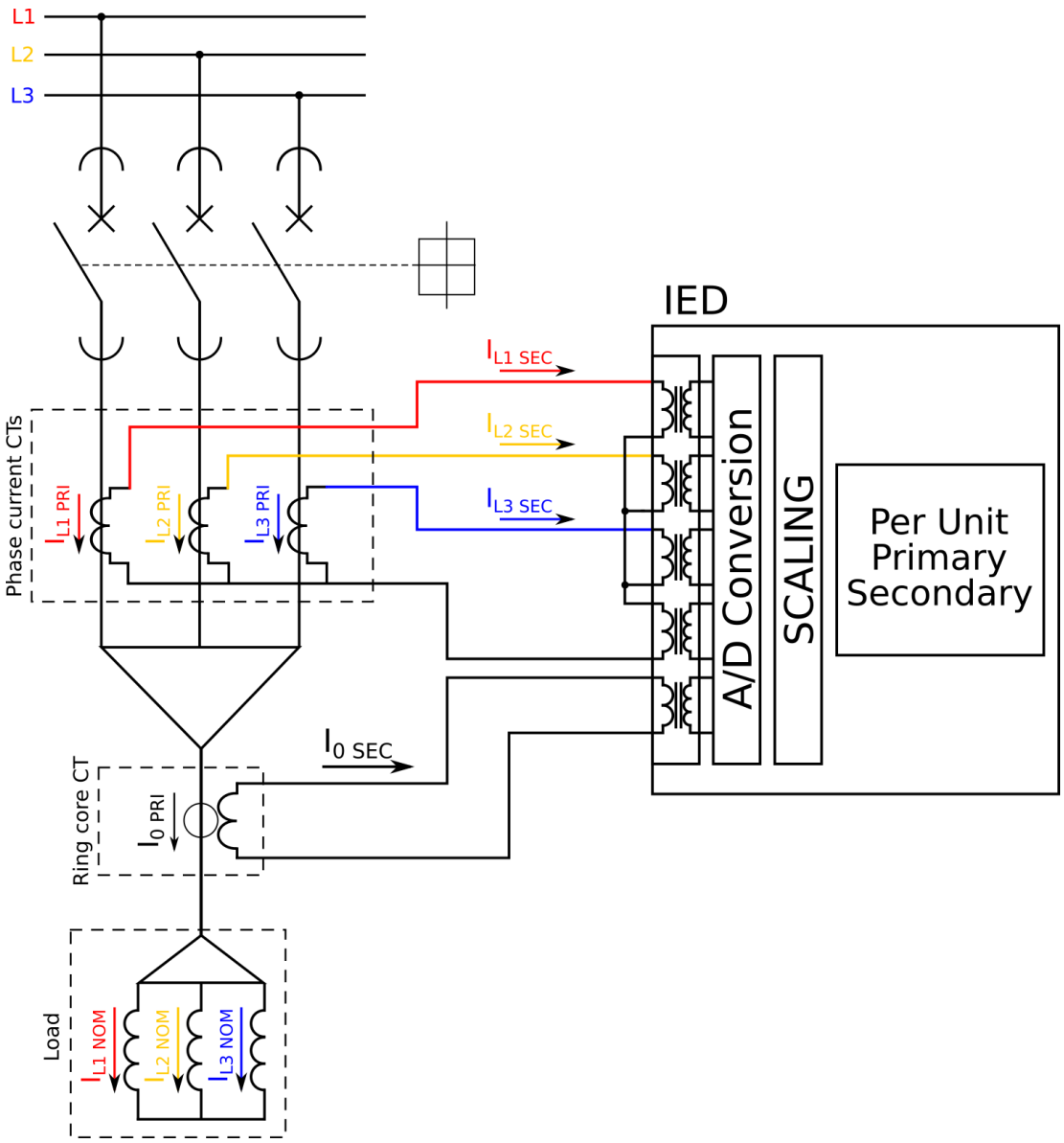
| Name | IEC | ANSI | Description |
|---|---|---|---|
| CTS | - | - | Current transformer supervision |
| VTS | - | 60 | Voltage transformer supervision |
| DR | - | - | Disturbance recorder |
| CBW | - | - | Circuit breaker wear monitor |
| THD | - | - | Total harmonic distortion |
| FLX | - | 21FL | Fault locator |
| MR | - | - | Measurement recorder |
| VREC | - | - | Measurement value recorder |

## 5.2 Measurements

### 5.2.1 Current measurement and scaling

The current measurement module (CT module, or CTM) is used for measuring the currents from current transformers. The measured values are processed into the measurement database and they are used by measurement and protection functions. It is essential to understand the concept of current measurements to be able to get correct measurements.

Figure. 5.2.1 - 2. Current measurement terminology




PRI: The primary current, i.e. the current which flows in the primary circuit and through the primary side of the current transformer.

SEC: The secondary current, i.e. the current which the current transformer transforms according to its ratios. This current is measured by the device.

NOM: The nominal primary current of the protected object.

For the measurements to be correct the user needs to ensure that the measurement signals are connected to the correct inputs, that the current direction is connected to the correct polarity, and that the scaling is set according to the nominal values of the current transformer.



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The device calculates the scaling factors based on the set values of the CT primary, the CT secondary and the nominal current settings. The device measures the secondary current, the current output from the current transformer installed into application's primary circuit. The rated primary and secondary currents of the CT need to be set for the device to "know" the primary and per-unit values. With motors and other specific electrical apparatus protections, the motor's nominal current should be set for the values to be in per unit with regards to the apparatus nominal instead of the CT nominal. This is not always mandatory as some devices still require manual calculations for the correct settings; however, setting the motors nominal current makes motor protection much easier and more straightforward. In modern protection devices this scaling calculation is done internally after the current transformer's primary current, secondary current and motor nominal current are set.

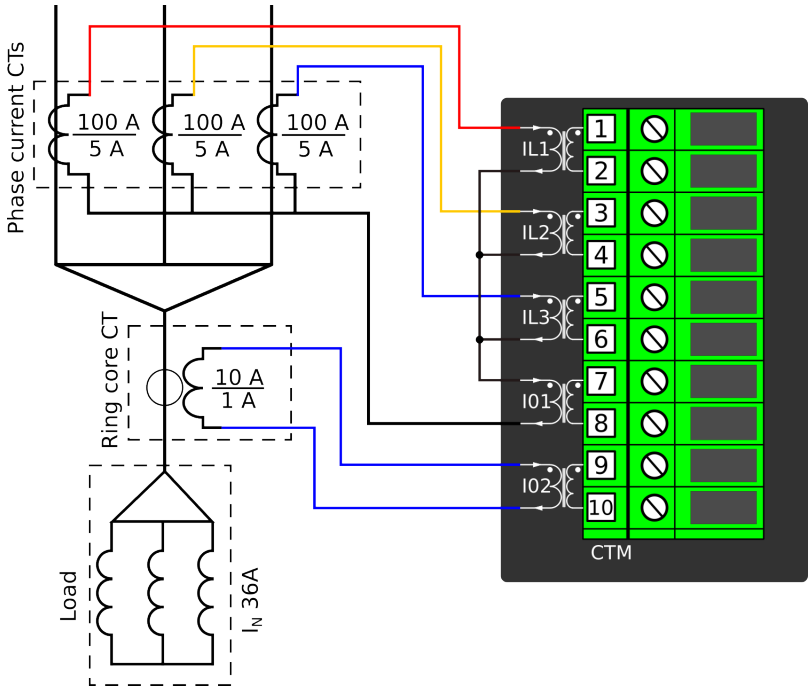
Normally, the primary current ratings for phase current transformers are 10 A, 12.5 A, 15 A, 20 A, 25 A, 30 A, 40 A, 50 A, 60 A and 75 A as well as their decimal multiples, while the secondary current ratings are 1 A and 5 A. Other, non-standard ratings can be directly connected as the scaling settings are flexible and have large ranges. For example, the ring core current transformer ratings may vary. Ring core current transformers are commonly used for sensitive earth fault protection and their rated secondary current may be as low as 0.2 A in some cases.

The following chapter is an example on how to set the scaling of the current measurements for the selected current transformer and system load.

## Example of CT scaling

The following figure presents how CTs are connected to the device's measurement inputs. It also shows example CT ratings and nominal current of the load.

Figure. 5.2.1 - 3. Connections.




The following table presents the initial data of the connection.

Table. 5.2.1 - 6. Initial data.

| | | |
|---|---|---|
| Phase current CT<br><br>- CT primary: 100 A<br><br>- CT secondary: 5 A | Ring core CT in Input I02<br><br>- I0CT primary: 10 A<br><br>- I0CT secondary: 1 A | Load (nominal)<br><br>36 A |

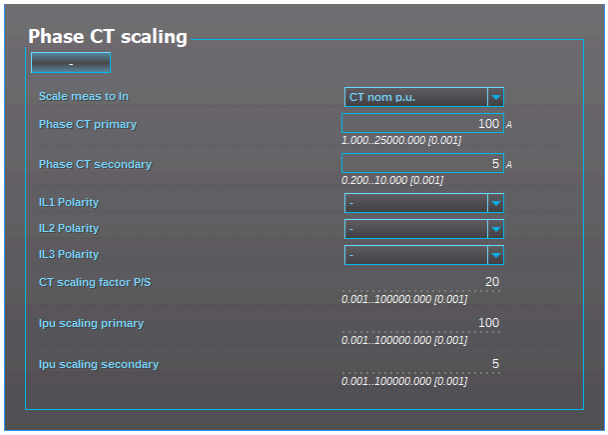
| |
|---|
| - the phase currents are connected to the I01 residual via a Holmgren connection<br><br>- the starpoint of the phase current CT's secondary current is towards the line |

*Phase CT scaling*

Next, to scale the current to per-unit values, we have to select whether the basis of the phase CT scaling is the protected object's nominal current or the CT primary value.

If the CT values are chosen to be the basis for the per-unit scaling, the option "CT nom. p.u." is selected for the "Scale meas to In" setting (see the image below).

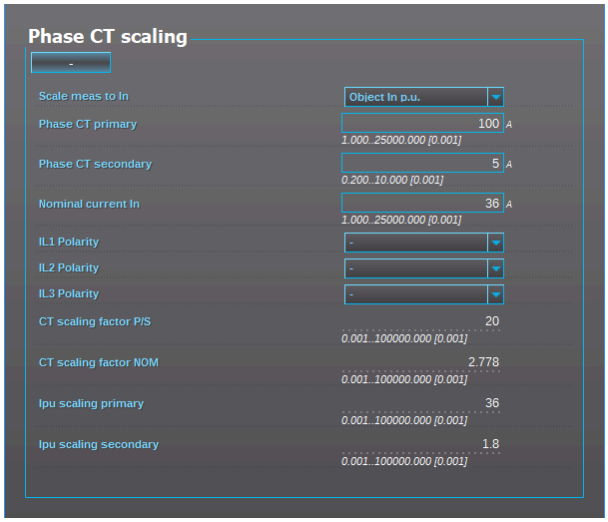
Figure. 5.2.1 - 4. Setting the phase current transformer scalings to CT nominal.




Once the setting have been sent to the device, device calculates the scaling factors and displays them for the user. The "CT scaling factor P/S" describes the ratio between the primary current and the secondary current. The per-unit scaling factors ("Ipu scaling") for both primary and secondary values are also displayed (in this case they are the set primary and secondary currents of the CT).

If the protected object's nominal current is chosen to be the basis for the per-unit scaling, the option "Object in p.u." is selected for the "Scale meas to In" setting (see the image below).

Figure. 5.2.1 - 5. Setting the phase current transformer scalings to the protected object's nominal current.






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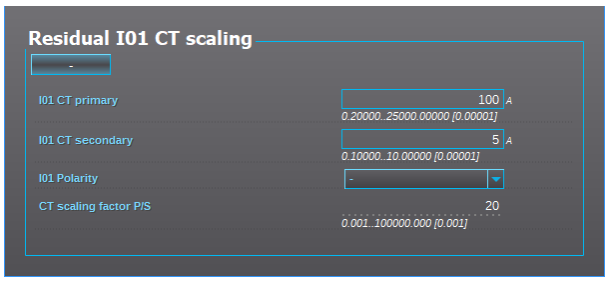
Once the measurement scaling is tied to the protected object's nominal current, the user must set the appropriate input for the "Nominal current In" setting. One can now see the differences between the two scaling options (CT nominal vs. object nominal). The "CT scaling factor P/S" is the direct ratio between the set CT current values, and the "CT scaling factor NOM" is now the ratio between the set CT primary and the nominal current. The "Ipu scaling primary" is now equal to the set nominal current, and the "Ipu scaling secondary" is the ratio between the nominal current and the "CT scaling factor P/S".

*Residual I0 CT scaling*

Next, we set the residual IO CT scalings according to how the phase current CTs and the ring core CT are connected to the module (see the Connections image at the beginning of this chapter).

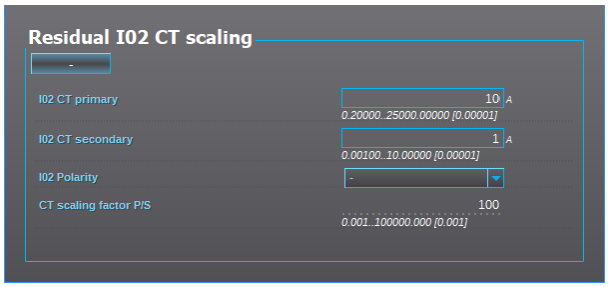
The phase current CTs are connected to the module via a Holmgren (summing) connection, which requires the use of coarse residual current measurement settings: the "I01 CT" settings are set according to the phase current CTs' ratings (100/5 A).

Figure. 5.2.1 - 6. Residual I01 CT scaling (coarse).




The ring core CT is connected to the CTM directly, which requires the use of sensitive residual current measurement settings: the "I02 CT" settings are set according to the ring core CT's ratings (10/1 A).

Figure. 5.2.1 - 7. Residual I02 CT scaling (sensitive).




*Displaying the scaling*

Depending on whether the scaling was done based on the CT primary values or the protected object's nominal current, the measurements are displayed slightly differently. The first of the two images shows how the measurements are displayed when the CT primary values are the basis for the scaling; the second shows them when the protected object's nominal current is the basis for the scaling.

Figure. 5.2.1 - 8. Scalings display (based on the CT nominal).

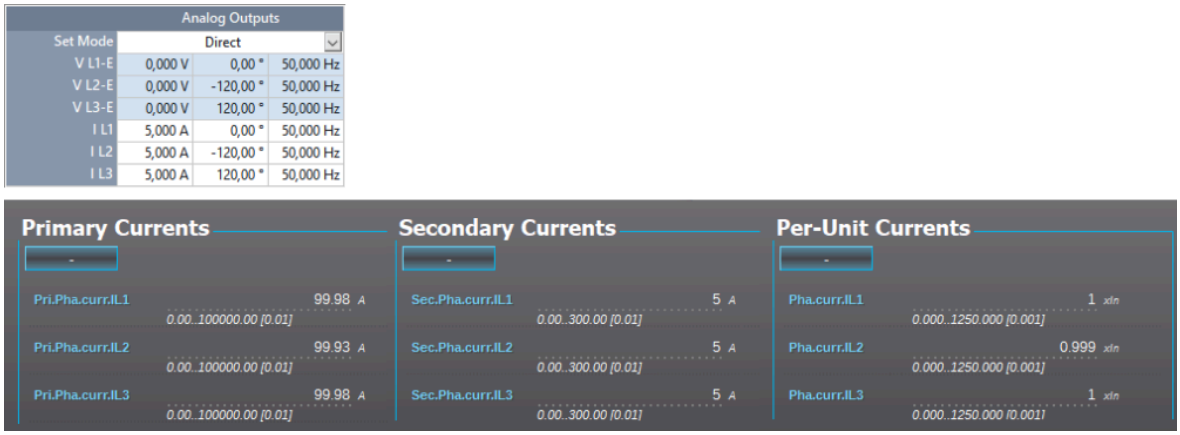
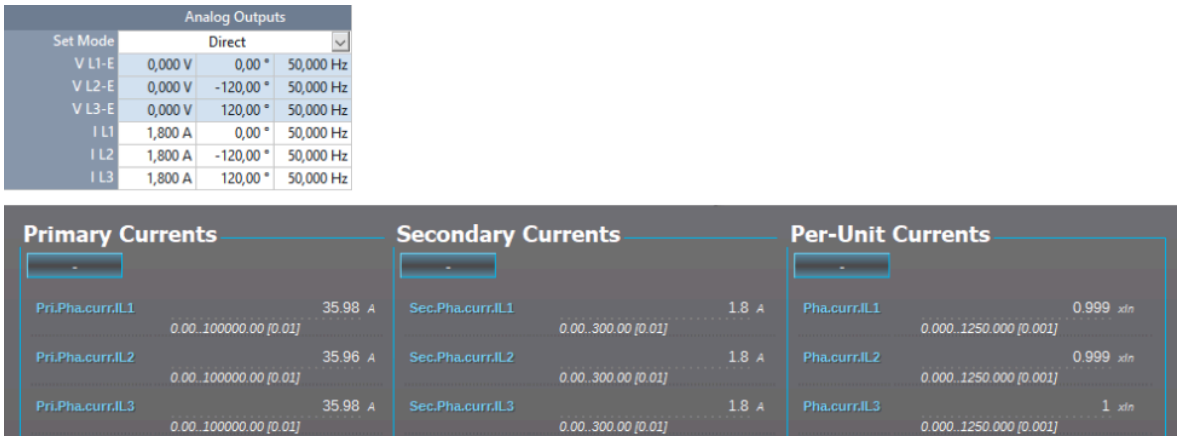



Figure. 5.2.1 - 9. Scalings display (based on the protected object's nominal current).




As the images above show, the scaling selection does not affect how primary and secondary currents are displayed (as actual values). The only effect is that the per-unit system in the device is scaled either to the CT nominal or to the object nominal, making the settings input straightforward.

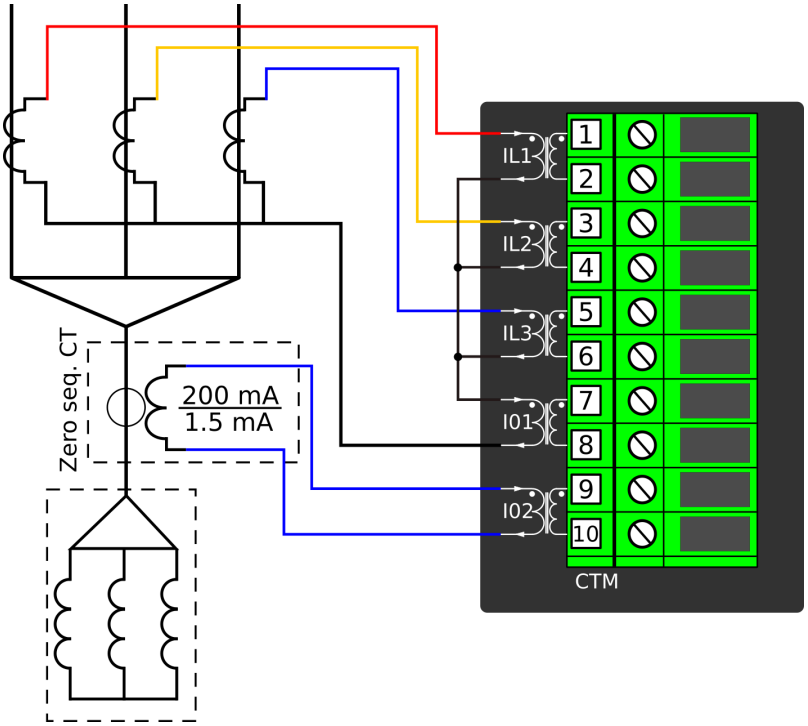
## Example of zero sequence CT scaling

Zero sequence CT scaling (ZCT scaling) is done when a zero sequence CT instead of a ring core CT is part of the measurement connection. In such a case the zero sequence CT should be connected to the I02 channel which has lower CT scaling ranges (see the image below).



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Figure. 5.2.1 - 10. Connections of ZCT scaling.



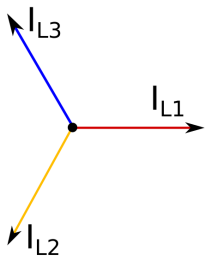

## Troubleshooting

When the measured current values differ from the expected current values, the following table offers possible solutions for the problems.

NOTE!

If you work with energized CTs, extreme caution needs to be taken when checking the connections! An opened CT secondary circuit may generate dangerously high voltages. A "buzzing" sound from the connector can indicate an open circuit.

| Problem | Solution |
|---|---|
| The measured current amplitude in all phases does not match the injected current. | The scaling settings may be wrong, check that the settings match with the connected current transformer (*Measurement → Transformers → Phase CT scaling*). Also check that the "Scale meas. to In" is set accordingly. If possible, check the actual CTs and their ratings as there may have been a need to change the original plan. |
| The measured current amplitude does not match one of the measured phases./<br><br>The calculated I0 is measured even though it should not. | Check the wiring connections between the injection device or the CTs and the device. |

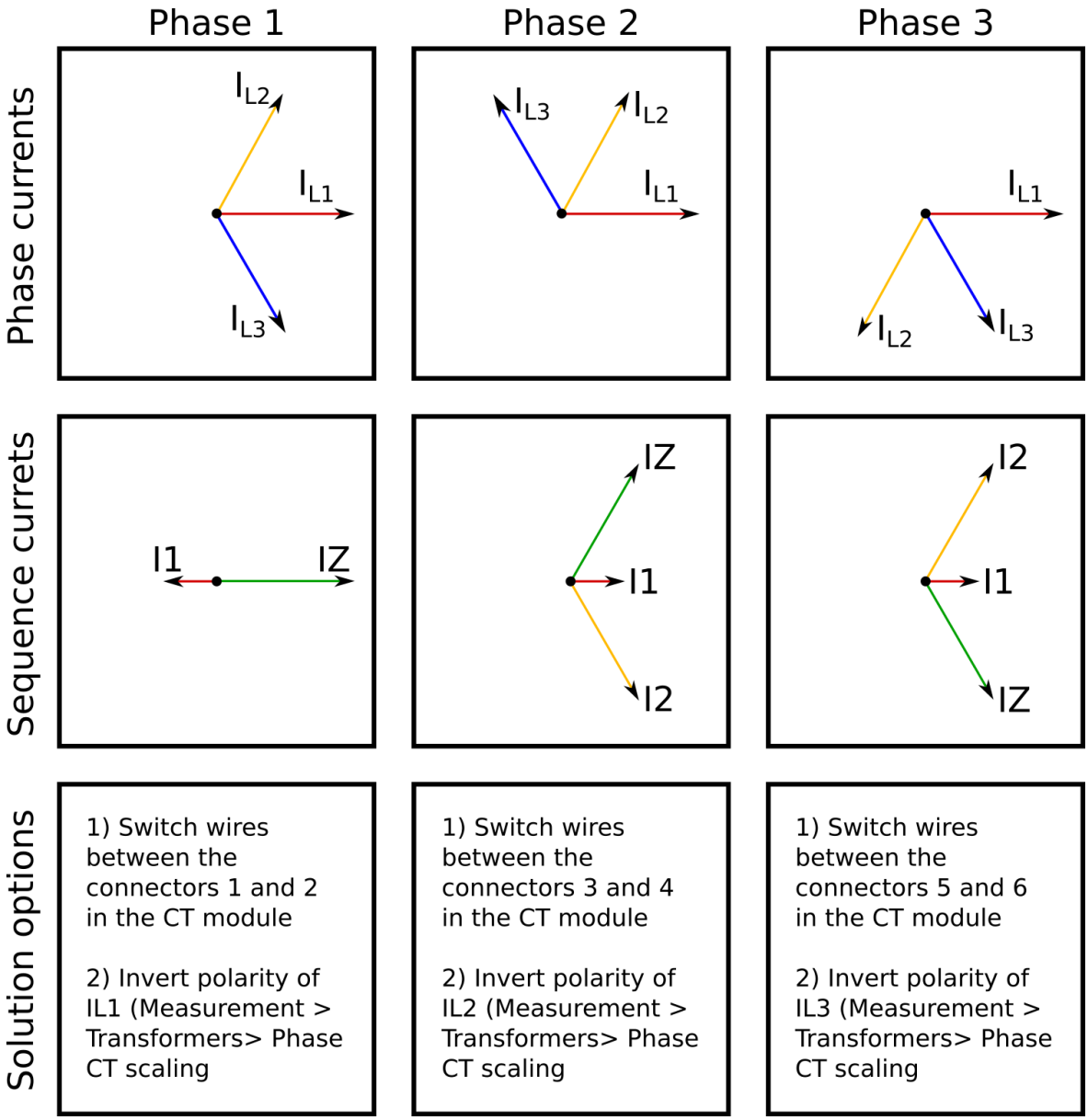
| Problem | Solution |
|---|---|
| The measured current amplitudes are OK but the angles are strange./<br><br>The phase unbalance protection trips immediately after activation./<br><br>The earth fault protection trips immediately after activation. | The phase currents are connected to the measurement module but the order or polarity of one or all phases is incorrect. In device settings, go to *Measurement → Phasors* and check the "Phase current vectors" diagram. When all connections are correct, the diagram (symmetric feeding) should look like this:<br><br>  <br><br><br>See the following tables for the most common problems with phase polarity and network rotation (mixed phases). |

The following image presents the most common problems with phase polarity. Problems with phase polarity are easy to find because the vector diagram points towards the opposite polarity when a phase has been incorrectly connected.



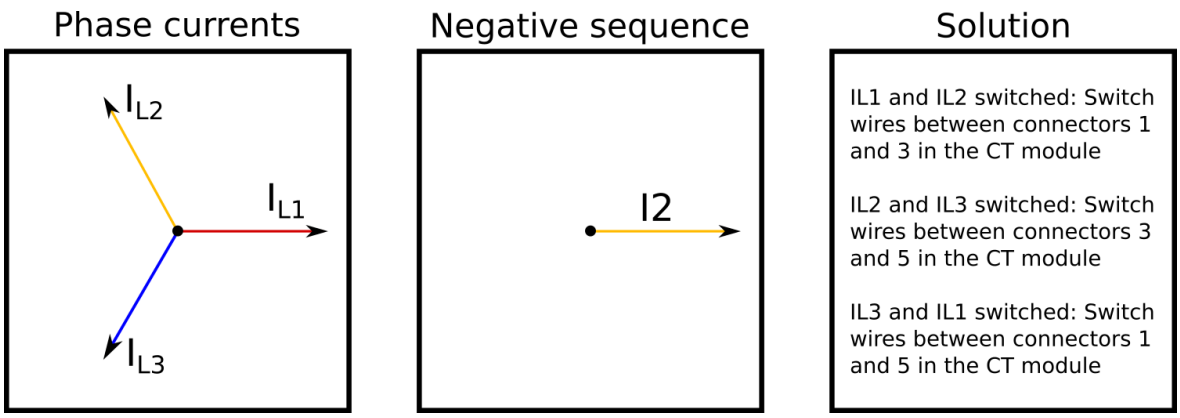
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Figure. 5.2.1 - 11. Common phase polarity problems.




The following image presents the most common problems with network rotation (mix phases). These problems can be difficult to find because the measurement result is always the same in the device. If two phases are mixed together, the network rotation always follows the pattern IL1-IL3-IL2 and the measured negative sequence current is therefore always 1.00 (in. p.u.).

Figure. 5.2.1 - 12. Common network rotation (mixed phases) problems.




## Settings

Table. 5.2.1 - 7. Settings of the Phase CT scaling.

| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| Scale measurement to In | - | 0: CT nom p.u.<br>1: Object In p.u. | - | 0: CT nom p.u. | The selection of the reference used in the device's per-unit system scaling. Either the set phase current CT primary or the protected object's nominal current. |
| Phase CT primary | A | 1…25000 | 0.001 | 100 | The rated primary current of the current transformer. |
| Phase CT secondary | A | 0.2…10 | 0.001 | 5 | The rated secondary current of the current transformer. |
| Nominal current In | A | 1…25000 | 0.001 | 100 | The nominal current of the protected object. This setting is only visible if the option "Object In p.u." has been selected in the "Scale measurement to In" setting. |
| IL1 Polarity | - | 0: -<br>1: Invert | - | 0: - | The selection of the first current measurement channel's (IL1) polarity (direction). The default setting is for the positive current to flow from connector 1 to connector 2, with the secondary currents' starpoint pointing towards the line. |
| IL2 Polarity | - | 0: -<br>1: Invert | - | 0: - | The selection of the second current measurement channel's (IL2) polarity (direction). The default setting is for the positive current to flow from connector 3 to connector 4, with the secondary currents' starpoint pointing towards the line. |
| IL3 Polarity | - | 0: -<br>1: Invert | - | 0: - | The selection of the third current measurement channel's (IL3) polarity (direction). The default setting is for the positive current to flow from connector 5 to connector 6, with the secondary currents' starpoint pointing towards the line. |
| CT scaling factor P/S | - | - | - | - | A feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current. |
| CT scaling factor NOM | - | - | - | - | A feedback value; the calculated scaling factor that is the ratio between the set primary current and the set nominal current. This parameter is only visible if the option "Object In p.u." has been selected in the "Scale measurement to In" setting. |
| Ipu scaling primary | - | - | - | - | A feedback value; the scaling factor for the primary current's per-unit value. |
| Ipu scaling secondary | - | - | - | - | A feedback value; the scaling factor for the secondary current's per-unit value. |



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Table. 5.2.1 - 8. Settings of the Residual I01 CT scaling.

| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| I01 CT primary | A | 0.2…25000 | 0.00001 | 100 | The rated primary current of the current transformer. |
| I01 CT secondary | A | 0.1…10.000 | 0.00001 | 1 | The rated secondary current of the current transformer. |
| I01 Polarity | - | 0: -<br>1: Invert | - | 0: - | The selection of the coarse residual measurement channel's (I01) polarity (direction). The default setting is for the positive current to flow from connector 7 to connector 8. |
| CT scaling factor P/S | - | - | - | - | A feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current. |

Table. 5.2.1 - 9. Settings of the Residual I02 CT scaling.

| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| I02 CT primary | A | 0.2…25000 | 0.00001 | 100 | The rated primary current of the current transformer. |
| I02 CT secondary | A | 0.001…10 | 0.00001 | 0.2 | The rated secondary current of the current transformer. |
| I02 Polarity | - | 0: -<br>1: Invert | - | 0: - | The selection of the sensitive residual measurement channel's (I02) polarity (direction). The default setting is for the positive current to flow from connector 9 to connector 10. |
| CT scaling factor P/S | - | - | - | - | A feedback value; the calculated scaling factor that is the ratio between the primary current and the secondary current. |

## Measurements

The following measurements are available in the measured current channels.

Table. 5.2.1 - 10. Per-unit phase current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Phase current ILx ("Pha.curr.ILx") | × In | 0.000…1250.000 | 0.001 | The RMS current measurement (in p.u.) from each of the phase current channels. |
| Phase current ILx TRMS ("Pha.curr.ILx TRMS") | × In | 0.00…1250.00 | 0.01 | The TRMS current (inc. harmonics up to 31$^{st}$) measurement (in p.u.) from each of the phase current channels. |
| Peak-to-peak current ILx ("P-P curr.ILx") | × In | 0.00…500.00 | 0.01 | The peak-to-peak current measurement (in p.u.) from each of the phase current channels. |

Table. 5.2.1 - 11. Primary phase current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary phase current ILx ("Pri.Pha.curr.ILx") | A | 0.00…1000000.00 | 0.01 | The primary RMS current measurement from each of the phase current channels. |
| Primary phase current ILx TRMS ("Pha.curr.ILx TRMS Pri") | A | 0.00…1000000.00 | 0.01 | The primary TRMS current (inc. harmonics up to 31$^{st}$) measurement from each of the phase current channels. |

Table. 5.2.1 - 12. Secondary phase current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary phase current ILx ("Sec.Pha.curr.ILx") | A | 0.00…300.00 | 0.01 | The primary RMS current measurement from each of the phase current channels. |
| Secondary phase current ILx TRMS ("Pha.curr.ILx TRMS Sec") | A | 0.00…300.00 | 0.01 | The primary TRMS current (inc. harmonics up to 31$^{st}$) measurement from each of the phase current channels. |

Table. 5.2.1 - 13. Phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Phase angle ILx ("Pha.angle ILx") | deg | 0.00…360.00 | 0.01 | The phase angle measurement from each of the three phase current inputs. |

Table. 5.2.1 - 14. Per-unit residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Residual current I0x ("Res.curr.I0x") | × In | 0.00…1250.00 | 0.01 | The RMS current measurement (in p.u.) from the residual current channel I01 or I02. |
| Calculated I0 | × In | 0.00…1250.00 | 0.01 | The RMS current measurement (in p.u.) from the calculated I0 current channel. |
| Phase current I0x TRMS ("Res.curr.I0x TRMS") | × In | 0.00…1250.00 | 0.01 | The TRMS current (inc. harmonics up to 31$^{st}$) measurement (in p.u.) from the residual current channel I01 or I02. |
| Peak-to-peak current I0x ("P-P curr.I0x") | × In | 0.00…500.00 | 0.01 | The peak-to-peak current measurement (in p.u.) from the residual current channel I01 or I02. |

Table. 5.2.1 - 15. Primary residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary residual current I0x ("Pri.Res.curr.I0x") | A | 0.00…1000000.00 | 0.01 | The primary RMS current measurement from the residual current channel I01 or I02. |
| Primary calculated I0 ("Pri.calc.I0") | A | 0.00…1000000.00 | 0.01 | The primary RMS current measurement from the calculated current channel I0. |
| Primary residual current I0x TRMS ("Res.curr.I0x TRMS Pri") | A | 0.00…1000000.00 | 0.01 | The TRMS current (inc. harmonics up to 31$^{st}$) measurement from the primary residual current channel I01 or I02. |

Table. 5.2.1 - 16. Secondary residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary residual current I0x ("Sec.Res.curr.I0x") | A | 0.00…300.00 | 0.01 | The secondary RMS current measurement from the residual current channel I01 or I02. |
| Secondary calculated I0 ("Sec.calc.I0") | A | 0.00…300.00 | 0.01 | The secondary RMS current measurement from the calculated current channel I0. |



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| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary residual current I0x TRMS (Res.curr.I0x TRMS Sec") | A | 0.00…300.00 | 0.01 | The secondary TRMS current (inc. harmonics up to 31$^{st}$) measurement from the secondary residual current channel I01 or I02. |

Table. 5.2.1 - 17. Residual phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Residual current angle I0x ("Res.curr.angle I0x") | deg | 0.00…360.00 | 0.01 | The residual current angle measurement from the I01 or I02 current input. |
| calc.I0 Pha.angle | deg | 0.00…360.00 | 0.01 | The calculated residual current angle measurement. |

Table. 5.2.1 - 18. Per-unit sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence current | × In | 0.00…1250.00 | 0.01 | The measurement (in p.u.) from the calculated positive sequence current. |
| Negative sequence current | × In | 0.00…1250.00 | 0.01 | The measurement (in p.u.) from the calculated negative sequence current. |
| Zero sequence current | × In | 0.00…1250.00 | 0.01 | The measurement (in p.u.) from the calculated zero sequence current. |

Table. 5.2.1 - 19. Primary sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary positive sequence current ("Pri.Positivesequence curr.") | A | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated positive sequence current. |
| Primary negative sequence current ("Pri.Negative sequence curr.") | A | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated negative sequence current. |
| Primary zero sequence current ("Pri.Zero sequence curr.") | A | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated zero sequence current. |

Table. 5.2.1 - 20. Secondary sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary positive sequence current ("Sec.Positive sequence curr.") | A | 0.00…300.00 | 0.01 | The secondary measurement from the calculated positive sequence current. |
| Secondary negative sequence current ("Sec.Negative sequence curr") | A | 0.00…300.00 | 0.01 | The secondary measurement from the calculated negative sequence current. |
| Secondary zero sequence current ("Sec.Zero sequence curr.") | A | 0.00…300.00 | 0.01 | The secondary measurement from the calculated zero sequence current. |

Table. 5.2.1 - 21. Sequence phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence current angle ("Positive sequence curr.angle") | deg | 0.00…360.00 | 0.01 | The calculated positive sequence current angle. |
| Negative sequence current angle ("Negative sequence curr.angle") | deg | 0.00…360.00 | 0.01 | The calculated negative sequence current angle. |
| Zero sequence current angle ("Zero sequence curr.angle") | deg | 0.00…360.00 | 0.01 | The calculated zero sequence current angle. |

Table. 5.2.1 - 22. Harmonic current measurements.

| Name | | Range | Step | Description |
|---|---|---|---|---|
| Harmonics calculation values ("Harm Abs.or Perc.") | - | 0: Percent<br>1: Absolute | - | Defines whether the harmonics are calculated as percentage or absolute values. |
| Harmonics display | - | 0: Per unit<br>1: Primary A<br>2: Secondary A | - | Defines how the harmonics are displayed: in p.u values, as primary current values, or as secondary current values. |
| Maximum harmonics value ("Ixx maximum harmonic") | A | 0.00...100000.00 | 0.01 | Displays the maximum harmonics value of the selected current input ILx or I0x. |
| Fundamental frequency ("Ixx fundamental") | A | 0.00...100000.00 | 0.01 | Displays the current value of the fundamental frequency (RMS) from the selected current input ILx or I0x. |
| Ixx harmonics ($2^{nd}$...$31^{st}$ harmonic) | A | 0.00…100000.00 | 0.01 | Displays the selected harmonic from the current input ILx or I0x. |
| Ixx Amplitude THD | % | 0.000...100.000 | 0.001 | Amplitude ratio THD voltage. Recognized by IEC. |
| Ixx Power THD | % | 0.000...100.000 | 0.001 | Power ratio THD voltage. Recognized by the IEEE. |

## Current component measurements

The current component measurements indicate the resistive (wattmetric cos[φ]) and reactive (varmetric sin[φ]) current values. These are calculated with the following formulas:

$$\text{Wattmetric resistive component} = I_X * \cos\varphi$$

$$\text{Varmetric reactive component} = I_X * \sin\varphi$$

Where:

- $I_X$ = the magnitude of a phase current or a residual current
- φ = the angle difference between the phase or residual voltage and the phase or residual current.

The following measurements are available from the measured current channels.



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Table. 5.2.1 - 23. Per-unit phase current component measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| ILx resistive current ("ILx Resistive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The resistive current component measurement (in p.u.) from each of the phase current channels. |
| ILx reactive current ("ILx Reactive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The reactive current component measurement (in p.u.) from each of the phase current channels. |
| Positive sequence resistive current ("Pos.Seq Resistive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The resistive current component measurement (in p.u.) from the positive sequence current channel. |
| Positive sequence reactive current ("Pos.Seq Reactive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The reactive current component measurement (in p.u.) from the positive sequence current channel. |
| Residual resistive current I0x ("I0x Residual Resistive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The resistive current component measurement (in p.u.) from the residual current channel I0x. |
| Residual reactive current I0x ("I0x Residual Reactive Current p.u.") | × In | -1250.00…1250.00 | 0.01 | The reactive current component measurement (in p.u.) from the residual current channel I0x. |

Table. 5.2.1 - 24. Primary phase current component measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary resistive current ILx ("ILx Resistive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary resistive current component measurement from each of the phase current channels. |
| Primary reactive current ILx ("ILx Reactive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary reactive current component measurement from each of the phase current channels. |
| Primary positive sequence resistive current ("Pos.Seq. Resistive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary resistive current component measurement from the positive sequence current channel. |
| Primary positive sequence reactive current ("Pos.Seq. Reactive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary reactive current component measurement from the positive sequence current channel. |
| Primary residual resistive current I0x ("I0x Residual Resistive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary resistive current component measurement from both of the residual current channels. |
| Primary residual reactive current I0x ("I0x Residual Reactive Current Pri.") | A | -100000.00 …100000.00 | 0.01 | The primary reactive current component measurement from both of the residual current channels. |

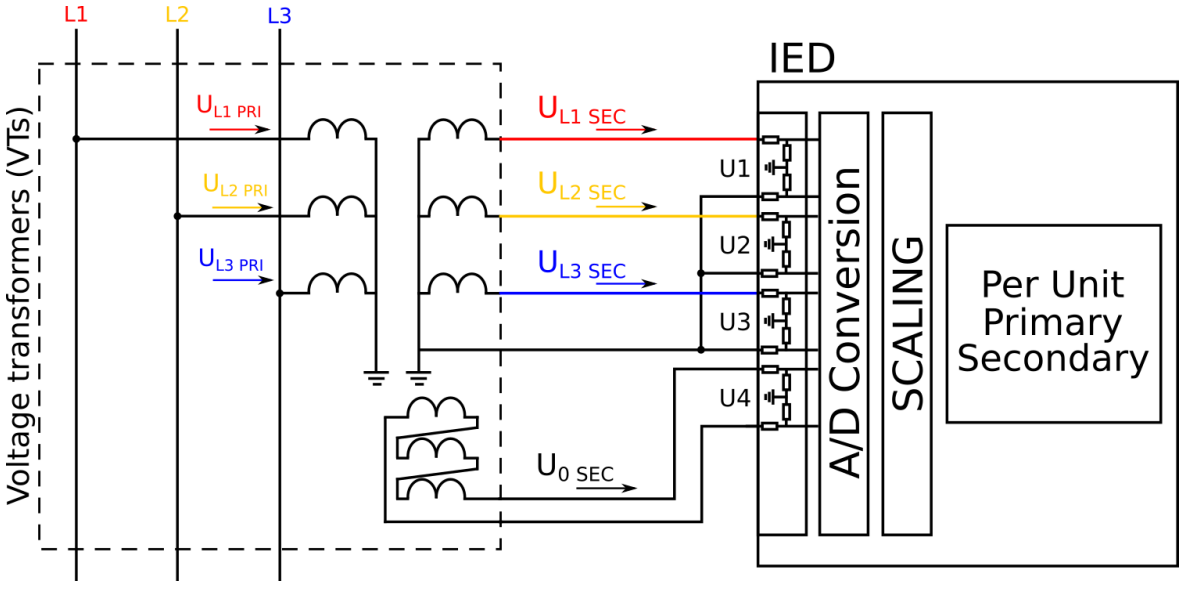
Table. 5.2.1 - 25. Secondary phase current component measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary resistive current ILx ("ILx Resistive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary resistive current component measurement from each of the phase current channels. |
| Secondary reactive current ILx ("ILx Reactive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary reactive current component measurement from each of the phase current channels. |
| Secondary resistive current (PSC) ("Pos.Seq Resistive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary resistive current component measurement from the positive sequence current channel. |
| Secondary reactive current (PSC) ("Pos.Seq Reactive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary reactive current component measurement from the positive sequence current channel. |
| Secondary residual resistive current ("I0x Resistive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary resistive current component measurement from both of the residual current channels. |
| Secondary residual reactive current ("I0x Reactive Current Sec.") | A | -300.00…300.00 | 0.01 | The secondary reactive current component measurement from both of the residual current channels. |

## 5.2.2 Voltage measurement and scaling

The voltage measurement module (VT module, or VTM) is used for measuring the voltages from voltage transformers. The measured values are processed into the measurement database and they are used by measurement and protection functions (the protection function availability depends of the device type). It is essential to understand the concept of voltage measurements to be able to get correct measurements.

Figure. 5.2.2 - 13. Voltage measurement terminology




**PRI:** The primary voltage, i.e. the voltage in the primary circuit which is connected to the primary side of the voltage transformer.



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SEC: The secondary voltage, i.e. the voltage which the voltage transformer transforms according to the ratio. This voltage is measured by the device.

For the measurements to be correct the user needs to ensure that the measurement signals are connected to the correct inputs, that the voltage direction correct, and that the scaling is set correctly.

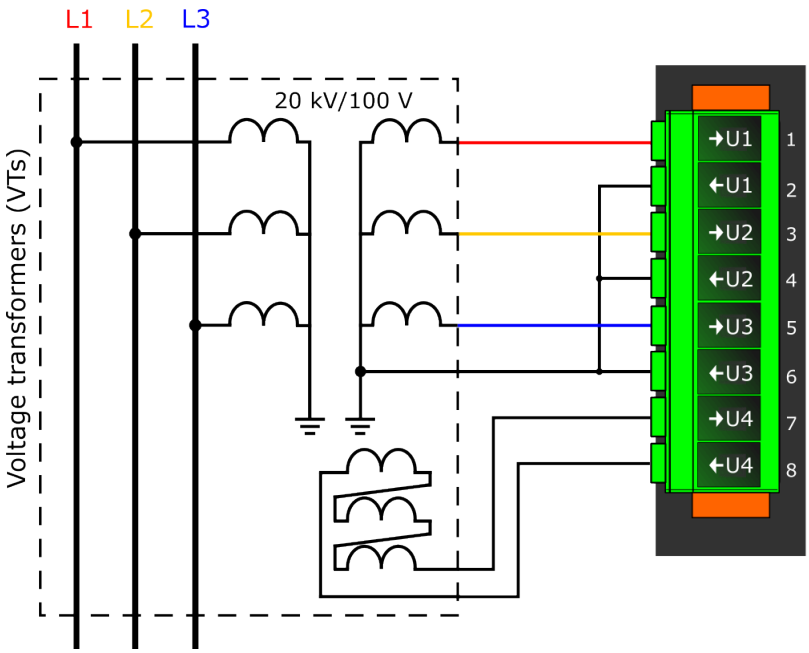
The device calculates the scaling factors based on the set VT primary, and secondary voltage values. The device measures secondary voltages, which are the voltage outputs from the VT installed into the application's primary circuit. The voltage can be measured directly from the system as well (up to 400 V nominal line to neutral voltage). When connecting voltage directly, measuring mode must be set to 3LN+U4 mode. The rated primary and secondary voltages of the VT need to be set for the device to "know" the primary and per-unit values. In modern protection devices this scaling calculation is done internally after the voltage transformer's primary and secondary voltages are set.

Normally, the primary line-to-line voltage rating for VTs is 400 V...60 kV, while the secondary voltage ratings are 100 V...210 V. Non-standard ratings can also be directly connected as the scaling settings are flexible and have large ranges.

## Example of VT scaling

The following figure presents how VTs are connected to the device's measurement inputs. It also shows the VT ratings. In the figure below, three line-to-neutral voltages are connected along with the zero sequence voltage; therefore, the 3LN+U4 mode must be selected and the U4 channel must be set as U0. Other possible connections are presented later in this chapter.

Figure. 5.2.2 - 14. Connections.



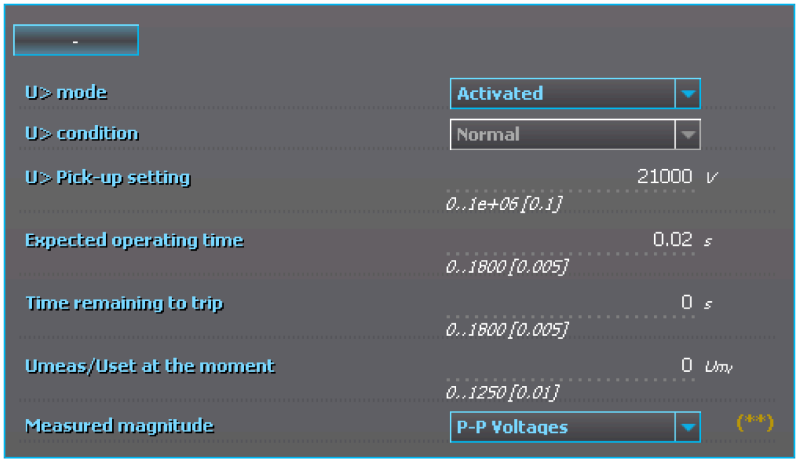

The following table presents the initial data of the connection.

Table. 5.2.2 - 26. Initial data.

| | |
|---|---|
| Phase voltage VT<br>- VT primary: 20 000 V<br>- VT secondary: 100 V | Zero sequence voltage VT<br>- U4 VT primary: 20 000 V<br>- U4 VT secondary: 100 V |
| - the zero sequence voltage is connected similarly to line-to-neutral voltages (+U0).<br>- in case wiring is incorrect, all polarities can be individually switched by 180 degrees in the device. | |

If the protection is voltage-based, the supervised voltage can be based either on line-to-line voltages or on line-to-earth voltages. This selection is defined in the "Measured magnitude" of each protection stage menu separately (*Protection* → *Voltage* → [protection stage menu] → *INFO*; see the image below). The number of available protection functions depends on the device type.

Figure. 5.2.2 - 15. Selecting the measured magnitude.

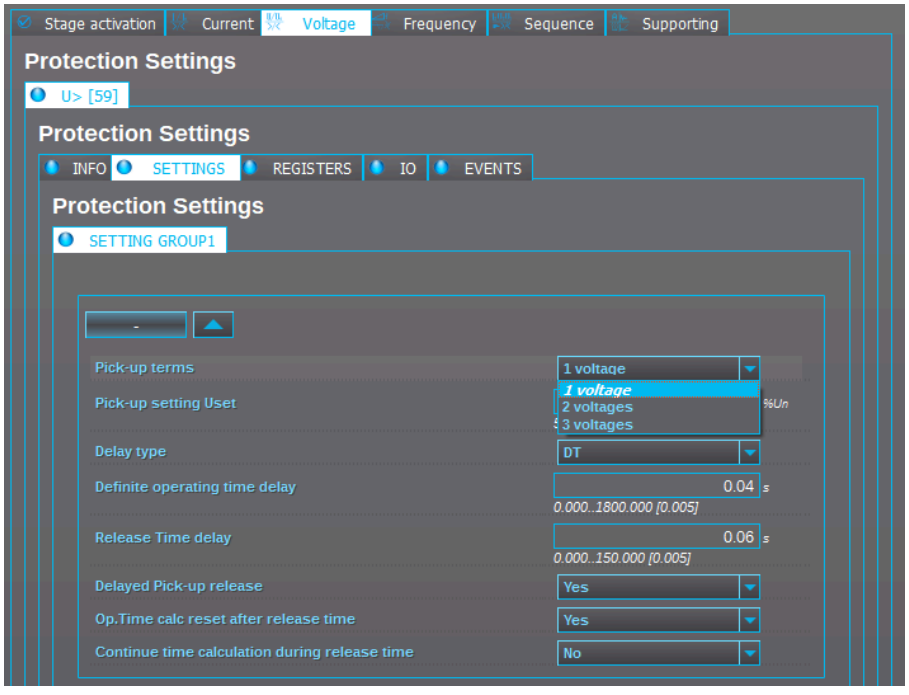



Voltage protection itself is based on the nominal voltage. A 20 000 V nominal voltage equals a 100 % setting in voltage-based protection functions. A 120 % trip setting in the overvoltage stage equals to 24 000 V on the primary level (in this case a 20 % increase equals 4000 V).

Once the settings have been sent to the device, device calculates the scaling factors and displays them for the user. The "VT scaling factor P/S" describes the ratio between the primary voltage and the secondary voltage. The per-unit scaling factors ("VT scaling factor p.u.") for both primary and secondary values are also displayed.

The triggering of a voltage protection stage can be based on one, two, or three voltages (the "Pick-up terms" setting at *Protection* → *Voltage* → [protection stage menu] → *Settings*). Fault loops are either line-to-line or line-to-neutral according to the "Measured magnitude" setting. As a default, the activation of any one voltage trips the voltage protection stage.

Figure. 5.2.2 - 16. Selecting the operating mode.





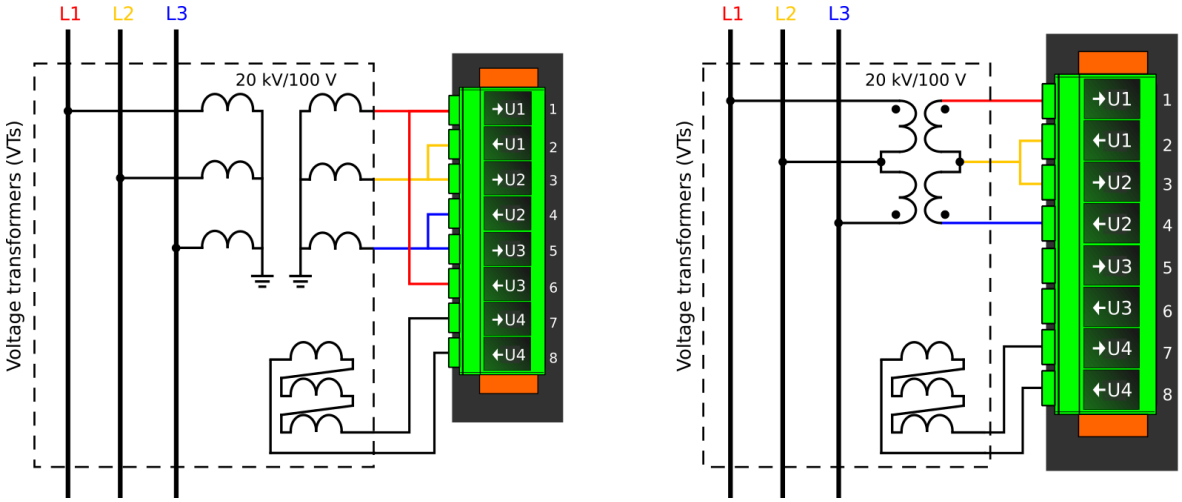

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There are several different ways to use all four voltage channels. The voltage measurement modes are the following:

- 3LN+U4 (three line-to-neutral voltages and U4 can be used for either zero sequence voltage or synchrochecking)
- 3LL+U4 (three line-to-line voltages and U4 can be used either for zero sequence voltage or synchrochecking)
- 2LL+U3+U4 (two line-to-line voltages and the U3 and the U4 channels can be used for synchrochecking, zero sequence voltage, or for both)

The 3LN+U0 is the most common voltage measurement mode. See below for example connections of voltage line-to-line measurement (3LL on the left, 2LL on the right).

Figure. 5.2.2 - 17. Example connections for voltage line-to-line measurement.

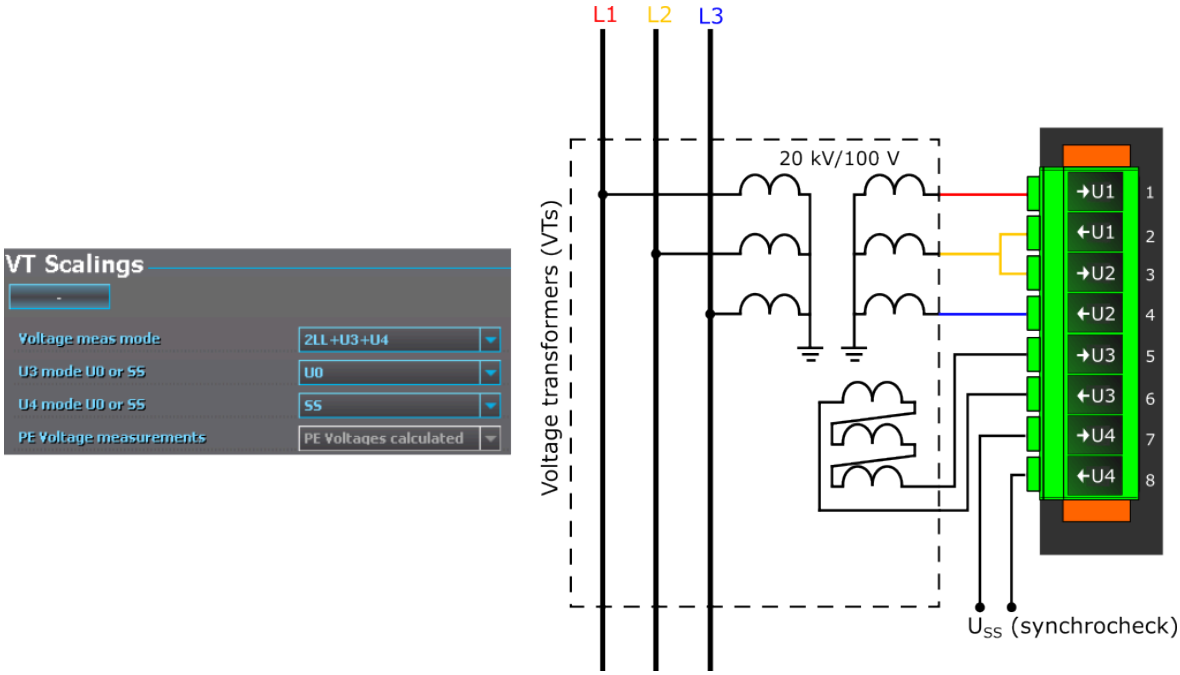



If only two line-to-line voltages are measured, the third one ($U_{L31}$) is calculated based on the $U_{L12}$ and $U_{L23}$ vectors. When measuring line-to-line voltages, the line-to-neutral voltages can also be calculated as long as the value of U0 is measured and known.

The voltage measurement channel U4 can also be used to measure either the zero sequence voltage (U0) or the side 2 voltage of the circuit breaker (Synchrocheck). If the 2LL+U3+U4 mode is selected, the third channel (U3) can be used for this purpose. Please note that U0 can only be measured by using a single channel.

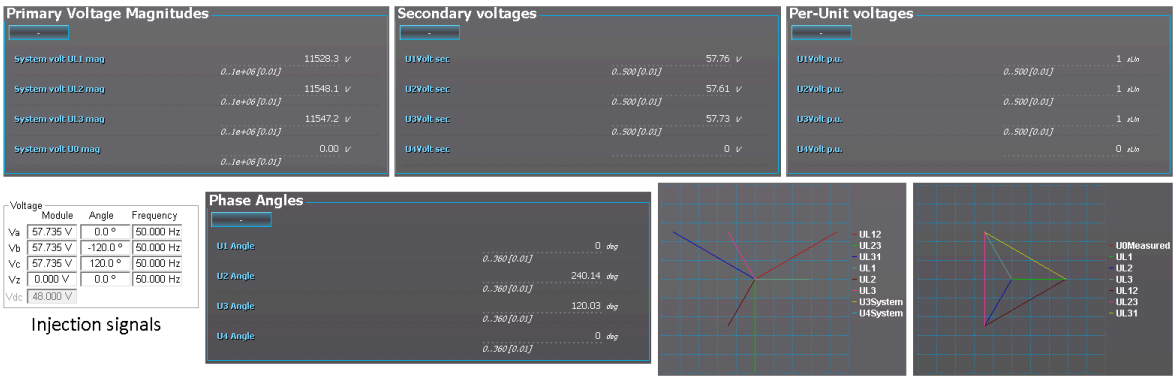
In the image below is an example of 2LL+U0+SS, that is, two line-to-line measurements with the zero sequence voltage and voltage from side 2 for Synchrocheck. Since U0 is available, line-to-neutral voltages can be calculated.

Figure. 5.2.2 - 18. 2LL+U0+SS settings and connections.




The image collection below presents the device's behavior when nominal voltage is injected into the device via secondary test equipment. The measurement mode is 3LN+U4 which means that the device is measuring line-to-neutral voltages. The VT scaling has been set to 20 000 : 100 V. The U4 channel measures the zero sequence voltage which has the same ratio (20 000 : 100 V).

Figure. 5.2.2 - 19. Measurement behavior when nominal voltage injected.

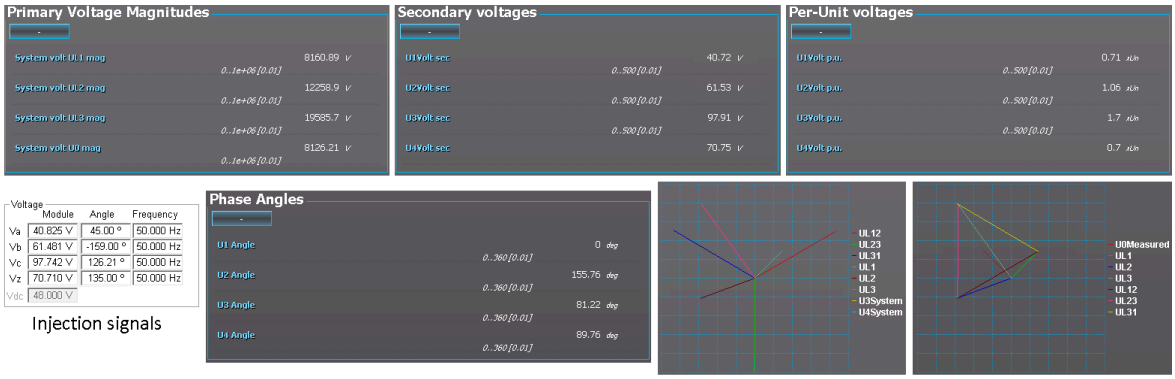



The image collection below presents the device's behavior when voltage is injected into the device via secondary test equipment during an earth fault. The measurement mode is 3LN+U4 which means that the device is measuring line-to-neutral voltages. The VT scaling has been set to 20 000 : 100 V. The U4 channel measures the zero sequence voltage which has the same ratio (20 000 : 100 V).



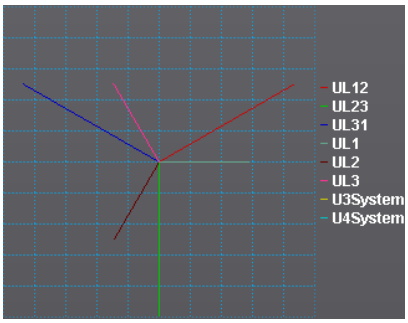
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Figure. 5.2.2 - 20. Device behavior when voltage injected during an earth fault.




## Troubleshooting

When the measured voltage values differ from the expected voltage values, the following table offers possible solutions for the problems.

| Problem | Check / Resolution |
|---|---|
| The measured voltage amplitude in all phases does not match the injected voltage. | The scaling settings or the voltage measurement mode may be wrong, check that the settings match with the connected voltage transformer (*Measurement → Transformers → VT Module*). |
| The measured voltage amplitude does not match one of the measured phases./<br><br>The calculated U0 is measured even though it should not. | Check the wiring connections between the injection device or the VTs and the device. |
| The measured voltage amplitudes are OK but the angles are strange./<br><br>The voltage unbalance protection trips immediately after activation./<br><br>The earth fault protection trips immediately after it is activated and voltage calculated. | The voltages are connected to the measurement module but the order or polarity of one or all phases is incorrect. In device settings, go to *Measurement → Phasors* and check the "System voltage vectors" diagram. When all connections are correct, the diagram (symmetric feeding) should look like this:<br>  |

## Settings

Table. 5.2.2 - 27. Settings of the VT scaling.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Voltage measurement mode | 0: 3LN+U4<br>1: 3LL+U4<br>2: 2LL+U3+U4 | - | 0: 3LN+U4 | The device's voltage wiring method. The voltages are scaled according the set voltage measurement mode. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| U3 mode U0 or SS | 0: Not Used<br>1: U0<br>2: SS | - | 0: Not Used | The voltage channel U3 can be used to measure zero sequence voltage (U0) or the Synchrocheck voltage (SS). If neither is needed, the (default) option "Not Used" should be active. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U0 (U3) Measured from | 0: Broken Delta<br>1: Neutral point<br>2: Open delta | - | 0: Broken delta | Defines how the secondary voltage is scaled to the primary. Does not affect how protection operates, it only affects the displayed primary voltages. This parameter is visible when the "U3 mode U0 or SS" has been set to the "U0" mode. |
| U4 mode U0 or SS | 0: Not Used<br>1: U0<br>2: SS | - | 0: Not Used | The voltage channel U4 can be used to measure zero sequence voltage (U0) or the Synchrocheck voltage (SS). If neither is needed, the (default) option "Not Used" should be active. |
| U0 (U4) Measured from | 0: Broken Delta<br>1: Neutral point<br>2: Open delta | - | 0: Broken delta | Defines how the secondary voltage is scaled to the primary. Does not affect how protection operates, it only affects the displayed primary voltages. This parameter is visible when the "U4 mode U0 or SS" has been set to the "U0" mode. |
| Voltage memory | 0: Disabled<br>1: Activated | - | 0: Disabled | Activates the voltage memory. The "Voltage memory" chapter describes the function in more detail. |
| P-E Voltage measurements | 0: No P-E voltages available<br>1: P-E Voltages calculated<br>2: P-E Voltages measured | - | - | Indicates whether or not phase-to-earth voltages are available. Also indicates whether P-E voltages are measured from the voltage channels directly or if they are calculated from measured line-to-line and zero sequence voltages. |
| VT primary | 1…1000000.0V | 0.1V | 20000.0V | The rated primary voltage of the voltage transformer. |
| VT secondary | 0.2…400.0V | 0.1V | 100.0V | The rated secondary voltage of the voltage transformer. |
| U3 Res/SS VT primary | 1…1000000V | 0.1V | 20000.0V | The primary nominal voltage of the connected U0 or SS VT. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U3 Res/SS VT secondary | 0.2…400V | 0.1V | 100.0V | The secondary nominal voltage of the connected U0 or SS VT. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U4 Res/SS VT primary | 1…1000000V | 0.1V | 20000.0V | The primary nominal voltage of the connected U0 or SS VT. |
| U4 Res/SS VT secondary | 0.2…400V | 0.1V | 100.0V | The secondary nominal voltage of the connected U0 or SS VT. |
| U1 Polarity | 0: -<br>1: Invert | - | 0: - | The selection of the first voltage measurement channel's (U1) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line. |
| U2 Polarity | 0: -<br>1: Invert | - | 0: - | The selection of the second voltage measurement channel's (U2) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line. |
| U3 Polarity | 0: -<br>1: Invert | - | 0: - | The selection of the third voltage measurement channel's (U3) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line. |
| U4 Polarity | 0: -<br>1: Invert | - | 0: - | The selection of the fourth voltage measurement channel's (U4) polarity (direction). The default setting is for the positive voltage to flow from connector 1 to connector 2, with the secondary voltage's starpoint pointing towards the line. |
| VT scaling factor P/S | - | - | - | A feedback value; the calculated scaling factor that is the ratio between the primary voltage and the secondary voltage. |
| VT scaling factor p.u. Pri | - | - | - | A feedback value; the scaling factor for the primary voltage's per-unit value. |
| VT scaling factor p.u. Sec | - | - | - | A feedback value; the scaling factor for the secondary voltage's per-unit value. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| U3 VT scaling factor P/S U0/SS | - | - | - | A feedback value; the scaling factor that is the ratio between the U3 channel's primary and secondary voltages. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U3 scaling factor p.u. Pri | - | - | - | A feedback value for channel U3; the scaling factor for the primary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U3 scaling factor p.u. Sec | - | - | - | A feedback value for channel U3; the scaling factor for the secondary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U4 VT scaling factor P/S U0/SS | - | - | - | A feedback value; the scaling factor that is the ration between the U4 channel's primary and secondary voltages. This setting is only valid is the "2LL+U3+U4" mode is selected. |
| U4 scaling factor p.u. Pri | - | - | - | A feedback value for channel U4; the scaling factor for the primary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected. |
| U4 scaling factor p.u. Sec | - | - | - | A feedback value for channel U4; the scaling factor for the secondary voltage's per-unit value. This setting is only valid if the "2LL+U3+U4" mode is selected. |

## Measurements

The following measurements are available in the measured voltage channels.

Table. 5.2.2 - 28. Per-unit voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Voltage Ux ("UxVolt p.u.") | × $U_n$ | 0.00…500.0 | 0.01 | The RMS voltage measurement (in p.u.) from each of the voltage channels. |
| Voltage Ux TRMS ("UxVolt TRMS p.u.") | × $U_n$ | 0.00…500.0 | 0.01 | The TRMS voltage (inc. harmonics up to 31$^{st}$) measurement (in p.u.) from each of the voltage channels. |

Table. 5.2.2 - 29. Secondary voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary voltage Ux ("Ux Volt sec") | V | 0.00…500.0 | 0.01 | The secondary RMS voltage measurement from each of the voltage channels. |
| Secondary voltage Ux TRMS ("UxVolt TRMS sec") | V | 0.00…500.0 | 0.01 | The secondary TRMS voltage (inc. harmonics up to 31$^{st}$) measurement from each of the voltage channels. |

Table. 5.2.2 - 30. Voltage phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Ux Angle | deg | 0.00…360.00 | 0.01 | The phase angle measurement from each of the four voltage inputs. |

Table. 5.2.2 - 31. Per-unit sequence voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence voltage ("Pos.seq.Volt.p.u.") | × $U_n$ | 0.00…500.0 | 0.01 | The measurement (in p.u.) from the calculated positive sequence voltage. |

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Negative sequence voltage ("Neg.seq.Volt.p.u.") | × $U_n$ | 0.00…500.0 | 0.01 | The measurement (in p.u.) from the calculated negative sequence voltage. |
| Zero sequence voltage ("Zero.seq.Volt.p.u.") | × $U_n$ | 0.00…500.0 | 0.01 | The measurement (in p.u.) from the calculated zero sequence voltage. |

Table. 5.2.2 - 32. Primary sequence voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary positive sequence voltage ("Pos.seq.Volt.pri") | V | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated positive sequence voltage. |
| Primary negative sequence voltage ("Neg.seq.Volt.pri") | V | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated negative sequence voltage. |
| Primary zero sequence voltage ("Zero.seq.Volt.pri") | V | 0.00…1000000.00 | 0.01 | The primary measurement from the calculated zero sequence voltage. |

Table. 5.2.2 - 33. Secondary sequence voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary positive sequence voltage ("Pos.seq.Volt.sec") | V | 0.00…4800.0 | 0.01 | The secondary measurement from the calculated positive sequence voltage. |
| Secondary negative sequence voltage ("Neg.seq.Volt.sec") | V | 0.00…4800.0 | 0.01 | The secondary measurement from the calculated negative sequence voltage. |
| Secondary zero sequence voltage ("Zero.seq.Volt.sec") | V | 0.00…4800.0 | 0.01 | The secondary measurement from the calculated zero sequence voltage. |

Table. 5.2.2 - 34. Sequence voltage angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence voltage angle ("Pos.seq.Volt.Angle") | deg | 0.00…360.0 | 0.01 | The calculated positive sequence voltage angle. |
| Negative sequence voltage angle ("Neg.seq.Volt.Angle") | deg | 0.00…360.0 | 0.01 | The calculated negative sequence voltage angle. |
| Zero sequence voltage angle ("Zero.seq.Volt.Angle") | deg | 0.00…360.0 | 0.01 | The calculated zero sequence voltage angle. |

Table. 5.2.2 - 35. System primary voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| System voltage magnitude UL12 ("System volt UL12 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-line UL12 voltage (measured or calculated). You can also select the row where the unit for this is kV. |



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| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| System voltage magnitude UL23 ("System volt UL23 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-line UL23 voltage (measured or calculated). You can also select the row where the unit for this is kV. |
| System voltage magnitude UL31 ("System volt UL31 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-line UL31 voltage (measured or calculated). You can also select the row where the unit for this is kV. |
| System voltage magnitude UL1 ("System volt UL1 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-neutral UL1 voltage (measured or calculated). You can also select the row where the unit for this is kV. |
| System voltage magnitude UL2 ("System volt UL2 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-neutral UL2 voltage (measured or calculated). You can also select the row where the unit for this is kV. |
| System voltage magnitude UL3 ("System volt UL3 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS line-to-neutral UL3 voltage (measured or calculated). You can also select the row where the unit for this is kV. |
| System voltage magnitude U0 ("System volt U0 mag") | V | 0.00…1000000.00 | 0.01 | The primary RMS zero sequence U0 voltage (measured or calculated). You can also select the row where the unit for this is kV. There is also a row where the unit is %. |
| System voltage magnitude U3 ("System volt U3 mag") | V | 0.00…1000000.00 | 0.01 | The primary measured RMS Synchrocheck voltage (SS). This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. You can also select the row where the unit for this is kV. |
| System voltage magnitude U4 ("System volt U4 mag") | V | 0.00…1000000.00 | 0.01 | The primary measured RMS Synchrocheck voltage (SS). This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. You can also select the row where the unit for this is kV. |

Table. 5.2.2 - 36. Primary system voltage angles.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| System voltage angle UL12 ("System volt UL12 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-line angle UL12 (measured or calculated). |
| System voltage angle UL23 ("System volt UL23 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-line angle UL23 (measured or calculated). |
| System voltage angle UL31 ("System volt UL31 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-line angle UL23 (measured or calculated). |
| System voltage angle UL1 ("System volt UL1 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-neutral angle UL1 (measured or calculated). |
| System voltage angle UL2 ("System volt UL2 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-neutral angle UL2 (measured or calculated). |
| System voltage angle UL3 ("System volt UL3 ang") | deg | 0.00…360.0 | 0.01 | The primary line-to-neutral angle UL3 (measured or calculated). |
| System voltage angle U0 ("System volt U0 ang") | deg | 0.00…360.0 | 0.01 | The primary zero sequence angle U0 (measured or calculated). |
| System voltage angle U3 ("System volt U3 ang") | deg | 0.00…360.0 | 0.01 | The primary measured Synchrocheck angle SS. This magnitude is only valid when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. |
| System voltage angle U4 ("System volt U4 ang") | deg | 0.00…360.0 | 0.01 | The primary measured Synchrocheck angle SS. This magnitude is displayed only when the "2LL+U3+U4" mode is selected and both U3 and U4 are in use. |

Table. 5.2.2 - 37. Harmonic voltage measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Harmonics calculation values ("Harm Abs.or Perc.") | - | 0: Percent<br>1: Absolute | - | Defines whether the harmonics are calculated as percentages or absolute values. |
| Harmonics display | - | 0: Per unit<br>1: Primary V<br>2: Secondary V | - | Defines how the harmonics are displayed: in p.u. values, as primary voltage values, or as secondary voltage values. |



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| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Maximum harmonics value ("UxMaxH") | V | 0.00…100000.00 | 0.01 | Displays the maximum harmonics value of the selected voltage input Ux. |
| Fundamental frequency ("Ux Fund") | V | 0.00…100000.00 | 0.01 | Displays the voltage value of the fundamental frequency value (RMS) of the selected voltage input Ux. |
| Ux harmonics ($2^{nd}$...$31^{st}$ harmonic) | V | 0.00...100000.00 | 0.01 | Displays the selected harmonic from the voltage input Ux. |
| Ux Amplitude THD | % | 0.000...100.000 | 0.001 | Amplitude ratio THD voltage. Recognized by IEC. |
| Ux Power THD | % | 0.000...100.000 | 0.001 | Power ratio THD voltage. Recognized by the IEEE. |

### 5.2.3 Power and energy calculation

The devices that are equipped with both a voltage and a current measurement card can calculate power, and can therefore have power-based protection and monitoring functions (the number of available functions depends of the device type). In addition to power calculations, energy magnitudes are also calculated.

Power is divided into three magnitudes: apparent power (S), active power (P) and reactive power (Q). Energy measurement calculates magnitudes for active and reactive energy. Energy can flow to the forward direction (exported) or to the reverse direction (imported).

If a unit has more than one CT measurement module, the user can choose which module's current measurement is used by the power calculation.

#### Line-to-neutral voltages available

Power is calculated from line-to-neutral voltages and phase currents. If line-to-line voltages are connected, the device can calculate line-to-neutral voltages based on the measured zero sequence voltage. The following equations apply for power calculations with the line-to-neutral mode and the line-to-line voltage mode (with U0 connected and measured):

Figure. 5.2.3 - 21. Three-phase power (S) calculation.

$$S_{L1} = U_{L1} \times I_{L1}$$

$$S_{L2} = U_{L2} \times I_{L2}$$

$$S_{L3} = U_{L3} \times I_{L3}$$

$$S = S_{L1} + S_{L2} + S_{L3}$$

Figure. 5.2.3 - 22. Three-phase active power (P) calculation.

$$P_{L1} = U_{L1} \times I_{L1} \cos\varphi$$

$$P_{L2} = U_{L2} \times I_{L2} \cos\varphi$$

$$P_{L3} = U_{L3} \times I_{L3} \cos\varphi$$

$$P = P_{L1} + P_{L2} + P_{L3}$$

In these equations, phi (φ) is the angle difference between voltage and current.

Figure. 5.2.3 - 23. Three-phase reactive power (Q) calculation.

$$Q_{L1} = U_{L1} \times I_{L1} \sin \varphi$$

$$Q_{L2} = U_{L2} \times I_{L2} \sin \varphi$$

$$Q_{L3} = U_{L3} \times I_{L3} \sin \varphi$$

$$Q = Q_{L1} + Q_{L2} + Q_{L3}$$

Active power can be to the forward or the reverse direction. The direction of active power can be indicated with the power factor (Cos (φ), or Cosine phi), which is calculated according the following formula:

$$3PH\ Cos(phi) = {}^{P}/_{S}$$

$$L1\ Cos(phi) = {}^{P_{L1}}/_{S_{L1}}$$

$$L2\ Cos(phi) = {}^{P_{L2}}/_{S_{L2}}$$

$$L3\ Cos(phi) = {}^{P_{L3}}/_{S_{L3}}$$

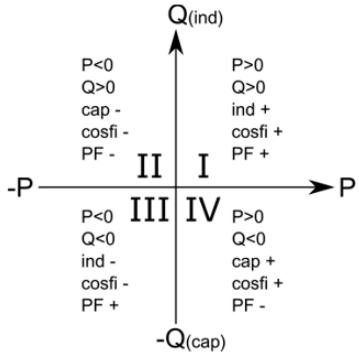
The direction of reactive power is divided into four quadrants. Reactive power may be inductive or capacitive on both forward and reverse directions. Reactive power quadrant can be indicated with Tan (φ) (tangent phi), which is calculated according the following formula:

$$3PH\ Tan(phi) = {}^{Q}/_{P}$$

$$L1\ Tan(phi) = {}^{Q_{L1}}/_{P_{L1}}$$

$$L2\ Tan(phi) = {}^{Q_{L2}}/_{P_{L2}}$$

$$L3\ Tan(phi) = {}^{Q_{L3}}/_{P_{L3}}$$




Power factor calculation is done similarly to the Cosine phi calculation but the polarity is defined by the reactive power direction. Therefore, the power factor is calculated with the following formula:

$$3PH\ PF = {}^{P}/_{S} * {}^{Q}/_{|Q|}$$

$$L1\ PF = {}^{P_{L1}}/_{S_{L1}} * {}^{Q_{L1}}/_{|Q_{L1}|}$$

$$L2\ PF = {}^{P_{L2}}/_{S_{L2}} * {}^{Q_{L2}}/_{|Q_{L2}|}$$

$$L3\ PF = {}^{P_{L3}}/_{S_{L3}} * {}^{Q_{L3}}/_{|Q_{L3}|}$$


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Only line-to-line voltages available

If the line-to-line voltages are measured but the zero sequence voltage is not measured or is not otherwise known, the three-phase power calculation is based on Aron's theorem:

$$S = U_{23} \times I_{L1} \cos(30) + U_{31} \times I_{L2} \cos(30)$$

$$P = U_{23} \times I_{L1} \cos(30 - \varphi) + U_{31} \times I_{L2} \cos(30 + \varphi)$$

$$Q = U_{23} \times I_{L1} + \sin(30 - \varphi) + U_{31} \times I_{L2} \sin(30 + \varphi)$$

Both cos(φ) and tan(φ) are calculated in the same way as in the line-to-neutral mode.

## Troubleshooting

Check the "Troubleshooting" section in chapters "Current measurement and scaling" and "Voltage measurement and scaling" for more information. Most power and energy measurement problems are usually related to the same issues (i.e. wiring errors, wrong measurement modes, faulty frequency settings, etc.).

## Settings

Table. 5.2.3 - 38. Power and energy measurement settings

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 3ph active energy measurement | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables/disables the active energy measurement. |
| 3ph reactive energy measurement | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables/disables the reactive and apparent energy measurement. |
| 3ph energy megas or kilos | 0: Mega<br>1: Kilo | - | 0: Mega | Defines whether energy is measured with the prefix 'kilo' ($10^3$) or 'mega' ($10^6$). |
| Edit energy values | 0: Disabled<br>1: Enabled | - | 0: Disabled | When this parameter is enabled it is possible to manually edit exported and imported active energy values.<br><br>NOTE: "E 3ph M or k" parameter has to be set to "kilo" for this feature to function. |
| Invert imp/exp energy directions | 0: Not inverted<br>1: Inverted | - | 0: Not inverted | Inverts the direction of imported and exported energy without affecting the direction of power calculation. |
| Nominal power kVA | 0.10...500000.00kVA | 0.01kVA | 100kVA | Defines the nominal power of the protected object. |
| PQ Quadrant | 0: Undefined<br>1: Q1 Fwd Ind<br>2: Q2 Rev Cap<br>3: Q3 Rev Ind<br>4: Q4 Fwd Cap | - | 0: Undefined | Indicates what the power PQ quadrant is at that moment. |
| VA Quadrant | 0: Undefined<br>1: Q1 Fwd Cap AV<br>2: Q2 Rev Ind AV<br>3: Q3 Rev Cap VA<br>4: Q4 Fwd Ind VA | - | 0: Undefined | Indicates what the power VA quadrant is at that moment. |
| Reset energy calculators ("Reset 3ph Energies") | 0: -<br>1: Reset | - | 0: - | Resets the memory of the three-phase energy calculators. Goes automatically back to the "-" state after the reset is finished. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Phase active energy measurement | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables/disables the active energy per phase measurement. |
| Phase reactive energy measurement | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables/disables the reactive energy per phase measurement. |
| Phase energies megas or kilos | 0: Mega<br>1: Kilo | - | 0: Mega | Defines whether energy (per phase) is measured with the prefix 'kilo' ($10^3$) or 'mega' ($10^6$). |
| Reset energy calculators (per phase) ("Reset E per phase") | 0: -<br>1: Reset | - | 0: - | Resets the memory of the indivisual phase energy calculator. Goes automatically back to the "-" state after the reset is finished. |

Table. 5.2.3 - 39. Energy Dose Counter 1 settings

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Energy dose counter mode | 0: Disabled<br>1: Activated | - | 0: Disabled | Enables/disables energy dose counters generally. |
| Energy dose counter LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | 0: On | Set mode of DOS block.<br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Energy does counter LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | - | Displays the mode of DOS block.<br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Clear pulse counter | 0: -<br>1: Clear | - | 0: - | Resets the "DC 1…4 Pulses sent" counters back to zero. |
| DC 1…4 enable | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables/disables the energy dose counter 1…4 individually. |
| DC 1…4 Input signal select | 0: 3PH.Fwd.Act.EP<br>1: 3PH.Rev.Avt.EP<br>2: 3PH.Fwd.React.EQ.CAP<br>3: 3PH.Fwd.React.EQ.IND<br>4: 3PH.Rev.React.EQ.CAP<br>5: 3PH.Rev.React.EQ.IND | - | 0: 3PH.Fwd.Act.EP | Selects whether the energy is active or reactive, whether the direction of the energy is forward of reverse, and whether reactive energy is inductive or capacitive. |
| DC 1…4 Input signal | $-1 \times 10^6 \ldots 1 \times 10^6$ | 0.01 | - | The total amount of energy consumed. |
| DC 1…4 Pulse magnitude | 0…1800kW/var | 0.005kW/var | 1kW/Var | The set pulse size. An energy pulse is given every time the set magnitude is exceeded. |
| DC 1…4 Pulse length | 0…1800s | 0.005s | 1s | The total length of a control pulse. |
| DC1…4 Pulses sent | 0…4 294 967 295 | 1 | - | Indicates the total number of pulses sent. |



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Table. 5.2.3 - 40. DC 1…4 Pulse out settings

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| DC 1…4 Pulse out | OUT1…OUTx | - | None selected | The selection of the controlled physical outputs. |

## Power measurements

The following power calculations are available when the voltage and the current cards are available.

Table. 5.2.3 - 41. Three-phase power calculations.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| 3PH Apparent power (S) | kVA | $-1x10^6 \ldots 1x10^6$ | 0.01 | The total three-phase apparent power in kilo-volt-ampere |
| 3PH Active power (P) | kW | $-1x10^6 \ldots 1x10^6$ | 0.01 | The total three-phase active power in kilowatts |
| 3PH Reactive power (Q) | kVar | $-1x10^6 \ldots 1x10^6$ | 0.01 | The total three-phase reactive power in kilovars |
| 3PH Apparent power (S MVA) | MVA | $-1x10^5 \ldots 1x10^5$ | 0.01 | The total three-phase apparent power in megawatts |
| 3PH Active power (P MW) | MW | $-1x10^5 \ldots 1x10^5$ | 0.01 | The total three-phase active power in mewatts |
| 3PH Reactive power (QMVar) | MVar | $-1x10^5 \ldots 1x10^5$ | 0.01 | The total three-phase active power in megavars |
| 3PH Tan(phi) | - | $-1x10^6 \ldots 1x10^6$ | 0.01 | The direction of three-phase active power |
| 3PH Cos(phi) | - | $-1x10^6 \ldots 1x10^6$ | 0.01 | The direction of three-phase reactive power |
| 3PH Power factor | - | $-1x10^6 \ldots 1x10^6$ | 0.0001 | The three-phase power factor |

Table. 5.2.3 - 42. Single-phase power calculations (L1...L3).

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Lx Apparent power (S) | kVA | $-1x10^6 \ldots 1x10^6$ | 0.01 | The apparent power of Phase Lx in kilo-volt-amperes |
| Lx Active power (P) | kW | $-1x10^6 \ldots 1x10^6$ | 0.01 | The active power of Phase Lx in kilowatts |
| Lx Reactive power (Q) | kVar | $-1x10^6 \ldots 1x10^6$ | 0.01 | The reactive power of Phase Lx kilovars |
| Lx Tan(phi) | - | $-1x10^6 \ldots 1x10^6$ | 0.01 | The direction of Phase Lx's active power |
| Lx Cos(phi) | - | $-1x10^6 \ldots 1x10^6$ | 0.01 | The direction of Phase Lx's reactive power |
| Lx Power factor | - | $-1x10^6 \ldots 1x10^6$ | 0.0001 | The power factor of Phase Lx |

## Energy measurements

The following energy calculations are available when the voltage and the current cards are available. Please note that the unit prefix is determined by the user's selection between 'kilo' and 'mega' in "Three-phase energy prefix ("E 3ph M or k")" under the general "Power and energy measurement settings".

Table. 5.2.3 - 43. Three-phase energy calculations.

| Name | Range | Step | Description |
|---|---|---|---|
| Exported Active Energy (P) (kWh or MWh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of exported active energy. |

| Name | Range | Step | Description |
|---|---|---|---|
| Imported Active Energy (P) (kWh or MWh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of imported active energy. |
| Active Energy (P) Export/Import balance (kWh or MWh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The sum of imported and exported active energy. |
| Exported (Q) while Export (P) (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of exported reactive energy while active power is exported. |
| Imported (Q) while Export (P). (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | Total amount of imported reactive energy while active energy is exported. |
| Reactive energy (Q) balance while export (P) (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The sum of imported and exported reactive capacitive energy while active power is exported. |
| Exported (Q) while Import (P) (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of exported reactive energy while active energy is imported. |
| Imported (Q) while Import (P) (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of imported reactive energy while active energy is imported. |
| Reactive energy (Q) balance while Import (P) (kVarh or MVarh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The sum of imported and exported reactive energy while active energy is imported. |
| Apparent Energy (S) while Export (P) (kVAh or MVAh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of exported apparent energy while active energy is exported. |
| Apparent Energy (S) while Import (P) (kVAh or MVAh) | -999 999 995 904.00…999 999 995 904.00 | 0.01 | The total amount of exported apparent energy while active energy is imported. |

Table. 5.2.3 - 44. Single-phase energy calculations (L1...L3).

| Name | Range | Step | Description |
|---|---|---|---|
| Export Active Energy Lx (kWh or MWh) | $-1x10^9…1x10^9$ | 0.01 | The exported active energy of the phase. |
| Import Active Energy (kWh or MWh) | $-1x10^9…1x10^9$ | 0.01 | The imported active energy of the phase. |
| Active Energy (P) Export/Import balance (kWh or MWh) | $-1x10^9…1x10^9$ | 0.01 | The sum of the phase's imported and exported active energy. |
| Exported (Q) while Export (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The exported reactive energy of the phase while active energy is exported. |
| Imported (Q) while Export (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The imported reactive energy of the phase while active energy is exported. |
| Reactive Energy (Q) balance while Export (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The sum of the phase's imported and exported reactive energy while active energy is exported. |
| Exported (Q) while Import (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The exported reactive energy of the phase while active energy is imported. |
| Imported (Q) while Import (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The imported reactive energy of the phase while active energy is imported. |
| Reactive energy (Q) balance while Import (P) Lx (kVarh or MVarh) | $-1x10^9…1x10^9$ | 0.01 | The sum of the phase's imported and exported reactive energy while active energy is imported. |
| Apparent Energy (S) while Export (P) Lx | $-1x10^9…1x10^9$ | 0.01 | The apparent energy of the phase while active energy is exported. |



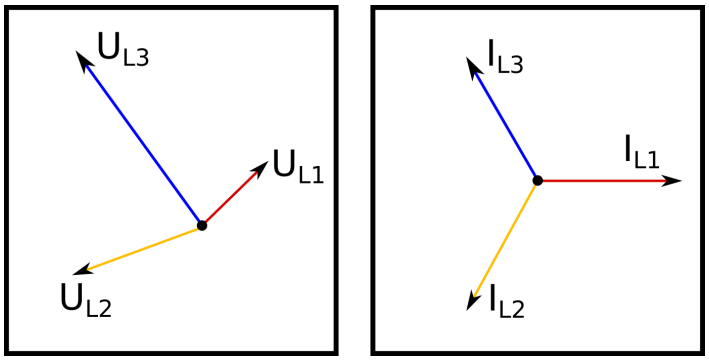
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| Name | Range | Step | Description |
|---|---|---|---|
| Apparent Energy (S) while Import (P) Lx | $-1x10^9 \ldots 1x10^9$ | 0.01 | The apparent energy of the phase while active energy is imported. |

## Calculation examples

Here is an example of power calculation. Both wiring methods (line-to-line and line-to-neutral) are checked with the same signal injection. The voltage scaling is set to 20 000 : 100 V and the current scaling is set to 1000 : 5 A.

| Voltages (line-to-neutral): | Currents: |
|---|---|
| $U_{L1}$ = 40.825 V, 45.00° | $I_{L1}$ = 2.5 A, 0.00° |
| $U_{L2}$ = 61.481 V, -159.90° | $I_{L2}$ = 2.5 A, -120.00° |
| $U_{L3}$ = 97.742 V, 126.21° | $I_{L3}$ = 2.5 A, 120.00° |




$$S_{L1} = U_{L1} \times I_{L1} = 40.825\ \text{V} \times 2.5\ \text{A} = 102\ \text{VA (secondary)}\ 4.08\ \text{MVA (primary)}$$

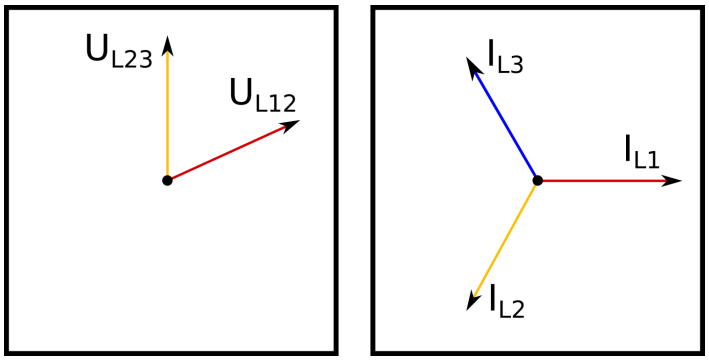
$$P_{L1} = U_{L1} \times I_{L1} \cos\varphi = 40.825\ \text{V} \times 2.5\ \text{A} \cos(45° - 0°) = 72.2\ \text{W (secondary)}\ 2.89\ \text{MW (primary)}$$

$$Q_{L1} = U_{L1} \times I_{L1} \sin\varphi = 40.825\ \text{V} \times 2.5\ \text{A} \sin(45° - 0°) = 72.2\ \text{var (secondary)}\ 2.89\ \text{MVar (primary)}$$

$$L1\ Tan(phi) = {}^{Q_{L1}}/_{P_{L1}} = {}^{2.89}/_{2.89} = 1.00 \qquad L1\ Cos(phi) = {}^{P_{L1}}/_{S_{L1}} = {}^{2.89}/_{4.08} = 0.71$$

| Name | Value | Name | Value | Name | Value | Name | Value |
|---|---|---|---|---|---|---|---|
| L1 (S) | 4.08 MVA | L2 (S) | 6.15 MVA | L3 (S) | 9.77 MVA | 3PH (S) | 20.00 MVA |
| L1 (P) | 2.89 MW | L2 (P) | 4.72 MW | L3 (P) | 9.71 MW | 3PH (P) | 17.32 MW |
| L1 (Q) | 2.89 Mvar | L2 (Q) | -3.94 Mvar | L3 (Q) | 1.06 Mvar | 3PH (Q) | 0.01 Mvar |
| L1 Tan | 1.00 | L2 Tan | -0.83 | L3 Tan | 0.11 | 3PH Tan | 0.00 |
| L1 Cos | 0.71 | L2 Cos | 0.77 | L3 Cos | 0.99 | 3PH Cos | 0.87 |

| Voltages (line-to-line): | Currents: |
|---|---|
| $U_{L12}$ = 100.00 V, 30.00° | $I_{L1}$ = 2.5 A, 0.00° |
| $U_{L23}$ = 100.00 V, -90.00° | $I_{L2}$ = 2.5 A, -120.00° |
| | $I_{L3}$= 2.5 A, 120.00° |




$$S = U_{12} \times I_{L1} + U_{23} \times I_{L2}$$

$$S = 100\ \text{V} \times 2.5\ \text{A} + 100\ \text{V} \times 2.5\ \text{A} = 500\ \text{VA (sec)}\ 20.00\ \text{MVA (pri)}$$

$$P = U_{12} \times I_{L1} \cos(-\varphi) + U_{23} \times I_{L2} \cos(\varphi)$$

$$P = 100\ \text{V} \times 2.5\ \text{A} \cos -(30° - 0°) + 100\ \text{V} \times 2.5\ \text{A} \cos(270° - 240°) = 433\ \text{W}\ (sec)\ 17.32\ \text{MW}\ (pri)$$

$$Q = U_{12} \times I_{L1} + \sin(-\varphi) + U_{23} \times I_{L2} \sin(\varphi)$$

$$Q = 100\ \text{V} \times 2.5\ \text{A} \sin -(30° - 0°) + 100\ \text{V} \times 2.5\ \text{A} \sin(270° - 240°) = 0\ \text{var (sec)}\ 0\ \text{Mvar}\ (pri)$$

$$3PH\ Tan(phi) = {}^{Q}/_{P} = {}^{0.01}/_{17.32} = 0.00 \qquad 3PH\ Cos(phi) = {}^{P}/_{S} = {}^{17.32}/_{20.00} = 0.87$$

| Name | Values |
|---|---|
| 3PH (S) | 20.00 MVA |
| 3PH (P) | 17.32 MW |
| 3PH (Q) | 0.00 Mvar |
| 3PH Tan | 0.00 |
| 3PH Cos | 0.87 |

### 5.2.4 Frequency tracking and scaling

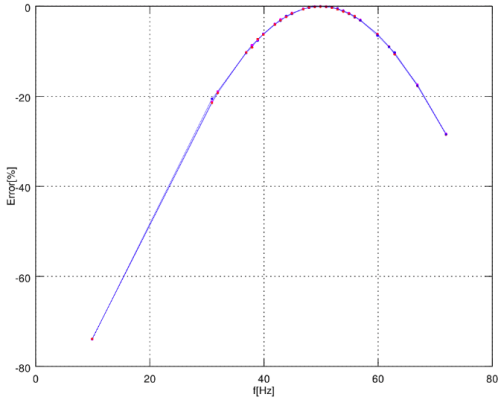
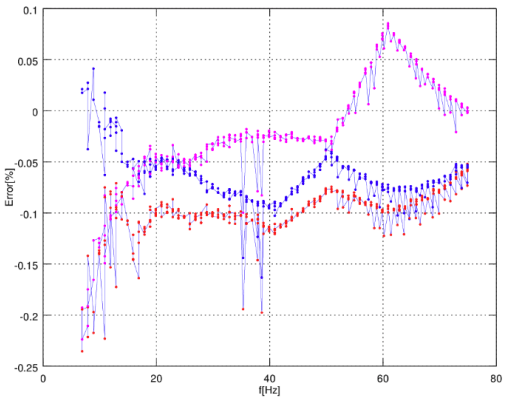
Measurement sampling can be set to the frequency tracking mode or to the fixed user-defined frequency sampling mode. The benefit of frequency tracking is that the measurements are within a pre-defined accuracy range even when the fundamental frequency of the power system changes.

Frequency independent current and voltage measurement accuracy is achieved with algorithms specified in patent US 10,809,287.



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Table. 5.2.4 - 45. Frequency tracking effect (FF changes from 6 Hz to 75 Hz).

| | |
|---|---|
|  |  |
| The measurement error with a fixed 50 Hz sampling frequency when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz. | The measurement error with frequency tracking when the frequency changes. The constant current is 5 A, the frequency sweep is from 6 Hz to 75 Hz. |

As the figures above show, the sampling frequency has a major effect on the device's measurement accuracy. If the sampling is not tracked to the system frequency, for example a 10 Hz difference between the measured and the set system frequency can give a measurement error of over 5 %. The figures also show that when the frequency is tracked and the sampling is adjusted according to the detected system frequency, the measurement accuracy has an approximate error of 0.1...- 0.2 % error in the whole frequency range.

AQ -200 series devices have a measurement accuracy that is independent of the system frequency. This has been achieved by adjusting the sample rate of the measurement channels according to the measured system frequency; this way the FFT calculation always has a whole power cycle in the buffer. The measurement accuracy is further improved by Arcteq's patented calibration algorithms that calibrate the analog channels against eight (8) system frequency points for both magnitude and angle. This frequency-dependent correction compensates the frequency dependencies in the used, non-linear measurement hardware and improves the measurement accuracy significantly. Combined, these two methods give an accurate measurement result that is independent of the system frequency.

## Troubleshooting

When the measured current, voltage or frequency values differ from the expected values, the following table offers possible solutions for the problems.

| Problem | Check / Resolution |
|---|---|
| The measured current or voltage amplitude is lower than it should be./<br>The values are "jumping" and are not stable. | The set system frequency may be wrong. Please check that the frequency settings match the local system frequency, or change the measurement mode to "Tracking" (*Measurement → Frequency* → "Smpl mode") so the device adjusts the frequency itself. |
| The frequency readings are wrong. | In Tracking mode the device may interpret the frequency incorrectly if no current is injected into the CT (or voltage into the VT). Please check the frequency measurement settings (*Measurement → Frequency*). |

## Settings

Table. 5.2.4 - 46. Settings of the frequency tracking.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Sampling mode | 0: Fixed<br>1: Tracking | - | 0: Fixed | Defines which measurement sampling mode is in use: the fixed user-defined frequency, or the tracked system frequency. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| System nominal frequency | 7.000…75.000Hz | 0.001Hz | 50Hz | The user-defined system nominal frequency that is used when the "Sampling mode" setting has been set to "Fixed". |
| Tracked system frequency | 0.000…75.000Hz | 0.001Hz | - | Displays the rough measured system frequency. |
| Sampling frequency in use | 0.000…75.000Hz | 0.001Hz | - | Displays the tracking frequency that is in use at that moment. |
| Frequency reference 1 | 0: None<br>1: CT1IL1<br>2: CT2IL1<br>3: VT1U1<br>4: VT2U1 | - | 1: CT1IL1 | The first reference source for frequency tracking. |
| Frequency reference 2 | 0: None<br>1: CT1IL2<br>2: CT2IL2<br>3: VT1U2<br>4: VT2U2 | - | 1: CT1IL2 | The second reference source for frequency tracking. |
| Frequency reference 3 | 0: None<br>1: CT1IL3<br>2: CT2IL3<br>3: VT1U3<br>4: VT2U3 | - | 1: CT1IL3 | The third reference source for frequency tracking. |
| Frequency tracking quality | 0: No trackable channels<br>1: Reference 1 trackable<br>2: Reference 2 trackable<br>3: References 1 & 2 trackable<br>4: Reference 3 trackable<br>5: Reference 1 & 3 trackable<br>6: References 2 & 3 trackable<br>7: All references trackable | - | - | Defines the frequency tracker quality. If the measured current (or voltage) amplitude is below the threshold, the channel tracking quality is 0 and cannot be used for frequency tracking. If all channels' magnitudes are below the threshold, there are no trackable channels. |
| Frequency measurement in use | 0: No track ch<br>1: Ref1<br>2: Ref2<br>3: Ref3 | - | - | Indicates which reference is used at the moment for frequency tracking. |
| Start behavior | 0: Start tracking immediately<br>1: First nominal or tracked | - | 0: Start tracking immediately | Defines the how the tracking starts. Tracking can start immediately, or there can be a set delay time between the receiving of the first trackable channel and the start of the tracking. |
| Start sampling with | 0: Use track frequency<br>1: Use nom frequency | - | 0: Use track frequency | Defines the start of the sampling. Sampling can begin with a previously tracked frequency, or with a user-set nominal frequency. |
| Use nominal frequency until | 0…1800.000s | 0.005s | 0.100s | Defines how long the nominal frequency is used after the tracking has started. This setting is only valid when the "Sampling mode" setting is set to "Tracking" and when the "Start behavior" is set to "First nominal or tracked". |
| Tracked f channel A | 0.000…75.000Hz | 0.001Hz | - | Displays the rough value of the tracked frequency in Channel A. |
| Tracked f channel B | 0.000…75.000Hz | 0.001Hz | - | Displays the rough value of the tracked frequency in Channel B. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Tracked f channel C | 0.000…75.000Hz | 0.001Hz | - | Displays the rough value of the tracked frequency in Channel C. |
| Alg f fast | 0.000…75.000Hz | 0.001Hz | - | Frequency measurement built from tracked frequencies and U4 voltage channel samples. |
| Alg f avg | 0.000…75.000Hz | 0.001Hz | - | Averaged frequency measurement built from tracked frequencies and U4 voltage channel samples. |
| System measured frequency | 0: One f measured<br>1: Two f measured<br>2: Three f measured | - | - | Displays the amount of frequencies that are measured. |
| f.atm. Protections | 0.000…75.000Hz | 0.001Hz | - | Frequency measurement value used by protection functions. When frequency is not measurable this value returns to value set to "System nominal frequency" parameter. |
| f.atm. Display | 0.000…75.000Hz | 0.001Hz | - | Frequency measurement value used in display. When frequency is not measurable this value is "0 Hz". |
| f measurement from | 0: Not measurable<br>1: Avg Ref 1<br>2: Avg Ref 2<br>3: Avg Ref 3<br>4: Track Ref 1<br>5: Track Ref 2<br>6: Track Ref 3<br>7: Fast Ref 1<br>8: Fast Ref 2<br>9: Fast Ref 3 | - | - | Displays which reference is used for frequency measurement. |
| SS1.meas.frqs | 0.000…75.000Hz | 0.001Hz | - | Displays frequency used by "system set" channel 1 and 2. |
| SS2.meas.frqs | | | | |
| SS1f meas.from | 0: Not measurable<br>1: Fast Ref U3<br>2: Fast Ref U4 | - | - | Displays which voltage channel frequency reference is used by "system set" voltage channel. |
| SS2f meas.from | 0: Not measurable<br>1: Fast Ref U4 | - | - | Displays if U4 channel frequency reference is measurable or not when the channel has been set to "system set" mode. |

## 5.3 General menu

The *General* menu consists of basic settings and indications of the device. Additionally, the all activated functions and their status are displayed in the *Protection*, *Control* and *Monitor* profiles.

Table. 5.3 - 47. The *General* menu read-only parameters

| Name | Description |
|---|---|
| Serial number | The unique serial number identification of the unit. |
| Firmware version | The firmware software version of the unit. |
| Hardware configuration | The order code identification of the unit. |
| System phase rotating order at the moment | The selected system phase rotating order. Can be changed with parameter "System phase rotating order". |
| UTC time | The UTC time value which the device's clock uses. |

Table. 5.3 - 48. Parameters and indications in the *General* menu.

| Name | Range | Default | Description |
|---|---|---|---|
| Device name | - | Unitname | The file name uses these fields when loading the .aqs configuration file from the AQ-200 unit. |
| Device location | - | Unitlocation | |
| Enable stage forcing | 0: Disabled<br>1: Enabled | 0: Disabled | When this parameter is enabled it is possible for the user to force the protection, control and monitoring functions to different statuses like START and TRIP. This is done in the function's *Info* page with the *Force status to* parameter. |
| Allow setting of device mode | 0: Prohibited<br>1: From HMI/setting tool only<br>2: Allowed | 0: Prohibited | Allows global mode to be modified from setting tool, HMI and IEC61850.<br><br>Prohibited: Cannot be changed.<br><br>From HMI/setting tool only: Can only be changed from the setting tool or HMI<br><br>Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client. |
| Allow setting of individual LN mode | 0: Prohibited<br>1: From HMI/setting tool only<br>2: Allowed | 0: Prohibited | Allow local modes to be modified from setting tool, HMI and IEC61850.<br><br>Prohibited: Cannot be changed.<br><br>From HMI/setting tool only: Can only be changed from the setting tool or HMI<br><br>Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client. |
| System phase rotating order | 0: A-B-C<br>1: A-C-B | 0: A-B-C | Allows the user to switch the expected order in which the phase measurements are wired to the unit. |
| Language | 0: User defined<br>1: English<br>2: Finnish<br>3: Swedish<br>4: Spanish<br>5: French<br>6: German<br>7: Russian<br>8: Ukrainian | 1: English | Changes the language of the parameter descriptions in the HMI. If the language has been set to "Other" in the settings of the AQtivate setting tool, AQtivate follows the value set into this parameter. |
| AQtivate ethernet port | 1: All<br>2: COM A<br>3: Double Ethernet card | 1: All | If the device has a double Ethernet option card it is possible to choose which ports are available for connecting with AQtivate software. |
| Clear events | 0: -<br>1: Clear | 0: - | Clears the event history recorded in the AQ-200 device. |
| Display brightness | 0…8 | 4 | Changes the display brightness. Brightness level 0 turns the display off. |
| Display sleep timeout | 0…3600s | 0s | If no buttons are pressed after a set time, the display changes the brightness to whatever is set on the "Display sleep brightness" parameter. If set to 0 s, this feature is not in use.<br><br>When the device is in sleep mode pressing any of the buttons on the front panel of the device will wake the display. |
| Display sleep brightness | 0…8 | 0 | Defines the brightness of the display when the set display sleep timeout has elapsed. The brightness level "0" turns the display off. |
| Return to default view | 0…3600s | 0s | If the user navigates to a menu and gives no input after a period of time defined with this parameter, the unit automatically returns to the default view. If set to 0 s, this feature is not in use. |
| LED test | 0: -<br>1: Activated | 0: - | When activated, all LEDs are lit up. LEDs with multiple possible colors blink each color. |



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| Name | Range | Default | Description |
|---|---|---|---|
| LCD restart | 0: -<br>1: Restart | 0: - | When activated, display restarts. |
| Display color theme | 0: Light theme<br>1: Dark theme | 0: Light theme | Defines the color theme used in the HMI. |
| Reset latches | 0: -<br>1: Reset | 0: - | Resets the latched signals in the logic and the matrix. When a reset command is given, the parameter automatically returns back to "-". |
| Measurement recorder | 0: Disabled<br>1: Enabled | 0: Disabled | Enables the measurement recorder tool, further configured in *Tools → Misc → Measurement recorder*. |
| I/0 default object selection | 0: OBJ1<br>1: OBJ2<br>2: OBJ3<br>3: OBJ4<br>4: OBJ5<br>5: OBJ6<br>6: OBJ7<br>7: OBJ8<br>8: OBJ9<br>9: OBJ10 | 0: OBJ1 | "I" and "0" push buttons on the front panel of the device have an indication LED. This parameter defines which objects' status push buttons follow when lighting up the LEDs. |
| Device Mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of device block.<br><br>This parameter is visible only when *Allow setting of device mode* is enabled in *General* menu. |
| Reconfigure mimic | 0: -<br>1: Reconfigure | 0: - | Reloads the mimic to the unit. |

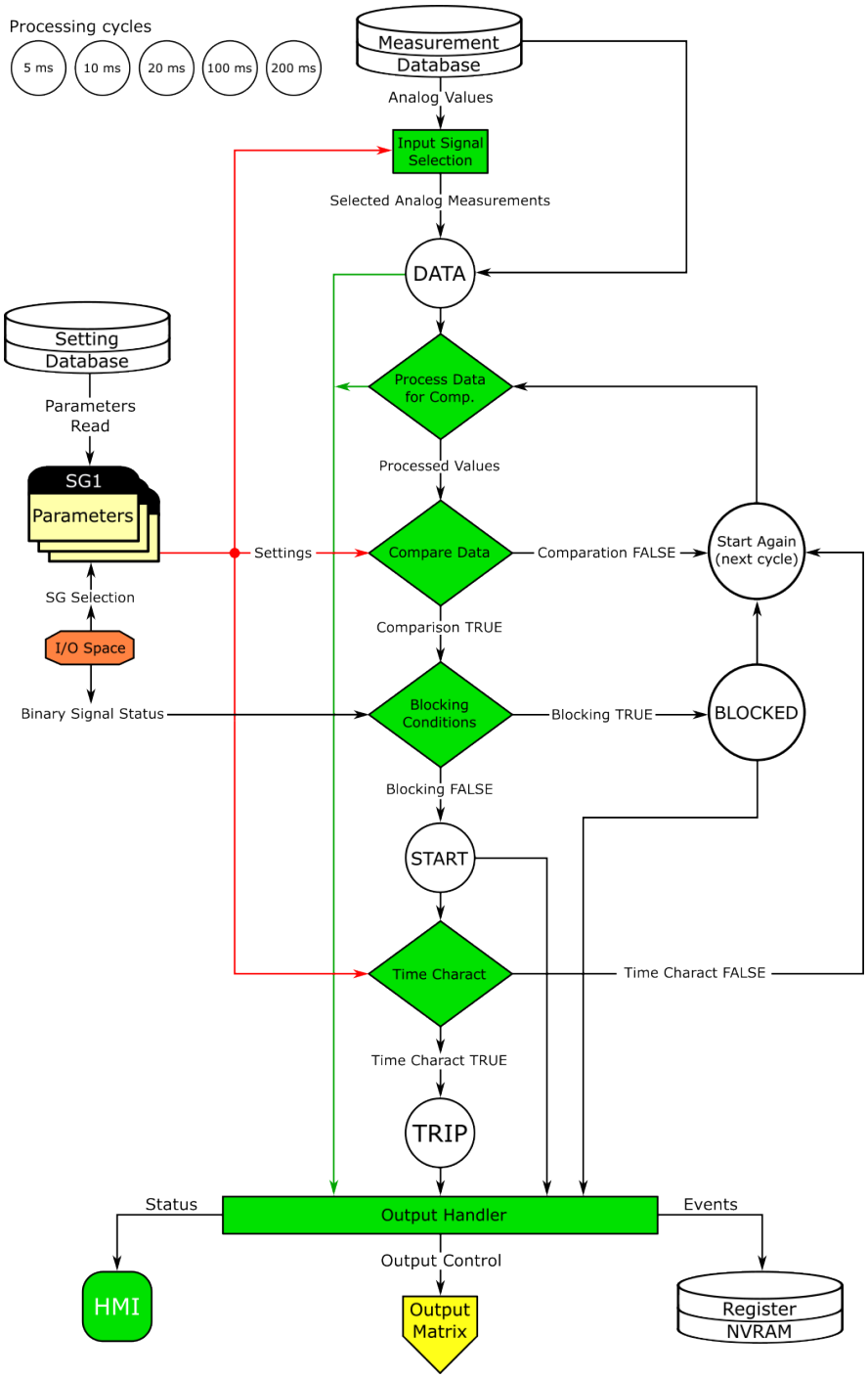
Table. 5.3 - 49. General menu logical inputs.

| Name | Description |
|---|---|
| Reset last fault registers | Signal set to this point can be used for resetting latest recorded fault register. |
| Reset latches | Signals set to this point can be used for resetting latched signals. An alternative to using the "Back" button on the front panel of the device. |
| Ph.Rotating Logic control 0=A-B-C, 1=A-C-B | Signals set to this point can be used for switching the expected phase rotating order. |

## 5.4 Protection functions

### 5.4.1 General properties of a protection function

The following flowchart describes the basic structure of any protection function. The basic structure is composed of analog measurement values being compared to the pick-up values and operating time characteristics.

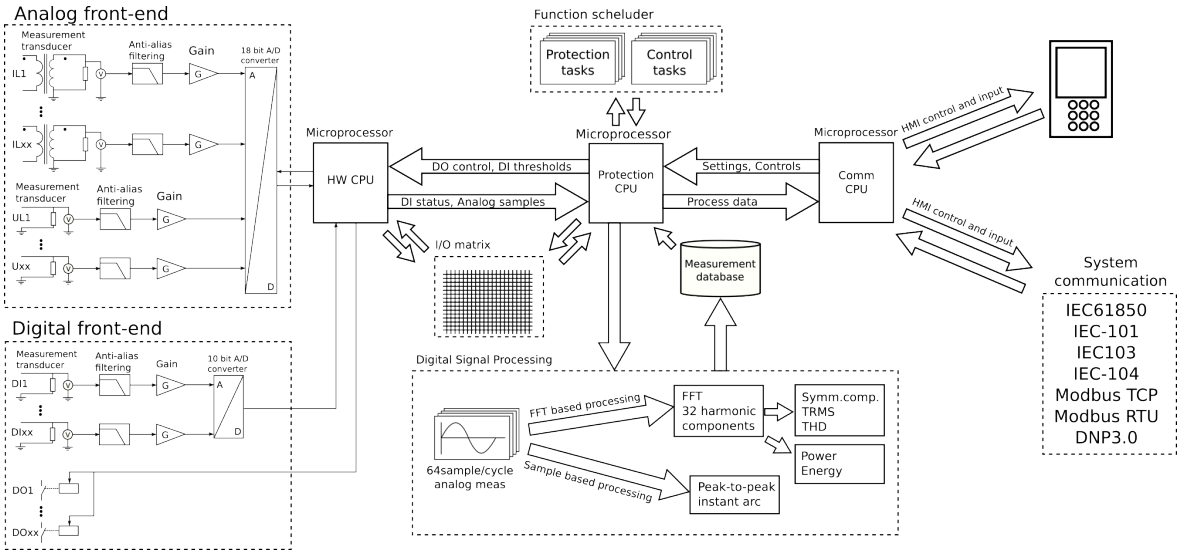



The protection function is run in a completely digital environment with a protection CPU microprocessor which also processes the analog signals transformed into the digital form.



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Figure. 5.4.1 - 24. Principle diagram of the protection relay platform.

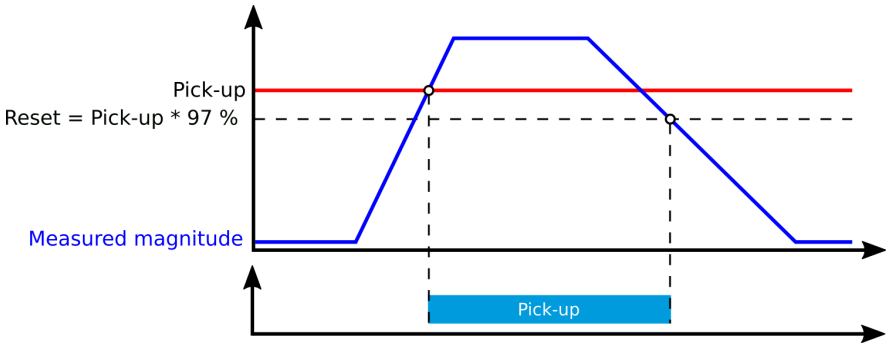



In the following chapters the common functionalities of protection functions are described. If a protection function deviates from this basic structure, the difference is described in the corresponding chapter of the manual.

## Pick-up

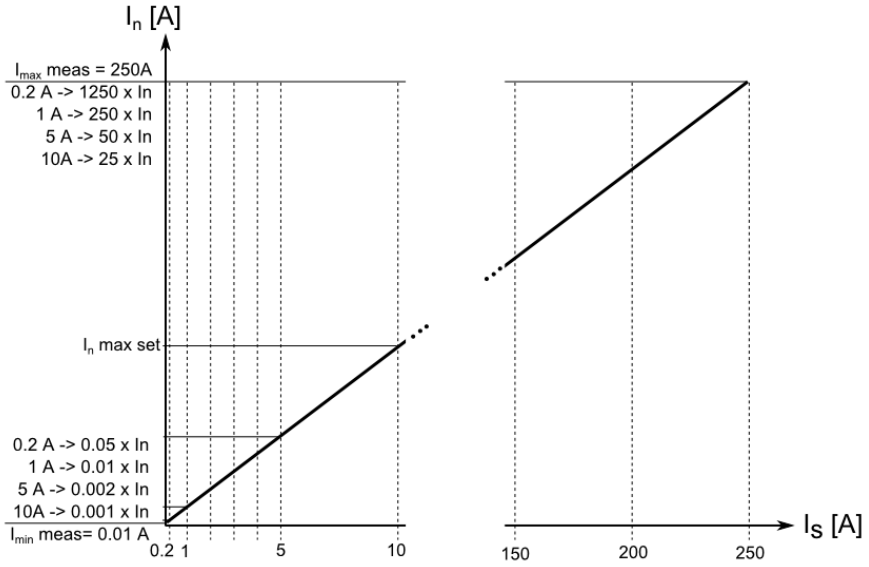
The $X_{set}$ parameter defines the pick-up level of the function, and this in turn defines the maximum or minimum allowed measured magnitude (in per unit, absolute or percentage value) before the function takes action. The function constantly calculates the ratio between the pick-up parameter set by the user and the measured magnitude ($X_m$). The reset ratio of 97 % is built into the function and is always relative to the $X_{set}$ value. If a function's pick-up characteristics vary from this description, they are defined in the function section in the manual.

Figure. 5.4.1 - 25. Pick up and reset.




The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if a blocking condition is not active.

Figure. 5.4.1 - 26. Measurement range in relation to the nominal current.




The $I_n$ magnitude refers to the user set nominal current which can range from 0.2…10 A, typically 0.2 A, 1A or 5 A. With its own current measurement card, the IED will measure secondary currents from 0.001 A up to 250 A. To this relation the pick-up setting in secondary amperes will vary.

## Function blocking

The blocking signals are checked in the beginning of each program cycle. A blocking signal is received from the blocking matrix for the function dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when pick-up element activates, a BLOCKED signal is generated and the function will not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time stamped blocking event with information of the startup current values and its fault type to be issued.

The variables users can set are binary signals from the system. The blocking signal needs to reach the IED minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for trip signal and for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: activates the trip signal with no additional time delay simultaneously with the start signal.
- Definite time operation (DT): activates the trip signal after a user-defined time delay regardless of the measured current as long as the current is above or below the $X_{set}$ value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): activates the trip signal after a time which is in relation to the set pick-up value $X_{set}$ and the measured value $X_m$ (dependent time characteristics).


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Both IEC and IEEE/ANSI standard characteristics as well as user settable parameters are available for the IDMT operation. Please note that in the IDMT mode *Definite (Min)* operating time delay is also determines the minimum time for protection tripping (see the figure below). If this function is not desired the parameter should be set to 0 seconds.

Figure. 5.4.1 - 27. Operating time delay: *Definite (Min)* and the minimum for tripping.

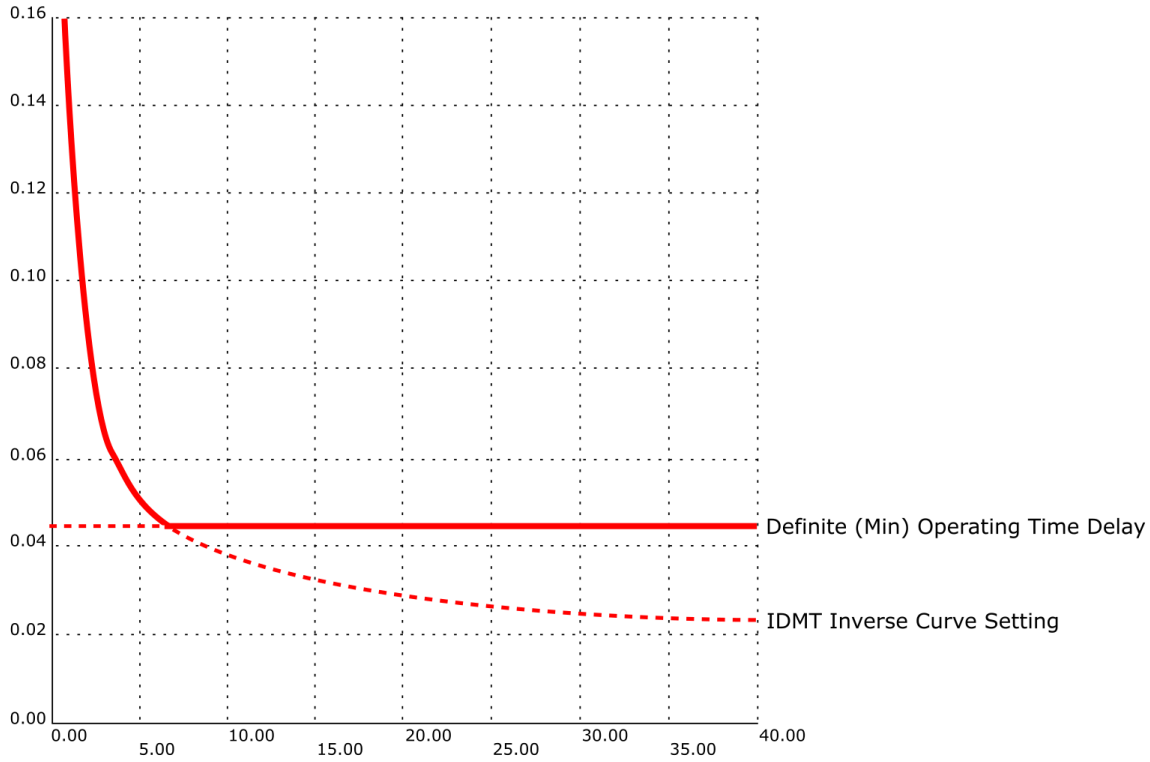



Table. 5.4.1 - 50. Operating time characteristics setting parameters (general).

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay type | 0: DT<br>1: IDMT | - | 0: DT | Selects the delay type for the time counter. The selection is made between dependent (IDMT) and independent (DT) characteristics. |
| Definite (min) operating time delay | 0.000…1800.000s | 0.005s | 0.040s | When the "Delay type" parameter is set to "DT", this parameter acts as the expected operating time for the protection function.<br><br>When set to 0 s, the stage operates instantaneously without any additional delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed.<br><br>When the "Delay type" parameter has been set to "IDMT", this parameter can be used to determine the minimum operating time for the protection function. Example of this is presented in the figure above. |
| Delay curve series | 0: IEC<br>1: IEEE | - | 0: IEC | Selects whether the delay curve series for an IDMT operation follows either IEC or IEEE/ANSI standard defined characteristics.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT". |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay characteristics IEC | 0: NI<br>1: EI<br>2: VI<br>3: LTI<br>4: Param | - | 0: NI | Selects the IEC standard delay characteristics.<br><br>The options include the following: Normally Inverse ("NI"), Extremely Inverse ("EI"), Very Inverse ("VI") and Long Time Inverse ("LTI") characteristics. Additionally, the "Param" option allows the tuning of the constants A and B which then allows the setting of characteristics following the same formula as the IEC curves mentioned here.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay curve series" parameter is set to "IEC". |
| Delay characteristics IEEE | 0: ANSI NI<br>1: ANSI VI<br>2: ANSI EI<br>3: ANSI LTI<br>4: IEEE MI<br>5: IEEE VI<br>6: IEEE EI<br>7: Param | - | 0: ANSI NI | Selects the IEEE and ANSI standard delay characteristics.<br><br>The options for ANSI include the following: Normal Inverse ("ANSI NI"), Very Inverse ("ANSI VI"), Extremely inverse ("ANSI EI"), Long time inverse ("ANSI LTI") characteristics. IEEE: Moderately Inverse ("IEEE MI"), Very Inverse ("IEEE VI"), Extremely Inverse ("IEEE EI") characteristics. Additionally, the "Param" option allows the tuning of the constants A, B and C which then allows the setting of characteristics following the same formula as the IEEE curves mentioned here.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay curve series" parameter is set to "IEEE". |
| Time dial setting k | 0.01…25.00s | 0.01s | 0.05s | Defines the time dial/multiplier setting for IDMT characteristics.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT". |
| A | 0.0000…250.0000 | 0.0001 | 0.0860 | Defines the Constant A for IEC/IEEE characteristics.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param". |
| B | 0.0000…5.0000 | 0.0001 | 0.1850 | Defines the Constant B for IEC/IEEE characteristics.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param". |
| C | 0.0000…250.0000 | 0.0001 | 0.0200 | Defines the Constant C for IEEE characteristics.<br><br>This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param". |



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Figure. 5.4.1 - 28. Inverse operating time formulas for IEC and IEEE standards.

<table>
<tr><th>IEC</th><th>IEEE/ANSI</th></tr>
<tr><td>$t = \frac{kA}{\left(\frac{I_m}{I_{set}}\right)^B - 1}$</td><td>$t = k\left(\frac{A}{\left(\frac{I_m}{I_{set}}\right)^C - 1} + B\right)$</td></tr>
<tr><td>$t$ = Operating delay (s)<br>$k$ = Time dial setting<br>$I_m$ = Measured maximum current<br>$I_{set}$ = Pick-up setting<br>$A$ = Operating characteristics constant<br>$B$ = Operating characteristics constant</td><td>$t$ = Operating delay (s)<br>$k$ = Time dial setting<br>$I_m$ = Measured maximum current<br>$I_{set}$ = Pick-up setting<br>$A$ = Operating characteristics constant<br>$B$ = Operating characteristics constant<br>$C$ = Operating characteristics constant</td></tr>
<tr><td>Standard delays IEC constants
<table>
<tr><th>Type</th><th>A</th><th>B</th></tr>
<tr><td>Normally Inverse (NI)</td><td>0,14</td><td>0,02</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>80</td><td>2</td></tr>
<tr><td>Very Inverse (VI)</td><td>13,5</td><td>1</td></tr>
<tr><td>Long Time Inverse (LTI)</td><td>120</td><td>1</td></tr>
</table></td><td>Standard delays ANSI constants
<table>
<tr><th>Type</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Normally Inverse (NI)</td><td>8,934</td><td>0,1797</td><td>2,094</td></tr>
<tr><td>Very Inverse (VI)</td><td>3,922</td><td>0,0982</td><td>2</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>5,64</td><td>0,02434</td><td>2</td></tr>
<tr><td>Long Time Inverse (LTI)</td><td>5,614</td><td>2,186</td><td>1</td></tr>
</table>
Standard delays IEEE constants
<table>
<tr><th>Type</th><th>A</th><th>B</th><th>C</th></tr>
<tr><td>Moderately Inverse (MI)</td><td>0,0515</td><td>0,114</td><td>0,02</td></tr>
<tr><td>Very Inverse (VI)</td><td>19,61</td><td>0,491</td><td>2</td></tr>
<tr><td>Extremely Inverse (EI)</td><td>28,2</td><td>0,1217</td><td>2</td></tr>
</table></td></tr>
</table>

## Non-standard delay characteristics

In addition to the previously mentioned delay characteristics, some functions also have delay characteristics that deviate from the IEC or IEEE standards. These functions are the following:

- overcurrent stages
- residual overcurrent stages
- directional overcurrent stages
- directional residual overcurrent stages.

The setting parameters and their ranges are documented in the chapters of the respective function blocks.

Table. 5.4.1 - 51. Inverse operating time formulas for nonstandard characteristics.

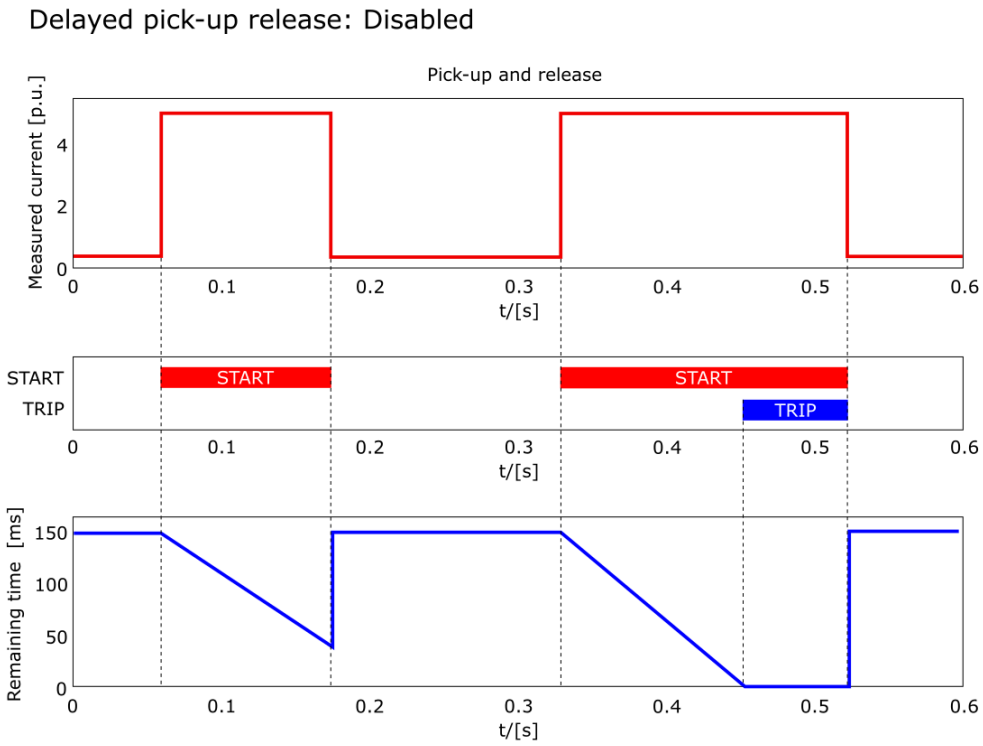
| RI-type | RD-type |
|---|---|
| Used to get time grading with mechanical relays | Mostly used in earth fault protection which grants selective tripping even in non-directional protection |
| $t = \frac{k}{0.339 - 0.236 * \frac{I_{set}}{I_m}}$ | $t = 5.8 - 1.35 * \ln\left(\frac{I_m}{k * I_{set}}\right)$ |
| $t$ = Operating delay (s)<br>$k$ = Time dial setting<br>$I_m$ = Measured maximum current<br>$I_{set}$ = Pick-up setting | $t$ = Operating delay (s)<br>$k$ = Time dial setting<br>$I_m$ = Measured maximum current<br>$I_{set}$ = Pick-up setting |

Table. 5.4.1 - 52. Setting parameters for reset time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delayed pick-up release | 0: No<br>1: Yes | - | 1: Yes | Resetting characteristics selection (either time-delayed or instant) after the pick-up element is released. If activated, the START signal is reset after a set release time delay. |
| Release time delay | 0.000…150.000s | 0.005s | 0.06s | Resetting time. The time allowed between pick-ups if the pick-up has not led into a trip operation.<br><br>If the "Delayed pick-up release" setting is active, the START signal is held on for the duration of the timer. |
| Op.Time calculation reset after release time | 0: No<br>1: Yes | - | 1: Yes | Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element is reset. |
| Continue time calculation during release time | 0: No<br>1: Yes | - | 0: No | Time calculation characteristics selection. If activated, the operating time counter continues until a set release time even if the pick-up element is reset. |

The behavior of the stages with different release time configurations are presented in the figures below.

Figure. 5.4.1 - 29. No delayed pick-up release.






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Figure. 5.4.1 - 30. Delayed pick-up release, delay counter is reset at signal drop-off.

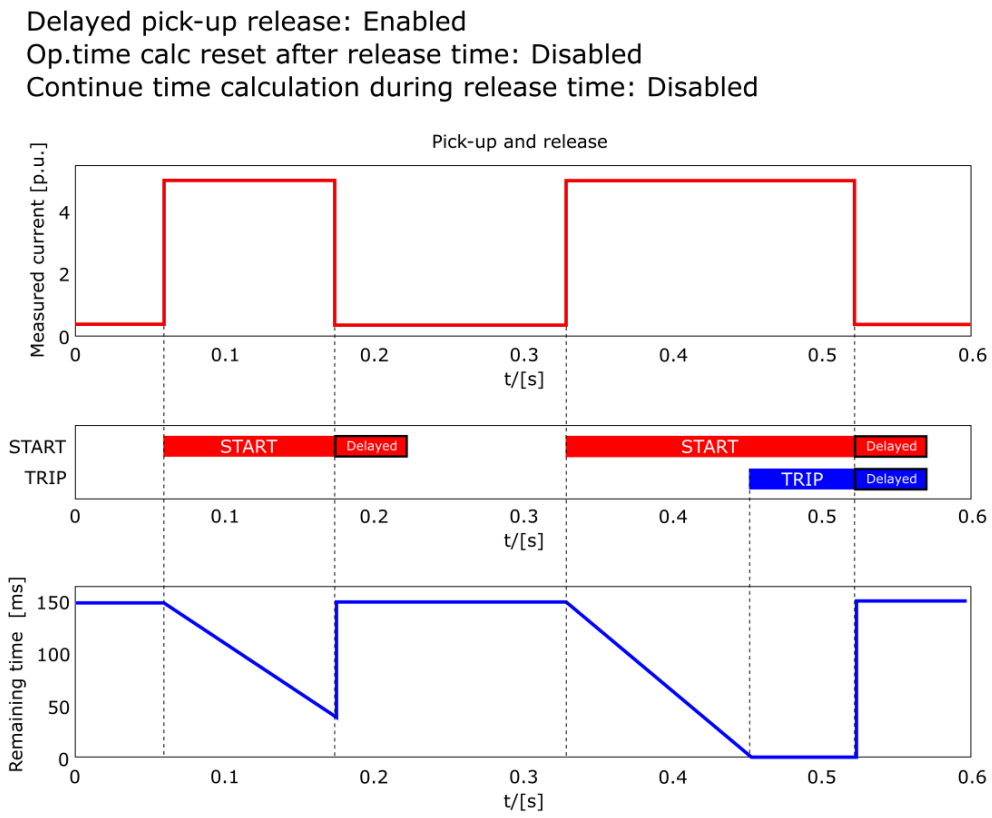



Figure. 5.4.1 - 31. Delayed pick-up release, delay counter value is held during the release time.

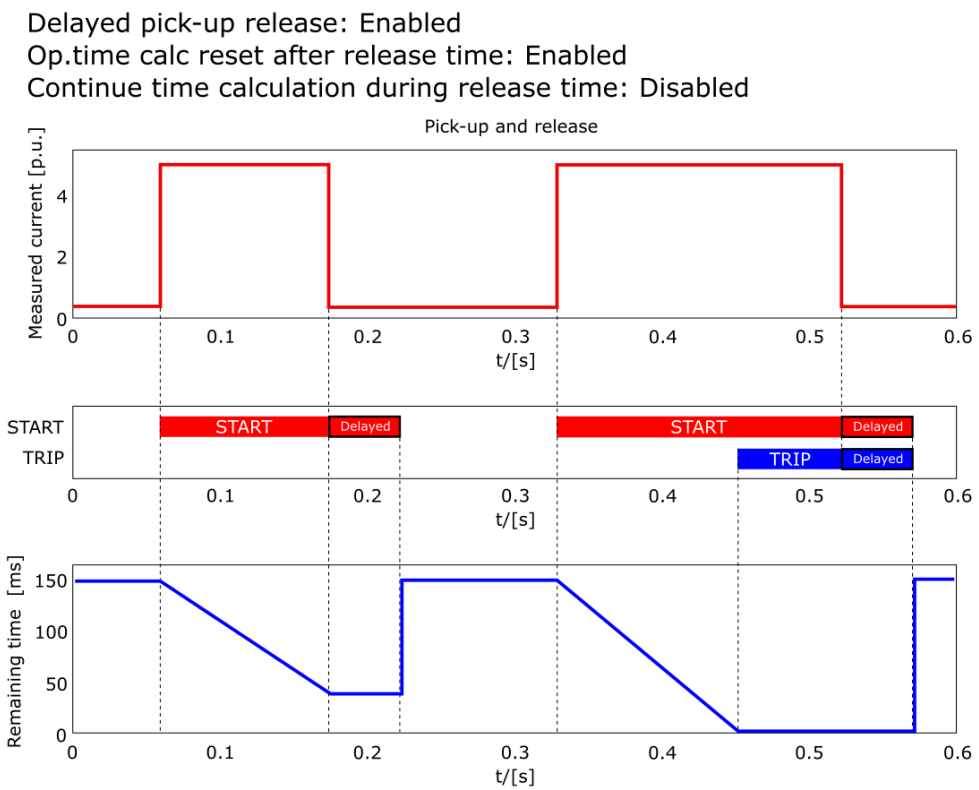
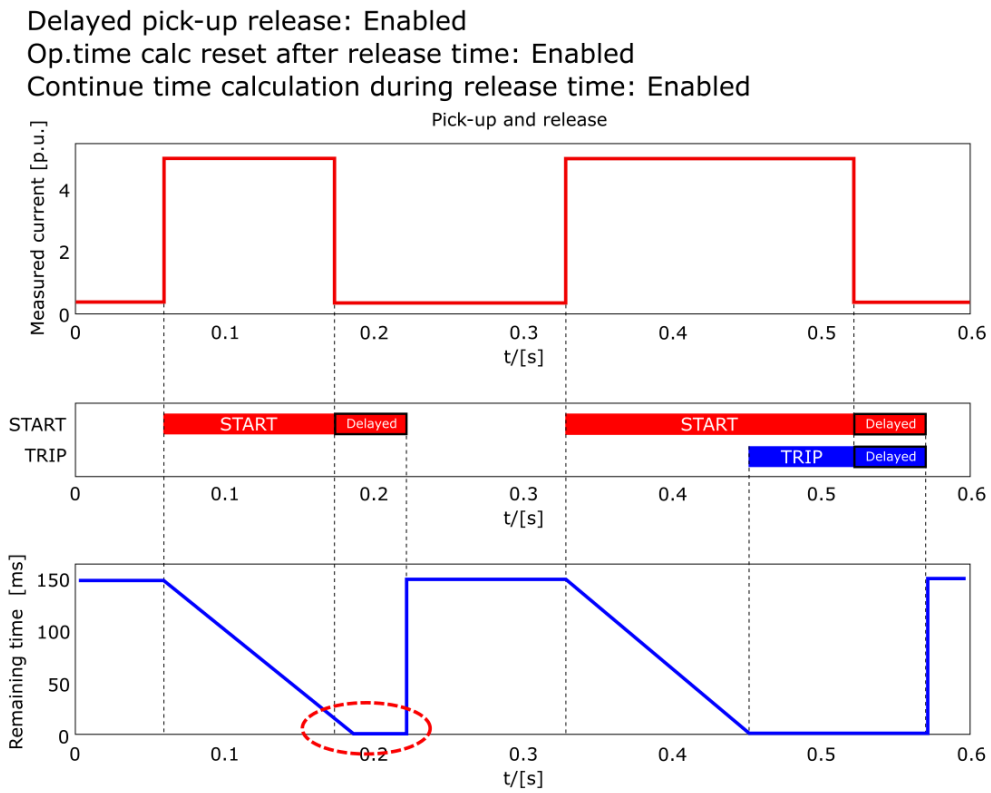


Figure. 5.4.1 - 32. Delayed pick-up release, delay counter value is decreasing during the release time.




The resetting characteristics can be set according to the application. The default setting is delayed 60 ms and the time calculation is held during the release time.

When using the release delay option where the operating time counter is calculating the operating time during the release time, the function will not trip if the input signal is not activated again during the release time counting.

### Stage forcing

It is possible to test the logic, event processing and the operation of the relay's protection system by controlling the state of the protection functions manually without injecting any current into the device with stage forcing. To enable *Stage forcing* set the *Enable stage forcing* to ENABLED in the *General* menu. After this it is possible to control the status of a protection function (Normal, Start, Trip, Blocked etc.) in the *Info* page of the function.

NOTE!

When *Stage forcing* is enabled protection functions will also change state through user input. Injected currents/voltages also affect the behavior of the device. Regardless, it is recommended to disable *Stage Forcing* after testing has ended.

## 5.4.2 Non-directional overcurrent protection (I>; 50/51)

The non-directional overcurrent function is used for instant and time-delayed overcurrent and short-circuit protection. The number of stages in the function depends on the relay model. The operating decisions are based on phase current magnitude, constantly measured by the function. The available phase current magnitudes are equal to RMS values, to TRMS values (including harmonics up to 32$^{nd}$), or to peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.


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The non-directional overcurrent function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT) mode. The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes CT saturation checking which allows the function to start and operate accurately during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

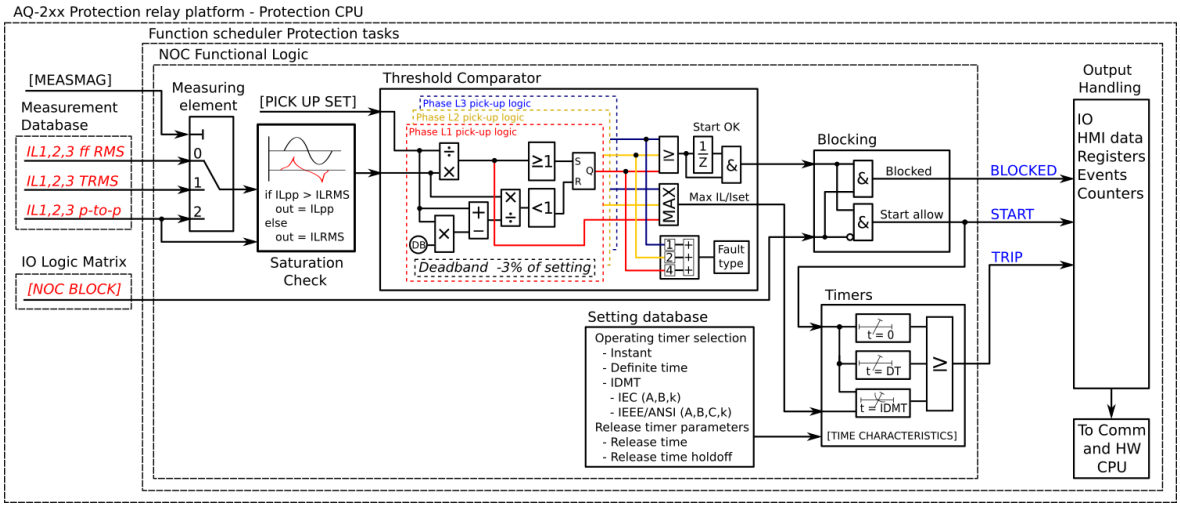
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional overcurrent function.

Figure. 5.4.2 - 33. Simplified function block diagram of the I> function.



## Measured input

The function block uses analog current measurement values. However, when the peak-to-peak mode is selected for the function's "Measured magnitude" setting , the values are taken directly from the samples. The user can select the monitored magnitude to be equal either to RMS values, to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values. A -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.2 - 53. Measurement inputs of the I> function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| IL1TRMS | TRMS measurement of phase L1 (A) current | 5ms |
| IL2TRMS | TRMS measurement of phase L2 (B) current | 5ms |
| IL3TRMS | TRMS measurement of phase L3 (C) current | 5ms |
| IL1PP | Peak-to-peak measurement of phase L1 (A) current | 5ms |
| IL2PP | Peak-to-peak measurement of phase L2 (B) current | 5ms |
| IL3PP | Peak-to-peak measurement of phase L3 (C) current | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.2 - 54. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Setting control from comm bus | 1: Disabled<br>2: Allowed | 1: Disabled | Activating this parameter allows changing the pick-up level of the protection stage via SCADA. |
| I> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of NOC block.<br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |



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| Name | Range | Default | Description |
|---|---|---|---|
| I> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked<br>4: Start A<br>5: Start B<br>6: Start C<br>7: Trip A<br>8: Trip B<br>9: Trip C<br>10: Start AB<br>11: Start BC<br>12: Start CA<br>13: Start ABC<br>14: Trip AB<br>15: Trip BC<br>16: Trip CA<br>17: Trip ABC | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: RMS<br>2: TRMS<br>3: Peak-to-peak | 1: RMS | Defines which available measured magnitude is used by the function. |

## Pick-up

The $I_{set}$ setting parameter controls the pick-up of the I> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $I_{set}$ and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $I_{set}$ value. The setting value is common for all measured phases, and when the $I_m$ exceeds the $I_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.2 - 55. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $I_{set}$ | Pick-up setting | 0.10…50.00×$I_n$ | 0.01×$I_n$ | 1.20×$I_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.2 - 56. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of NOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays status of the protection function. |
| I> phases condition | 0: Normal<br>1: Start A<br>2: Start B<br>3: Start C<br>4: Trip A<br>5: Trip B<br>6: Trip C<br>7: Start AB<br>8: Start BC<br>9: Start CA<br>10: Start ABC<br>11: Trip AB<br>12: Trip BC<br>13: Trip CA<br>14: Trip ABC | - | Displays the status of phases individually. |
| Expected operating time | -1800.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured highest phase current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | 0.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $I_{meas}/I_{set}$ at the moment | 0.00...1250.00 | 0.01 | The ratio between the highest measured phase current and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the non-directional overcurrent function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 5.4.2 - 57. Internal inrush harmonic blocking settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Inrush harmonic blocking (internal-only trip) | 0: No<br>1: Yes | - | 0: No | Enables and disables the $2^{nd}$ harmonic blocking. |
| $2^{nd}$ harmonic blocking limit (Iharm/Ifund) | 0.10…50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ | Defines the limit of the $2^{nd}$ harmonic blocking. |

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.



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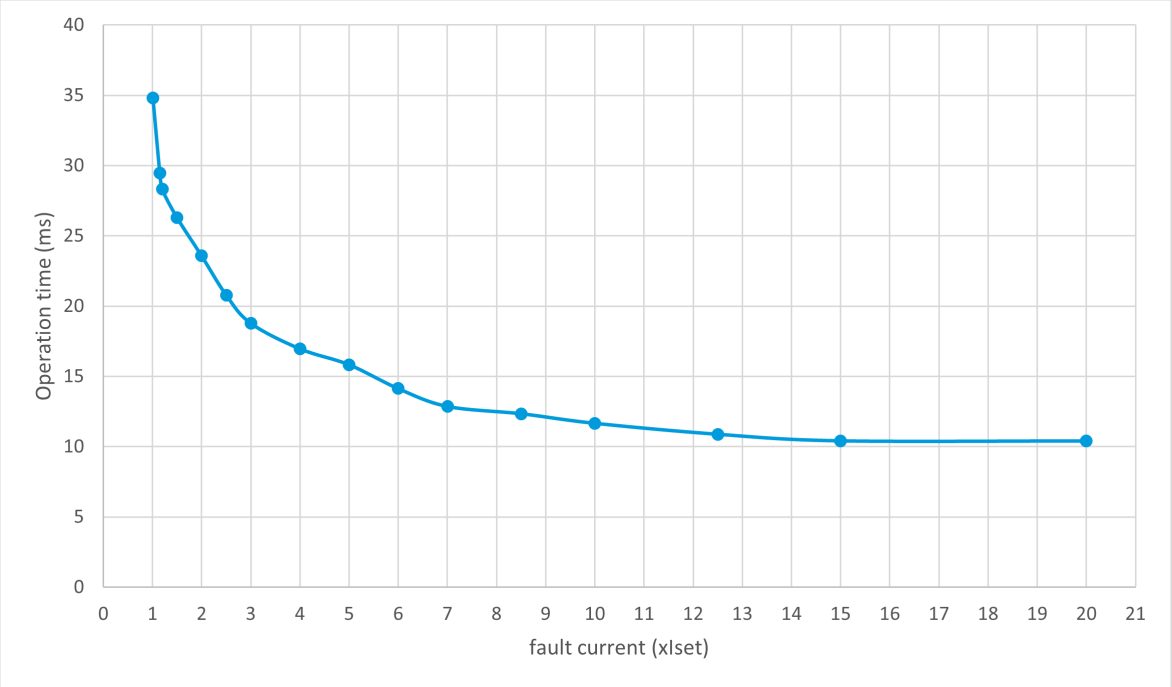
The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

Figure. 5.4.2 - 34. Typical operation time delays with different current to setting ratios in instant operation mode.




## Events and registers

The non-directional overcurrent function (abbreviated "NOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.2 - 58. Event messages.

| Event block name | Event names |
|---|---|
| NOC1 | Start ON |
| NOC1 | Start OFF |
| NOC1 | Trip ON |
| NOC1 | Trip OFF |
| NOC1 | Block ON |
| NOC1 | Block OFF |

| Event block name | Event names |
|---|---|
| NOC1 | Phase A Start ON |
| NOC1 | Phase A Start OFF |
| NOC1 | Phase B Start ON |
| NOC1 | Phase B Start OFF |
| NOC1 | Phase C Start ON |
| NOC1 | Phase C Start OFF |
| NOC1 | Phase A Trip ON |
| NOC1 | Phase A Trip OFF |
| NOC1 | Phase B Trip ON |
| NOC1 | Phase B Trip OFF |
| NOC1 | Phase C Trip ON |
| NOC1 | Phase C Trip OFF |
| NOC2 | Start ON |
| NOC2 | Start OFF |
| NOC2 | Trip ON |
| NOC2 | Trip OFF |
| NOC2 | Block ON |
| NOC2 | Block OFF |
| NOC2 | Phase A Start ON |
| NOC2 | Phase A Start OFF |
| NOC2 | Phase B Start ON |
| NOC2 | Phase B Start OFF |
| NOC2 | Phase C Start ON |
| NOC2 | Phase C Start OFF |
| NOC2 | Phase A Trip ON |
| NOC2 | Phase A Trip OFF |
| NOC2 | Phase B Trip ON |
| NOC2 | Phase B Trip OFF |
| NOC2 | Phase C Trip ON |
| NOC2 | Phase C Trip OFF |
| NOC3 | Start ON |
| NOC3 | Start OFF |
| NOC3 | Trip ON |
| NOC3 | Trip OFF |
| NOC3 | Block ON |
| NOC3 | Block OFF |
| NOC3 | Phase A Start ON |
| NOC3 | Phase A Start OFF |



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| Event block name | Event names |
|---|---|
| NOC3 | Phase B Start ON |
| NOC3 | Phase B Start OFF |
| NOC3 | Phase C Start ON |
| NOC3 | Phase C Start OFF |
| NOC3 | Phase A Trip ON |
| NOC3 | Phase A Trip OFF |
| NOC3 | Phase B Trip ON |
| NOC3 | Phase B Trip OFF |
| NOC3 | Phase C Trip ON |
| NOC3 | Phase C Trip OFF |
| NOC4 | Start ON |
| NOC4 | Start OFF |
| NOC4 | Trip ON |
| NOC4 | Trip OFF |
| NOC4 | Block ON |
| NOC4 | Block OFF |
| NOC4 | Phase A Start ON |
| NOC4 | Phase A Start OFF |
| NOC4 | Phase B Start ON |
| NOC4 | Phase B Start OFF |
| NOC4 | Phase C Start ON |
| NOC4 | Phase C Start OFF |
| NOC4 | Phase A Trip ON |
| NOC4 | Phase A Trip OFF |
| NOC4 | Phase B Trip ON |
| NOC4 | Phase B Trip OFF |
| NOC4 | Phase C Trip ON |
| NOC4 | Phase C Trip OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.2 - 59. Register content.

| Date and time | Event | Fault type | Pre-trigger current | Fault current | Pre-fault current | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-E…L1-L2-L3 | Start/Trip -20ms current | Start/ Trip current | Start -200ms current | 0 ms...1800s | Setting group 1...8 active |

### 5.4.3 Single-pole non-directional overcurrent protection (I>; 50/51)

The single-pole non-directional overcurrent function is used for instant and time-delayed overcurrent and short-circuit protection. The number of stages in the function depends on the relay model. The operating decisions are based on phase current magnitude, constantly measured by the function. The available phase current magnitudes are equal to RMS values, to TRMS values (including harmonics up to 32$^{nd}$), or to peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT) mode. The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes CT saturation checking which allows the function to start and operate accurately during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

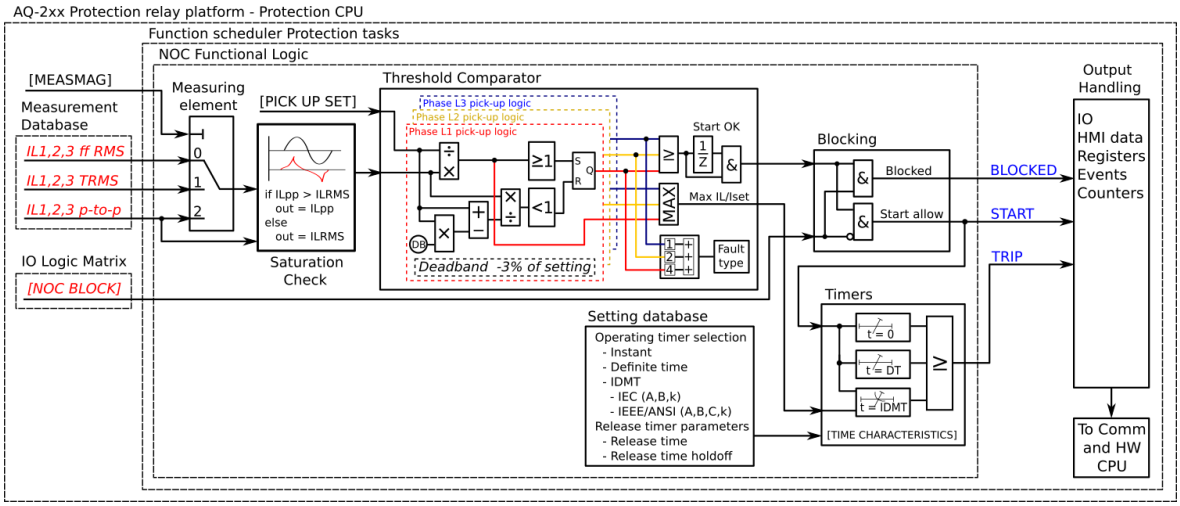
The function's outputs are START (Phase A, B, C and General), TRIP (Phase A, B, C and General) and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The non-directional overcurrent function uses a total of eight (8) separate setting groups which can be selected from one common source.

The following figure presents a simplified function block diagram of the non-directional overcurrent function.


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Figure. 5.4.3 - 35. Simplified function block diagram of the I> function.




## Measured input

The function block uses analog current measurement values. However, when the peak-to-peak mode is selected for the function's "Measured magnitude" setting , the values are taken directly from the samples. The user can select the monitored magnitude to be equal either to RMS values, to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values. A -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.3 - 60. Measurement inputs of the I> function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| IL1TRMS | TRMS measurement of phase L1 (A) current | 5ms |
| IL2TRMS | TRMS measurement of phase L2 (B) current | 5ms |
| IL3TRMS | TRMS measurement of phase L3 (C) current | 5ms |
| IL1PP | Peak-to-peak measurement of phase L1 (A) current | 5ms |
| IL2PP | Peak-to-peak measurement of phase L2 (B) current | 5ms |
| IL3PP | Peak-to-peak measurement of phase L3 (C) current | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.3 - 61. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Setting control from comm bus | 1: Disabled<br>2: Allowed | 1: Disabled | Activating this parameter allows changing the pick-up level of the protection stage via SCADA. |
| I> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of NOC block.<br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| IPW> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked<br>4: StartL1<br>5: StartL2<br>6: StartL3<br>7: TripL1<br>8: TripL2<br>9: TripL3 | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: RMS<br>2: TRMS<br>3: Peak-to-peak | 1: RMS | Defines which available measured magnitude is used by the function. |

## Pick-up

The $I_{set}$ setting parameter controls the pick-up of the I> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $I_{set}$ and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $I_{set}$ value. The setting value is common for all measured phases, and when the $I_m$ exceeds the $I_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.3 - 62. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $I_{set}$ | Pick-up setting | 0.10…50.00×$I_n$ | 0.01×$I_n$ | 1.20×$I_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.


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Table. 5.4.3 - 63. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of NOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays status of the protection function. |
| I> phases condition | 0: Normal<br>1: Start A<br>2: Start B<br>3: Start C<br>4: Trip A<br>5: Trip B<br>6: Trip C<br>7: Start AB<br>8: Start BC<br>9: Start CA<br>10: Start ABC<br>11: Trip AB<br>12: Trip BC<br>13: Trip CA<br>14: Trip ABC | - | Displays the status of phases individually. |
| Expected operating time | -1800.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured highest phase current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | 0.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $I_{meas}/I_{set}$ at the moment | 0.00...1250.00 | 0.01 | The ratio between the highest measured phase current and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the non-directional overcurrent function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 5.4.3 - 64. Internal inrush harmonic blocking settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Inrush harmonic blocking (internal-only trip) | 0: No<br>1: Yes | - | 0: No | Enables and disables the $2^{nd}$ harmonic blocking. |
| $2^{nd}$ harmonic blocking limit (Iharm/Ifund) | 0.10…50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ | Defines the limit of the $2^{nd}$ harmonic blocking. |

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The non-directional overcurrent function (abbreviated "NOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.3 - 65. Event messages.

| Event block name | Event names |
|---|---|
| NOCS1 | Start ON |
| NOCS1 | Start OFF |
| NOCS1 | Trip ON |
| NOCS1 | Trip OFF |
| NOCS1 | Block ON |
| NOCS1 | Block OFF |
| NOCS1 | L1 Start ON |
| NOCS1 | L1 Start OFF |
| NOCS1 | L2 Start ON |
| NOCS1 | L2 Start OFF |
| NOCS1 | L3 Start ON |
| NOCS1 | L3 Start OFF |
| NOCS1 | L1 Trip ON |
| NOCS1 | L1 Trip OFF |
| NOCS1 | L2 Trip ON |
| NOCS1 | L2 Trip OFF |
| NOCS1 | L3 Trip ON |
| NOCS1 | L3 Trip OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.


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Table. 5.4.3 - 66. Register content.

| Date and time | Event | Fault type | Pre-trigger current | Fault current | Pre-fault current | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-E…L1-L2-L3 | Start/Trip -20ms current | Start/ Trip current | Start -200ms current | 0 ms...1800s | Setting group 1...8 active |

## 5.4.4 Non-directional earth fault protection (I0>; 50N/51N)

The non-directional earth fault function is used for instant and time-delayed earth fault protection. The number of stages in the function depend on the device model. The operating characteristics are based on the selected neutral current magnitudes which the function measures constantly. The available analog measurement channels are I01 and I02 (residual current measurement) and I0Calc (residual current calculated from phase current). The user can select these channels to use RMS values, TRMS values (including harmonics up to 32$^{nd}$), or peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The non-directional earth fault function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes the checking of CT saturation which allows the function to start and operate accurately even during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

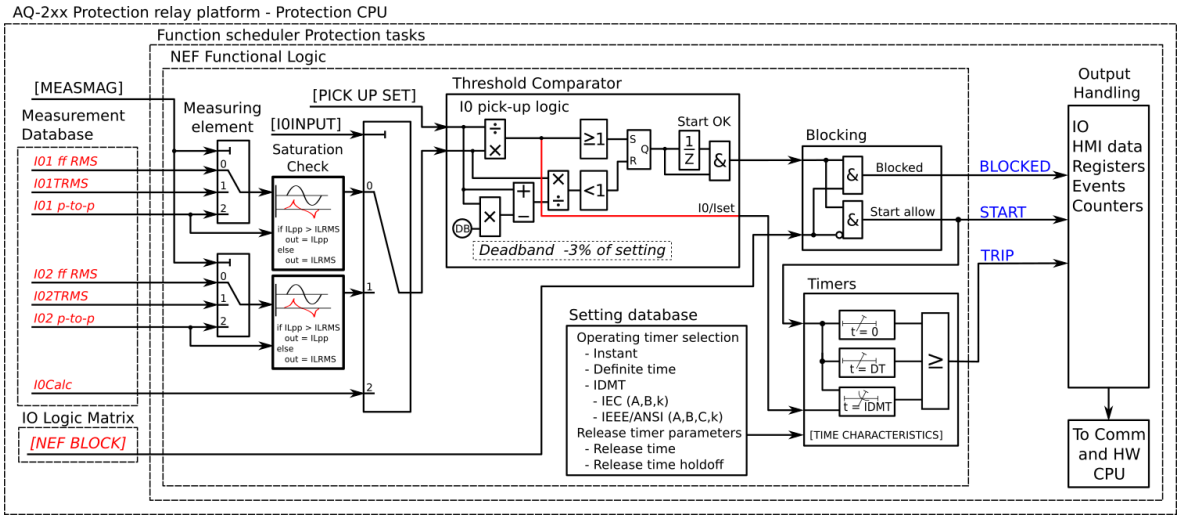
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional earth fault function.

Figure. 5.4.4 - 36. Simplified function block diagram of the I0> fucntion.




## Measured input

The function block uses analog current measurement values. The user can select the monitored magnitude to be equal either to RMS values, to TRMS values, or to peak-to-peak values. TRMS mode uses values from the whole harmonic spectrum of 32 components. Peak-to-peak mode picks measurement values directly from the samples. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.4 - 67. Measurement inputs of the I0> function.

| Signal | Description | Time base |
|---|---|---|
| I01RMS | RMS measurement of coarse residual current measurement input I01 | 5 ms |
| I01TRMS | TRMS measurement of coarse residual current measurement input I01 | 5 ms |
| I01PP | Peak-to-peak measurement of coarse residual current measurement input I01 | 5 ms |
| I02RMS | RMS measurement of sensitive residual current measurement input I02 | 5 ms |
| I02TRMS | TRMS measurement of coarse sensitive current measurement input I02 | 5 ms |
| I02PP | Peak-to-peak measurement of sensitive residual current measurement input I02 | 5 ms |
| I0Calc | RMS value of the calculated zero sequence current from the three phase currents | 5 ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.4 - 68. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Setting control from comm bus | 1: Disabled 2: Allowed | 1: Disabled | Activating this parameter permits changing the pick-up level of the protection stage via SCADA. |



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| Name | Range | Default | Description |
|---|---|---|---|
| I0> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of NEF block.<br><br>This parameter is visible only when Allow setting of individual LN mode is enabled in General menu. |
| I0> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: RMS<br>2: TRMS<br>3: Peak-to-peak | 1: RMS | Defines which available measured magnitude is used by the function. This parameter is available when "Input selection" has been set to "I01" or "I02". |
| Input selection | 1: I01<br>2: I02<br>3: I0Calc | 1: I01 | Defines which measured residual current is used by the function. |

## Pick-up

The $I0_{set}$ setting parameter controls the the pick-up of the I0> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $I0_{set}$ and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $I0_{set}$ value. The setting value is common for all measured phases. When the $I_m$ exceeds the $I0_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.4 - 69. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $I0_{set}$ | Pick-up setting | 0.0001…40.00 × $I_n$ | 0.0001 × $I_n$ | 1.20 × $I_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.4 - 70. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I0> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of NEF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays status of the protection function. |

| Name | Range | Step | Description |
|---|---|---|---|
| Detected I0 angle | -360.00...360.00 deg | 0.01 deg | Angle of I0 against reference. If phase voltages are available, positive sequence voltage angle is used as reference. If voltages are not available, positive sequence current angle is used as reference. |
| Detected fault type | 0: -<br>1: A-G-R<br>2: B-G-F<br>3: C-G-R<br>4: A-G-F<br>5: B-G-R<br>6: C-G-F | - | Displays the detected fault type and direction of previous fault. "A/B/C" stand for one of the three phases. "G" stands for "ground". "F" stands for "forward" direction and "R" stands for "reverse" direction. |
| Expected operating time | -1800.000...1800.000 s | 0.005 s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | 0.000...1800.000 s | 0.005 s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $I_{meas}/I_{set}$ at the moment | 0.00...1250.00 | 0.01 | The ratio between the measured current and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, non-directional earth fault protection includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 5.4.4 - 71. Internal inrush harmonic blocking settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Inrush harmonic blocking (internal-only trip) | $2^{nd}$ harmonic blocking enable/ disable | 0: No<br>1: Yes | - | 0: No |
| $2^{nd}$ harmonic block limit (Iharm/Ifund) | $2^{nd}$ harmonic blocking limit | 0.10…50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ |

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".



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## Events and registers

The non-directional earth fault function (abbreviated "NEF" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.4 - 72. Event messages.

| Event block name | Event names |
|---|---|
| NEF1 | Start ON |
| NEF1 | Start OFF |
| NEF1 | Trip ON |
| NEF1 | Trip OFF |
| NEF1 | Block ON |
| NEF1 | Block OFF |
| NEF2 | Start ON |
| NEF2 | Start OFF |
| NEF2 | Trip ON |
| NEF2 | Trip OFF |
| NEF2 | Block ON |
| NEF2 | Block OFF |
| NEF3 | Start ON |
| NEF3 | Start OFF |
| NEF3 | Trip ON |
| NEF3 | Trip OFF |
| NEF3 | Block ON |
| NEF3 | Block OFF |
| NEF4 | Start ON |
| NEF4 | Start OFF |
| NEF4 | Trip ON |
| NEF4 | Trip OFF |
| NEF4 | Block ON |
| NEF4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.4 - 73. Register content.

| Date and time | Event | Fault type | Pre-trigger current | Fault current | Pre-fault current | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | A-G-R…C-G-F | Start/trip -20 ms current | Start/Trip current | Start -200ms current | 0 ms...1800s | Setting group 1...8 active |

### 5.4.5 Directional overcurrent protection (Idir>; 67)

The directional overcurrent function is used for instant and time-delayed overcurrent and short-circuits. A device with both voltage and current protection modules can have four (4) available stages of the function (Idir>, Idir>>, Idir>>>, Idir>>>>). The operating decisions are based on phase current magnitudes which the function constantly measures. The selectable monitored phase current magnitudes are equal to RMS values, to TRMS values (including harmonics up to 31$^{st}$), or to peak-to-peak values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The directional overcurrent function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT). The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters. The function includes CT saturation checking which allows the function to start and operate accurately during CT saturation.

The operational logic consists of the following:

- input magnitude selection
- input magnitude and angle processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

The inputs for the function are the following:

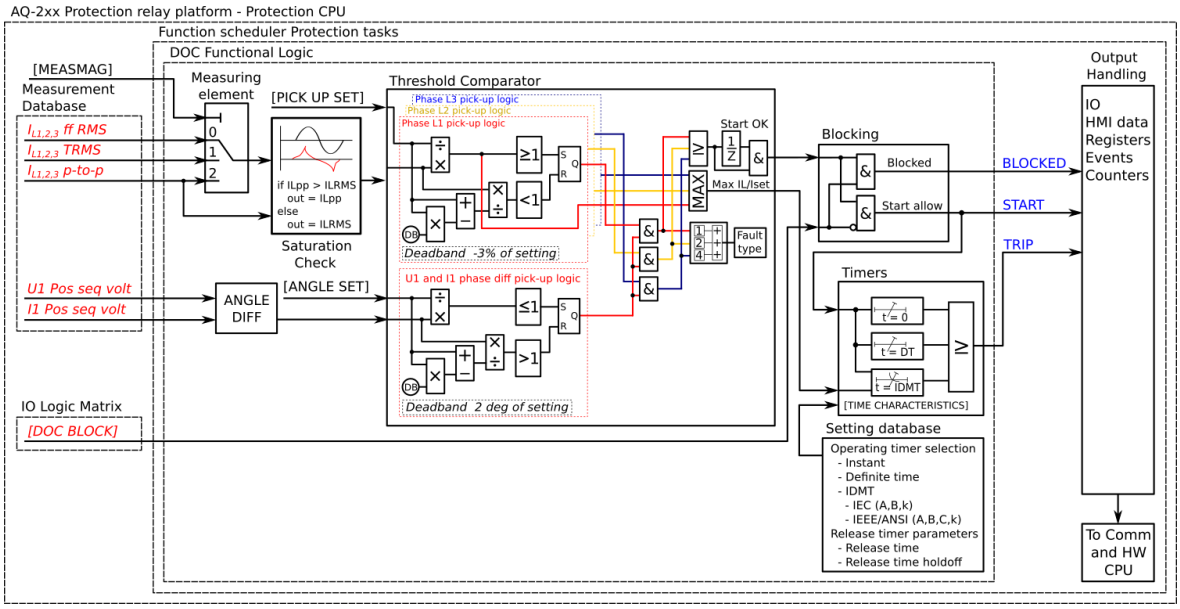
- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the directional overcurrent function.


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Figure. 5.4.5 - 37. Simplified function block diagram of the Idir> function.




## Measured input

The function block uses analog current measurement values. The user can select the monitored magnitude to be equal either to RMS values, to TRMS values, or to peak-to-peak values. TRMS mode uses values from the whole harmonic spectrum of 32 components. Peak-to-peak mode picks measurement values directly from the samples. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

The fault current angle is based on the comparison between the positive sequence voltage $U_1$ and the positive sequence current $I_1$. If the positive sequence voltage is not available (three line-to-line voltages but no $U_0$), the voltage angle is based on a faulty phase line-to-line voltage. If the voltage drops below 1 V in the secondary side during a fault, the voltage memory is used for 0.5 seconds. After that the reference angle of voltage is forced to 0°.

Table. 5.4.5 - 74. Measurement inputs of the Idir> function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| IL1TRMS | TRMS measurement of phase L1 (A) current | 5ms |
| IL2TRMS | TRMS measurement of phase L2 (B) current | 5ms |
| IL3TRMS | TRMS measurement of phase L3 (C) current | 5ms |
| IL1PP | Peak-to-peak measurement of phase L1 (A) current | 5ms |
| IL2PP | Peak-to-peak measurement of phase L2 (B) current | 5ms |
| IL3PP | Peak-to-peak measurement of phase L3 (C) current | 5ms |
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |
| $U_4$RMS | RMS measurement of voltage $U_4$/V | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.5 - 75. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Idir> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of DOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Idir> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: RMS<br><br>2: TRMS<br><br>3: Peak-to-peak | 1: RMS | Defines which available measured magnitude is used by the function. |

## Pick-up

The $I_{set}$ setting parameter controls the pick-up of the I> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $I_{set}$ and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $I_{set}$ value. The setting value is common for all measured phases, and when the $I_m$ exceeds the $I_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

The trip characteristic can be set to directional or non-directional. In the non-directional mode only the pick-up value of the positive sequence current magnitude must be fulfilled in order for the function to trip. In the directional mode the fault must also be in the monitored direction to fulfill the terms to trip. By default, the tripping area is ±88° (176°). The reference angle is based on the calculated positive sequence voltage $U_1$ angle. If the $U_1$voltage is not available and only line-to-line voltages are measured, the reference angle is based on a healthy line-to-line voltage. During a short-circuit the reference angle is based on impedance calculation.

If the voltage drops below 1 V in the secondary side, the angle memory is used for 0.5 seconds. The angle memory forces the reference angle to be equal to the value measured or calculated before the fault. The angle memory captures the measured voltage angle 100 ms before the fault starts. After 0.5 seconds the angle memory is no longer used, and the reference angle is forced to 0°. The inbuilt reset ratio for the tripping area angle is 2°.

Table. 5.4.5 - 76. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Characteristic direction | Switches between directional and non-directional overcurrent mode. | Directional<br>Non-directional | - | Directional |

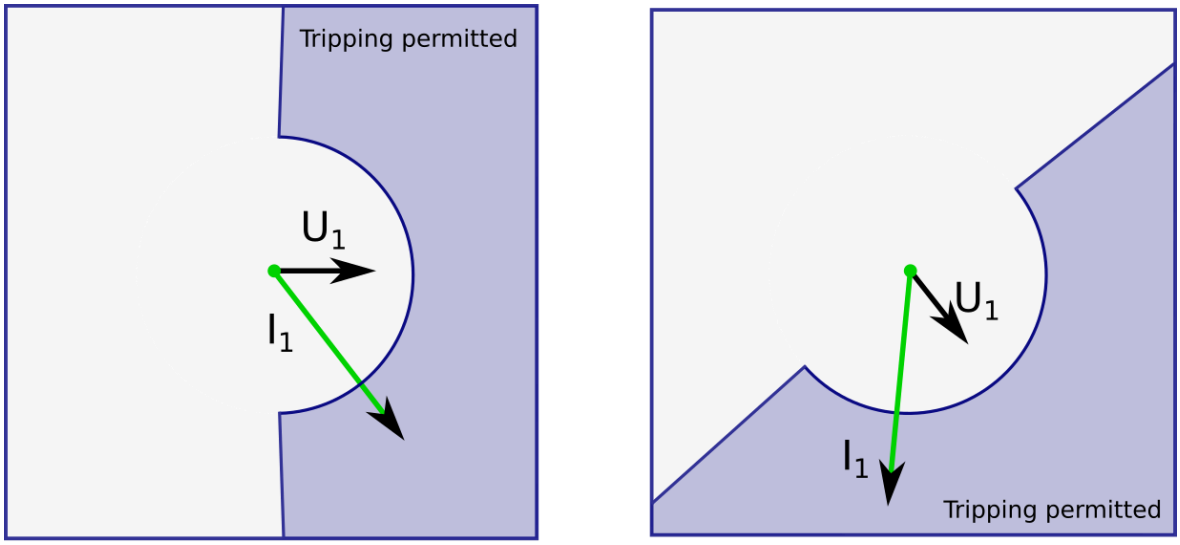


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| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Operating sector size (+ / -) | Pick-up area size in degrees. | ±1.0…170.0° | 0.1° | ±88° |
| Operating sector center | Turns the operating sector | -180.0…180.0° | 0.1° | 0° |
| Pick-up setting $I_{set}$ | Pick-up setting | 0.10…40.00×$I_n$ | 0.01×$I_n$ | 1.20×$I_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed also when the blocking condition is active.

Figure. 5.4.5 - 38. Angle tracking of the Idir> function (3LN/3LL + $U_0$ mode).




Please note in the picture above that the tripping area is linked to the angle of the positive sequence voltage $U_1$. The angle of the positive sequence current $I_1$ is compared to $U_1$ angle, and if the fault is in the correct direction, it is possible to perform a trip when the amplitude of $I_{L1}$, $I_{L2}$ or $I_{L3}$ increases above the pick-up limit.

If the 3LL mode is used without the $U_0$ measurement in a single-phase fault situation, the voltage reference comes from the healthy phase and the current reference from the faulty phase. In a short-circuit the angle comes from impedance calculation.

Figure. 5.4.5 - 39. Operation sector area when the sector center has been set to -45 degrees.

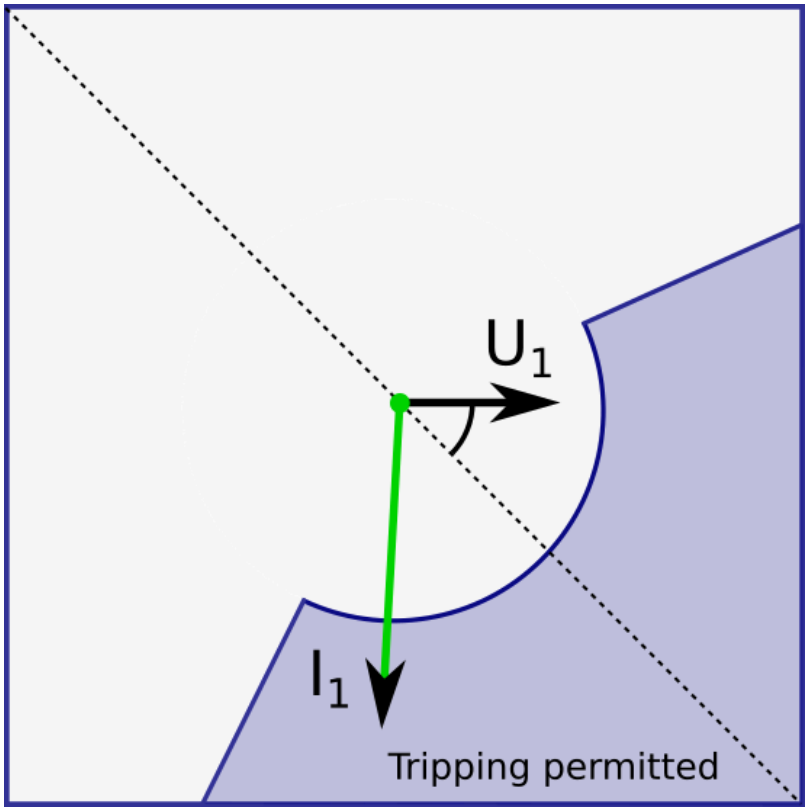
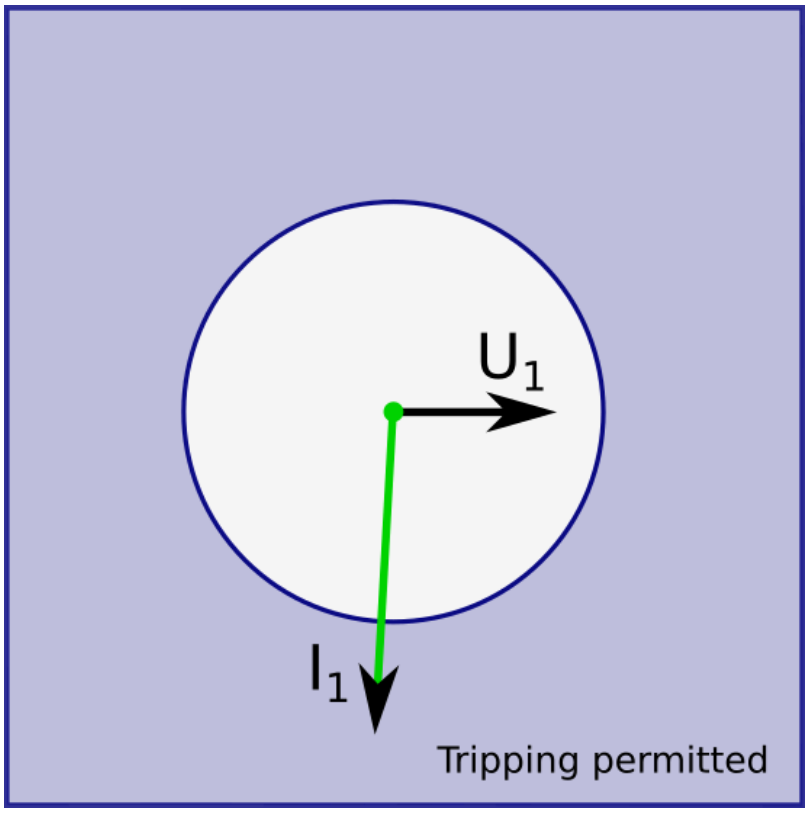



Figure. 5.4.5 - 40. When Idir> function has been set to "Non-directional" the function works basically just like a traditional non-directional overcurrent protection function.






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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.5 - 77. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Idir> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of DOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Operating angle now | -360.00...360.00deg | 0.01deg | The positive sequence current angle in relation to the positive sequence voltage. |
| Expected operating time | 0.000...1800.00s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the highest measured phase current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.00s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $I_{meas}/I_{set}$ at the moment | 0.00...1250.00$I_m/I_{set}$ | 0.01$I_m/I_{set}$ | The ratio between the highest measured phase current and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the directional overcurrent function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. When the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 5.4.5 - 78. Internal inrush harmonic blocking settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Inrush harmonic blocking (internal-only trip) | Enables and disables the 2$^{nd}$ harmonic blocking. | 0: No<br>1: Yes | - | 0: No |
| 2$^{nd}$ harmonic blocking limit (Iharm/Ifund) | The 2$^{nd}$ harmonic blocking limit. | 0.10...50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ |

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

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## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The directional overcurrent function (abbreviated "DOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.5 - 79. Event messages.

| Event block name | Event names |
|---|---|
| DOC1 | Start ON |
| DOC1 | Start OFF |
| DOC1 | Trip ON |
| DOC1 | Trip OFF |
| DOC1 | Block ON |
| DOC1 | Block OFF |
| DOC1 | No voltage, Blocking ON |
| DOC1 | Voltage measurable, Blocking OFF |
| DOC1 | Measuring live angle ON |
| DOC1 | Measuring live angle OFF |
| DOC1 | Using voltmem ON |
| DOC1 | Using voltmem OFF |
| DOC2 | Start ON |
| DOC2 | Start OFF |
| DOC2 | Trip ON |
| DOC2 | Trip OFF |
| DOC2 | Block ON |
| DOC2 | Block OFF |
| DOC2 | No voltage, Blocking ON |
| DOC2 | Voltage measurable, Blocking OFF |
| DOC2 | Measuring live angle ON |
| DOC2 | Measuring live angle OFF |
| DOC2 | Using voltmem ON |
| DOC2 | Using voltmem OFF |
| DOC3 | Start ON |
| DOC3 | Start OFF |
| DOC3 | Trip ON |


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| Event block name | Event names |
|---|---|
| DOC3 | Trip OFF |
| DOC3 | Block ON |
| DOC3 | Block OFF |
| DOC3 | No voltage, Blocking ON |
| DOC3 | Voltage measurable, Blocking OFF |
| DOC3 | Measuring live angle ON |
| DOC3 | Measuring live angle OFF |
| DOC3 | Using voltmem ON |
| DOC3 | Using voltmem OFF |
| DOC4 | Start ON |
| DOC4 | Start OFF |
| DOC4 | Trip ON |
| DOC4 | Trip OFF |
| DOC4 | Block ON |
| DOC4 | Block OFF |
| DOC4 | No voltage, Blocking ON |
| DOC4 | Voltage measurable, Blocking OFF |
| DOC4 | Measuring live angle ON |
| DOC4 | Measuring live angle OFF |
| DOC4 | Using voltmem ON |
| DOC4 | Using voltmem OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.5 - 80. Register content.

| Register name | Description |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| Fault type | L1-E...L1-L2-L3 |
| Pre-trigger current | Start/Trip -20ms current |
| Fault current | Start/Trip current |
| Pre-fault current | Start -200ms averages |
| Trip time remaining | 0s...1800s |
| Used SG | Setting group 1...8 active |
| Operating angle | 0...250° |

### 5.4.6 Directional earth fault protection (I0dir>; 67N/32N)

The directional earth fault function is used for instant and time-delayed earth fault protection. A device with both voltage and current protection modules can have four (4) stages in the function (I0dir>, I0dir>>, I0dir>>>, I0dir>>>>). The operating decisions are based on selected neutral current and voltage magnitudes which the function constantly measures. The available residual current magnitudes are RMS values, TRMS values (including harmonics up to 31$^{st}$), or peak-to-peak values that come from inputs I01 or I02 (residual current measurement) or from I0Calc (residual current calculated from phase current measurements). The current angle is compared to the angle of measured or calculated zero sequence voltage. A certain amount of zero sequence voltage has to be present to activate the trip. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The directional earth fault function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- angle check
- block signal check
- time delay characteristics
- output processing.

The inputs for the function are the following:

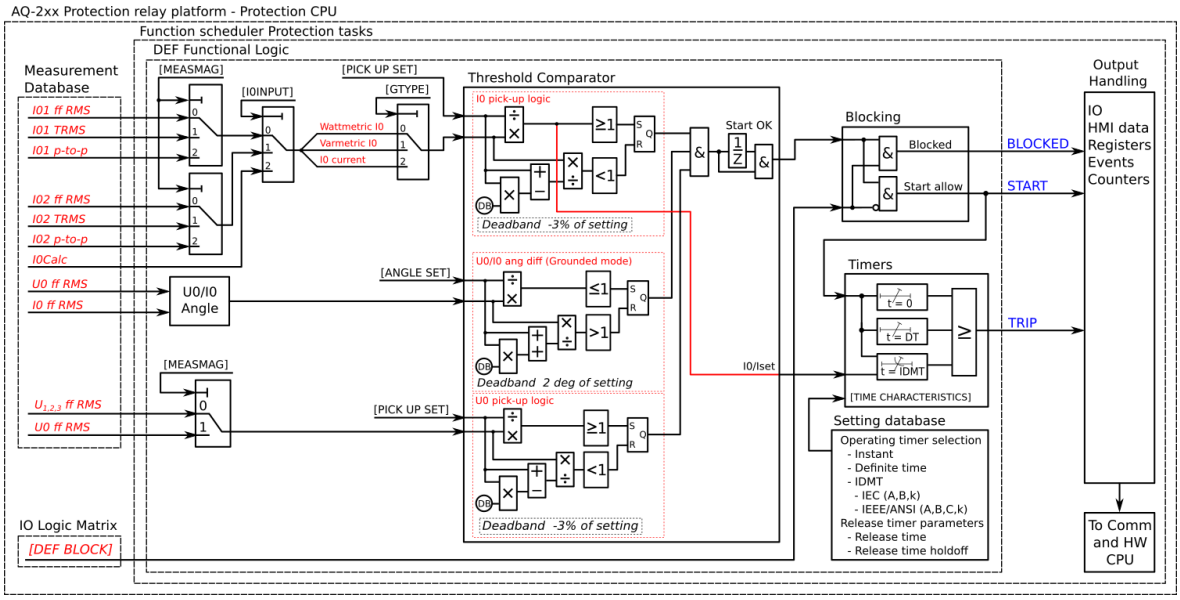
- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the directional earth fault function.


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Figure. 5.4.6 - 41. Simplified function block diagram of the I0dir> function.




## Measured input

The function block uses analog current measurement values. The user can select the monitored magnitude to be equal either to RMS values, to TRMS values, or to peak-to-peak values. TRMS mode uses values from the whole harmonic spectrum of 32 components. Peak-to-peak mode picks measurement values directly from the samples. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

The fault current angle is based on comparing the neutral voltage $U_0$ angle to the residual current $I_0$ angle. Both $I_0$ and $U_0$ must be above the squelch limit to be able to detect the angle. The squelch limit for the $I_0$ current is 0.01 x $I_n$ and for the $U_0$ voltage 0.01 x $U_n$.

Table. 5.4.6 - 81. Measurement inputs of the I0dir> function.

| Signal | Description | Time base |
|---|---|---|
| I01RMS | RMS measurement of coarse residual current measurement input I01 | 5ms |
| I01TRMS | TRMS measurement of coarse residual current measurement input I01 | 5ms |
| I01PP | Peak-to-peak measurement of coarse residual current measurement input I01 | 5ms |
| I02RMS | RMS measurement of sensitive residual current measurement input I02 | 5ms |
| I02TRMS | TRMS measurement of coarse sensitive current measurement input I02 | 5ms |
| I02PP | Peak-to-peak measurement of sensitive residual current measurement input I02 | 5ms |
| I0Calc | RMS value of the calculated residual current from the three phase currents | 5ms |
| U0RMS | RMS measurement of zero sequence voltage measurement input U0 | 5ms |
| U0Calc | RMS value of the calculated zero sequence voltage from the three phase voltages | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.6 - 82. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| I0dir> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of DEF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0dir> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked<br>4: Unearthed Start<br>5: Unearthed Trip<br>6: Compensated Start<br>7: Compensated Trip | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| U0 directional phase | 1: U0<br>2: -U0 | 1: U0 | If the connected neutral voltage polarity is opposite to the connected residual current, this parameter can swap the angle reference. |
| U0> Meas input select | 1: Select<br>2: U0 Calculated<br>3: U3 Input<br>4: U4 Input | 1: Select | Defines which available neutral voltage measurement is used. Available neutral voltages depend on measurement settings (*Measurements → Transformers → VT module*). |
| Measured magnitude | 1: RMS<br>2: TRMS<br>3: Peak-to-peak | 1: RMS | Defines which available measured magnitude is used by the function. This parameter is available when "Input selection" has been set to "I01" or "I02". |
| Input selection | 1: I01<br>2: I02<br>3: I0Calc | 1: I01 | Defines which measured residual current is used by the function. |

## Pick-up

The the pick-up of the I0dir> function is controlled by the $I0_{set}$ setting parameter and the $U0_{set}$ setting parameter. The former defines the maximum allowed measured current, while the latter defines the maximum allowed measured voltage and checks the angle difference before action from the function. The function constantly calculates the ratio between the $I0_{set}$ and the $U0_{set}$ and the measured magnitudes ($I_m$and $U_m$). The reset ratio of 97 % is built into the function and is always relative to the $I0_{set}$ (or $U0_{set}$) value. When the $I_m$ exceeds the $I0_{set}$ value it triggers the pick-up operation of the function.

Table. 5.4.6 - 83. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $I0_{set}$ | Pick-up setting | 0.005…40.00×$I_n$ | 0.001×$I_n$ | 1.20×$I_n$ |
| $U0_{set}$ | Pick-up setting | 1…75%$U_n$ | 0.01%$U_n$ | 20%$U_n$ |



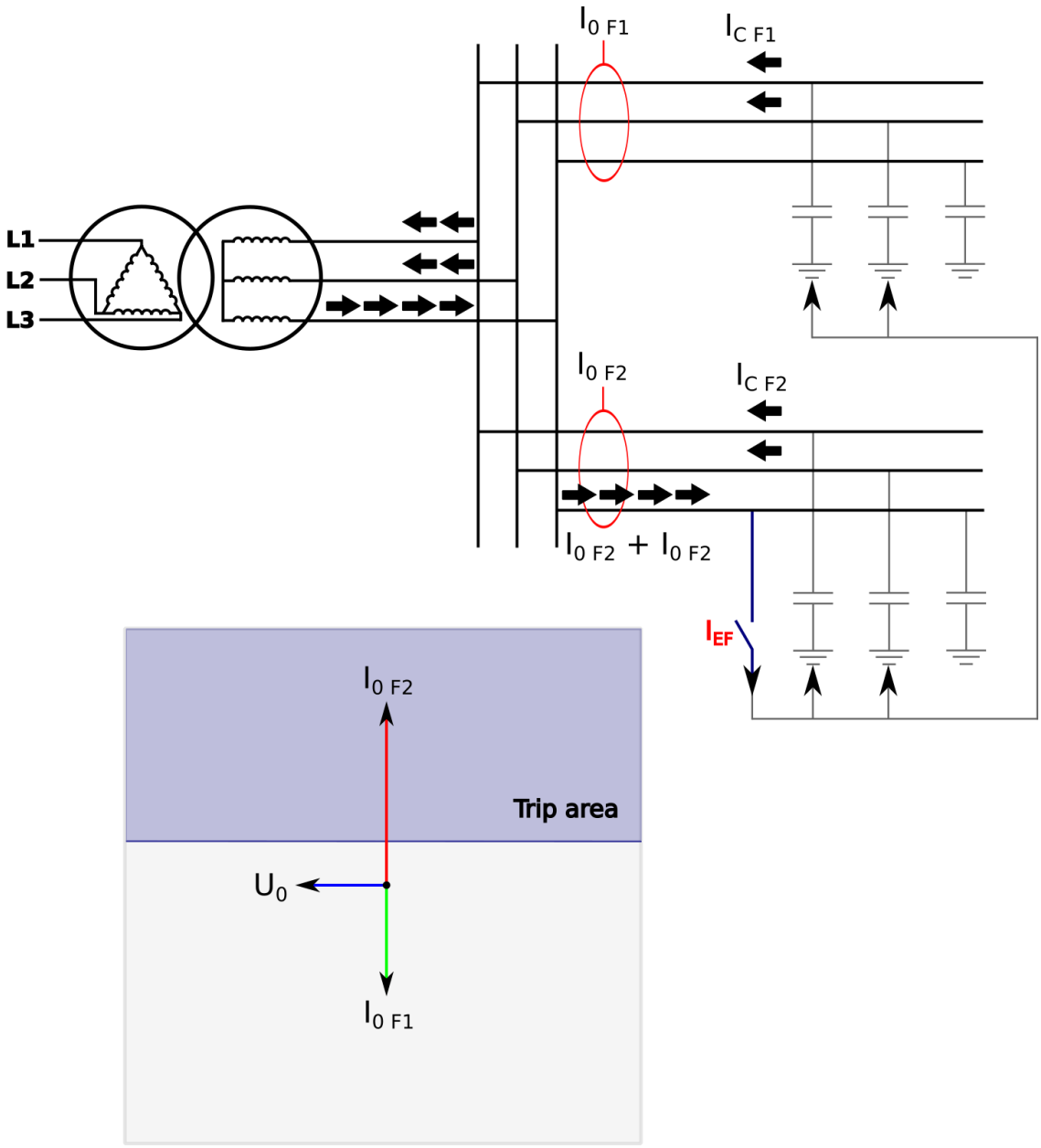
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| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Grounding type | Network grounding method | 1: Unearthed [32N Var]<br>2: Petersen coil GND [32N Watt]<br>3: Grounded [67N]<br>4: $I0_{Cos}$ & $I0_{Sin}$ broad range with MCD [32N Var/ Watt] | - | 1: Unearthed |
| Multi-criteria detection | Activation of detecting healthy or unhealthy feeder by analyzing symmetrical components of currents and voltages. Visible when earthing type is set to $I0_{Cos}$ & $I0_{Sin}$ broad range mode. | 1: Not used<br>2: Used | - | 1: Not used |
| Unearthed/ Compensated border angle | Dividing the angle between unearthed and compensated tripping (see description later in this document). Visible when earthing type is set to $I0_{Cos}$ & $I0_{Sin}$ broad range mode. | -45.0…90° | 0.1° | 45° |
| Angle | Tripping area size (earthed network) | ±45.0…135.0° | 0.1° | ±88° |
| Angle offset | Protection area direction (earthed network) | 0.0…360.0° | 0.1° | 0.0° |
| Angle blinder | I0 angle blinder (Petersen coil earthed) | -90.0…0.0° | 0.1° | -90° |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Unearthed network

Figure. 5.4.6 - 42. Angle tracking of I0dir> function (unearthed network model) (32N)




When the unearthed (capacitive) network mode is chosen, the device expects the fault current to be lagging zero sequence voltage by 90 degrees. Healthy phases of healthy feeders produce capacitive current during earth fault just like a faulty feeder but the current is floating towards the busbar and through an incoming transformer or a earthing transformer and into a faulty feeder. Healthy feeders do not trip since capacitive current is floating to the opposite direction and selective tripping can be ensured.

The amplitude of the fault current depends on the capacitance of the network. The outgoing feeders are the sources for capacitive currents. The bigger the network the greater the capacitive current during a fault. Each outgoing feeder produces capacitance according to the zero sequence capacitive reactance of the line (ohms per kilometer). It is normal that in cable networks fault currents are higher than in overhead lines.



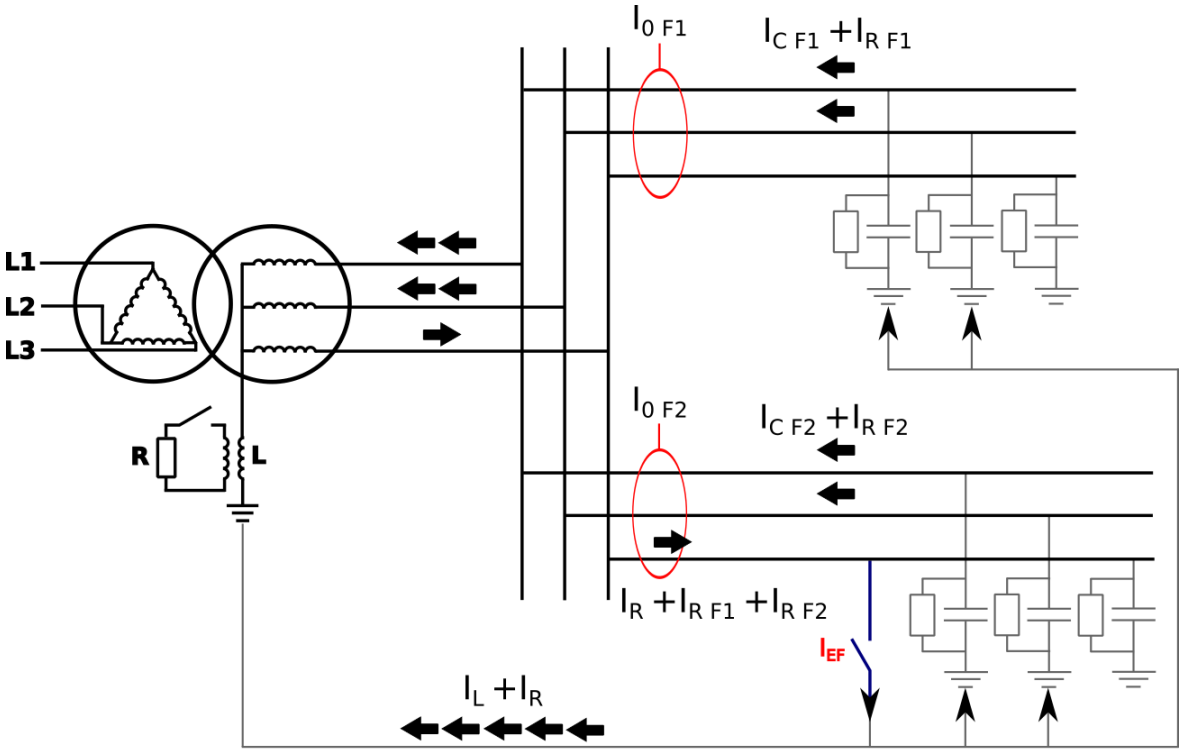
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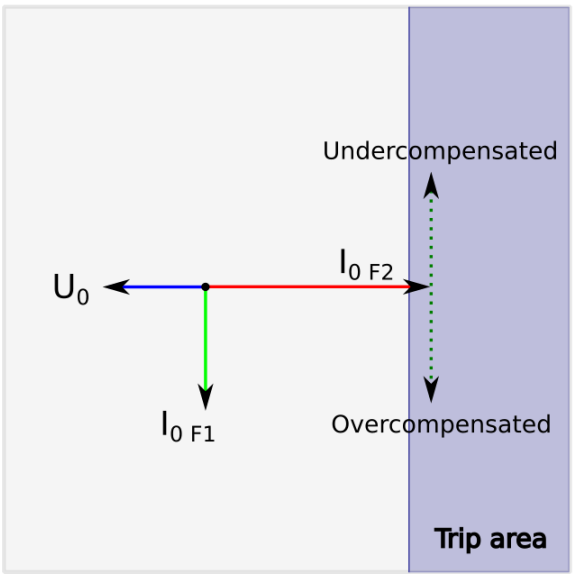
The resistance of the fault affects the size of the voltage drop during a fault. In direct earth fault the zero sequence voltage amplitude is equal to the system's line-to-earth voltage. In direct earth fault the voltage of a faulty phase drops close to zero and healthy phase voltages increase to the amplitude of line-to-line voltages.

## Petersen coil earthed (Compensated) network (32N)

There are many benefits to a Petersen coil earthed network. The amount of automatic reclosing is highly decreased and the maintenance of the breakers is therefore diminished. Arc faults die on their own, and cables and equipment suffer less damage. In emergency situations a line with an earth fault can be used for a specific time.

Figure. 5.4.6 - 43. Angle tracking of I0dir> function (Petersen coil earthed network model).



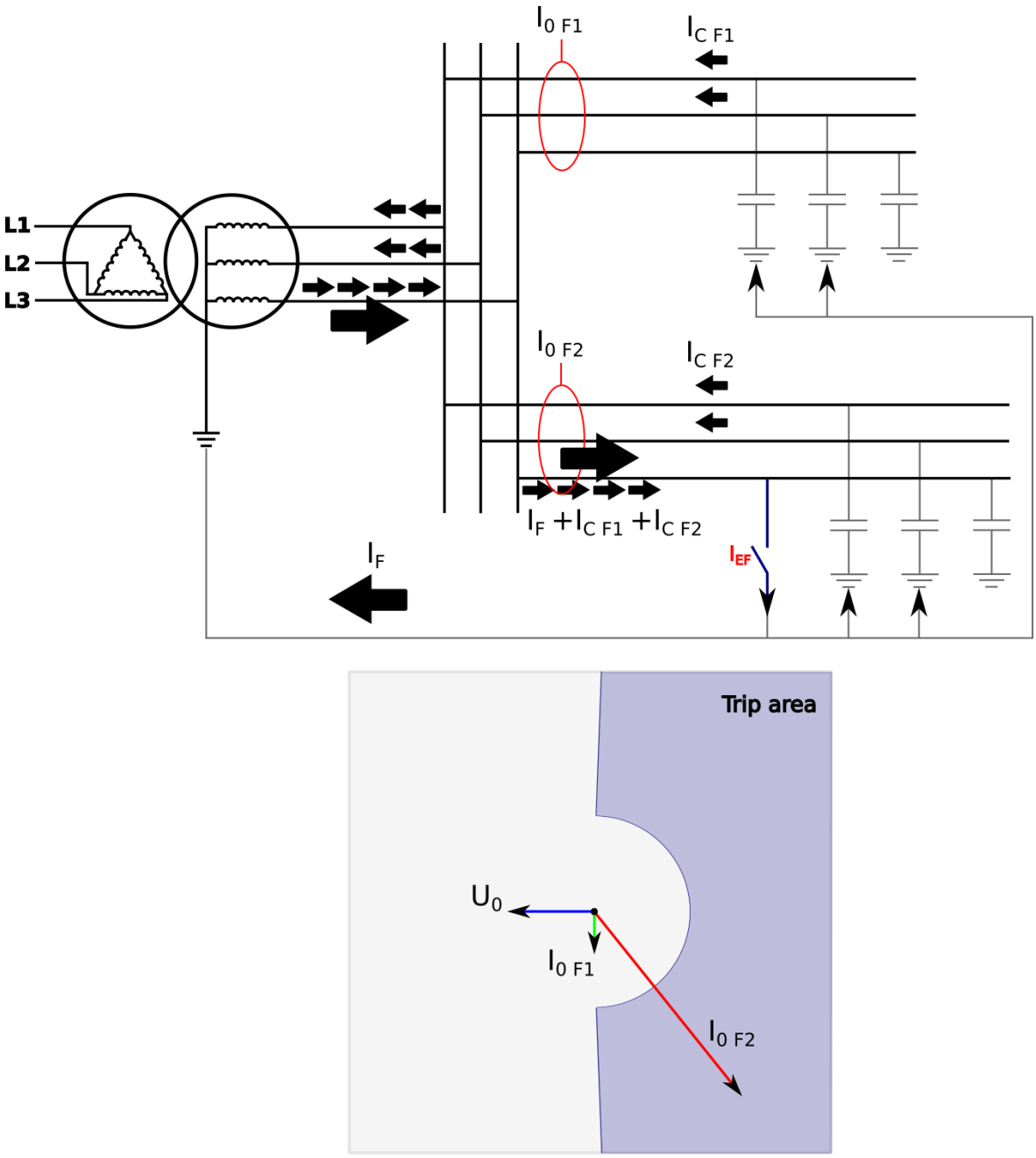
When the Petersen coil earthed (compensated) network mode is chosen, the device expects the fault current to be in the opposite direction to the zero sequence voltage. Healthy phases of both healthy and faulty feeders produce a capacitive current similar to the unearthed network. The inductance of the Petersen coil compensates the capacitive current and therefore the residual current in a fault location is close to zero. The size of the inductance is chosen according to the prospective earth fault current of the network. The desired compensation grade is achieved when the K factor is close to 1.0 and the network is fully compensated. The network is overcompensated when the K factor is greater than 1.0, and undercompensated when the K factor is smaller than 1.0.

The inductance connected to the star point of an incoming transformer or -as in most cases- to a earthing transformer compensates the capacitance of the network; however, this prevents the capacitive fault current to be measured. The fault detection is handled by connecting the resistance in parallel with the inductance. This resistance includes the amplitude of the fault current. In undercompensated or overcompensated situations the resistive component does not change during the fault; therefore, selective tripping is ensured even when the network is slightly undercompensated or overcompensated.


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## Directly earthed or small impedance network (67N)

Figure. 5.4.6 - 44. Angle tracking of I0dir> function (directly earthed or small impedance network).



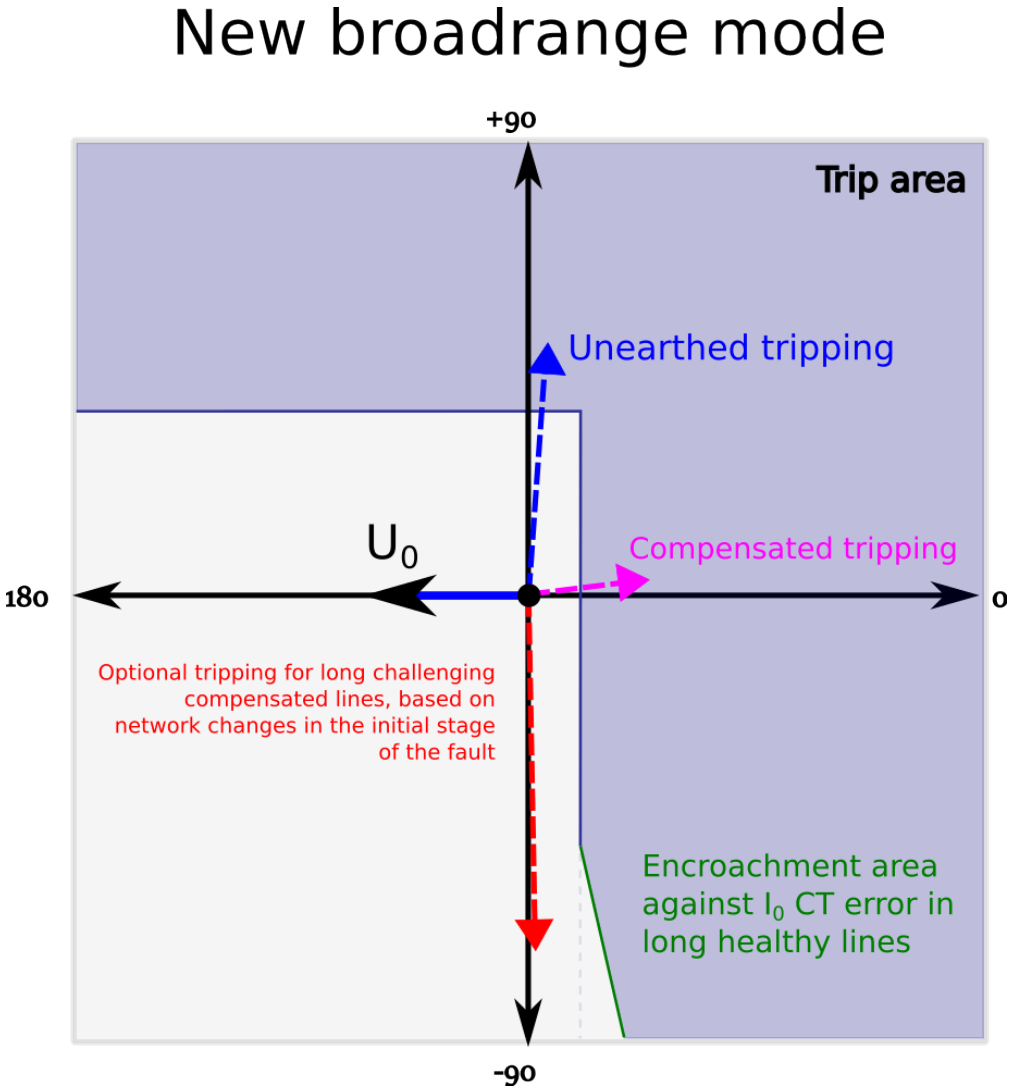

In a directly earthed network the amplitude of a single-phase fault current is similar to the amplitude of a short-circuit current. Directly earthed or small impedance network schemes are normal in transmission, distribution and industry.

The phase angle setting of the tripping area is adjustable as is the base direction of the area (angle offset).

## Broad range mode with multi-criteria detection for unearthed and compensated networks

When detecting earth faults in compensated long-distance cables and overhead lines, it is in some cases difficult to distinguish between a healthy and a faulty feeder. Merely measuring the angle and the magnitude of residual voltage and currents is not always enough, as changes in symmetrical components of phase currents and voltages are also needed. Additionally, when protecting feeders from earth faults, two modes are used depending on the network status (unearthed or compensated). When changing between these two statuses the setting group must be changed, and especially with distributed compensation the change may be difficult or impossible to arrange. Finally, in a compensated network protection the relay with traditional algorithms may sporadically detect an earth fault in a long healthy feeder due to CT errors. For all these reasons, Arcteq has developed an improved alternative to these traditional directional earth fault protections.

Figure. 5.4.6 - 45. Angle tracking of the I0dir> function (broad range mode).



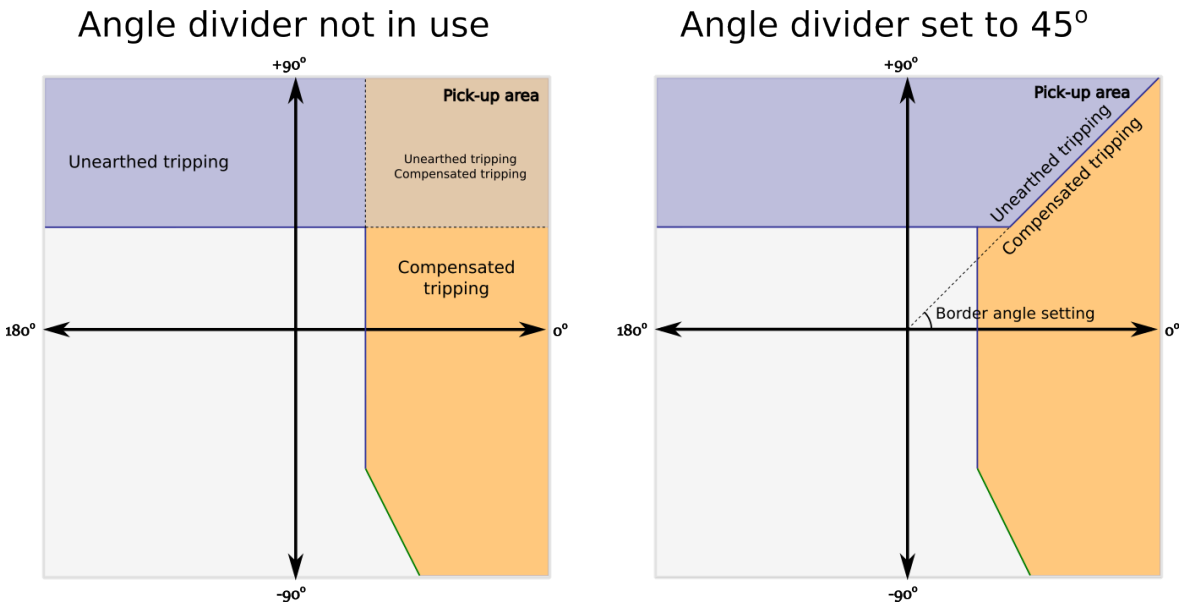



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IM00015

The new broad range mode is capable of detecting an earth fault directionally in both unearthed and compensated networks not only by combining the two stages together but by using a new multi-criteria detection. This optional additional tripping condition for compensated networks uses Arcteq's patented, high-resolution intermittent earth fault algorithm with added symmetrical component calculation of phase currents and voltages. If this mode is activated, the alarming criteria is comprised of a measured residual current in the fourth quadrant and the symmetrical components of voltages and currents detecting a fault. No extra parameterization is required compared to the traditional method. The multi-criteria algorithm can be tested with COMTRADE files supplied by Arcteq. The function requires a connection of three-phase currents, residual current and residual voltage to operate correctly.

To avoid unnecessary alarms the user can add an encroachment area against I0 CT errors in compensated long healthy lines.

Figure. 5.4.6 - 46. Effect of angle divider when in use and when disabled.




To receive a more accurate indication as to whether the fault was in a compensated or an unearthed network the angle divider can divide the area which would otherwise be overlapped between the two network models. By default the setting is 45 degrees. When the divider is disabled the angle is set to zero degrees.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.6 - 84. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I0dir> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 1: On | Set mode of NOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0dir> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |

| Name | Range | Step | Description |
|---|---|---|---|
| U0> Measuring now | 0: No U0 avail!<br>1: U0Calc<br>2: U3 Input<br>3: U4 Input | - | Displays which voltage channel is used by the function. If no voltage channel has been selected the function defaults to calculated residual voltage if line-to-neutral voltages have been connected to device. If no channel is set to "U0" mode and line-to-line voltages are connected, no residual voltage is available and "No U0 avail!" will be displayed. |
| U0> Pick-up setting | 0.0...1 000 000V | 0.1V | The required residual voltage on the primary side for the relay to trip. |
| Detected U0/ I0 angle (fi) | -360.00...360.00deg | 0.01deg | The angle in degrees between the monitored residual voltage and the current. |
| I0 Magnitude | 0.000...250.000×$I0_n$ | 0.001×$I0_n$ | The per-unit-value of the monitored residual current. |
| I0 Wattmetric I0xCos(fi) | -250.000...250.000×$I0_n$ | 0.001×$I0_n$ | The wattmetric per-unit-value of the monitored residual current. |
| I0 Varmetric I0xSin(fi) | -250.000...250.000×$I0_n$ | 0.001×$I0_n$ | The varmetric per-unit-value of the monitored residual current. |
| I0 direction now | 0: Undefined<br>1: Forward<br>2: Reverse | - | The detected direction of the residual current. |
| I0 meas/ I0 set now | -250.000...250.000×$I0_n$ | 0.001×$I0_n$ | The ratio between the monitored residual current and the pick-up value. |
| U0 measurement now | 0.000...500.000%$U0_n$ | 0.001%$U0_n$ | The measured voltage in the chosen voltage channel. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. Additionally, the directional earth fault protection function includes an internal inrush harmonic blocking option which is applied according to the parameters set by the user. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

Table. 5.4.6 - 85. Internal inrush harmonic blocking settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Inrush harmonic blocking (internal-only trip) | Enables and disables the $2^{nd}$ harmonic blocking. | 0: No<br>1: Yes | - | 0: No |
| $2^{nd}$ harmonic blocking limit (Iharm/ Ifund) | The $2^{nd}$ harmonic blocking limit. | 0.10…50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ |

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.



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The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The directional overcurrent function (abbreviated "DEF" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.6 - 86. Event messages.

| Event block name | Event name |
|---|---|
| DEF1 | Start ON |
| DEF1 | Start OFF |
| DEF1 | Trip ON |
| DEF1 | Trip OFF |
| DEF1 | Block ON |
| DEF1 | Block OFF |
| DEF1 | I0Cosfi Start ON |
| DEF1 | I0Cosfi Start OFF |
| DEF1 | I0Sinfi Start ON |
| DEF1 | I0Sinfi Start OFF |
| DEF1 | I0Cosfi Trip ON |
| DEF1 | I0Cosfi Trip OFF |
| DEF1 | I0Sinfi Trip ON |
| DEF1 | I0Sinfi Trip OFF |
| DEF2 | Start ON |
| DEF2 | Start OFF |
| DEF2 | Trip ON |
| DEF2 | Trip OFF |
| DEF2 | Block ON |
| DEF2 | Block OFF |
| DEF2 | I0Cosfi Start ON |
| DEF2 | I0Cosfi Start OF |

| Event block name | Event name |
|---|---|
| DEF2 | I0Sinfi Start ON |
| DEF2 | I0Sinfi Start OFF |
| DEF2 | I0Cosfi Trip ON |
| DEF2 | I0Cosfi Trip OFF |
| DEF2 | I0Sinfi Trip ON |
| DEF2 | I0Sinfi Trip OFF |
| DEF3 | Start ON |
| DEF3 | Start OFF |
| DEF3 | Trip ON |
| DEF3 | Trip OFF |
| DEF3 | Block ON |
| DEF3 | Block OFF |
| DEF3 | I0Cosfi Start ON |
| DEF3 | I0Cosfi Start OFF |
| DEF3 | I0Sinfi Start ON |
| DEF3 | I0Sinfi Start OFF |
| DEF3 | I0Cosfi Trip ON |
| DEF3 | I0Cosfi Trip OFF |
| DEF3 | I0Sinfi Trip ON |
| DEF3 | I0Sinfi Trip OFF |
| DEF4 | Start ON |
| DEF4 | Start OFF |
| DEF4 | Trip ON |
| DEF4 | Trip OFF |
| DEF4 | Block ON |
| DEF4 | Block OFF |
| DEF4 | I0Cosfi Start ON |
| DEF4 | I0Cosfi Start OFF |
| DEF4 | I0Sinfi Start ON |
| DEF4 | I0Sinfi Start OFF |
| DEF4 | I0Cosfi Trip ON |
| DEF4 | I0Cosfi Trip OFF |
| DEF4 | I0Sinfi Trip ON |
| DEF4 | I0Sinfi Trip OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.



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Table. 5.4.6 - 87. Register content.

| Register | Description |
|---|---|
| Event | Event name |
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| $I_0$ pre-triggering current | Start/Trip -20ms current |
| $I_0$ fault current | Start/Trip current |
| Fault capacitive $I_0$ | Start/Trip capacitive current |
| Fault resistive $I_0$ | Start/Trip resistive current |
| Fault $U_0$ (%) | Start/Trip voltage (percentage of nominal) |
| Fault $U_0$ (V) | Start/Trip voltage (in Volts) |
| $I_0$ fault angle | 0...360° |
| Trip time remaining | 0 ms...1800s |
| Used SG | Setting group 1...8 active |
| Network GND | Unearthed, Petersen coil earthed, Earthed network |
| $I_0$ pre-fault current | Start -200ms current |

## 5.4.7 Intermittent earth fault protection (I0int>; 67NT)

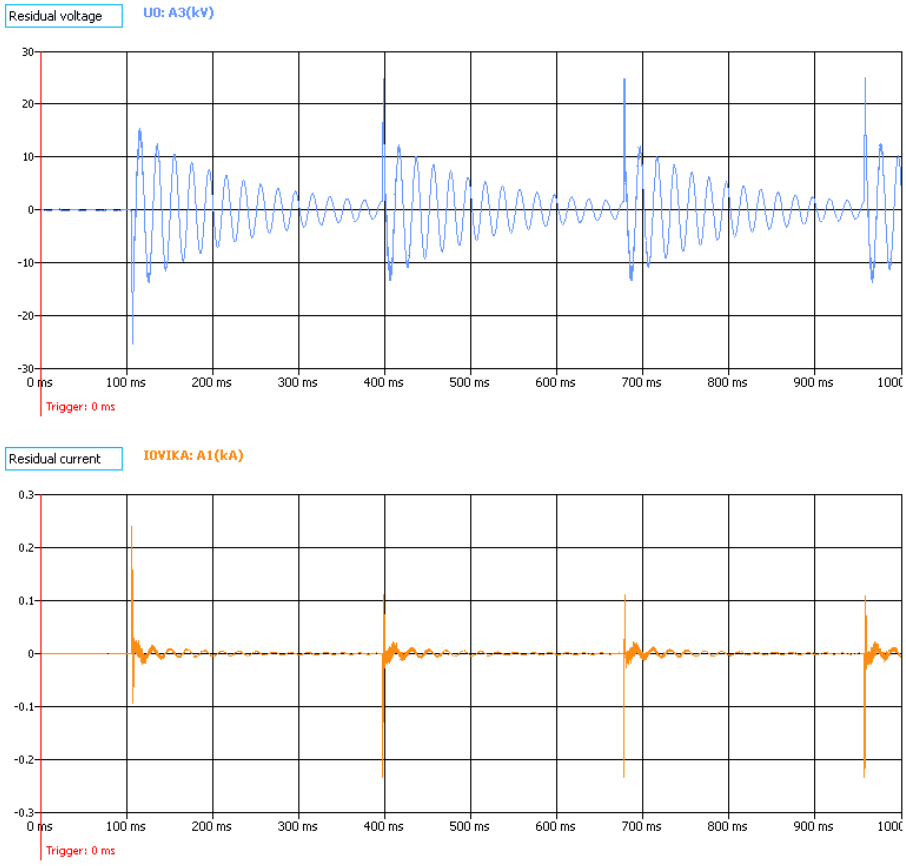
The intermittent earth fault is a transient type of single-phase-to-earth fault where the actual fault phenomenon lasts for about a few hundred microseconds. The intermittent earth fault is commonly seen in Petersen coil grounded (compensated) medium voltage networks. The intermittent earth fault is commonly thought only as a cable network problem but it can also occur in overhead line networks. The key point for this type of fault appearance is the compensation of earth fault currents with a Petersen coil.

This phenomenon is becoming more frequent as more utilities networks are replacing overhead lines with cables dug into the ground. This development in distribution networks is very understandable as overhead lines are more vulnerable to possible seasonal storm damages. Also, the annual maintenance costs as well as the annual power-down time are both significantly lower with underground cable networks than with overhead line networks. However, the problem at hand is caused by the increasing amount of cabling in the network which in turn causes dramatic increases in the capacitive earth fault currents in the distribution networks. When the capacitive earth fault current increases in the network, it becomes necessary to detect the earth fault current with a Petersen coil.

Problems caused by intermittent earth fault are normally seen in compensated network substations: an earth fault can trip multiple feeders simultaneously, or an entire substation can be tripped by residual voltage back-up protection from the incomer. This is typical of old-fashioned relay protection as it is not capable of differentiating between a normal consistent earth fault and an intermittent earth fault. As the intermittent earth fault is a transient type of fault where the actual fault lasts only for a few hundred microseconds, this causes traditional directional earth fault protection relays to lose their directional sensitivity, and as a result their directional decision algorithms go haywire and the trip decisions will be completely random. Typically, when a whole substation goes dark the logs of all protection relays show how they have experienced multiple incorrect directional earth fault starts and releases, as well as an incomer relay residual voltage trip. This is also the worst case scenario. In another typical scenario a few feeders, including the correct faulty feeder, have tripped at the same time. In this case, as in the previous, all the relays' logs show various incorrect directional earth fault starts and releases.

Previously, these scenarios were usually ignored and filed under 'Mysteries of the universe' because they only occured once or twice a year and because disturbance recordings were not commonly used in normal medium-voltage substations for fault verification. However, when disturbance recorders were introduced as a common feature of protection relays this phenomenon received a name and defined characteristics. One such characteristic is the occurence of high magnitude current spikes, which –compared to residual voltage– are in the opposite direction of the current spike in faulty feeders and concurrent in healthy feeders. Handling these unique characteristics requires a completely different set of tools than what traditional directional earth fault protection can offer. The following figures present three intermittent earth fault situations experienced by relays in a substation..

Figure. 5.4.7 - 47. An intermittent earth fault in a medium size network tuned close to resonance, as seen by a faulty feeder relay.






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Figure. 5.4.7 - 48. An intermittent earth fault in a network tuned close to resonance, as seen by a healthy feeder relay.

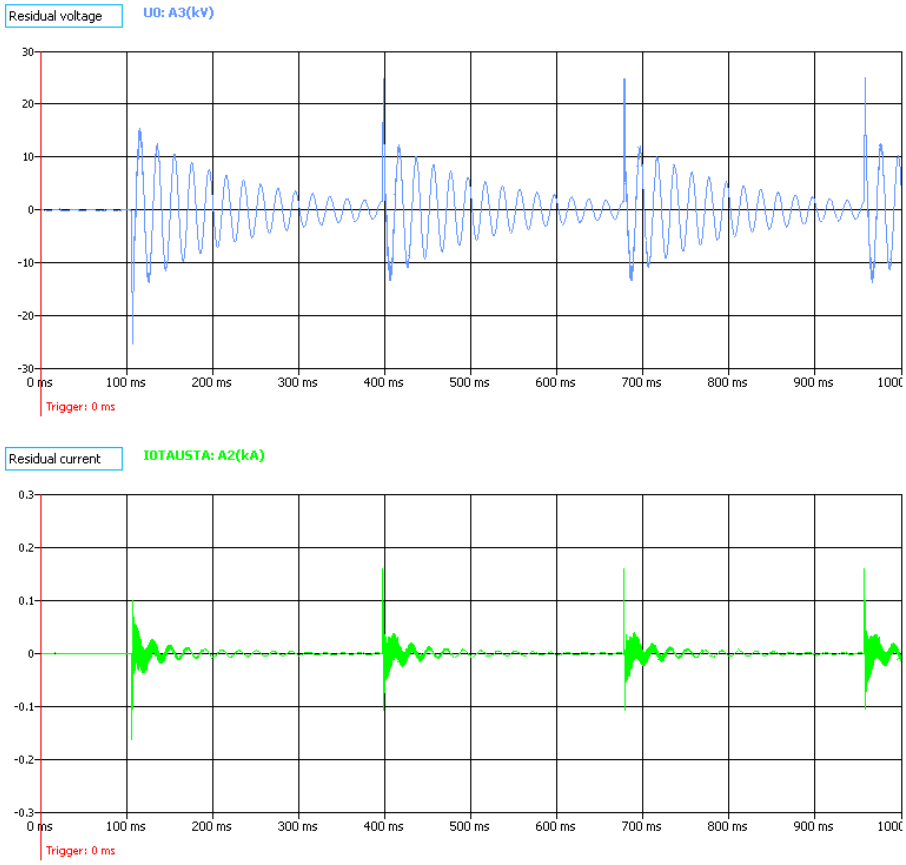
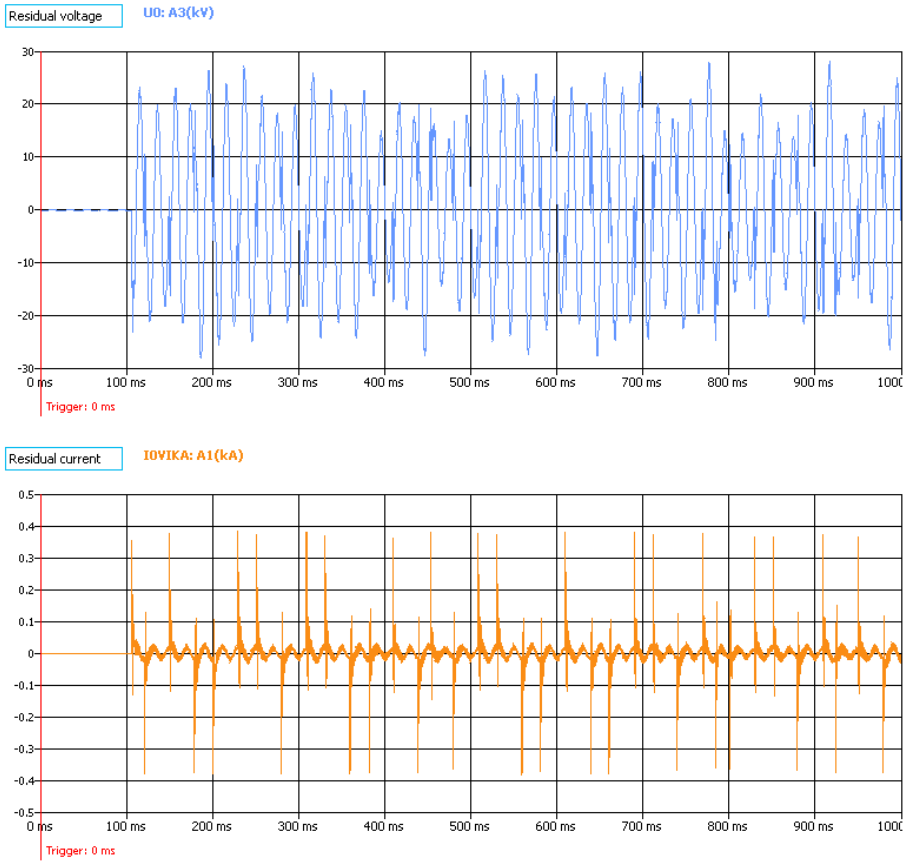


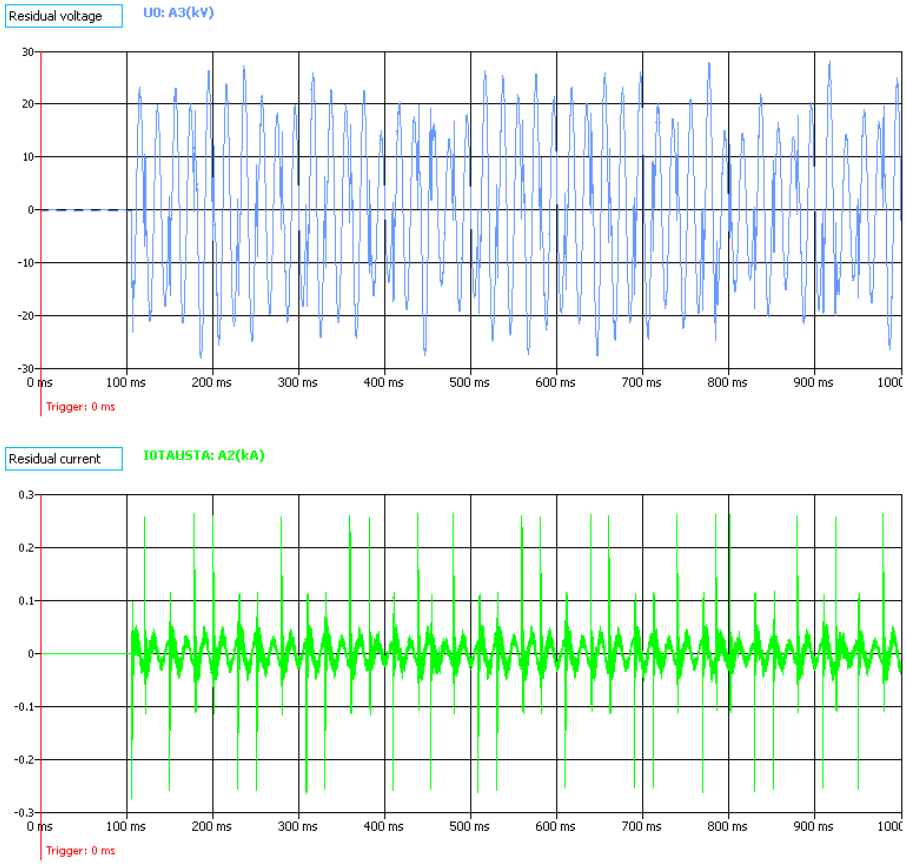
Figure. 5.4.7 - 49. An intermittent earth fault in an undercompensated medium size network, as seen by a faulty feeder relay.






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Figure. 5.4.7 - 50. Undercompensated medium size network intermittent earth fault seen by healthy feeder relay.




As can be seen from the figures above, the residual voltage is high both in the network tuned close to resonance and in the undercompensated network. In the case of a normal directional earth fault protection, a network tuned close to resonance would probably not even pick up on the fault, and if it did it would release before the set operating time. The residual voltage stays on for a longer period of time. Although the release would most likely come before the set tripping time, this situation could last for quite some time and put a lot of unnecessary stress on the network, possibly causing an insulator breakdown in another part of the network.

In undercompensated and overcompensated networks the residual voltage stays near the maximum level all the time, and current flashover spikes occur every power cycle. In this case, normal FFT-based directional earth fault protection algorithms lose their directional sense because an FFT-processed input signal expects the power cycle to provide long, stable data for accurate directional output. There are multiple zero crossings during a normal power cycle and therefore the FFT result may be anything from 0 to 180 degrees. When analyzing the situation from the point of view of normal directional earth fault protection,  the result may be an expected trip in a faulty feeder, a false trip in a healthy feeder, or no trip whatsoever, all equally probable.

## Description of the patented intermittent earth fault algorithm

The algorithm relates to a method for identifying transient-type earth faults in an electrical network and for selectively tripping a faulty branch line (A/D). The absolute value ($I0_{max}$) and its index in a zero-current buffer are retrieved from the samples of a zero-current sampling buffer. This is done by means of value-depicting the admittance-delta which is calculated using the ratio DELTAI0/DELTAU0: that is, the ratio between the zero current I0 difference DELTAI0 and the residual voltage UC difference DELTAU0. A negative admittance-delta is classified as forward (FWD). A transient-type earth fault is detected in the branch line with the aid of at least one forward (FWD) spike during a selected time (FWDreset).

More detailed information of the patent can be found on the European Patent Office webpages. The patent's data code is EP3213381 (A1).
A link to the patent: https://worldwide.espacenet.com/publicationDetails/biblio?II=2&ND=3&adjacent=true&locale=en_EP&FT=D&date=20170906&CC=EP&NR=3213381A1&KC=A1.

## Setting principles

The intermittent earth fault protection will be coordinated with bus bar residual voltage protection. This way, during an intermittent earth fault, a faulty feeder's protection function will trip in all three previously described scenarios. Also, an intermittent earth fault protection function tripping before the residual voltage protection function results in a sufficient safety margin. However, since an intermittent earth fault causes significant network stress the protection trip should be performed as fast as possible.

The strike-through time of an intermittent earth fault in a network tuned close to resonance sets the limit for the minimum operating time for an intermittent earth fault protection stage. To ensure a correct protection operation in all cases, the reset time of an intermittent earth fault stage will be set according to the network in question, to such a level that ensures that the fault has disappeared and no new strike-throughs are expected after a prescribed reset time.

The size of the network is a dominant factor in defining the time interval of a strike-through. One can expect less frequent strike-throughs in larger (in amperes) networks. The following can be presented as a rule of a thumb: in a small or medium size network (<60 A) the strike-through interval is appr. 250...350 ms, in a large network (~100 A) it is appr. 500 ms. It is recommended that the reset time of an intermittent earth fault stage should not be set lower than 450 ms in order to obtain a network independent setting. Using this recommended value one can ensure that the function will not reset too early even in resonance tuned networks.

Usually the maximum operating time of an intermittent earth fault function is dictated by the residual voltage protection of the bus bar. If the residual voltage protection is set to very fast tripping, it may be necessary to also prolong its set value. It is recommended that the operating time of an intermittent earth fault stage should be 500 ms counting from the first strike-through. Using this recommended value the protection tripping requires a minimum of two strike-troughs even in resonance tuned networks in which strike-throughs occur less frequently. If the residual voltage protection is set to very fast tripping (<1 s), it may be necessary to verify the reset value of the residual voltage protection. The residual voltage protection operating time will never be faster than the sum of the following: the prescribed intermittent earth fault operating time, the circuit breaker operating time, and the reset time of the residual voltage protection stage.

If an intermittent earth fault protection start is used to block regular non-intermittent directional earth fault protection, the blocking should be applied to both healthy and faulty feeder relays. In general, if intermittent earth fault protection is not used to block directional earth fault protection, it should be verified that the operating time of regular directional earth fault protection is longer than the set intermittent earth fault protection operating time. It is recommended to block regular directional earth fault protection to avoid start events in directional earth fault protection during intermittent earth faults (if start events are considered disturbing), or if directional non-intermittent earth fault protection is set to a faster operating time than intermittent earth fault protection.

If intermittent earth fault protection would be set for optimal operation, sensitive pick-up settings should be avoided. General setting parameter values are presented below.

| Setting parameter | Value |
|---|---|
| U0 Detect spike > | 60 % |
| I0 Detect spike > | 0.5 x $I0_n$ |
| FWD reset time | 0.250 s |
| REV reset time | 0.250 s |
| Definite operating time delay | 0.500 s |


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| Setting parameter | Value |
|---|---|
| Spikes to trip > | 2 |

The best verification for the settings is a field test with a test system capable of intermittent earth faults. One network characteristic may vary significantly from another. By following the basic rules presented in this chapter it should be easier to define the correct setting range.

It is also important to check that the reset time settings are never set longer than the desired operating time delay setting.

## Measured input

The function block uses analog current measurement values from the residual magnitudes. The residual voltage has to be measured for this function to operate correctly. Either the I01 or the I02 channel can be selected for residual current samples.

Table. 5.4.7 - 88. Measurement inputs of the I0int> function.

| Signal | Description | Time base |
|---|---|---|
| U0 samples | $U_0$ residual voltage circular buffer of samples (in p.u.) | 5 ms |
| I01 samples | $I_0$ residual current circular buffer of samples (in p.u.) | 5 ms |
| I02 samples | $I_0$ residual current circular buffer of samples (in p.u.) | 5 ms |

The selection of the used AI channel is made with a setting parameter.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.7 - 89. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| I0Int> [67NT] mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of IEF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0Int> force status to | 0: Normal<br>1: Blocked<br>2: StartFWD<br>3: StartREV<br>4: Trip | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Input selection | 1: I01<br>2: I02 | 1: I01 | Defines which measured residual current is used by the function. |

## Pick-up

The setting parameters *U0 Detect spike>* and *I0 Detect spike>* control the pick-up of the I0int> function. They define the maximum allowed measured residual current and voltage before action from the function. The function constantly calculates the ratio between the setting and the maximum value of the circular buffer.

Table. 5.4.7 - 90. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| U0 Detect spike > | 1.00…100.00%$U_n$ | 0.01%$U_n$ | 80.00%$U_n$ | Pick-up setting $U_0$ |
| I0 Detect spike > | 0.05…40.00x$I0_n$ | 0.01x$I0_n$ | 0.50x$I0_n$ | Pick-up setting $I_0$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active and if the threshold of the admittance delta calculated by the input signal exceeds these settings:

- I0 Detect spike > = set admittance delta threshold
- U0 Detect spike > = set admittance delta threshold.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.7 - 91. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I0Int> [67NT] behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of IEF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0Int> condition | 0: Normal<br>1: StartFWD<br>2: StartREV<br>3: Trip<br>4: Blocked | - | Displays status of the protection function. |
| U0> measuring now | 0: No U0 avail!<br>1: U3 Input<br>2: U4 Input | - | Displays which voltage channel is used by the function. If no voltage channel has been selected the function defaults to "No U0 avail!". |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | 0.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| Spikes remaining to trip > | 0...4294967295 | 1 | Displays how many spikes need to be detected before tripping can occur. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.


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The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for trip signal and for the release of the function in case the pick-up element is reset before the trip time has been reached. A definite time (DT) operation gives the trip signal after a user-defined time delay regardless of the measured current as long as the pick-up element is active. The following table presents the setting parameters for the function time characteristics.

Table. 5.4.7 - 92. Operating time characteristics setting parameters.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| FWD reset time | 0.000…1800.000s | 0.005s | 0.300s | Forward start detection reset time. Starts to count from the first detected forward (faulty feeder) spike. If while counting another spike is detected, it resets and starts from the beginning. If it runs to the end, it resets the function's STARTFWD signal. |
| REV reset time | 0.000…1800.000s | 0.005s | 0.300s | Reverse start detection reset time. Starts to count from the first detected reverse (healthy feeder) spike. If while counting another spike is detected, it resets and starts from the beginning. If it runs to the end, it resets the function's STARTREV signal. |
| Definite operating time delay | 0.000…1800.000s | 0.005s | 0.500s | Operating time counter that starts from the beginning of the fault if the FWD reset time is running and the function has a START signal on. If the FWD reset time is reached and the function releases, this timer is reset as well. |
| Spikes to trip > | 1...50 | 1 | 2 | The calculated cumulative spikes comparator. In order for the function to trip, a set number of spikes must be exceeded. If the set operating time is reached but the calculated spike number is below this, the setting function releases without a trip when the FWD reset time has elapsed. |

## Events and registers

The intermittent earth fault function (abbreviated "IEF" in event block names) generates events and registers from the status changes in the detected earth fault, in the FWD start, in the REV start, in TRIP, and in BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.7 - 93. Event messages.

| Event block name | Event names |
|---|---|
| IEF1 | Start FWD ON |
| IEF1 | Start FWD OFF |
| IEF1 | Start REV ON |
| IEF1 | Start REV OFF |
| IEF1 | Trip ON |
| IEF1 | Trip OFF |
| IEF1 | Block ON |

| Event block name | Event names |
|---|---|
| IEF1 | Block OFF |
| IEF1 | Intermittent EF detected ON |
| IEF1 | Intermittent EF detected OFF |
| IEF1 | Normal earthfault detected |
| IEF1 | Intermittent EF Locked |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.7 - 94. Register content.

| Date and time | Event | Trip time remaining | Started FWD | Spikes FWD | Started REV | Spikes REV | Spikes to trip | Setting group in use |
|---|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Time remaining from the set operating time. | YES/ NO indication of the forward start in this fault. | The calculated cumulative amount of forward (faulty) feeder spikes. | YES/ NO indication of the reverse start in this fault. | The calculated cumulative amount of reverse (healthy) feeder spikes | Set spikes to trip subtracted by the cumulative forward spikes. If 0 spikes, it trips. | 1...8 |

## 5.4.8 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L)

The current unbalance function is used for instant and time-delayed unbalanced network protection and for detecting broken conductors. The number of stages in the function depends on the relay model. The operating decisions are based on negative and positive sequence current magnitudes which the function constantly measures. In the broken conductor mode (I2/I1) the minimum allowed loading current is also monitored in the phase current magnitudes.

There are two possible operating modes available: the I2 mode monitors the negative sequence current, while the I2/I1 mode monitors the ratio between the negative sequence current and the positive sequence current. The relay calculates the symmetrical component magnitudes in use from the phase current inputs $I_{L1}$, $I_{L2}$ and $I_{L3}$. The zero sequence current is also recorded into the registers as well as the angles of the positive, negative and zero sequence currents in order to better verify any fault cases. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The current unbalance function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) or inverse definite minimum time (IDMT). The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selelction
- input magnitude processing
- threshold comparator


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- block signal check
- time delay characteristics
- output processing.

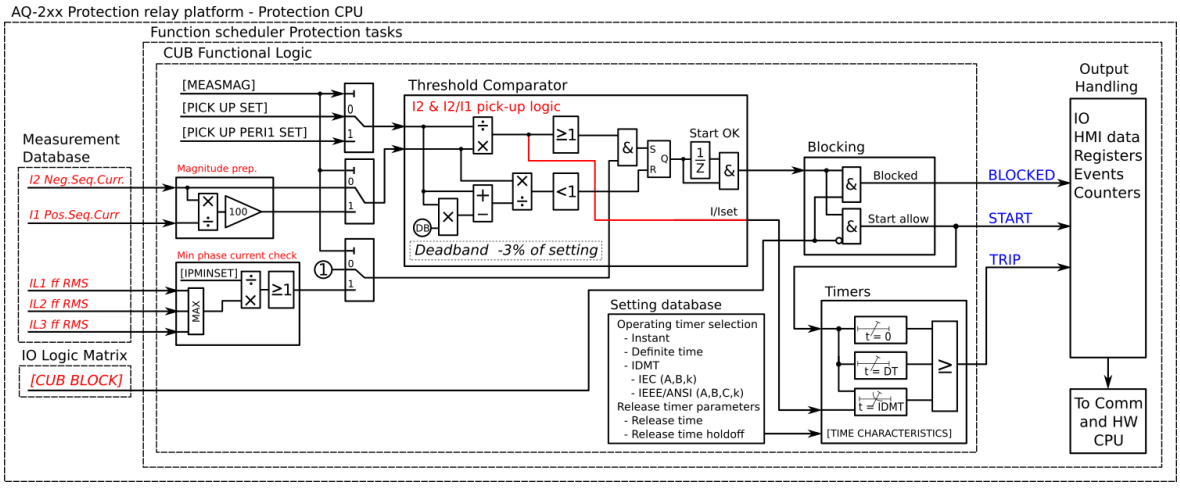
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the current unbalance function.

Figure. 5.4.8 - 51. Simplified function block diagram of the I2> function.




## Measured input

The function block uses analog current measurement values and always uses calculated positive and negative sequence currents. In the broken conductor mode (I2/I1) the function also uses the RMS values of all phase currents to check the minimum current. Zero sequence and component sequence angles are used for fault registering and for fault analysis processing. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.8 - 95. Measurement inputs of the I2> function.

| Signal | Description | Time base |
|---|---|---|
| I1 | Positive sequence current magnitude | 5 ms |
| I2 | Negative sequence current magnitude | 5 ms |
| IZ | Zero sequence current magnitude | 5 ms |
| I1 ANG | Positive sequence current angle | 5 ms |
| I2 ANG | Negative sequence current angle | 5 ms |
| IZ ANG | Zero sequence current angle | 5 ms |

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | Phase L1 (A) measured RMS current | 5 ms |
| IL2RMS | Phase L2 (B) measured RMS current | 5 ms |
| IL3RMS | Phase L3 (C) measured RMS current | 5 ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.8 - 96. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| I2> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of CUB block.<br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I2> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: I2pu<br>2: I2/I1 | 1: I2pu | Defines whether the ratio between the positive and the negative sequence currents are supervised or whether only the negative sequence is used in detecting unbalance. |

## Pick-up

The setting parameters $I2_{set}$ *and* $I2/I1_{set}$ control the the pick-up of the I2> function. They define the maximum allowed measured negative sequence current or the negative/positive sequence current ratio before action from the function. The function constantly calculates the ratio between the $I_{set}$ and the measured magnitude ($I_m$). The reset ratio of 97 % is built into the function and is always relative to the $I_{xset}$ value. The reset ratio is the same for both modes.

Table. 5.4.8 - 97. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| I2set | Pick-up setting for I2 mode. | 0.01…40.00×$I_n$ | 0.01×$I_n$ | 0.2×$I_n$ |
| I2/I1set | Pick-up setting for I2/I1 mode | 1…200% | 0.01% | 20% |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.



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Table. 5.4.8 - 98. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| I2> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | - | Displays the mode of CUB block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I2> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for TRIP signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: gives the TRIP signal with no additional time delay simultaneously with the start signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured current as long as the current is above or below the $i_{set}$ value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up value $I_{set}$ and the measured current $I_m$ (dependent time characteristics).

Both IEC and IEEE/ANSI standard characteristics as well as user settable parameters are available for the IDMT operation.

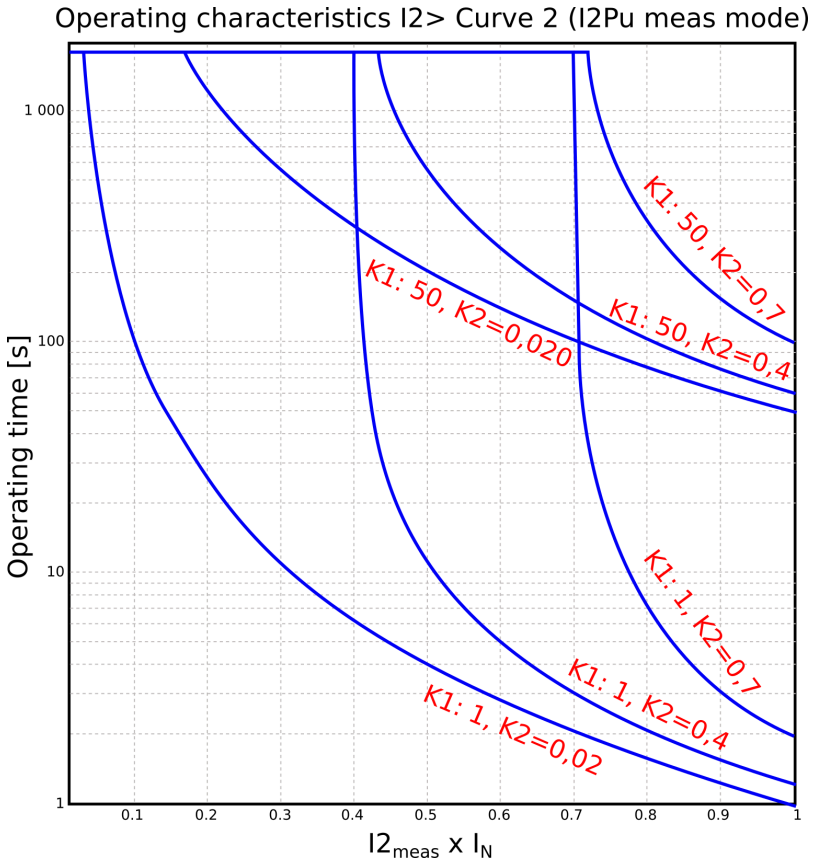
Unique to the current unbalance protection is the availability of the "Curve2" delay which follows the formula below:

$$t = \frac{k}{{I_{2meas}}^2 - {I_{set}}^2}$$

- $t$ = Operating time

- $I_{2meas}$ = Calculated negative sequence
- $k$ = Constant k value (user settable delay multiplier)
- $I_{set}$= Pick-up setting of the function

Figure. 5.4.8 - 52. Operation characteristics curve for I2> Curve2.




For a more detailed description on the time characteristics and their setting parameters, please refer to the "General properties of a protection function" chapter and its "Operating time characteristics for trip and reset" section.

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

## Events and registers

The current unbalance function (abbreviated "CUB" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select the status ON or OFF for messages in the main event buffer. The function offers four (4) independent stages; the events are segregated for each stage operation.

The triggering event of the function (START, TRIP or BLOCKED) is recorded with a time stamp and with process data values.


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Table. 5.4.8 - 99. Event messages.

| Event block name | Event names |
|---|---|
| CUB1 | Start ON |
| CUB1 | Start OFF |
| CUB1 | Trip ON |
| CUB1 | Trip OFF |
| CUB1 | Block ON |
| CUB1 | Block OFF |
| CUB2 | Start ON |
| CUB2 | Start OFF |
| CUB2 | Trip ON |
| CUB2 | Trip OFF |
| CUB2 | Block ON |
| CUB2 | Block OFF |
| CUB3 | Start ON |
| CUB3 | Start OFF |
| CUB3 | Trip ON |
| CUB3 | Trip OFF |
| CUB3 | Block ON |
| CUB3 | Block OFF |
| CUB4 | Start ON |
| CUB4 | Start OFF |
| CUB4 | Trip ON |
| CUB4 | Trip OFF |
| CUB4 | Block ON |
| CUB4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.8 - 100. Register content.

| Date and time | Event | Pre-trigger current | Fault current | Pre-fault current | Fault currents | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip -20ms current | Start/Trip current | Start -200ms current | I1, I2, IZ mag. and ang. | 0 ms...1800s | Setting group 1...8 active |

### 5.4.9 Harmonic overcurrent protection (Ih>; 50H/51H/68H)

The harmonic overcurrent function is used for non-directional instant and time-delayed overcurrent detection and clearing. The number of stages in the function depends on the relay model. The function constantly measures the selected harmonic component of the selected measurement channels, the value being either absolute value or relative to the RMS value. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The non-directional harmonic overcurrent function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. Either START or TRIP signal can be used when the instant mode is selected to block other protection stages. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT) mode. The START signal can be used to block other stages; if the situation lasts longer, the TRIP signal can be used on other actions as time-delayed.The IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

The inputs of the function are the following:

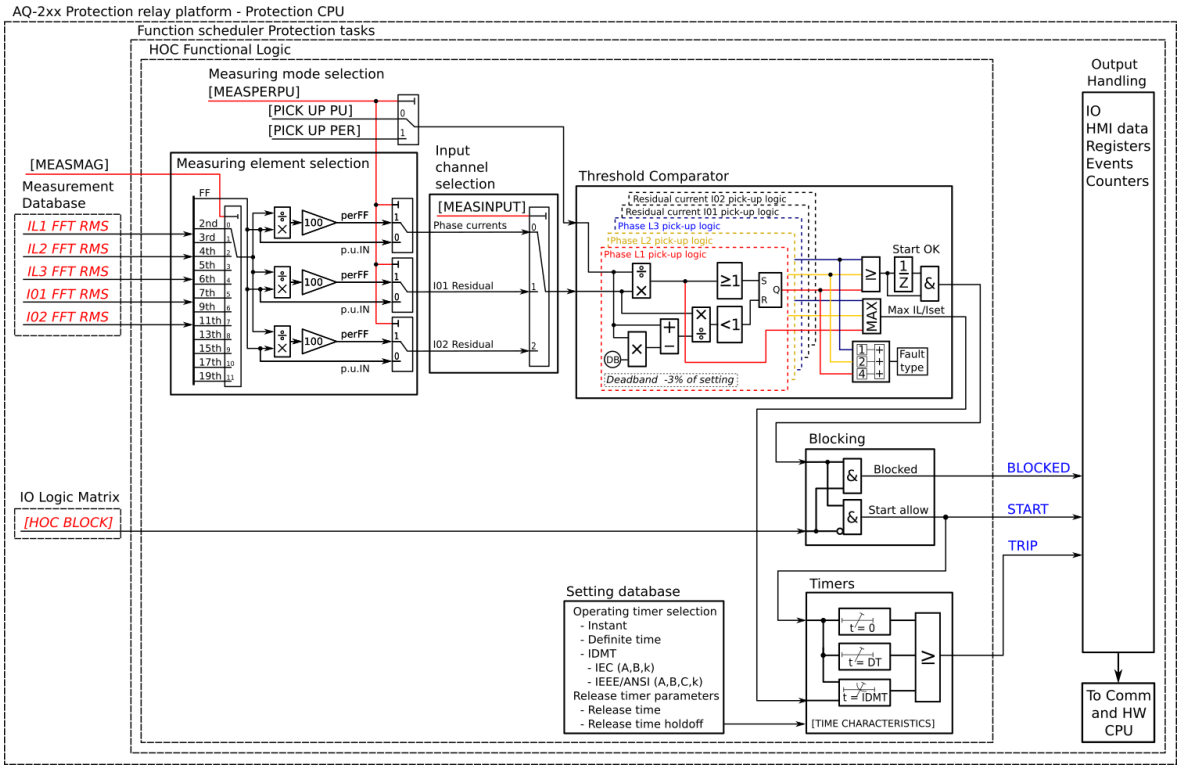
- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional harmonic overcurrent function.


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Figure. 5.4.9 - 53. Simplified function block diagram of the Ih> function.




## Measured input

The function block uses analog current measurement values from phase or residual currents. Each measurement input of the function block uses RMS values and harmonic components of the selected current input. The user can select the monitored magnitude to be equal to the per-unit RMS values of the harmonic component, or to the harmonic component percentage content compared to the RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.9 - 101. Measurement inputs of the Ih> function.

| Signal | Description | Time base |
|---|---|---|
| IL1FFT | The magnitudes (RMS) of phase L1 (A) current components:<br><br>- Fundamental<br>- 2nd harmonic<br>- 3rd harmonic<br>- 4th harmonic<br>- 5th harmonic<br>- 6th harmonic<br>- 7th harmonic<br>- 9th harmonic<br>- 11th harmonic<br>- 13th harmonic<br>- 15th harmonic<br>- 17th harmonic<br>- 19th harmonic. | 5 ms |

| Signal | Description | Time base |
|---|---|---|
| IL2FFT | The magnitudes (RMS) of phase L2 (B) current components:<br><br>- Fundamental<br>- 2nd harmonic<br>- 3rd harmonic<br>- 4th harmonic<br>- 5th harmonic<br>- 6th harmonic<br>- 7th harmonic<br>- 9th harmonic<br>- 11th harmonic<br>- 13th harmonic<br>- 15th harmonic<br>- 17th harmonic<br>- 19th harmonic. | 5 ms |
| IL3FFT | The magnitudes (RMS) of phase L3 (C) current components:<br><br>- Fundamental<br>- 2nd harmonic<br>- 3rd harmonic<br>- 4th harmonic<br>- 5th harmonic<br>- 6th harmonic<br>- 7th harmonic<br>- 9th harmonic<br>- 11th harmonic<br>- 13th harmonic<br>- 15th harmonic<br>- 17th harmonic<br>- 19th harmonic. | 5 ms |
| I01FFT | The magnitudes (RMS) of residual $I0_1$ current components:<br><br>- Fundamental<br>- 2nd harmonic<br>- 3rd harmonic<br>- 4th harmonic<br>- 5th harmonic<br>- 6th harmonic<br>- 7th harmonic<br>- 9th harmonic<br>- 11th harmonic<br>- 13th harmonic<br>- 15th harmonic<br>- 17th harmonic<br>- 19th harmonic. | 5 ms |



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| Signal | Description | Time base |
|---|---|---|
| I02FFT | The magnitudes (RMS) of residual $I0_2$ current components:<br><br>- Fundamental<br>- 2nd harmonic<br>- 3rd harmonic<br>- 4th harmonic<br>- 5th harmonic<br>- 6th harmonic<br>- 7th harmonic<br>- 9th harmonic<br>- 11th harmonic<br>- 13th harmonic<br>- 15th harmonic<br>- 17th harmonic<br>- 19th harmonic. | 5 ms |

The selection of the used AI channel, the monitored harmonic, and the monitoring type (per unit or percentage of fundamental frequency) are made with setting parameters. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The function can be set to monitor the ratio between the measured harmonic and either the measured fundamental component or the per unit value of the harmonic current. The user must select the correct measurement input.

Table. 5.4.9 - 102. Operating mode selection settings.

| Name | Range | Default | Description |
|---|---|---|---|
| Ih> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of HOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Ih> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

| Name | Range | Default | Description |
|---|---|---|---|
| Harmonic selection | 2nd harmonic<br>3rd harmonic<br>4th harmonic<br>5th harmonic<br>6th harmonic<br>7th harmonic<br>9th harmonic<br>11th harmonic<br>13th harmonic<br>15th harmonic<br>17th harmonic<br>19th harmonic | 2nd harmonic | Selection of the monitored harmonic component. |
| Per unit or relative | × $I_n$<br>Ih/IL | × $I_n$ | Selection of the monitored harmonic mode. Either directly per unit x $I_n$ or in relation to the fundamental frequency magnitude. |
| Measurement input | IL1/IL2/IL3<br>I01<br>I02 | IL1/IL2/IL3 | Selection of the measurement input (either phase current or residual current). |

Each function stage provides these same settings. Multiple stages of the function can be set to operate independently of each other.

## Pick-up

The setting parameter $Ih_{set}$ per unit or *Ih/IL* (depending on the selected operating mode) controls the pick-up of the Ih> function. This defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the $Ih_{set}$ per unitor *Ih/IL* and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the $Ih_{set}$ per unit or *Ih/IL*value. The setting value is common for all measured phases, and when the $I_m$ exceeds the $I_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.9 - 103. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| $Ih_{set}$ pu | 0.05…2.00×$I_n$ | 0.01×$I_n$ | 0.20×$I_n$ | Pick-up setting<br>(per unit monitoring) |
| Ih/IL | 5.00…200.00% | 0.01% | 20.00% | Pick-up setting<br>(percentage monitoring) |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.



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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.9 - 104. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Ih> behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of HOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Ih> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| Ih meas/ Ih set now | 0.00...100000.00$I_m/I_{set}$ | 0.01$I_m/I_{set}$ | The ratio between the monitored residual current and the pick-up value. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The harmonic overcurrent function (abbreviated "HOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.9 - 105. Event description.

| Event block name | Event names |
|---|---|
| HOC1 | Start ON |
| HOC1 | Start OFF |
| HOC1 | Trip ON |
| HOC1 | Trip OFF |
| HOC1 | Block ON |
| HOC1 | Block OFF |
| HOC2 | Start ON |
| HOC2 | Start OFF |
| HOC2 | Trip ON |
| HOC2 | Trip OFF |
| HOC2 | Block ON |
| HOC2 | Block OFF |
| HOC3 | Start ON |
| HOC3 | Start OFF |
| HOC3 | Trip ON |
| HOC3 | Trip OFF |
| HOC3 | Block ON |
| HOC3 | Block OFF |
| HOC4 | Start ON |
| HOC4 | Start OFF |
| HOC4 | Trip ON |
| HOC4 | Trip OFF |
| HOC4 | Block ON |
| HOC4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.



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Table. 5.4.9 - 106. Register content.

| Date and time | Event | Fault type | Pre-trigger current | Fault current | Pre-fault current | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-G…L1-L2-L3 | Start/Trip -20ms current | Start/Trip current | Start -200ms current | 0 ms...1800s | Setting group 1...8 active |

## 5.4.10 Circuit breaker failure protection (CBFP; 50BF/52BF)

The circuit breaker failure protection function is used for monitoring the circuit breaker operation after it has received a TRIP signal. The function can also be used to retrip a failing breaker; if the retrip fails, an incomer breaker can be tripped by using the function's CBFP output. The retrip functionality can be disabled if the breaker does not have two trip coils.

The function can be triggered by the following:

- overcurrent (phase and residual)
- digital output monitor
- digital signal
- any combination of the above-mentioned triggers.

In the current-dependent mode the function constantly measures phase current magnitudes and the selected residual current. In the signal-dependent mode any of the device's binary signals (trips, starts, logical signals etc.) can be used to trigger the function. In the digital output-dependent mode the function monitors the status of the selected output relay control signal. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The circuit breaker failure protection function uses a total of eight (8) separate setting groups which can be selected from one common source. Additionally, the function's operating mode can be changed via setting group selection.

The operational logic consists of the following:

- input magnitude processing
- input magnitude selection
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

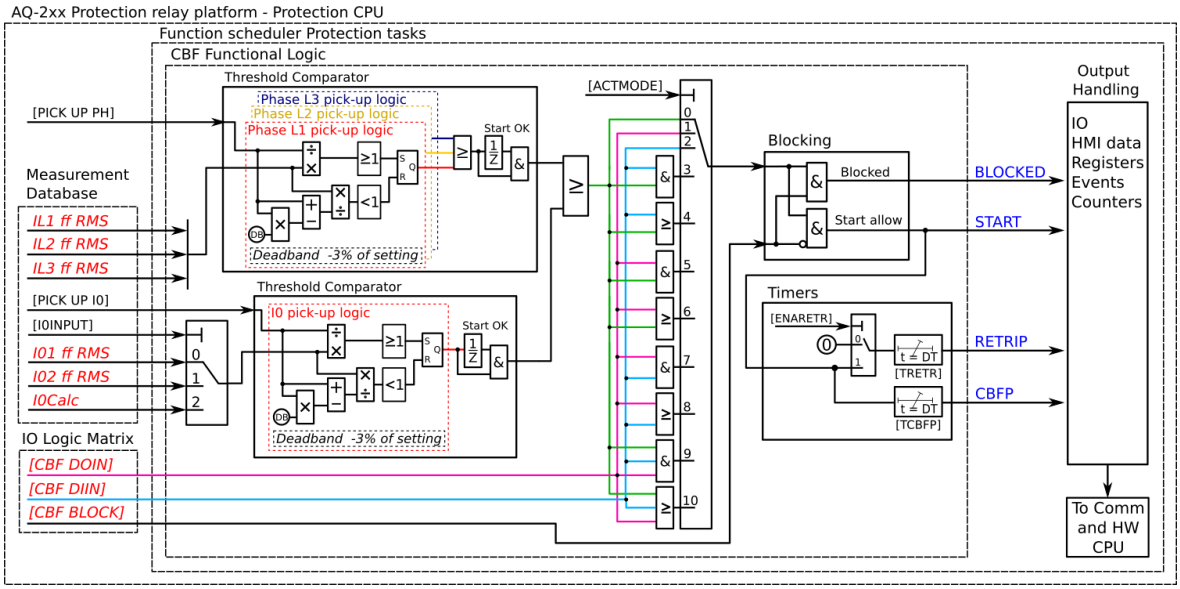
The inputs of the function are the following:

- operating mode selections
- setting parameters
- digital input signals
- measured and pre-processed current magnitudes.

The function's outputs are CBFP START, RETRIP, CBFP ACT and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counters for RETRIP, CBFP, CBFP START and BLOCKED events.

The following figure presents a simplified function block diagram of the circuit breaker failure protection function.

Figure. 5.4.10 - 54. Simplified function block diagram of the CBFP function.




## Measured input

The function block uses analog current measurement values. It always uses the RMS magnitude of the current measurement input. The user can select I01, I02 or the calculated I0 for the residual current measurement. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.10 - 107. Measurement inputs of the CBFP function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| I01RMS | RMS measurement of residual input I01 | 5ms |
| I02RMS | RMS measurement of residual input I02 | 5ms |
| I0Calc | Calculated residual current from the phase current inputs | 5ms |
| DOIN | Monitors digital output relay status | 5ms |
| DIIN | Monitors digital input status | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.



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Table. 5.4.10 - 108. CBFP monitoring signal definitions.

| Name | Description |
|---|---|
| Signal in monitor | Defines which TRIP events of the used protection functions trigger the CBFP countdown. For the CBFP function to monitor the signals selected here, the "Operation mode selection" parameter must be set to a mode that includes signals (e.g. "Signals only", "Signals or DO", "Current and signals and DO"). |
| Trip monitor | Defines which output relay of the used protection functions trigger the CBFP countdown. For the CBFP function to monitor the output relays selected here, the "Operation mode selection" parameter must be set to a mode that includes digital outputs (e.g. "DO only", "Current and DO", "Current or signals or DO"). |

Table. 5.4.10 - 109. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| CBFP LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of CBF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CBFP force status to | 0: Normal<br>1: Start<br>2: ReTrip<br>3: CBFP<br>4: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The setting parameters $I_{set}$ and $I0_{set}$ control the pick-up and the activation of the current-dependent CBFP function. They define the minimum allowed measured current before action from the function. The function constantly calculates the ratio between the $I_{set}$ or the $I0_{set}$ and the measured magnitude ($I_m$) for each of the three phases and the selected residual current input. The reset ratio of 97 % is built into the function and is always relative to the $I_{set}$ value. The setting value is common for all measured phases. When the $I_m$ exceeds the $I_{set}$ value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.4.10 - 110. Operating mode and input signals selection.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| I0Input | 0: Not in use<br>1: I01<br>2: I02<br>3: I0Calc | - | 0: Not in use | Selects the residual current monitoring source, which can be either from the two separate residual measurements (I01 and I02) or from the phase current's calculated residual current. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Actmode | 0: Current only<br>1: DO only<br>2: Signals only<br>3: Current and DO<br>4: Current or DO<br>5: Current and signals<br>6: Current or signals<br>7: Signals and DO<br>8: Signals or DO<br>9: Current or DO or signals<br>10: Current and DO and Signals | - | 0: Current only | Selects the operating mode. The mode can be dependent on current measurement, binary signal status, output relay status ("DO"), or a combination of the three. |

Table. 5.4.10 - 111. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| $I_{set}$ | 0.01…40.00×$I_n$ | 0.01×$I_n$ | 0.20×$I_n$ | The pick-up threshold for the phase current measurement. This setting limit defines the upper limit for the phase current pick-up element. |
| $I0_{set}$ | 0.005...40.000×$I_n$ | 0.001×$I_n$ | 1.200×$I_n$ | The pick-up threshold for the residual current measurement. This setting limit defines the upper limit for the phase current pick-up element. |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active. There is no delay between the activation of the monitored signal and the activation of the pick-up when using binary signals.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.10 - 112. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| CBFP LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of CBF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CBFP condition | 0: Normal<br>1: Start<br>2: ReTrip<br>3: CBFP On<br>4: Blocked | Displays status of the protection function. |



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## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics

The operating timers' behavior during a function can be set depending on the application. The same pick-up signal starts both timers. When retrip is used the time grading should be set as follows: the sum of specific times (i.e. the retrip time, the expected operating time, and the pick-up conditions' release time) is shorter the set CBFP time. This way, when retripping another breaker coil clears the fault, any unnecessary function triggers are avoided.

The following table presents the setting parameters for the function's operating time characteristics.

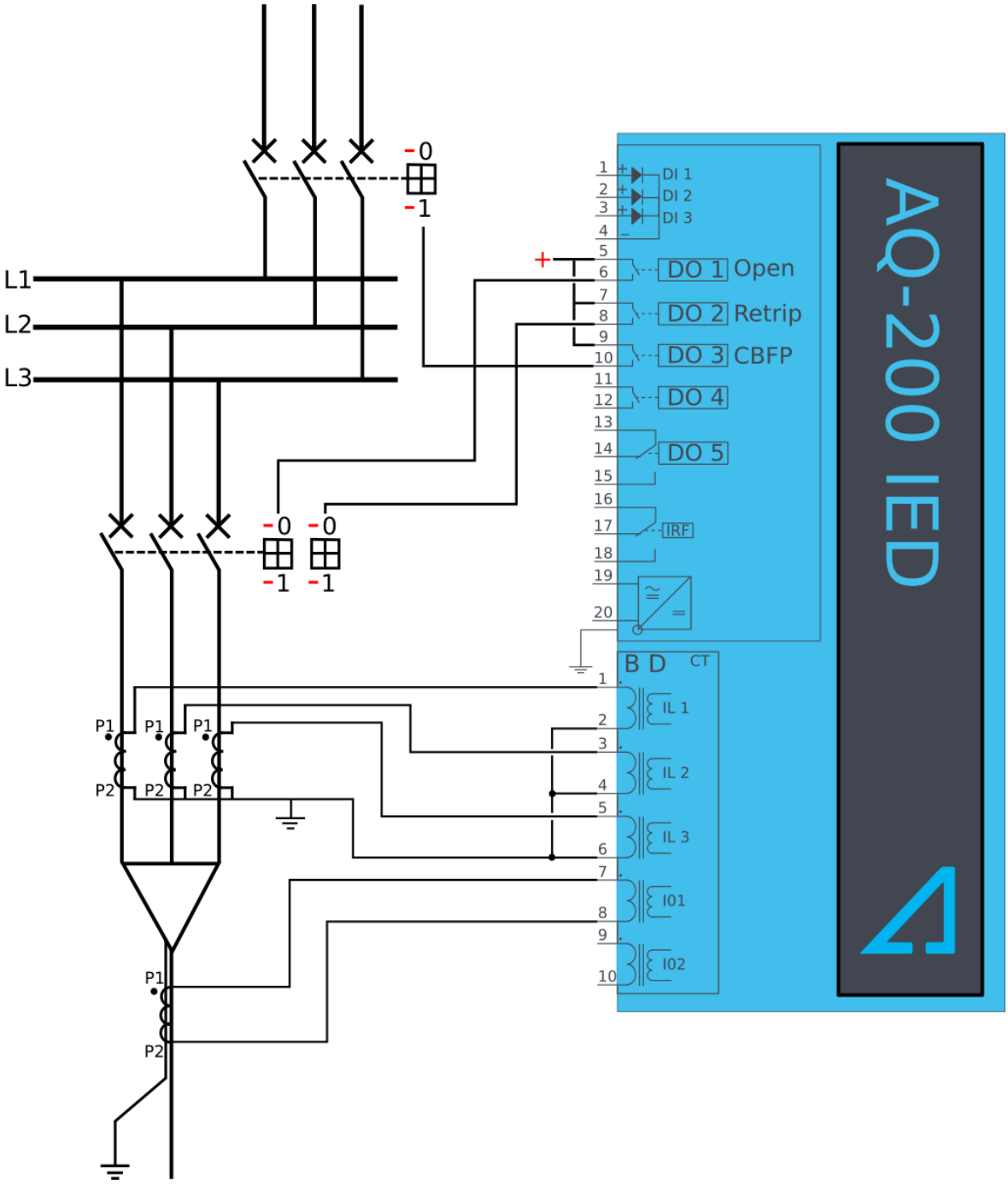
Table. 5.4.10 - 113. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Retrip | 0: No<br>1: Yes | - | 1: Yes | Retrip enabled or disabled. When the retrip is disabled, the output will not be visible and the TRetr setting parameter will not be available. |
| Retrip time delay | 0.000…1800.000s | 0.005s | 0.100s | Retrip start the  timer. This setting defines how long the starting condition has to last before a RETRIP signal is activated. |
| CBFP | 0.000…1800.000s | 0.005s | 0.200s | CBFP starts the timer. This setting defines how long the starting condition has to last before the CBFP signal is activated. |

The following figures present some typical cases of the CBFP function.

## Trip, Retrip and CBFP in the device configuration

Figure. 5.4.10 - 55. Wiring diagram when Trip, Retrip and CBFP are configured to the device.

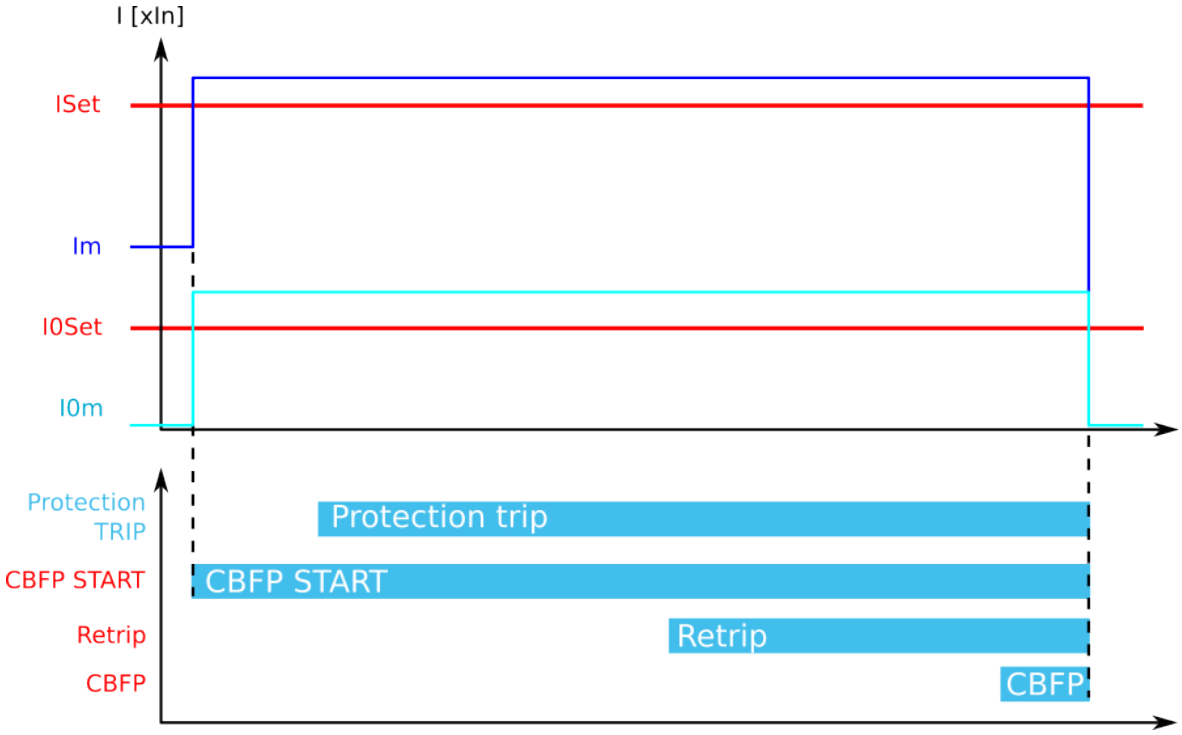



The retrip functionality can be used in applications whose circuit breaker has a retrip or a redundant trip coil available. The TRIP signal is normally wired to the breaker's trip coil from the device's trip output. The retrip is wired from its own device output contact in parallel with the circuit breaker's redundant trip coil. The CBFP signal is normally wired from its device output contact to the incomer breaker. Below are a few operational cases regarding the various applications.



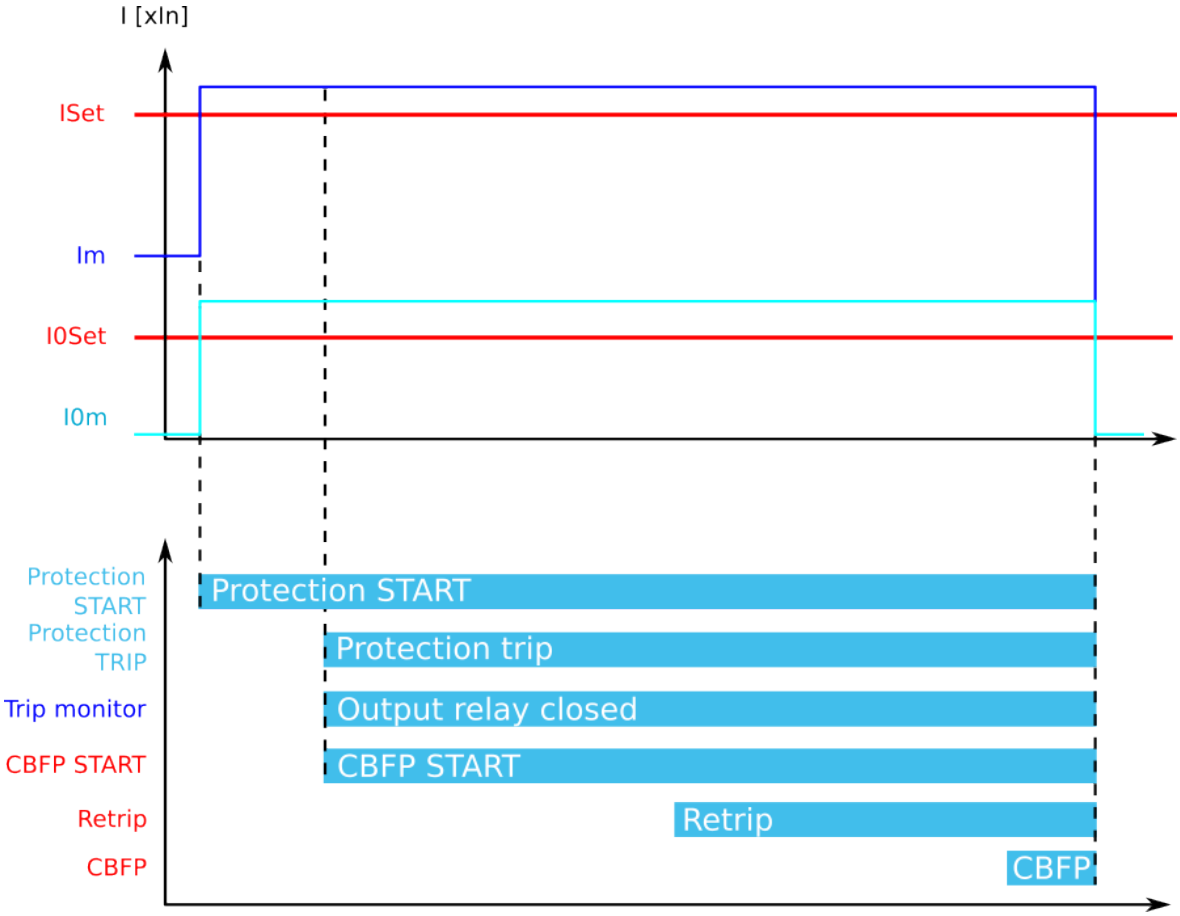
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Figure. 5.4.10 - 56. Retrip and CBFP when "Current" is the selected criterion.




When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counters for RETRIP and CBFP start calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the current is not reduced below the setting limit, a RETRIP signal is sent to the redundant trip coil. If the current is not reduced within the set time limit, the function also sends a CBFP signal to the incomer breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings.

Figure. 5.4.10 - 57. Retrip and CBFP when "Current and DO" is the selected criterion.

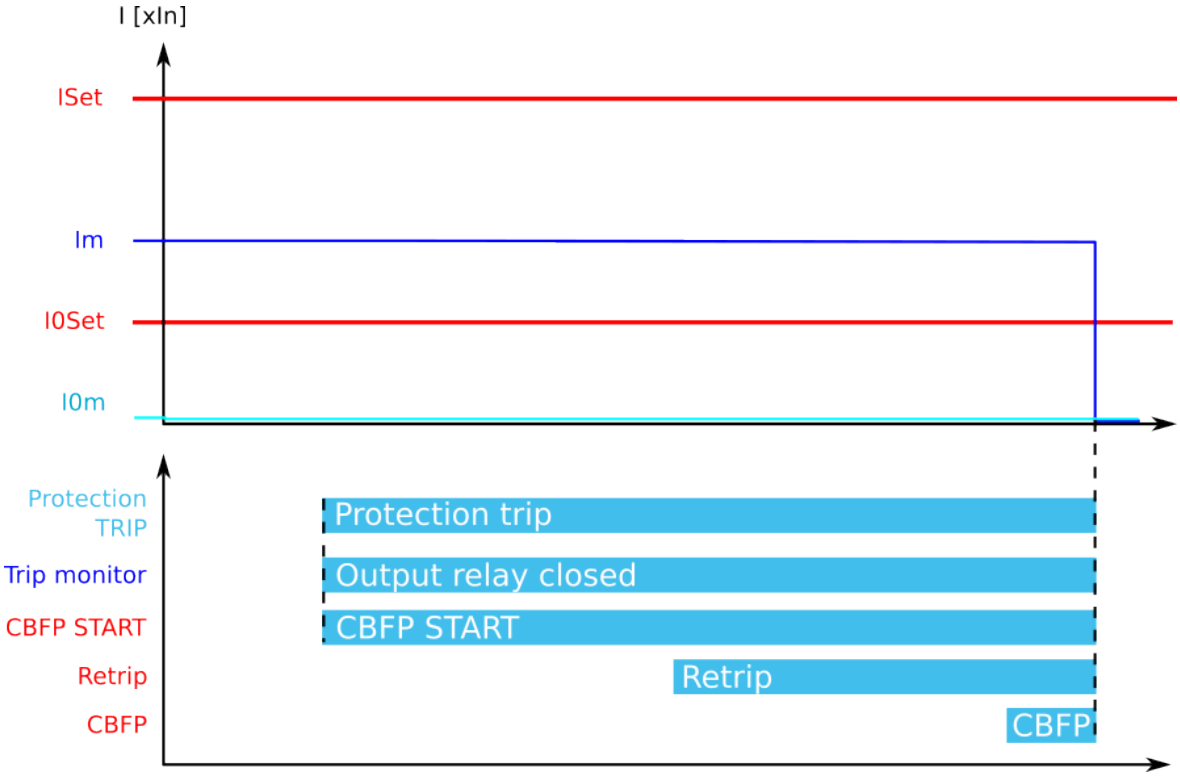



When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, the current-based protection is activated. At the same time, the counters for RETRIP and CBFP are halted until the monitored output contact is controlled (that is, until the primary protection operates). When the tripping signal reaches the primary protection stage, the RETRIP and CBFP counters start calculating the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration. If the current is not reduced below the setting limit or the primary stage tripping signal is not reset, a RETRIP signal is sent to the redundant trip coil. If the retripping fails and the current is not reduced below the setting limit or the primary stage tripping signal is not reset, the function also sends a CBFP signal to the incomer breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings or the tripping signal is reset. This configuration allows the CBFP to be controlled with current-based functions alone, and other function trips can be excluded from the CBFP functionality.



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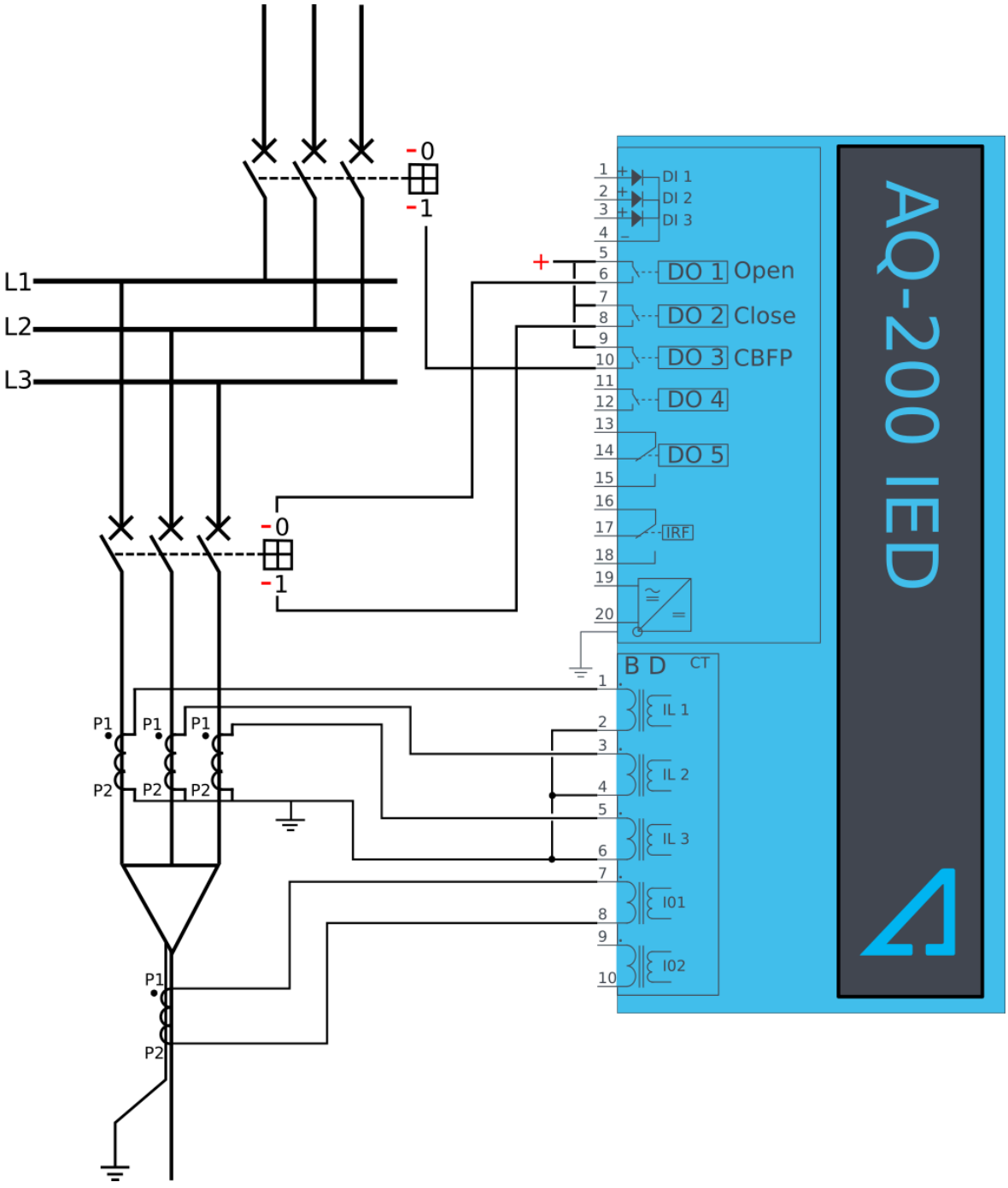
Figure. 5.4.10 - 58. Retrip and CBFP when "Current or DO" is the selected criterion.




When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, or the TRIP signal reaches the primary protection stage, the function starts counting down towards the RETRIP and CBFP signals. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current's status. The pick-up of the CBFP is active unless the current is reduced below the setting limit and the primary stage tripping signal is reset. If either of these conditions is met (i.e. the current is above the limit or the signal is active) for the duration of the set RETRIP time delay, a RETRIP signal is sent to the redundant trip coil. If either of the conditions is active for the duration of the set CBFP time delay, a CBFP signal is sent to the incomer breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled with current-based functions alone, with added security from current monitoring. Other function trips can also be included in the CBFP functionality.

## Trip and CBFP in the device configuration

Figure. 5.4.10 - 59. Wiring diagram when Trip and CBFP are configured to the device.

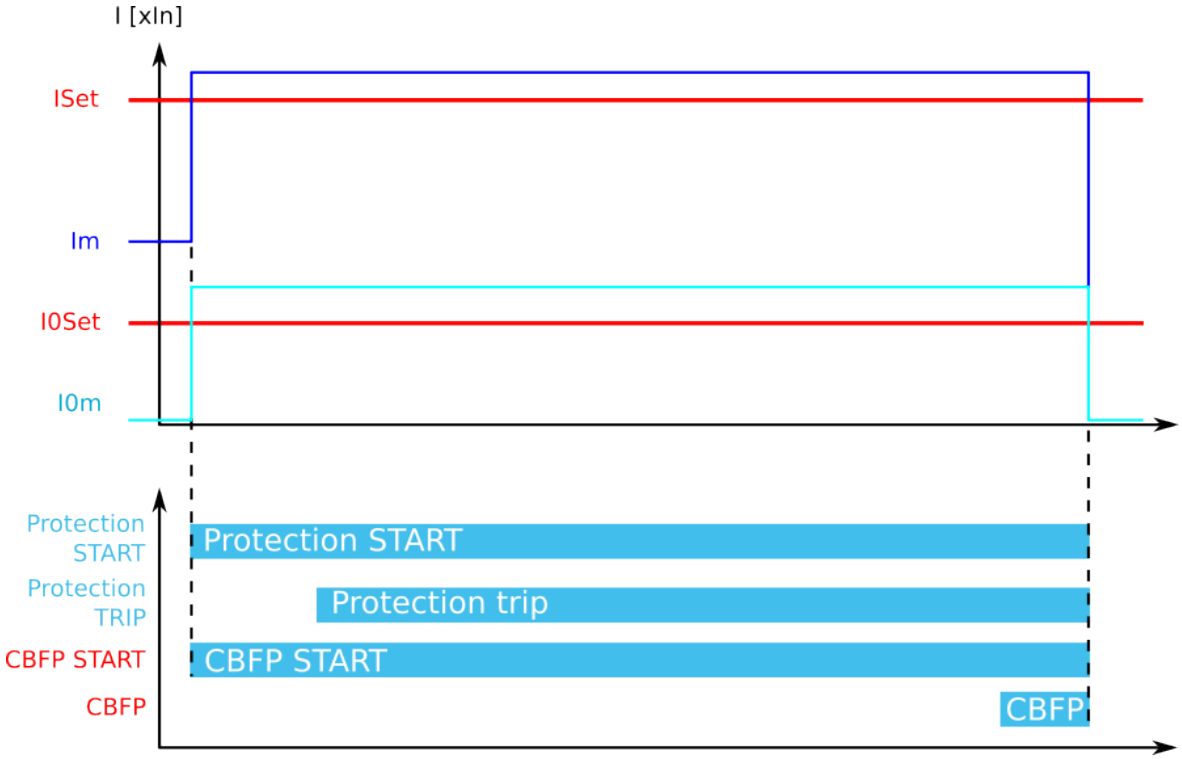



Probably the most common application is when the device's trip output controls the circuit breaker trip coil, while one dedicated CBFP contact controls the CBFP function. Below are a few operational cases regarding the various applications and settings of the CBFP function.



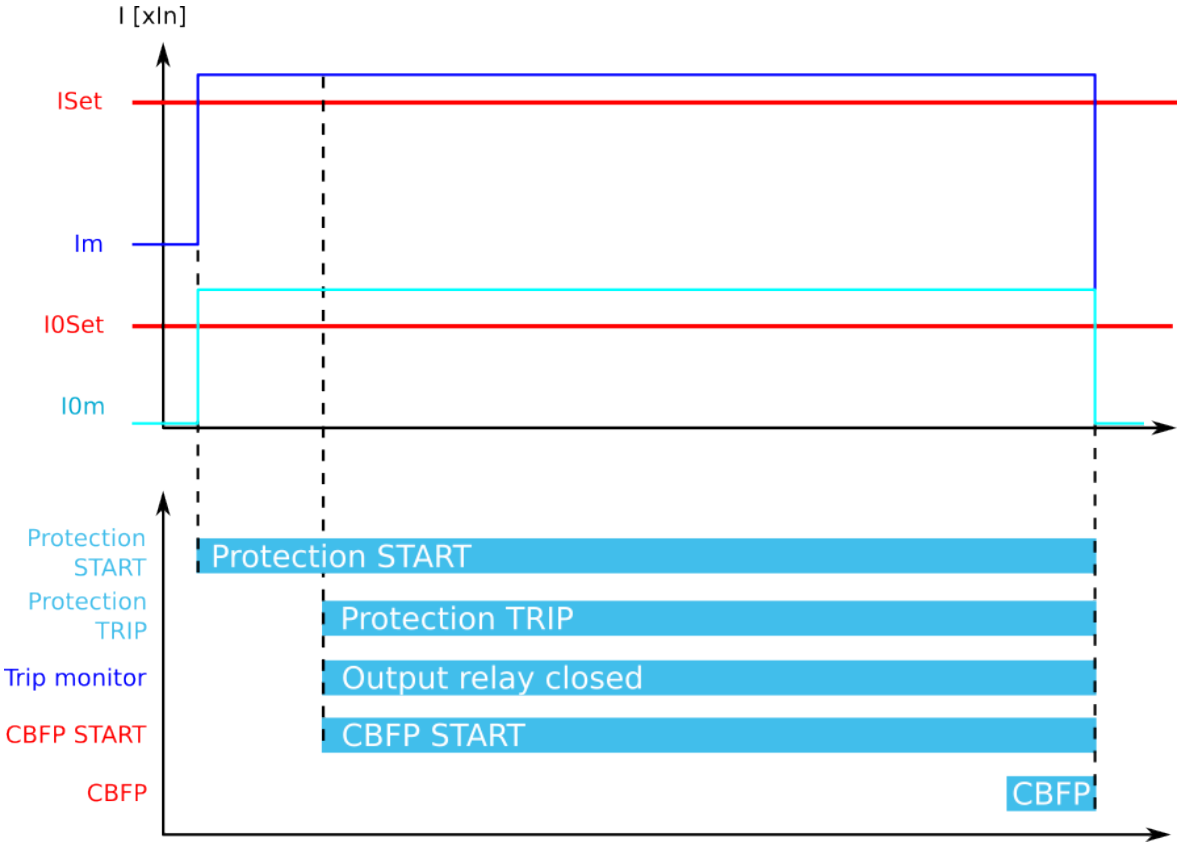
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Figure. 5.4.10 - 60. CBFP when "Current" is the selected criterion.




When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counter for CBFP starts calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the current is not reduced below the setting limit, a CBFP signal is sent to the incomer breaker. If the primary protection function clears the fault, the counter for CBFP resets as soon as the measured current is below the threshold settings.

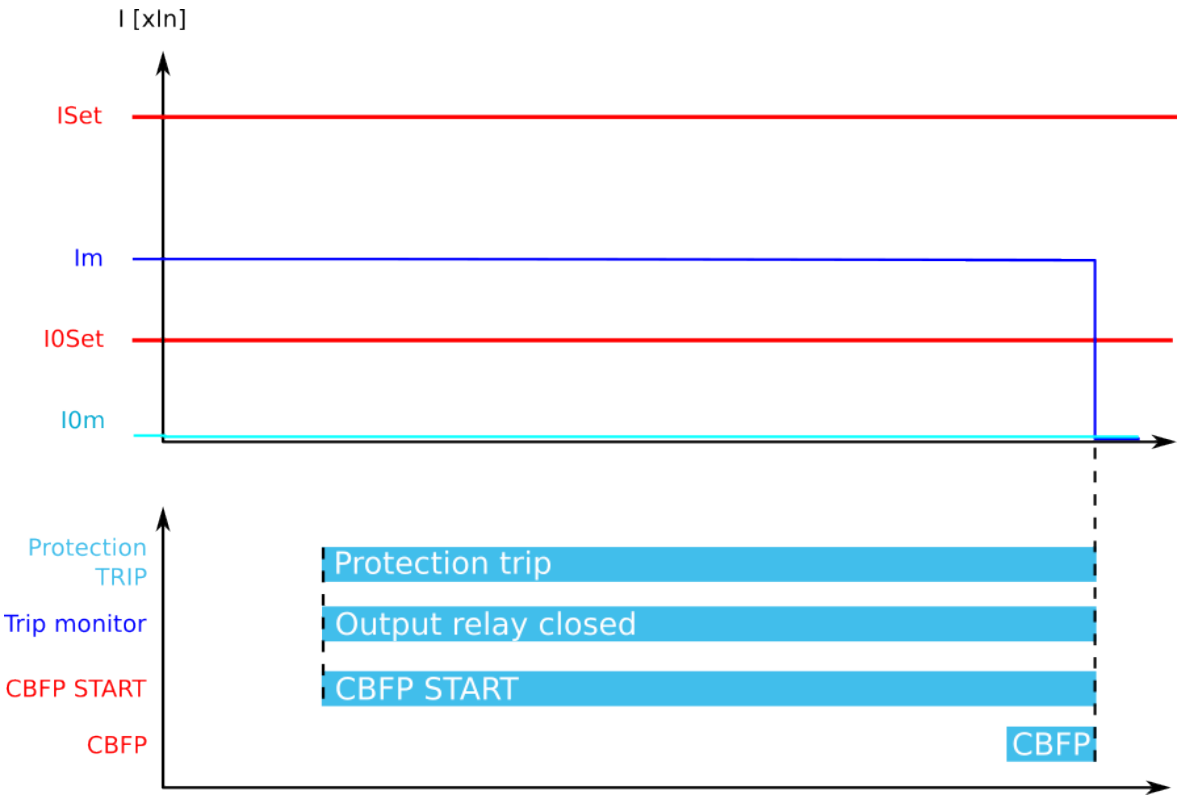
Figure. 5.4.10 - 61. CBFP when "Current and DO" is the selected criterion.




When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, the current-based protection is activated. At the same time, the counter for CBFP is halted until the monitored output contact is controlled (that is, until the primary protection operates). When the tripping signal reaches the primary protection stage, the CBFP counter starts calculating the set operating time. The tripping of the primary protection stage is constantly monitored in this configuration. If the current is not reduced below the setting limit or the primary stage tripping signal is not reset, a CBFP signal is sent to the incomer breaker. The time delay counter for CBFP is reset as soon as the measured current is below the threshold settings or the tripping signal is reset. This configuration allows the CBFP to be controlled by current-based functions alone, and other function trips can be excluded from the CBFP functionality.


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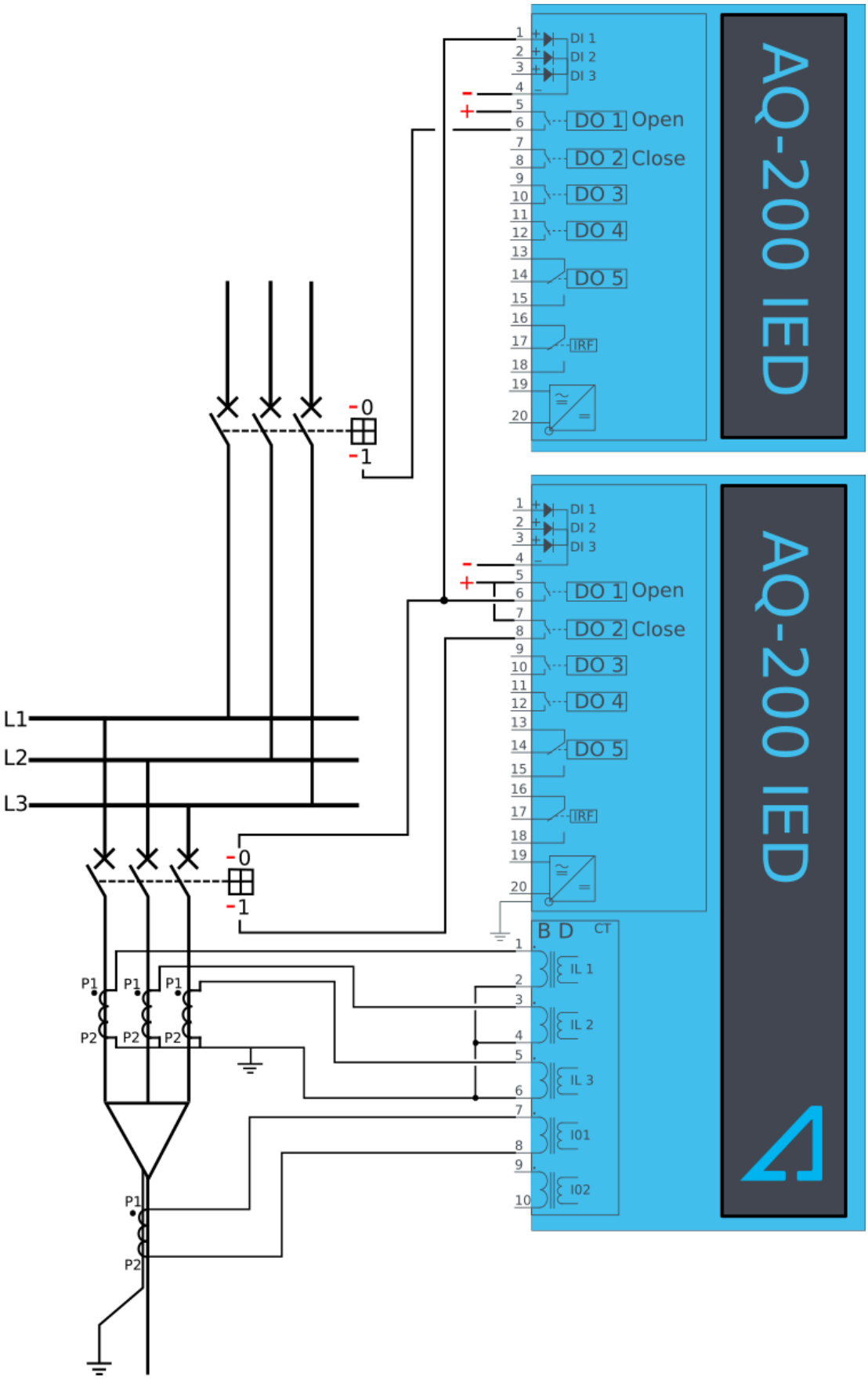
Figure. 5.4.10 - 62. CBFP when "Current or DO" is the selected criterion.




When the current threshold setting of $I_{set}$ and/or $I0_{set}$ is exceeded, or the TRIP signal reaches the primary protection stage, the function starts counting down towards the CBFP signal. The tripping of the primary protection stage is constantly monitored in this configuration regardless of the current's status. The pick-up of the CBFP is active unless the current is reduced below the setting limit and the primary stage tripping signal is reset. If either of these conditions is met (i.e. the current is above the limit or the signal is active) for the duration of the set CBFP time delay, a CBFP signal is sent to the incomer breaker. The time delay counter for CBFP is reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled by current-based functions alone, with added security from current monitoring. Other function trips can also be included to the CBFP functionality.

## Device configuration as a dedicated CBFP unit

Figure. 5.4.10 - 63. Wiring diagram when the device is configured as a dedicated CBFP unit.

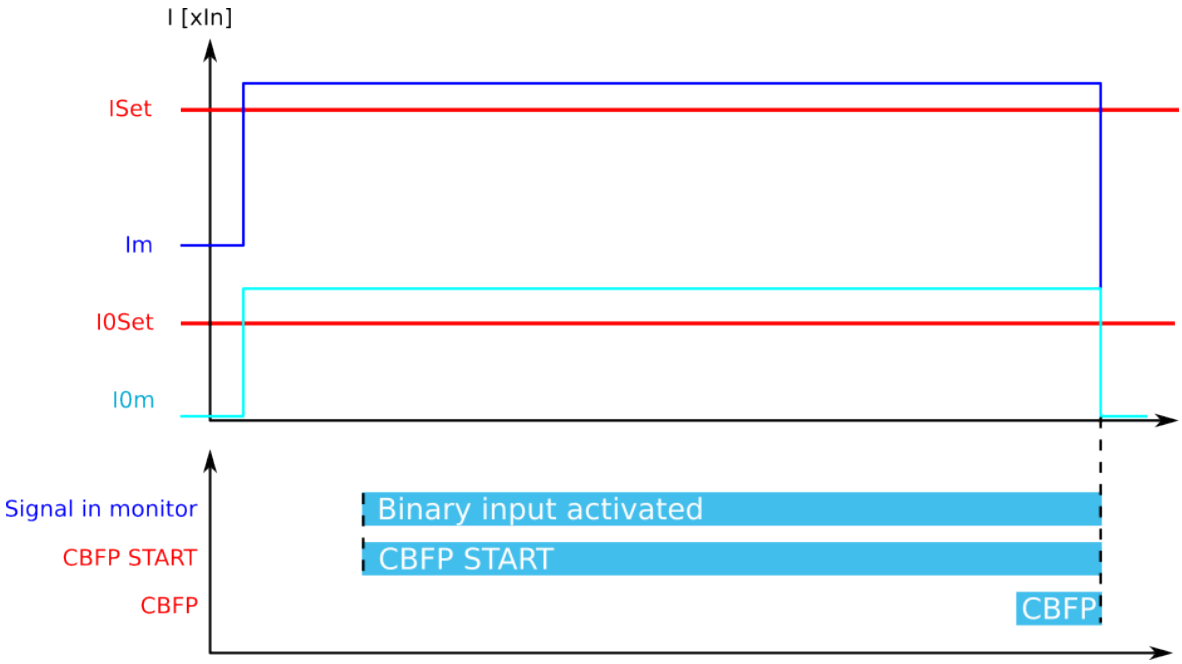





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Some applications require a dedicated circuit breaker protection unit. When the CBFP function is configured to operate with a digital input signal, it can be used in these applications. When a device is used for this purpose, the tripping signal is wired to the device's digital input and the device's own TRIP signal is used only for the CBFP purpose. In this application's incomer the RETRIP and CBFP signals are also available with different sets of requirements. The RETRIP signal can be used for tripping the section's feeder breaker and the CBFP signal for tripping the incomer. The following example does not use retripping and the CBFP signal is used as the incomer trip from the outgoing breaker trip signal. The TRIP signal can also be transported between different devices by using GOOSE messages.

Figure. 5.4.10 - 64. Dedicated CBFP operation from digital input signal.




In this mode the CBFP operates only from a digital input signal. Both current and output relay monitoring can be used. The counter for the CBFP signal begins when the digital input is activated. If the counter is active until the CBFP counter is used, the device issues a CBFP command to the incomer breaker. In this application the device tripping signals from all outgoing feeders can be connected to one, dedicated CBFP device which operates either on current-based protection or on all possible faults' CBFP protection.

## Events and registers

The circuit breaker failure protection function (abbreviated "CBF" in event block names) generates events and registers from the status changes in RETRIP,  in CBFP-activated and CBFP-blocked signals, as well as in internal pick-up comparators. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.10 - 114. Event messages.

| Event block name | Event names |
|---|---|
| CBF1 | Start ON |
| CBF1 | Start OFF |
| CBF1 | Retrip ON |
| CBF1 | Retrip OFF |

| Event block name | Event names |
|---|---|
| CBF1 | CBFP ON |
| CBF1 | CBFP OFF |
| CBF1 | Block ON |
| CBF1 | Block OFF |
| CBF1 | DO monitor ON |
| CBF1 | DO monitor OFF |
| CBF1 | Signal ON |
| CBF1 | Signal OFF |
| CBF1 | Phase current ON |
| CBF1 | Phase current OFF |
| CBF1 | Res current ON |
| CBF1 | Res current OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.4.10 - 115. Register content.

| Date and time | Event | Max phase current | Residual current | Time to RETR | Time to CBFP | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Highest phase current | I01, I02 channel or calculated residual current | Time remaining to retrip activation | Time remaining to CBFP activation | Setting group 1...8 active |

## 5.4.11 Low-impedance or high-impedance restricted earth fault/ cable end differential protection (I0d>; 87N)

The low-impedance or high-impedance restricted earth fault function is used for residual differential current measurement for transformers. This function can also be used as the cable end differential function. The operating principle is low-impedance differential protection with bias characteristics the user can set. A differential current is calculated with the sum of the phase currents and the selected residual current input. In cable end differential mode the function provides natural measurement unbalance compensation for higher operating sensitivity in monitoring cable end faults.

The restricted earth fault function constantly monitors phase currents and selected residual current instant values as well as calculated bias current and differential current magnitudes.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The function uses a total of eight (8) separate setting groups which can be selected from one common source. The operating mode of the function can be changed via setting group selection.

The operational logic consists of the following:

- input magnitude selection


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- input magnitude processing
- differential characteristic comparator
- block signal check
- output processing.

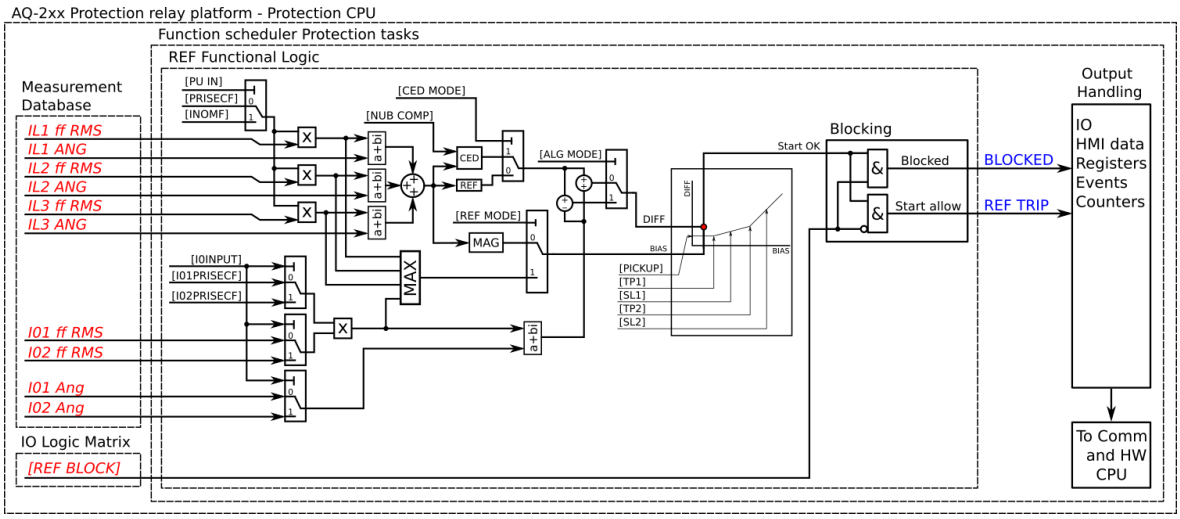
The inputs for the function are the following:

- setting parameters
- measured and pre-processed current magnitudes.

The function's outputs are TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the REF, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the restricted earth fault function.

Figure. 5.4.11 - 65. Simplified function block diagram of the I0d> function.




## Measured input

The function block uses analog current measurement values. It uses the RMS magnitude of the current measurement inputs. Both calculated residual currents and measured residual currents are always used. The user can select inputs I01 or I02 for residual current measurement.

Please note that when the function is in cable end differential mode, the difference is only calculated when the measured I0 current is available.

Table. 5.4.11 - 116. Measurement inputs of the I0d> function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| I01RMS | RMS measurement of residual input I01 | 5ms |
| I02RMS | RMS measurement of residual input I02 | 5ms |
| IL1Ang | Angle of phase L1 (A) current | 5ms |
| IL2 Ang | Angle of phase L2 (B) current | 5ms |

| Signal | Description | Time base |
|---|---|---|
| IL3 Ang | Angle of phase L3 (C) current | 5ms |
| I01 Ang | Angle of residual input I01 | 5ms |
| I02 Ang | Angle of residual input I02 | 5ms |

The selection of the used AI channel is made with a setting parameter.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.11 - 117. General settings.

| Name | Range | Default | Description |
|---|---|---|---|
| I0d> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of NOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0d> force status to | 0: Normal<br>1: Trip<br>2: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Restricted earth fault (REF) or Cable End Differential | 0: REF<br>1: CED | 0: REF | Selection of the operating characteristics. If REF is selected, the function operates with normal accuracies. If CED is selected, the natural unbalance created by the phase current CT:s can be compensated for more sensitive operation. The default setting is REF. |
| Compenstate natural unbalance | 0:-<br>1: Comp | - | When activated while the line is energized, the currently present calculated residual current is compensated to 0. This compensation only has an effect in the CED mode. |

## Operating characteristics

The current-dependent pick-up and activation of the function are controlled by setting parameters, which define the current calculating method used as well as the operating characteristics.

Table. 5.4.11 - 118. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| I0 Input | 0: I01<br>1: I02 | - | 0: I01 | Selection of the used residual current measurement input. |
| I0 Direction | 0: Add<br>1: Subtract | - | 0: Add | Differential current calculation mode. This matches the directions of the calculated and measured residual currents to the application. The default setting (0: Add) means that I0Calc + I01 or I0Calc + I02 in a through fault yields no differential current. |
| Bias current calculation | 0: Residual current (3I0 + I0Calc)/2<br>1: Maximum (Phase and I0 max) | - | 0: Residual current | Selection of the bias current calculation. Differential characteristics biasing can use either the calculated residual current averages or the maximum of all measured currents. The residual current mode is more sensitive while the maximum current is coarser. |
| I0d> pick-up | 0.01…50.00% (of $I_n$) | 0.01% | 10% | Setting for basic sensitivity of the differential characteristics. |

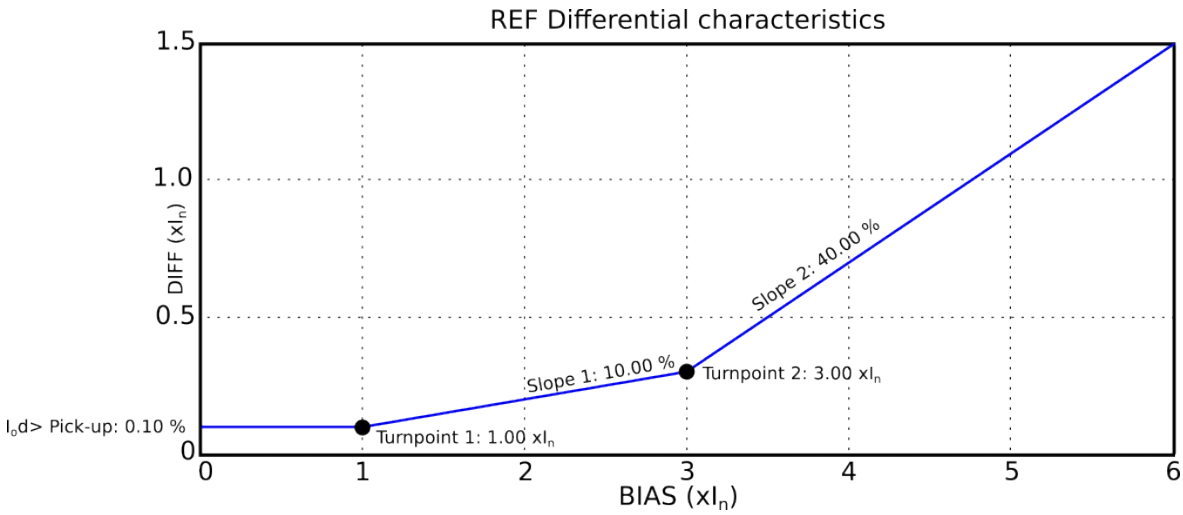

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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Turnpoint 1 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 1.00×$I_n$ | Setting for first turn point in the bias axe of the differential characteristics. |
| Slope 1 | 0.01…150.00% | 0.01% | 10.00% | Setting for the first slope of the differential characteristics. |
| Turnpoint 2 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 3.00×$I_n$ | Setting for second turn point in the bias axe of the differential characteristics. |
| Slope 2 | 0.01…250.00% | 0.01% | 40.00% | Setting for the second slope of the differential characteristics. |

The pick-up settings can be selected via setting groups. The pick-up activation of the function is not directly equal to the TRIP signal generation of the function. The TRIP signal is allowed if the blocking condition is not active.

The following figure presents the differential characteristics with default settings.

Figure. 5.4.11 - 66. Differential characteristics for the I0d> function with default settings.




The equations for the differential characteristics are the following:

Figure. 5.4.11 - 67. Differential current (the calculation is based on user-selected inputs and direction).

$$I_{Diff+I01} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) + \overline{I01}$$

$$I_{Diff-I01} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) - \overline{I01}$$

$$I_{Diff+I02} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) + \overline{I02}$$

$$I_{Diff-I02} = \left(\overline{IL1} + \overline{IL2} + \overline{IL3}\right) - \overline{I02}$$

Figure. 5.4.11 - 68. Bias current (the calculation is based on the user-selected mode).

$$I_{Bias\ average\ I01} = \frac{\left|\overline{IL1} + \overline{IL2} + \overline{IL3}\right| + \left|\overline{I01}\right|}{2}$$

$$I_{Bias\ average\ I02} = \frac{\left|\overline{IL1} + \overline{IL2} + \overline{IL3}\right| + \left|\overline{I02}\right|}{2}$$

$$I_{Bias\ \max I01} = MAX(|IL1|, |IL2|, |IL3|, |I01|)$$

$$I_{Bias\ \max I01} = MAX(|IL1|, |IL2|, |IL3|, |I02|)$$

Figure. 5.4.11 - 69. Characteristics settings.

$$Diff_{bias<TP1} = I0_{d>pick-up}$$

$$Diff_{biasTP1\ldots TP2} = SL1 \times (Ix - TP1) + I0_{d>pick-up}$$

$$Diff_{bias>TP2} = SL2 \times (Ix - TP2) + SL1 \times (TP2 - TP1) + I0_{d>pick-up}$$

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.11 - 119. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| I0d> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Set mode of REF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I0d> condition | 0: Normal<br>1: Trip<br>2: Blocked | Displays the status of the protection function. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a TRIP signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the TRIP function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

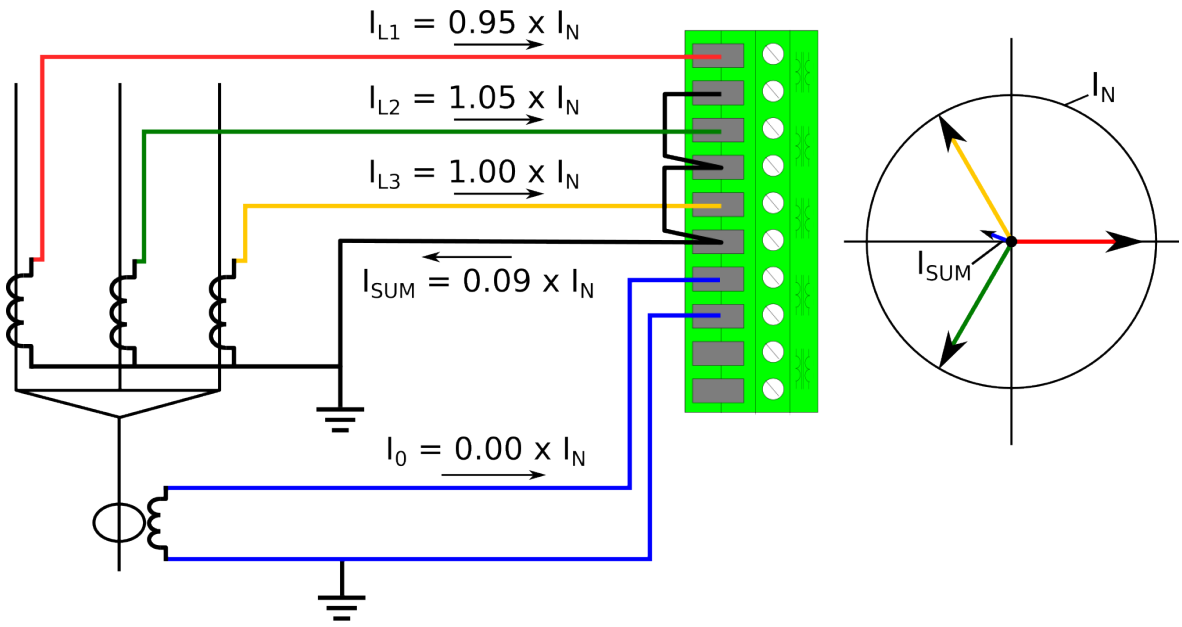
The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

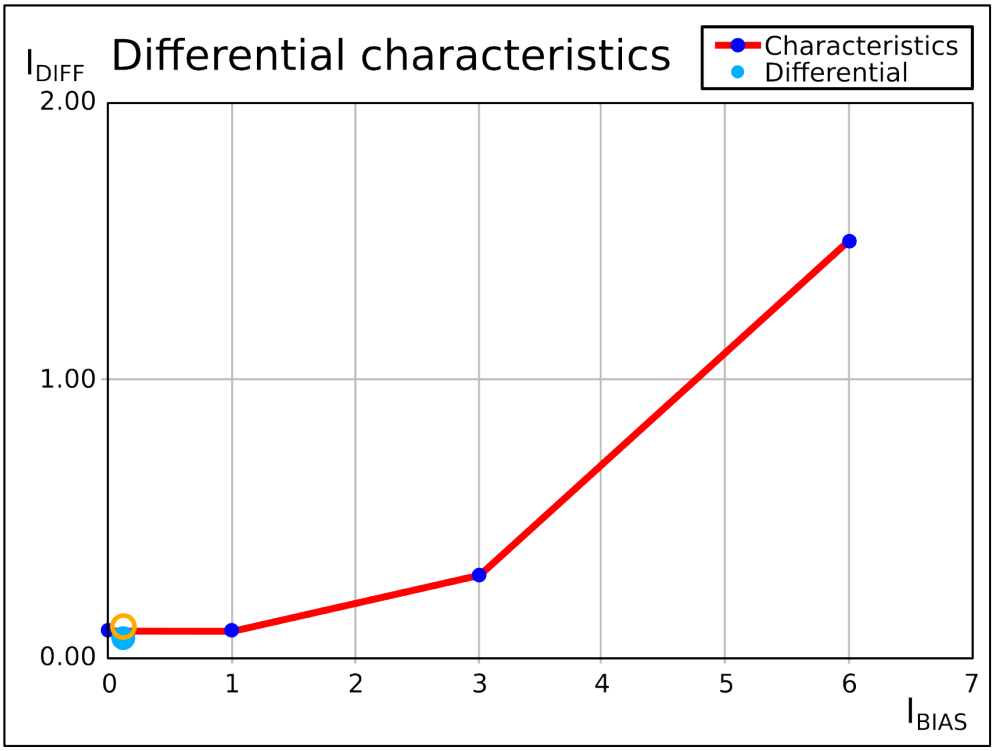
The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.


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The following figures present some typical applications for this function.

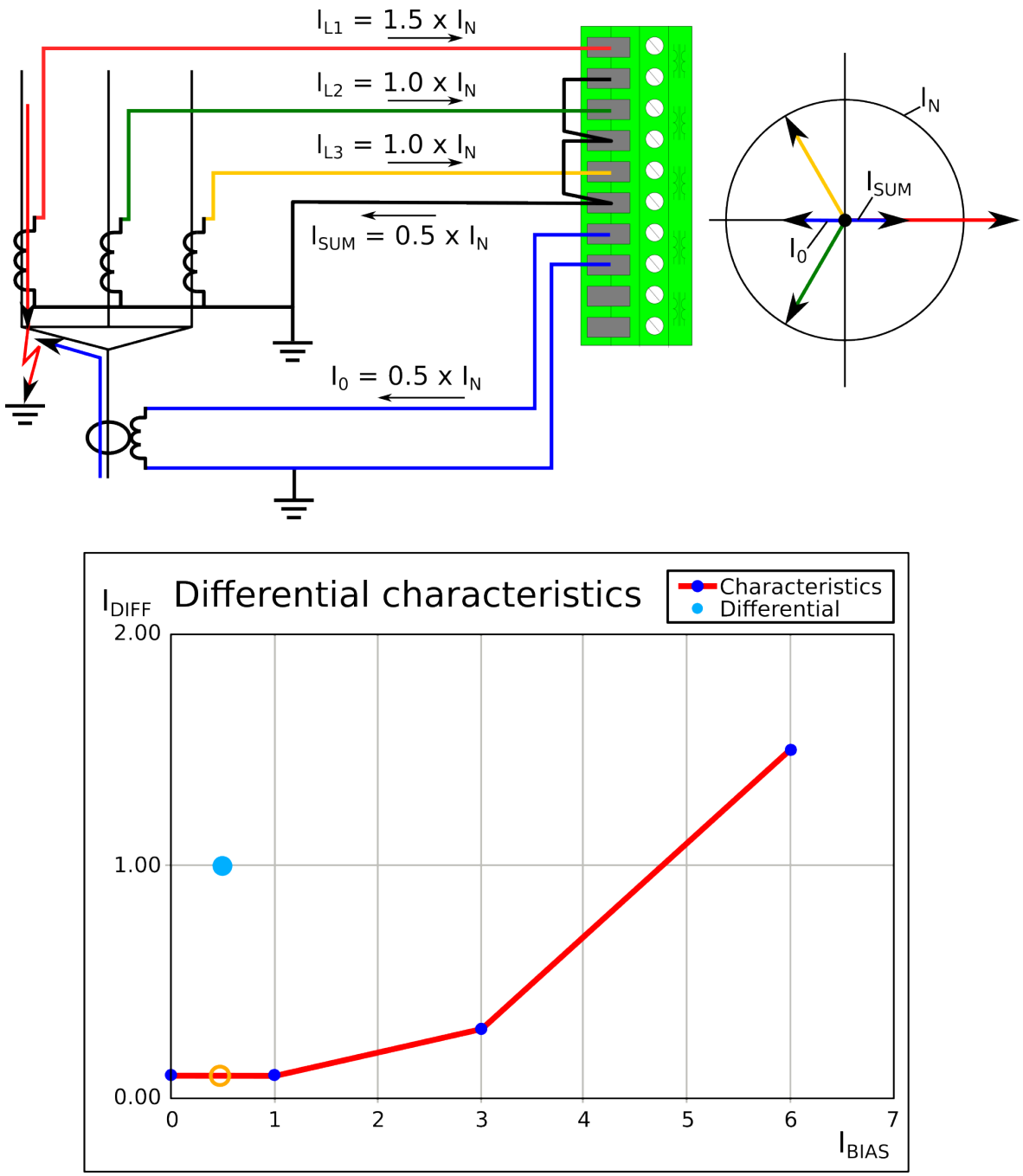
Figure. 5.4.11 - 70. Cable end differential with natural unbalance in the phase current measurement.




When calculating residual current from the phase currents, the natural unbalance can be around 10 % while the used CTs are still within the promised 5P class (which is probably the most common CT accuracy class). When the current natural unbalance is compensated in this situation, the differential settings may be set to be more sensitive and the natural unbalance does not, therefore, affect the calculation.

Figure. 5.4.11 - 71. Cable end differential when a fault occurs.

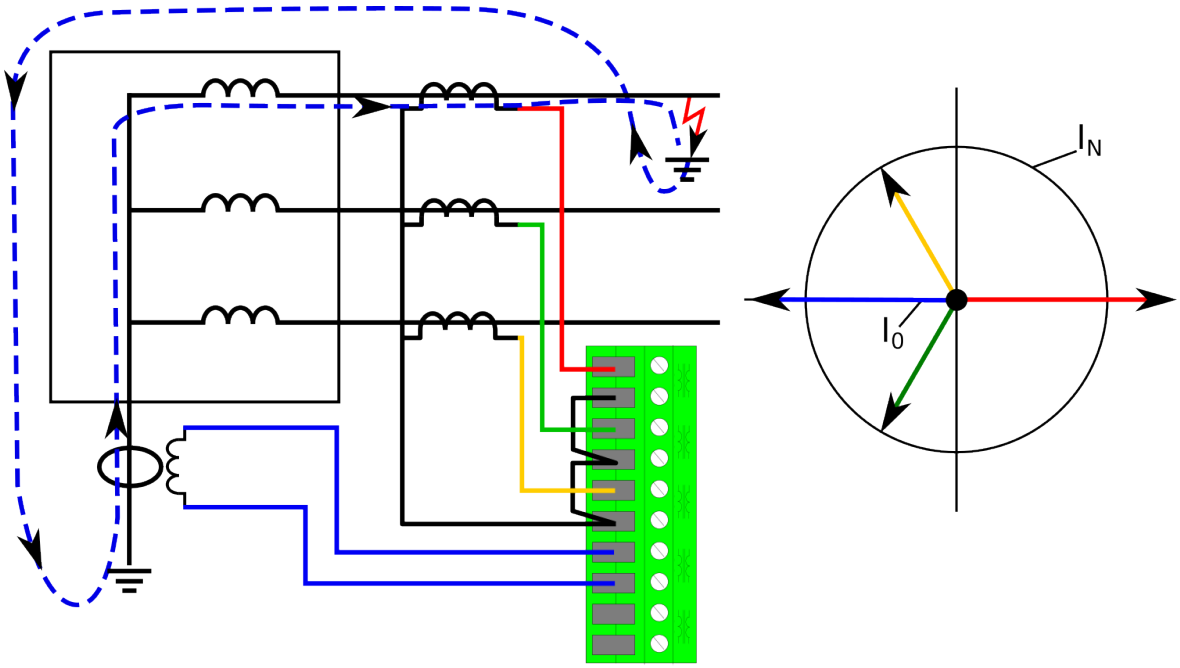


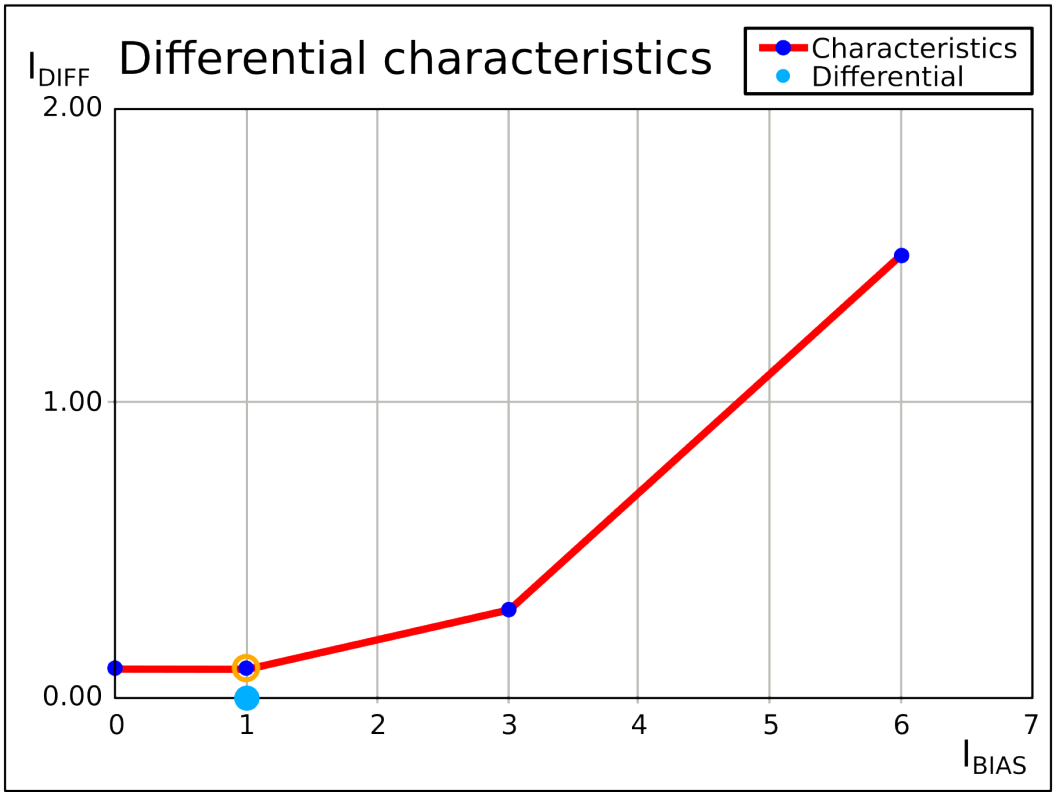

If a starting fault occurs in the cable end, the CED mode catches the difference between the ingoing and the outgoing residual currents. The resulting signal can be used for alarming or tripping purposes for the feeder with the failing cable end. The user can freely change both the settings and the sensitivity of the algorithm.

Restricted earth fault protection is usually used in the Y winding of a power transformer. This function is needed to prevent the main differential protection from being tripped by faults occurring outside the protection area; in some cases, the function has to be disabled or its sensitivity limited to catch earth faults inside the protection area. For this purpose, the restricted earth fault function is stable since it only monitors the side it is wired to, and compares the calculated and measured residual currents. During an outside earth fault the circulating residual current in the faulty phase winding does not cause a trip because the comparison of the measured starpoint current and the calculated residual current differential is close to zero.


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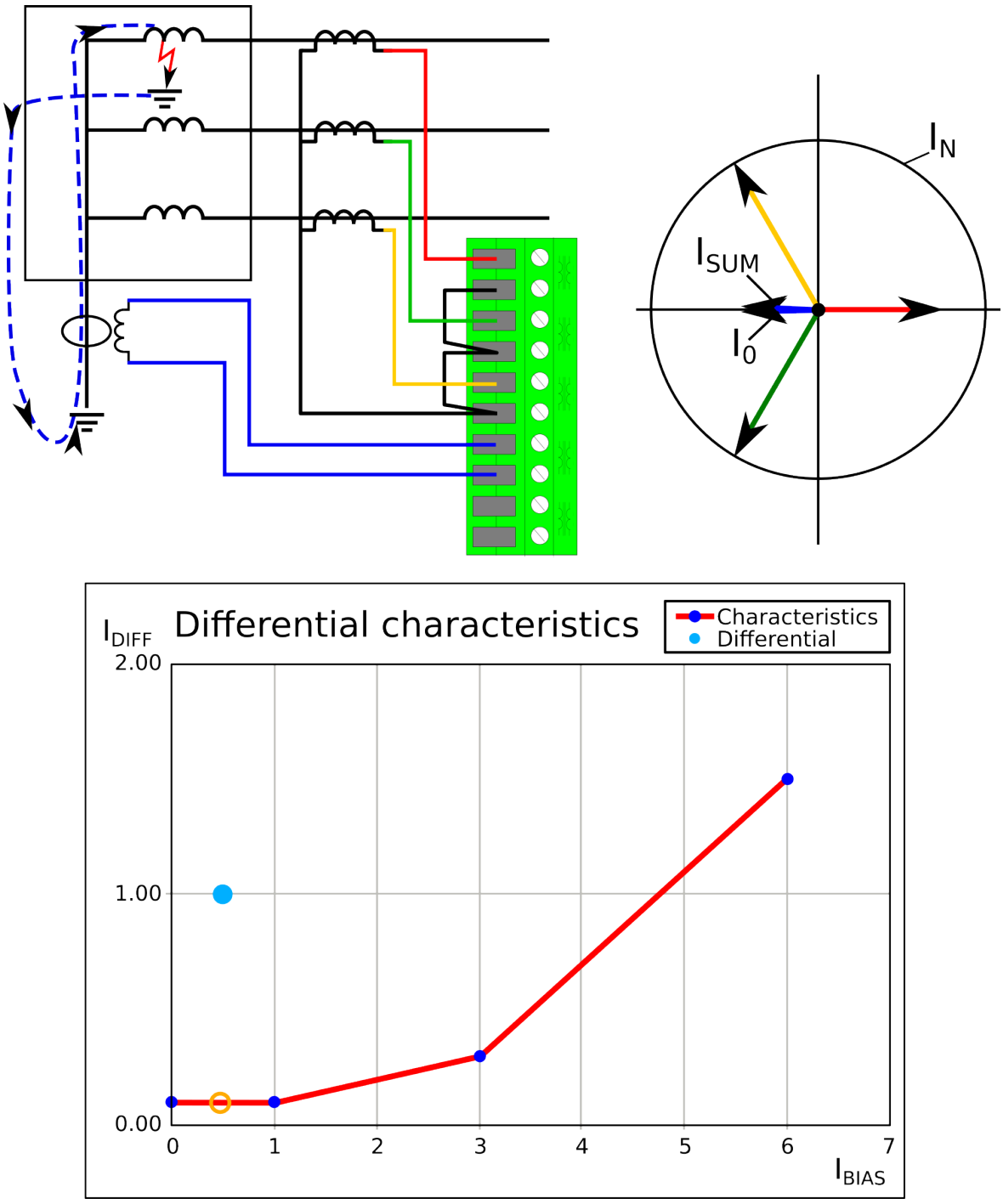
Figure. 5.4.11 - 72. Restricted earth fault outside a Y winding transformer.




If the fault is located inside of the transformer and thus inside of the protection area, the function catches the fault with high sensitivity. Since the measured residual current now flows in the opposite direction than in the outside fault situation, the measured differential current is high.

Figure. 5.4.11 - 73. Restricted earth fault inside a Y winding transformer.




## Events and registers

The restricted earth fault function (abbreviated "REF" in event block names) generates events and registers from the status changes in TRIP-activated and BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.



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Table. 5.4.11 - 120. Event messages.

| Event block name | Event names |
|---|---|
| REF1 | I0d> (87N) Trip ON |
| REF1 | I0d> (87N) Trip OFF |
| REF1 | I0d> (87N) Block ON |
| REF1 | I0d> (87N) Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.4.11 - 121. Register content.

| Date and time | Event | Trigger currents | Maximum trigger currents | Residual currents | Used SG |
|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Biascurrent<br>Diffcurrent<br>Characteristics diff | Biascurrent max<br>Diffcurrent max<br>Characteristics diff max | I0Calc<br>I0 meas | Setting group 1...8 active |

## 5.4.12 Overvoltage protection (U>; 59)

The overvoltage function is used for instant and time-delayed overvoltage protection. Each device with a voltage protection module has four (4) available stages of the function (U>, U>>, U>>>, U>>>>). The function constantly measures phase voltage magnitudes or line-to-line magnitudes. Overvoltage protection is based on line-to-line RMS measurement or to line-to-neutral RMS measurement (as the user selects). If the protection is based on line-to-line voltage, overvoltage protection is not affected by earth faults in isolated or compensated networks. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT).

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

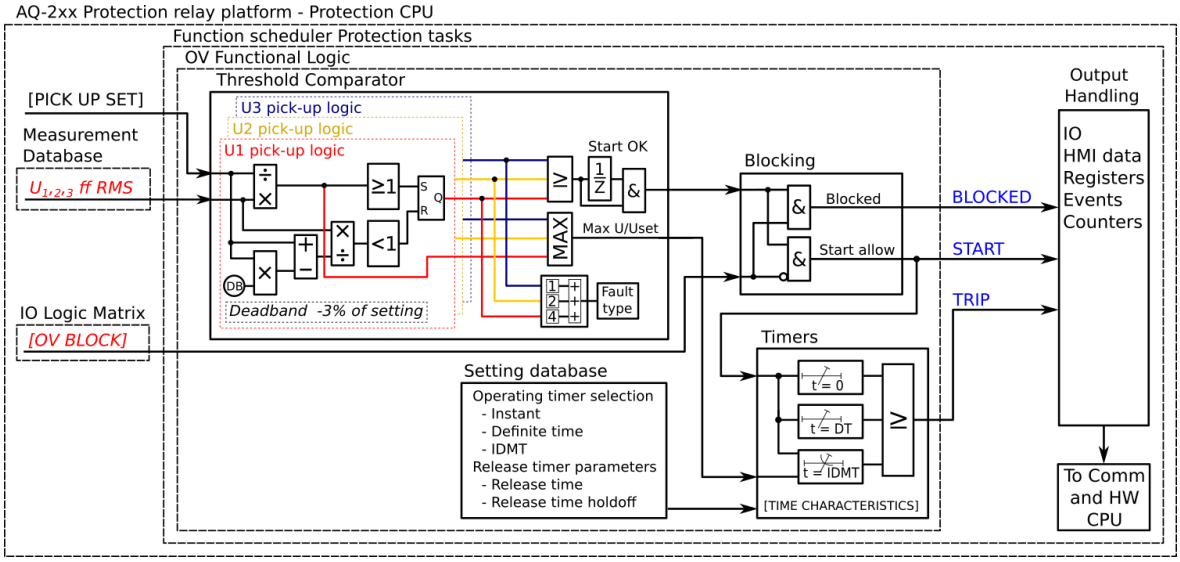
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the overvoltage function.

Figure. 5.4.12 - 74. Simplified function block diagram of the U> function.




## Measured input

The function block uses analog voltage measurement values. The monitored magnitudes are equal to RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.12 - 122. Measurement input of the U> function.

| Signal | Description | Time base |
|---|---|---|
| $U_{L12}$RMS | RMS measurement of voltage $U_{L12}$/V | 5ms |
| $U_{L23}$RMS | RMS measurement of voltage $U_{L23}$/V | 5ms |
| $U_{L31}$RMS | RMS measurement of voltage $U_{L31}$/V | 5ms |
| $U_{L1}$RMS | RMS measurement of voltage $U_{L1}$/V | 5ms |
| $U_{L2}$RMS | RMS measurement of voltage $U_{L2}$/V | 5ms |
| $U_{L3}$RMS | RMS measurement of voltage $U_{L3}$/V | 5ms |

Table. 5.4.12 - 123. Measured magnitude selection settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Measured magnitude | Selection of phase-to-phase or phase-to-earth voltages. Additionally, the U3 or U4 input can be assigned as the voltage channel to be supervised. | 0: P-P voltages<br>1: P-E voltages<br>2: U3 input (2LL-U3SS)<br>3: U4 input (SS) | - | 0: P-P voltages |



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IM00015

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Figure. 5.4.12 - 75. Selectable measurement magnitudes with 3LN+U4 VT connection.

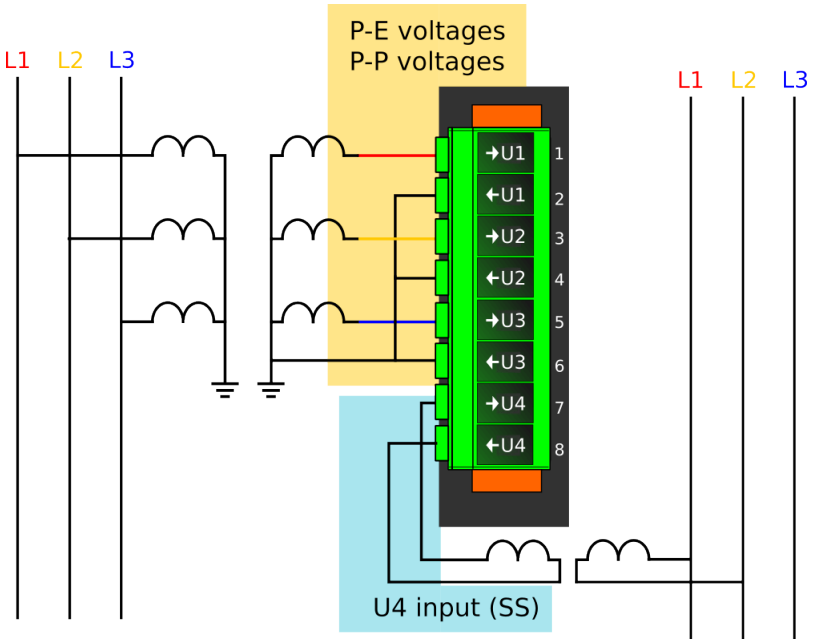



Figure. 5.4.12 - 76. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

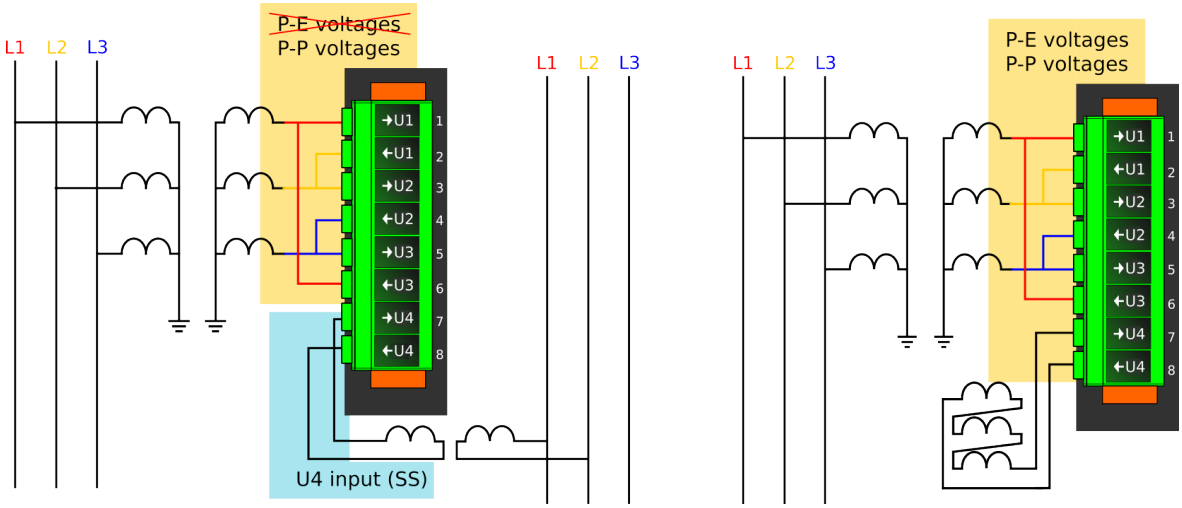
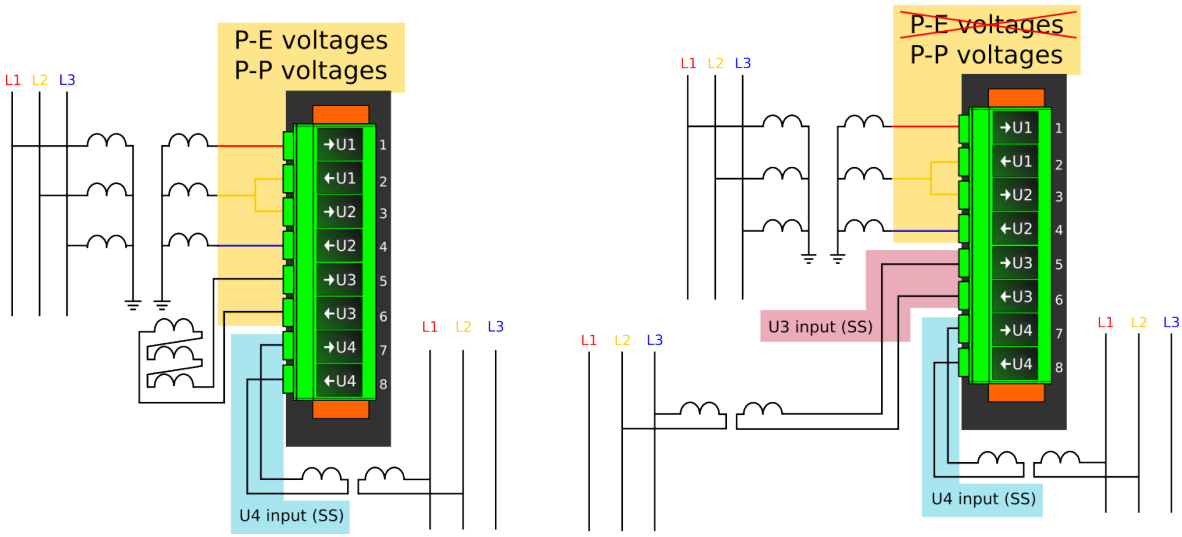


Figure. 5.4.12 - 77. Selectable measurement magnitudes with 2LL+U3+U4 VT connection (P-E voltages not available without residual voltage).




*P-P Voltages* and *P-E Voltages* selections follow phase-to-neutral or phase-to-phase voltages in the first three voltage channels (or two first voltage channels in the 2LL+U3+U4 mode). *U4 input* selection follows the voltage in Channel 4. *U3Input* selection only follows the voltage in Channel 3 if the 2LL+U3+U4 mode is in use.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.12 - 124. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| U> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of OV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The $U_{set}$ setting parameter controls the pick-up of the U> function. This defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio between the $U_{set}$ and the measured magnitude ($U_m$) for each of the three voltages. The reset ratio of 97 % is built into the function and is always relative to the $U_{set}$ value. The setting value is common for all measured amplitudes, and when the $U_m$ exceeds the $U_{set}$ value (in single, dual or all voltages) it triggers the pick-up operation of the function.


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Table. 5.4.12 - 125. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Operation mode | Pick-up criteria selection | 0: 1 voltage<br>1: 2 voltages<br>2: 3 voltages | - | 0: 1 voltage |
| $U_{set}$ | Pick-up setting | 50.00…150.00%$U_n$ | 0.01%$U_n$ | 105%$U_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.12 - 126. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| U> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of OV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U< pick-up setting | 0.0...1 000 000.0V | 0.1V | The primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $U_{A(B)meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_A$ or $U_{AB}$ voltage and the pick-up value. |
| $U_{B(c)meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_B$ or $U_{BC}$ voltage and the pick-up value. |
| $U_{C(A)meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_C$ or $U_{CA}$ voltage and the pick-up value. |
| $U_{meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between the measured voltage and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for TRIP signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: gives the TRIP signal with no additional time delay simultaneously with the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured voltage as long as the voltage is above the $U_{set}$ value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage $U_{set}$ and the measured voltage $U_m$ (dependent time characteristics).

The IDMT function follows this formula:

$$t = \frac{k}{\left(\frac{Um}{Us}\right)^{a} - 1}$$

Where:

- $t$ = operating time
- $k$ = time dial setting
- $U_m$ = measured voltage
- $U_s$ = pick-up setting
- $a$ = IDMT Multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.12 - 127. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay type | 1: DT<br>2: IDMT | - | 1: DT | Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics. |
| Definite operating time delay | 0.000…800.000s | 0.005s | 0.040s | Definite time operating delay. The setting is active and visible when DT is the selected delay type.<br><br>When set to 0.000 s, the stage operates as instant stage without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Time dial setting k | 0.01…60.00s | 0.01s | 0.05s | This setting is active and visible when IDMT is the selected delay type.<br><br>Time dial/multiplier setting for IDMT characteristics. |
| IDMT Multiplier | 0.01…25.00s | 0.01s | 1.00s | This setting is active and visible when IDMT is the selected delay type.<br><br>IDMT time multiplier in the $U_m/U_{set}$ power. |

Table. 5.4.12 - 128. Setting parameters for reset time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Release time delay | 0.000…150.000s | 0.005s | 0.06s | Resetting time. The time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active. |
| Delayed pick-up release | 1: No<br>2: Yes | - | 1: Yes | Resetting characteristics selection either as time-delayed or as instant after the pick-up element is released. If activated the START signal is reset after the set release time delay. |
| Time calc reset after release time | 1: No<br>2: Yes | - | 2: Yes | Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element is reset. |
| Continue time calculation during release time | 1: No<br>2: Yes | - | 1: No | Time calculation characteristics selection. If activated, the operating time counter is continuing until a set release time has passed even if the pick-up element is reset. |

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

## Events and registers

The overvoltage function (abbreviated "OV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.12 - 129. Event messages.

| Event block name | Event names |
|---|---|
| OV1 | Start ON |
| OV1 | Start OFF |
| OV1 | Trip ON |
| OV1 | Trip OFF |
| OV1 | Block ON |
| OV1 | Block OFF |
| OV2 | Start ON |

| Event block name | Event names |
|---|---|
| OV2 | Start OFF |
| OV2 | Trip ON |
| OV2 | Trip OFF |
| OV2 | Block ON |
| OV2 | Block OFF |
| OV3 | Start ON |
| OV3 | Start OFF |
| OV3 | Trip ON |
| OV3 | Trip OFF |
| OV3 | Block ON |
| OV3 | Block OFF |
| OV4 | Start ON |
| OV4 | Start OFF |
| OV4 | Trip ON |
| OV4 | Trip OFF |
| OV4 | Block ON |
| OV4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.12 - 130. Register content.

| Date and time | Event | Fault type | Pre-trigger voltage | Fault voltage | Pre-fault voltage | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-E… L1-L2-L3 | Start/Trip -20ms voltage | Start/Trip voltage | Start -200ms voltage | 0 s...1800s | Setting group 1...8 active |

## 5.4.13 Undervoltage protection (U<; 27)

The undervoltage function is used for instant and time-delayed undervoltage protection. Each device with a voltage protection module has four (4) available stages of the function (U>, U>>, U>>>, U>>>>). The function constantly measures phase voltage magnitudes or line-to-line voltage magnitudes. Undervoltage protection is based on line-to-line voltages or to line-to-neutral voltages (as the user selects). If the protection is based on line-to-line voltage, undervoltage protection is not affected by earth faults in isolated or compensated networks. Undervoltage protection has two blocking stages: internal blocking (based on voltage measurement and low voltage), or external blocking (e.g. during voltage transformer fuse failure). The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The undervoltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT).


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The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal checks (undervoltage block or stage external signal)
- time delay characteristics
- output processing.

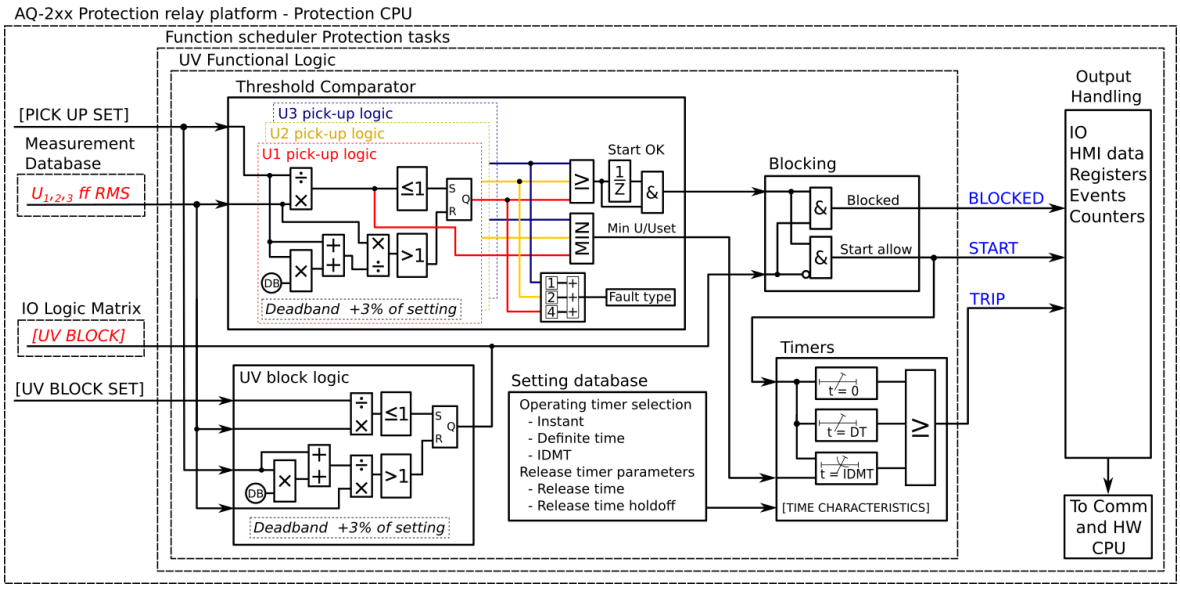
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the undervoltage function.

Figure. 5.4.13 - 78. Simplified function block diagram of the U< function.




## Measured input

The function block uses analog voltage measurement values. The monitored voltage magnitudes are equal to RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.13 - 131. Measurement inputs of the U< function.

| Signal | Description | Time base |
|---|---|---|
| $U_{L12}$RMS | RMS measurement of voltage $U_{L12}$/V | 5ms |
| $U_{L23}$RMS | RMS measurement of voltage $U_{L23}$/V | 5ms |

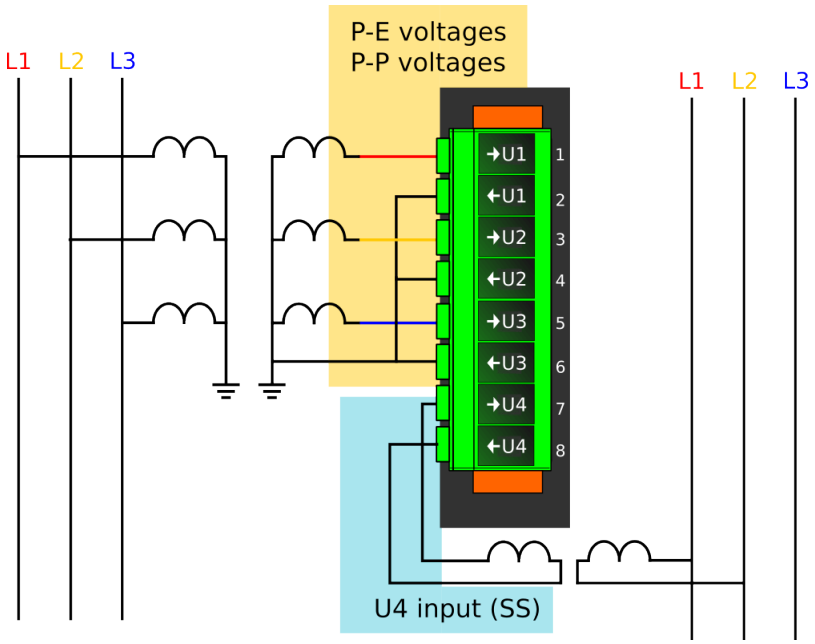
| Signal | Description | Time base |
|---|---|---|
| $U_{L31}$RMS | RMS measurement of voltage $U_{L31}$/V | 5ms |
| $U_{L1}$RMS | RMS measurement of voltage $U_{L1}$/V | 5ms |
| $U_{L2}$RMS | RMS measurement of voltage $U_{L2}$/V | 5ms |
| $U_{L3}$RMS | RMS measurement of voltage $U_{L3}$/V | 5ms |

Table. 5.4.13 - 132. Measured magnitude selection settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Measured magnitude | Selection of P-P or P-E voltages. Additionally, the U3 or U4 input can be assigned as the voltage channel to be supervised. | 0: P-P voltages<br>1: P-E voltages<br>2: U3 input (2LL-U3SS)<br>3: U4 input (SS) | - | 0: P-P voltages |

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

Figure. 5.4.13 - 79. Selectable measurement magnitudes with 3LN+U4 VT connection.






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Figure. 5.4.13 - 80. Selectable measurement magnitudes with 3LL+U4 VT connection (P-E voltages not available without residual voltage).

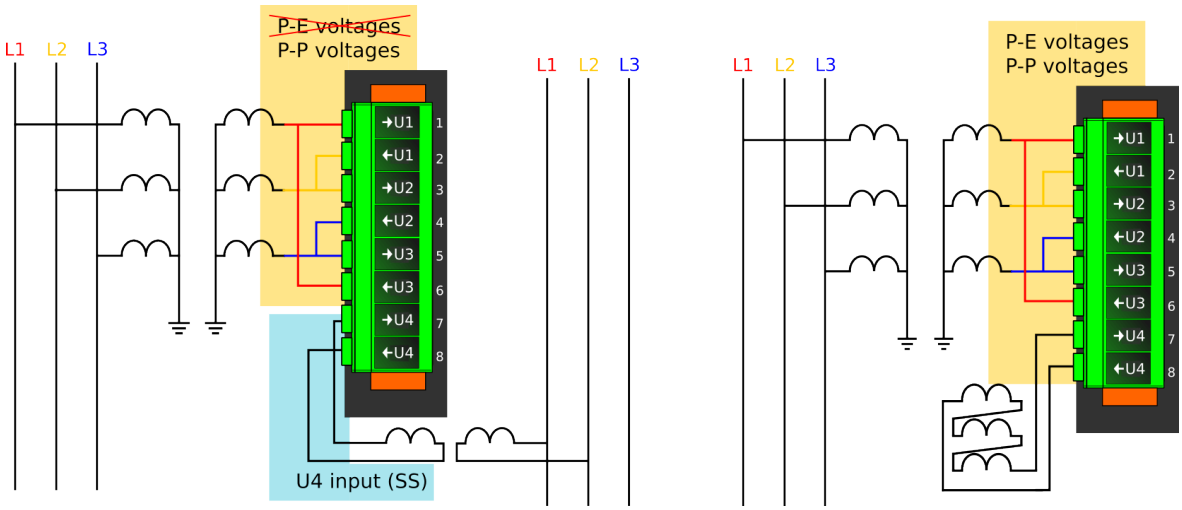
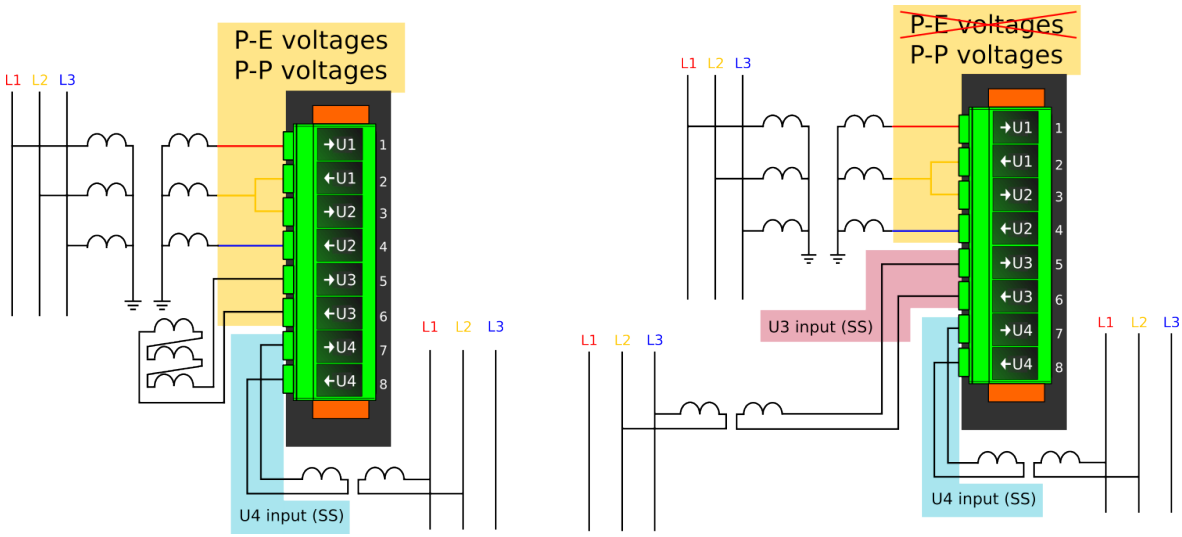



Figure. 5.4.13 - 81. Selectable measurement magnitudes with 2LL+U4 VT connection (P-E voltages not available without residual voltage).




*P-P Voltages* and *P-E Voltages* selections follow phase-to-neutral or phase-to-phase voltages in the first three voltage channels (or two first voltage channels in the 2LL+U3+U4 mode). *U4 input* selection follows the voltage in Channel 4. *U3Input* selection only follows the voltage in Channel 3 if the 2LL+U3+U4 mode is in use.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.13 - 133. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| U< LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of UV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |

| Name | Range | Default | Description |
|---|---|---|---|
| U< force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The $U_{set}$ setting parameter controls the pick-up of the U< function. This defines the minimum allowed measured voltage before action from the function. The function constantly calculates the ratio between the $U_{set}$ and the measured magnitude ($U_m$) for each of the three voltages. The reset ratio of 103 % is built into the function and is always relative to the $U_{set}$ value. The setting value is common for all measured amplitudes, and when the $U_m$ exceeds the $U_{set}$ value (in single, dual or all voltages) it triggers the pick-up operation of the function.

Table. 5.4.13 - 134. Pick-up settings.

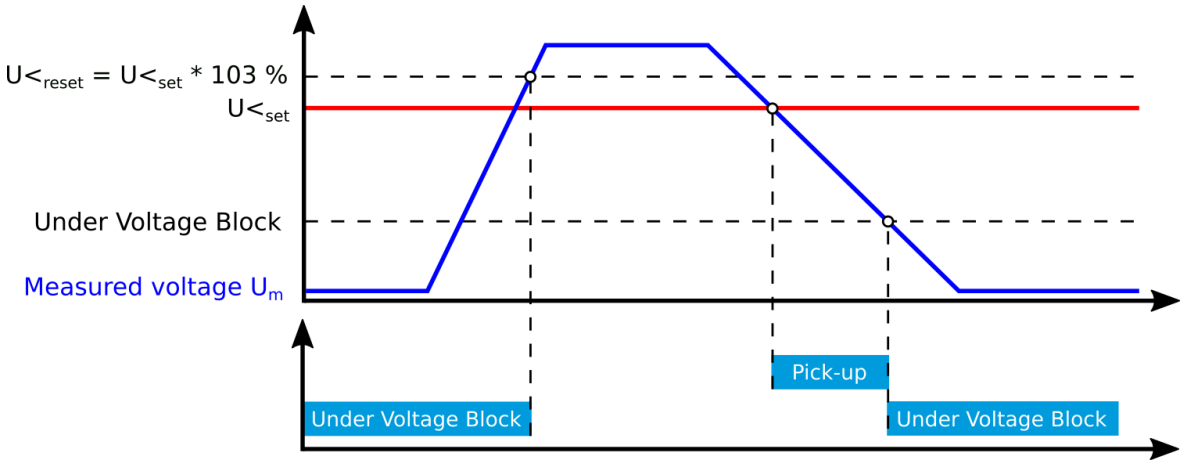
| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $U_{set}$ | Pick-up setting | 0.00…120.00%$U_n$ | 0.01%$U_n$ | 60%$U_n$ |
| U Block setting | Block setting. If set to zero, blocking is not in use. The operation is explained in the next chapter. | 0.00…100.00%$U_n$ | 0.01%$U_n$ | 10%$U_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Using *Block setting* to prevent nuisance trips

It is recommended to use the *Block setting* parameter to prevent the relay from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the relay does not give a tripping signal. If the measured voltage has dropped below the *Block setting* parameter, the blocking continues until all of the line voltages have increased above the U< pick-up setting. Please see the image below for a visualization of this function. If the block level is set to zero (0), blocking is not in use.

Figure. 5.4.13 - 82. Example of the block setting operation.




## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.


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Table. 5.4.13 - 135. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| U< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of UV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U< pick-up setting | 0.0...1 000 000.0V | 0.1V | The primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings. |
| U< block setting | 0.0...1 000 000.0V | 0.1V | The primary voltage level required for trip blocking. If the measured voltage is below this value, the network is considered de-energized and the function will not trip. To deactivate the blocking the measured voltage must exceed the pick-up setting value. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $U_{A(B)\,meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_A$ or $U_{AB}$ voltage and the pick-up value. |
| $U_{B(c)\,meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_B$ or $U_{BC}$ voltage and the pick-up value. |
| $U_{C(A)\,meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between $U_C$ or $U_{CA}$ voltage and the pick-up value. |
| $U_{meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between the lowest measured phase or line voltage and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for TRIP signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: gives the TRIP signal with no additional time delay simultaneously with the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured voltage as long as the voltage is above the $U_{set}$ value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage $U_{set}$ and the measured voltage $U_m$ (dependent time characteristics).

The IDMT function follows this formula:

$$t = \frac{k}{1 - \left(\frac{Um}{Us}\right)^a}$$

Where:

- $t$ = operating time
- $k$ = time dial setting
- $U_m$ = measured voltage
- $U_s$ = pick-up setting
- $a$ = IDMT multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.13 - 136. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay type | 1: DT<br>2: IDMT | - | 1: DT | Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics. |
| Definite operating time delay | 0.000…1800.000s | 0.005s | 0.040s | Definite time operating delay. This setting is active and visible when DT is the selected delay type.<br><br>When set to 0.000 s, the stage operates as instant stage without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed. |
| Time dial setting k | 0.01…60.00s | 0.01s | 0.05s | This setting is active and visible when IDMT is the selected delay type.<br><br>Time dial/multiplier setting for IDMT characteristics. |
| IDMT Multiplier | 0.01…25.00s | 0.01s | 1.00s | This setting is active and visible when IDMT is the selected delay type.<br><br>IDMT time multiplier in the $U_m/U_{set}$ power. |



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Table. 5.4.13 - 137. Setting parameters for reset time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Release time delay | 0.000…150.000s | 0.005s | 0.06s | Resetting time. The time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active. |
| Delayed pick-up release | 1: No<br>2: Yes | - | 2: Yes | Resetting characteristics selection, either time-delayed or instant after the pick-up element is released. If activated, the START signal is reset after a set release time delay. |
| Time calc reset after release time | 1: No<br>2: Yes | - | 2: Yes | Operating timer resetting characteristics selection. When actived, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element reset. |
| Continue time calculation during release time | 1: No<br>2: Yes | - | 1: No | Time calculation characteristics selection. If activated, the operating time counter continues until a set release time even when the pick-up element is reset. |

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

## Events and registers

The undervoltage function (abbreviated "UV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.13 - 138. Event messages.

| Event block name | Event names |
|---|---|
| UV1 | Start ON |
| UV1 | Start OFF |
| UV1 | Trip ON |
| UV1 | Trip OFF |
| UV1 | Block ON |
| UV1 | Block OFF |
| UV1 | Undervoltage Block ON |
| UV1 | Undervoltage Block OFF |
| UV2 | Start ON |
| UV2 | Start OFF |
| UV2 | Trip ON |
| UV2 | Trip OFF |
| UV2 | Block ON |

| Event block name | Event names |
|---|---|
| UV2 | Block OFF |
| UV2 | Undervoltage Block ON |
| UV2 | Undervoltage Block OFF |
| UV3 | Start ON |
| UV3 | Start OFF |
| UV3 | Trip ON |
| UV3 | Trip OFF |
| UV3 | Block ON |
| UV3 | Block OFF |
| UV3 | Undervoltage Block ON |
| UV3 | Undervoltage Block OFF |
| UV4 | Start ON |
| UV4 | Start OFF |
| UV4 | Trip ON |
| UV4 | Trip OFF |
| UV4 | Block ON |
| UV4 | Block OFF |
| UV4 | Undervoltage Block ON |
| UV4 | Undervoltage Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.13 - 139. Register content.

| Date and time | Event | Fault type | Pre-trigger voltage | Fault voltage | Pre-fault voltage | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | A…A-B-C | Start/Trip -20ms voltage | Start/Trip voltage | Start -200ms voltage | 0 ms...1800s | Setting group 1...8 active |

## 5.4.14 Neutral overvoltage protection (U0>; 59N)

The neutral overvoltage function is used for non-directional instant and time-delayed earth fault protection. Each device with a voltage protection module has four (4) available stages of the function (U0>, U0>>, U0>>>, U0>>>>). The function constantly measures phase-to-earth voltage magnitudes and calculates the zero sequence component. Neutral overvoltage protection is scaled to line-to-line RMS level. When the line-to-line voltage of a system is 100 V in the secondary side, the earth fault is 100 % of the $U_n$ and the calculated zero sequence voltage reaches 100/√3 V = 57.74 V.

Below is the formula for symmetric component calculation (and therefore to zero sequence voltage calculation).



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$$U0 = 1/3(U_{L1} + U_{L2} + U_{L3})$$

$$U_{L1...3} = \text{Line to neutral voltages}$$

Below are some examples of zero sequence calculation.

Figure. 5.4.14 - 83. Normal situation.

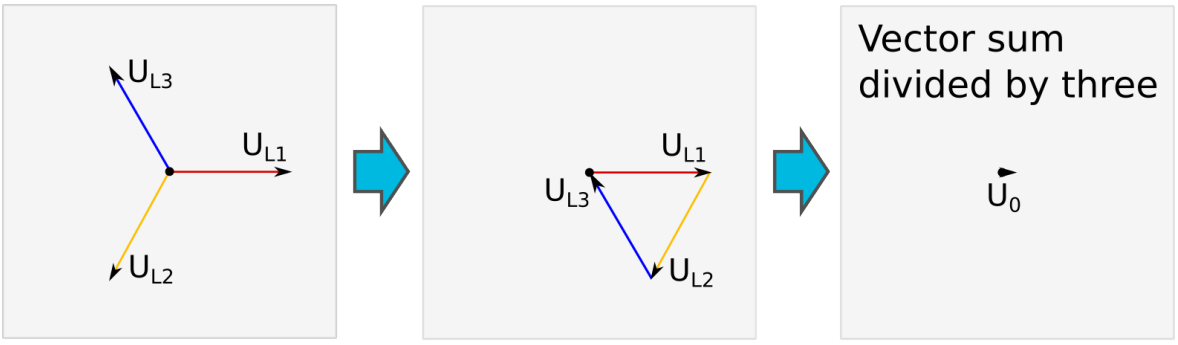



Figure. 5.4.14 - 84. Earth fault in isolated network.

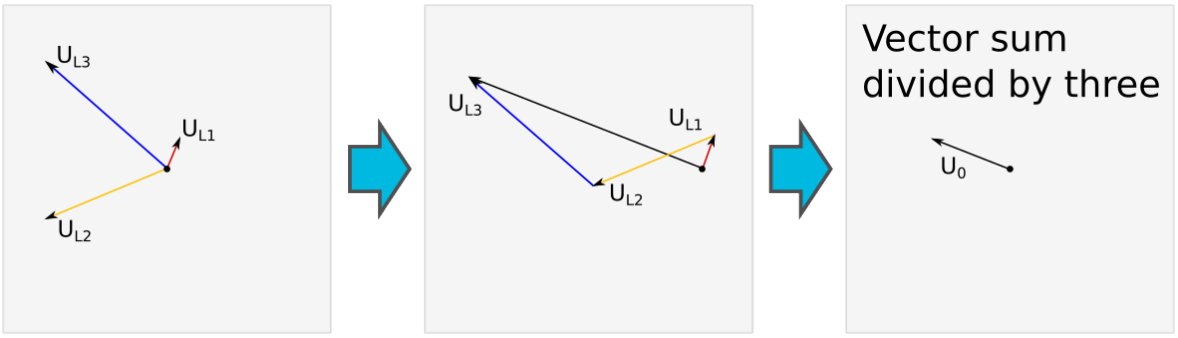
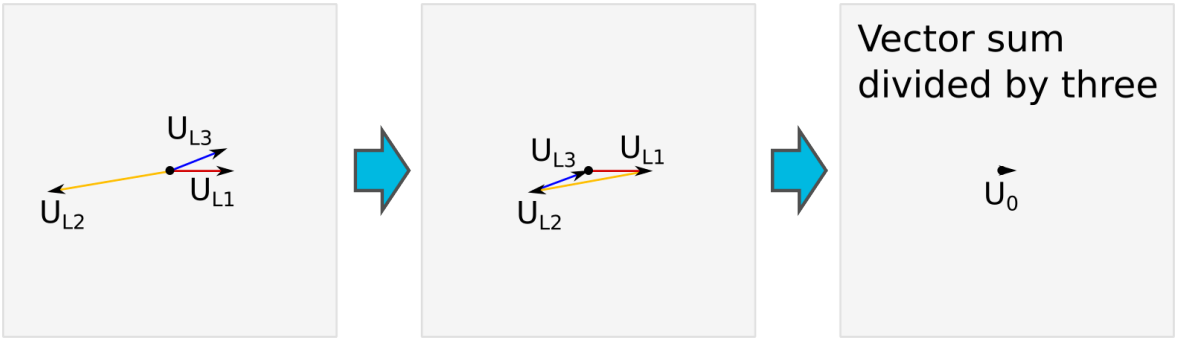



Figure. 5.4.14 - 85. Close-distance short-circuit between phases 1 and 3.




The monitored voltage magnitudes are equal to RMS values. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The neutral overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In the time-delayed mode the operation can be selected for definite time (DT) or for inverse definite minimum time (IDMT); the IDMT operation supports both IEC and ANSI standard time delays as well as custom parameters.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

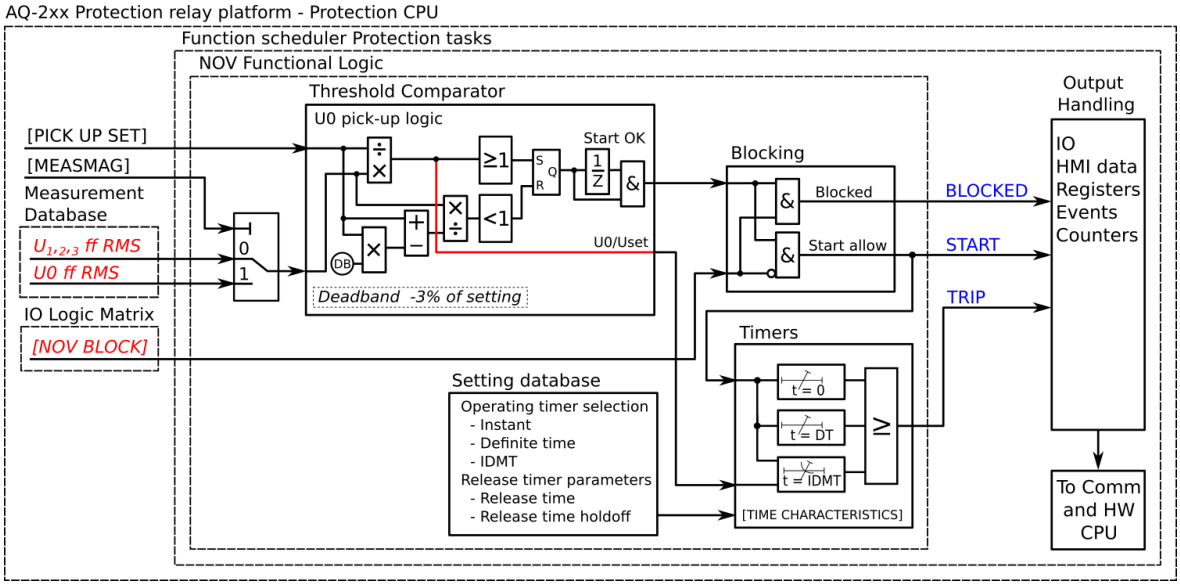
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the neutral overvoltage function.

Figure. 5.4.14 - 86. Simplified function block diagram of the U0> function.




## Measured input

The function block uses analog voltage measurement values. The function block uses RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.14 - 140. Measurement inputs of the U0> function.

| Signal | Description | Time base |
|---|---|---|
| U0RMS | RMS measurement of voltage U0/V | 5ms |
| $U_{L1}$RMS | RMS measurement of voltage $U_{L1}$/V | 5ms |
| $U_{L2}$RMS | RMS measurement of voltage $U_{L2}$/V | 5ms |
| $U_{L3}$RMS | RMS measurement of voltage $U_{L3}$/V | 5ms |


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The selection of the AI channel currently in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from a START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.14 - 141. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| U0> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of NOV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U0> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| U0> meas input select | 1: Select<br>2: U0Calc<br>3: U3 Input<br>4: U4 Input | 1: Select | Defines which available measured magnitude is used by the function. U0Calc calculates the voltage from phase voltages.<br><br>Please note that U3 Input and U4 Input selections are available only if the channel has been set to U0 mode at *Measurements → Transformers → VT module*. |

## Pick-up

The $U_{set}$ setting parameter controls the pick-up of the U0> function. This defines the maximum allowed measured voltage before action from the function. The function constantly calculates the ratio between the $U_{set}$ and the measured magnitude ($U_m$) for neutral voltage. The reset ratio of 97 % is built into the function and is always relative to the $U_{set}$ value. The setting value is common for all measured amplitudes, and when the $U_m$ exceeds the $U_{set}$ value it triggers the pick-up operation of the function.

Table. 5.4.14 - 142. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Pick-up setting U0set> | Pick-up setting | 1.00…99.00%$U_n$ | 0.01%$U_n$ | 20.00%$U_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

| Name | Range | Step | Description |
|---|---|---|---|
| U0> LN mode behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of NOV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U0> Measuring now | 0: No U0 avail!<br>1: U0Calc<br>2: U3 Input<br>3: U4 Input | - | Displays which voltage channel is used by the function. If no voltage channel has been selected the function defaults to calculated residual voltage if line-to-neutral voltages have been connected to device. If no channel is set to "U0" mode and line-to-line voltages are connected, no residual voltage is available and "No U0 avail!" will be displayed. |
| U0> Pick-up setting | 0.0...1 000 000.0V | 0.1V | Primary voltage required for tripping. The displayed pick-up voltage level depends on the chosen U0 measurement input selection, on the pick-up settings and on the voltage transformer settings. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $U_{meas}/U_{set}$ at the moment | 0.00...1250.00 | 0.01 | The ratio between the measured or calculated neutral voltage and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for TRIP signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: gives the TRIP signal with no additional time delay simultaneously with the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured or calculated voltage as long as the voltage is above the $U_{set}$ value and thus the pick-up element is active (independent time characteristics).
- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage $U_{set}$ and the measured voltage $U_m$ (dependent time characteristics).


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The IDMT function follows this formula:

$$t = \frac{k}{\left(\frac{Um}{Us}\right)^{a} - 1}$$

Where:

- $t$ = operating time
- $k$ = time dial setting
- $U_m$ = measured voltage
- $U_s$ = pick-up setting
- $a$ = IDMT multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.14 - 143. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay type | 1: DT<br>2: IDMT | - | 1: DT | Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics. |
| Definite operating time delay | 0.000…1800.000s | 0.005s | 0.040s | Definite time operating delay. The setting is active and visible when DT is the selected delay type.<br><br>When set to 0.000 s, the stage operates as instant without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed. |
| Time dial setting k | 0.01…60.00s | 0.01s | 0.05s | The setting is active and visible when IDMT is the selected delay type.<br><br>Time dial/multiplier setting for IDMT characteristics. |
| IDMT Multiplier | 0.01…25.00s | 0.01s | 1.00s | The setting is active and visible when IDMT is the selected delay type.<br><br>IDMT time multiplier in the $U_m/U_{set}$ power. |

Table. 5.4.14 - 144. Setting parameters for reset time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Release time delay | 0.000…150.000s | 0.005s | 0.06s | Resetting time. Time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active. |
| Delayed pick-up release | 1: No<br>2: Yes | - | 2: Yes | Resetting characteristics selection either as time-delayed or as instant after the pick-up element is released. If activated, the START signal is reset after a set release time delay. |
| Time calc reset after release time | 1: No<br>2: Yes | - | 2: Yes | Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element reset. |
| Continue time calculation during release time | 1: No<br>2: Yes | - | 1: No | Time calculation characteristics selection. If activated, the operating time counter continues until a set release time has passed even if the pick-up element is reset. |

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

## Events and registers

The neutral overvoltage function (abbreviated "NOV" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.14 - 145. Event messages.

| Event block name | Event names |
|---|---|
| NOV1 | Start ON |
| NOV1 | Start OFF |
| NOV1 | Trip ON |
| NOV1 | Trip OFF |
| NOV1 | Block ON |
| NOV1 | Block OFF |
| NOV2 | Start ON |
| NOV2 | Start OFF |
| NOV2 | Trip ON |
| NOV2 | Trip OFF |
| NOV2 | Block ON |
| NOV2 | Block OFF |
| NOV3 | Start ON |
| NOV3 | Start OFF |
| NOV3 | Trip ON |
| NOV3 | Trip OFF |
| NOV3 | Block ON |
| NOV3 | Block OFF |
| NOV4 | Start ON |
| NOV4 | Start OFF |
| NOV4 | Trip ON |
| NOV4 | Trip OFF |
| NOV4 | Block ON |
| NOV4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.


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Table. 5.4.14 - 146. Register content.

| Date and time | Event | Fault type | Pre-trigger voltage | Fault voltage | Pre-fault voltage | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-G…L1-L2-L3 | Start/Trip -20ms voltage | Start/Trip voltage | Start -200ms voltage | 0 ms...1800s | Setting group 1...8 active |

## 5.4.15 Sequence voltage protection (U1/U2>/<; 47/27P/59PN)

The sequence voltage function is used for instant and time-delayed voltage protection. It has positive and negative sequence protection for both overvoltage and undervoltage (the user selects the needed function). Each device with a voltage protection module has four (4) available stages of the function. The function constantly measures the RMS value of phase-to-earth voltage magnitudes, or line-to-line and neutral voltage magnitudes to calculate the positive or negative sequence voltage. The user can select the voltage used. Sequence voltage is based on the system's line-to-line voltage level. Protection stages can be set to protect against both undervoltage and overvoltage. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

### Positive sequence voltage calculation

Below is the formula for symmetric component calculation (and therefore to positive sequence voltage calculation).

$$U1 = {}^{1}/_{3}\,(U_{L1} + aU_{L2} + a^2U_{L3})$$

$$a = 1\angle 120°$$

$$a^2 = 1\angle 240°$$

$$U_{L1\ldots3} = Line\ to\ neutral\ voltages$$

In what follows are three examples of positive sequence calculation (positive sequence component vector).

Figure. 5.4.15 - 87. Normal situation.

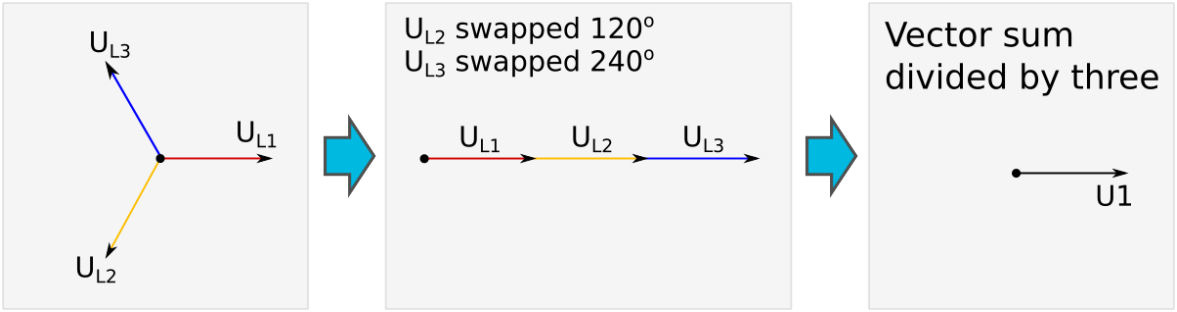


Figure. 5.4.15 - 88. Earth fault in an isolated network.

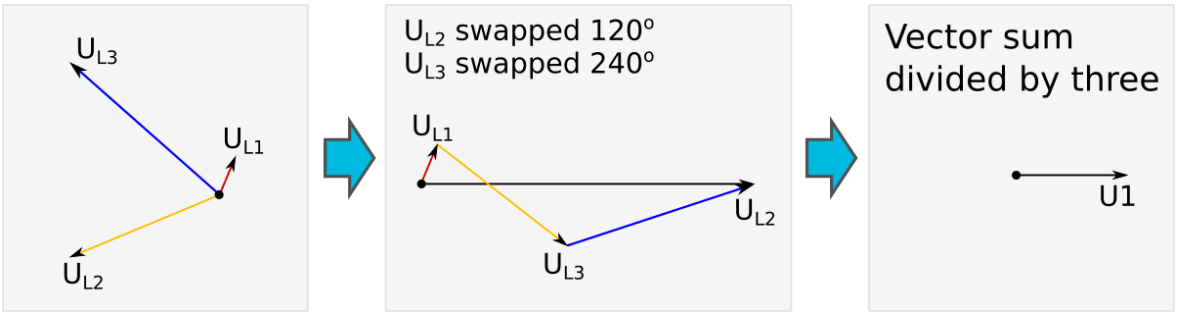
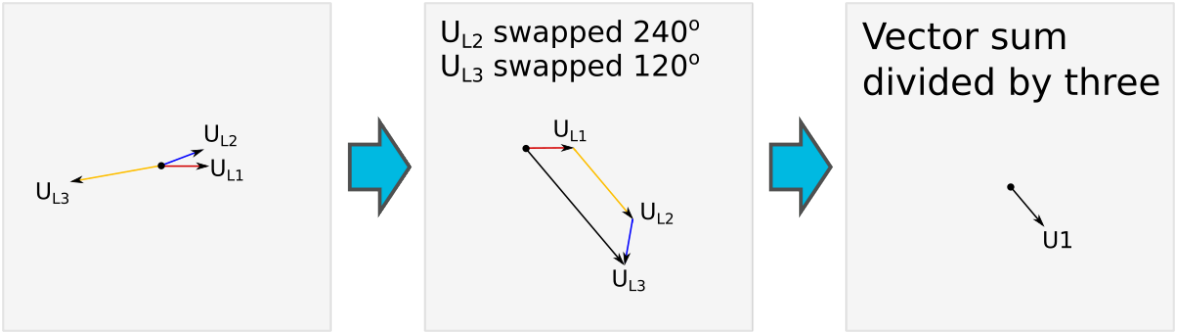



Figure. 5.4.15 - 89. Close-distance short-circuit between phases 1 and 3.




## Negative sequence voltage calculation

Below is the formula for symmetric component calculation (and therefore to negative sequence voltage calculation).

$$U2 = {}^{1}/_{3}\,(U_{L1} + a^2 U_{L2} + a U_{L3})$$

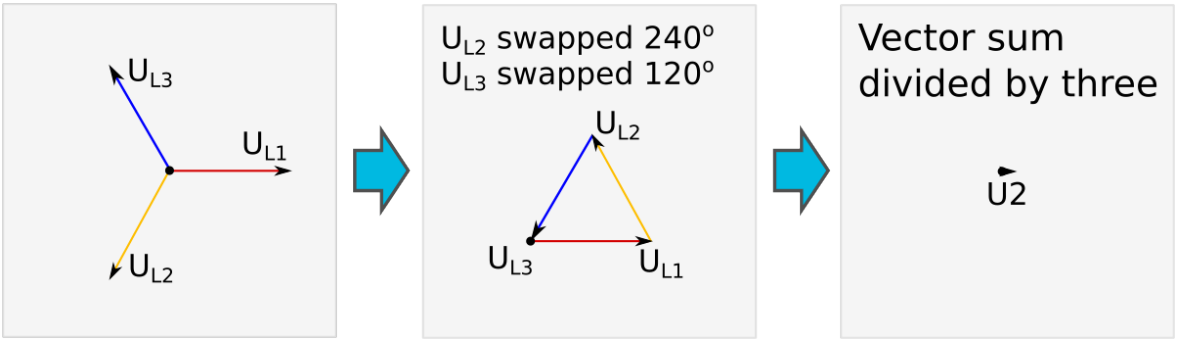
$$a = 1\angle 120°$$

$$a^2 = 1\angle 240°$$

$$U_{L1\ldots3} = Line\ to\ neutral\ voltages$$

In what follows are three examples of negative sequence calculation (negative sequence component vector).

Figure. 5.4.15 - 90. Normal situation.






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Figure. 5.4.15 - 91. Earth fault in isolated network.

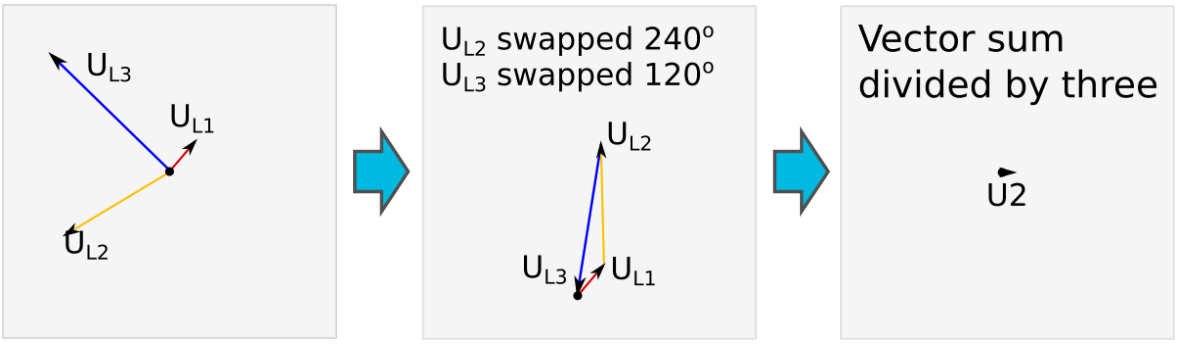
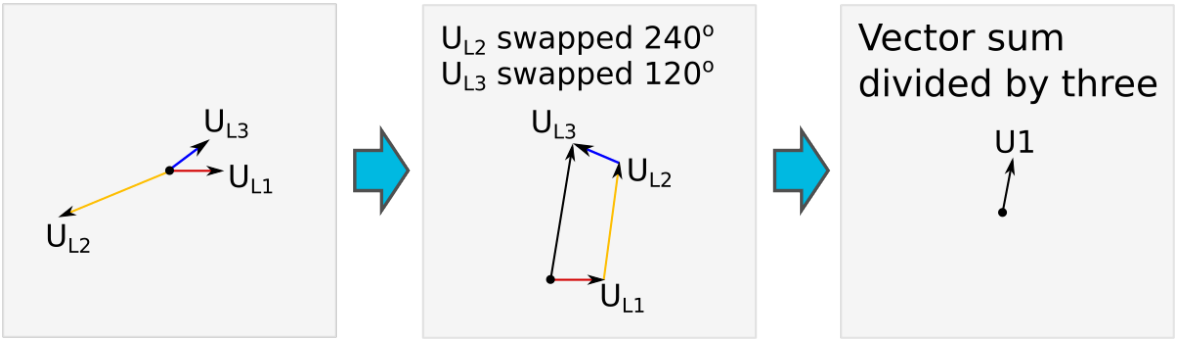



Figure. 5.4.15 - 92. Close-distance short-circuit between phases 1 and 3.




The sequence voltage function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode. In time-delayed mode the operation can be selected between definite time (DT) mode and inverse definite minimum time (IDMT).

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

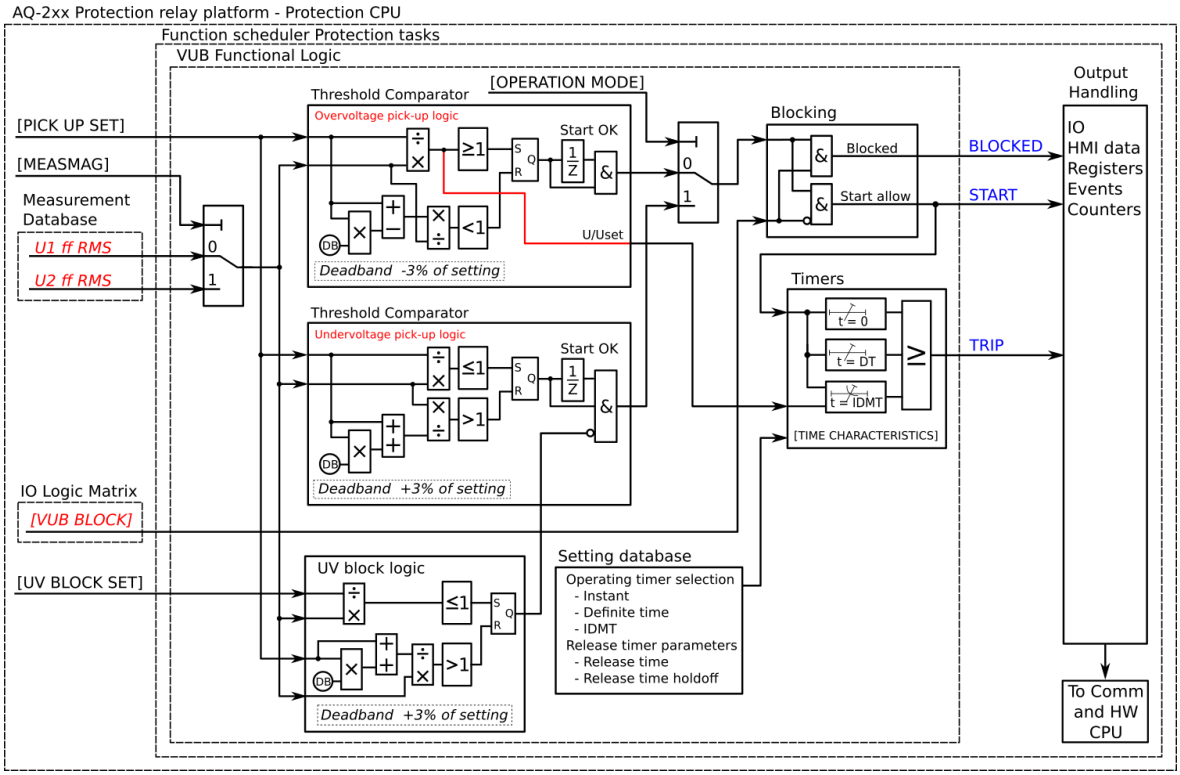
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the sequence voltage function.

Figure. 5.4.15 - 93. Simplified function block diagram of the U1/U2>/< function.




## Measured input

The function block uses analog voltage measurement values and always uses RMS values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.15 - 147. Measurement inputs of the U1/U2>/< function.

| Signal | Description | Time base |
|---|---|---|
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |

In RMS values the pre-fault condition is presented with 20 ms averaged history value from -20 ms of START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.15 - 148. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| U1/2 >/< LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 0: On | Set mode of VUB block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |



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| Name | Range | Default | Description |
|---|---|---|---|
| U1/2 >/< force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Measured magnitude | 1: U1 Positive sequence voltage<br>2: U2 Negative sequence voltage | 1: U1 Positive sequence voltage | Selects which calculated voltage is supervised. |

## Pick-up

The $U_{set}$ setting parameter controls the pick-up of the U1/U2>/< function. This defines the maximum or minimum allowed calculated U1 or U2 voltage before action from the function. The function constantly calculates the ratio between the $U_{set}$ and the calculated U1 or U2 magnitude ($U_C$). The monitored voltage is chosen in the *Info* page with the parameter *Measured magnitude*. The reset ratio of 97 % in overvoltage applications is built into the function and is always relative to the $U_{set}$ value. The reset ratio of 103 % in undervoltage applications is built into the function and is always relative to the $U_{set}$ value. When the $U_C$ goes above or below the $U_{set}$ value it triggers the pick-up operation of the function.

Table. 5.4.15 - 149. Pick-up settings.

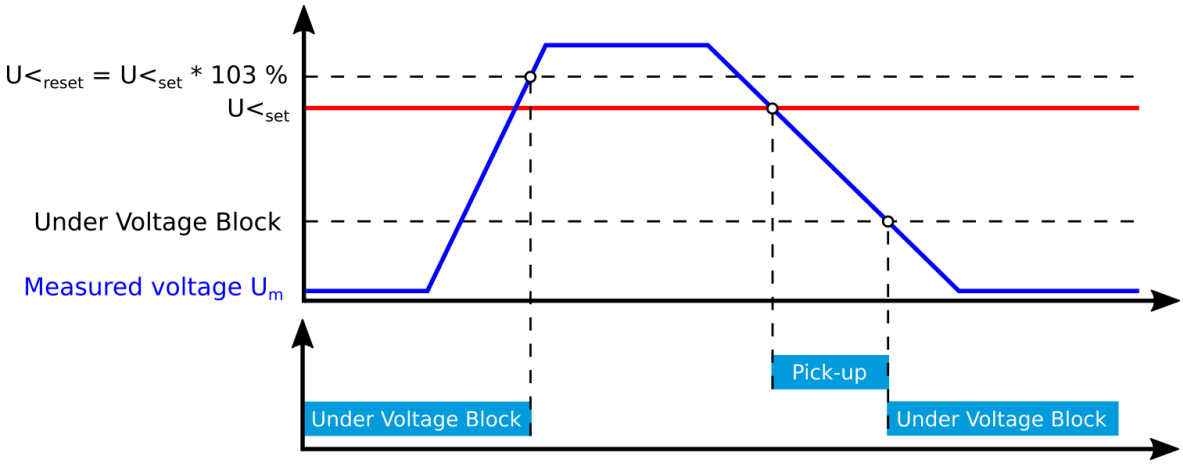
| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Pick-up terms | Selects whether the function picks-up when the monitored voltage is under or over the set pick-up value. | Over ><br>Under< | - | Over> |
| $U_{set}$ | Pick-up setting | 5.00…150.00%$U_n$ | 0.01%$U_n$ | 105%$U_n$ |
| $U_{blk}$ | Undervoltage blocking (visible when the pick-up term is Under<) | 0.00…80.00%$U_n$ | 0.01%$U_n$ | 5%$U_n$ |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Using *Block setting* to prevent nuisance trips

It is recommended to use the *Under block setting* $U_{blk}$ parameter when Under< is the chosen tripping condition to prevent the relay from tripping in a situation where the network is de-energized. When the measured voltage drops below the set value, the relay does not give a tripping signal. If the measured voltage has dropped below the *Under block setting* $U_{blk}$ parameter, the blocking continues until all of the line voltages have increased above the U< pick-up setting. Please see the image below for a visualization of this function. If the block level is set to zero (0), blocking is not in use.

Figure. 5.4.15 - 94. Example of the block setting operation.



## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.15 - 150. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| U1/2 >/< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of VUB block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U1/2 >/< Pick-up setting | 0.0...1 000 000.0V | 0.1V | The primary voltage required for tripping. The displayed pick-up voltage level depends on the pick-up setting and the voltage transformer settings. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured voltage value. If the measured voltage changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| $U_{meas}/U_{set}$ at the moment | 0.00...1250.00$U_m/U_{set}$ | 0.01$U_m/U_{set}$ | The ratio between the measured voltage and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

The operating timers' behavior during a function can be set for TRIP signal and also for the release of the function in case the pick-up element is reset before the trip time has been reached. There are three basic operating modes available for the function:

- Instant operation: gives the TRIP signal with no additional time delay simultaneously with the START signal.
- Definite time operation (DT): gives the TRIP signal after a user-defined time delay regardless of the measured or calculated voltage as long as the voltage is above the $U_{set}$ value and thus the pick-up element is active (independent time characteristics).


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- Inverse definite minimum time (IDMT): gives the TRIP signal after a time which is in relation to the set pick-up voltage $U_{set}$ and the measured voltage $U_m$ (dependent time characteristics).

The IDMT function follows one of the following formulas:

Overvoltage

$$t = \frac{k}{\left(\frac{Um}{Us}\right)^a - 1}$$

Undervoltage

$$t = \frac{k}{1 - \left(\frac{Um}{Us}\right)^a}$$

Where:

- $t$ = operating time
- $k$ = time dial setting
- $U_m$ = measured voltage
- $U_s$ = pick-up setting
- $a$ = IDMT multiplier setting

The following table presents the setting parameters for the function's time characteristics.

Table. 5.4.15 - 151. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Delay type | 1: DT<br>2: IDMT | - | 1: DT | Selection of the delay type time counter. The selection possibilities are dependent (IDMT, Inverse Definite Minimum Time) and independent (DT, Definite Time) characteristics. |
| Definite operating time delay | 0.000…1800.000s | 0.005s | 0.040s | Definite time operating delay. The setting is active and visible when DT is the selected delay type.<br><br>When set to 0.000 s, the stage operates as instant without added delay. When the parameter is set to 0.005...1800 s, the stage operates as independent delayed. |
| Time dial setting k | 0.01…60.00s | 0.01s | 0.05s | The setting is active and visible when IDMT is the selected delay type.<br><br>Time dial/multiplier setting for IDMT characteristics. |
| IDMT Multiplier | 0.01…25.00s | 0.01s | 1.00s | The setting is active and visible when IDMT is the selected delay type.<br><br>IDMT time multiplier in the $U_m/U_{set}$ power. |

Table. 5.4.15 - 152. Setting parameters for reset time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Release time delay | 0.000…150.000s | 0.005s | 0.06s | Resetting time. Time allowed between pick-ups if the pick-up has not led to a trip operation. During this time the START signal is held on for the timers if the delayed pick-up release is active. |
| Delayed pick-up release | 1: No<br>2: Yes | - | 2: Yes | Resetting characteristics selection either as time-delayed or as instant after the pick-up element is released. If activated, the START signal is reset after a set release time delay. |
| Time calc reset after release time | 1: No<br>2: Yes | - | 2: Yes | Operating timer resetting characteristics selection. When active, the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When disabled, the operating time counter is reset directly after the pick-up element reset. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Continue time calculation during release time | 1: No<br>2: Yes | - | 1: No | Time calculation characteristics selection. If activated, the operating time counter continues until a set release time has passed even if the pick-up element is reset. |

The user can reset characteristics through the application. The default setting is a 60 ms delay; the time calculation is held during the release time.

In the release delay option the operating time counter calculates the operating time during the release. When using this option the function does not trip if the input signal is not re-activated while the release time count is on-going.

## Events and registers

The sequence voltage function (abbreviated "VUB" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers four (4) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.15 - 153. Event messages.

| Event block name | Event names |
|---|---|
| VUB1 | Start ON |
| VUB1 | Start OFF |
| VUB1 | Trip ON |
| VUB1 | Trip OFF |
| VUB1 | Block ON |
| VUB1 | Block OFF |
| VUB2 | Start ON |
| VUB2 | Start OFF |
| VUB2 | Trip ON |
| VUB2 | Trip OFF |
| VUB2 | Block ON |
| VUB2 | Block OFF |
| VUB3 | Start ON |
| VUB3 | Start OFF |
| VUB3 | Trip ON |
| VUB3 | Trip OFF |
| VUB3 | Block ON |
| VUB3 | Block OFF |
| VUB4 | Start ON |
| VUB4 | Start OFF |
| VUB4 | Trip ON |


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| Event block name | Event names |
|---|---|
| VUB4 | Trip OFF |
| VUB4 | Block ON |
| VUB4 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.15 - 154. Register content.

| Date and time | Event | Pre-trigger voltage | Fault voltage | Pre-fault voltage | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip -20ms voltage | Start/Trip voltage | Start -200ms voltage | 0 ms...1800s | Setting group 1...8 active |

## 5.4.16 Overfrequency and underfrequency protection (f>/<; 81O/81U)

The frequency protection function can be used both in overfrequency and in underfrequency situations, and it has four (4) stages for both. Frequency protection can be applied to protect feeder, bus, transformer, motor and generator applications. The difference between the generated power and the load demand can cause the frequency to drop below or rise above the allowed level. When the consumption is larger than the generated power, the frequency may drop. When more power is generated than is consumed, overfrequency can occur.

In generator applications too big a load or a malfunction in the power controller can cause the frequency to decrease. Underfrequency causes damage to turbine wings through vibration as well as heating due to increased iron losses, dropped cooling efficieny and over-magnetization in step-up transformers. Overfrequency protection prevents the generator from running too fast which can cause damage to the generator turbine.

Underfrequency and overfrequency protection can be used as an indicator of an accidental island operation in distributed generation and in some consumers (as it is unlikely that the consumed and generated power are the same). Overfrequency is also often used to control power generation to keep the system's frequency consistent.

Each stage can be activated and deactivated individually. After the f>/< mode has been activated (*Protection → Stage activation → Frequency stages*), the user can activate and deactivate the individual stages at will (*Protection → Frequency → Frequency protection f >/< → INFO → Stage operational setup*).

The frequency protection function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed frequency magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signal. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figures present simplified function block diagrams of the frequency function.

Figure. 5.4.16 - 95. Simplified function block diagram of the f> function.

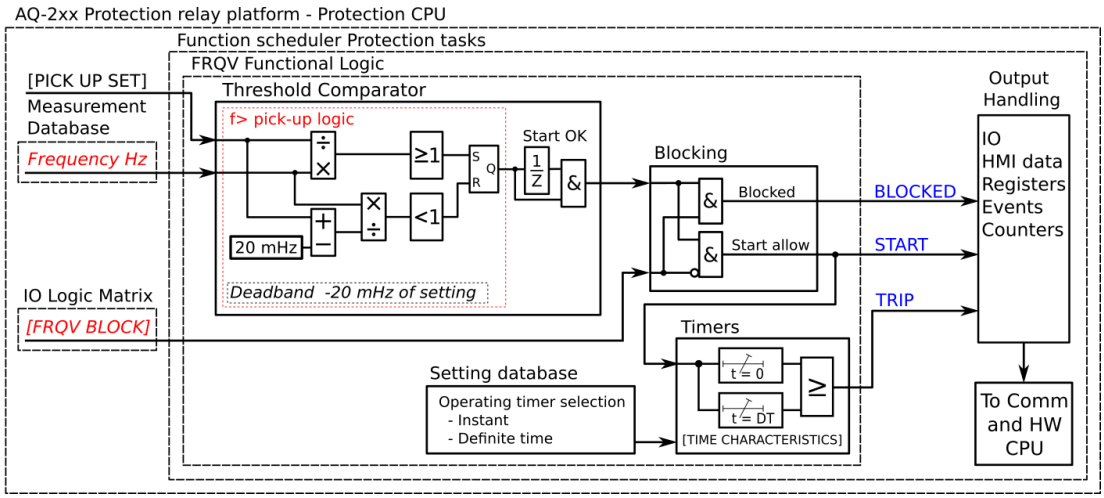
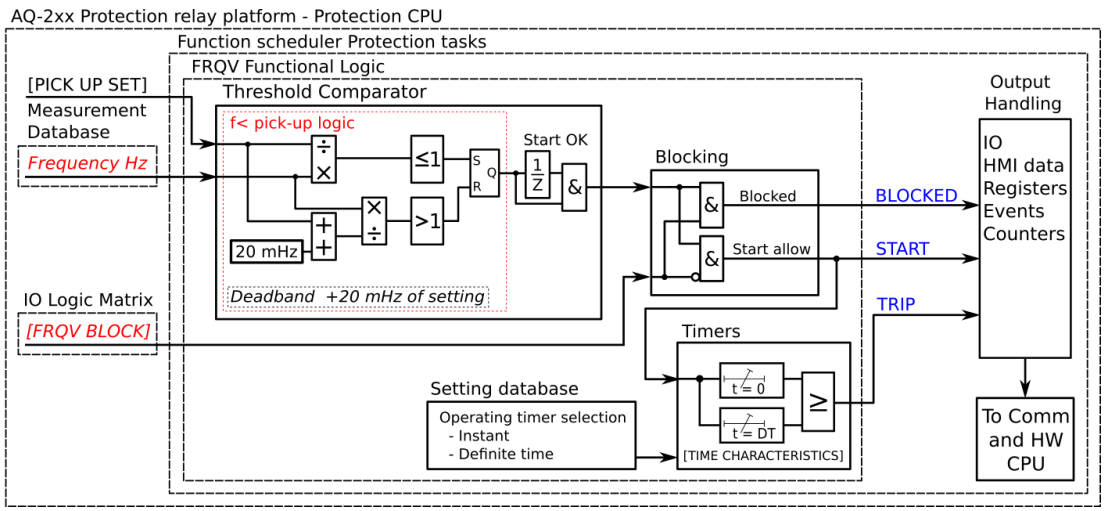



Figure. 5.4.16 - 96. Simplified function block diagram of the f< function.




## Measured input

The frequency protection function compares the measured frequency to the pick-up setting (given in Hz). The source of the measured frequency depends on the user-defined tracking reference which can be chosen from the *Frequency* tab of the *Measurement* menu.



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Table. 5.4.16 - 155. Measurement inputs of the f>/< function.

| Signals | Description | Time base |
|---|---|---|
| VT1 U1, U2, U3 | L-N voltages of the first voltage transformer | 5ms |
| VT2 U1, U2, U3 | L-N voltages of the second voltage transformer | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.16 - 156. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| f</> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of FRQV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| f> enable<br>f>> enable<br>f>>> enable<br>f>>>> enable<br>f< enable<br>f<< enable<br>f<<< enable<br>f<<<< enable | 1: No<br>2: Yes | 0: No | Enables or disables the stage. |
| f> force status to<br>f>> force status to<br>f>>> force status to<br>f>>>> force status to<br>f< force status to<br>f<< force status to<br>f<<< force status to<br>f<<<< force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up and time delay

The $f_{set}$>, $f_{set}$>>, etc.setting parameters control the pick-up of each stage of the f>/< function. They define the maximum or minimum allowed measured frequency before action from the function. The function constantly calculates the ratio between the pick-up setting and the measured frequency. The reset ratio of 20mHz is built into the function and is always relative to the pick-up value.

Table. 5.4.16 - 157. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| f> used in setting group<br>f>> used in setting group<br>f>>> used in setting group<br>f>>>> used in setting group<br>f< used in setting group<br>f<< used in setting group<br>f<<< used in setting group<br>f<<<< used in setting group | Enables or disables the protection stage in the setting group. | 0: No<br>1: Yes | - | 0: No |
| fset><br>fset>><br>fset>>><br>fset>>>> | Pick-up setting | 10.00…80.00Hz | 0.01Hz | 51Hz |
| fset<<br>fset<<<br>fset<<<<br>fset<<<< | Pick-up setting | 5.00…75.00Hz | 0.01Hz | 49Hz |
| f> operating time<br>f>> operating time<br>f>>> operating time<br>f>>>> operating time<br>f< operating time<br>f<< operating time<br>f<<< operating time<br>f<<<< operating time | Operation time | 0.000...1800.00s | 0.005s | 0.1s |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.16 - 158. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| f</> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of FRQV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| f</> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| f meas / f set | 0.000..20.000$f_m/f_{set}$ | 0.001$f_m/f_{set}$ | The ratio between the measured frequency and the pick-up value. |


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| Name | Range | Step | Description |
|---|---|---|---|
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup frequency values.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events and registers

The frequency function (abbreviated "FRQV" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.16 - 159. Event messages.

| Event block name | Event names |
|---|---|
| FRQV1 | f> Start ON |
| FRQV1 | f> Start OFF |
| FRQV1 | f> Trip ON |
| FRQV1 | f> Trip OFF |
| FRQV1 | f>> Start ON |
| FRQV1 | f>> Start OFF |
| FRQV1 | f>> Trip ON |
| FRQV1 | f>> Trip OFF |
| FRQV1 | f>>> Start ON |
| FRQV1 | f>>> Start OFF |
| FRQV1 | f>>> Trip ON |
| FRQV1 | f>>> Trip OFF |
| FRQV1 | f>>>> Start ON |

| Event block name | Event names |
|---|---|
| FRQV1 | f>>>> Start OFF |
| FRQV1 | f>>>> Trip ON |
| FRQV1 | f>>>> Trip OFF |
| FRQV1 | f< Start ON |
| FRQV1 | f< Start OFF |
| FRQV1 | f< Trip ON |
| FRQV1 | f< Trip OFF |
| FRQV1 | f<< Start ON |
| FRQV1 | f<< Start OFF |
| FRQV1 | f<< Trip ON |
| FRQV1 | f<< Trip OFF |
| FRQV1 | f<<< Start ON |
| FRQV1 | f<<< Start OFF |
| FRQV1 | f<<< Trip ON |
| FRQV1 | f<<< Trip OFF |
| FRQV1 | f<<<< Start ON |
| FRQV1 | f<<<< Start OFF |
| FRQV1 | f<<<< Trip ON |
| FRQV1 | f<<<< Trip OFF |
| FRQV1 | f> Block ON |
| FRQV1 | f> Block OFF |
| FRQV1 | f>> Block ON |
| FRQV1 | f>> Block OFF |
| FRQV1 | f>>> Block ON |
| FRQV1 | f>>> Block OFF |
| FRQV1 | f>>>> Block ON |
| FRQV1 | f>>>> Block OFF |
| FRQV1 | f< Block ON |
| FRQV1 | f< Block OFF |
| FRQV1 | f<< Block ON |
| FRQV1 | f<< Block OFF |
| FRQV1 | f<<< Block ON |
| FRQV1 | f<<< Block OFF |
| FRQV1 | f<<<< Block ON |
| FRQV1 | f<<<< Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.



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Table. 5.4.16 - 160. Register content.

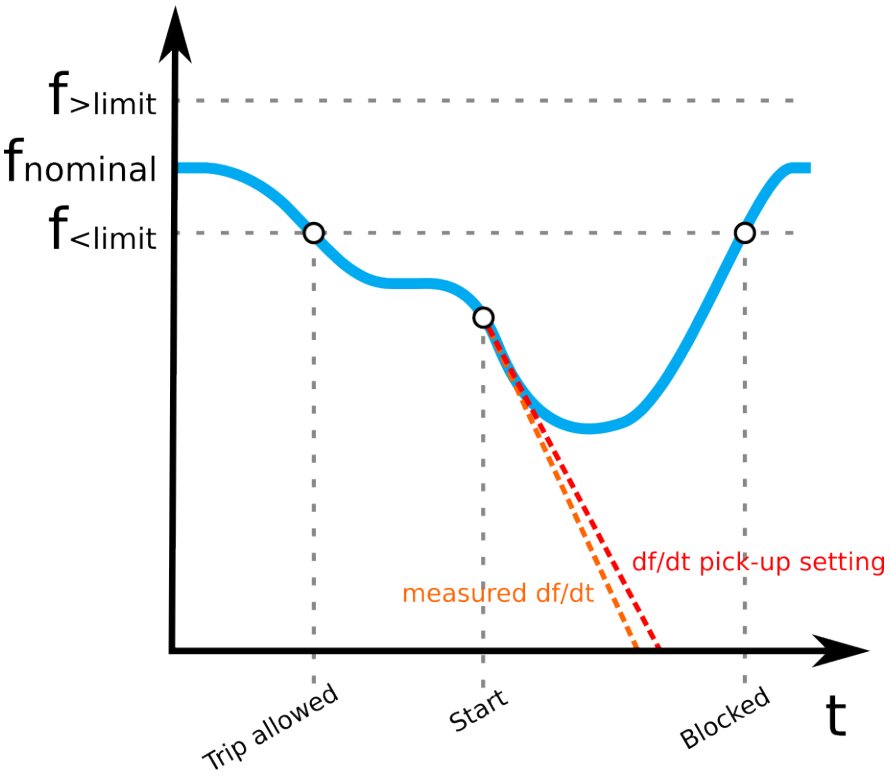
| Date and time | Event | f Pre-trig (Hz) | f Fault (Hz) | Used SG |
|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip –20ms frequency | Fault frequency | Setting group 1...8 active |

## 5.4.17 Rate-of-change of frequency (df/dt>/<; 81R)

The rate-of-change of frequency function is used to detect fast drops or increases in frequency. If the load changes fast this function detects and clears the frequency-based faults faster than conventional underfrequency and overfrequency protections. One of the most common causes for the frequency to deviate from its nominal value is an unbalance between the generated power and the load demand. If the unbalance is big the frequency changes rapidly.

The rate-of-change of frequency protection can also be applied to detect a loss of mains situation. Loss of mains is a situation where a part of the network (incorporating generation) loses its connection with the rest of the system (i.e. becomes an islanded network). A generator that is not disconnected from the network can cause safety hazards. A generator can also be automatically reconnected to the network, which can cause damage to the generator and the network.

Figure. 5.4.17 - 97. Operation of the df/dt>/< function when the frequency starts but doesn't trip.




The figure above presents an example of the df/dt>/< function's operation when the frequency is decreasing. If the $f<_{limit}$ and/or $f>_{limit}$ is activated, the function does not trip no matter how fast the measured frequency changes if it's over the $f<_{limit}$ or under $f>_{limit}$. As can be seen in the figure above, when the frequency decreases under the $f<_{limit}$,tripping is allowed although the change of frequency is not yet fast enough for the function to trip. Later the frequency makes a fast dip and as a result the change of frequency is faster than the set pick-up value which then causes the relay to operate.

Each stage can be activated and deactivated individually. After the f>/< mode has been activated (*Protection → Stage activation → Frequency stages*), the user can activate and deactivate the individual stages at will (*Protection → Frequency → Frequency protection f >/< → INFO → Stage operational setup*).

The frequency protection function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

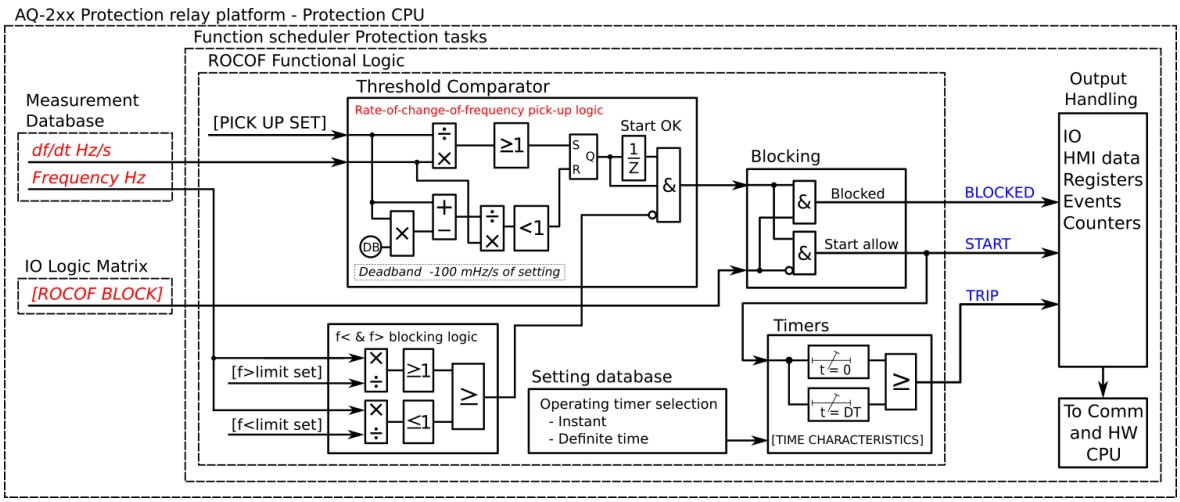
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed frequency magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the df/dt>/< function.

Figure. 5.4.17 - 98. Simplified function block diagram of the df/dt>/< function.




## Measured input

The rate-of-change of frequency protection function compares the measured df/dt>/< ratio to the pick-up setting (given in Hz/s). The source of the measured frequency depends on the user-defined tracking reference which can be changed from the *Frequency* tab of the *Measurement* menu. There are three (3) frequency references available:

- Frecuency reference 1: CT1IL1, CT2IL1, VT1U1, VT2U1
- Frecuency reference 2: CT1IL2, CT2IL2, VT1U2, VT2U2
- Frecuency reference 3: CT1IL3, CT2IL3, VT1U3, VT2U3.


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Table. 5.4.17 - 161. Measurement inputs of the df/dt>/< function.

| Signals | Description | Time base |
|---|---|---|
| VT1 U1, U2, U3 | L-N voltages of the first voltage transformer | 5 ms |
| VT2 U1, U2, U3 | L-N voltages of the second voltage transformer | 5 ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.17 - 162. General settings of the function.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| df/dt >/< LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | 0: On | Set mode of DFT block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Max allowed df/dt rate | 0.10...50.00Hz/s | 0.10Hz/s | 20Hz/s | If df/dt rate exceeds this setting, the function is blocked. |
| df/dt >/< (1...8) enable | 1: No<br>2: Yes | - | 1: No | Enables or disables the stage. |
| df/dt >/< (1...8) force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up and time delay

The df/dt>/< (1) pick-up, df/dt>/< (2) pick-up, etc. setting parameters control the pick-up of each stage of the df/dt>/< function. They define the maximum or minimum allowed change of frequency before action from the function. The function constantly calculates the ratio between the pick-up setting and the measured df/dt>/<. The reset ratio of +/- 100 mHz/s is built into the function and is always relative to the pick-up value. The f>/< limit value is used to block the funtion from operating near the nominal frequency.

Table. 5.4.17 - 163. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| df/dt>/< (1…8) used in setting group | Enables the protection stage in setting group. | 0: No<br>1: Yes | - | 0: No |
| df/dt>/< (1…8) operating mode | Defines the operation mode of the protection stage. In "Rising" mode df/dt function can trip only from increasing frequency. In "Falling" mode df/dt function can trip only from decreasing frequency. "Both" allows df/dt to trip from both. | 0: Rising<br>1: Falling<br>2: Both | - | 0: Rising |
| df/dt>/< (1…8) frequency limit | Displays if frequency limits are used or not. | 0: Not used<br>1: Use f limit | - | 0: Not used |
| df/dt>/< (1…8) pick-up | Pick-up setting. | 0.01…10.00Hz/s | 0.01Hz/s | 0.2Hz/s |
| df/dt>/< (1…8) f< limit | Underfrequency limit. Tripping is permitted when measured frequency is under this value. This parameter is visible only when operation mode is set to "Falling" or "Both". | 7.00…65.00Hz/s | 0.01Hz/s | 49.95Hz/s |

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| df/dt>/< (1…8) f> limit | Overfrequency limit. Tripping is permitted if measured frequency is above this value. This parameter is visible only when operation mode is set to "Rising" or "Both". | 10.00…70.00Hz/s | 0.01Hz/s | 51Hz/s |
| df/dt>/< (1…8) operating time | Operation time delay. | 0.000...1800.000s | 0.005s | 0.1s |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.17 - 164. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| df/dt >/< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of DFT block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Measured df/dt | 0.000...20.000Hz/s | 0.001Hz/s | Rate-of-change-of-frequency at the moment. |
| df/dt >/< (1...8) condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| df/dt >/< (1...8) df/dt meas / df/dt set | 0.000...20.000p.u. | 0.005p.u. | The ratio between the rate-of-change-of-frequency and the pick-up value. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.


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The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup frequency values.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events and registers

The rate-of-change of frequency function (abbreviated "DFT" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.17 - 165. Event messages.

| Event block name | Event names |
|---|---|
| DFT1 | df/dt>/< (1) Start ON |
| DFT1 | df/dt>/< (1) Start OFF |
| DFT1 | df/dt>/< (1) Trip ON |
| DFT1 | df/dt>/< (1) Trip OFF |
| DFT1 | df/dt>/< (2) Start ON |
| DFT1 | df/dt>/< (2) Start OFF |
| DFT1 | df/dt>/< (2) Trip ON |
| DFT1 | df/dt>/< (2) Trip OFF |
| DFT1 | df/dt>/< (3) Start ON |
| DFT1 | df/dt>/< (3) Start OFF |
| DFT1 | df/dt>/< (3) Trip ON |
| DFT1 | df/dt>/< (3) Trip OFF |
| DFT1 | df/dt>/< (4) Start ON |
| DFT1 | df/dt>/< (4) Start OFF |
| DFT1 | df/dt>/< (4) Trip ON |
| DFT1 | df/dt>/< (4) Trip OFF |
| DFT1 | df/dt>/< (5) Start ON |
| DFT1 | df/dt>/< (5) Start OFF |
| DFT1 | df/dt>/< (5) Trip ON |
| DFT1 | df/dt>/< (5) Trip OFF |
| DFT1 | df/dt>/< (6) Start ON |
| DFT1 | df/dt>/< (6) Start OFF |
| DFT1 | df/dt>/< (6) Trip ON |
| DFT1 | df/dt>/< (6) Trip OFF |
| DFT1 | df/dt>/< (7) Start ON |
| DFT1 | df/dt>/< (7) Start OFF |
| DFT1 | df/dt>/< (7) Trip ON |

| Event block name | Event names |
|---|---|
| DFT1 | df/dt>/< (7) Trip OFF |
| DFT1 | df/dt>/< (8) Start ON |
| DFT1 | df/dt>/< (8) Start OFF |
| DFT1 | df/dt>/< (8) Trip ON |
| DFT1 | df/dt>/< (8) Trip OFF |
| DFT1 | df/dt>/< (1) Block ON |
| DFT1 | df/dt>/< (1) Block OFF |
| DFT1 | df/dt>/< (2) Block ON |
| DFT1 | df/dt>/< (2) Block OFF |
| DFT1 | df/dt>/< (3) Block ON |
| DFT1 | df/dt>/< (3) Block OFF |
| DFT1 | df/dt>/< (4) Block ON |
| DFT1 | df/dt>/< (4) Block OFF |
| DFT1 | df/dt>/< (5) Block ON |
| DFT1 | df/dt>/< (5) Block OFF |
| DFT1 | df/dt>/< (6) Block ON |
| DFT1 | df/dt>/< (6) Block OFF |
| DFT1 | df/dt>/< (7) Block ON |
| DFT1 | df/dt>/< (7) Block OFF |
| DFT1 | df/dt>/< (8) Block ON |
| DFT1 | df/dt>/< (8) Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.17 - 166. Register content.

| Date and time | Event | df/dt>/< Pre-trig (Hz/s) | f Pre-trig (Hz) | df/dt>/< Fault (Hz/s) | f Fault (Hz) | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip –20ms df/dt>/< | Start/Trip –20ms frequency | Fault df/dt>/< | Fault frequency | Setting groups 1...8 active |

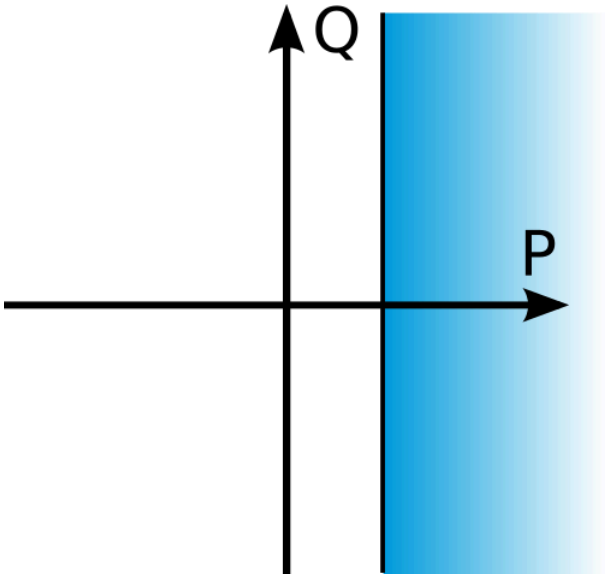
## 5.4.18 Overpower protection (P>; 32O)

The overpower function is used for instant and time-delayed active over-power protection. In applications like feeder, generator and motor protection this function is used to detect overload situations by measuring three-phase active power.



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Figure. 5.4.18 - 99. Operating characteristics of overpower protection.




The overpower function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

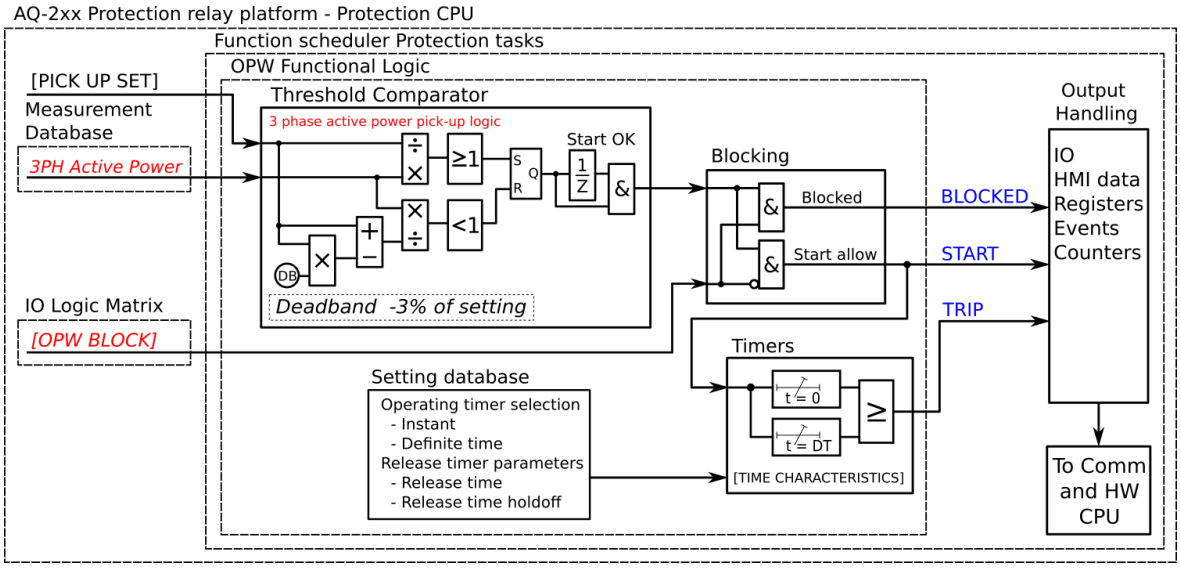
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed power magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the overpower function.

Figure. 5.4.18 - 100. Simplified function block diagram of the P> function.




## Measured input

The function block uses three-phase active power values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering. If the protection relay has more than one CT module, the *Measured side* parameter determines which current measurement is used for the power measurement.

Table. 5.4.18 - 167. Measurement inputs of the P> function.

| Signal | Description | Time base |
|---|---|---|
| 3PH Active power (P) | Total three-phase active power | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.18 - 168. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| P> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of OPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| P> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The $P_{set}$>setting parameter controls the pick-up of the P> function. This defines the maximum allowed measured three-phase active power before action from the function. The function constantly calculates the ratio between the $P_{set}$>and the measured magnitude ($P_m$). The reset ratio of 97 % is built into the function and is always relative to the $P_{set}$>value.


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Table. 5.4.18 - 169. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $P_{set}$> | Pick-up setting | 0.0…100 000kW | 0.01kW | 100kW |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.18 - 170. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| P> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of OPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| P> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| P meas/P set at the moment | 1250.00$P_m/P_{set}$ | 0.01$P_m/P_{set}$ | The ratio between the measured power and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup power value to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

### Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

### Events and registers

The overpower function (abbreviated "OPW" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers one (1) independent stage.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.18 - 171. Event messages.

| Event block name | Event names |
|---|---|
| OPW1 | Start ON |
| OPW1 | Start OFF |
| OPW1 | Trip ON |
| OPW1 | Trip OFF |
| OPW1 | Block ON |
| OPW1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.18 - 172. Register content.

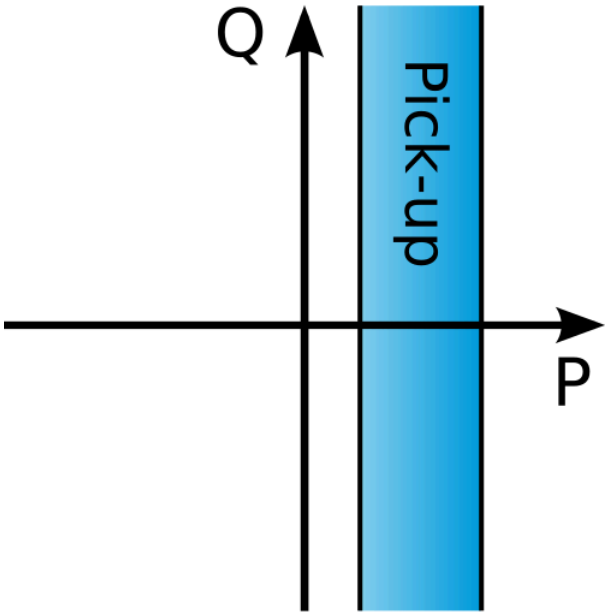
| Date and time | Event | Pre-trigger power | Fault power | Pre-fault power | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip -20ms power | Start/Trip power | Start -200ms power | 0 ms...1800s | Setting groups 1...8 active |

## 5.4.19 Underpower protection (P<; 32U)

The underpower function is used for instant and time-delayed active underpower protection. This function is used to detect loss of load conditions when there is no significant loss of current.


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Figure. 5.4.19 - 101. Operating characteristics of underpower protection.




The underpower function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal check
- time delay characteristics
- output processing.

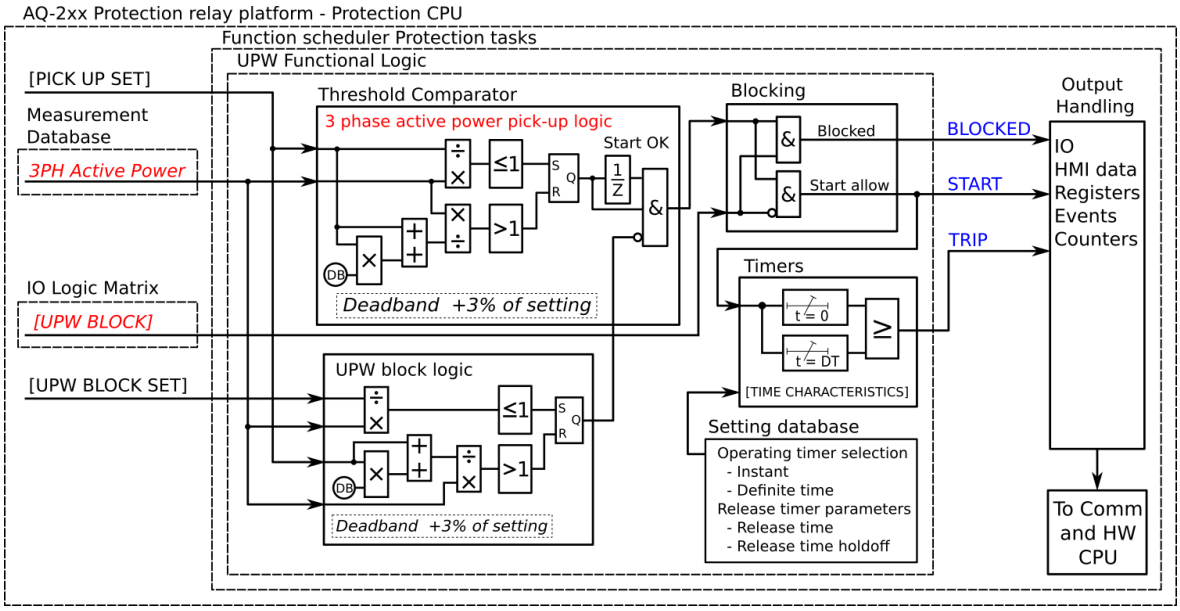
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed power magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the underpower function.

Figure. 5.4.19 - 102. Simplified function block diagram of the P< function.




## Measured input

The function block uses three-phase active power values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering. If the protection relay has more than one CT module, the parameter *Measured side* determines which current measurement is used for the power measurement.

Table. 5.4.19 - 173. Measurement inputs of the P< function.

| Signal | Description | Time base |
|---|---|---|
| 3PH Active power (P) | Total three-phase active power | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.19 - 174. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| P< LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of UPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| P< force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

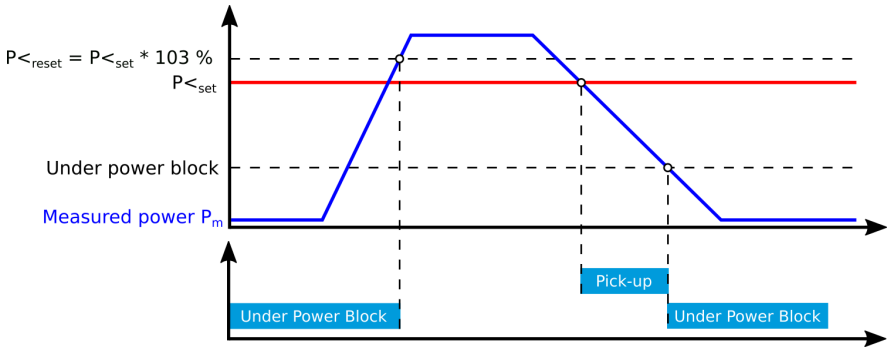


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## Pick-up

The $P_{set}<$ setting parameter controls the pick-up of the P< function. This defines the maximum allowed measured three-phase active power before action from the function. The function constantly calculates the ratio between the $P_{set}<$ and the measured magnitude ($P_m$). The reset ratio of 103 % is built into the function and is always relative to the $P_{set}<$ value.

Figure. 5.4.19 - 103. Activation and deactivation characteristics of low power blocking.




The *Low power block* setting parameter can be used to prevent an accidental trip before active power exceeds the pick-up setting. The LPB signal is deactivated when the measured active power exceeds the pick-up settings reset value (= 1.03 x $P_{set}$).

Table. 5.4.19 - 175. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $P_{set}<$ | Pick-up setting | 0.0…100 000kW | 0.01kW | 100kW |
| $P_{set}<$ | Low power block | 0.0…100 000kW | 0.01kW | 50kW |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.19 - 176. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| P< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of UPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| P< condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |

| Name | Range | Step | Description |
|---|---|---|---|
| P meas/P set at the moment | 1250.00$P_m/P_{set}$ | 0.01$P_m/P_{set}$ | The ratio between the measured power and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup power value to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The underpower function (abbreviated "UPW" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers one (1) independent stage.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.19 - 177. Event messages.

| Event block name | Event names |
|---|---|
| UPW1 | Start ON |
| UPW1 | Start OFF |
| UPW1 | Trip ON |
| UPW1 | Trip OFF |
| UPW1 | Block ON |
| UPW1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.


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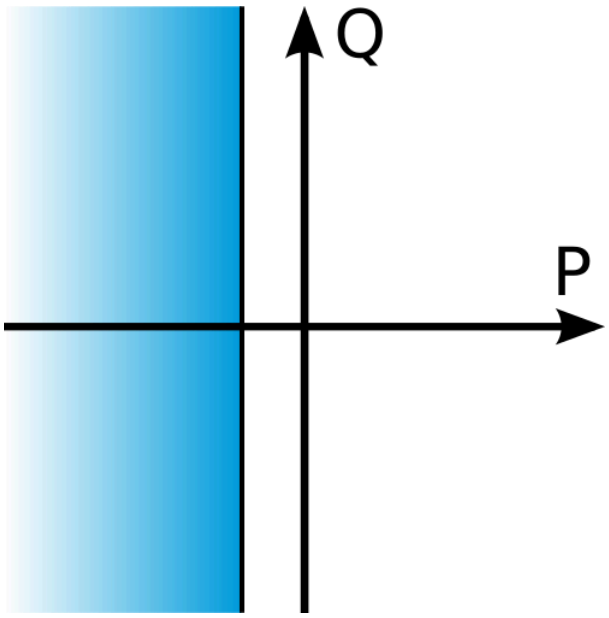
Table. 5.4.19 - 178. Register content.

| Date and time | Event | Pre-trigger power | Fault power | Pre-fault power | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip -20ms power | Start/Trip -20ms power | Start -200ms power | 0 ms...1800s | Setting groups 1...8 active |

## 5.4.20 Reverse power protection (Pr; 32R)

The reverse power function is used for instant and time-delayed active reverse power protection. In generator protection applications the reverse power protection function is used to prevent damage in situations where a synchronous generator is running like a motor when the generator draws active power. Reverse power protection is not used to protect the generator itself but to protect the generator's turbine.

Figure. 5.4.20 - 104. Operating characteristics of reverse power protection.




The reverse power function uses a total of eight (8) separate setting groups which can be selected from one common source.

The function can operate on instant or time-delayed mode.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal check
- time delay characteristics
- output processing.

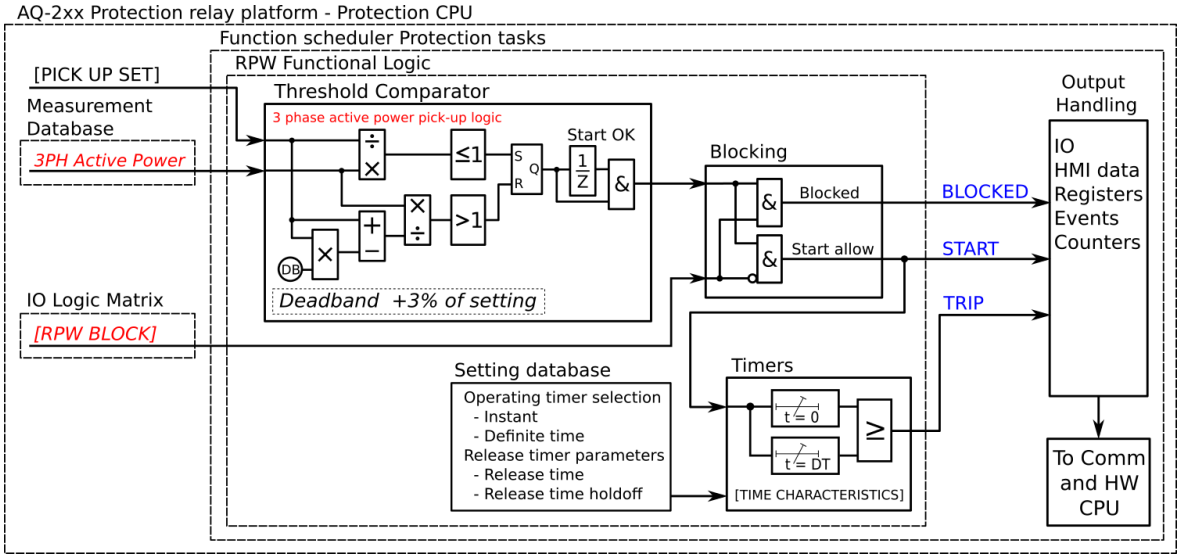
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed power magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the reverse power function.

Figure. 5.4.20 - 105. Simplified function block diagram of the Pr function.




## Measured input

The function block uses three-phase active power values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering. If the protection relay has more than one CT module, the parameter *Measured side* determines which current measurement is used for the power measurement.

Table. 5.4.20 - 179. Measurement inputs of the Pr function.

| Signal | Description | Time base |
|---|---|---|
| 3PH Active power (P) | Total three-phase active power | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.20 - 180. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Prev> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of RPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |



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| Name | Range | Default | Description |
|---|---|---|---|
| Prev> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The $P_{set}$ *rev.*setting parameter controls the pick-up of the Pr function. This defines the maximum allowed measured three-phase active power before action from the function. The function constantly calculates the ratio between the $P_{set}$ *rev.* and the measured magnitude ($P_m$). The reset ratio of 97 % is built into the function and is always relative to the $P_{set}$ *rev.* value.

Table. 5.4.20 - 181. Pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| $P_{set}$ rev. | Pick-up setting | 0.0…100 000kW | 0.01kW | 100kW |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.20 - 182. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Prev> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of RPW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Prev> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the status of the protection function. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| P meas/P set at the moment | 1250.00$P_m/P_{set}$ | 0.01$P_m/P_{set}$ | The ratio between the measured power and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup power value to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

### Operating time characteristics for trip and reset

This function supports definite time delay (DT). For detailed information on this delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

### Events and registers

The reverse power function (abbreviated "RPW" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers one (1) independent stage.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.20 - 183. Event messages.

| Event block name | Event names |
|---|---|
| RPW1 | Start ON |
| RPW1 | Start OFF |
| RPW1 | Trip ON |
| RPW1 | Trip OFF |
| RPW1 | Block ON |
| RPW1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.20 - 184. Register content.

| Date and time | Event | Pre-trigger power | Fault power | Pre-fault power | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Trip -20ms power | Start/Trip power | Start -200ms power | 0 ms...1800s | Setting group 1...8 active |

## 5.4.21 Voltage-restrained overcurrent protection (Iv>; 51V)

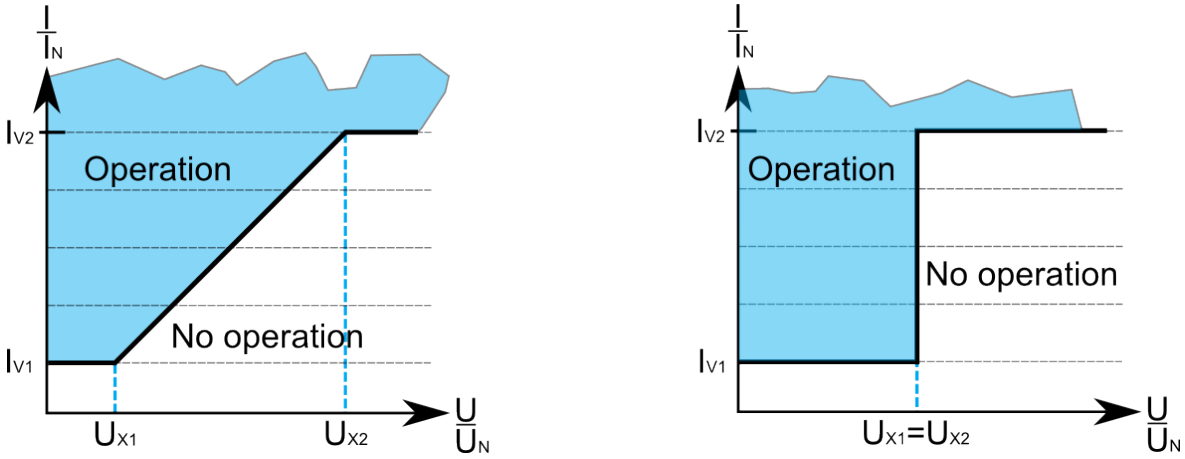
Short-circuits that occur close to the generator decrease the fault current which in turn inhibits the operation of a high-set overcurrent stage. The decreasing voltage caused by these faults can be used to decrease the current pick-up level and thus to improve sensitivity. This voltage-restrained overcurrent protection function can be used as an alternative for the underimpedance function for more sensitive short-circuit detection in generator protection applications.


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When there is a short-circuit near the generator, the voltage decreases which in this function's case decreases the overcurrent's pick-up level according to set parameters. The function can work as voltage-controlled overcurrent protection or as voltage-restrained overcurrent protection. When the set parameter value Ux2 is greater than Ux1, the protection function works as voltage-restrained overcurrent protection. In this case the overcurrent pick-up value increases as the voltage increases between the set values Ux1 and Ux2. The protection function uses positive sequence voltage to define the pick-up level at that moment.

When the set value of Ux1 is equal to Ux2, the function works as voltage-controlled overcurrent protection. Now the overcurrent protection doesn't operate until a fault reduces the voltage below a set value, usually about 80 % of the normal. A fixed pick-up level of voltage-controlled overcurrent protection is easier to coordinate with other relays. However, the voltage-restrained overcurrent protection function is less prone to making unwanted operations on motor starting currents and system swings.

Figure. 5.4.21 - 106. Pick-up levels in the two modes.




Just like the other overcurrent protection functions, this function can be set to definite time (DT) or inverse definite minimum time (IDMT) delay. However, if IDMT is selected for this function, the time delay depends on the ratio between the measured current and the current pick-up level at that moment. This means that the operation time can also shorten as a result of the reduced voltage.

The operational logic consists of the following:

- input magnitude processing
- saturation check
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The basic design of the protection function is the three-pole operation.

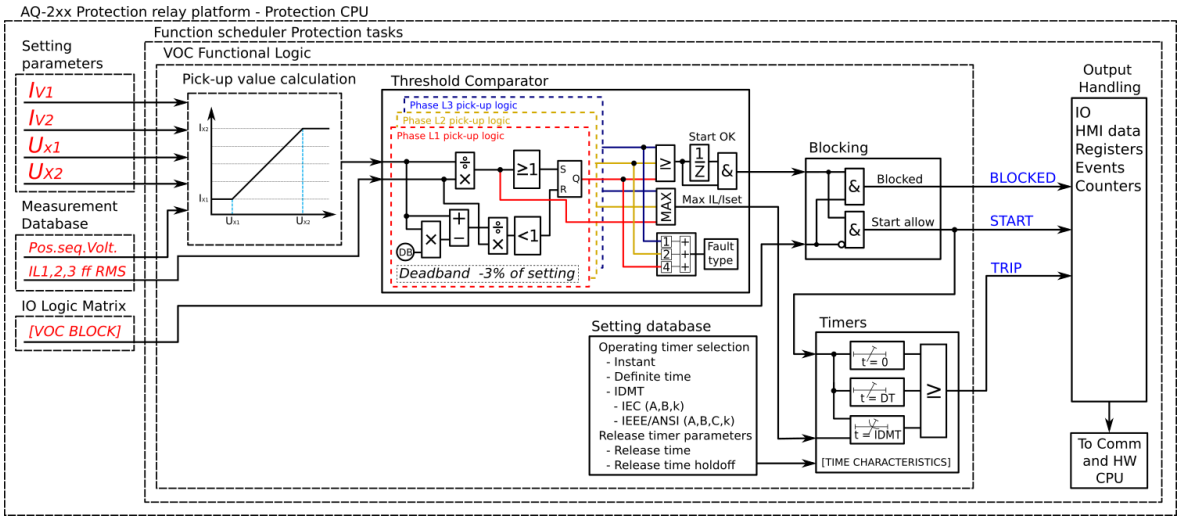
The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the non-directional overcurrent function.

Figure. 5.4.21 - 107. Simplified function block diagram of the Iv> function.




## Measured input

The function block uses the calculated positive sequence voltage to determine the pick-up level. Analog current measurement values are used to detect faults. A -20ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.4.21 - 185. Measurement inputs of the voltage-restrained overcurrent protection function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| U1 | Positive sequence voltage | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.21 - 186. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Iv> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of VOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |


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| Name | Range | Default | Description |
|---|---|---|---|
| Iv> force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The *Iv1*, *Iv2*, *Ux1*, *Ux2* setting parameters and *the positive sequence voltage measurement* control the pick-up level of the voltage-restrained overcurrent protection function. The pick-up level defines the maximum allowed measured current before action from the function. The function constantly calculates the ratio between the current pick-up level and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the current pick-up value.

Table. 5.4.21 - 187. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 1st knee point (Iv>) | 0.10…40.00x$I_n$ | 0.01x$I_n$ | 0.2 x$I_n$ | The lower current limit. |
| 2nd knee point (Iv2>) | 0.10…40.00x$I_n$ | 0.01x$I_n$ | 1.2x$I_n$ | The higher current limit. |
| 1st knee point voltage (Ux1) | 0.00…150.00%$U_n$ | 0.01%$U_n$ | 20%$U_n$ | The lower voltage limit. |
| 2nd knee point voltage (Ux2) | 0.00…150.00%$U_n$ | 0.01%$U_n$ | 100%$U_n$ | The higher voltage limit.<br><br>When this value is higher than Ux1, the function operates as voltage-restrained overcurrent protection. If the two values are equal, the function operates as voltage-controlled overcurrent protection. |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.21 - 188. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Iv> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of VOC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Iv> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays status of the protection function. |

| Name | Range | Step | Description |
|---|---|---|---|
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured highest phase current value. If the measured current changes during a fault, the expected operating time changes accordingly. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| Voltage measurement | 0: Invalid U1 not avail.<br>1: Ok | - | If phase voltages are not available the function is not able to calculate positive sequence voltage (U1). This can happen when voltage measurement mode has been set to "3LL+U4" or "2LL+U3+U4" mode but none of the channels have been set to "U0" mode. |
| I> pick-up level now | 0.00...1250.00xIn | 0.01xIn | Overcurrent pick-up level used by the function at the moment. The pick-up level changes with positive sequence voltage setting changes. |
| Measured voltage now | 0.00...1250.00%Un | 0.01%Un | Calculated positive sequence voltage at the moment. This influences the overcurrent pick-up level used by the function. |
| $I_{meas}/I_{set}$ at the moment | 0.00...1250.00 | 0.01 | The ratio between the highest measured phase current and the pick-up value. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for trip and reset

This function supports definite time delay (DT) and inverse definite minimum time delay (IDMT). For detailed information on these delay types please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The voltage-restrained overcurrent protection function (abbreviated "VOC" in event block names) generates events and registers from the status changes in START, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.


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Table. 5.4.21 - 189. Event messages.

| Event block name | Event names |
|---|---|
| VOC1 | Start ON |
| VOC1 | Start OFF |
| VOC1 | Trip ON |
| VOC1 | Trip OFF |
| VOC1 | Block ON |
| VOC1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.21 - 190. Register content.

| Date and time | Event | Fault type | Pre-trigger current | Fault current | U1 Voltage | Current pick-up | Pre-fault current | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-E…L1-L2-L3 | Start/Trip -20ms current | Start/ Trip current | Positive sequence voltage | Pick-up current level | Start -200ms current | 0 ms...1800s | Setting group 1...8 active |

## 5.4.22 Line thermal overload protection (TF>; 49F)

The line thermal overload function is used for the thermal capacity monitoring and protection of cables and overhead lines. This function can also be used for any single time constant application like inductor chokes, certain types of transformers and any other static units which do not have active cooling apart from the cables and overhead lines.

The function constantly monitors the instant values of phase TRMS currents (including harmonics up to 31$^{st}$) and calculates the set thermal replica status in 5 ms cycles. The function includes a total memory function of the load current conditions according to IEC 60255-8.

The function is based on a thermal replica which represents the protected object's or cable's thermal loading in relation to the current going through the object. The thermal replica includes the calculated thermal capacity that the "memory" uses; it is an integral function which tells this function apart from a normal overcurrent function and its operating principle for overload protection applications.

The thermal image for the function is calculated according to the equation described below:

$$\theta_{t\%} = \left( \left( \theta_{t-1} - \left( \frac{I_{max}}{I_n \times k_{SF} \times k_{amb}} \right)^2 \times e^{-\frac{t}{\tau}} \right) + \left( \frac{I_{max}}{I_n \times k_{SF} \times k_{amb}} \right)^2 \right) \times 100\%$$

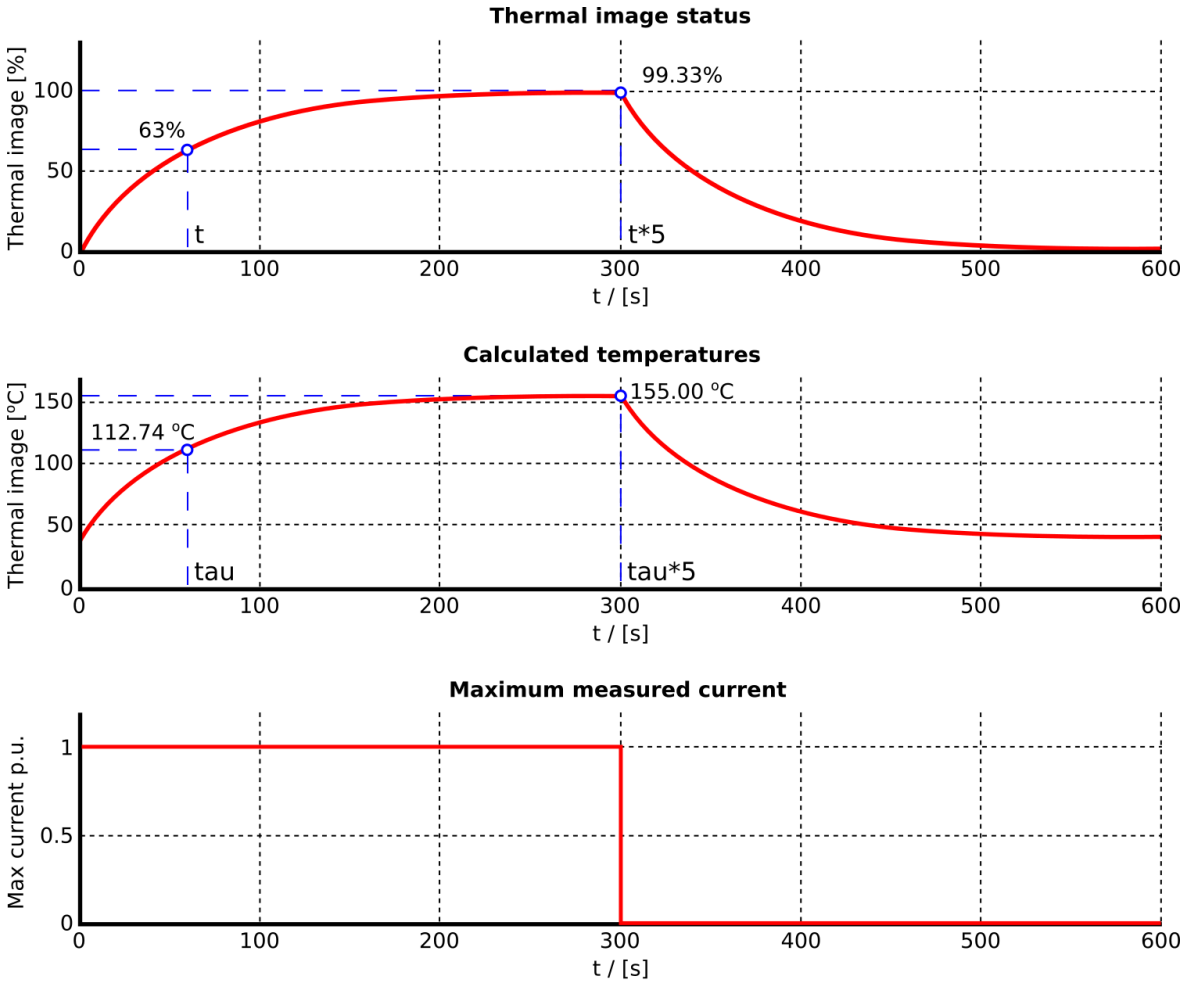
Where:

- $\theta_{t\%}$ = Thermal image status in percentages of the maximum thermal capacity available
- $\theta_{t-1}$ = Thermal image status in a previous calculation cycle (the memory of the function)
- $I_{max}$ = Measured maximum of the three TRMS phase currents
- $I_n$ = Current for the 100 % thermal capacity to be used (the pick-up current in p.u., $t_{max}$ achieved in τ x 5)

- $k_{SF}$ = Loading factor (service factor), the maximum allowed load current in p.u., dependent on the protected object or the cable/line installation
- $k_{amb}$ = Temperature correction factor, either from a linear approximation or from a settable ten-point thermal capacity curve
- e = Euler's number
- t = Calculation time step in seconds (0.005 s)
- τ = Thermal time constant of the protected object (in minutes)

The basic operating principle of the thermal replica is based on the nominal temperature rise, which is achieved when the protected object is loaded with a nominal load in a nominal ambient temperature. When the object is loaded with a nominal load for a time equal to its heating constant tau (τ), 63% of the nominal thermal capacity is used. When the loading continues until five times this given constant, the used thermal capacity approaches 100 % indefinitely but never exceeds it. With a single time constant model the cooling of the object follows this same behavior, the reverse of the heating when the current feeding is zero.

Figure. 5.4.22 - 108. Example of thermal image calculation with nominal conditions.




**Settings**

| | |
|---|---|
| Qt-1 = 0.01 % | Max. temperature rise = 115 ºC |
| tau = 1.00 minutes | Ambient temperature = 40 ºC |
| Serv.Fact = 1.00 | Max End. Temp = 155.00 ºC |
| | Temp k fact = 1.00 |



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The described behavior is based on the assumption that the monitored object (whether a cable, a line or an electrical device) has a homogenous body which generates and dissipates heat with a rate proportional to the temperature rise caused by the current squared. This is usually the case with cables and other objects while the heat dissipation of overhead lines is dependent on the weather conditions. Weather conditions considering the prevailing conditions in the thermal replica are compensated with the ambient temperature coefficient which is constantly calculated and changing when using RTD sensor for the measurement. When the ambient temperature of the protected object is stable it can be set manually (e.g. underground cables).

The ambient temperature compensation takes into account the set minimum and maximum temperatures and the load capacity of the protected object as well as the measured or set ambient temperature. The calculated coefficient is a linear correction factor, as the following formula shows:

$$t_{amb} < t_{min} = k_{min}$$

$$t_{amb} < t_{ref} = \left(\frac{1 - k_{min}}{t_{ref} - t_{min}} \times (t_{amb} - t_{min})\right) + k_{min}$$

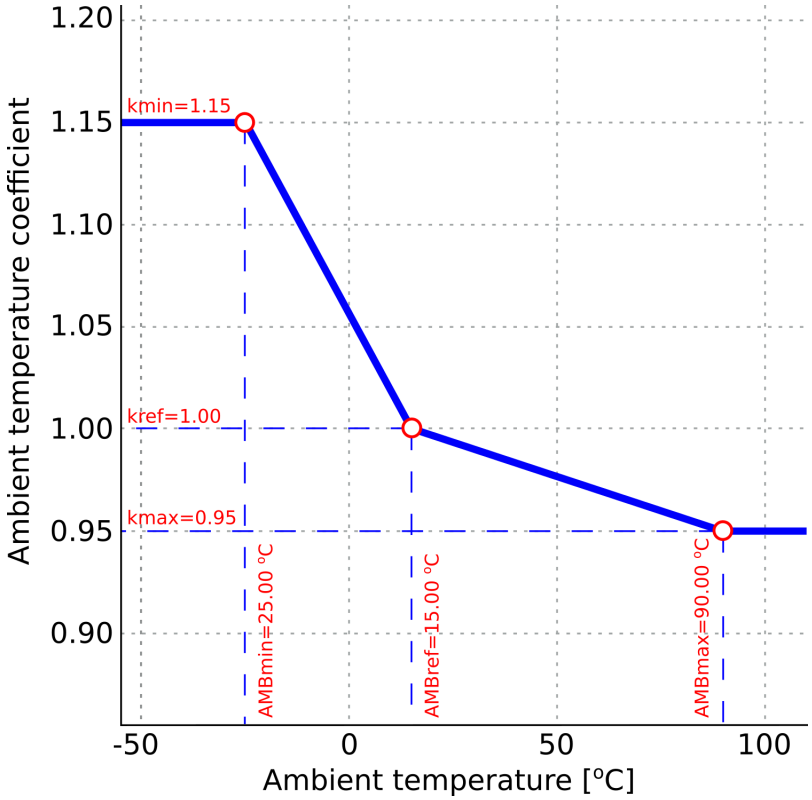
$$t_{amb} > t_{ref} = \left(\frac{k_{max} - 1}{t_{max} - t_{ref}} \times (t_{amb} - t_{ref})\right) + 1.0$$

$$t_{amb} > t_{max} = k_{max}$$

Where:

- $t_{amb}$ = Measured (or set) ambient temperature (can be set in ℃ or in ℉)
- $t_{max}$ = Maximum temperature (can be set in ℃ or in ℉) for the protected object
- $k_{max}$ = Ambient temperature correction factor for the maximum temperature
- $t_{min}$ = Minimum temperature (can be set in ℃ or in ℉) for the protected object
- $k_{min}$ = Ambient temperature correction factor for the minimum temperature
- $t_{ref}$ = Ambient temperature reference (can be set in ℃ or in ℉, the temperature in which the manufacturer's temperature presumptions apply, the temperature correction factor is 1.0)

Figure. 5.4.22 - 109. Ambient temperature coefficient calculation (a three-point linear approximation and a settable correction curve).




As can be seen in the diagram above, the ambient temperature coefficient is relative to the nominal temperature reference. By default the temperature reference is +15 °C (underground cables) which gives the correction factor value of 1.00 for the thermal replica.

A settable thermal capacity curve uses the linear interpolation for ambient temperature correction with a maximum of ten (10) pairs of temperature–correction factor pairs.

Figure. 5.4.22 - 110. Example of the relationship between ground temperature and correction factor.

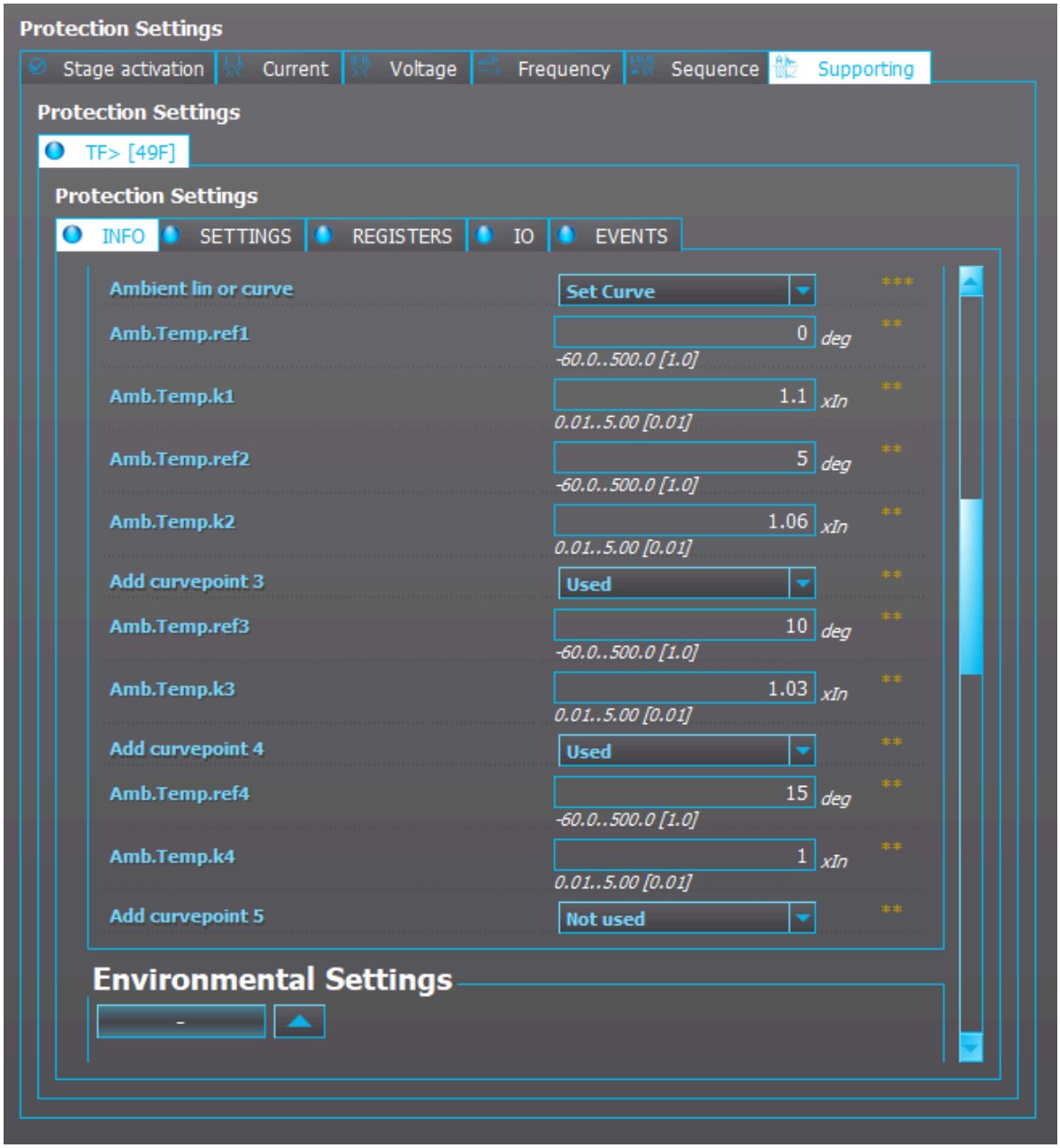
| Conductor temperature | Ground temperature, C° | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C° | -5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| 90 | 1.13 | 1.10 | 1.06 | 1.03 | 1.00 | 0.96 | 0.93 | 0.89 | 0.86 | 0.82 | 0.77 |

The temperature coefficient may be informed in a similar manner to the figure above in a datasheet provided by the manufacturer.



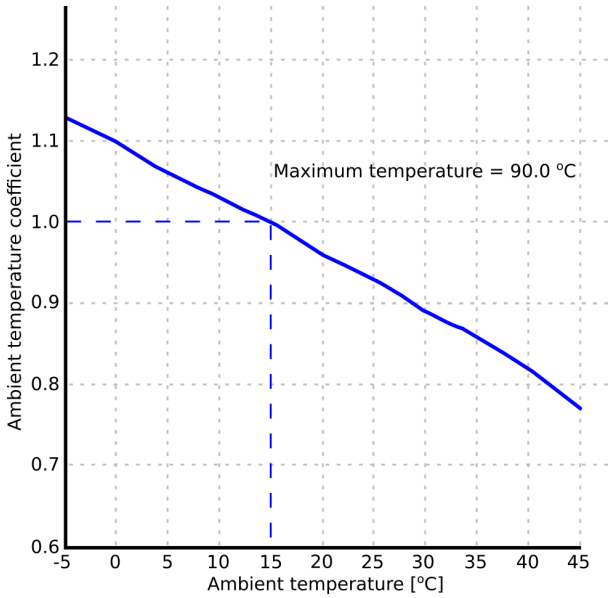
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Figure. 5.4.22 - 111. Settings of the function's ambient temperature coefficient curve.




The temperature and correction factor pairs are set to the function's settable curve.

Figure. 5.4.22 - 112. Set correction curve for ambient temperature.




The correction curve for ambient temperature is shown in the figure above. The reference temperature for underground cables is usually +15 ℃ which gives a correction factor of 1.00 (in this case also the nominal temerature). The curve does not need to use as all the available points. The minimum setting is two pairs, resulting in a straight line.

For cables the ambient temperature correction is just one correction factor. The $k_{SF}$ correction factor is used for non-changing corrections; its calculation is explained later in this manual. Calculating correction factors for a cable or overhead installation requires the consulting of the datasheet for the technical specifications of the used cable. This information is usually provided by the cable manufacturer. For example, cable data may be presented as in the figures below (an example from a Prysmian Group cable datasheet) which show the cable's temperature characteristics and voltage ratings (1st image) with different installations and copper or aluminum conductors (2nd and 3rd image).



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Figure. 5.4.22 - 113. Example of a high-voltage cable datasheet.

## Sample Constructions

Rated voltages
$U_o/U$ = 38/66 kV
$U_m$ = 72.5 kV
$U_p$ = 325 kV
Rated temperatures
- Maximum permissible temp. of conductor in continuous use 90°C
- Maximum permissible temp. of conductor in short-circuit 250°C (for durations up to 5 sec.)

Standard IEC 60840

## 72 kV Cables 36/66 kV Single core, XLPE-insulated high voltage power cables

| Nominal cross-sectional area of conductor | mm² | 300 | 500 | 800 | 1200 | 1600 |
|---|---|---|---|---|---|---|

### Continuous current-carrying capacities

| Conductor | Cables laid | Conductor temperature | Laying formation | Screen circuit | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Aluminium | In ground of 15°C | 65°C | Flat | Open | A | 435 | 575 | 750 | 910 | 1040 |
| | | | | Closed | A | 415 | 525 | 640 | 710 | 750 |
| | | | Trefoil | Open | A | 415 | 545 | 700 | 830 | 930 |
| | | | | Closed | A | 410 | 535 | 680 | 790 | 870 |
| | | 90°C | Flat | Open | A | 515 | 680 | 890 | 1080 | 1235 |
| | | | | Closed | A | 490 | 625 | 770 | 860 | 920 |
| | | | Trefoil | Open | A | 490 | 645 | 830 | 990 | 1110 |
| | | | | Closed | A | 485 | 635 | 805 | 945 | 1045 |
| | In air of 25°C | 90°C | Flat | Open | A | 685 | 930 | 1265 | 1555 | 1815 |
| | | | | Closed | A | 660 | 865 | 1105 | 1270 | 1390 |
| | | | Trefoil | Open | A | 605 | 820 | 1095 | 1335 | 1535 |
| | | | | Closed | A | 600 | 810 | 1085 | 1320 | 1515 |
| Copper | In ground of 15°C | 65°C | Flat | Open | A | 560 | 730 | 940 | 1200 | 1390 |
| | | | | Closed | A | 520 | 635 | 740 | 820 | 855 |
| | | | Trefoil | Open | A | 535 | 685 | 860 | 1095 | 1240 |
| | | | | Closed | A | 525 | 670 | 820 | 1005 | 1105 |
| | | 90°C | Flat | Open | A | 660 | 865 | 1115 | 1415 | 1645 |
| | | | | Closed | A | 620 | 765 | 900 | 1005 | 1055 |
| | | | Trefoil | Open | A | 630 | 815 | 1025 | 1305 | 1485 |
| | | | | Closed | A | 620 | 795 | 980 | 1205 | 1335 |
| | In air of 25°C | 90°C | Flat | Open | A | 880 | 1185 | 1585 | 2040 | 2420 |
| | | | | Closed | A | 830 | 1065 | 1305 | 1505 | 1620 |
| | | | Trefoil | Open | A | 775 | 1035 | 1355 | 1765 | 2065 |
| | | | | Closed | A | 770 | 1025 | 1340 | 1685 | 1940 |

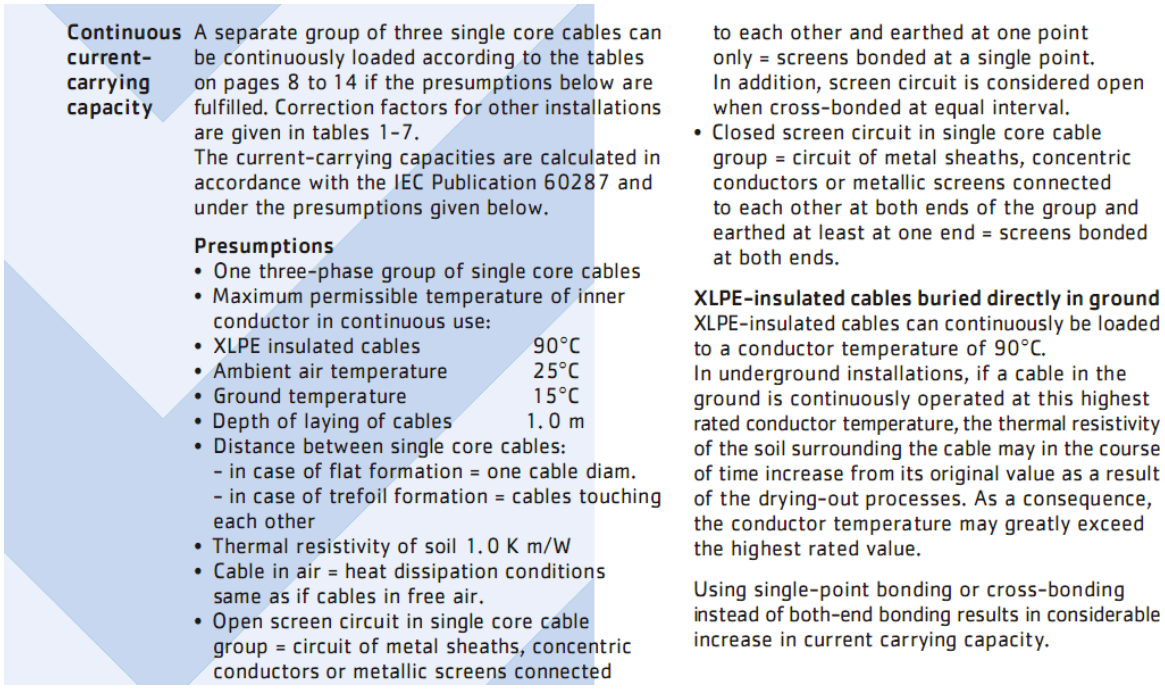
### Maximum permissible short-circuit currents for short-circuit duration of one second

| | | | | | | |
|---|---|---|---|---|---|---|
| Aluminium conductor | kA | 28.3 | 47.2 | 75.6 | 113.4 | 151.2 |
| Copper conductor | kA | 42.8 | 71.4 | 114.2 | 171.4 | 228.5 |

The datasheet shows the currents which in a combination with a specific installation and a specific construction method achieve a specific conductor temperature in give standard conditions (e.g. a copper conductor reaches a temperature of 90 °C when, for example, it has a continuous current-carrying capacity of 815 A, an open screen circuit, and is laid in a trefoil formation in soil whose temperature is 15 °C).

The most important parameters for setting a working thermal image are the cable's current and the installation place. In addition to the above-mentioned current-carrying capacity table, the manufacturer should also provide data to allow for fine-tuning the thermal image. Equally important to the ampere–temperature values are the presumptive conditions under which the given continuous current-carrying capacity values can be expected to apply. The following figure is an example of these general presumption as presented in a Prysmian Group cable datasheet.

Figure. 5.4.22 - 114. General presumptions of high-voltage cables.



**Continuous current-carrying capacity**

A separate group of three single core cables can be continuously loaded according to the tables on pages 8 to 14 if the presumptions below are fulfilled. Correction factors for other installations are given in tables 1-7.
The current-carrying capacities are calculated in accordance with the IEC Publication 60287 and under the presumptions given below.

**Presumptions**

- One three-phase group of single core cables
- Maximum permissible temperature of inner conductor in continuous use:
- XLPE insulated cables 90°C
- Ambient air temperature 25°C
- Ground temperature 15°C
- Depth of laying of cables 1.0 m
- Distance between single core cables:
  - in case of flat formation = one cable diam.
  - in case of trefoil formation = cables touching each other
- Thermal resistivity of soil 1.0 K m/W
- Cable in air = heat dissipation conditions same as if cables in free air.
- Open screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other and earthed at one point only = screens bonded at a single point. In addition, screen circuit is considered open when cross-bonded at equal interval.
- Closed screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other at both ends of the group and earthed at least at one end = screens bonded at both ends.

**XLPE-insulated cables buried directly in ground**

XLPE-insulated cables can continuously be loaded to a conductor temperature of 90°C.
In underground installations, if a cable in the ground is continuously operated at this highest rated conductor temperature, the thermal resistivity of the soil surrounding the cable may in the course of time increase from its original value as a result of the drying-out processes. As a consequence, the conductor temperature may greatly exceed the highest rated value.

Using single-point bonding or cross-bonding instead of both-end bonding results in considerable increase in current carrying capacity.

If the installation conditions vary from the presumed conditions manufacturers may give additional information on how to correct the the current-carrying capacity to match the changed conditions. Below is an example of the correction factors provided a manufacturer (Prysmian) for correcting the current-carrying capacity.



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Figure. 5.4.22 - 115. Example of correction factors for the current-carrying capacity as given by a manufacturer.

## Correction factors for the current-carrying capacity

The following tables of correction factors are to be applied to the current-carrying capacity when installation conditions vary from the presumptions above.

The rating for most conditions can be quickly estimated by multiplying the continuous current-carrying capacity value by the correction factors given in the appropriate tables 1-7.

**Table 1. Correction factors for groups of cables buried directly in ground**

| Spacing between groups of cables, mm | Numbers of groups of single core cables beside each other | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 6 | 8 | 10 |
| 0 (touching) | 0.79 | 0.69 | 0.63 | 0.58 | 0.55 | 0.50 | 0.46 |
| 70 | 0.85 | 0.75 | 0.68 | 0.64 | 0.60 | 0.56 | 0.53 |
| 250 | 0.87 | 0.79 | 0.75 | 0.72 | 0.69 | 0.66 | 0.64 |

The values apply to groups of three single core cables (in trefoil or flat formation) without or with spacing between the cable groups horizontally placed.

**Table 2. Correction factors for different thermal resistivities of soil**

| Thermal resistivity of soil Km/W | 0.7 | 1.0 | 1.2 | 1.5 | 2.0 | 2.5 | 3.0 |
|---|---|---|---|---|---|---|---|
| Correction factor | 1.10 | 1.00 | 0.92 | 0.85 | 0.75 | 0.69 | 0.63 |

**Examples of thermal resistivities of soil:**

- dry sand (moisture content 0%) 3.0 K m/W
- dry gravel and clay 1.5 K m/W
- semi-dry gravel and sand (moisture content 10%) 1.2 K m/W
- semi-dry and moist gravel 1.0 K m/W
- moist clay and sand (moisture content 25%) 0.7 K m/W

**Table 3. Correction factors for different installation depths in ground**

| Depth of laying, m | 0.50-0.70 | 0.71-0.90 | 0.91-1.10 | 1.11-1.30 | 1.31-1.50 |
|---|---|---|---|---|---|
| Rating factor | 1.05 | 1.02 | 1.00 | 0.97 | 0.95 |

**Table 4. Correction factors for different ground temperatures**

| Conductor temperature C° | Ground temperature, C° | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | -5 | 0 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 |
| 90 | 1.13 | 1.10 | 1.06 | 1.03 | 1.00 | 0.96 | 0.93 | 0.89 | 0.86 | 0.82 | 0.77 |
| 80 | 1.14 | 1.11 | 1.07 | 1.04 | 1.00 | 0.96 | 0.92 | 0.88 | 0.83 | 0.78 | 0.73 |
| 70 | 1.17 | 1.13 | 1.09 | 1.04 | 1.00 | 0.95 | 0.90 | 0.85 | 0.80 | 0.73 | 0.67 |
| 65 | 1.18 | 1.14 | 1.10 | 1.05 | 1.00 | 0.95 | 0.89 | 0.84 | 0.77 | 0.71 | 0.63 |

**Table 5. Correction factors for different cables in unfilled plastic pipes**

| Spacing between the tubes, mm | Numbers of tubes beside each other | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 8 | 10 |
| 0 (touching) | 0.80 | 0.75 | 0.65 | 0.60 | 0.60 | 0.55 | 0.55 | 0.50 |
| 70 | | 0.75 | 0.70 | 0.65 | 0.60 | 0.60 | 0.55 | 0.55 |
| 250 | | 0.75 | 0.70 | 0.70 | 0.70 | 0.65 | 0.65 | 0.65 |

For parallel ducts with a group of three single core cables in each and with the cables equally loaded the current-carrying capacity indicated on pages 8 to 14 for cables buried directly in ground shall be reduced by correction factors given above.

The reduction in current carrying capacity can be avoided if the pipes after cable pulling are filled with material thermally equal to the ambient ground.

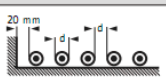
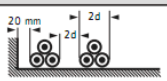
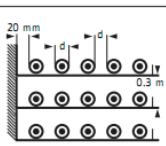
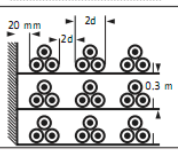
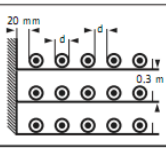
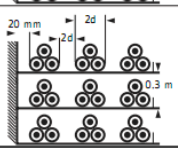
If factors in table 5 are used, factors in table 1 are not applicable.

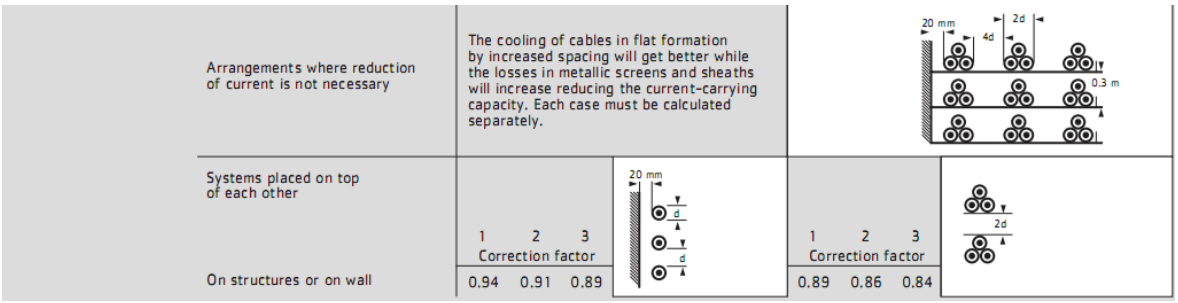
**Table 6. Correction factors for different ambient air temperatures**

| Conductor temperature C° | Ambient air temperature, C° | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 |
| 90 | 1.12 | 1.08 | 1.04 | 1.00 | 0.95 | 0.90 | 0.85 | 0.80 | 0.74 | 0.68 |
| 80 | 1.14 | 1.09 | 1.05 | 1.00 | 0.95 | 0.89 | 0.84 | 0.77 | 0.69 | 0.61 |
| 70 | 1.18 | 1.12 | 1.06 | 1.00 | 0.93 | 0.86 | 0.79 | 0.71 | 0.62 | 0.52 |
| 65 | 1.20 | 1.14 | 1.07 | 1.00 | 0.93 | 0.85 | 0.77 | 0.68 | 0.57 | 0.45 |

**Table 7. Correction factors for different groups of three single core cables laid in the air**

This applies only when the cable temperature does not affect the ambient air temperature.

| Type of laying | | Cables laid in flat formation Spacing = One cable diameter (d). Distance from the wall not less than 20 mm. | | | | Cables laid in trefoil formation Spacing = Two cable diameters (2d). Distance from the wall not less than 20 mm. | | | |
|---|---|---|---|---|---|---|---|---|---|
| Number of groups | | 1 | 2 | 3 | | 1 | 2 | 3 | |
| | | Correction factor | | | | Correction factor | | | |
| On floor | | 0.92 | 0.89 | 0.88 |  | 0.95 | 0.90 | 0.88 |  |
| | Number of trays | | | | | | | | |
| On metal trays (restricted air circulation) | 1 | 0.92 | 0.89 | 0.88 |  | 0.95 | 0.90 | 0.88 |  |
| | 2 | 0.87 | 0.84 | 0.83 | | 0.90 | 0.85 | 0.83 | |
| | 3 | 0.84 | 0.82 | 0.81 | | 0.88 | 0.83 | 0.81 | |
| | 6 | 0.82 | 0.80 | 0.79 | | 0.86 | 0.81 | 0.79 | |
| | Number of ladders | | | | | | | | |
| On metal ladders | 1 | 1.00 | 0.97 | 0.96 |  | 1.00 | 0.98 | 0.96 |  |
| | 2 | 0.97 | 0.94 | 0.93 | | 1.00 | 0.95 | 0.93 | |
| | 3 | 0.96 | 0.93 | 0.92 | | 1.00 | 0.94 | 0.92 | |
| | 6 | 0.94 | 0.91 | 0.90 | | 1.00 | 0.93 | 0.90 | |




To demonstrate the importance of the $k_{SF}$ (service factor, current-carrying capacity), let us calculate a cable installation with the correct k factor but without setting it to correct value.

First we read the initial data for the setup of the thermal image:

*A 66 kV copper cable with a cross-section of 500 mm$^2$ is installed into ground. Its 1 s permissible short-circuit current is 71.4 kA and its insulation is XLPE. The cable's screen circuit is open and the laying formation is flat. Its current-carrying capacity is 575 A in 65 ℃ and 680 A in 90 ℃. The reference temperature for ground installation is 15 ℃.*

Let us calculate an estimation of the time constant τ based on the known one-second short-circuit current related to $I_n$. If the manufacturer has not provided the time constant, it can be estimated from the maximum permissable short-circuit current (usually a one second value). The function uses this same method to estimate the heating time constant.

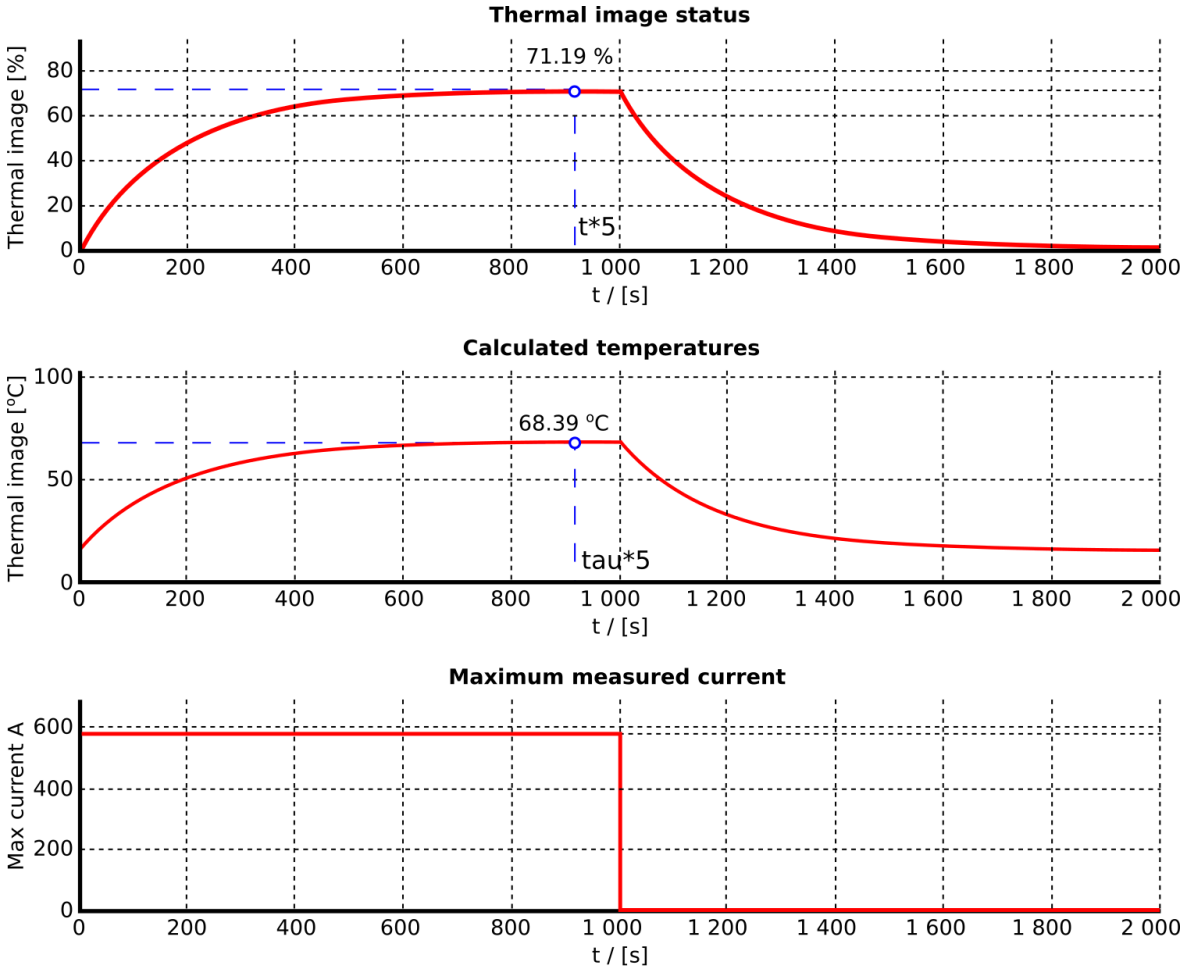
$$\tau_{cable} = \frac{1\ \text{s}}{60\ \text{s}} \times \left(\frac{I_{1\,s}}{I_n}\right)^2 = \frac{1\ \text{s}}{60\ \text{s}} \times \left(\frac{71\,400\ \text{A}}{680\ \text{A}}\right)^2 = 183.75\ \text{min}$$

The rest of the settings are in the initial data text above:

- $I_n$ = 680 A
- $T_{max}$ = 90 ℃
- $T_{amb}$ = 15 ℃
- $T_{ref}$ = 15 ℃
- $k_{SF}$ = 1.0.


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Figure. 5.4.22 - 116. Thermal image response with nominal load (installation according to presumptions).

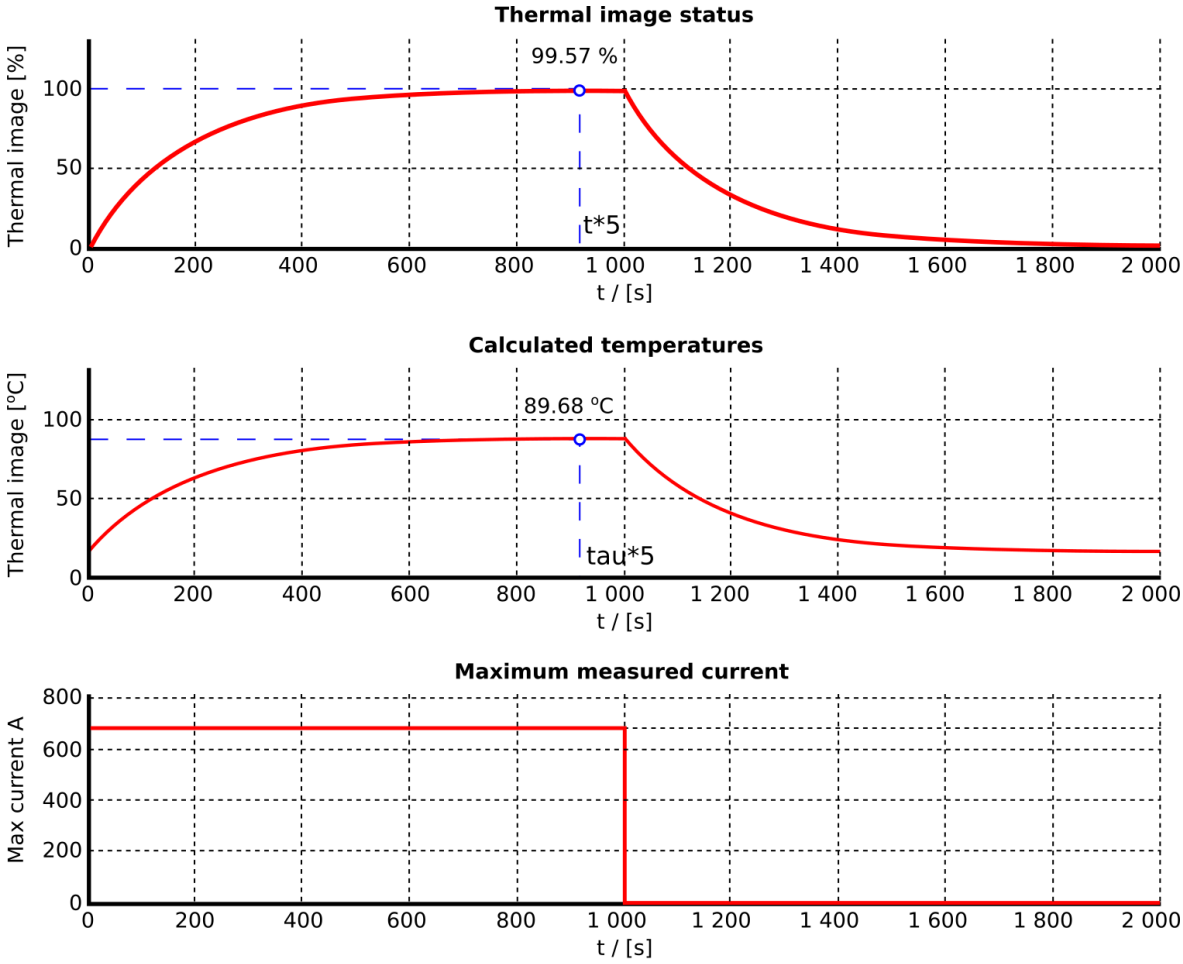



**Settings**

| | | |
|---|---|---|
| $I_N$ = 680 A | Max. temperature rise = 75 °C | Reference temperature = 15 °C |
| Starting temp = 0 % | Ambient temperature = 15 °C | $I_{MAX}$ = 575 A |
| tau = 183.75 min | Max End. Temp = 90 °C | |
| Service factor = 1.00 | Temperature k factor = 1.00 | |

As the results show, the end temperature of 68.39 ℃ is reached when the cable is loaded with a stable current for time equalling five times the time constant τ. This uses approximately 71 % of the thermal capacity. According to the datasheet, this current should set the temperature around 65 ℃; therefore, the model overprotects by three degrees.

Figure. 5.4.22 - 117. Thermal image response with maximum load (installation according presumptions).




The maximum allowed load results in the end temperature of 89.68 ℃ which means that 99.57 % of the thermal capacity is used. This result matches the expectations of the thermal image perfectly. The user can now securely set the cable's overheating alarm.

When comparing the result to the fully-tuned model in the application, let us include all of the installation correction factors to the image.

A 66 kV copper cable with a cross-section of 500 $mm^2$ is installed *with no adjacent cables (k=1)* into a *ground consisting of dry gravel and clay (k=0.85)* and *into the depth of 1.5 meters (k=0.95)*. The cable's 1 s permissible short-circuit current is 71.4 kA and its insulation is XLPE. The cable's screen circuit is open and the laying formation is flat. Its current-carrying capacity is 575 A in 65 ℃ and 680 A in 90 ℃. The reference temperature for ground installation is 15 ℃. The cable's thermal time constant is 183.8 min.

From this initial data one can calculate the $k_{SF}$ correction factor according to the following formula (k factor related information in italics):

$$k_{SF} = 1 \times 0.85 \times 0.95 = 0.81$$

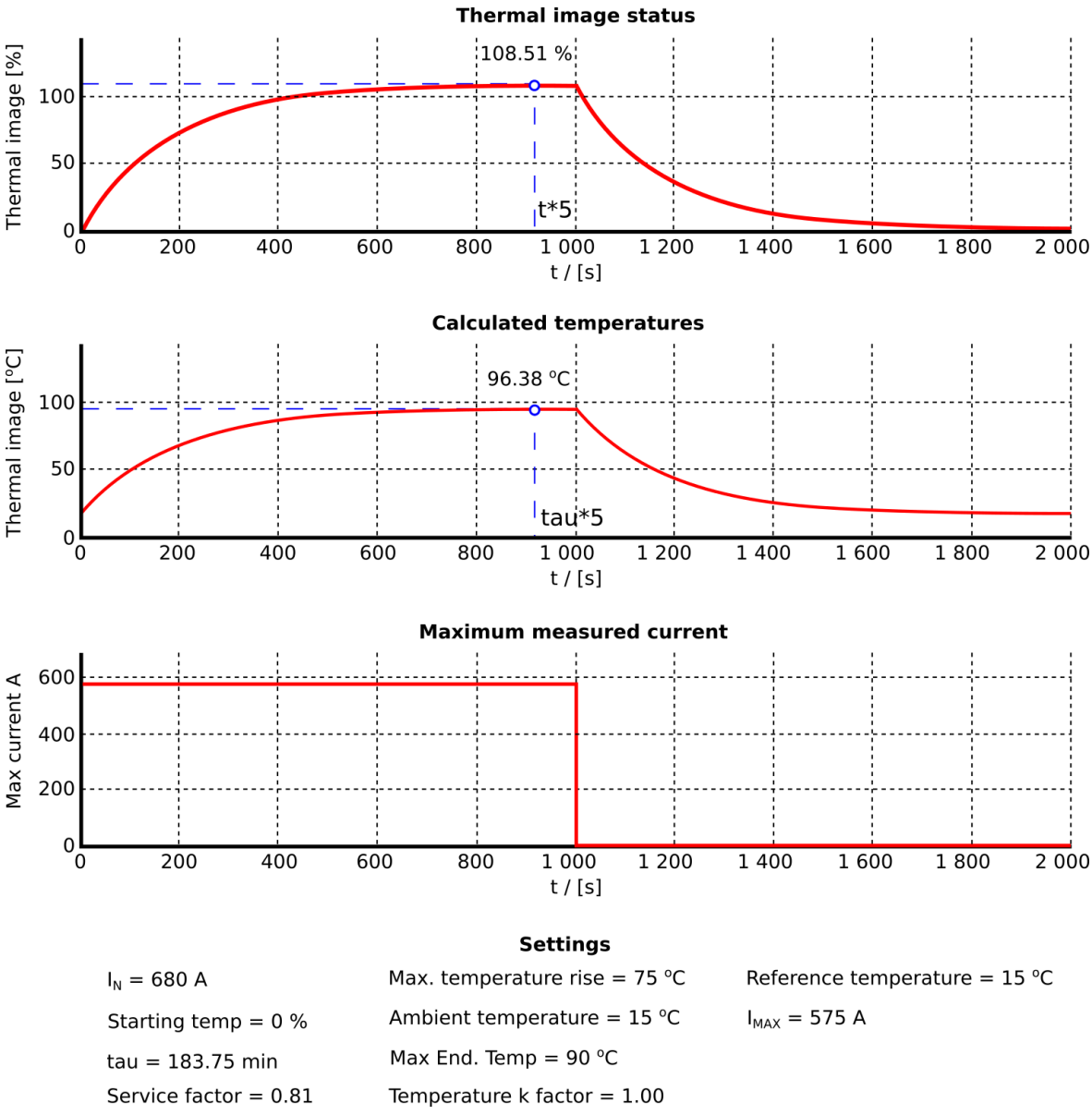


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Therefore, the settings are as follows:

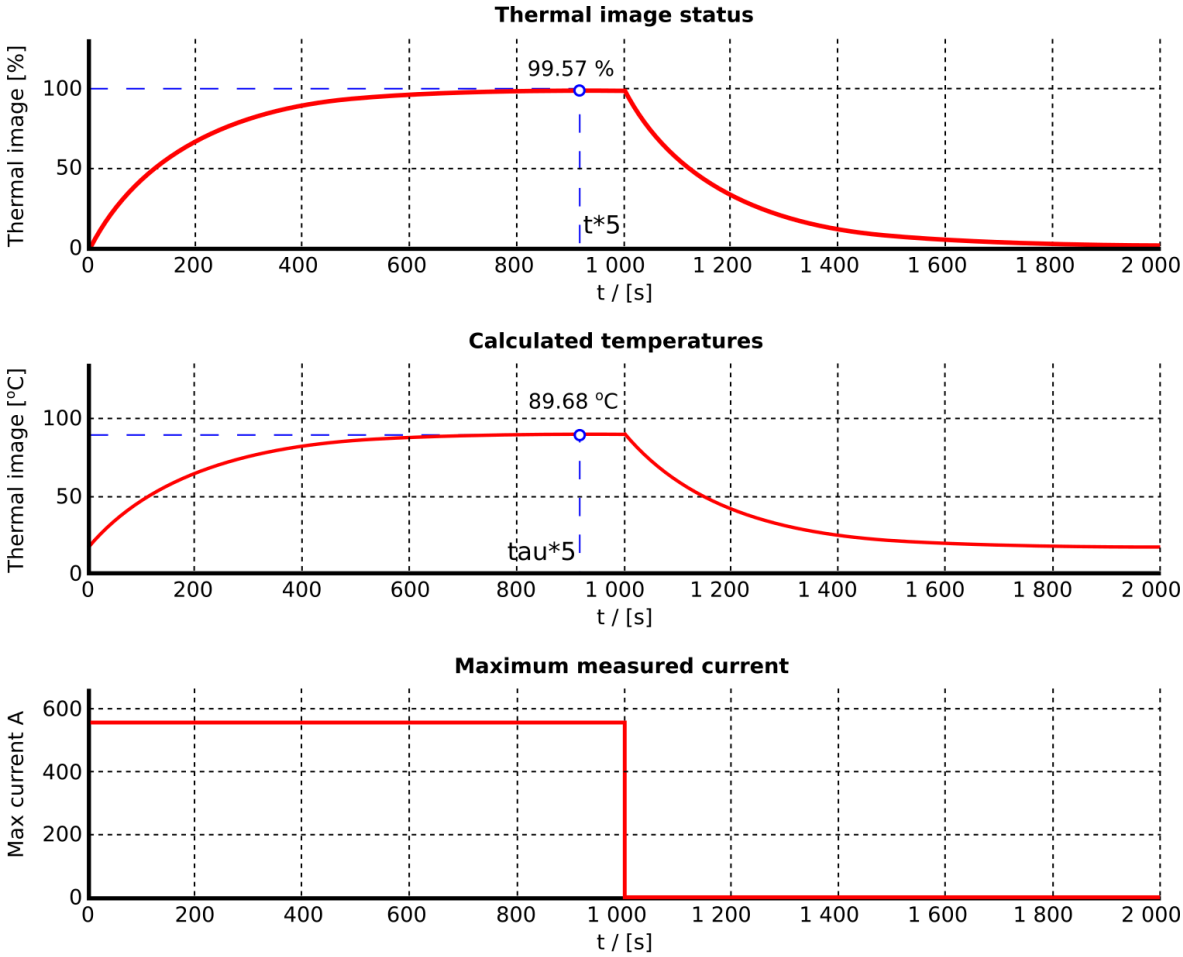
- $I_n$ = 680 A
- $T_{max}$ = 90 ℃
- $T_{amb}$ = 15 ℃
- $T_{ref}$ = 15 ℃
- τ = 183.8 min
- $k_{SF}$ = 0.81.

Figure. 5.4.22 - 118. Thermal image response with nominal currents and fine-tuned $k_{SF}$ correction factor.




When trying to load the cable with the nominal current one can see the actual current-carrying capacity of the cable is much lower than in the presumptive conditions. A normal loading current can now warm up the cable too much and threaten its withstandability. If the $k_{SF}$ had not been set, the thermal image would show a temperature of appr. 68 ℃ instead of the real temperature of 96 ℃.

Figure. 5.4.22 - 119. Thermal response with $k_{SF}$ factor correctly set.




**Settings**

| | | |
|---|---|---|
| $I_N$ = 680 A | Max. temperature rise = 75 °C | Reference temperature = 15 °C |
| Starting temp = 0 % | Ambient temperature = 15 °C | $I_{MAX}$ = 550.8 A |
| tau = 183.75 min | Max End. Temp = 90 °C | |
| Service factor = 0.81 | Temperature k factor = 1.00 | |

When the installation conditions vary from the presumptive conditions, the cable's current-carrying capacity can be reduced so that the temperature of 90 ℃ is achieved with a 550 A current instead of the 680 A current given in the initial data.

## Estimating trip time

Calculated effective nominal current:

$I_N = k_{SF} \times tamb_{fact} \times I_{Nom}$

Where:

- $I_N$ = calculated effective nominal current
- $k_{SF}$ = the service factor
- $k_{amb}$ = the ambient temperature factor
- $I_{Nom}$ = the nominal current of the protected device

Calculated end heating:



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$\theta_{End} = (I_{meas}/I_N)^2$

Where:

- $I_{meas}$ = the measured current
- $I_N$ = the calculated effective nominal current

Calculated time constant:

$\tau = e^{(-0.005[s] \times (Tc[min] \times 60)[s])}$

Where:

- e = Euler's number
- $\tau_c$ = the time constant set by the user
- 0.005s is the program cycle time

Calculated active thermal status:

$\theta_{Calc} = ((\theta_{-1} - \theta_{End}) \times \tau) + \theta_{End}$

Where:

- $\theta_{-1}$ = previous cycle calculation result (integrating function needs the memory to operate)
- $\theta_{End}$ = the calculated end heating (dependent on the measured current)
- $\tau$ = the calculated time constant

The tripping time can be calculated based on these previous calculations according to the following formula (the result in seconds). With this base information the tripping time can be calculated with the formula above (in seconds) when replacing the $\theta_{Calc}$ with the value of the thermal level which from the tripping time is wanted to be calculated (in per-unit value).

$$t_{est.\ trip} = l_n\left(\frac{I_{meas}{}^2 - (k_{fact} \times tamb_{fact} \times \sqrt{\theta_{Calc}} \times I_n)^2}{(I_{meas}{}^2 - I_n{}^2)}\right) \times \tau \times 60$$

## Function inputs and outputs

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The outputs of the function are the TRIP and BLOCKED signals. The overvoltage function uses a total of eight (8) separate setting groups which can be selected from one common source. Additionally, the function's operating mode can be changed via the setting group selection.

The operational logic consists of the following:

- input magnitude processing
- thermal replica
- block signal check
- output processing.

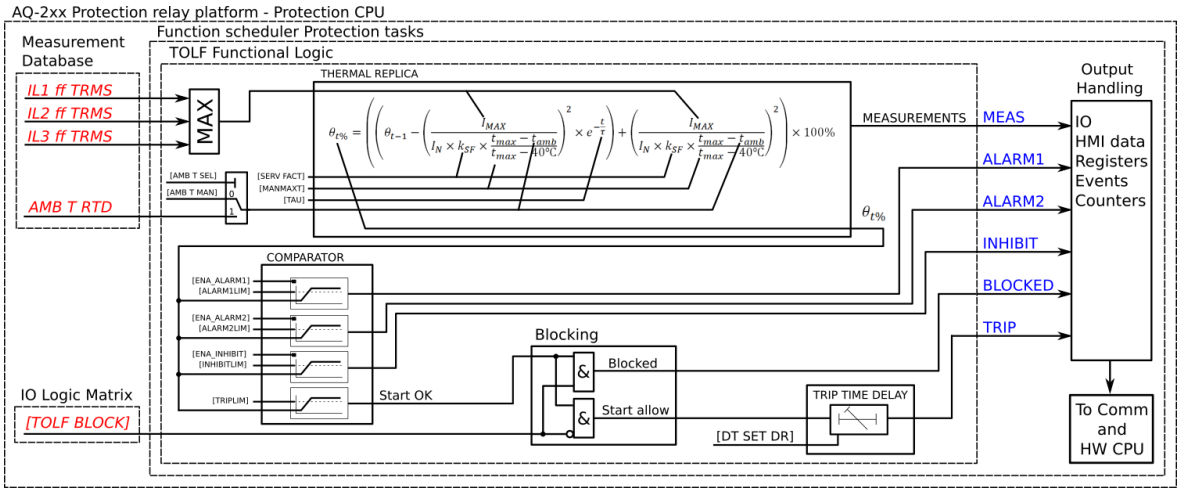
The inputs for the function are the following:

- setting parameters
- measured and pre-processed current magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signal. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the TRIP, ALARM 1, ALARM 2, INHIBIT and BLOCKED events.

The following figure presents a simplified function block diagram of the line thermal overload protection function.

Figure. 5.4.22 - 120. Simplified function block diagram of the TF> function.




## Measured input

The function block uses analog phase current measurement values. The function block uses TRMS values from the whole harmonic specter of 32 components.

Table. 5.4.22 - 191. Measurement inputs of the TF> function.

| Signal | Description | Time base |
|---|---|---|
| IL1 TRMS | TRMS measurement of phase L1 (A) current | 5ms |
| IL2 TRMS | TRMS measurement of phase L2 (B) current | 5ms |
| IL3 TRMS | TRMS measurement of phase L3 (C) current | 5ms |
| RTD | Temperature measurement for the ambient correction | 5ms |

Table. 5.4.22 - 192. General settings (not selectable under setting groups)

| Name | Range | Default | Description |
|---|---|---|---|
| TF> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of TOLF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TF> mode | 0: Disabled<br>1: Activated | 0: Disabled | The selection of the function is activated or disabled in the configuration. By default it is not in use. |



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| Name | Range | Default | Description |
|---|---|---|---|
| TF> force status to | 0: Normal<br>1: Blocked<br>2: Alarm1 On<br>3: Alarm2 On<br>4: Inhibit On<br>5: Trip On | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Temp C or F deg | 0: C<br>1: F | 0: C | The selection of whether the temperature values of the thermal image and RTD compensation are shown in Celsius or in Fahrenheit. |

Table. 5.4.22 - 193. Settings for thermal replica.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| IN thermal cap current | 0.10…40.00x$I_n$ | 0.01x$I_n$ | 1.00x$I_n$ | The current for the 100 % thermal capacity to be used (the pick-up current in p.u., with $t_{max}$ achieved in time τ x 5). |
| Set or Estimate tau (t const) | 0: Set<br>1: Estimate | - | 0: Set | The selection of the time constant setting. If "Set" is selected, the Tau (t const) setting is available and the time constant to be used can be set there. If "Estimate" is selected, the cable's initial data parameters are visible. |
| Tau (t const) | 0.1…500.0min | 0.1min | 10.0min | The time constant setting. This time constant is used for heating and cooling of the protected object. This setting is visible if the "Set" is selected for the "Set or Estimate tau" setting. |
| Max. perm. OC. current (norm **ik**1s) | 1…1 000 000A | 1A | 75 000A | The maximum-rated short-circuit current of the protected object (cable). Usually this value is presented as a one second value. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting. |
| Max. OC. time (norm 1 s) | 0.1…5s | 0.1s | 1.0s | The time of the maximum-rated short-circuit current of the protected object (usually 1 s). This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting. |
| Nominal current | 1…1 000 000A | 1A | 700A | The rated nominal current in the primary value of the protected object under nominal-rated conditions. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting. |
| Estimated tau | 0…1800min | 0.005min | 191.3min (from defaults) | The estimated result which is used for the thermal replica's time constant. After the previous three required parameters are set the IED will calculate this value. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting. |
| $k_{SF}$ (service factor) | 0.01…5.00 | 0.01 | 1.00 | The service factor which corrects the value of the maximum allowed current according to installation and other conditions varying from the presumptive conditions. |
| Cold reset default theta | 0.0…150.0% | 0.1% | 60.0% | The thermal image status in the restart of the function/ IED. The value is given in percentages of the used thermal capacity of the protected object. It is also possible to reset the thermal element.<br><br>This parameter can be used when testing the function to manually set the current thermal cap to any value. |

Table. 5.4.22 - 194. Environmental settings

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Object max. temp. ($t_{max}$ = 100%) | 0…500deg | 1deg | 90deg | The maximum allowed temperature for the protected object. The default suits for Celsius range and for PEX-insulated cables. |
| Ambient temp. sel. | 0: Manual set<br>1: RTD | - | 0: Manual set | The selection of whether fixed or measured ambient temperature is used for the thermal image biasing. |
| Man. amb. temp. set. | 0…500deg | 1deg | 15deg | The manual fixed ambient temperature setting for the thermal image biasing. Underground cables usually use 15 °C. This setting is visible if "Manual set" is selected for the "Ambient temp. sel." setting. |
| RTD amb. temp. read. | 0…500deg | 1deg | 15deg | The RTD ambient temperature reading for the thermal image biasing. This setting is visible if "RTD" is selected for the "Ambient temp. sel." setting. |
| Ambient lin. or curve | 0: Linear est.<br>1: Set curve | - | 0: Linear est. | The selection of how to correct the ambient temperature, either by internally calculated compensation based on end temperatures or by a user-settable curve. The default setting is "0: Linear est." which means the internally calculated correction for ambient temperature. |
| Temp. reference ($t_{ref}$) $k_{amb}$=1.0 | -60…500deg | 1deg | 15deg | The temperature reference setting. The manufacturer's temperature presumptions apply and the thermal correction factor is 1.00 (rated temperature). For underground cables the set value for this is usually 15 ℃ and for cables in the air it is usually 25 ℃.<br><br>This setting is visible if "Ambient lin. or curve" is set to "Linear est." |
| Max. ambient temp. | 0…500deg | 1deg | 45deg | The maximum ambient temperature setting. If the measured temperature is more than the maximum set temperature, the set correction factor for the maximum temperature is used. This setting is visible if "Ambient lin. or curve" is set to "Linear est." |
| k at max. amb. temp. | 0.01…5.00x$I_n$ | 0.01x$I_n$ | 1.00x$I_n$ | The temperature correction factor for the maximum ambient temperature setting. This setting is visible if "Ambient lin. or curve" is set to "Linear est." |
| Min. ambient temp. | -60…500deg | 1deg | 0deg | The minimum ambient temperature setting. If the measured temperature is below the minimum set temperature, the set correction factor for minimum temperature is used. This setting is visible if "Ambient lin. or curve" is set to "Linear est." |
| k at min. amb. temp. | 0.01…5.00x$I_n$ | 0.01x$I_n$ | 1.00x$I_n$ | The temperature correction factor for the minimum ambient temperature setting. This setting is visible if "Ambient lin. or curve" is set to "Linear est." |
| Amb. temp. ref. 1...10 | -50.0…500.0deg | 0.1deg | 15deg | The temperature reference points for the user-settable ambient temperature coefficient curve. This setting is visible if "Ambient lin. or curve" is set to "Set curve". |
| Amb. temp. k1...k10 | 0.01…5.00 | 1.00 | 0.01 | The coefficient value for the temperature reference point. The coefficient and temperature reference points must be set as pairs. This setting is visible if "Ambient lin. or curve" is set to "Set curve". |
| Add curvepoint 3…10 | 0: Not used<br>1: Used | - | 0: Not used | The selection of whether or not the curve temperature/coefficient pair is in use. The minimum number to be set for the temperature/coefficient curve is two pairs and the maximum is ten pairs. If the measured temperature is below the set minimum temperature reference or above the maximum set temperature reference, the used temperature coefficient is the first or last value in the set curve. This setting is visible if "Ambient lin. or curve" is set to "Set curve". |

## Operation characteristics

The operating characteristics of the machine thermal overload protection function are completely controlled by the thermal image. The thermal capacity value calculated from the thermal image can set the I/O controls with ALARM 1, ALARM 2, INHIBIT and TRIP signals.


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Table. 5.4.22 - 195. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable TF> Alarm 1 | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 1 signal and the I/O. |
| TF> Alarm 1 level | 0.0…150.0% | 0.1% | 40% | ALARM 1 activation threshold. |
| Enable TF> Alarm 2 | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 2 signal and the I/O. |
| TF> Alarm 2 level | 0.0…150.0% | 0.1% | 40% | ALARM 2 activation threshold. |
| Enable TF> Rest Inhibit | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 1 signal and the I/O. |
| TF> Inhibit level | 0.0…150.0% | 0.1% | 80% | INHIBIT activation threshold. |
| Enable TF> Trip | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 1 signal and the I/O. |
| TF> Trip level | 0.0…150.0% | 0.1% | 100% | TRIP activation threshold. |
| TF> Trip delay | 0.000…3600.000s | 0.005s | 0.000s | The trip signal's additional delay. This delay delays the trip signal generation by a set time. The default setting is 0.000 s which does not give an added time delay for the trip signal. |

The pick-up activation of the function is direct for all other signals except the TRIP signal which also has a blocking check before the signal is generated.

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Measurements and indications

The function outputs measured process data from the following magnitudes:

Table. 5.4.22 - 196. General status codes.

| Name | Range | Description |
|---|---|---|
| TF> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of TOLF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TF> Condition | 0: Normal<br>1: Alarm 1 ON<br>2: Alarm 2 ON<br>3: Inhibit ON<br>4: Trip ON<br>5: Blocked | The function's operating condition at the moment considering binary IO signal status. No outputs are controlled when the status is "Normal". |
| Thermal status | 0: Light / No load<br>1: High overload<br>2: Overloading<br>3: Load normal | The function's thermal image status. When the measured current is below 1 % of the nominal current, the status "Light/No load" is shown. When the measured current is below the trip limit, the status "Load normal" is shown. When the measured current is above the pick-up limit but below 2 x $I_n$ , the status "Overloading" is shown. When the measured current is above 2 x $I_n$, the status "High overload" is shown. |
| TF> Setting alarm | 0: SF setting ok<br>1: Service factor set fault. Override to 1.0 | Indicates if SF setting has been set wrong and the actually used setting is 1.0. Visible only when there is a setting fault. |
| TF> Setting alarm | 0: Ambient setting ok<br>1: Ambient t set fault. Override to 1.0 | Indicates if ambient temperature settings have been set wrong and actually used setting is 1.0. Visible only when there is a setting fault. |
| TF> Setting alarm | 0: Nominal current calc ok<br>1: Nominal current set fault. Override to 1.0 | Indicates if nominal current calculation is set wrong and actually used setting is 1.0. Visible only when there is a setting fault. |
| TF> Setting alarm | 0: Ambient setting ok<br>1: Inconsistent setting of ambient k | Indicates if ambient k setting has been set wrong. Visible only when there is a setting fault. |

Table. 5.4.22 - 197. Measurements.

| Name | Range | Description/values |
|---|---|---|
| Currents | 0: Primary A<br>1: Secondary A<br>2: Per unit | The active phase current measurement from IL1 (A), IL2 (B) and IL3 (C) phases in given scalings. |



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| Name | Range | Description/values |
|---|---|---|
| Thermal image | 0: Thermal image calc. | - TF> Trip expect mode: No trip expected/Trip expected<br>- TF> Time to 100 % theta: Time to reach the 100 % thermal cap<br>- TF> Rreference T curr.: reference/pick-up value (IEQ)<br>- TF> Active meas. curr.: the measured maximum TRMS current at a given moment<br>- TF> T est. with act. curr.: estimation of the used thermal capacity including the current at a given moment<br>- TF> T at a given moment: the thermal capacity used at that moment |
| | 1: Temp. estimates | - TF> Used k for amb. temp: the ambient correction factor at a givenmoment<br>- TF> Max. temp. rise all.: the maximum allowed temperature rise<br>- TF> Temp. rise atm: the calculated temperature rise at a given moment<br>- TF> Hot spot estimate: the estimated hot spot temperature including the ambient temperature<br>- TF> Hot spot max. all.: the maximum allowed temperature for the object |
| | 2: Timing status | - TF> Trip delay remaining: the time to reach 100% theta<br>- TF> Trip time to rel.: the time to reach theta while staying below the trip limit during cooling<br>- TF> Alarm 1 time to rel.: the time to reach theta while staying below the Alarm 1 limit during cooling<br>- TF> Alarm 2 time to rel.: the time to reach theta while staying below the Alarm 2 limit during cooling<br>- TF> Inhibit time to rel.: the time to reach theta while staying below the Inhibit limit during cooling |

Table. 5.4.22 - 198. Counters.

| Name | Description / values |
|---|---|
| Alarm1 inits | The number of times the function has activated the Alarm 1 output |
| Alarm2 inits | The number of times the function has activated the Alarm 2 output |
| Restart inhibits | The number of times the function has activated the Restart inhibit output |
| Trips | The number of times the function has tripped |
| Trips Blocked | The number of times the function trips has been blocked |

## Events and registers

The line thermal overload protection function (abbreviated "TOLF" in event block names) generates events and registers from the status changes in TRIP and BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.22 - 199. Event messages.

| Event block name | Event names |
|---|---|
| TOLF1 | Alarm1 ON |
| TOLF1 | Alarm1 OFF |
| TOLF1 | Alarm2 ON |
| TOLF1 | Alarm2 OFF |
| TOLF1 | Inhibit ON |
| TOLF1 | Inhibit OFF |
| TOLF1 | Trip ON |
| TOLF1 | Trip OFF |
| TOLF1 | Block ON |

| Event block name | Event names |
|---|---|
| TOLF1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.4.22 - 200. Register content.

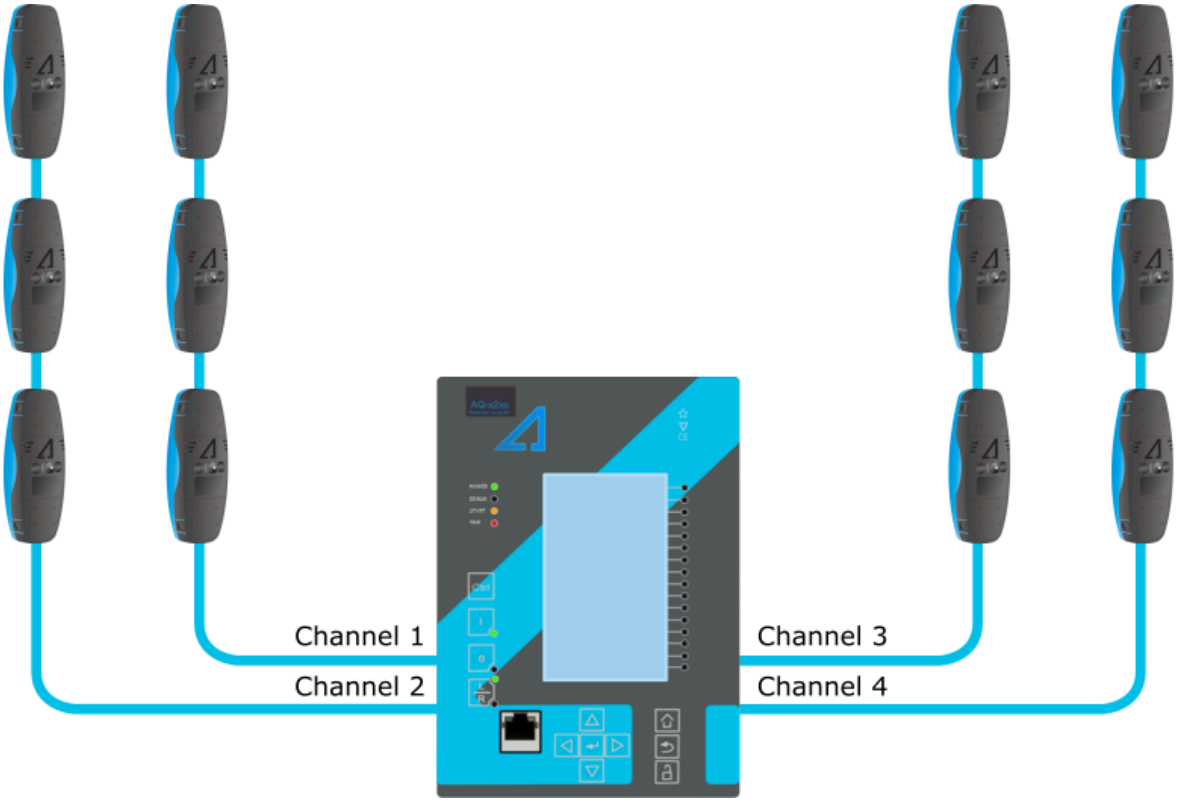
| Name | Description |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| Time to reach 100 % theta | seconds |
| Ref. T current | x $I_n$ |
| Active meas. current | x $I_n$ |
| T at a given moment | % |
| Max. temp. rise allowed | degrees |
| Temp. rise at a given moment | degrees |
| Hot spot estimate | degrees |
| Hot spot maximum allowed | degrees |
| Trip delay rem. | seconds |
| Used SG | Setting group 1...8 active |

## 5.4.23 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc)

Arc faults occur for a multitude of reasons: e.g. insulation failure, incorrect operation of the protected device, corrosion, overvoltage, dirt, moisture, incorrect wiring, or even because of aging caused by electric load. It is important to detect the arc as fast as possible in order to minimize its effects. Using arc sensors to detect arc faults is much faster than merely measuring currents and voltages. In busbar protection IEDs with normal protection can be too slow to disconnect arcs within a safe time frame. For example, it may be necessary to delay operation time for hundreds of milliseconds when setting up an overcurrent protection relay to control the feeder breakers to achieve selectivity. This delay can be avoided by using arc protection. The arc protection card has a high-speed output to trip signals faster as well as to extend the speed of arc protection.


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IM00015

Figure. 5.4.23 - 121. IED equipped with arc protection.




The arc protection card has four (4) sensor channels, and up to three (3) arc point sensors can be connected to each channel. The sensor channels support Arcteq AQ-01 (light sensing) and AQ-02 (pressure and light sensing) units. Optionally, the protection function can also be applied with a phase current or a residual current condition: the function trips only if the light and overcurrent conditions are met.

The outputs of the function are the following:

- Light In
- Pressure In
- Arc binary input signal status
- Zone trip
- Zone blocked
- Sensor fault signals.

The arc protection function uses a total of eight (8) separate setting groups which can be selected from one common source.

Table. 5.4.23 - 201. Output signals of the IArc>/I0Arc> function.

| Outputs | Activation condition |
|---|---|
| Channel 1 Light In<br>Channel 2 Light In<br>Channel 3 Light In<br>Channel 4 Light In | The arc protection card's sensor channel detects light. |
| Channel 1 Pressure In<br>Channel 2 Pressure In<br>Channel 3 Pressure In<br>Channel 4 Pressure In | The arc protection card's sensor channel detects pressure. |
| ARC Binary input signal | The arc protection card's binary input is energized. |

| Outputs | Activation condition |
|---|---|
| I/I0 Arc> Ph. curr. START<br>I/I0 Arc> Res. curr. START | The measured phase current or the residual current is over the set limit. |
| I/I0 Arc> Ph. curr. BLOCKED<br>I/I0 Arc> Res. curr. BLOCKED | The phase current or the residual current measurement is blocked by an input. |
| I/I0 Arc> Zone 1 TRIP<br>I/I0 Arc> Zone 2 TRIP<br>I/I0 Arc> Zone 3 TRIP<br>I/I0 Arc> Zone 4 TRIP | All required conditions for tripping the zone are met (light OR light and current). |
| I/I0 Arc> Zone 1 BLOCKED<br>I/I0 Arc> Zone 2 BLOCKED<br>I/I0 Arc> Zone 3 BLOCKED<br>I/I0 Arc> Zone 4 BLOCKED | All required conditions for tripping the zone are met (light OR light and current) but the tripping is blocked by an input. |
| I/I0 Arc> S1 Sensor fault<br>I/I0 Arc> S2 Sensor fault<br>I/I0 Arc> S3 Sensor fault<br>I/I0 Arc> S4 Sensor fault | The detected number of sensors in the channel does not match the settings. |
| I/I0 Arc> IO unit fault | The number of connected AQ-100 series units does not match the number of units set in the settings. |

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- block signal check
- output processing.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function's outputs are TRIP, BLOCKED, light sensing etc. signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the 26 output signals. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for the TRIP and BLOCKED events for each zone.

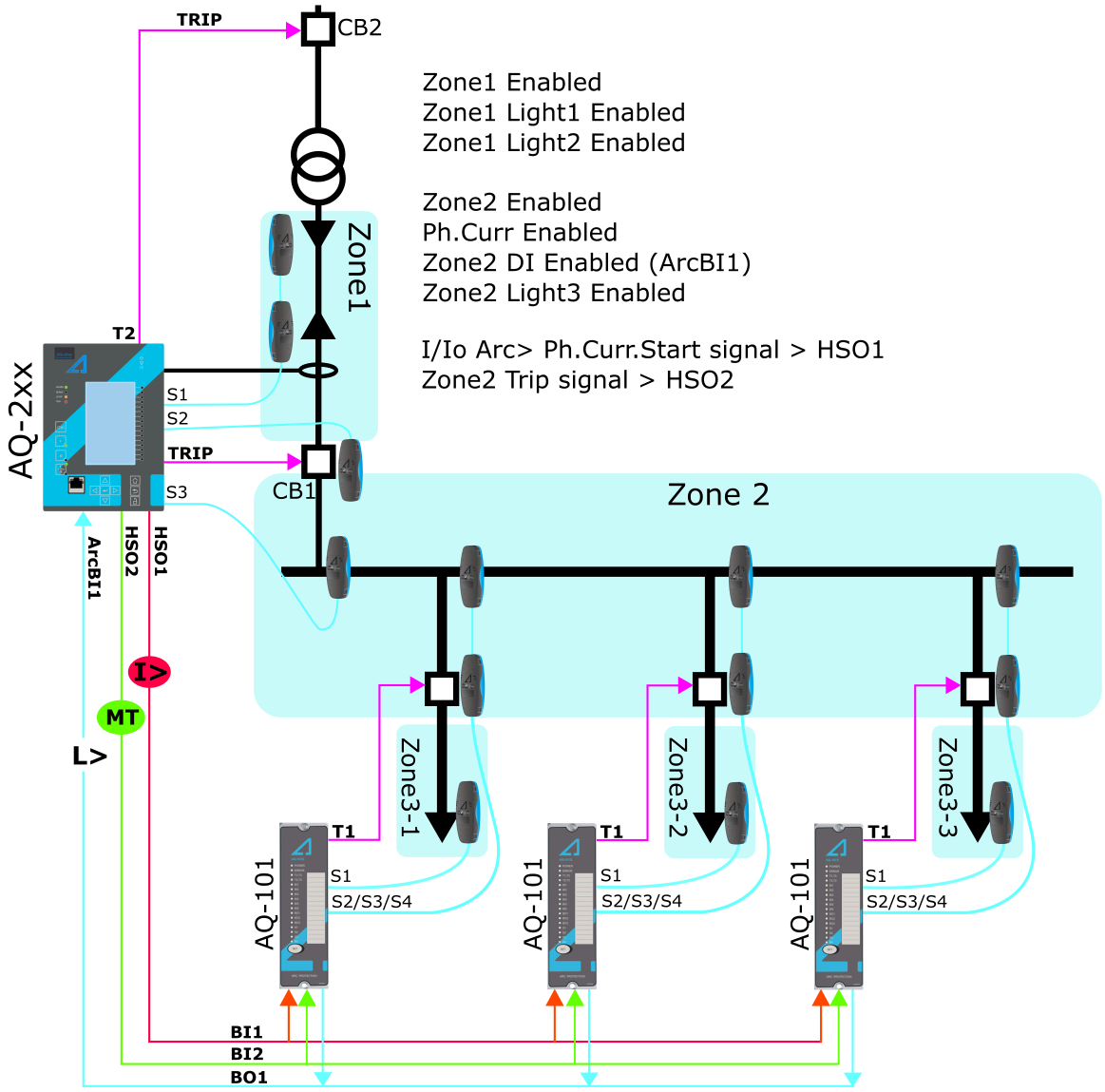
## Example of scheme setting

The following examples helps the user better understand how the arc protection function is set. In the examples AQ-101 models are used to extend the protection of Zone 2 and to protect each outgoing feeder (Zone 3).

Scheme IA1 is a single-line diagram with AQ-2xx series relays and with AQ-101 arc protection relays. The settings are for an incomer AQ-200 relay.


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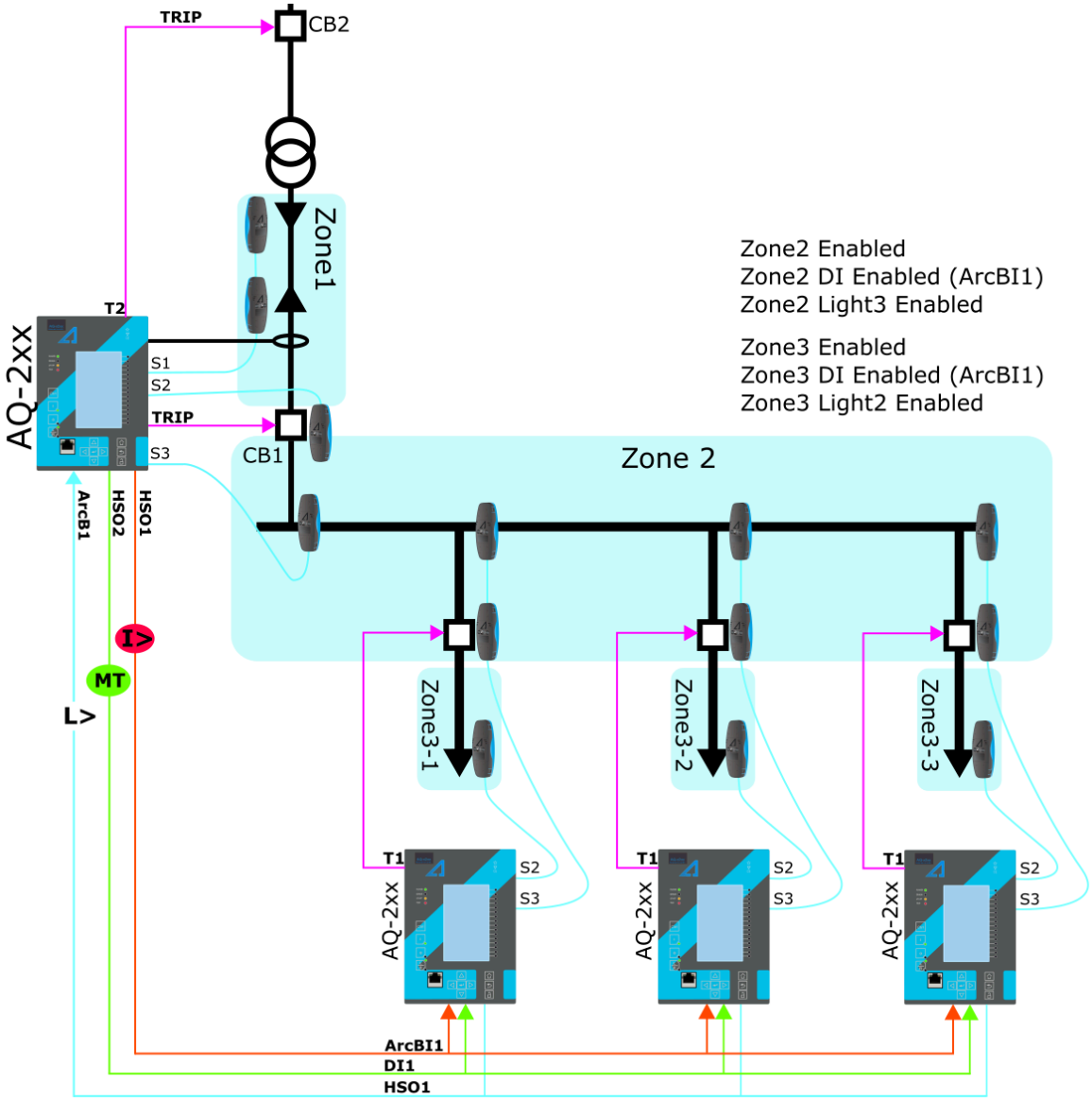
Figure. 5.4.23 - 122. Scheme IA1 (with AQ-101 arc protection relays).




To set the zones for the AQ-2xx models sensor channels start by enabling the protected zones (in this case, Zones 1 and 2). Then define which sensor channels are sensing which zones (in this case, sensor channels S1 and S2 are protecting Zone 1). Enable Light 1 of Zone 1 as well as Light 2 of Zone 2. The sensor channel S3 deals with Zone 2. Enable Light 3 of Zone 2. The high-speed output contacts HSO1 and HSO2 have been set to send overcurrent and master trip signals to the AQ-101 arc protection relays. The AQ-100 series units send out test pulses in specific intervals to check the health of the wiring between the AQ-100 series units. The parameter *I/I0 Arc> Self supervision test pulse* should be activated when connecting the AQ-100 series units to the AQ-200 series arc protection card to prevent the pulses from activating ArcBI1.

The next example is almost like the previous one: it is also a single-line diagram with AQ-2xx series relays. However, this time each outgoing feeder has an AQ-2xx protection relay instead of an AQ-101 arc protection relay.

Figure. 5.4.23 - 123. Scheme IA1 (with AQ-200 protection relays).




The settings for the relay supervising the incoming feeder are the same as in the first example. The relays supervising the busbar and the outgoing feeder, however, have a different setting. Both Zones 2 and 3 need to be enabled as there are sensors connected to both Zone 2 and 3 starts. Sensors connected to the channel S3 are in Zone 2. Then enable Light 3 of Zone 2. The sensor connected to the channel S2 is in Zone 3. Then enable Light 2 of Zone 3.

If any of the channels have a pressure sensing sensor, enable it the same way as the regular light sensors. If either phase overcurrent or residual overcurrent is needed for the tripping decision, they can be enabled in the same way as light sensors in the zone. When a current channel is enabled, the measured current needs to be above the set current limit in addition to light sensing.

## Measured input

Arc protection uses samples based on current measurements. If the required number of samples is found to be above the setting limit, the current condition activates. The arc protection can alternatively use either phase currents or residual currents in the tripping decision.



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## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.4.23 - 202. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| I/I0 Arc> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of ARC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I/I0 Arc> force status to | 0: Normal<br>1: PH curr blocked<br>2: PH curr Start<br>3: ResCurr Blocked<br>4: ResCurr Start<br>5: Zone 1 Trip<br>6: Zone1 Blocked<br>7: Zone2 Trip<br>8: Zone2 Blocked<br>9: Zone3 Trip<br>10: Zone3 Blocked<br>11: Zone4 Trip<br>12: Zone4 Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Channel 1 sensors<br>Channel 2 sensors<br>Channel 3 sensors<br>Channel 4 sensors | 0: No sensors<br>1: 1 sensor<br>2: 2 sensors<br>3: 3 sensors | 1: No sensors | Defines the number of sensors connected to the channel (channels 1/2/3/4). |
| Channel 1 sensor status<br>Channel 2 sensor status<br>Channel 3 sensor status<br>Channel 4 sensor status | 0: Sensors OK<br>1: Configuration fault state | - | Displays the status of the sensor channel. If the number of sensors connected to the channel does not match with the set "Channel 1/2/3/4 sensors" setting, this parameter will go to the "Configuration fault" state. |

## Pick-up

The pick-up of each zone of the Iarc>/I0arc> function is controlled by one of the following: the phase current pick-up setting, the residual current pick-up setting, or the sensor channels. The pick-up setting depends on which of these are activated in the zone.

Table. 5.4.23 - 203. Enabled Zone pick-up settings.

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| Phase current pick-up | The phase current measurement's pick-up value (in p.u.). | 0.05...40.00 x $I_n$ | 0.01 x $I_n$ | 1.2 x $I_n$ |
| I0 input selection | Selects the residual current channel (I01 or I02). | 0: None<br>1: I01<br>2: I02 | - | 0: None |
| Res.current pick-up | The residual current measurement's pick-up value (in p.u.). | 0.05...40.00 x $I_{0n}$ | 0.01 x $I_{0n}$ | 1.2 x $I_{0n}$ |
| Zone1/2/3/4 Enabled | Enables the chosen zone. Up to 4 zones can be enabled. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Ph. curr. Enabled | The phase overcurrent allows the zone to trip when light is detected. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Res. curr. Enabled | The residual overcurrent allows the zone to trip when light is detected. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Light 1 Enabled | Light detected in sensor channel 1 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Light 2 Enabled | Light detected in sensor channel 2 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Light 3 Enabled | Light detected in sensor channel 3 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Light 4 Enabled | Light detected in sensor channel 4 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Pres. 1 Enabled | Pressure detected in sensor channel 1 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Pres. 2 Enabled | Pressure detected in sensor channel 2 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Pres. 3 Enabled | Pressure detected in sensor channel 3 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 Pres. 4 Enabled | Pressure detected in sensor channel 4 trips the zone. | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Zone1/2/3/4 DI Enabled | Arc protection option card digital input function selection. "Light In" mode trips the zone when digital input is active. In "Current In" mode digital input must be active at the same time as any of the sensor channels for the zone to trip. | 0: Disabled<br>1: Light In<br>2: Current In | - | 0: Disabled |

The pick-up activation of the function is not directly equal to the TRIP signal generation of the function. The TRIP signal is allowed if the blocking condition is not active.



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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.4.23 - 204. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| I/I0 Arc> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Displays the mode of ARC block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| I/I0 Arc> condition | 0: Z1 Trip<br>1: Z1 Blocked<br>2: Z2 Trip<br>3: Z2 Blocked<br>4: Z3 Trip<br>5: Z3 Blocked<br>6: Z4 Trip<br>7:Z4 Blocked | Displays status of the protection function. |
| Sensor status | 0: Ph Curr Blocked<br>1: Ph Curr Start<br>2: Res Curr Blocked<br>3: Res Curr Start<br>4: Channel1 Light<br>5: Channel1 Pressure<br>6: Channel2 Light<br>7: Channel2 Pressure<br>8: Channel3 Light<br>9: Channel3 Pressure<br>10: Channel4 Ligh<br>t11: Channel4 Pressure<br>12: Digital input<br>13: I/I0 Arc> Sensor 1 Fault<br>14: I/I0 Arc> Sensor 2 Fault<br>15: I/I0 Arc> Sensor 3 Fault<br>16: I/I0 Arc> Sensor 4 Fault<br>17: I/I0 Arc> I/O-unit Fault | Displays the general status of sensors. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a TRIP signal is generated.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events and registers

The arc fault protection function (abbreviated "ARC" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.4.23 - 205. Event messages.

| Event block name | Event names |
|---|---|
| ARC1 | Zone 1 Trip ON |
| ARC1 | Zone 1 Trip OFF |
| ARC1 | Zone 1 Block ON |
| ARC1 | Zone 1 Block OFF |
| ARC1 | Zone 2 Trip ON |
| ARC1 | Zone 2 Trip OFF |
| ARC1 | Zone 2 Block ON |
| ARC1 | Zone 2 Block OFF |
| ARC1 | Zone 3 Trip ON |
| ARC1 | Zone 3 Trip OFF |
| ARC1 | Zone 3 Block ON |
| ARC1 | Zone 3 Block OFF |
| ARC1 | Zone 4 Trip ON |
| ARC1 | Zone 4 Trip OFF |
| ARC1 | Zone 4 Block ON |
| ARC1 | Zone 4 Block OFF |
| ARC1 | Phase current Blocked ON |
| ARC1 | Phase current Blocked OFF |
| ARC1 | Phase current Start ON |
| ARC1 | Phase current Start OFF |
| ARC1 | Residual current Blocked ON |
| ARC1 | Residual current Blocked OFF |
| ARC1 | Residual current Start ON |
| ARC1 | Residual current Start OFF |
| ARC1 | Channel 1 Light ON |
| ARC1 | Channel 1 Light OFF |
| ARC1 | Channel 1 Pressure ON |
| ARC1 | Channel 1 Pressure OFF |
| ARC1 | Channel 2 Light ON |
| ARC1 | Channel 2 Light OFF |
| ARC1 | Channel 2 Pressure ON |
| ARC1 | Channel 2 Pressure OFF |


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| Event block name | Event names |
|---|---|
| ARC1 | Channel 3 Light ON |
| ARC1 | Channel 3 Light OFF |
| ARC1 | Channel 3 Pressure ON |
| ARC1 | Channel 3 Pressure OFF |
| ARC1 | Channel 4 Light ON |
| ARC1 | Channel 4 Light OFF |
| ARC1 | Channel 4 Pressure ON |
| ARC1 | Channel 4 Pressure OFF |
| ARC1 | DI Signal ON |
| ARC1 | DI Signal OFF |
| ARC1 | I/I0 Arc> Sensor 1 Fault ON |
| ARC1 | I/I0 Arc> Sensor 1 Fault OFF |
| ARC1 | I/I0 Arc> Sensor 2 Fault ON |
| ARC1 | I/I0 Arc> Sensor 2 Fault OFF |
| ARC1 | I/I0 Arc> Sensor 3 Fault ON |
| ARC1 | I/I0 Arc> Sensor 3 Fault OFF |
| ARC1 | I/I0 Arc> Sensor 4 Fault ON |
| ARC1 | I/I0 Arc> Sensor 4 Fault OFF |
| ARC1 | I/I0 Arc> I/O-unit Fault ON |
| ARC1 | I/I0 Arc> I/O-unit Fault OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.4.23 - 206. Register content.

| Date and time | Event | Phase A current | Phase B current | Phase C current | Residual current | Active sensors | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Trip current | Trip current | Trip current | Trip current | 1...4 | Setting group 1...8 active |

## 5.4.24 Voltage memory

Certain protection functions (such as impedance or directional overcurrent) use the relay's measured current and voltage to determine whether the electrical network fault appears to be inside the protected area. The determination is made by comparing the angle between the operating quantity (zone/tripping area) and the actual measured quantity. The function then produces an output when the required terms are met.

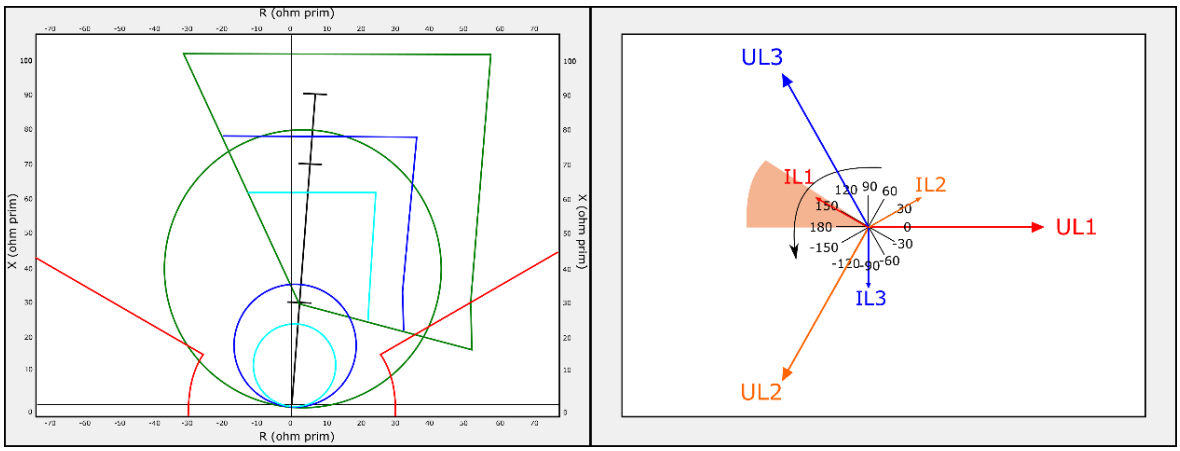
In close-in faults the system voltage on the secondary side may fall down to a few volts or close to nothing. In such cases, when the measured voltage is absent, the fault direction cannot be solved. As backup, non-directional protection can be used for tripping, but in such cases the selectivity of the network will reduce. However, an angle memory for voltage can be used to prevent this from happening. An adjustable voltage level with pre-fault voltage angles can be used as a reference for fault direction and/or distance. The reference can be set manually for duration. Thanks to the configurable voltage memory even time-delayed backup tripping can be initiated.

The user can activate voltage memory (and find all related settings) by following this path in relay settings: *Measurement → Transformers → VT Module (3U/4U) 1 → Voltage memory* ("Activated"/"Disabled").

The activation of voltage memory depends of following criteria:

1. All used line-to-line or line-to-neutral voltages need to be below the set value for the "VMEM activation voltage" parameter.
2. At least one phase current must be above the set value for the "Measured current condition 3I>" parameter. This setting limit is optional.

Figure. 5.4.24 - 124. Distance protection characteristics and directional overcurrent.

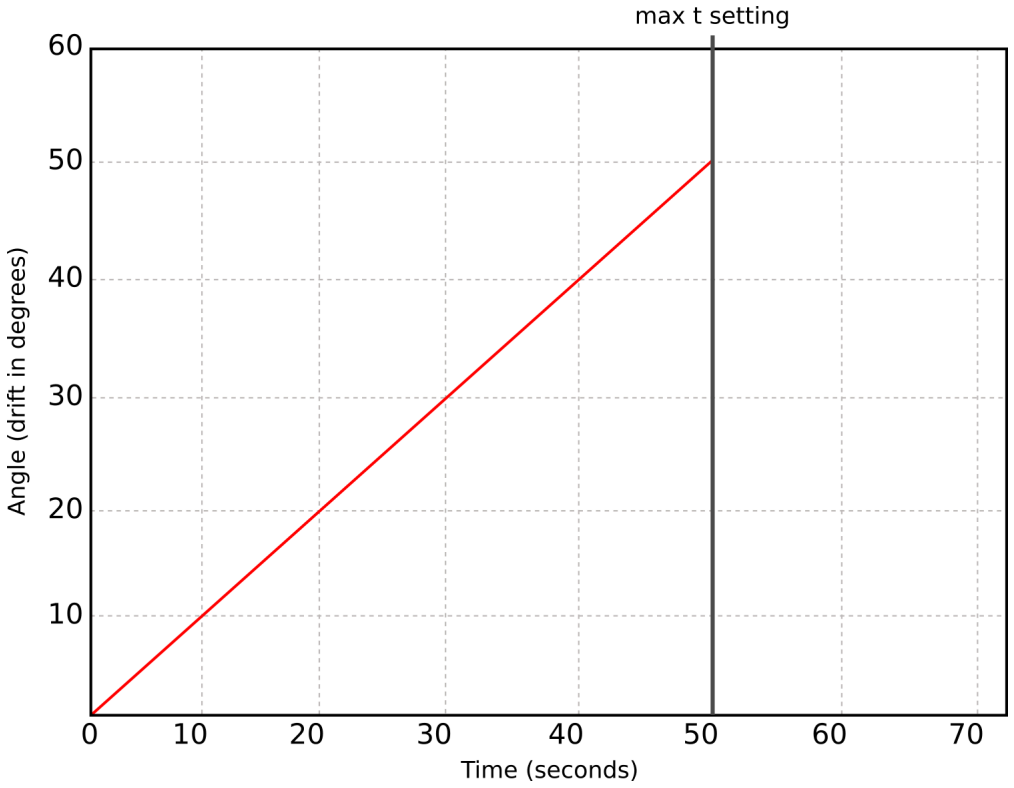



Voltage memory activates when the above-mentioned criteria are met. Voltage memory uses the "VMEM activation voltage" parameter as voltage amplitude even when the actual measured voltage has decreased below it or close to zero. The angle used by this function is the one captured the moment before the fault occurred and voltage memory was activated. When voltage memory is activated, the output "Voltage memory on" signal is activated. This signal can be found in the device's I/O matrix.

While voltage memory is active, voltages are absent and therefore angle measurement is not possible. Healthy state angles (before a fault) are used during a fault. This is why a drift between the assumed voltage angle and the actual measured phase current angle takes place. While voltage memory is used, the angle of phase currents drifts approximately one degree for each passing second (see the graph below).


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Figure. 5.4.24 - 125. Voltage angle drift.




The blocking signal for voltage memory can be found among other stage-related settings in the tab *VT Module (3U/4U) 1*. The blocking signal is checked in the beginning of each program cycle.

## Measured input

The function block uses analog voltage and current measurements' RMS values.

Table. 5.4.24 - 207. Measurement inputs of the voltage memory function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |
| $U_4$RMS | RMS measurement of voltage $U_4$/V | 5ms |

Voltage measurement modes 3LN and 3LL use three voltage inputs: channels $U_A$, $U_B$ and $U_C$. When the voltage mode is set to 2LL, only two channels ($U_A$ and $U_B$) are in use, and the memory is based on the line-to-line voltages $U_{12}$ and $U_{32}$. When the mode 2LL+U0 is used, the memory is based on calculated phase-to-neutral voltages.

## Pick-up

VMEM activation voltage and Measured current condition 3I>

When the voltage memory function is enabled, it activates when all line voltages drop below the "VMEM activation voltage" threshold limit. This limit can be set to be anything between 2...50 V AC. When "Measured current condition 3I>" is used, activation cannot be based on just the voltage. Therefore, at least one of the three-phase currents must also rise above the set current pick-up setting.

### VMEM max active time

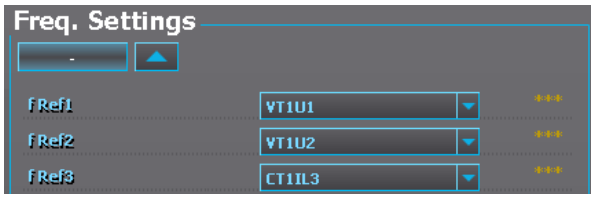
Voltage memory can be active for a specific period of time, set in "VMAX active time". It can be anything between 0.02...50.00 seconds. The function supports the definite time (DT) delay type. It depends on the application for how long the memory should be used. During massive bolted faults, the fault should be cleared and the breaker opened as soon as possible; therefore, a short operating time for voltage memory is usually applied. A typical delay for voltage memory is between 0.5...1.0 s. When the operating time passes and voltage memory is no longer used, directional overcurrent and/or distance protection goes to the unidirectional mode to secure a safe tripping. The memory uses longer operating times when a backup protection is applied (e.g. in distance-protection zones are farther away).

### Forced CT f tracking on VMEM

While fixed frequency tracking is used, all protection stage-based sampling (apart from frequency protection) is based on a set fixed frequency such as 50 Hz or 60 Hz. When the frequency drops massively during a fault while angle memory is in use, it is also possible that the frequency of the system starts to fluctuate. In such cases, if current sampling of used protection stages is based on 50/60 Hz, there could be an error in current magnitude and in angle measurement. To minimize these errors, it is recommended that the frequency is measured and protection-based sampling from the current is performed while voltages are gone.

When the "Forced CT f tracking" parameter is activated and voltages are gone, the frequency from the selected current-based reference channel 3 (the current from IL3) is used for current sampling. This eliminates any possible measurement errors in the fixed frequency mode.

Figure. 5.4.24 - 126. Frequency reference channels.




For example, let us say a 500 A current is measured on the primary side while the fixed frequency is set to 50 Hz. This results in the frequency dropping to 46 Hz, while the actual current measurement would be 460 A. Therefore, the system would have an error of 40 A.

## Events

The voltage memory function (abbreviated "M1VT" in event block names) generates events from the status changes in various activities. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.4.24 - 208. Event messages.

| Event block name | Event names |
|---|---|
| M1VT1 | Voltage memory enabled |
| M1VT1 | Voltage memory disabled |
| M1VT1 | Voltage low detected ON |
| M1VT1 | Voltage low detected OFF |


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| Event block name | Event names |
|---|---|
| M1VT1 | Current high detected ON |
| M1VT1 | Current high detected OFF |
| M1VT1 | Frequency tracked from CT ON |
| M1VT1 | Frequency tracked from CT OFF |
| M1VT1 | Using Voltage memory ON |
| M1VT1 | Using Voltage memory OFF |
| M1VT1 | Voltage memory blocked ON |
| M1VT1 | Voltage memory blocked OFF |

## 5.5 Control functions

### 5.5.1 Common signals

Common signals function has all protection function start and trip signals internally connected to Common START and TRIP output signals. When any of the activated protection functions generate a START or a TRIP signal, Common signals function will also generate the same signal.

The function's outputs are START and TRIP signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START and TRIP events.

### General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.5.1 - 209. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Common force status to | 0: Normal<br>1: Start<br>2: Trip | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

Common signals function has all START and TRIP signals of protection functions internally connected to Common START and TRIP output signals. But it is also possible to assign extra signals to activate Common START and TRIP.

Table. 5.5.1 - 210. Common signals extra inputs.

| Name | Description |
|---|---|
| Common Start In | Assign extra signals to activate common START signal. Please note that all protection function START signals are already assigned internally to Common START. |
| Common Trip In | Assign extra signals to activate common TRIP signal. Please note that all protection function TRIP signals are already assigned internally to Common TRIP. |

### Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.1 - 211. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Common signals condition | 0: Normal<br>1: Start<br>2: Trip | - | Displays status of the function. |

### Function blocking

Common signals function itself doesn't have blocking input signals. Blocking of tripping should be done in each protection function settings.

### Events and registers

The common signals function (abbreviated "GNSIG" in event block names) generates events and registers from the status changes in START and TRIP. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.1 - 212. Event messages.

| Event block name | Event names |
|---|---|
| GNSIG | Common Start ON |
| GNSIG | Common Start OFF |
| GNSIG | Common Trip ON |
| GNSIG | Common Trip OFF |

## 5.5.2 Setting group selection

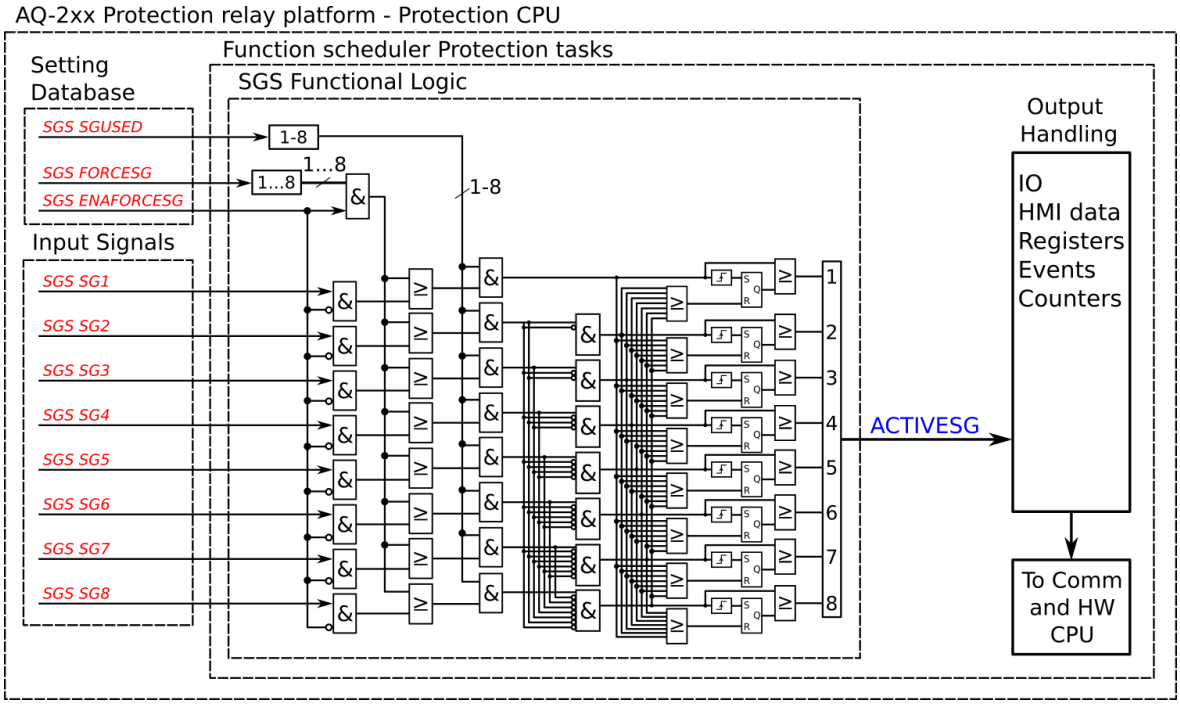
All relay types support up to eight (8) separate setting groups. The Setting group selection function block controls the availability and selection of the setting groups. By default, only Setting group 1 (SG1) is active and therefore the selection logic is idle. When more than one setting group is enabled, the setting group selector logic takes control of the setting group activations based on the logic and conditions the user has programmed.

The following figure presents a simplified function block diagram of the setting group selection function.



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Figure. 5.5.2 - 127. Simplified function block diagram of the setting group selection function.

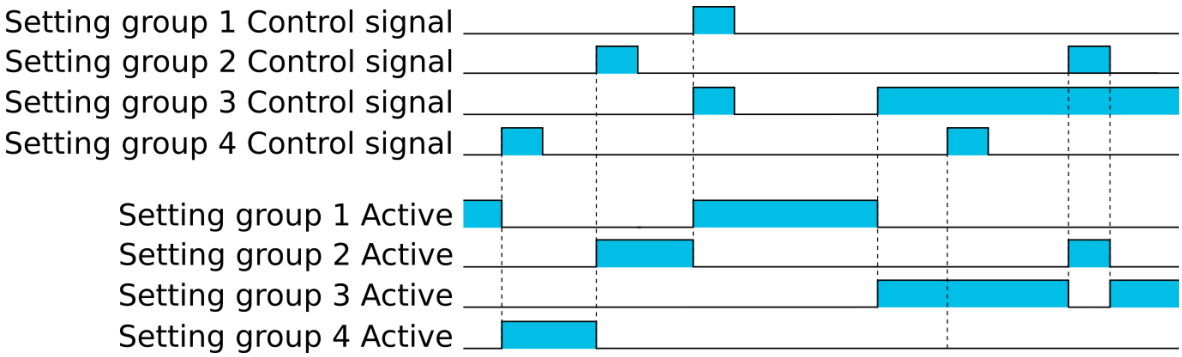



Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs and connected digital inputs. The user can also force any of the setting groups on when the "Force SG change" setting is enabled by giving the wanted quantity of setting groups as a number in the communication bus or in the local HMI, or by selecting the wanted setting group from *Control → Setting groups*. When the forcing parameter is enabled, the automatic control of the local device is overridden and the full control of the setting groups is given to the user until the "Force SG change" is disabled again.

Setting groups can be controlled either by pulses or by signal levels. The setting group controller block gives setting groups priority values for situations when more than one setting group is controlled at the same time: the request from a higher-priority setting group is taken into use.

Setting groups follow a hierarchy in which setting group 1 has the highest priority, setting group 2 has second highest priority etc. If a static activation signal is given for two setting groups, the setting group with higher priority will be active. If setting groups are controlled by pulses, the setting group activated by pulse will stay active until another setting groups receives and activation signal.

Figure. 5.5.2 - 128. Example sequences of group changing (control with pulse only, or with both pulses and static signals).



## Settings and signals

The settings of the setting group control function include the active setting group selection, the forced setting group selection, the enabling (or disabling) of the forced change, the selection of the number of active setting groups in the application, as well as the selection of the setting group changed remotely. If the setting group is forced to change, the corresponding setting group must be enabled and the force change must be enabled. Then, the setting group can be set from communications or from HMI to any available group. If the setting group control is applied with static signals right after the "Force SG" parameter is released, the application takes control of the setting group selection.

Table. 5.5.2 - 213. Settings of the setting group selection function.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Active setting group | | | SG1 | Displays which setting group is active. |
| Force setting group | 0: None<br>1: SG1<br>2: SG2<br>3: SG3<br>4: SG4<br>5: SG5<br>6: SG6<br>7: SG7<br>8: SG8 | - | 0: None | The selection of the overriding setting group. After "Force SG change" is enabled, any of the configured setting groups in the relay can be overriden. This control is always based on the pulse operating mode. It also requires that the selected setting group is specifically controlled to ON after "Force SG" is disabled. If there are no other controls, the last set setting group remains active. |
| Force setting group change | 0: Disabled<br>1: Enabled | - | 0: Disabled | The selection of whether the setting group forcing is enabled or disabled. This setting has to be active before the setting group can be changed remotely or from a local HMI. This parameter overrides the local control of the setting groups and it remains on until the user disables it. |
| Used setting groups | 0: SG1<br>1: SG1...2<br>2: SG1...3<br>3: SG1...4<br>4: SG1...5<br>5: SG1...6<br>6: SG1...7<br>7: SG1...8 | - | 0: SG1 | The selection of the activated setting groups in the application. Newly-enabled setting groups use default parameter values. |
| Remote setting group change | 0: None<br>1: SG1<br>2: SG2<br>3: SG3<br>4: SG4<br>5: SG5<br>6: SG6<br>7: SG7<br>8: SG8 | - | 0: None | This parameter can be controlled through SCADA to change the setting group remotely. Please note that if a higher priority setting group is being controlled by a signal, a lower priority setting group cannot be activated with this parameter. |

Table. 5.5.2 - 214. Signals of the setting group selection function.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Setting group 1 | 0: Not active<br>1: Active | - | 0: Not active | The selection of Setting group 1 ("SG1"). Has the highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no other SG requests will be processed. |



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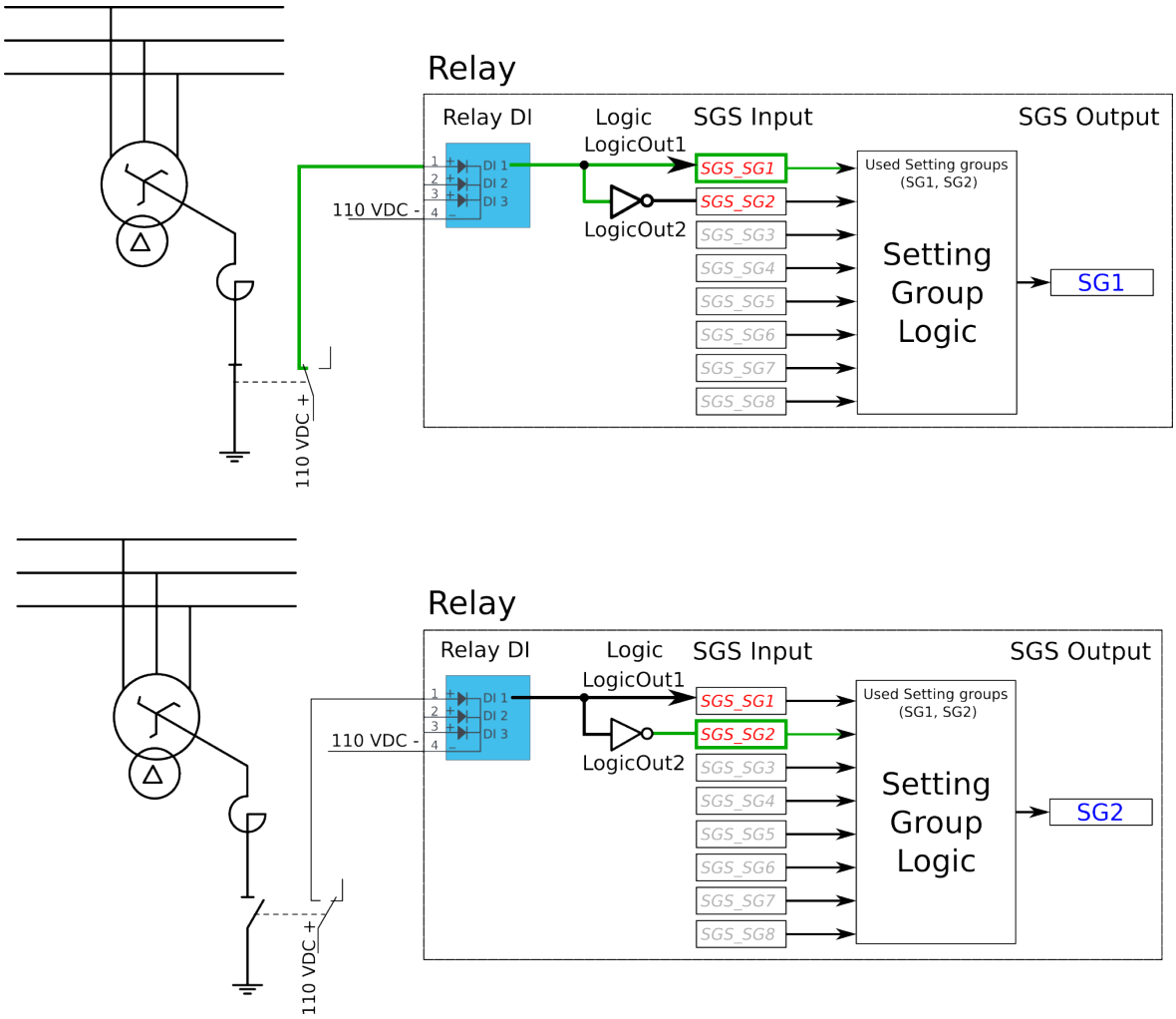
| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Setting group 2 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 2 ("SG2"). Has the second highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1 will be processed. |
| Setting group 3 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 3 ("SG3"). Has the third highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1 and SG2 will be processed. |
| Setting group 4 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 4 ("SG4"). Has the fourth highest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, no requests with a lower priority than SG1, SG2 and SG3 will be processed. |
| Setting group 5 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 5 ("SG5"). Has the fourth lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, SG6, SG7 and SG8 requests will not be processed. |
| Setting group 6 | 0:Not active 1:Active | - | 0:Not active | The selection of Setting group 6 ("SG6"). Has the third lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, SG7 and SG8 requests will not be processed. |
| Setting group 7 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 7 ("SG7"). Has the second lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, only SG8 requests will not be processed. |
| Setting group 8 | 0: Not active 1: Active | - | 0: Not active | The selection of Setting group 8 ("SG8"). Has the lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, all other SG requests will be processed regardless of the signal status of this setting group. |

## Example applications for setting group control

This chapter presents some of the most common applications for setting group changing requirements.

A Petersen coil compensated network usually uses directional sensitive earth fault protection. The user needs to control its characteristics between varmetric and wattmetric; the selection is based on whether the Petersen coil is connected when the network is compensated, or whether it is open when the network is unearthed.

Figure. 5.5.2 - 129. Setting group control – one-wire connection from Petersen coil status.




Depending on the application's requirements, the setting group control can be applied either with a one-wire connection or with a two-wire connection by monitoring the state of the Petersen coil connection.

When the connection is done with one wire, the setting group change logic can be applied as shown in the figure above. The status of the Petersen coil controls whether Setting group 1 is active. If the coil is disconnected, Setting group 2 is active. This way, if the wire is broken for some reason, the setting group is always controlled to SG2.



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Figure. 5.5.2 - 130. Setting group control – two-wire connection from Petersen coil status.

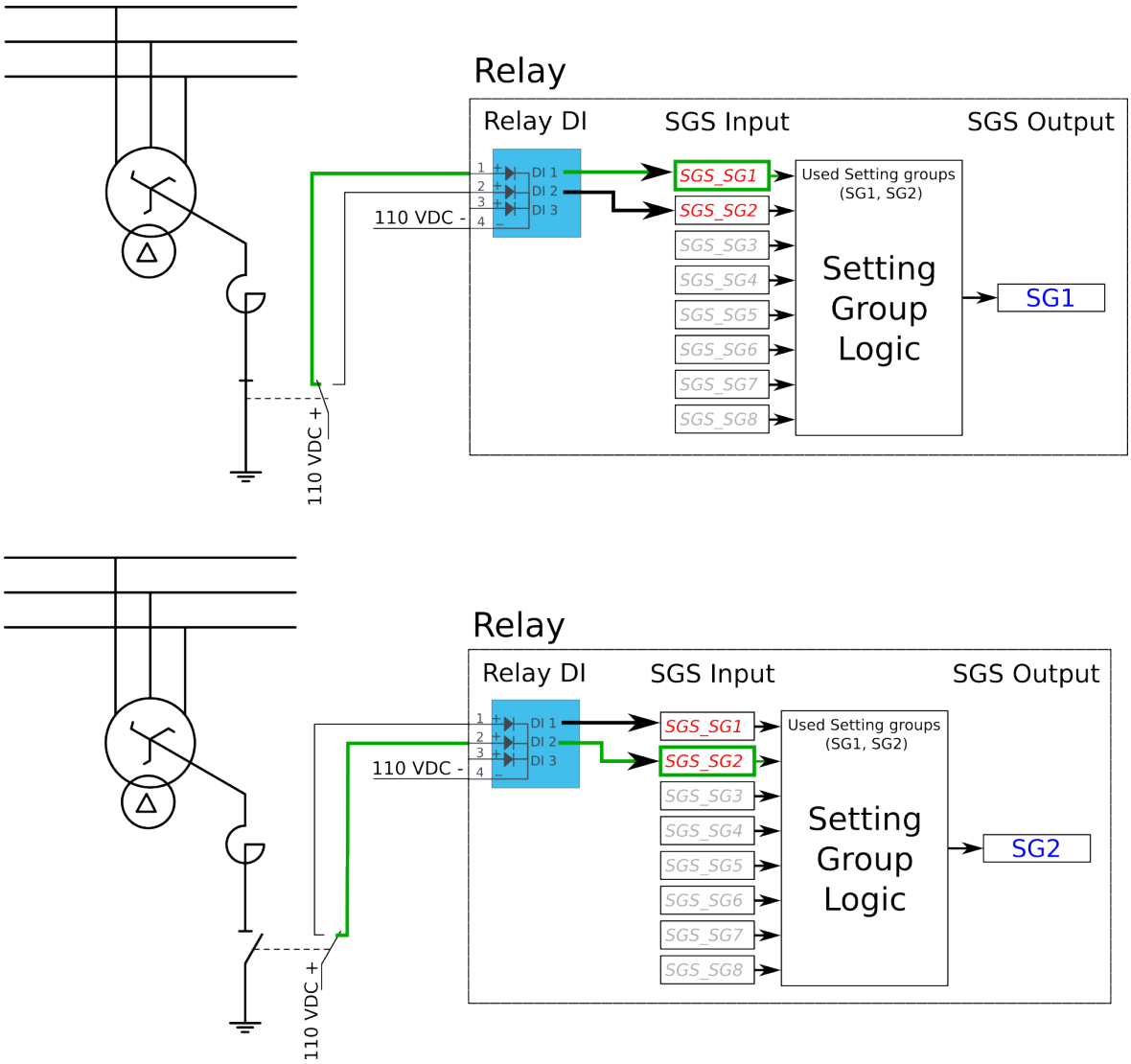
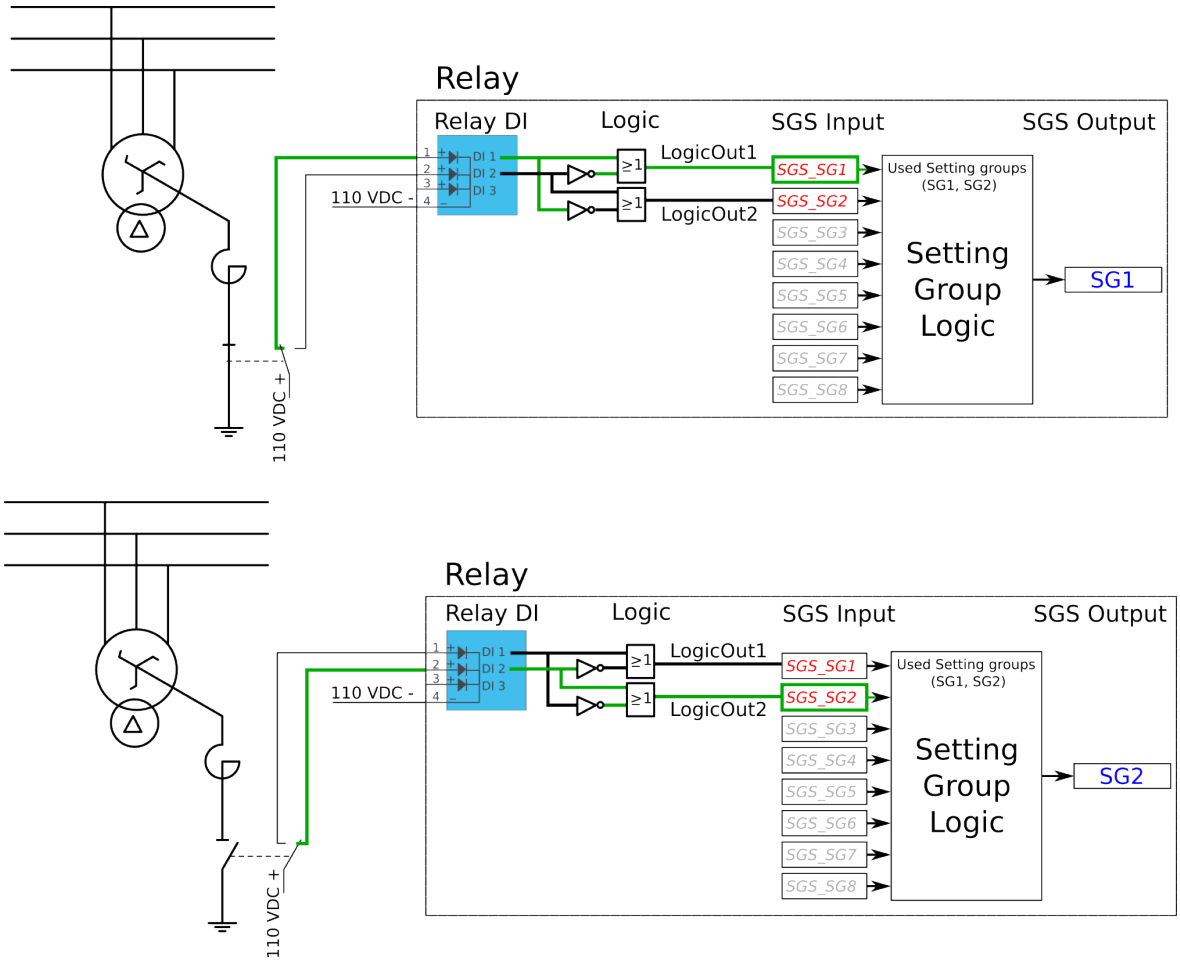


Figure. 5.5.2 - 131. Setting group control – two-wire connection from Petersen coil status with additional logic.



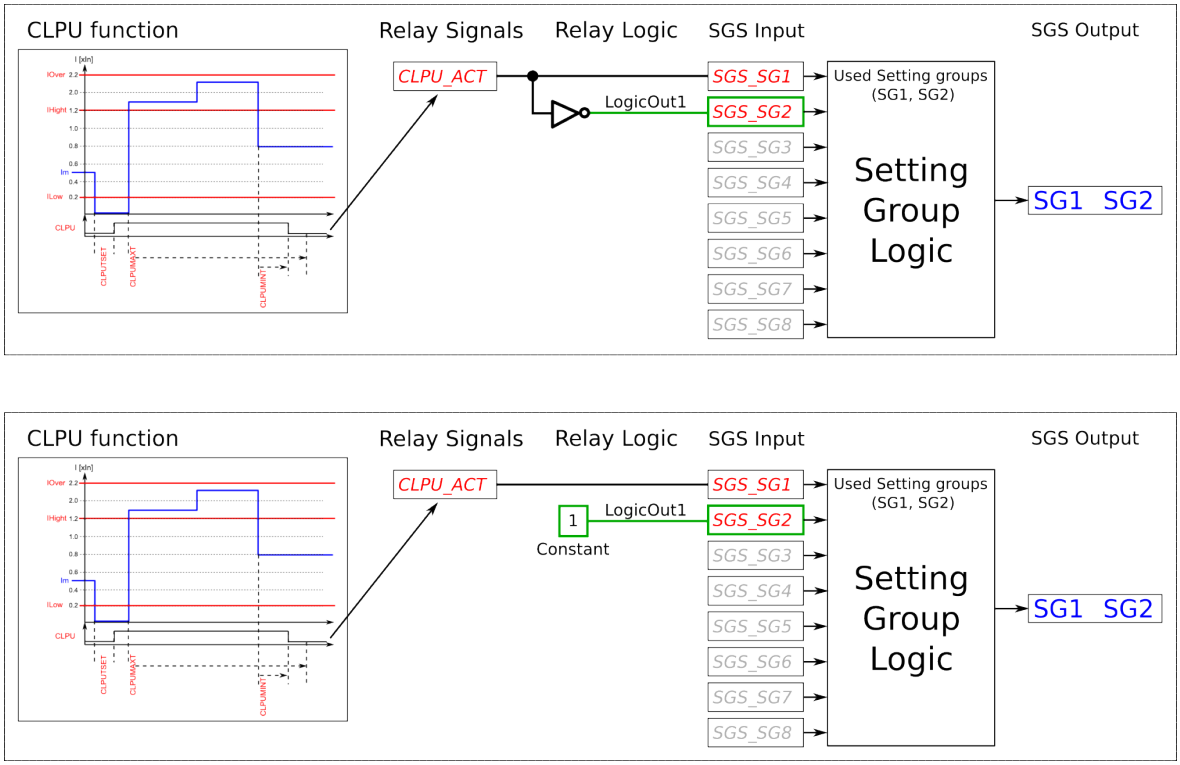

The images above depict a two-wire connection from the Petersen coil: the two images at the top show a direct connection, while the two images on the bottom include additional logic. With a two-wire connection the state of the Petersen coil can be monitored more securely. The additional logic ensures that a single wire loss will not affect the correct setting group selection.

The application-controlled setting group change can also be applied entirely from the relay's internal logics. For example, the setting group change can be based on the cold load pick-up function (see the image below).



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IM00015

Figure. 5.5.2 - 132. Entirely application-controlled setting group change with the cold load pick-up function.




In these examples the cold load pick-up function's output is used for the automatic setting group change. Similarly to this application, any combination of the signals available in the relay's database can be programmed to be used in the setting group selection logic.

As all these examples show, setting group selection with application control has to be built fully before they can be used for setting group control. The setting group does not change back to SG1 unless it is controlled back to SG1 by this application; this explains the inverted signal NOT as well as the use of logics in setting group control. One could also have SG2 be the primary SG, while the ON signal would be controlled by the higher priority SG1; this way the setting group would automatically return to SG2 after the automatic control is over.

## Events

The setting group selection function block (abbreviated "SGS" in event block names) generates events from its controlling status, its applied input signals, enabling and disabling of setting groups, as well as unsuccessful control changes. The function does not have a register.

Table. 5.5.2 - 215. Event messages.

| Event block name | Event names |
|---|---|
| SGS | SG2 Enabled |
| SGS | SG2 Disabled |
| SGS | SG3 Enabled |
| SGS | SG3 Disabled |
| SGS | SG4 Enabled |
| SGS | SG4 Disabled |
| SGS | SG5 Enabled |
| SGS | SG5 Disabled |

| Event block name | Event names |
|---|---|
| SGS | SG6 Enabled |
| SGS | SG6 Disabled |
| SGS | SG7 Enabled |
| SGS | SG7 Disabled |
| SGS | SG8 Enabled |
| SGS | SG8 Disabled |
| SGS | SG1 Request ON |
| SGS | SG1 Request OFF |
| SGS | SG2 Request ON |
| SGS | SG2 Request OFF |
| SGS | SG3 Request ON |
| SGS | SG3 Request OFF |
| SGS | SG4 Request ON |
| SGS | SG4 Request OFF |
| SGS | SG5 Request ON |
| SGS | SG5 Request OFF |
| SGS | SG6 Request ON |
| SGS | SG6 Request OFF |
| SGS | SG7 Request ON |
| SGS | SG7 Request OFF |
| SGS | SG8 Request ON |
| SGS | SG8 Request OFF |
| SGS | Remote Change SG Request ON |
| SGS | Remote Change SG Request OFF |
| SGS | Local Change SG Request ON |
| SGS | Local Change SG Request OFF |
| SGS | Force Change SG ON |
| SGS | Force Change SG OFF |
| SGS | SG Request Fail Not configured SG ON |
| SGS | SG Request Fail Not configured SG OFF |
| SGS | Force Request Fail Force ON |
| SGS | Force Request Fail Force OFF |
| SGS | SG Req. Fail Lower priority Request ON |
| SGS | SG Req. Fail Lower priority Request OFF |
| SGS | SG1 Active ON |
| SGS | SG1 Active OFF |
| SGS | SG2 Active ON |
| SGS | SG2 Active OFF |



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| Event block name | Event names |
|---|---|
| SGS | SG3 Active ON |
| SGS | SG3 Active OFF |
| SGS | SG4 Active ON |
| SGS | SG4 Active OFF |
| SGS | SG5 Active ON |
| SGS | SG5 Active OFF |
| SGS | SG6 Active ON |
| SGS | SG6 Active OFF |
| SGS | SG7 Active ON |
| SGS | SG7 Active OFF |
| SGS | SG8 Active ON |
| SGS | SG8 Active OFF |

### 5.5.3 Object control and monitoring

The object control and monitoring function takes care of both for circuit breakers and disconnectors. The monitoring and controlling are based on the statuses of the relay's configured digital inputs and outputs. The number of controllable and monitored objects in each relay depends on the device type and amount of digital inputs. One controllable object requires a minimum of two (2) output contacts. The status monitoring of one monitored object usually requires two (2) digital inputs. Alternatively, object status monitoring can be performed with a single digital input: the input's active state and its zero state (switched to 1 with a NOT gate in the Logic editor).

An object can be controlled manually or automatically. Manual control can be done by local control, or by remote control. Local manual control can be done by relays front panel (HMI) or by external push buttons connected to relays digital inputs. Manual remote control can be done through one of the various communication protocols available (Modbus, IEC101/103/104 etc.). The function supports the modes "Direct control" and "Select before execute" while controlled remotely. Automatic controlling can be done with functions like auto-reclosing function (ANSI 79).

Object control consists of the following:

- control logic
- control monitor
- output handler.

The main outputs of the function are the OBJECT OPEN and OBJECT CLOSE control signals. Additionally, the function reports the monitored object's status and applied operations. The setting parameters are static inputs for the function, which can only be changed by the user in the function's setup phase.

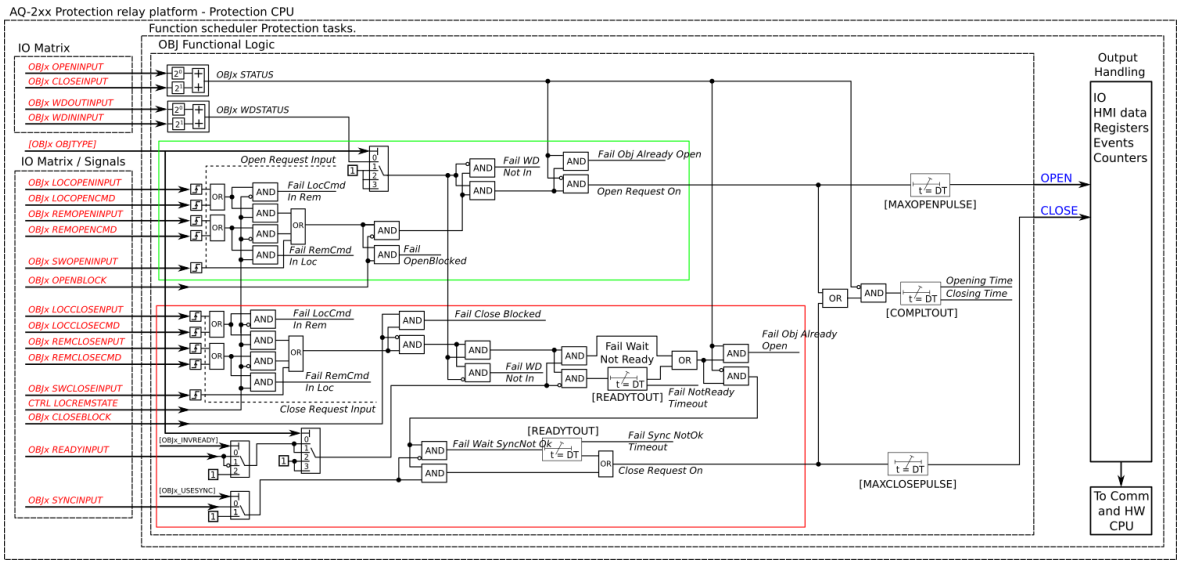
The inputs for the function are the following:

- digital input status indications (the OPEN and CLOSE status signals)
- blockings (if applicable)
- the OBJECT READY and SYNCHROCHECK monitor signals (if applicable).
- Withdrawable cart IN and OUT status signals (if applicable).

The function generates general time stamped ON/OFF events to the common event buffer from each of the two (2) output signals as well as several operational event signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAILED, and CLOSE FAILED events.

The following figure presents a simplified function block diagram of the object control and monitoring function.

Figure. 5.5.3 - 133. Simplified function block diagram of the object control and monitoring function.




## Settings

The following parameters help the user to define the object. The operation of the function varies based on these settings and the selected object type. The selected object type determines how much control is needed and which setting parameters are required to meet those needs.

Table. 5.5.3 - 216. Object settings and status parameters.

| Name | Range | Default | Description |
|---|---|---|---|
| Local/Remote status | 0: Local<br>1: Remote | 1: Remote | Displays the status of the relay's "local/remote" switch. Local controls cannot override the open and close commands while device is in "Remote" status. The remote controls cannot override the open and close commands while device is in "Local" status. |



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| Name | Range | Default | Description |
|---|---|---|---|
| Object status force to | 0: Normal<br>1: Openreq On<br>2: Closereq On<br>3: Opensignal On<br>4: Closesignal On<br>5: WaitNoRdy On<br>6: WaitNoSnc On<br>7: NotrdyFail On<br>8: NosyncFail On<br>9: Opentout On<br>10: Clotout On<br>11: OpenreqUSR On<br>12: CloreqUSR On | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| OBJ LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 1: On | Set mode of OBJ block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| OBJ LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of OBJ block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Object name | - | Objectx | The user-set name of the object, at maximum 32 characters long. |
| Object type | 0: Withdrawable circuit breaker<br>1: Circuit breaker<br>2: Disconnector (MC)<br>3: Disconnector (GND) | 1: Circuit breaker | The selection of the object type. This selection defines the number of required digital inputs for the monitored object. This affects the symbol displayed in the HMI and the monitoring of the circuit breaker. It also affects whether the withdrawable cart is in/out status is monitored. See the next table ("Object types") for a more detailed look at which functionalities each of the object types have. |
| Objectx Breaker status | 0: Intermediate<br>1: Open<br>2: Closed<br>3: Bad | - | Displays the status of breaker. Intermediate is displayed when neither of the status signals (open or close) are active. Bad status is displayed when both status signals (open and close) are active. |
| Objectx Withdraw status | 0: WDIntermediate<br>1: WDCartOut<br>2: WDCart In<br>3: WDBad<br>4: Not in use | - | Displays the status of circuit breaker cart. WDIntermediate is displayed when neither of the status signals (in or out) are active. WDBad status is displayed when both status signals (in and out) are active. If the selected object type is not set to "Withdrawable circuit breaker", this setting displays the "No in use" option. |
| Additional status information | 0: Open Blocked<br>1: Open Allowed<br>2: Close Blocked<br>3: Close Allowed<br>4: Object Ready<br>5: Object Not Ready<br>6: Sync Ok<br>7: Sync Not Ok | - | Displays additional information about the status of the object. |

| Name | Range | Default | Description |
|---|---|---|---|
| Use Synchrocheck | 0: Not in use<br>1: Synchrocheck in use | 0: Not in use | Selects whether the "Synchrocheck" condition is in use for the circuit breaker close command. If "In use" is selected the input chosen to "Sync.check status in" has to be active to be able to close circuit breaker.<br><br>Synchrocheck status can be either an internal signal generated by synchrocheck function or digital input activation with an external synchrocheck device. |
| Use Object ready | 0: Ready High<br>1: Ready Low<br>2: Not in use | 2: Not in use | Selects whether the "Object ready" condition is in use for the circuit breaker close command. If in use the signal connected to "Object ready status In" has to be high or low to be able to close the breaker (depending on "Ready High or Low" selection). |
| Open requests | 0…$2^{32}$–1 | - | Displays the number of successful "Open" requests. |
| Close requests | 0…$2^{32}$–1 | - | Displays the number of successful "Close" requests. |
| Open requests failed | 0…$2^{32}$–1 | - | Displays the number of failed "Open" requests. |
| Close requests failed | 0…$2^{32}$–1 | - | Displays the number of failed "Close" requests. |
| Clear statistics | 0: -<br>1: Clear | 0: - | Clears the request statistics, setting them back to zero (0). Automatically returns to "-" after the clearing is finished. |

Table. 5.5.3 - 217. Object types.

| Name | Functionalities | Description |
|---|---|---|
| Withdrawable circuit breaker | Breaker cart position<br>Circuit breaker position<br>Circuit breaker control<br>Object ready check before closing breaker<br>Synchrochecking before closing breaker<br>Interlocks | The monitor and control configuration of the withdrawable circuit breaker. |
| Circuit breaker | Position indication<br>Control<br>Object ready check before closing breaker<br>Synchrochecking before closing breaker<br>Interlocks | The monitor and control configuration of the circuit breaker. |
| Disconnector (MC) | Position indication<br>Control | The position monitoring and control of the disconnector. |
| Disconnector (GND) | Position indication | The position indication of the earth switch. |

Table. 5.5.3 - 218. I/O.

| Signal | Range | Description |
|---|---|---|
| Objectx Open input ("Objectx Open Status In") | Digital input or other logical signal selected by the user<br><br>(SWx) | A link to a physical digital input. The monitored object's OPEN status. "1" refers to the active open state of the monitored object. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Objectx Close input ("Objectx Close Status In") | | A link to a physical digital input. The monitored object's CLOSE status. "1" refers to the active close state of the monitored object. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| WD Object In ("Withdrw.CartIn.Status In") | | A link to a physical digital input. The monitored withdrawable object's position is IN. "1" means that the withdrawable object cart is in. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |


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| Signal | Range | Description |
|---|---|---|
| WD Object Out ("Withdrw.CartOut.Status In") | | A link to a physical digital input. The monitored withdrawable object's position is OUT. "1" means that the withdrawable object cart is pulled out. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Object Ready (Objectx Ready status In") | | A link to a physical digital input. Indicates that status of the monitored object. "1" means that the object is ready and the spring is charged for a close command. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Syncrocheck permission ("Sync.Check status In") | | A link to a physical digital input or a synchrocheck function. "1" means that the synchrocheck conditions are met and the object can be closed. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Objectx Open command ("Objectx Open Command") | OUT1…OUTx | The physical "Open" command pulse to the device's output relay. |
| Objectx Close command ("Objectx Close Command") | | The physical "Close" command pulse to the device's output relay. |

Table. 5.5.3 - 219. Operation settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Breaker traverse time | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum time between open and close statuses when the breaker switches. If this set time is exceeded and both open and closed status inputs are active, the status "Bad" is activated in the "Objectx Breaker status" setting. If neither of the status inputs are active after this delay, the status "Intermediate" is activated. |
| Maximum Close command pulse length | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum length for a Close pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected. |
| Maximum Open command pulse length | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum length for a Open pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected. |
| Control termination timeout | 0.02…500.00 s | 0.02 s | 10 s | Determines the control pulse termination timeout. If the object has not changed it status in this given time the function will issue error event and the control is ended. This parameter is common for both open and close commands. |
| Final trip pulse length | 0.00…500.00 s | 0.02 s | 0.2 s | Determines the length of the final trip pulse length. When the object has executed the final trip, this signal activates. If set to 0 s, the signal is continuous. If auto-recloser function controls the object, "final trip" signal is activated only when there are no automatic reclosings expected after opening the breaker. |

Table. 5.5.3 - 220. Control settings (DI and Application).

| Signal | Range | Description |
|---|---|---|
| Access level for MIMIC control | 0: User<br>1: Operator<br>2: Configurator<br>3: Super user | Defines what level of access is required for MIMIC control. The default is the "Configurator" level. |
| Objectx LOCAL Close control input | Digital input or other logical signal selected by the user | The local Close command from a physical digital input (e.g. a push button). |
| Objectx LOCAL Open control input | | The local Open command from a physical digital input (e.g. a push button). |

| Signal | Range | Description |
|---|---|---|
| Objectx REMOTE Close control input | | The remote Close command from a physical digital input (e.g. RTU). |
| Objectx REMOTE Open control input | | The remote Open command from a physical digital input (e.g. RTU). |
| Objectx Application Close | | The Close command from the application. Can be any logical signal. |
| Objectx Application Open | | The Close command from the application. Can be any logical signal. |

## Blocking and interlocking

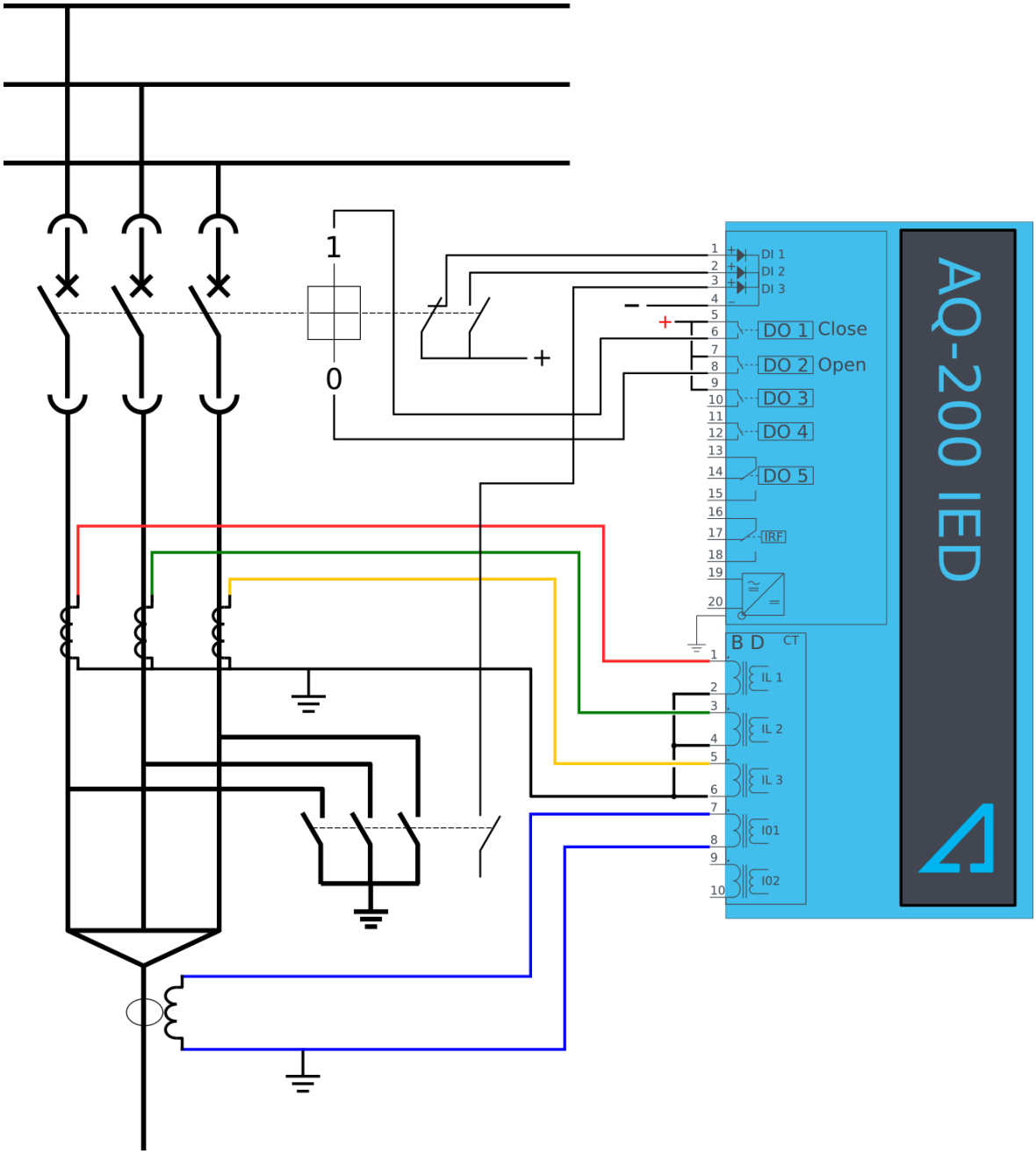
The interlocking and blocking conditions can be set for each controllable object, with Open and Close set separately. Blocking and interlocking can be based on any of the following: other object statuses, a software function or a digital input.

The image below presents an example of an interlock application, where the closed earthing switch interlocks the circuit breaker close command.



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Figure. 5.5.3 - 134. Example of an interlock application.

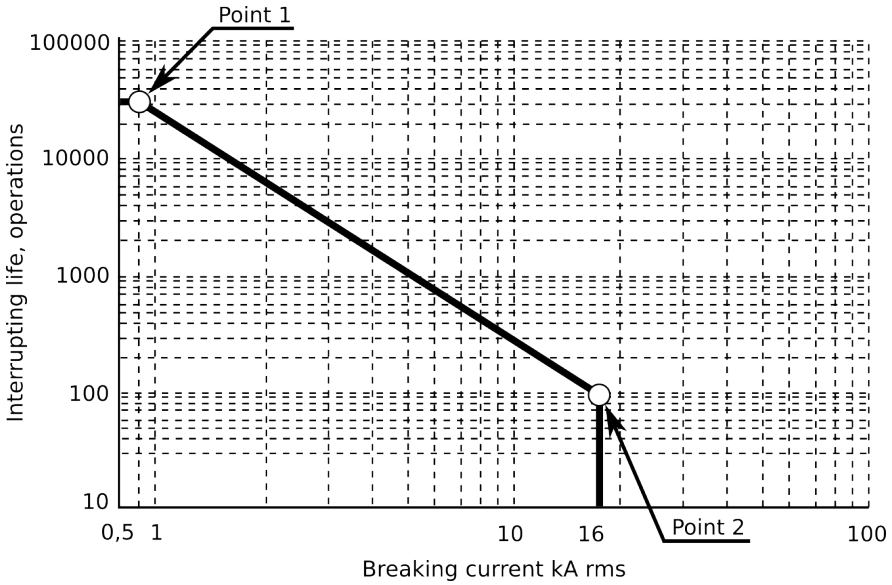



In order for the blocking signal to be received on time, it has to reach the function 5 ms before the control command.

## Object condition monitoring (circuit breaker wear monitor)

Each object has integrated circuit breaker wear monitor. The circuit breaker wear function is used for monitoring the circuit breaker's lifetime and its maintenance needs caused by interrupting currents and mechanical wear. The function uses the circuit breaker's manufacturer-supplied data for the breaker operating cycles in relation to the interrupted current magnitudes.

Figure. 5.5.3 - 135. Example of the circuit breaker interrupting life operations. Points 1 and 2 are user settable.




The function is triggered from the circuit breaker's "Open" command output and it monitors the three-phase current values in both the tripping moment and the normal breaker opening moment. The maximum value of interrupting life operations for each phase is calculated from these currents. The value is cumulatively deducted from the starting operations starting value. The user can set up two separate alarm levels, which are activated when the value of interrupting life operations is below the setting limit. The "Trip contact" setting defines the output that triggers the current monitoring at the breaker's "Open" command. The function's outputs are ALARM 1 and ALARM 2 signals which can be used for direct I/O controlling and user logic programming.

The function block uses analog current measurement values and always uses the RMS magnitude of the current measurement input.

Table. 5.5.3 - 221. Measurement inputs of the circuit breaker wear function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |

Condition monitoring parameters can be found from *Control → Objects → Object X → APP CONTR → Condition Monitoring*.

Table. 5.5.3 - 222. Breaker supervision settings and status indications.

| Name | Range | Default | Description |
|---|---|---|---|
| Condition monitoring | 0: Disabled<br>1: Enabled | 0: Disabled | Enabled the breaker condition monitoring function. |
| Condition monitor status | 0: Normal<br>1: Alarm1 On<br>2: Alarm2 On | - | Displays the status of the monitor. |
| Open operations | 0...4 294 967 295 | - | Displays the total amount of breaker open operations. |
| Operation time open | 0...4 294 967 295 ms | - | Displays the latest breaker opening time. |



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| Name | Range | Default | Description |
|---|---|---|---|
| Close operations | 0...4 294 967 295 | - | Displays the total amount of breaker close operations. |
| Operation time close | 0...4 294 967 295 ms | - | Displays the latest breaker closing time. |
| L1 Operations Left | 0...4 294 967 295 | - | Displays the amount of operations left in each phase. |
| L2 Operations Left | | | |
| L3 Operations Left | | | |
| Object Cumulated operations | 0...4 294 967 295 | - | Displays the total amount of operations. |
| Clear condition monitoring statistics | 0: -<br>1: Clear | - | Clears the operation statistics. |
| Operations with Current 1 Value allowed | 0...200 000 | 50000 | Defines the amount of operations with lower current values. See figure above. |
| Current 1 Value | 0.00...100.00 kA | 1.00 kA | Defines the lower current turnpoint. See figure above. |
| Operations with Current 2 Value allowed | 0...200 000 | 100 | Defines amount of operations with higher current values. See figure above. |
| Current 2 Value | 0.00...100.00 kA | 20.00 kA | Defines the higher current turnpoint. See figure above. |
| Condition Alarm 1 Enable | 0: Disabled<br>1: Enabled | 0: Disabled | Enables Alarm 1. |
| Condition Alarm 1 when operations less than | 0...200 000 | 1000 | When the amount of operations left is less than value set here, Alarm 1 will activate. |
| Condition Alarm 2 Enable | 0: Disabled<br>1: Enabled | 0: Disabled | Enables Alarm 2. |
| Condition Alarm 2 when operations less than | 0...200 000 | 100 | When the amount of operations left is less than value set here, Alarm 2 will activate. |

## Events and registers

The object control and monitoring function (abbreviated "OBJ" in event block names) generates events and registers from the status changes in monitored signals as well as control command fails and operations. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The function registers its operation into the last twelve (12) time-stamped registers. The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.3 - 223. Event messages of the OBJ function instances 1 – 10.

| Event block name | Description |
|---|---|
| OBJ1...OBJ10 | Object Intermediate |
| OBJ1...OBJ10 | Object Open |
| OBJ1...OBJ10 | Object Close |
| OBJ1...OBJ10 | Object Bad |
| OBJ1...OBJ10 | WD Intermediate |
| OBJ1...OBJ10 | WD Out |
| OBJ1...OBJ10 | WD in |

| Event block name | Description |
|---|---|
| OBJ1...OBJ10 | WD Bad |
| OBJ1...OBJ10 | Open Request On |
| OBJ1...OBJ10 | Open Request Off |
| OBJ1...OBJ10 | Open Command On |
| OBJ1...OBJ10 | Open Command Off |
| OBJ1...OBJ10 | Close Request On |
| OBJ1...OBJ10 | Close Request Off |
| OBJ1...OBJ10 | Close Command On |
| OBJ1...OBJ10 | Close Command Off |
| OBJ1...OBJ10 | Open Blocked On |
| OBJ1...OBJ10 | Open Blocked Off |
| OBJ1...OBJ10 | Close Blocked On |
| OBJ1...OBJ10 | Close Blocked Off |
| OBJ1...OBJ10 | Object Ready |
| OBJ1...OBJ10 | Object Not Ready |
| OBJ1...OBJ10 | Sync Ok |
| OBJ1...OBJ10 | Sync Not Ok |
| OBJ1...OBJ10 | Open Command Fail |
| OBJ1...OBJ10 | Close Command Fail |
| OBJ1...OBJ10 | Final trip On |
| OBJ1...OBJ10 | Final trip Off |
| OBJ1...OBJ10 | Contact Abrasion Alarm On |
| OBJ1...OBJ10 | Contact Abrasion Alarm Off |
| OBJ1...OBJ10 | Switch Operating Time Exceeded On |
| OBJ1...OBJ10 | Switch Operating Time Exceeded Off |
| OBJ1...OBJ10 | XCBR Loc On |
| OBJ1...OBJ10 | XCBR Loc Off |
| OBJ1...OBJ10 | XSWI Loc On |
| OBJ1...OBJ10 | XSWI LOC Off |

Table. 5.5.3 - 224. Register content.

| Name | Description |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| Recorded Object opening time | Time difference between the object receiving an "Open" command and the object receiving the "Open" status. |
| Recorded Object closing time | Time difference between the object receiving a "Close" command and object receiving the "Closed" status. |
| Object status | The status of the object. |



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| Name | Description |
|---|---|
| WD status | The status of the withdrawable circuit breaker. |
| Open fail | The cause of an "Open" command's failure. |
| Close fail | The cause of a "Close" command's failure. |
| Open command | The source of an "Open" command. |
| Close command | The source of an "Open" command. |
| General status | The general status of the function. |

### 5.5.4 Single-pole object control and monitoring

The single-pole object control and monitoring function takes care of both for circuit breakers and disconnectors. The monitoring and controlling are based on the statuses of the relay's configured digital inputs and outputs. The number of controllable and monitored objects in each relay depends on the device type and amount of digital inputs. One controllable single-pole object requires a minimum of four (4) output contacts. The status monitoring of single-pole object usually requires six (6) digital inputs. Alternatively, object status monitoring can be performed with a three digital inputs: the input's active state and its zero state (switched to 1 with a NOT gate in the Logic editor).

An object can be controlled manually or automatically. Manual control can be done by local control, or by remote control. Local manual control can be done by relays front panel (HMI) or by external push buttons connected to relays digital inputs. Manual remote control can be done through one of the various communication protocols available (IEC 61650, Modbus, IEC101/103/104 etc.). The function supports the modes "Direct control" and "Select before execute" while controlled remotely. Automatic controlling can be done with functions like auto-reclosing function (ANSI 79).

Object control consists of the following:

- control logic
- control monitor
- output handler.

The main outputs of the function are the OBJECT OPEN and OBJECT CLOSE control signals. Additionally, the function reports the monitored object's status and applied operations. The setting parameters are static inputs for the function, which can only be changed by the user in the function's setup phase.

The inputs for the function are the following:

- digital input status indications (the OPEN and CLOSE status signals)
- blockings (if applicable)
- the OBJECT READY and SYNCHROCHECK monitor signals (if applicable).
- Withdrawable cart IN and OUT status signals (if applicable).

The function generates general time stamped ON/OFF events to the common event buffer from each of the two (2) output signals as well as several operational event signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAILED, and CLOSE FAILED events.

The following figure presents a simplified function block diagram of the object control and monitoring function.

## Settings

The following parameters help the user to define the object. The operation of the function varies based on these settings and the selected object type. The selected object type determines how much control is needed and which setting parameters are required to meet those needs.

Table. 5.5.4 - 225. Object set and status.

| Name | Range | Default | Description |
|---|---|---|---|
| Local/Remote status | 0: Local<br>1: Remote | 1: Remote | Displays the status of the relay's "local/remote" switch. Local controls cannot override the open and close commands while device is in "Remote" status. The remote controls cannot override the open and close commands while device is in "Local" status. |
| OBJS LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 1: On | Set mode of OBJS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| OBJS LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of OBJ block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Single-pole object operating mode | 0: PhaseWise<br>1: SinglePhase<br>2: ThreePhase | 0: Phase | Selects the operating mode of the object. PhaseWise opens all breakers if more than one phase gets open command. Three phase mode always opens every phase. Single phase mode opens each phase individually. |
| Single-pole object force status to | 0: Normal<br>1: OpenL1 On<br>2: OpenL2 On<br>3: OpenL3 On<br>4: Closesignal On<br>5: WaitNoRdy On<br>6: WaitNoSnc On<br>7: NotrdyFail On<br>8: NosyncFail On<br>9: Opentout On<br>10: Clotout On<br>11: OpenreqUSR On<br>12: CloreqUSR On | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Object name | - | Objectx | The user-set name of the object, at maximum 32 characters long. |
| Object type | 0: Withdrawable circuit breaker<br>1: Circuit breaker<br>2: Disconnector (MC)<br>3: Disconnector (GND) | 1: Circuit breaker | The selection of the object type. This selection defines the number of required digital inputs for the monitored object. This affects the symbol displayed in the HMI and the monitoring of the circuit breaker. It also affects whether the withdrawable cart is in/out status is monitored. See the next table ("Object types") for a more detailed look at which functionalities each of the object types have. |
| Single-pole object Breaker status A/B/C | 0: Intermediate<br>1: Open<br>2: Closed<br>3: Bad | - | Displays the status of each phase. Intermediate is displayed when neither of the status signals (open or close) are active. Bad status is displayed when both status signals (open and close) are active. |



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| Name | Range | Default | Description |
|---|---|---|---|
| Objectx Withdraw status | 0: WDIntermediate<br>1: WDCartOut<br>2: WDCart In<br>3: WDBad<br>4: Not in use | - | Displays the status of circuit breaker cart. WDIntermediate is displayed when neither of the status signals (in or out) are active. WDBad status is displayed when both status signals (in and out) are active. If the selected object type is not set to "Withdrawable circuit breaker", this setting displays the "No in use" option. |
| Additional status information | 0: Open Blocked<br>1: Open Allowed<br>2: Close Blocked<br>3: Close Allowed<br>4: Object Ready<br>5: Object Not Ready<br>6: Sync Ok<br>7: Sync Not Ok | - | Displays additional information about the status of the object. |
| Use Synchrocheck | 0: Not in use<br>1: Synchrocheck in use | 0: Not in use | Selects whether the "Synchrocheck" condition is in use for the circuit breaker close command. If "In use" is selected the input chosen to "Sync.check status in" has to be active to be able to close circuit breaker.<br><br>Synchrocheck status can be either an internal signal generated by synchrocheck function or digital input activation with an external synchrocheck device. |
| Use Object ready | 0: Ready High<br>1: Ready Low<br>2: Not in use | 2: Not in use | Selects whether the "Object ready" condition is in use for the circuit breaker close command. If in use the signal connected to "Object ready status In" has to be high or low to be able to close the breaker (depending on "Ready High or Low" selection). |
| Open commands A/B/C | $0…2^{32}–1$ | - | Displays the number of successful "Open" requests. |
| Close commands | $0…2^{32}–1$ | - | Displays the number of successful "Close" requests. |
| Open requests failed A/B/C | $0…2^{32}–1$ | - | Displays the number of failed "Open" requests. |
| Close requests failed | $0…2^{32}–1$ | - | Displays the number of failed "Close" requests. |
| Clear statistics | 0: -<br>1: Clear | 0: - | Clears the request statistics, setting them back to zero (0). Automatically returns to "-" after the clearing is finished. |

Table. 5.5.4 - 226. Object types.

| Name | Functionalities | Description |
|---|---|---|
| Withdrawable circuit breaker | Breaker cart position<br>Circuit breaker position<br>Circuit breaker control<br>Object ready check before closing breaker<br>Synchrochecking before closing breaker<br>Interlocks | The monitor and control configuration of the withdrawable circuit breaker. |

| Name | Functionalities | Description |
|---|---|---|
| Circuit breaker | Position indication<br>Control<br>Object ready check before closing breaker<br>Synchrochecking before closing breaker<br>Interlocks | The monitor and control configuration of the circuit breaker. |
| Disconnector (MC) | Position indication<br>Control | The position monitoring and control of the disconnector. |
| Disconnector (GND) | Position indication | The position indication of the earth switch. |

Table. 5.5.4 - 227. I/O.

| Signal | Range | Description |
|---|---|---|
| Single-pole object Open Status In Phase A (L1) | Digital input or other logical signal selected by the user<br><br>(SWx) | A link to a physical digital input. The monitored OPEN status of each phase. "1" refers to the active open state of the monitored object. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Single-pole object Open Status In Phase B (L2) | | |
| Single-pole object Open Status In Phase C (L3) | | |
| Single-pole object Close Status In Phase A (L1) | | A link to a physical digital input. The monitored CLOSE status of each phase. "1" refers to the active close state of the monitored object. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Single-pole object Close Status In Phase B (L2) | | |
| Single-pole object Close Status In Phase C (L3) | | |
| Withdrw.CartIn.Status In | | A link to a physical digital input. The monitored withdrawable object's position is IN. "1" means that the withdrawable object cart is in. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Withdrw.CartOut.Status In | | A link to a physical digital input. The monitored withdrawable object's position is OUT. "1" means that the withdrawable object cart is pulled out. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Single-pole object Ready status In | | A link to a physical digital input. Indicates that status of the monitored object. "1" means that the object is ready and the spring is charged for a close command. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Sync.Check status In | | A link to a physical digital input or a synchrocheck function. "1" means that the synchrocheck conditions are met and the object can be closed. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| Single-pole object Open Command Phase A (L1) | OUT1…OUTx | The physical "Open" command pulse to the device's output relay. Each phase has its own open command. |
| Single-pole object Open Command Phase B (L2) | | |
| Single-pole object Open Command Phase C (L3) | | |



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| Signal | Range | Description |
|---|---|---|
| Single-pole object Close Command Phase | OUT1…OUTx | The physical "Close" command pulse to the device's output relay. |

Table. 5.5.4 - 228. Operation settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Breaker traverse time | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum time between open and close statuses when the breaker switches. If this set time is exceeded and both open and closed status inputs are active, the status "Bad" is activated in the "Objectx Breaker status" setting. If neither of the status inputs are active after this delay, the status "Intermediate" is activated. |
| Maximum Close command pulse length | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum length for a Close pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected. |
| Maximum Open command pulse length | 0.02…500.00 s | 0.02 s | 0.2 s | Determines the maximum length for a Open pulse from the output relay to the controlled object. If the object operates faster than this set time, the control pulse is reset and a status change is detected. |
| Control termination timeout | 0.02…500.00 s | 0.02 s | 10 s | Determines the control pulse termination timeout. If the object has not changed it status in this given time the function will issue error event and the control is ended. This parameter is common for both open and close commands. |
| Final trip pulse length | 0.00…500.00 s | 0.02 s | 0.2 s | Determines the length of the final trip pulse length. When the object has executed the final trip, this signal activates. If set to 0 s, the signal is continuous. If auto-recloser function controls the object, "final trip" signal is activated only when there are no automatic reclosings expected after opening the breaker. |

Table. 5.5.4 - 229. Control settings (DI and Application).

| Signal | Range | Description |
|---|---|---|
| Access level for MIMIC control | 0: User<br>1: Operator<br>2: Configurator<br>3: Super user | Defines what level of access is required for MIMIC control. The default is the "Configurator" level. |
| Single-pole object LOCAL Close control input | Digital input or other logical signal selected by the user | The local Close command from a physical digital input (e.g. a push button). |
| Single-pole object LOCAL Open control input | | The local Open command from a physical digital input (e.g. a push button). |
| Single-pole object REMOTE Close control input | | The remote Close command from a physical digital input (e.g. RTU). |
| Single-pole object REMOTE Open control input | | The remote Open command from a physical digital input (e.g. RTU). |
| Objectx Application Close | | The Close command from the application. Can be any logical signal. |
| Single-pole object Application Open ABC (L1,L2,L3) | | The Open command from the application for all phases. Can be any logical signal. |
| Single-pole object Application Open A (L1) | | The Open command from the application for phase A (L1). Can be any logical signal. |
| Single-pole object Application Open B (L2) | | The Open command from the application for phase B (L2). Can be any logical signal. |

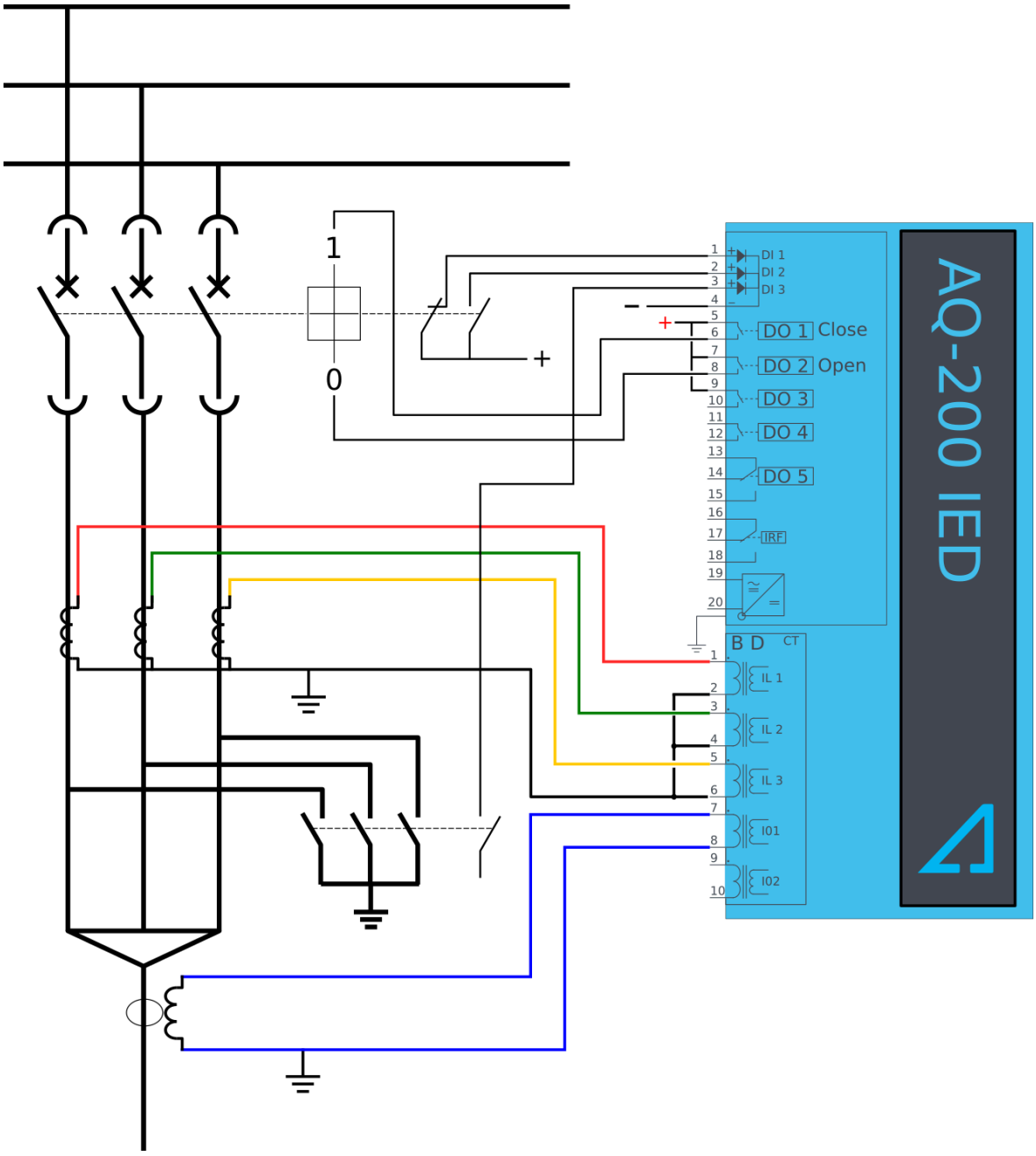
| Signal | Range | Description |
|---|---|---|
| Single-pole object Application Open ABC (L3) | | The Open command from the application for phase C (L3). Can be any logical signal. |

## Blocking and interlocking

The interlocking and blocking conditions can be set for each controllable object, with Open and Close set separately. Blocking and interlocking can be based on any of the following: other object statuses, a software function or a digital input.

The image below presents an example of an interlock application, where the closed earthing switch interlocks the circuit breaker close command.

Figure. 5.5.4 - 136. Example of an interlock application.






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In order for the blocking signal to be received on time, it has to reach the function 5 ms before the control command.

## Events and registers

The object control and monitoring function (abbreviated "OBJS" in event block names) generates events and registers from the status changes in monitored signals as well as control command fails and operations. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The function registers its operation into the last twelve (12) time-stamped registers. The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.4 - 230. Event messages of the OBJS function.

| Event block name | Event names |
|---|---|
| OBJS1 | Object A(L1) Intermediate |
| OBJS1 | Object A(L1) Open |
| OBJS1 | Object A(L1) Close |
| OBJS1 | Object A(L1) Bad |
| OBJS1 | Object B(L2) Open |
| OBJS1 | Object B(L2) Close |
| OBJS1 | Object B(L2) Bad |
| OBJS1 | Object B(L2) Intermediate |
| OBJS1 | Object C(L3) Open |
| OBJS1 | Object C(L3) Close |
| OBJS1 | Object C(L3) Bad |
| OBJS1 | Object C(L3) Intermediate |
| OBJS1 | WD Cart Intermediate |
| OBJS1 | WD Cart Open |
| OBJS1 | WD Cart Close |
| OBJS1 | WD Cart Bad |
| OBJS1 | Object A(L1) Open Command On |
| OBJS1 | Object A(L1) Open Command Off |
| OBJS1 | Object B(L2) Open Command On |
| OBJS1 | Object B(L2) Open Command Off |
| OBJS1 | Object C(L3) Open Command On |
| OBJS1 | Object C(L3) Open Command Off |
| OBJS1 | Close Command On |
| OBJS1 | Close Command Off |
| OBJS1 | Open Commands Blocked |
| OBJS1 | Open Commands Allowed |
| OBJS1 | Close Commands Blocked |
| OBJS1 | Close Commands Allowed |

| Event block name | Event names |
|---|---|
| OBJS1 | Object Is Ready |
| OBJS1 | Object Not Ready, Wait for Ready |
| OBJS1 | Sync Is Ok |
| OBJS1 | Sync Not Ok Wait for sync |
| OBJS1 | Final Trip On |
| OBJS1 | Final Trip Off |
| OBJS1 | Open Command Fail On |
| OBJS1 | Open Command Fail Off |
| OBJS1 | Close Command Fail On |
| OBJS1 | Close Command Fail Off |
| OBJS1 | L1 Open Command Timeout On |
| OBJS1 | L1 Open Command Timeout On |
| OBJS1 | L2 Open Command Timeout On |
| OBJS1 | L2 Open Command Timeout On |
| OBJS1 | L3 Open Command Timeout On |
| OBJS1 | L3 Open Command Timeout On |
| OBJS1 | Close Command Timeout On |
| OBJS1 | Close Command Timeout On |

Table. 5.5.4 - 231. Register content.

| Name | Description |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| L1 breaker status | The status of phase L1 (A). |
| L2 breaker status | The status of phase L2 (B). |
| L3 breaker status | The status of phase L3 (C). |
| WD status | The status of the withdrawable circuit breaker. |

### 5.5.5 Indicator object monitoring

The indicator object monitoring function takes care of the status monitoring of disconnectors. The function's sole purpose is indication and does not therefore have any control functionality. To control circuit breakers and/or disconnectors, please use the Object control and monitoring function. The monitoring is based on the statuses of the configured relay's digital inputs. The number of monitored indicators in a relay depends on the device type and available inputs. The status monitoring of one monitored object usually requires two (2) digital inputs. Alternatively, object status monitoring can be performed with a single digital input: the input's active state and its zero state (switched to 1 with a NOT gate in the Logic editor).

The outputs of the function are the monitored indicator statuses (Open, Close, Intermediate and Bad). The setting parameters are static inputs for the function, which can only be changed by the use in the function's setup phase.



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The inputs of the function are the binary status indications. The function generates general time stamped ON/OFF events to the common event buffer from each of the following signals: OPEN, CLOSE, BAD and INTERMEDIATE event signals. The time stamp resolution is 1 ms.

## Settings

Function uses available hardware and software digital signal statuses. These input signals are also setting parameters for the function.

Table. 5.5.5 - 232. Indicator status.

| Name | Range | Default | Description |
|---|---|---|---|
| Indicator name ("Ind. Name") | - | IndX | The user-set name of the object, at maximum 32 characters long. |
| IndicatorX Object status ("Ind.X Object Status") | 0: Intermediate<br>1: Open<br>2: Closed<br>3: Bad | - | Displays the status of the indicator object. Intermediate status is displayed when neither of the status conditions (open or close) are active. Bad status is displayed when both of the status conditions (open and close) are active. |

Table. 5.5.5 - 233. Indicator I/O.

| Signal | Range | Description |
|---|---|---|
| IndicatorX Open input ("Ind.X Open Status In") | Digital input or other logical signal selected by the user<br><br>(SWx) | A link to a physical digital input. The monitored indicator's OPEN status. "1" refers to the active "Open" state of the monitored indicator. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |
| IndicatorX Close input ("Ind.X Close Status In") | Digital input or other logical signal selected by the user<br><br>(SWx) | A link to a physical digital input. The monitored indicator's CLOSE status. "1" refers to the active "Close" state of the monitored indicator. If IEC 61850 is enabled, GOOSE signals can be used for status indication. |

## Events

The indicator object monitoring function (abbreviated "CIN" in event block names) generates events from the status changes in the monitored signals, including the continuous status indications. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.5.5 - 234. Event messages (instances 1-10).

| Event block name | Event names |
|---|---|
| CIN1 | Intermediate |
| CIN1 | Open |
| CIN1 | Close |
| CIN1 | Bad |
| CIN2 | Intermediate |
| CIN2 | Open |
| CIN2 | Close |
| CIN2 | Bad |

| Event block name | Event names |
|---|---|
| CIN3 | Intermediate |
| CIN3 | Open |
| CIN3 | Close |
| CIN3 | Bad |
| CIN4 | Intermediate |
| CIN4 | Open |
| CIN4 | Close |
| CIN4 | Bad |
| CIN5 | Intermediate |
| CIN5 | Open |
| CIN5 | Close |
| CIN5 | Bad |
| CIN6 | Intermediate |
| CIN6 | Open |
| CIN6 | Close |
| CIN6 | Bad |
| CIN7 | Intermediate |
| CIN7 | Open |
| CIN7 | Close |
| CIN7 | Bad |
| CIN8 | Intermediate |
| CIN8 | Open |
| CIN8 | Close |
| CIN8 | Bad |
| CIN9 | Intermediate |
| CIN9 | Open |
| CIN9 | Close |
| CIN9 | Bad |
| CIN10 | Intermediate |
| CIN10 | Open |
| CIN10 | Close |
| CIN10 | Bad |

### 5.5.6 Auto-recloser (79)

Auto-reclosing means a coordinated de-energization and re-energization of overhead lines (both transmission and distribution). Its purpose is to clear transient and semi-permanent fault causes from the line and automatically restore the supply to the line. These types of faults account for approximately 80...95 % of all faults found in transmission and distribution networks. The majority of these fault types can be cleared with high-speed auto-reclosing, while the rest can be cleared with delayed auto-reclosing by de-energizing the faulty line for a longer period of time.


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Only a minority of overhead line faults are of the permanent type which require maintenance or repair in the actual fault location. This type of fault include lightning striking the line, a tree branch touching the line, an arc caused by animals, and a short-circuit caused by some other object touching the line. If the fault is permanent (e.g. a broken insulator or a fallen tree leaning on the overhead line), the auto-recloser cannot clear the fault and the faulty feeder is locked and prevented from closing until the cause of the fault is repaired in the actual fault location. Also, when a fault cannot be cleared by auto-reclosing the line, any close-distance short-circuits should avoid initiating the auto-recloser because that would only cause unnecessary stress for the lines and the circuit breakers. Similar situations also rise in mixed networks since cable network faults cannot be cleared with the auto-recloser. The function must therefore be aware of the fault location before applying the auto-recloser to the faulty line.

## Auto-recloser as application

The main principle of the auto-recloser is to de-energize the faulty line and the fault location so the cause of the fault can drop out from the line. When the line is energized and an object either touches the line or drops onto the line, the current starts to flow through the object either to the ground or between the phases. This causes the surrounding air to heat and ionize, and it starts to operate as a conductor between the energized phase(s) and the ground causing an arc to ignite.

When the breaker is opened (either by an auto-recloser command or by a protection function), the voltage in the line goes to zero. This extinguishes the arc and lets the fault-causing object to drop from the line, thus clearing the cause of the fault. Auto-reclosing closes the breaker after a set time (called 'dead time' during which the line is not energized) and the supply is restored to the line. If the fault is not cleared by the first auto-recloser cycle (called 'shot'), more shots can be applied to the line. Alternatively, the function can be set to initiate the final trip, locking the feeder closing. The decision between a single-shot and a multi-shot auto-recloser depends on the following: protection type, switchgear, circuit breaker, stability requirements, network type, consumer loads as well as local utility knowledge and network practices.

The user can select whether there is a set time delay (called 'arcing time') between shots to burn the fault-causing object from the line, or whether normal protection operating times are applied. When a fault is not present when the breaker is closed but reappears soons after (called 'discrimination time' and 'reclaim time'), the auto-recloser function can either arm another shot or give the final trip command and the feeder becomes locked. The user can select the preferred method in the function's settings.

It is difficult to define a typical auto-recloser scheme because the above-mentioned parameters (and thus the main parameters of a scheme) vary greatly in distribution and transmission networks. This is why there are no universally applicable answers from the number of shots and the duration of the dead times to which protection functions should trigger the auto-recloser.

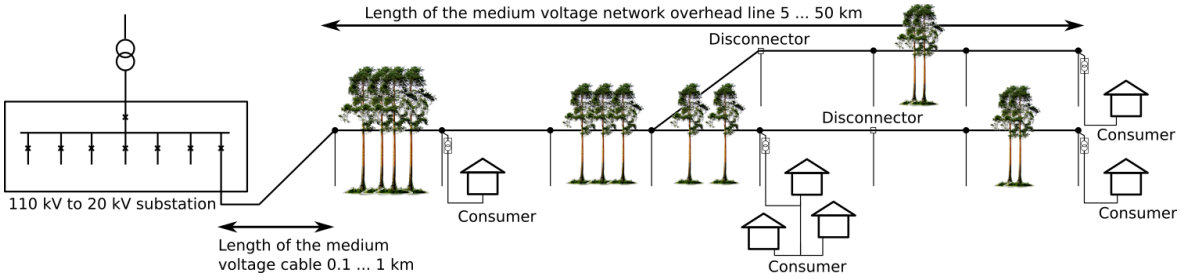
The minimum times for the "Dead time" setting is mostly dependent on the voltage level of the protected network: the air needs enough time to de-ionize before the circuit breaker is opened. For medium-voltage networks (20...75 kV) a 200 ms dead time should be sufficient. High-voltage networks require a longer dead time: a 110 kV network needs 300 ms and a 400 kV network needs 400...500 ms. This minimum time is not, however, less straightforward than this as it is affected by other parameters as well (such as conductor spacing, wind speed, fault type, fault duration, etc.). The main purpose of the "Dead time" setting is to give enough time for the air surrounding the fault location to return to its isolating state before the line is re-energized and therefore prevent the arc from reignite due to the heated and ionized air. The circuit breaker's open-close-open cycle capacity is another restricting factor for the minimum "Dead time" setting in low-voltage networks. In high-voltage networks, the time de-ionizing requires puts additional limitations on the minimum "Dead time" setting.

The user can build different schemes for evolving faults (such as transient earth faults that become multi-phase short-circuits or overcurrent faults) by changing the priorities and behaviors requests have. The auto-recloser function has five (5) independent priority requests for reclosing: REQ1 has the highest priority and REQ5 the lowest. The function also has one (1) critical request which halts the reclosing in any position when the request is received.

## Auto-recloser scheme in radial networks

A typical medium-voltage overhead network is usually radial in structure. This does not cause any additional requirements for the auto-recloser scheme apart from the above-mentioned limitations from the required air de-ionization time and the capacity of the circuit breaker. Also, a typical medium-voltage overhead line consists only of consumers and has no power generation; thus, the main objective of the structure is to provide a stable and continuous supply of electricity.

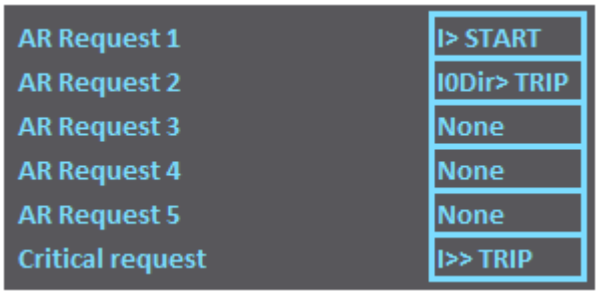
Figure. 5.5.6 - 137. Diagram of a typical radial medium-voltage network in rural areas.




Usually, a radially built medium-voltage network in rural areas consists of a short cable connection from the substation to the overhead line, followed by a relatively long overhead line that normally ends with the consumer. The consumer (residence, farm, etc.) can connect to basically any point in the overhead line with a 20 kV/0.4 kV distribution transformer. The overhead line can have many branches, and it is not uncommon (especially in rural areas) that there are multiple forest areas the line runs through between the consumer connections. In longer lines in sparsely populated areas it is possible to isolate areas of the overhead line by dividing it up with disconnectors (at least in branches).

This type of application normally uses an auto-recloser with two shots (one high-speed and one delayed) which are triggered by earth fault protection or overcurrent protection. Short-circuit protection is used for interlocking the auto-recloser in case a clear short-circuit fault occurs in the line.

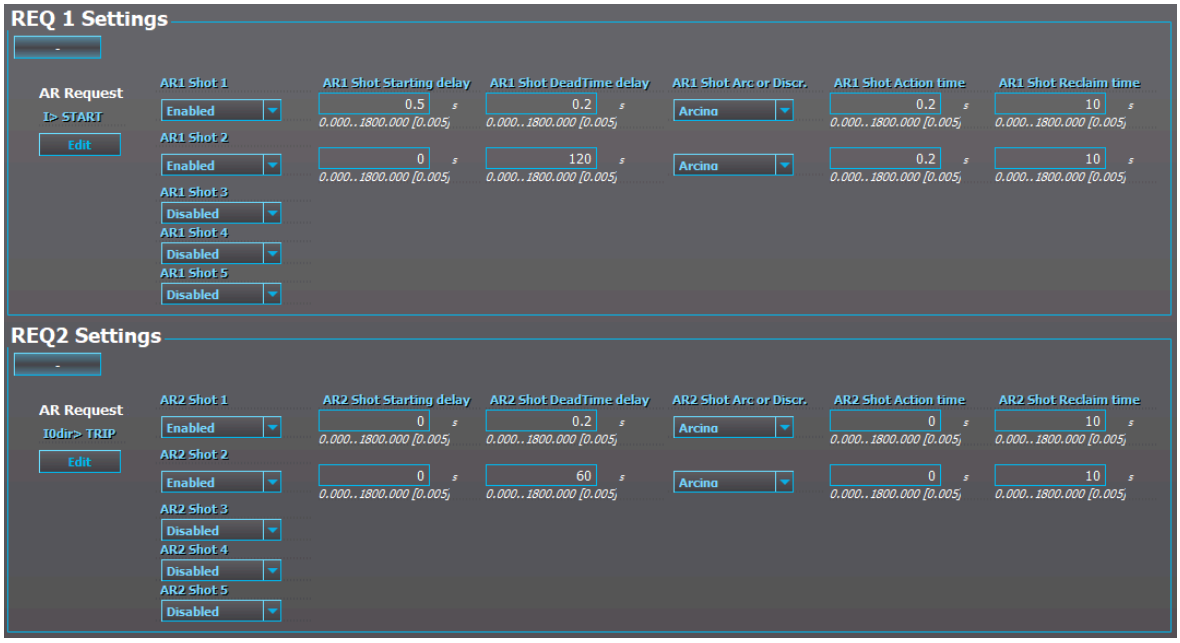
Figure. 5.5.6 - 138. Example of assigning request signals.






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Figure. 5.5.6 - 139. Example of shot settings (two requests and two initialized shots).




In this example, earth fault (REQ2) uses its own operating time settings, whereas the time delay for overcurrent (REQ1) comes from the auto-recloser's own settings. Both fault types can initialize both of the shots with different settings. If the fault evolves from earth fault into a multi-phase fault, the auto-recloser uses the AR1 settings for the reclosing. In this example, the dead time between the first and the second shot in REQ1 differs from the dead time in REQ2 because the air needs more time to cool and de-ionize after an overcurrent or a multi-phase fault than it does after an earth fault. If the high-set overcurrent stage activates in any situation, the auto-reclosing sequence is stopped, the final trip is issued and the feeder closing is locked by the auto-recloser. A manual reset of the auto-recloser's lock is required before one can attempt to close the breaker. A manual reset can be applied from SCADA or locally from the relay's HMI.

Based on the example above, the following six (6) sections present the principle signaling of the auto-recloser function. These are the auto-recloser sequence variations that can occur with this setup:

- from Trip with two shots (both fail)
- from Trip with two shots (high-speed fails, time-delayed succeeds)
- from Trip with two shots (high-speed succeeds)
- from Start with two shots (both fail)
- from Start with two shots (high-speed fails, time-delayed succeeds)
- from Start with two shots (high-speed succeeds).

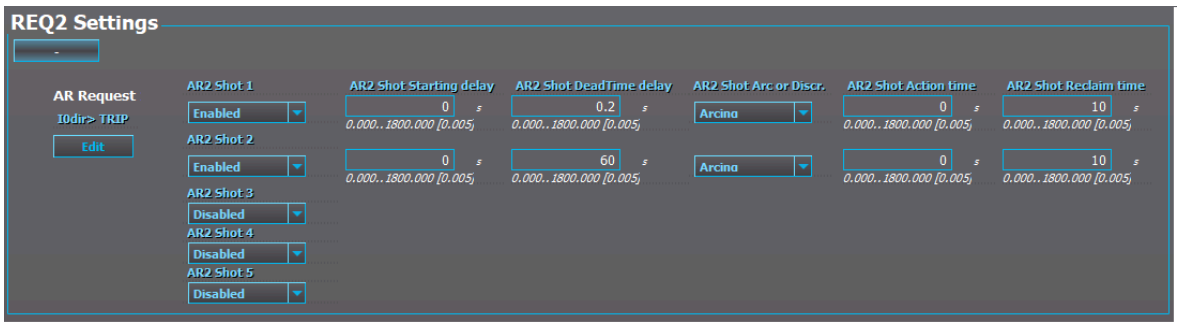
The signal status graphs describe the statuses of available requests, the statuses of the auto-recloser's internal signals, the statuses of the timers, the breaker controls from the auto-recloser function as well as the breaker status signals.

The auto-recloser function operates closely with the object control and monitoring function, and all breaker status and monitor signals are forwarded from the selected object to the auto-recloser function. The circuit breaker's "Open" and "Close" signals are also controlled through the dedicated object. When the breaker cannot be closed (because it is not ready or the closing is waiting for a Synchrocheck allowance), the wait state is forwarded to the auto-recloser function to wait for the object's acknowledgement either of a successful closing or of a failure time-out. A similar situation can arise in the circuit breaker's "Open" command, for example, if the command is blocked because of an $SF_6$ gas leakage. In failure acknowledgement situations the auto-recloser function is always put to a lock-out state with a requirement for resetting once the cause of the lock-out is cleared. Resetting is done by an external input to the function or by closing the breaker.

## Auto-recloser sequence from Trip with two shots (both fail).

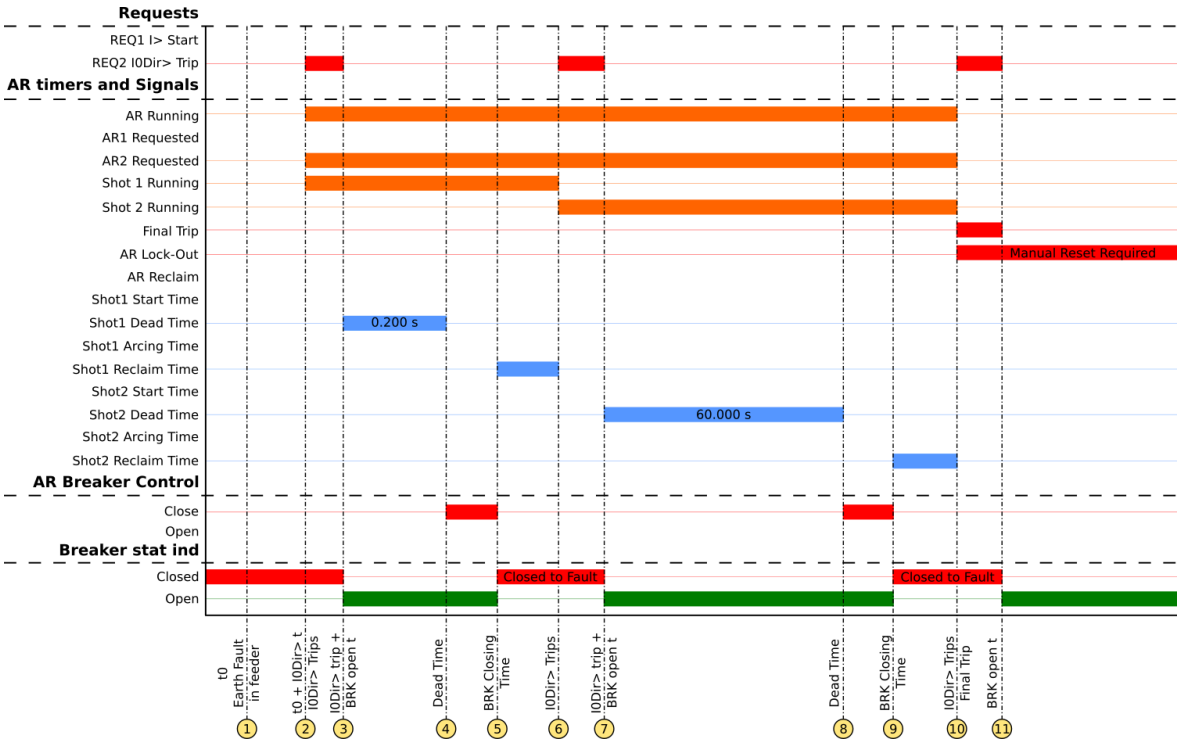
In this auto-recloser scheme, the TRIP signal from the directional eath fault protection function (I0dir> TRIP) was set up as the operation starter for Request 2 (REQ2). REQ2 has two shots (Shots 1 and 2) enabled with the setting detailed in the image below; the first one is a high-speed shot (0.2 s) that is then followed by a time-delayed shot (60 s).

Figure. 5.5.6 - 140. Settings for I0dir> with two shots.




When the TRIP signal is used to initiate the auto-recloser sequence, no additional starting or discrimination times are needed as the protection stage's own operation takes care of the breaker opening timings directly. Therefore, the auto-recloser function only monitors the status of the directional earth fault stage's tripping before initiating requests and shots.

Figure. 5.5.6 - 141. Signal status graph of the permanent earth fault auto-recloser cycle.




1. An earth fault is found in the protected line causing the I0Dir> protection to start calculating the operating time for a trip.
2. The I0Dir> trips and gives the "Open" command to the breaker's open coil. The auto-recloser function is initiated and the **AR Running**, **AR2 Requested** and **Shot 1 Running** signals are activated.
3. The circuit breaker is opened and the I0Dir> TRIP signal is released and simultaneously the REQ2 trip signal for the auto-recloser is released. The recloser starts calculating the **Shot1 Dead Time** to close the breaker.



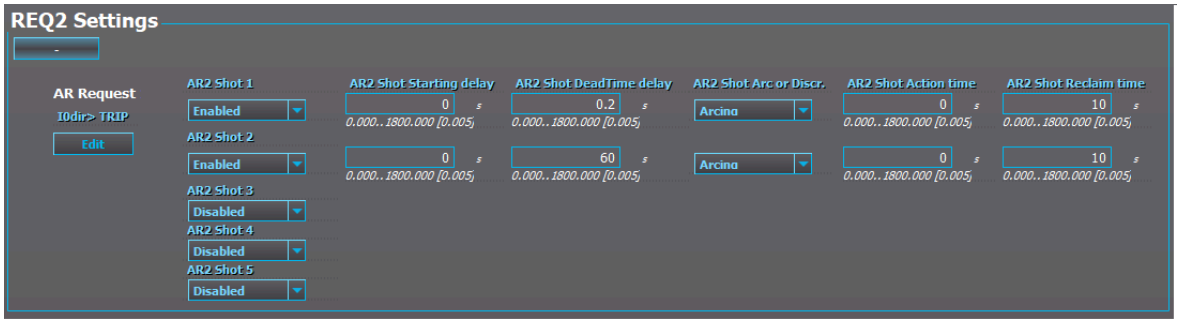
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IM00015

4. The Shot1 Dead Time (200 ms) is exceeded and the function sends a "Close" request to the object breaker (AR Breaker): the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed towards the fault as it was not cleared by Shot 1 given the non-energized time. The I0dir> stage picks up and starts calculating the operating time for a trip. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating Shot1 Reclaim Time.
6. The I0Dir> stage trips a second time and gives the REQ2 request to the function. However, as the function is in the process of calculating the Shot1 Reclaim Time when it receives this request, the function moves on to the next available shot (Shot 2) for the request. The Shot2 Running signal is set to active and the Shot1 Running is terminated.
7. The circuit breaker is opened and the I0Dir> TRIP signal is released and simultaneously REQ2 trip signal for auto-recloser is released. The recloser starts calculating the Shot2 Dead Time to close the breaker.
8. The Shot2 Dead Time (60 s) is exceeded and the function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
9. The circuit breaker is closed towards the fault since it was not cleared by Shot 2. The I0dir> stage picks up and starts calculating the operating time for a trip. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating Shot2 Reclaim Time.
10. The I0Dir> stage trips a third time and gives the REQ2 request to the function. However, as the function is in the process of calculating the Shot2 Reclaim Time when it receives this request, the function tries to move on to the next available shot. Alas, this scheme does not have any more available shots and so the function begins the Final Trip state and drops the AR Running, Shot2 Running and AR2 Requested signals. The function enters the AR Lock-out state to prevent any further requests for reclosing.
11. The circuit breaker is opened and the I0Dir> TRIP signal is released, and simultaneously the REQ2 trip signal for the auto-recloser is released. The function is now in a steady lock-out state and waits for the user to manually reset and re-initialize the function by closing the breaker.

## Auto-recloser sequence from Trip with two shots (high-speed fails, time-delayed succeeds).

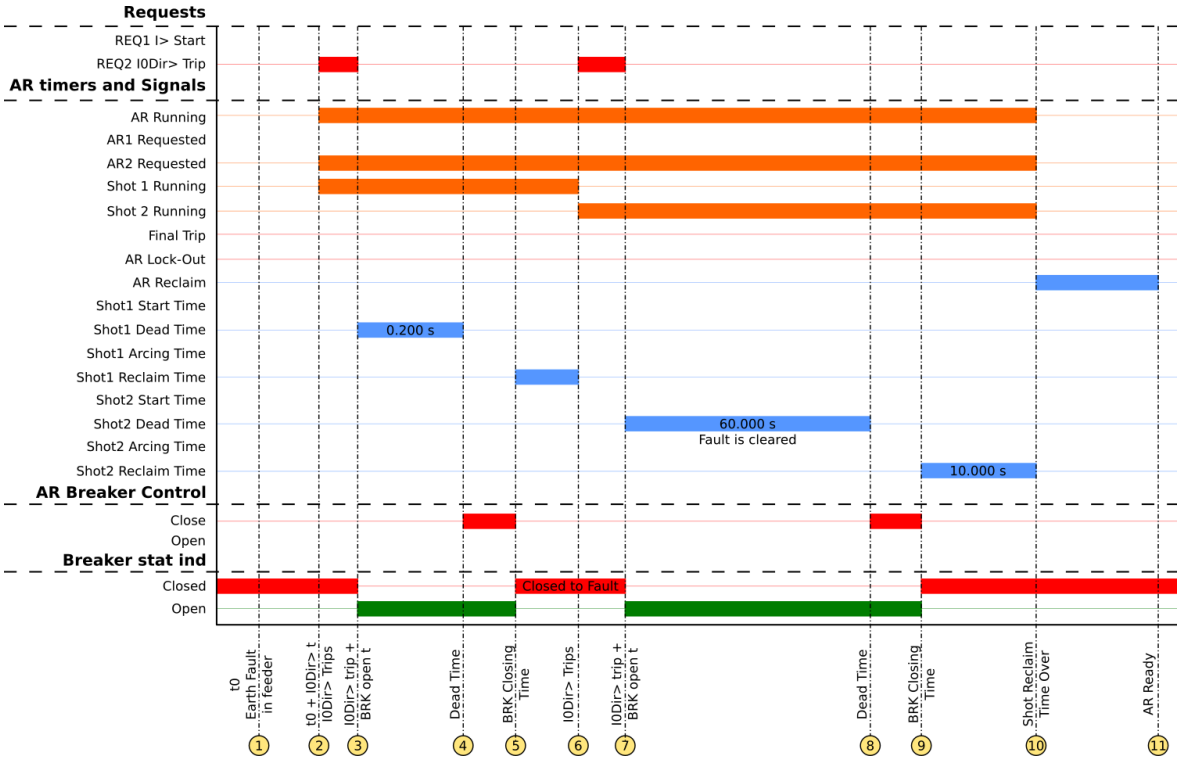
This auto-recloser scheme has the same starters and shots as the previous example. The setting and signals are also the same. However, in this example the fault persists the high-speed shot but is cleared by the time-delayed shot.

Figure. 5.5.6 - 142. Settings for I0dir> with two shots.




This type of sequence (i.e. two shots required to clear the fault) represents 10...15 % of all faults that occur in MV overhead line networks.

Figure. 5.5.6 - 143. Signal status graph of the semi-permanent earth fault auto-recloser cycle.




1. An earth fault is found in the protected line causing the I0Dir> protection to start calculating the operating time for a trip.
2. The I0Dir> trips and gives the "Open" command to the breaker's open coil. The auto-recloser function is initiated and the AR Running, AR2 Requested and Shot 1 Running signals are activated.
3. The circuit breaker is opened and the I0Dir> TRIP signal is released and simultaneously the REQ2 trip signal for the auto-recloser is released. The recloser starts calculating the Shot1 Dead Time to close the breaker.
4. The Shot1 Dead Time (200 ms) is exceeded and the function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed towards the fault as it was not cleared by Shot 1. The I0dir> stage picks up and starts calculating the operating time for a trip. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating Shot1 Reclaim Time.
6. The I0Dir> stage trips a second time and gives the REQ2 request to the function. However, as the function is in the process of calculating the Shot1 Reclaim Time when it receives this request, the function moves on to the next available shot (Shot 2) for the request. The Shot2 Running signal is set to active and the Shot1 Running is terminated.
7. The circuit breaker is opened and the I0Dir> TRIP signal is released and simultaneously REQ2 trip signal for the auto-recloser is released. The recloser starts calculating the Shot2 Dead Time to close the breaker.
8. The fault is cleared during Shot2 Dead Time. After that time (60 s) is exceeded, the function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
9. The circuit breaker is closed and since the fault has been cleared, no pick-ups are detected. The "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating Shot2 Reclaim Time.


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10. The Shot2 Reclaim Time (10 s) is exceeded, and so the AR Running, Shot 2 Running and AR2 Requested signals are terminated, and the AR Reclaim calculation begins. The difference between auto-reclosing and shot-specific reclaim times is that the function jumps to the next available shot should the fault return. If a fault returns after a successful cycle and the function's AR Reclaim signal is active, the function jumps directly to the Final Trip state and then enters the lock-out state. The user can control this behavior through the function settings. Both reclaim times can be set to 0 s when they are not needed, and the function skips all timers that are set to zero.
11. The AR Reclaim time is exceeded and the function is set to "Ready" to wait for the next request.

## Auto-recloser sequence from Trip with two shots (high-speed succeeds).

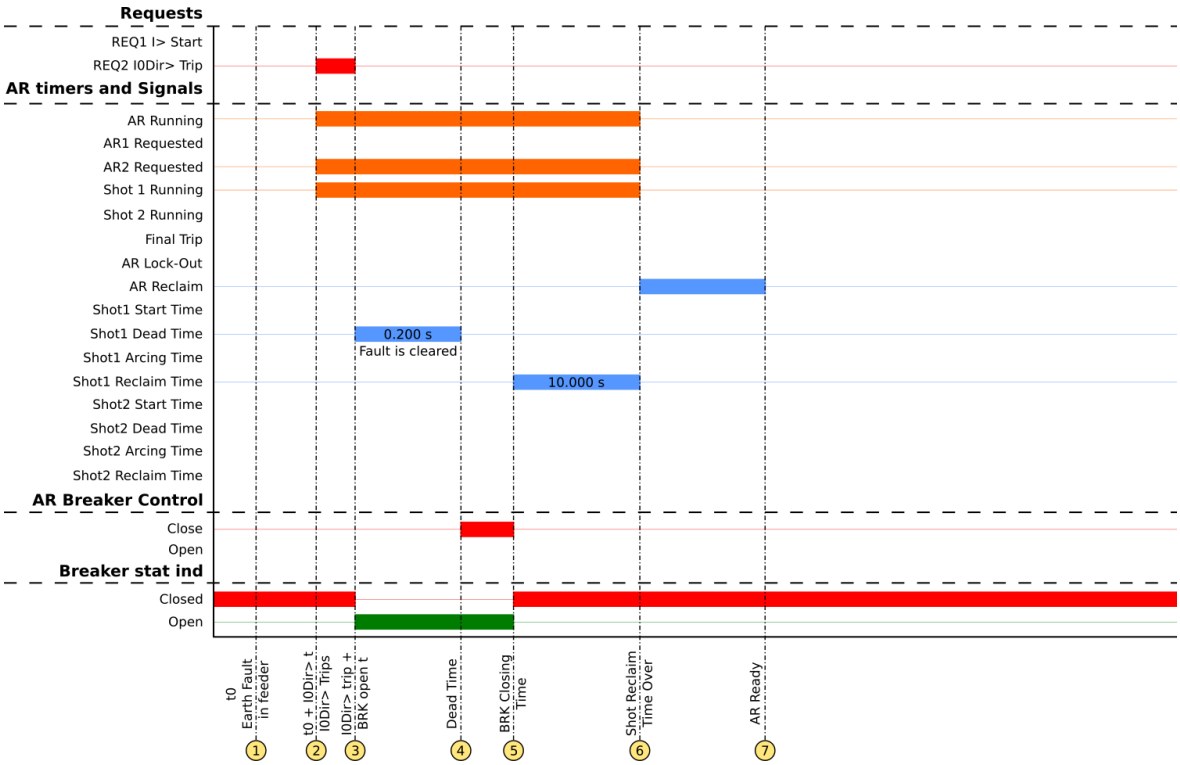
This auto-recloser scheme has the same starters and shots as the two previous examples. The setting and signals are also the same. However, in this example the fault is cleared by the high-speed shot.

Figure. 5.5.6 - 144. Settings for I0dir> with two shots.




This type of sequence (i.e. the first shot clears the fault) represents 75...85 % of all faults that occur in MV overhead line networks.

Figure. 5.5.6 - 145. Signal status graph of the transient earth fault auto-recloser cycle.

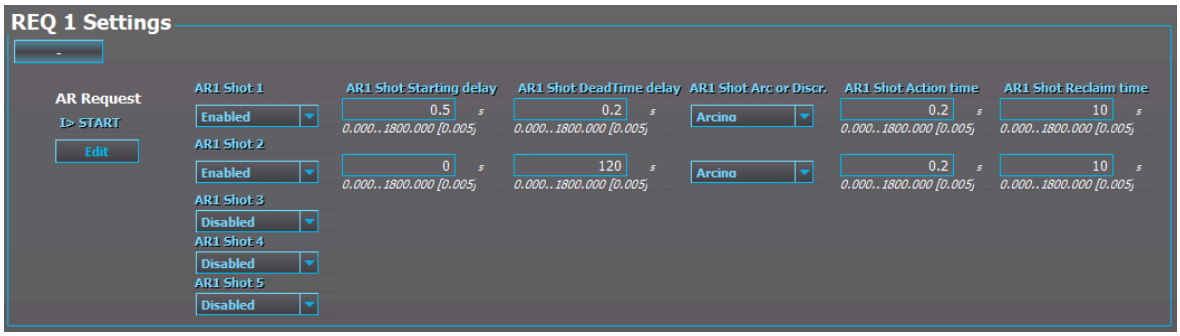


1. An earth fault is found in the protected line causing the I0Dir> protection to start calculating the operating time for a trip.
2. The I0Dir> trips and gives the "Open" command to the breaker's open coil. The auto-recloser function is initiated and the AR Running, AR2 Requested and Shot 1 Running signals are activated.
3. The circuit breaker is opened and the I0Dir> TRIP signal is released and simultaneously the REQ2 trip signal for the auto-recloser is released. The recloser starts calculating the Shot1 Dead Time to close the breaker.
4. The fault is cleared during Shot1 Dead Time calculation. When that time (200 ms) is exceeded and the function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed and since the fault was cleared, no pick-ups are detected. The "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating Shot1 Reclaim Time.
6. The Shot1 Reclaim Time (10 s) is exceeded, and so the AR Running, Shot 2 Running and AR2 Requested signals are terminated, and the AR Reclaim calculation begins. The difference between auto-reclosing and shot-specific reclaim times is that the function jumps to the next available shot should the fault returns. If a fault returns after a successful cycle and the function's AR Reclaim signal is active, the function jumps directly to the Final Trip state and then enters the lock-out state. The user can control this behavior through the function settings. Both reclaim times can be set to 0 s when they are not needed, and the function skips all timers that are set to zero. The user can also set is so that AR Reclaim is not used at all after a successful reclosing cycle.
7. The AR Reclaim time is exceeded and the function is set to "Ready" to wait for the next request.

## Auto-recloser sequence from Start with two shots (both fail).

In this auto-recloser scheme, the START signal from the non-directional overcurrent protection function (I> START) was set up as the operation starter for Request 1 (REQ1). REQ1 has two shots (Shots 1 and 2) enabled with the setting detailed in the image below; the first one is a high-speed shot (0.2 s) that is then followed by a time-delayed shot (120 s). In this scheme the starting delay time is longer that in REQ2's high-speed shot. The shot action time is also longer in REQ1. If the fault persists after both shots, the time determining how long the breaker stays closed is reduced.

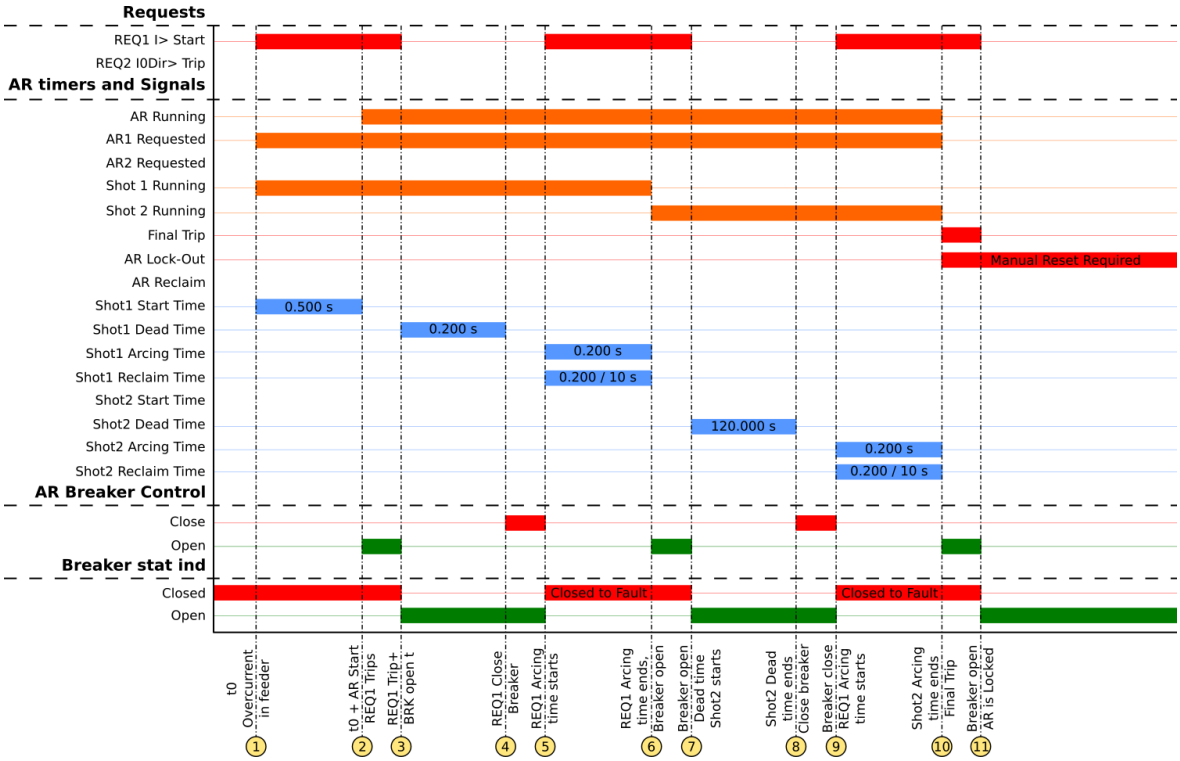
Figure. 5.5.6 - 146. Settings for I> with two shots.




When the START signal is used to initiate the auto-recloser sequence, the fault duration timings are overseen by the auto-recloser function and thus both the starting time and the arcing time need to be set accordingly. The protection's main operating time settings should be longer than the values set to the auto-recloser function; this way the state changes work properly with this function.


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Figure. 5.5.6 - 147. Signal status graph of the permanent overcurrent auto-recloser cycle.



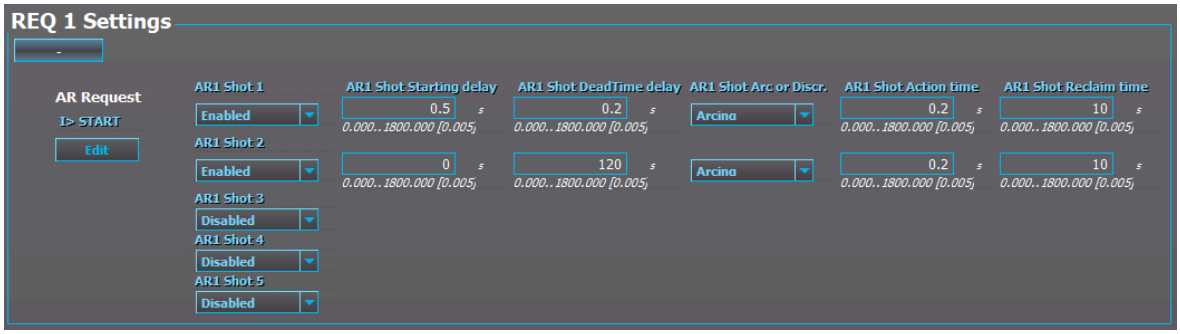

1. An overcurrent is found in the protected line causing the I> protection to pick up. This activates the AR1 Requested signal to begin to calculate the Shot1 Start Time. This activates the Shot 1 Running signal even though the auto-recloser function is not yet running.
2. The Shot1 Start Time (500 ms) for has elapsed and the auto-recloser function starts running (AR Running). This sends an "Open" command to the breaker.
3. The circuit breaker is opened and the I> stage's START signal is released and simultaneously REQ1 trip signal for auto-reclosing is released. The auto-recloser function starts calculating the Shot1 Dead Time to close the breaker.
4. The Shot1 Dead Time (200 ms) is exceeded and the auto-recloser function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed and since fault was not cleared, a new pick-up of I> is detected. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating the Shot1 Reclaim Time simultaneously with the Shot1 Arcing Time.
6. The Shot1 Arcing Time (200 ms) is exceeded which means that the fault is not cleared and the function sends an "Open" command to the breaker. The function deactivates the Shot1 Running signal and instead activates the Shot2 Running signal.
7. The circuit breaker opens and the Shot2 Dead Time calculation begins.
8. The Shot2 Dead Time (120 s) is exceeded and the auto-recloser function sends a "Close" command to the breaker.
9. The circuit breaker is closed towards the fault since it was not cleared by Shot 2. The I> stage picks up and starts calculating the Shot2 Arcing Time for the Final Trip. The "Close" command is dropped after the the breaker's "Closed" indication is received. The auto-recloser function also starts calculating the Shot2 Reclaim Time.
10. The Shot2 Arcing Time (200 ms) is exceeded and and the REQ1 request is given to the function. However, as the function is in the process of calculating the Shot2 Reclaim Time when it receives this request, the function tries to move on to the next available shot. Alas, this scheme does not have any more available shots and so the function begins the Final Trip state and drops the AR Running, Shot2 Running and AR1 Requested signals. The function enters the AR Lock-out state to prevent any further requests for reclosing.

11. The circuit breaker is opened and the I> function's START signal is released, and simultaneously the REQ1 trip signal for auto-reclosing is released. The function is now in a steady lock-out state and waits for the user to manually reset and re-initialize the function by closing the breaker.

## Auto-recloser sequence from Start with two shots (high-speed fails, time-delayed succeeds).

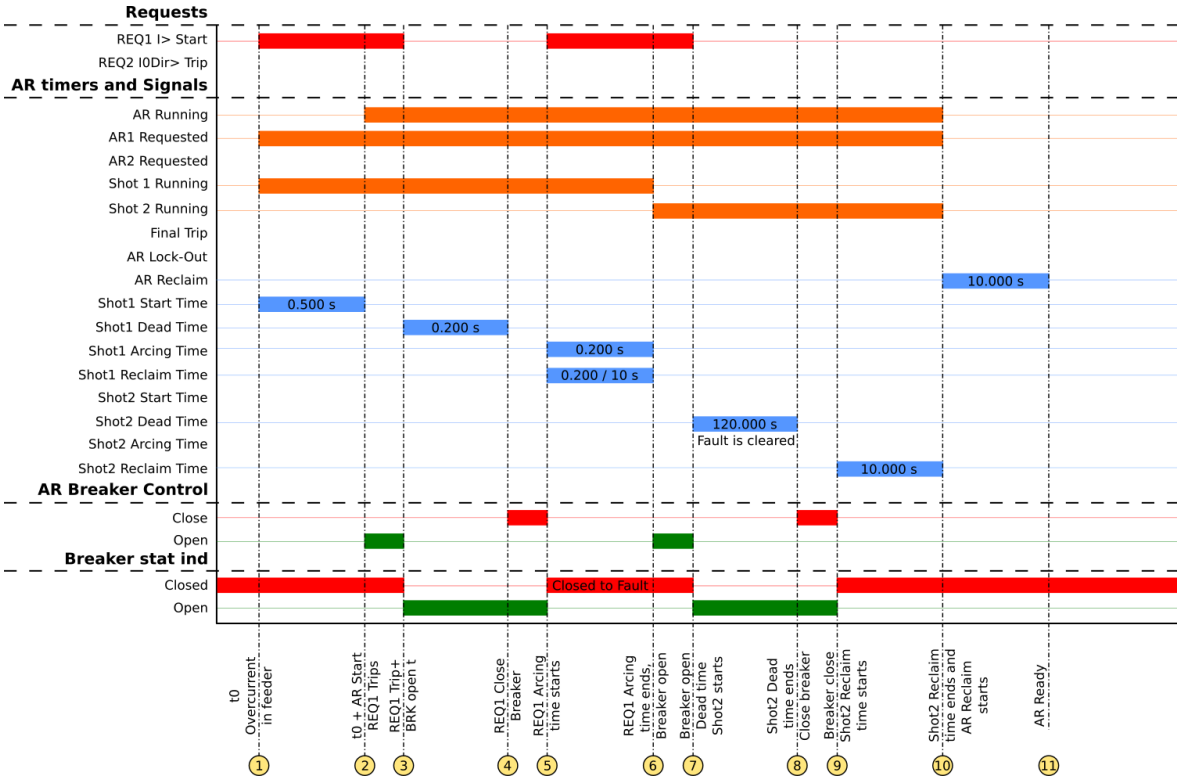
This auto-recloser scheme has the same starters and shots as the previous example. The setting and signals are also the same. However, in this example the fault persists the high-speed shot but is cleared by the time-delayed shot.

Figure. 5.5.6 - 148. Settings for I> with two shots.




This type of sequence (i.e. two shots required to clear the fault) represents 10...15 % of all faults that occur in MV overhead line networks.

Figure. 5.5.6 - 149. Signal status graph of the semi-permanent overcurrent auto-recloser cycle.




1. An overcurrent is found in the protected line causing the I> protection to pick up. This activates the AR1 Requested signal to begin to calculate the Shot1 Start Time. This activates the Shot 1 Running signal eventhough the auto-recloser function is not yet running.



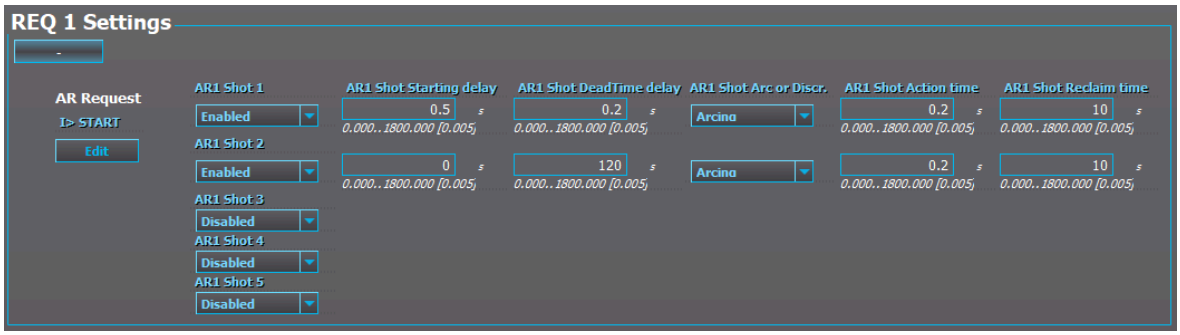
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2. The Shot1 Start Time (500 ms) for has elapsed and the auto-recloser function starts running (AR Running). This sends an "Open" command to the breaker.
3. The circuit breaker is opened and the I> stage's START signal is released and simultaneously REQ1 trip signal for auto-reclosing is released. The auto-recloser function starts calculating the Shot1 Dead Time to close the breaker.
4. The Shot1 Dead Time (200 ms) is exceeded and the auto-recloser function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed and since fault was not cleared, a new pick-up of I> is detected. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating the Shot1 Reclaim Time simultaneously with the Shot1 Arcing Time.
6. The Shot1 Arcing Time (200 ms) is exceeded which means that the fault is not cleared and the function sends an "Open" command to the breaker. The function deactivates the Shot1 Running signal and instead activates the Shot2 Running signal.
7. The circuit breaker opens and the Shot2 Dead Time calculation begins.
8. The fault is cleared during the Shot2 Dead Time (120 s). When that time is exceeded, the auto-recloser function sends a "Close" command to the breaker.
9. The circuit breaker is closed and since the fault was cleared by Shot 2, no more pick-ups are detected. The "Close" command is dropped after the the breaker's "Closed" indication is received. The auto-recloser function also starts calculating the Shot2 Reclaim Time.
10. The Shot2 Reclaim Time (10 s) is exceeded, and so the AR Running, Shot2 Running and AR1 Requested signals are terminated and the AR Reclaim calculation begins. The difference between auto-reclosing and shot-specific reclaim times is that the function jumps to the next available shot should the fault returns. If a fault returns after a successful cycle and the function's AR Reclaim signal is active, the function jumps directly to the Final Trip state and then enters the lock-out state. The user can control this behavior through the function settings. Both reclaim times can be set to 0 s when they are not needed, and the function skips all timers that are set to zero. The user can also set is so that AR Reclaim is not used at all after a successful recloser cycle.
11. The AR Reclaim time is exceeded and the function is set to "Ready" to wait for the next request.

## Auto-recloser sequence from Start with two shots (high-speed succeeds).

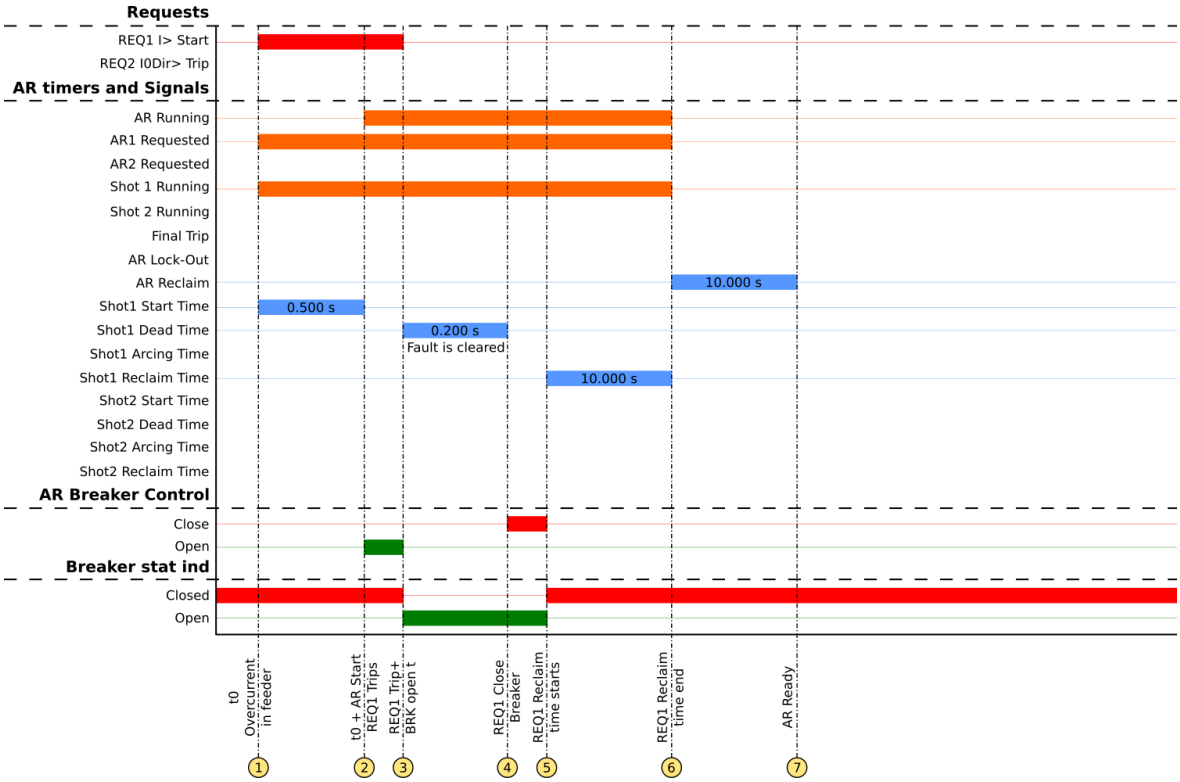
This auto-recloser scheme has the same starters and shots as the two previous examples. The setting and signals are also the same. However, in this example the fault is cleared by the high-speed shot.

Figure. 5.5.6 - 150. Settings for I> with two shots.




This type of sequence (i.e. the first shot clears the fault) represents 75...85 % of all faults that occur in MV overhead line networks.

Figure. 5.5.6 - 151. Signal status graph of the transient overcurrent auto-recloser cycle.




1. An overcurrent is found in the protected line causing the I> protection to pick up. This activates the AR1 Requested signal to begin to calculate the Shot1 Start Time. This activates the Shot 1 Running signal eventhough the auto-recloser function is not yet running.
2. The Shot1 Start Time (500 ms) for has elapsed and the auto-recloser function starts running (AR Running). This sends an "Open" command to the breaker.
3. The circuit breaker is opened and the I> stage's START signal is released and simultaneously REQ1 trip signal for auto-reclosing is released. The auto-recloser function starts calculating the Shot1 Dead Time to close the breaker.
4. The fault is cleared during the Shot1 Dead Time (200 ms). When this time is exceeded, the auto-recloser function sends a "Close" request to the object breaker: the conditions are met and the breaker's "Close" command is sent to the breaker's close coil.
5. The circuit breaker is closed and since the fault was cleared, no pick-ups are detected. A "Close" command is dropped after the breaker's "Closed" indication is received and the auto-recloser function starts calculating the Shot1 Reclaim Time.
6. The Shot1 Reclaim Time (10 s) is exceeded, and so the AR Running, AR1 Requested and Shot 1 Running signals are terminated and the AR Reclaim calculation begins. The difference between auto-reclosing and shot-specific reclaim times is that the function jumps to the next available shot should the fault returns. If a fault returns after a successful cycle and the function's AR Reclaim signal is active, the function jumps directly to the Final Trip state and then enters the lock-out state. The user can control this behavior through the function settings. Both reclaim times can be set to 0 s when they are not needed, and the function skips all timers that are set to zero. The user can also set is so that AR Reclaim is not used at all after a successful recloser cycle.
7. The AR Reclaim time is exceeded and the function is set to "Ready" to wait for the next request.

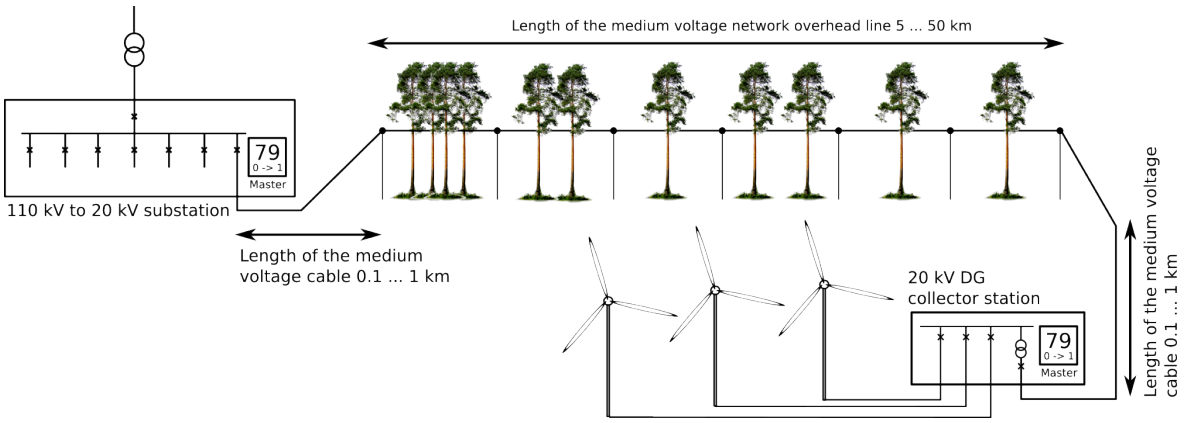


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## Auto-recloser in meshed or ring networks

A typical auto-recloser scheme cannot be applied directly to an overhead line network that has a distributed generation (DG) component; this situation will become more common as renewable power sources become more widespread. Instead, this requires a two-end auto-recloser scheme where the two relays at both ends of the line function in a master–follower operation. The DG power plant must be disconnected from the rest of the network before the breaker's "Close" command is applied; otherwise the plant keeps the fault on during the auto-recloser's dead time and thus fails the reclosing. Additionally, when the main grid is disconnected from the DG power plant, the closing of the breaker is likely to cause phase shifting issues during the dead time.

Figure. 5.5.6 - 152. Auto-reclosing with distributed generation in the line.




This operation requires a link between the 110/20 kV substation's master relay and the 20 kV collector substation's follower relay. When the auto-recloser function is initiated, the collector station's breaker is opened and remains open until the auto-recloser sequence is over as there is no reason to close the breaker until the auto-recloser cycle has successfully cleared the fault. When the sequence is succesful, the collector substation's breaker is given permission to close after the reclaim time; the breaker should be closed with the Synchrocheck function.

Once the collector substation is disconnected, the previously described basic principles of auto-reclosing apply. This method applies to all meshed or ring networks where the same line is fed power from multiple directions. This problem does not exist for typical consumer (radial) networks.

## Arcing time and discrimination time

Generally, after the dead time has elapsed and the breaker is closed by the auto-recloser, this happens: the reclaim time starts calculating and if the process is interrupted by a new reclosing request, the function continues to the next state (the next available shot, or the Final Trip if no more shots are available). However, the user can use the "Shot action time" setting to contol this behavior. The two settings are mutually exclusive: when "Arcing" is selected for a shot, "Discrimination" cannot be selected for the same shot.

The "Arcing" setting is used to control the auto-recloser when the START signal of a stage makes the requests. If the request (e.g. I> START) activates during the reclaim time, an arcing time calculation begins. If the fault persists, the function continues to the next state. If an arcing time calculation begins but stops before the set time has passed, the reclaim calculation continues normally. When that time has elapsed, the auto-recloser function returns either to the general reclaim time or to the Ready mode; the shot is considered successful. The arcing time counter does not reset when the reclaim calculation continues: every time it activates, it continues from where it left off. This means that the time set to the "ARx Shot action time" parameter is a cumulative counter of time allowed before deciding whether a shot is failed or successful.

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The auto-recloser is sometimes used in time-coordinated, IDMT-protected networks that have old mechanical relays with current-dependent release times. In these cases the operation of the protection selectivity must be guaranteed by allowing all relay timing devices to completely reset during dead time to maintain the correct time discrimination after reclosing to the fault. Some mechanical IDMT relays can require up to ten seconds (10 s) to reset. When short dead times are required, the relays should reset almost immediately for the current-dependent time grading to operate as expected, and set the discrimination time (instead of the arcing time) to start simultaneously with the reclaim time. If new reclosing requests are made during this discrimination time, the function halts and lets the protection devices operate based on their own settings, and does not interfere with the protection functions' or the breaker's operation. However, this means that the auto-recloser has to be manually reset and the breaker manually closed before further reclosing requests can be made.

## Auto-recloser I/O

The main outputs of the auto-recloser function are the control signals OBJECT OPEN and OBJECT CLOSE. The function also reports the recloser status information which is used in the logics, LED indications, and applied operations.

The inputs of the function are the following:

- binary recloser request signals
- blockings
- controlling signals
- the controlled object's monitoring and status signals.

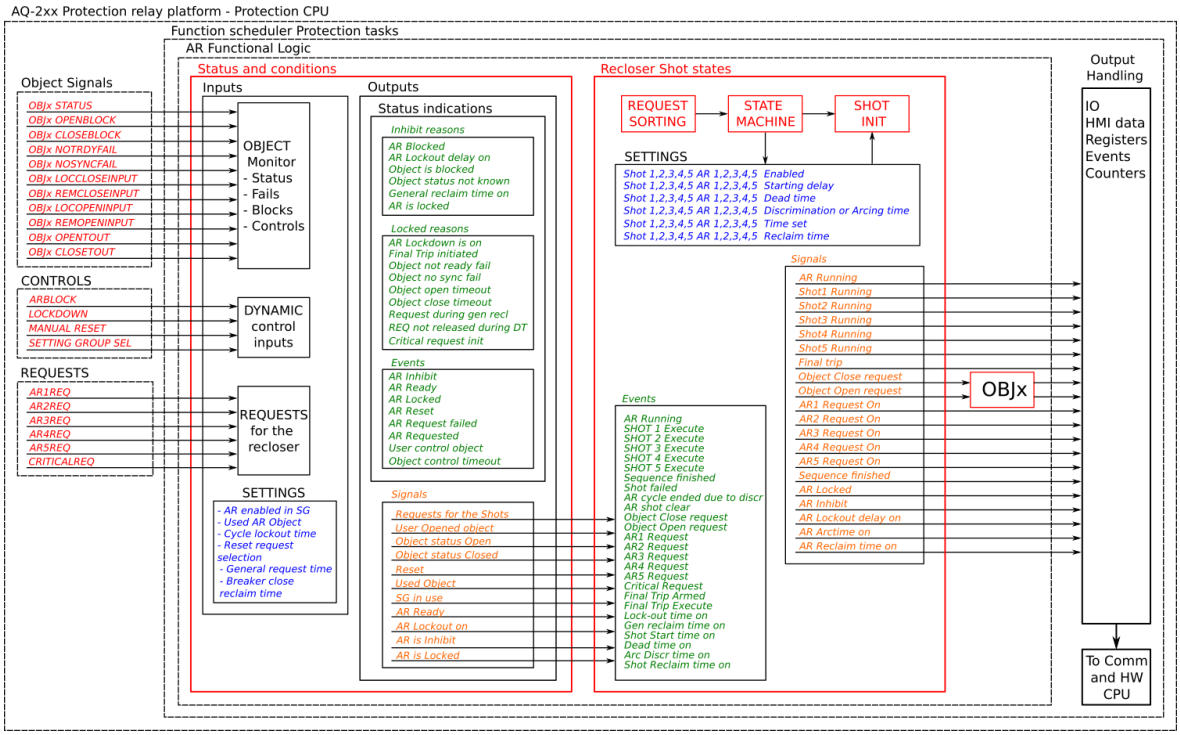
The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signal as well as from several operational event signals. The time stamp resolution is 1 ms. The function also a resettable cumulative counter for each of the applied reclosing events and requests.

The auto-recloser function can be divided into the starter, shot selector state machine, sorter and shot blocks which operate dynamically during the recloser sequences according to the given settings and input signal monitoring. The behavior of the function can be changed even during sequences that are based on programmed reclosing schemes and on active requests.

The following figure presents a simplified function block diagram of the auto-recloser function.


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Figure. 5.5.6 - 153. Simplified function block diagram of the auto-recloser function.




As the diagram above shows, the auto-recloser function is tied to and dependent on the block status information and configuration of the object control and monitoring function. This is why the controlled object must be configured before the auto-recloser function can be used. In AQ-2xx protection systems the object control block supervises all breaker operations: this means that breaker-related functionalitites (e.g. synchrocheck, breaker status monitoring) are not noted separately by the auto-recloser function. If any of these fail during the circuit breaker opening or closing, the object control function reports the event to the auto-recloser function which then takes the corresponding action.

In addition to the previously mentioned cases, the manual control of the breaker (whether open or close during the auto-recloser sequence) also always causes a reset of the auto-recloser. For example, if a breaker is closed manually during dead time towards a fault, the auto-recloser function enters the general reclaim mode and causes a lock-out of the function.

The auto-recloser function gives exhaustive information about its operations and statuses through online indications, events, registered data as well as output signals which can be configured to any output or logical input in the device. If the network configuration is altered during an auto-reclosing sequence, the operation of the auto-recloser function can also be modified accordingly by switching to a setting group that matches the changed network situation.

## Input signals of the auto-recloser function

The required auto-recloser scheme determines how many and which setting parameters are needed. All status changes in the input signals (inc. the requests) always cause recorded events, also in the object's registers and the object's continuous status indications. Events can be enabled or disabled according to the application requirements.

Table. 5.5.6 - 235. AR input signals.

| Signal | Range | Description |
|---|---|---|
| AR On/ Off | Any binary signal in the device | Enables or disables the auto-recloser function with any binary signal selected by the user. The parameter "Use AR On/Off signals" defines whether this input signal is in use or not. |

| Signal | Range | Description |
|---|---|---|
| AR Manual reset | Any binary signal in the device | Allows for the manual resetting of the recloser if locked (e.g. due to Final Trip). |
| AR Locking | Any binary signal in the device | Locks the auto-recloser so that it requires a manual reset before its operation can be set to "Ready". |
| AR Critical request | Any binary signal in the device | Defines the critical request for the function. If this signal is activated, the auto-recloser goes directly to the locked state the moment the request is received. |

Table. 5.5.6 - 236. Request signals.

| Signal | Range | Description |
|---|---|---|
| AR Request 1 (REQ1) | Any binary signal in the device | The request with the highest priority, it overrides all auto-reclosing requests with lower priorities. When this request signal is activated and other conditions for reclosing are met, a shot is applied. |
| AR Request 2 (REQ2) | Any binary signal in the device | The request with the second highest priority, it overrides all auto-reclosing requests with lower priorities. When this request signal is activated and other conditions for reclosing are met, a shot is applied. |
| AR Request 3 (REQ3) | Any binary signal in the device | The request with the third highest priority, it overrides all auto-reclosing requests with lower priorities. When this request signal is activated and other conditions for reclosing are met, a shot is applied. |
| AR Request 4 (REQ4) | Any binary signal in the device | The request with the fourth highest (and second lowest) priority, it overrides all auto-reclosing requests with lower priorities. When this request signal is activated and other conditions for reclosing are met, a shot is applied. |
| AR Request 5 (REQ5) | Any binary signal in the device | The request with the lowest priority, it is overridden by all other auto-reclosing requests. When this request signal is activated and other conditions for reclosing are met, a shot is applied. |

## Output signals of the auto-recloser function

The outputs of the function are only indication signals (*Control → Control functions → Auto-recloser → I/O*). The breaker's "Open" and "Close" commands are controlled by the object control and monitoring function.

Table. 5.5.6 - 237. AR output signals.

| Signal | Description |
|---|---|
| AR ON<br>AR OFF | The signal "AR ON" is displayed when the auto-recloser function is enabled. The signal "AR OFF" is displayed if the "Use AR On/Off signals" is set to "Yes" and the input of the AR On/Off is inactive. |
| AR In progress | The signal "AR In progress" is activated and displayed when the function has opened the breaker and is calculating the time towards closing it. |
| AR1 Request ON | The signal "AR1 Request ON" is activated and displayed when the function is executing a shot requested by REQ1. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR2 Request ON | The signal "AR2 Request ON" is activated and displayed when the function is executing a shot requested by REQ2. This signal can be connected to any relay I/O as well as into communication protocols. |
| AR3 Request ON | The signal "AR3 Request ON" is activated and displayed when the function is executing a shot requested by REQ3. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR4 Request ON | The signal "AR4 Request ON" is activated and displayed when the function is executing a shot requested by REQ4. This signal can be connected to any relay I/O as well as to communication protocols. |


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| Signal | Description |
|---|---|
| AR5 Request ON | The signal "AR5 Request ON" is activated and displayed when the function is executing a shot requested by REQ5. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Running | The signal "AR Running" is activated and displayed when the function is in Running mode. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Shot 1 Running | The signal "AR Shot 1 Running" is activated and displayed when the function is executing Shot 1. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Shot 2 Running | The signal "AR Shot 2 Running" is activated and displayed when the function is executing Shot 2. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Shot 3 Running | The signal "AR Shot 3 Running" is activated and displayed when the function is executing Shot 3. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Shot 4 Running | The signal "AR Shot 4 Running" is activated and displayed when the function is executing Shot 4. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Shot 5 Running | The signal "AR Shot 5 Running" is activated and displayed when the function is executing Shot 5. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Sequence finished | The signal "AR Sequence finished" is activated and displayed when the function has closed the breaker after the last shot and is waiting for the Final Trip to occur or for the reclaim time to run out. |
| AR Final Trip | The signal "AR Final Trip" is activated and displayed when the function has executed the Final Trip command. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Dead time ON | The signal "AR Dead time ON" is activated and displayed when the function has opened the breaker and is calculating the time towards closing it. |
| AR Arcing time ON | The signal "AR Arcing time ON" is activated and displayed when the function is calculating the arcing time. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Reclaim time ON | The signal "AR Reclaim time ON" is activated and displayed when the function is calculating the reclaim time. This signal can be connected to any relay I/O as well as to communication protocols. |
| AR Ready | The signal "AR Ready" is activated and displayed when the function is ready to execute the auto-reclosing sequence if a fault is detected. |
| AR Lockout after successful sequence | The signal "AR Reclaim time ON" is activated and displayed when the auto-recloser sequence has been successful but a new fault was detected before the lock-out time was depleted. No new sequence will be started while this signal is active, instead the function goes into the locked mode. |
| AR Operation inhibit | The signal "AR Operation inhibit" is activated and displayed when the function is in Inhibit mode. This signal can be connected to any relay I/O as well as into communication protocols. |
| AR Locked | The signal "AR Locked" is activated and displayed when the function is in Locked mode. This signal can be connected to any relay I/O as well as into communication protocols. |

## Setting parameters

The auto-recloser function has settings that the user can freely configure. The setting cover all areas of the function so that the user can control the operational details of the function as needed. The function's operation can be static or dynamic depending on the setting group that is in use. The function has both general settings and active settings concerning requests and shots. The general settings control the desired object selection as well as the general behavior of the function in different operating schemes.

Table. 5.5.6 - 238. AR Status and basic settings.

| Setting | Range | Default | Description |
|---|---|---|---|
| AR Mode | 0: Disabled<br>1: Enabled | 0: Disabled | Enables and disables the auto-recloser function in the configuration. |

| Setting | Range | Default | Description |
|---|---|---|---|
| AR LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of AR block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| AR LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | - | Displays the mode of AR block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Use AR On/Off signals | 0: Yes<br>1: No | 1: No | Selects whether or not the AR ON and AR OFF signals are used. If set to "No" the auto-recloser is always in use. If set to "Yes" binary signal set to "AR ON/OFF" has to be active for the auto-recloser to be enabled. |
| AR Status | 0: AR is inhibit<br>1: AR is ready<br>2: AR is locked<br>3: AR is running<br>4: AR is not running<br>5: Lock out delay is running<br>6: Reclaim time counting<br>7: Start time counting<br>8: Dead time counting<br>9: Arcing or discr. time counting<br>10: Reclaim time counting<br>11: AR1 Requested<br>12: AR2 Requested<br>13: AR3 Requested<br>14: AR4 Requested<br>15: AR5 Requested<br>16: Executing Shot1<br>17: Executing Shot2<br>18: Executing Shot3<br>19: Executing Shot4<br>20: Executing Shot5<br>21: Shot Clear | - | When clicked open, displays the status of the function. |



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| Setting | Range | Default | Description |
|---|---|---|---|
| Timer active | 0: -<br>1: AR Lockout<br>2: AR Reset Reclaim<br>3: AR Start Delay<br>4: AR Dead Time<br>5: AR Discrimination<br>6: AR Shot Reclaim | 0: - | When the function is counting down towards any action, this parameter displays what is the next expected action when the "AR Timer value" reaches zero. |
| AR Timer value | 0...1800.00s | 0s | When the function is counting down towards any action, this parameter displays how much time is left until the action is executed. The "Timer active" setting displays what is the action when this timer reaches zero. |

Table. 5.5.6 - 239. AR General settings.

| Setting | Range | Step | Default | SG | Description |
|---|---|---|---|---|---|
| Object for AR | 0: Object 1<br>1: Object 2<br>2: Object 3<br>3: Object 4<br>4: Object 5 | - | 0: Object 1 | 8 | Defines the monitored and/or controlled object, and the monitoring and/or controlling signals issued. This selection can be changed via the device's setting group selection in real time. |
| AR Enabled in SG | 0: Disabled<br>1: Enabled | - | 0: Disabled | 8 | Enables and disables the auto-recloser in the current setting group. Can be enabled and disabled in each setting group independently. This selection can be changed via the device's setting group selection in real time. |
| Require manual resetting | 0: Required<br>1: Obj Close CMD resets | - | 0: Required | 8 | Defines the auto-recloser resetting after locking (Final trip, error condition). Resetting can be set to be only done manually with a user defined signal, or it can be reset by a general breaker "Close" command (from any source). This selection can be changed via the device's setting group selection in real time. |
| Successful reclose start general reclaim | 0: Only shot reclaim<br>1: Shot reclaim and general reclaim | - | 0: Only shot reclaim | 8 | Defines whether the auto-recloser runs after a successful reclose (inc. shot reclaim time), or whether it enters the locked state after a request for auto-reclosing is applied. If "Shot reclaim and general reclaim" is selected, this selection defines the minimum time allowed between auto-reclosing cycles without changing the shot-specific reclaim times. This selection can be changed via the device's setting group selection in real time. |
| Lock-out time ("Lockout after successful AR") | 0.000…1800.000s | 0.005s | 0.000s | 8 | Defines the lock-out time after a successful reclosing. When set to 0.00 s, the recloser goes directly into the "Ready" state after a successful reclosing. If this time is running while a new reclosing request is applied, the auto-recloser opens the breaker and enters the locked state to prevent further reclosing attempts. This selection can be changed via the device's setting group selection in real time. |
| Object close reclaim time | 0.000…1800.000s | 0.005s | 10.000s | 8 | Defines the "Close" reclaim time of the object. This time starts when the object is manually closed or when the general reclaim time is selected after a successful auto-reclosing. If an auto-reclosing request is applied during this time, the auto-recloser enters the locked state to prevent further reclosing attempts. This selection can be changed via the device's setting group selection in real time. |

Table. 5.5.6 - 240. Auto-recloser shot settings.

| Setting | Range | Step | Default | SG | Description |
|---|---|---|---|---|---|
| ARx Shot x | 0: Disabled<br>1: Enabled | - | 0:<br>Disabled | 8 | Enables/disables Shot x for request ARx. If "Disabled", the ARx request skips Shot 1 and moves on to the next enabled shot. If "Enabled", the ARx request executes a shot according to Shot 1 settings. This selection can be changed via the device's setting group selection in real time. |
| ARx<br>Shot starting delay | 0.000…1800.000s | 0.005s | 0.000s | 8 | Defines the starting delay of the shot, i.e. the minimum time an ARx request has to be active before openign the breaker and entering the dead time delay counting. This setting is used only when the ARx request comes from the function's START signal. If the function's TRIP request starting delay in not 0.000 s, the auto-recloser is prevented from starting. Whenever the shot is not the first one, this setting should be set to 0.000 s. This selection can be changed via the setting group selection in real time. |
| ARx<br>Shot dead time delay | 0.000…1800.000s | 0.005s | 0.000s | 8 | Defines the dead time delay of the shot, i.e. the breaker's "Open" time before the auto-recloser closes the breaker. The time calculation starts from the breaker's "Open" signal. This selection can be changed via the device's setting group selection in real time. |
| ARx Shot<br>Arc or Discr. | 0: Arcing<br>1: Discrimination | - | 0:<br>Arcing | 8 | Determines what happens when a fault persists after a dead time when the breaker is closed. Can be chosen between arcing and discrimination behavior; the selection depends on the application. When "Arcing" time is selected, the auto-recloser keeps the breaker closed until Action time is spent (also with Discrimination time). If a new request received during the Action time calculation, the auto-recloser locks out during the reclaim time. This selection can be changed via the device's setting group selection in real time. |
| ARx Shot<br>action time | 0.000…1800.000s | 0.005s | 0.000s | 8 | Defines the action time for the shot after dead time and after the breaker is closed, i.e. the maximum arcing time or discrimination time when the reclaim time is running. When set to 0.000 s, the "Arcing" or "Discrimination" time is disabled in the auto-recloser scheme. This setting can be changed via the device's setting group selection in real time. |
| ARx Shot<br>reclaim time | 0.000…1800.000s | 0.0005s | 0.000s | 0.000s | After the dead time has elapsed and the breaker is closed by the auto-recloser, the reclaim time starts calculating. If the process is interrupted by a new reclosing request, the function continues to the next shot. |



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Figure. 5.5.6 - 154. Auto-recloser shot setting parameters.




The auto-recloser function's shot settings are grouped into corresponding rows to make the setting of each shot straightforward. From the settings the user can see how the reclosing cycle is executed by each request, which functions initiate requests, and which shots and requests are in use.

The setting example in the image above presents a two-shot auto-recloser. One can see that the REQ1 is started by I> START signal. The starting delay is 500 ms, followed by a 200 ms dead time; after a 200 ms "Arcing" time and a 10 s reclaim time Shot 1 is executed. If Shot 1 fails, there is a 120 s dead time, a 200 ms "Arcing" time and a 10 s reclaim time before Shot 2 is executed. If Shot 2 fails, the auto-recloser initiates the Final Trip. In REQ2, the settings are otherwise the same, except I> TRIP and I0dir> TRIP are used to activate the request, Shot 1 does not have a starting delay, the dead time delay for Shot 2 is different and the action time for both shots is zero. REQ3 has just one shot with a 60 second dead time and a 30 ms shot reclaim. If REQ4 or REQ5 are activated, no shots are executed as none are set.

## Inhibit and Locked states of the auto-recloser function

The auto-recloser function can have several reasons to go into "Lock-out" and "Inhibit" states where reclosing cannot be allowed for some reason. When the function enters the "Not ready" state, it gives an indication of the reason why it cannot be in the "Ready" state in order to quickly rectify whatever is causing the problem of the functions operation. The reason is indicated in the auto-recloser function's *Registers* menu.

The Inhibit reasons for the auto-recloser are the following:

- AR is blocked (from Blocking input)
- AR is not enabled (signal connected to "AR ON/OFF" is not active)
- AR is calculating the lock-out delay
- The object "Open" or "Close" command is blocked
- The object status is not known ("intermediate" or "bad" status)
- General reclaim time is running
- AR is locked

When the auto-recloser function is in the "Inhibit" state, it returns to the "Ready" state when the reason for the inhibition is removed.

The Lock-out reasons for the auto-recloser are the following:

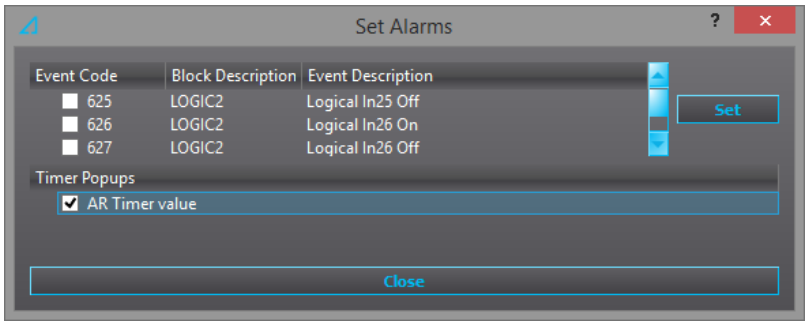
- The "AR Locked" signal is initiated (from "AR Locking" input)
- The Final Trip signal is given
- The "object not ready" failed within a given time (from Object)
- The "object no sync" failed within a given time (from Object)
- The object's "Open" timeout (from Object)
- The object's "Close" timeout (from Object)
- AR request initiated during General reclaim time
- AR request was not released during Dead Time
- Critical request initated in any state of the auto-reclosing cycle

When the auto-recloser function is in the "Locked" state, it can be recovered only through by reset input,  or by manually resetting the breaker. This depends on what the "Require manual resetting" parameter's setting is.

## Displaying auto-reclosing timers in MIMIC view

The user can enable timers to be displayed in the MIMIC view. Enable the AR timer value at *Tools → Events and logs → Set alarm events* (see the image below). The timer displays the reclaim time and the dead time delay.


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## Events and registers

The auto-recloser function (abbreviated "AR" in event block names) generates events and registers from the status changes in the monitored signals as well as the control command fails and operations. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.6 - 241. Event messages.

| Event block name | Event names |
|---|---|
| AR1 | AR Ready ON |
| AR1 | AR Ready OFF |
| AR1 | AR Locked reset |
| AR1 | AR Reclosing request rejected ON |
| AR1 | AR Reclosing request rejected OFF |
| AR1 | AR Reclosing request ON |
| AR1 | AR Reclosing request OFF |
| AR1 | User-operated Object AR halted and reset |
| AR1 | Object failure, AR locked |
| AR1 | Shot failed |
| AR1 | AR cycle ends due to a discrimination request |
| AR1 | AR Shot clear |
| AR1 | Object "Close" request |
| AR1 | Object "Open" request |
| AR1 | Inhibit condition ON |
| AR1 | Inhibit condition OFF |
| AR1 | Locking condition ON |
| AR1 | Locking condition OFF |
| AR1 | Reserved |
| AR1 | AR1 Request ON |
| AR1 | AR1 Request OFF |
| AR1 | AR2 Request ON |
| AR1 | AR2 Request OFF |
| AR1 | AR3 Request ON |

| Event block name | Event names |
|---|---|
| AR1 | AR3 Request OFF |
| AR1 | AR4 Request ON |
| AR1 | AR4 Request OFF |
| AR1 | AR5 Request ON |
| AR1 | AR5 Request OFF |
| AR1 | Critical request ON |
| AR1 | Critical request OFF |
| AR1 | AR Running ON |
| AR1 | AR Running OFF |
| AR1 | Shot 1 Execute ON |
| AR1 | Shot 1 Execute OFF |
| AR1 | Shot 2 Execute ON |
| AR1 | Shot 2 Execute OFF |
| AR1 | Shot 3 Execute ON |
| AR1 | Shot 3 Execute OFF |
| AR1 | Shot 4 Execute ON |
| AR1 | Shot 4 Execute OFF |
| AR1 | Shot 5 Execute ON |
| AR1 | Shot 5 Execute OFF |
| AR1 | Seqeunce finished, the Final trip armed |
| AR1 | Final trip executed |
| AR1 | Lock-out time ON |
| AR1 | Lock-out time OFF |
| AR1 | General reclaim time ON |
| AR1 | General reclaim time OFF |
| AR1 | Shot start time ON |
| AR1 | Shot start time OFF |
| AR1 | Dead time ON |
| AR1 | Dead time OFF |
| AR1 | Arc Discr time ON |
| AR1 | Arc Discr time OFF |
| AR1 | Shot reclaim time ON |
| AR1 | Shot reclaim time OFF |
| AR1 | Sequence finished OFF |
| AR1 | Final trip executed OFF |
| AR1 | Object "Close" request OFF |
| AR1 | AR ON |
| AR1 | AR OFF |


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| Event block name | Event names |
|---|---|
| AR1 | AR Running (DT) ON |
| AR1 | AR Running (DT) OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data from statuses, commands, etc.

The table below presents the structure of the auto-recloser function's register content.

Table. 5.5.6 - 242. Register content.

| Date and time | Event | Setting group in use | Inhibit condition active | Inhibit condition release | Locked condition active | Locked condition release | AR status | Active timer | Active time |
|---|---|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | 1...8 | Inhibit reason ON | Inhibit reason OFF | Locked reason ON | Locked reason OFF | The status code of the auto-recloser function | Timer ON | The value of the timer |

The auto-recloser function's registers are treated differently than the registers of other functions.

Below is an exhaustive example of how the registers work based on a partial auto-recloser sequence. First is how the register list is displayed:

| Date and time | Registers |
|---|---|
| dd.mm.yyyy hh:mm:ss.mss | AR Status: AR is ready, AR is not running, AR2 Requested, Executing Shot 1<br>AR Timers: No timers running 0.000 s |
| dd.mm.yyyy hh:mm:ss.mss | AR Status: AR is ready, AR is not running, Start time counting, AR2 Requested, Executing Shot 1<br>AR Timers: Start Delay 0.000 s |
| dd.mm.yyyy hh:mm:ss.mss | AR Status: AR is ready, AR is running, Start time counting, AR2 Requested, Executing Shot 1<br>AR Timers: Start Delay 0.000 s |
| dd.mm.yyyy hh:mm:ss.mss | AR Status: AR is ready, AR is running, Dead time counting, AR2 Requested, Executing Shot 1<br>AR Timers: Dead Time 0.195 s |
| dd.mm.yyyy hh:mm:ss.mss | AR Status: AR is ready, AR is running, Dead time counting, Reclaim time counting, AR2 Requested, Executing Shot1<br>AR Timers: Dead Time -0.270 s |

The corresponding event list is as presented below (inc. object and protection events):

| | | |
|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | 1664 | NEF1 Start ON |
| dd.mm.yyyy hh:mm:ss.mss | 1666 | NEF1 Trip ON |
| dd.mm.yyyy hh:mm:ss.mss | 4065 | AR1 Shot 1 Execute ON |
| dd.mm.yyyy hh:mm:ss.mss | 4037 | AR1 AR Reclosing request ON |
| dd.mm.yyyy hh:mm:ss.mss | 4053 | AR1 AR2 Request ON |
| dd.mm.yyyy hh:mm:ss.mss | 4081 | AR1 Shot start time ON |
| dd.mm.yyyy hh:mm:ss.mss | 4045 | AR1 Object "Open" request |
| dd.mm.yyyy hh:mm:ss.mss | 2944 | OBJ1 Object Intermediate |
| dd.mm.yyyy hh:mm:ss.mss | 2952 | OBJ1 Open request ON |
| dd.mm.yyyy hh:mm:ss.mss | 2955 | OBJ1 Open command ON |
| dd.mm.yyyy hh:mm:ss.mss | 4063 | AR1 AR Running ON |

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| | | |
|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | 2954 | OBJ1 Open request OFF |
| dd.mm.yyyy hh:mm:ss.mss | 1665 | NEF1 Start OFF |
| dd.mm.yyyy hh:mm:ss.mss | 1667 | NEF1 Trip OFF |
| dd.mm.yyyy hh:mm:ss.mss | 4038 | AR1 AR Reclosing request OFF |
| dd.mm.yyyy hh:mm:ss.mss | 2945 | OBJ1 Open request |
| dd.mm.yyyy hh:mm:ss.mss | 2956 | OBJ1 Open command OFF |
| dd.mm.yyyy hh:mm:ss.mss | 4082 | AR1 Shot start time OFF |
| dd.mm.yyyy hh:mm:ss.mss | 4083 | AR1 Dead time ON |
| dd.mm.yyyy hh:mm:ss.mss | 2963 | OBJ1 Status change OFF |
| dd.mm.yyyy hh:mm:ss.mss | 4044 | AR1 Object "Close" request |
| dd.mm.yyyy hh:mm:ss.mss | 2957 | OBJ1 Close request ON |
| dd.mm.yyyy hh:mm:ss.mss | 2958 | OBJ1 Close Fail |
| dd.mm.yyyy hh:mm:ss.mss | 2959 | OBJ1 Close request OFF |
| dd.mm.yyyy hh:mm:ss.mss | 2960 | OBJ1 Close command ON |
| dd.mm.yyyy hh:mm:ss.mss | 2962 | OBJ1 Status change ON |
| dd.mm.yyyy hh:mm:ss.mss | 2944 | OBJ1 Object Intermediate |
| dd.mm.yyyy hh:mm:ss.mss | 2946 | OBJ1 Object Close |
| dd.mm.yyyy hh:mm:ss.mss | 2961 | OBJ1 Close command OFF |
| dd.mm.yyyy hh:mm:ss.mss | 4087 | AR1 Shot reclaim time ON |

As these tables show, the register list complement the information from event lists when the control has encountered some unexpected behavior. The example above shows that the object had issues executing the "Close" command, which caused the dead time to be 270 ms longer that its set value. The reason for this behavior can be verified from the object control and monitoring function's registers.

The example below shows that the object was not ready when it received the closing request from the auto-recloser function and kept the request pending until it was ready to execute the "Close" command.

| | |
|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Object Open, WD In, Open Allowed, Close Allowed, Object Ready, Sync Ok, Obj open time: 0.025 s |
| dd.mm.yyyy hh:mm:ss.mss | Object Open, WD In, Object not ready for Close request, Open Allowed, Close Allowed, Object Not Ready, Sync Ok |
| dd.mm.yyyy hh:mm:ss.mss | Object Open, WD In, Close request from Auto-recloser, Close pending due to: Close wait for Ready, Open Allowed, Close Allowed, Object Not Ready, Sync Ok |
| dd.mm.yyyy hh:mm:ss.mss | Object Open, WD In,Open Allowed, Close Allowed, Object Ready, Sync Ok |
| dd.mm.yyyy hh:mm:ss.mss | Object Closed, WD In, Open Allowed, Close Allowed, Object Ready, Sync Ok , Obj close time: 0.030 s |

### Auto-recloser operation counters

The auto-recloser function keeps statistical track of the operated auto-reclosing cycles as well as of successful and failed shots.

The function records the following counters:

- Shot 1…5 started
- Shot 1…5 requested by AR1…5


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- Shots failed
- Final trips
- Shots cleared
- AR started

The counters are cumulative and they update automatically according to the operations of the auto-recloser function. They can be found in the *Statistics* tab at *Control → Auto-recloser → Registers*.

### 5.5.7 Zero sequence recloser (U0> RECL; 79N)

When earth fault current is so low that it is not possible for directional earth fault protection functions to detect the direction of the fault, zero sequence recloser control function can be used together with neutral overvoltage (59N) function as a backup for finding an outgoing feeder with a fault while disconnecting as few healthy feeders as possible and reconnecting them back as quickly as possible. Feeders are set up to trip one by one in small time increments. If the fault was not cleared by tripping the feeder the breaker will be closed and the next feeder will be opened. This will go on until faulty feeder is disconnected. No communication between needed between the feeder protection relays.

#### General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.5.7 - 243. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| U0> RECL [79] LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 0: On | Set mode of NJK block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U0> RECL force status to | 0: Normal<br>1: Block On<br>2: Requested On<br>3: BK clo cmd On<br>4: Bk Closed.U0> blocked On | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

Table. 5.5.7 - 244. U0> recloser activation inputs.

| Name | Description |
|---|---|
| Enable input | Input defined here must be active for the recloser to be enabled. |
| Function trip input | Detection of neutral overvoltage trip (U0> TRIP). Starts the reclosing sequence. |
| Function blocked input | Detection of neutral overvoltage protection being blocked (U0> BLOCKED). When this input is activated the breaker will be closed after time set to "Reclose time for U0> RECL" has passed. See *Application example* section for more detail. |

#### Operating time characteristics

When zero sequence recloser function detects neutral overvoltage trip it activates a circuit breaker close command after a set time delay. Please note that the zero sequence recloser function actually follows the "Function blocked input" status when counting down towards reclosing. See *Application example* for more details.

Table. 5.5.7 - 245. Operating time characteristics setting parameters.

| Name | Range | Step | Description |
|---|---|---|---|
| Reclose time for U0> RECL | 0.000...1800.000 s | 0.005 s | Breaker reclosing time delay after neutral overvoltage trip. "Function blocked input" signal must stay active for the duration of time delay. |

## Function outputs

Zero sequence recloser generates output signals listed in the table below. These signals are used together with neutral overvoltage function (59N) inputs and outputs to control the reclosing sequence.

Table. 5.5.7 - 246. Outputs of the zero sequence recloser function.

| Name | Description |
|---|---|
| U0> RECL Blocked | Zero sequence recloser function does not have "Enable input" active. The function will not generate reclosing command. |
| U0> RECL Active | Zero sequence recloser function has detected a neutral overvoltage trip. Stays active until fault is cleared. |
| U0> RECL CLOSE | Close command for circuit breaker. Activated after neutral overvoltage trip and time delay set to "Reclose time for U0> RECL" parameter has passed. |
| U0> RECL BLKU0 | Connect to neutral overvoltage protection U0> BLOCK input. Blocks neutral overvoltage protection from opening the breaker after reclosing. Stays active until the fault is cleared. |

## Application example

Figure. 5.5.7 - 155. Example application of zero sequence recloser. Each feeder has slighly longer operation time delay than the previous one.

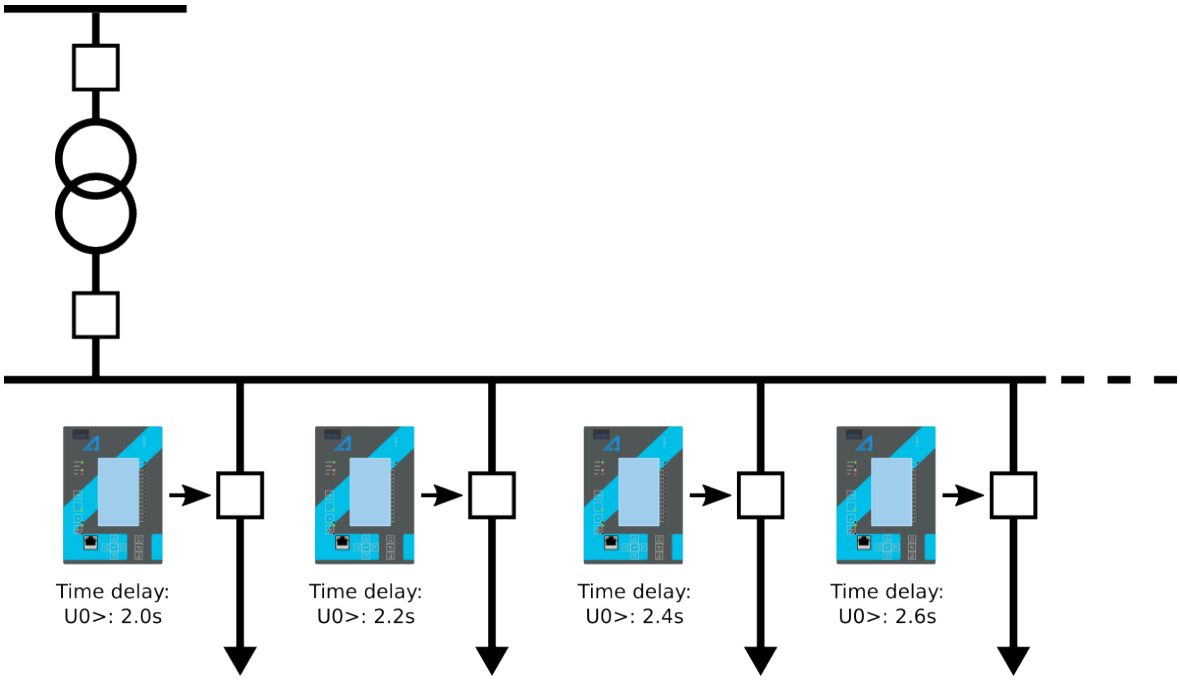



Table. 5.5.7 - 247. Common settings for each feeder.

| Setting | Connection |
|---|---|
| U0> BLOCK input | U0> RECL BLKU0<br><br>Circuit breaker open status |



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| Setting | Connection |
|---|---|
| U0> TRIP output | Digital output connected to circuit breaker open coil |
| U0 RECL Enable input | Programmable control switch, digital input or other binary signal |
| U0 RECL Function trip input | U0> TRIP signal |
| U0 RECL Function blocked input | U0> BLOCKED signal |

From the point of view of first feeder, with the settings used above, if the fault is in the first feeder the following sequence happens:

1. Neutral overvoltage function trips the breaker.
2. Neutral voltage drops. Fault is cleared.

If the fault is not in the first feeder, the following sequence happens:

1. Neutral overvoltage function trips the breaker.
2. Neutral voltage doesn't drop → U0> BLOCKED is activated from fault being still present and circuit breaker being opened → U0> RECL BLKU0 is activated from U0> BLOCKED.
3. Breaker is closed after "Reclose time for U0> RECL" has passed.
4. Both neutral overvoltage protection function and zero sequence reclosing function are blocked until fault is cleared.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.7 - 248. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| U0> RECL LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Displays the mode of NJK block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| U0> RECL condition | 0: Normal<br>1: Requested<br>2: Blocked<br>3: Active<br>4: BK clo cmd<br>5: Bk Closed.U0> blocked | Displays status of the control function. |

## Events and registers

The zero sequence recloser function (abbreviated "NJK" in event block names) generates events and registers from status changes. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp and with process data values. The time stamp resolution is 1 ms.

Table. 5.5.7 - 249. Event messages.

| Event block name | Event names |
|---|---|
| NJK1 | U0RECL Request On |
| NJK1 | U0RECL Request Off |

| Event block name | Event names |
|---|---|
| NJK1 | U0RECL Blocked On |
| NJK1 | U0RECL Blocked Off |
| NJK1 | U0RECL Active On |
| NJK1 | U0RECL Active Off |
| NJK1 | U0RECL Breaker close request On |
| NJK1 | U0RECL Breaker close request Off |
| NJK1 | U0RECL U0 Blocking On |
| NJK1 | U0RECL U0 Blocking Off |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for CLOSE and BLOCKED. The table below presents the structure of the function's register content.

Table. 5.5.7 - 250. Register content.

| Date and time | Event | Used SG | U0> RECL time before close | U0> RECL been active |
|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Setting group 1...8 active | - | - |

## 5.5.8 Cold load pick-up (CLPU)

The cold load pick-up function is used for detecting so-called cold load situations, where a loss of load diversity has occured after distribution has been re-energized. The characteristics of cold load situations vary according to the types of loads individual feeders have. This means that this function needs to be set specifically according to the load type of the feeder it is monitoring. For example, in residential areas there are relatively many thermostat-controlled devices (such as heating and cooling machinery) which normally run in asynchronous cycles. When restoring power after a longer power outage, these devices demand the full start-up power which can cause the inrush current to be significantly higher than what the load current was before the outage. This is uncommon in industrial environments since the restoring of the production process takes several hours, or even days, and the power level goes back to the level it was before the outage. However, some areas of the industrial network may find the cold load pick-up function useful.

The operating decisions are based on phase current magnitudes and magnitude changes which the function constantly measures. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The cold load pick-up function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The inputs for the function are the following:

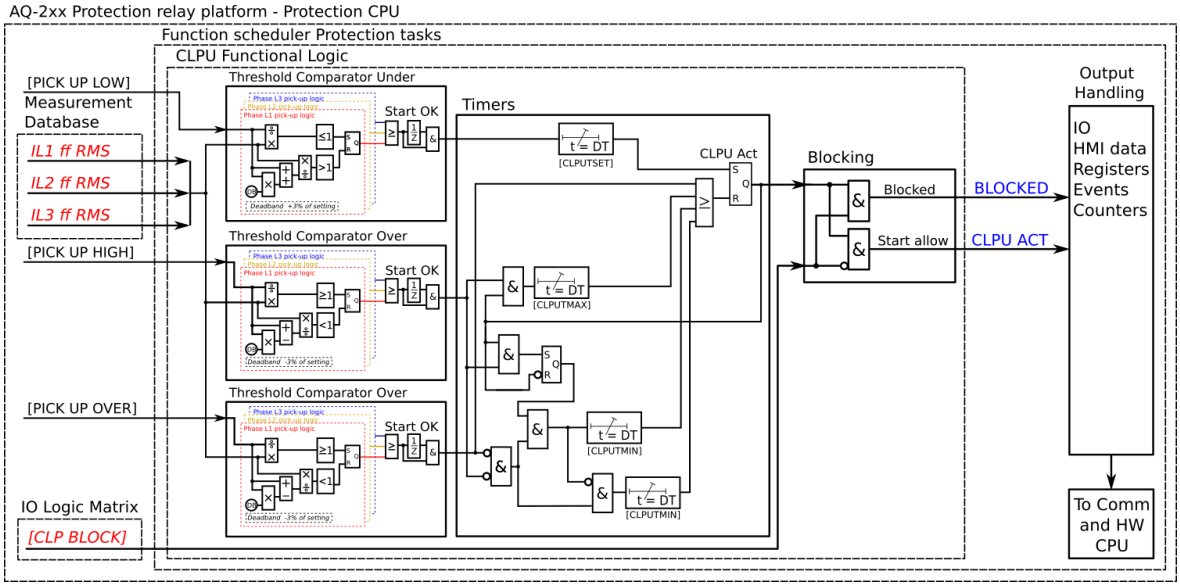

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- setting parameters
- digital input signals
- measured and pre-processed current magnitudes.

The function's outputs are CLPU ACT and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the two (2) output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the CLPU ACT and BLOCKED events.

The following figure presents a simplified function block diagram of the cold load pick-up function.

Figure. 5.5.8 - 156. Simplified function block diagram of the cold load pick-up function.




## Measured input

The function block uses analog current measurement values. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.5.8 - 251. Measurement inputs of the cold load pick-up function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |

The pre-fault condition is presented with a 20 ms averaged history value from -20 ms from CLPU ACT event.

## Pick-up

The $I_{low}$, $I_{high}$ and $I_{over}$ setting parameters control the the pick-up and activation of the cold load pick-up function. They define the maximum and minimum allowed measured current before action from the function. The function constantly calculates the ratio between the setting values and the measured magnitude ($I_m$) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the $I_m$ exceeds the setting value (in single, dual or all phases) it triggers the pick-up operation of the function.

Table. 5.5.8 - 252. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| $I_{low}$ | 0.01…40.00×In | 0.01×In | 0.20×In | The pick-up setting for low current detection. All measured currents must be below this setting in order for the cold load pick-up signal to be activated. |
| $I_{high}$ | 0.01…40.00×In | 0.01×In | 1.20×In | The pick-up setting for high current detection. All measured currents must exceed this setting in order for the cold load pick-up signal to be activated. |
| $I_{over}$ | 0.01…40.00×In | 0.01×In | 2.00×In | The pick-up setting for overcurrent detection. If this setting is exceeded by any of the measured currents, the cold load pick-up signal is released immediately. |

The pick-up activation of the function is not directly equal to the CLPU ACT signal generation of the function. The CLPU ACT signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.8 - 253. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| CLPU LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Displays the mode of CLP block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CLP condition | 0: Normal<br>1: Curr low<br>2: Overcurrent On<br>3: CLPU On<br>4: CLPU blocked | Displays status of the control function. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a CLPU ACT signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the CLPU ACT function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.


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## Operating time characteristics

The behavior of the function's operating timers can be set for activation as well as for the situation monitoring and release of the cold load pick-up.

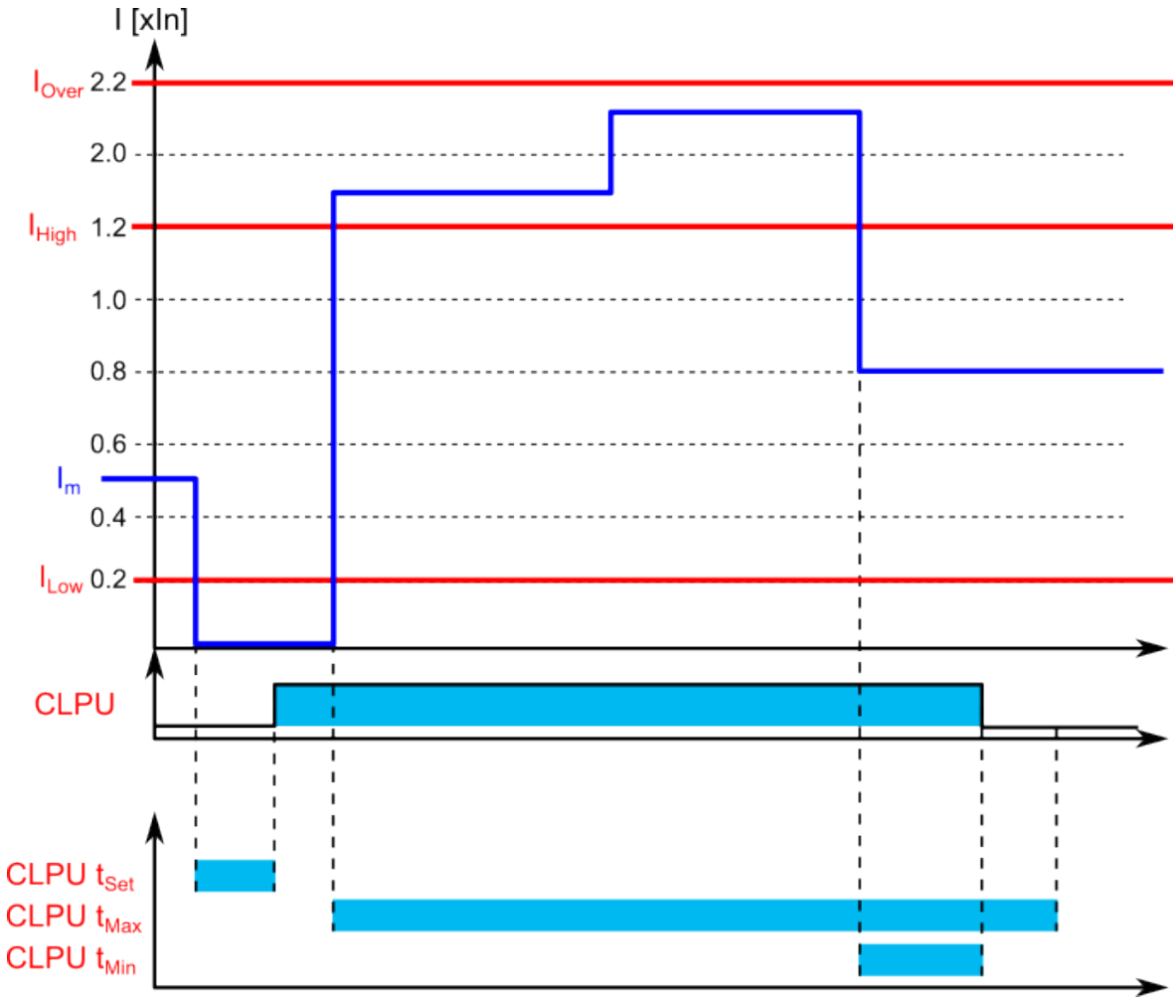
The table below presents the setting parameters for the function's time characteristics.

Table. 5.5.8 - 254. Setting parameters for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| $T_{set}$ | 0.000…1800.000s | 0.005s | 10.000s | The function's start timer which defines how long the $I_{low}$ condition has to last before the cold load pick-up is activated. |
| $T_{max}$ | 0.000…1800.000s | 0.005s | 30.000s | The function's maximum timer which defines how long the starting condition can last and for how long the current is allowed to be over $I_{high}$. |
| $T_{min}$ | 0.000…1800.000s | 0.005s | 0.040s | The function's minimum timer which defines how long the starting condition has to last at the minimum. If the start-up sequence includes more than one inrush situation, this parameter may be used to prolong the cold load pick-up time over the first inrush. Additionally, this parameter operates as the "reclaim" time for the function in case the inrush current is not immediately initiated in the start-up sequence. |

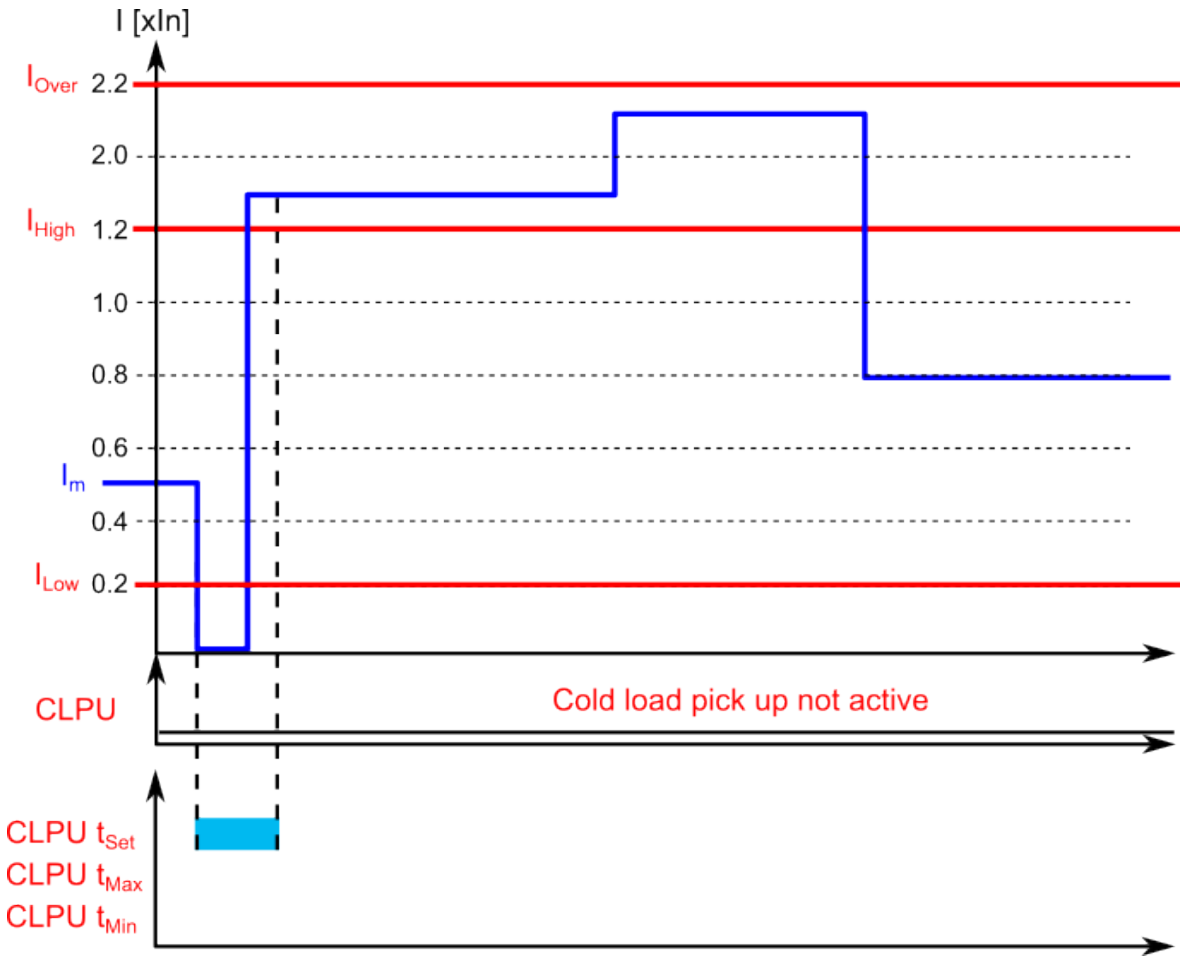
The six examples below showcase some typical cases with the cold load pick-up function.

Figure. 5.5.8 - 157. Example of timers and pick-up parameters (normal CLPU situation).



In the example above, the cold load pick-up function activates after the measured current dips below the $I_{low}$ setting and has been there for $T_{set}$ amount of time. When the current exceeds the $I_{high}$ setting value, a timer starts counting towards the $T_{max}$ time. The pick-up current is cleared before the the counter reaches the $T_{max}$ time, when the measured current goes between of $I_{low}$ and the $I_{high}$. This is when the start-up condition is considered to be over. The cold load pick-up signal can be prolonged beyond this time by setting the $T_{min}$ to a value higher than 0.000 s.

Figure. 5.5.8 - 158. Example of timers and pick-up parameters (no cold load pick-up, $I_{low}$ too short).

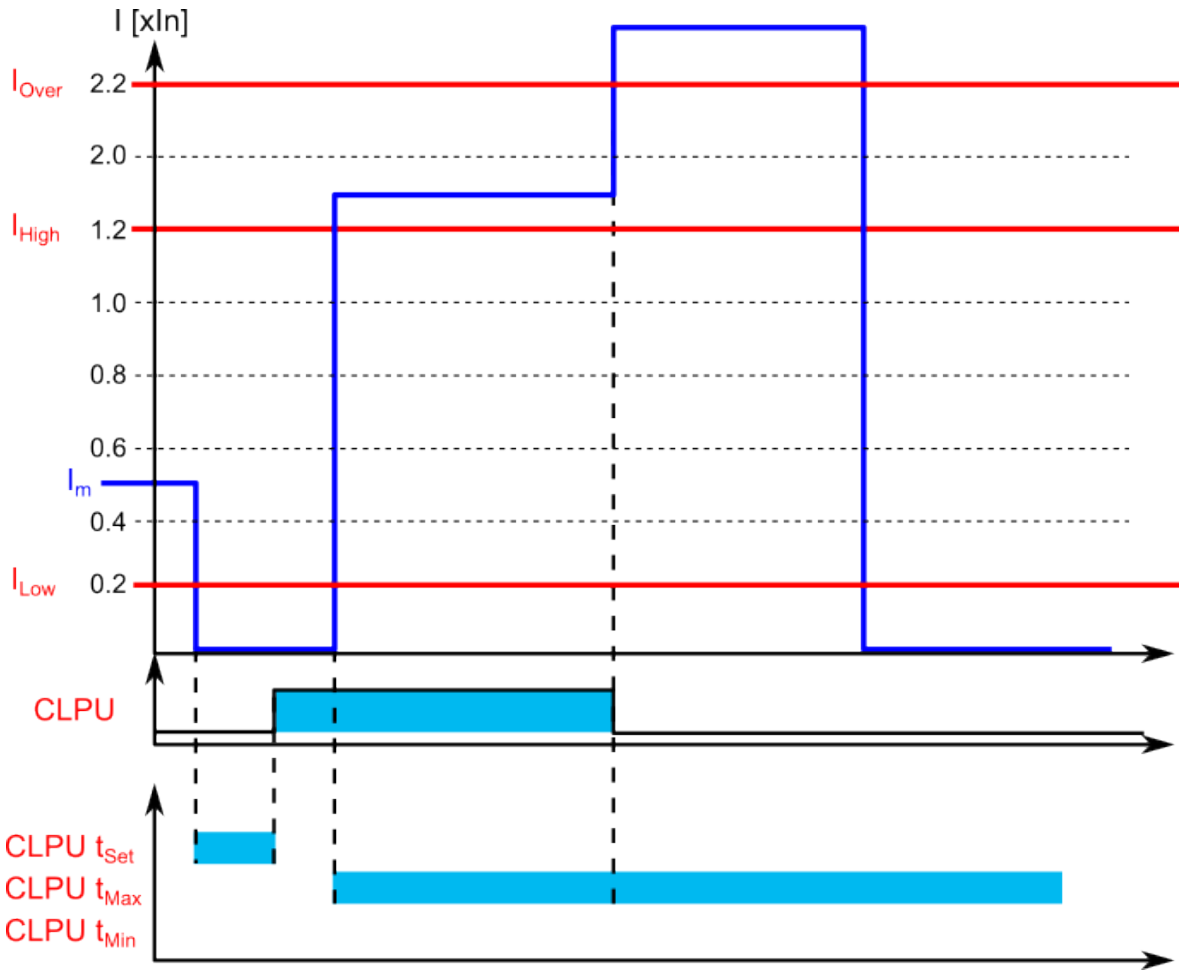



In the example above, the cold load pick-up function does not activate even when the measured current dips below the $I_{low}$ setting, because the $T_{set}$ is not exceeded and therefore no cold load pick-up signal is issued. If the user wants the function to activate within a shorter period of time, the $T_{set}$ parameter can be se to a lower value. If the user wants no delay, the $T_{set}$ can be zero seconds and the operation will be immediate.



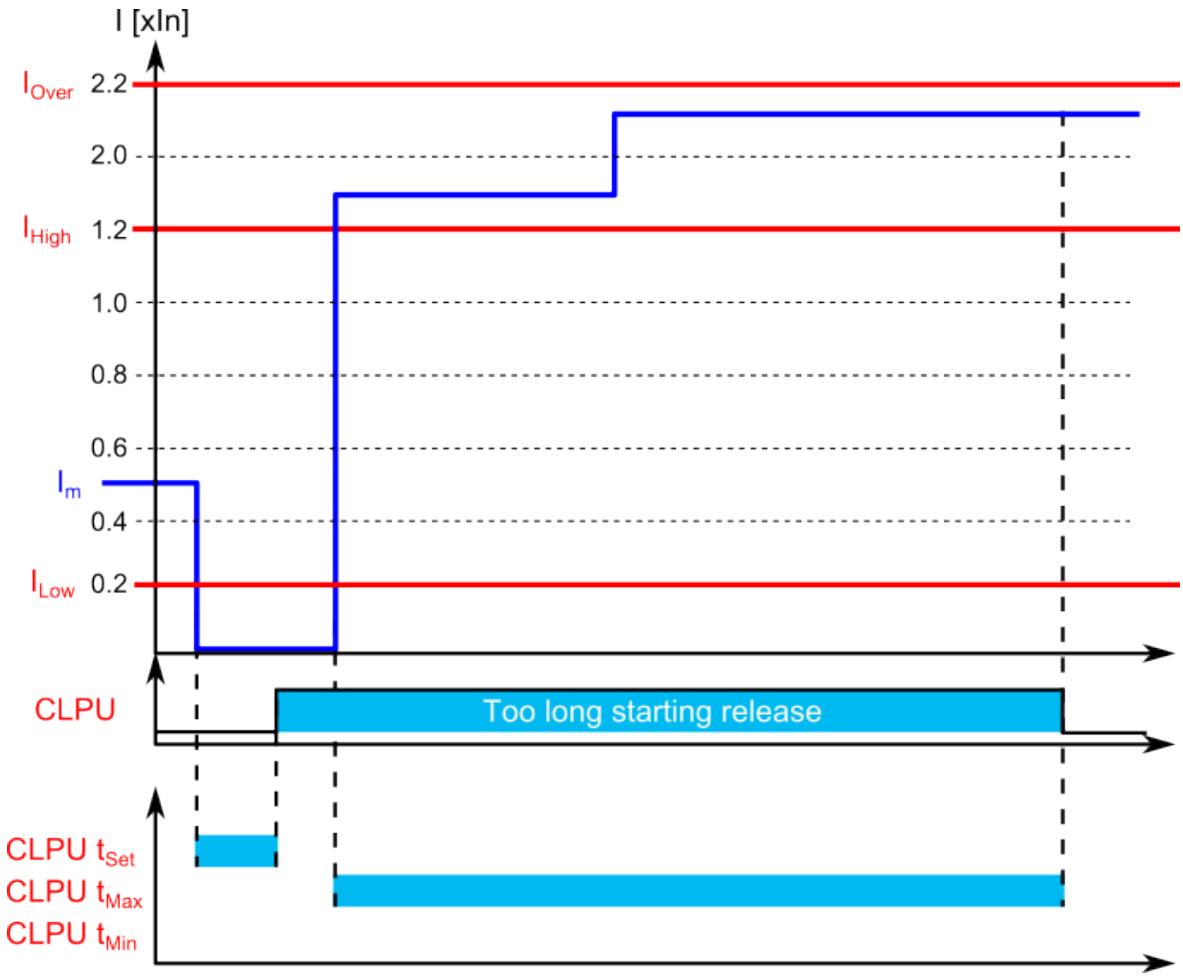
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Figure. 5.5.8 - 159. Example of timers and pick-up parameters (activated pick-up and instant release due to overcurrent).




In the example above, the cold load pick-up function activates after the measured current dips below the $I_{low}$ setting and has been there for $T_{set}$ amount of time. When the $I_m$ exceeds the $I_{high}$ setting, a counter starts counting towards the $T_{max}$ time. The measured current exceeds the $I_{over}$ setting during the start-up situation and causes the cold load pick-up signal to be released immediately.

Figure. 5.5.8 - 160. Example of timers and pick-up parameters (activated pick-up and instant release due to too long starting).

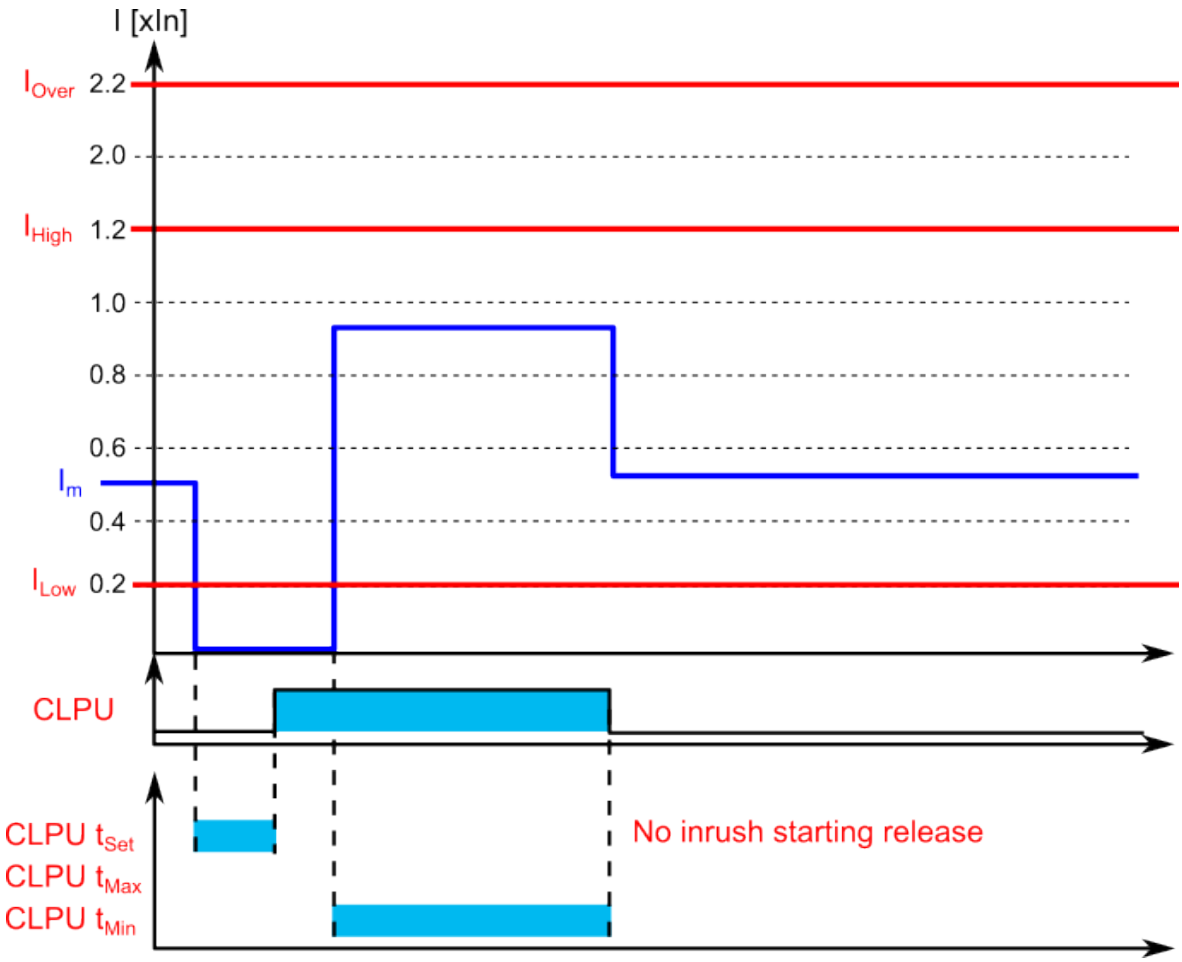



In the example above, the cold load pick-up function activates after the measured current has stayed below the $I_{low}$ setting for a $T_{set}$ amount of time. When the current exceeds the $I_{high}$ setting, a timer starts counting towards the $T_{max}$ time. The measured current stays above the $I_{high}$ setting until the $T_{max}$ is reached, which causes the release of the cold load pick-up signal.



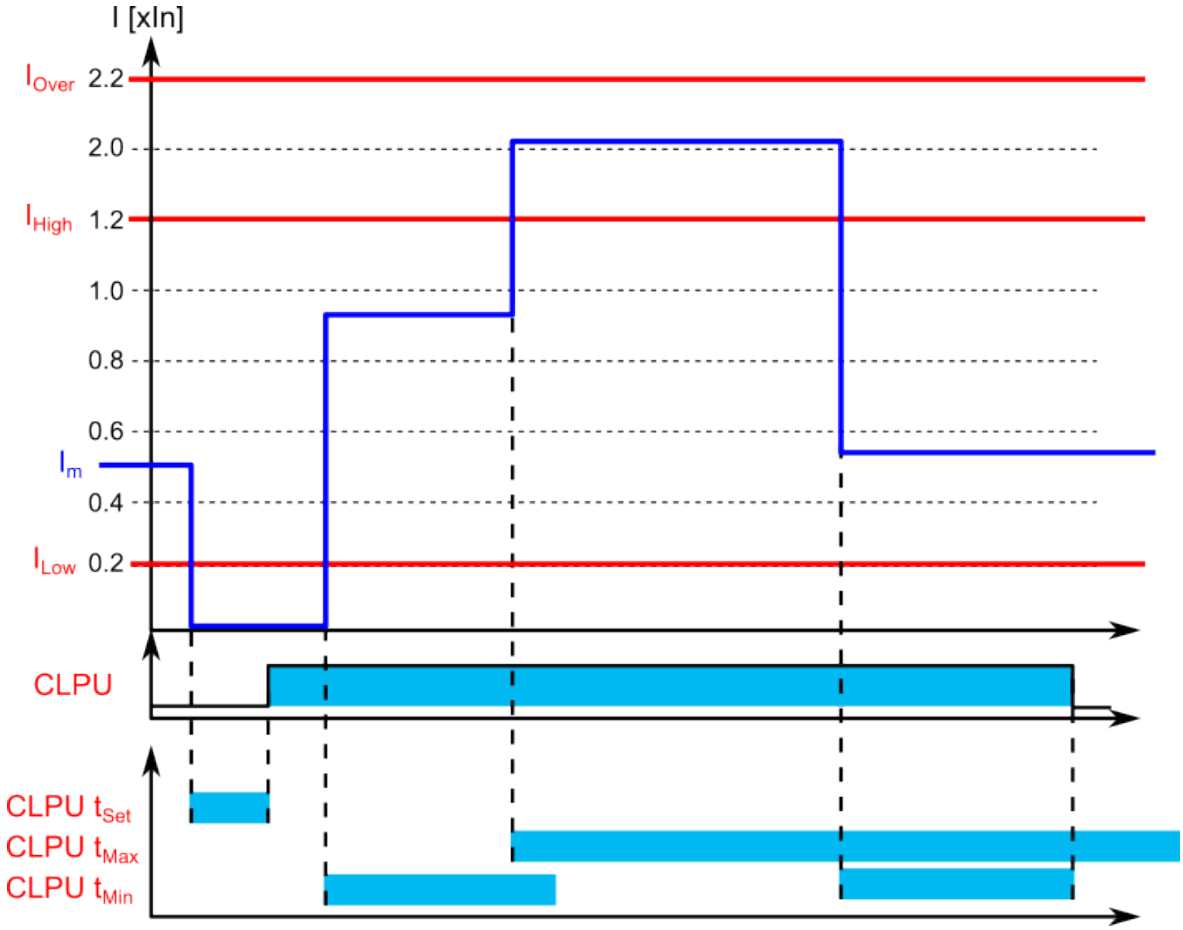
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Figure. 5.5.8 - 161. Example of timers and pick-up parameters (no inrush current detected in the starting).




In the example above, the cold load pick-up function activates after the measured current has stayed below the $I_{low}$ setting for a $T_{set}$ amount of time. The current stays between the $I_{low}$ setting and the $I_{high}$ setting, so the cold load pick-up signal is active for $T_{min}$ time. As no inrush current is detected during that time, the signal is released.

Figure. 5.5.8 - 162. Example of timers and pick-up parameters (an inrush current detected during $T_{min}$ time).




In the example above, the cold load pick-up function activates after the measured current has stayed below the $I_{low}$ setting for a $T_{set}$ amount of time. The current increases to between the $I_{low}$ setting and the $I_{high}$ setting, which causes a counter to start counting towards the $T_{min}$ time. Before the counter reaches $T_{min}$, the current exceeds the $I_{high}$ setting, which causes a counter to start counting towards the $T_{max}$ time. The cold load pick-up signal remains active until the $T_{max}$ has been reached, or until the start-up is over and the $_{Tmin}$ time is over.

## Events and registers

The cold load pick-up function (abbreviated "CLP" in event block names) generates events and registers from the status changes of the LowStart, HighStart, LoadNormal, Overcurrent, CLPUActivated and BLOCKED signals of the cold load pick-up function as well as from the internal pick-up comparators. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.8 - 255. Event messages.

| Event block name | Event names |
|---|---|
| CLP1 | LowStart ON |
| CLP1 | LowStart OFF |
| CLP1 | HighStart ON |
| CLP1 | HighStart OFF |


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| Event block name | Event names |
|---|---|
| CLP1 | LoadNormal ON |
| CLP1 | LoadNormal OFF |
| CLP1 | Overcurrent ON |
| CLP1 | Overcurrent OFF |
| CLP1 | CLPUActivated ON |
| CLP1 | CLPUActivated OFF |
| CLP1 | Block ON |
| CLP1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.5.8 - 256. Register content.

| Date and time | Event | L1/L2/L3 current | Time to CLPUact | CLPU active time | Start-up time | Releasing time of CLPU | Used SG |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Phase currents on trigger time | Time remaining before the function is active | The time the function has been active before starting | Recorded starting time | Reclaim time counter | Setting group 1...8 active |

### 5.5.9 Switch-on-to-fault (SOTF)

The switch-on-to-fault (SOTF) function is used for speeding up the tripping when the breaker is closed towards a fault or forgotten earthing to reduce the damage in the fault location. The function can be used to control protection functions, or it can be used to directly trip a breaker if any of the connected protection functions starts during the set SOTF time. The operation of the function is instant after the conditions are met and any one signal connected to the "*Function input*" input activates.

The inputs of the function are the following:

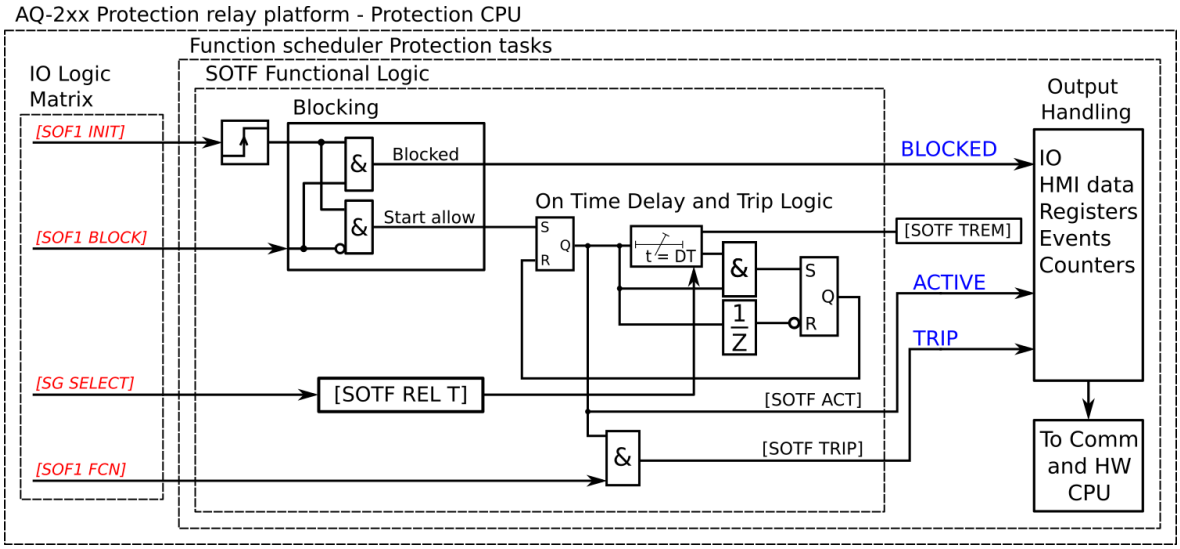
- initiating
- blocking
- setting group selection
- function trigger inputs.

The function can be initiated by a digital input, or by a circuit breaker "Close" command connected to the "*SOTF activate input*" input. The duration of the SOTF-armed condition can be set by the "Release time for SOTF" setting parameter; it can be changed if the application so requires through setting group selection.

The outputs of the function are BLOCKED, ACTIVE and TRIP signals. Additionally, the function outputs the corresponding events and registers when any of these mentioned signals activate.

The following figure presents a simplified function block diagram of the switch-on-to-fault function.

Figure. 5.5.9 - 163. Simplified function block diagram of the switch-on-to-fault function.




## Input signals

The function block does not use analog measurement inputs. Instead, its operation is based entirely on binary signal statuses.

Table. 5.5.9 - 257. Input signals.

| Input | Description |
|---|---|
| Activate input | The digital input or logic signal for the function to arm and start calculating the SOTF time. Any binary signal can be used to activate the function and start the calculation. The rising edge of the signal is considered as the start of the function. |
| Block input | The input for blocking the function. Any binary signal can be used to block the function from starting. |
| Function input | The function input activates the function's instant trip if applied when the function is calculating the SOTF time. |

## Settings

The switch-on-to-fault function has one setting and it determines how long the function remains active after it has been triggered. If the inputs receive any of the set signals during this time, the function's trip is activated.

Table. 5.5.9 - 258. Settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| SOTF LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 1: On | Set mode of SOF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| SOTF force status to | 0: Normal<br>1: Blocked<br>2: Active<br>3: Trip | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Release time for SOTF | 0.000…1800.000s | 1.000s | The time the function is active after triggering. |



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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.9 - 259. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| SOTF LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of SOF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| SOTF condition | 0: Normal<br>1: Init<br>2: Active<br>3: Trip<br>4: Blocked | Displays status of the control function. |

## Function blocking

The function can be blocked by activating the BLOCK input. This prevents the function's active time from starting.

## Events and registers

The switch-on-to-fault function (abbreviated "SOF" in event block names) generates events and registers from the status changes in ACTIVATED, TRIP and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.9 - 260. Event messages.

| Event block name | Event names |
|---|---|
| SOF1 | SOTF Init ON |
| SOF1 | SOTF Init OFF |
| SOF1 | SOTF Block ON |
| SOF1 | SOTF Block OFF |
| SOF1 | SOTF Active ON |
| SOF1 | SOTF Active OFF |
| SOF1 | SOTF Trip ON |
| SOF1 | SOTF Trip OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON process data of ACTIVATED events. The table below presents the structure of the function's register content.

Table. 5.5.9 - 261. Register content.

| Date and time | Event | Used SG | SOTF remaining time | SOTF been active time |
|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Setting group 1...8 active | The time remaining of the set release time. | The time the function has been active. |

## 5.5.10 Synchrocheck (ΔV/Δa/Δf; 25)

Checking the synchronization is important to ensure the safe closing of the circuit breaker between two systems. Closing the circuit breaker when the systems are not synchronized can cause several problems such as current surges which damage the interconnecting elements. The synchrocheck function has three stages: SYN1, SYN2 and SYN3. Their function and availability of these stages depend on which voltage channels are set to "SS" mode or not. Voltage measurement settings are located at *Measurements → Transformers → VT module*. SYN1 also includes synchroswitching. When synchroswitching is used, the function automatically closes the breaker when both sides of the breaker are synchronized.

When only U3 or U4 voltage measurement channel has been set to "SS" mode:

- SYN1 – Supervises the synchronization condition between the channel set to "SS" mode and the selected system voltage (UL1, UL2, UL3, UL12, UL23 or UL31). Synchroswitch is available.
- SYN2 – Not active and not visible.
- SYN3 – Not active and not visible.

When both U3 and U4 have been set to "SS" mode:

- SYN1 – Supervises the synchronization condition between the U3 channel and the selected system voltage (UL12, UL23 or UL31). Synchroswitch is available.
- SYN2 – Supervises the synchronization condition between the U4 channel and the selected system voltage (UL12, UL23 or UL31).
- SYN3 – Supervises the synchronization condition between the channels U3 and U4.

The seven images below present three different example connections and four example applications of the synchrocheck function.


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Figure. 5.5.10 - 164. Example connection of the synchrocheck function (3LN+U4 mode, SYN1 in use, UL1 as reference voltage).

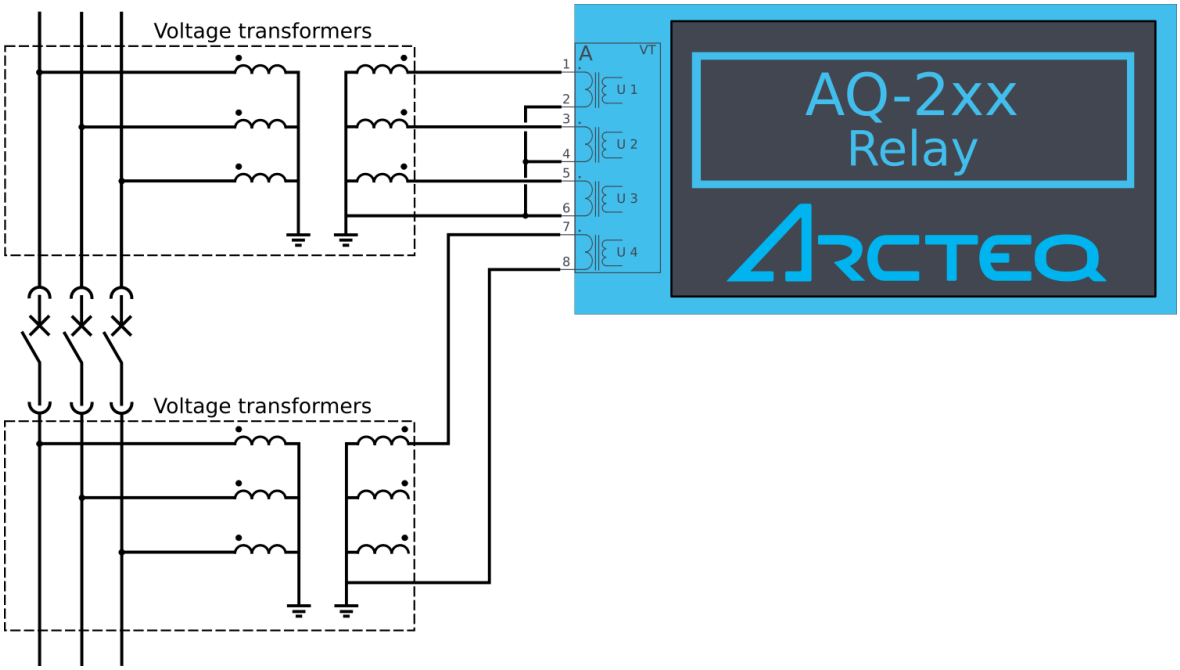



Figure. 5.5.10 - 165. Example connection of the synchrocheck function (2LL+U0+U4 mode, SYN1 in use, UL12 as reference voltage).

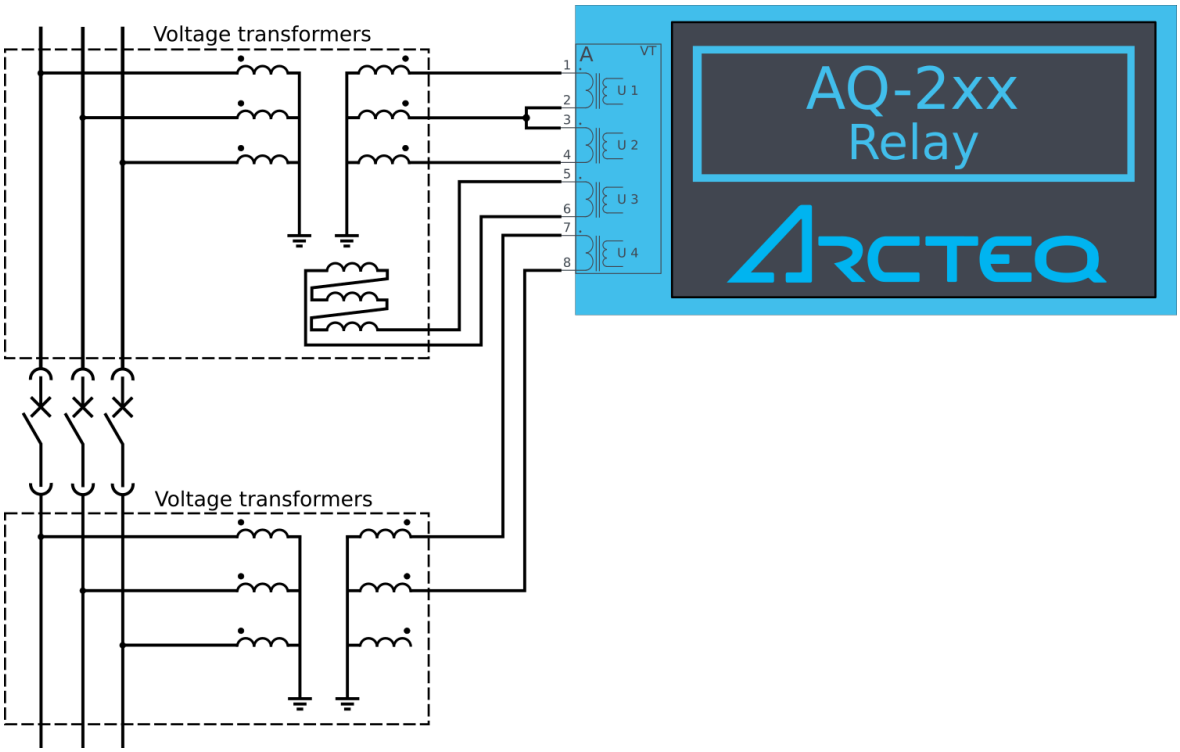


Figure. 5.5.10 - 166. Example connection of the synchrocheck function (2LL+U3+U4 mode, SYN3 in use, UL12 as reference voltage).

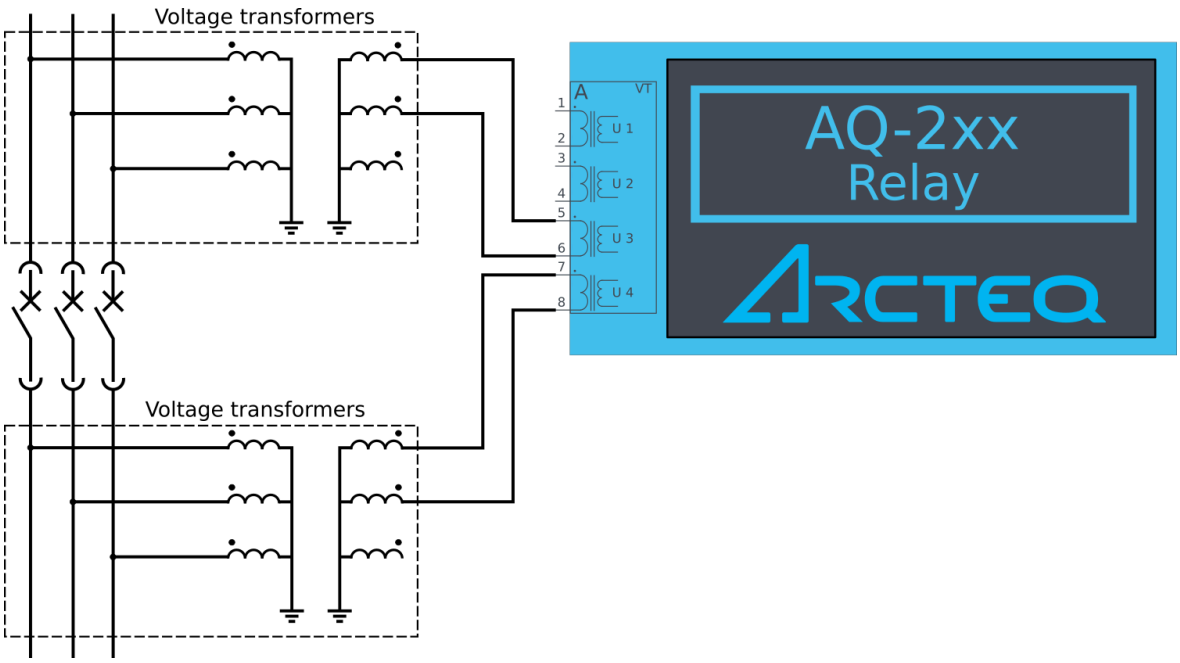
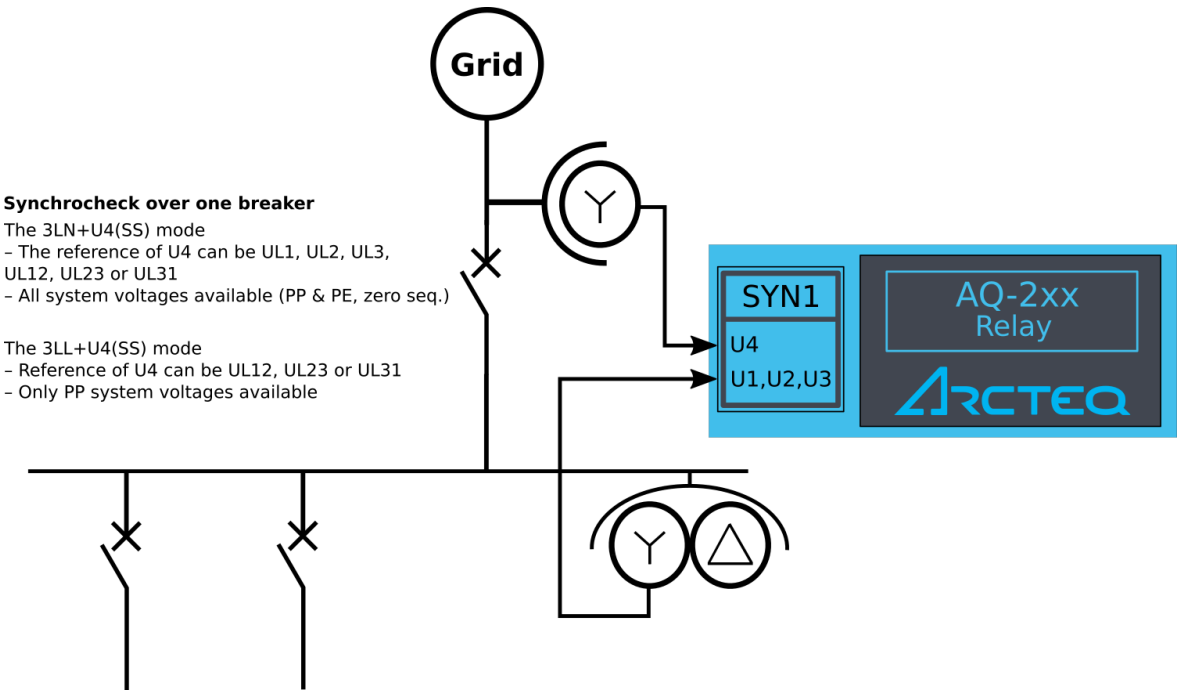



Figure. 5.5.10 - 167. Example application (synchrocheck over one breaker, with 3LL and 3LN VT connections).






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Figure. 5.5.10 - 168. Example application (synchrocheck over one breaker, with 2LL VT connection).

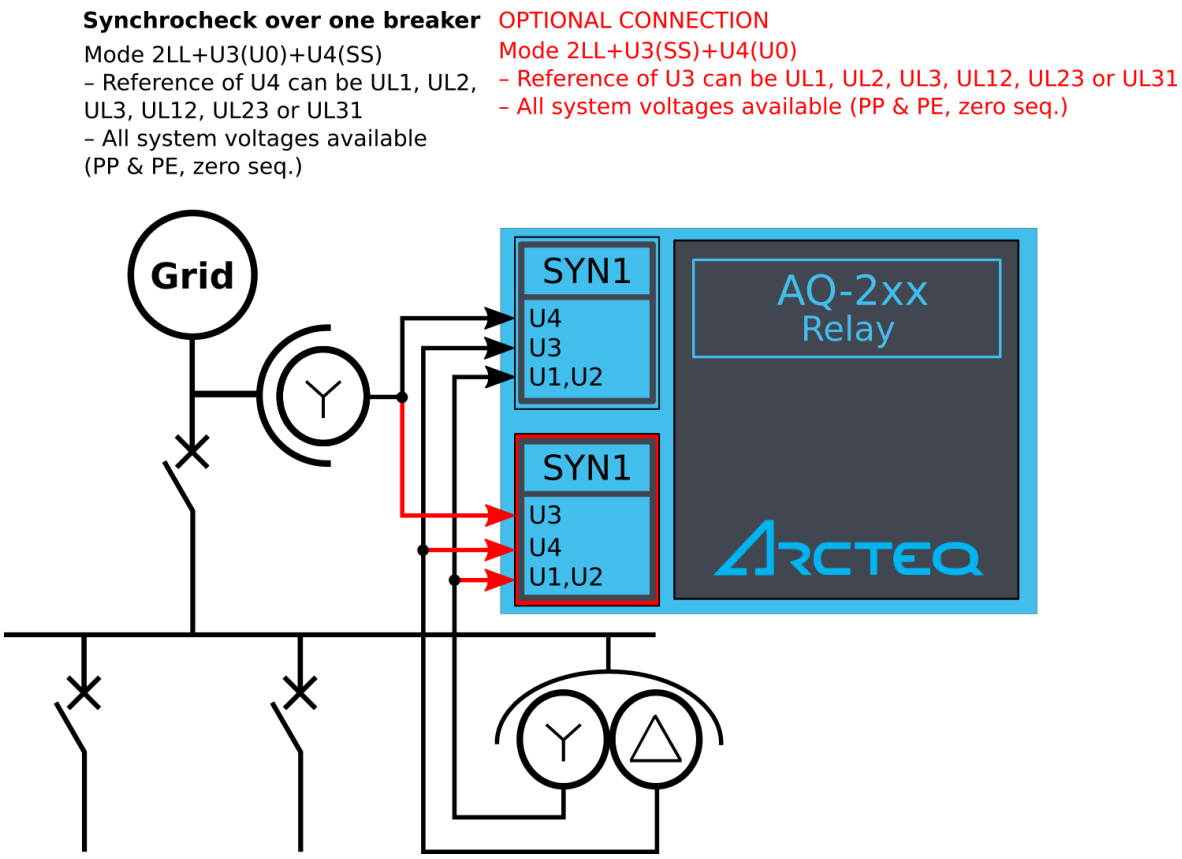
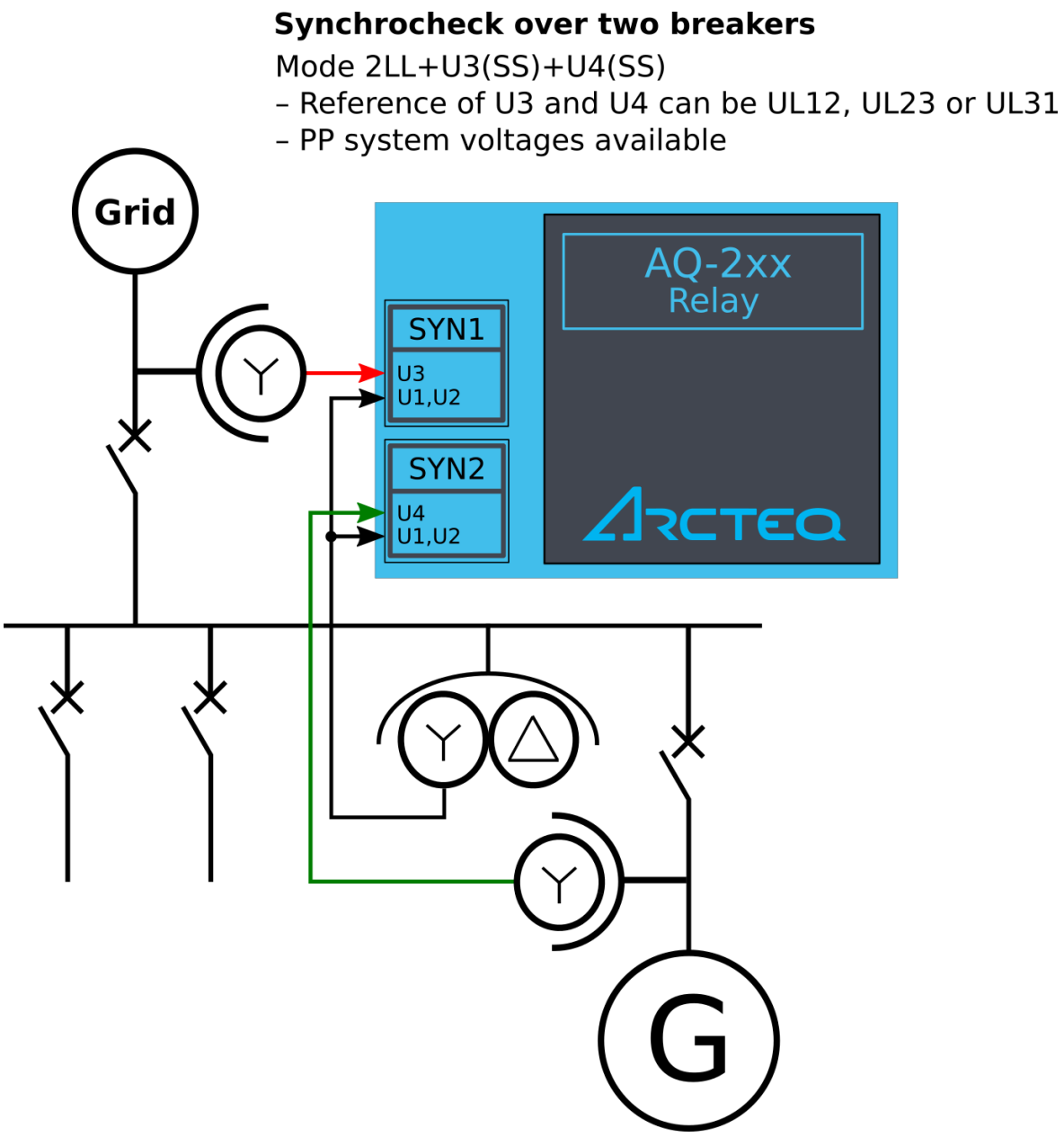


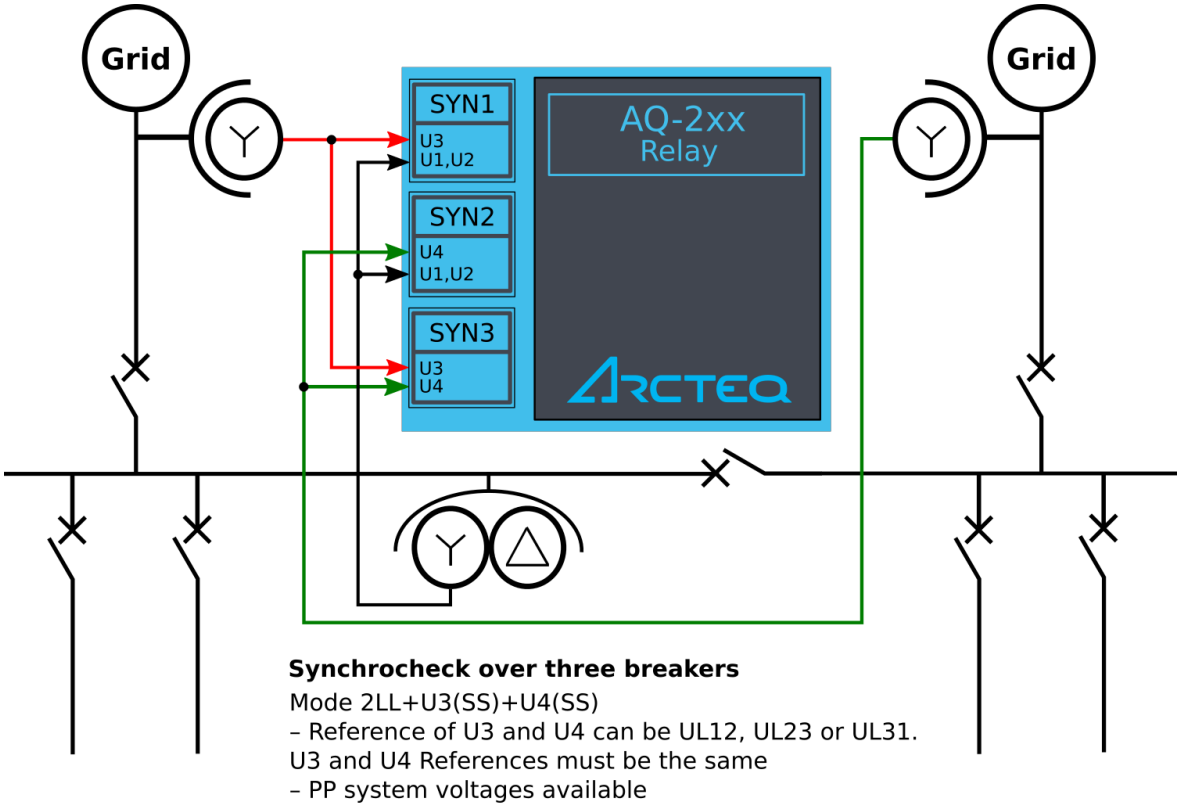
Figure. 5.5.10 - 169. Example application (synchrocheck over two breakers, with 2LL VT connection).






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IM00015

Figure. 5.5.10 - 170. Example application (synchrocheck over three breakers, with 2LL+U3+U4 connection).




The following aspects of the compared voltages are used in synchorization:

- voltage magnitudes
- voltage frequencies
- voltage phase angles

The two systems are synchronized when these three aspects are matched. All three cannot, of course, ever be exactly the same so the function requires the user to set the maximum difference between the measured voltages.

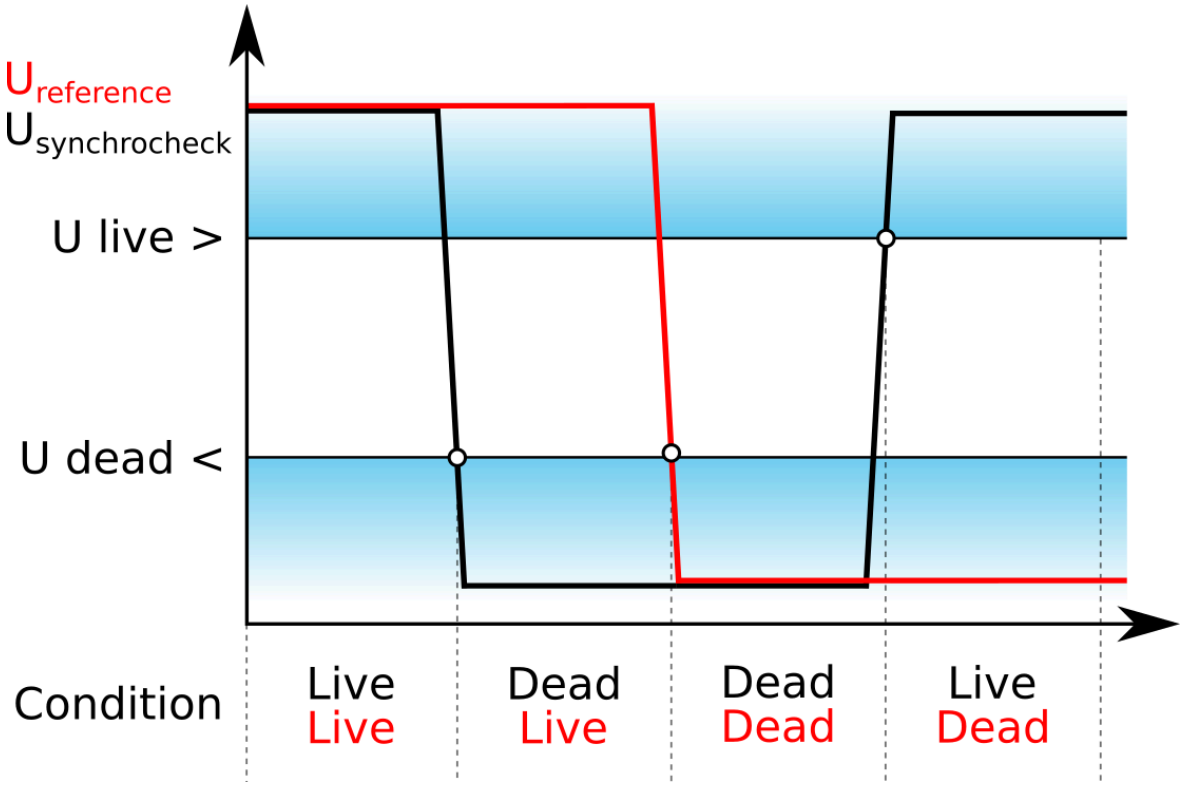
The function's outputs are SYN OK, BYPASS, and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms.

The synchrocheck function uses a total of eight (8) separate setting groups which can be selected from one common source.

Depending on how the measured voltage compares to the set *U live>* and *U dead<* parameters, either system can be in a "live" or a "dead" state. The parameter *SYNx U conditions* is used to determine the conditions (in addition to the three aspects) which are required for the systems to be considered synchronized.

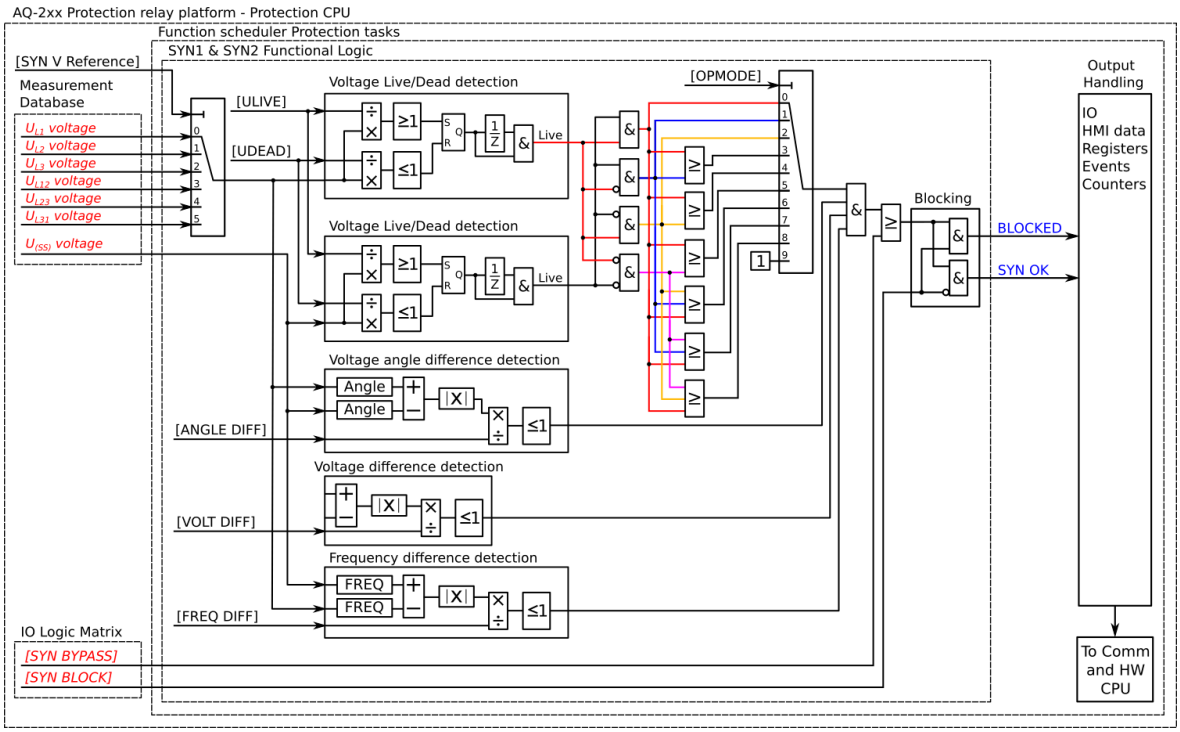
The image below shows the different states the systems can be in.

Figure. 5.5.10 - 171. System states.




The following figures present simplified function block diagrams of the synchrocheck function.

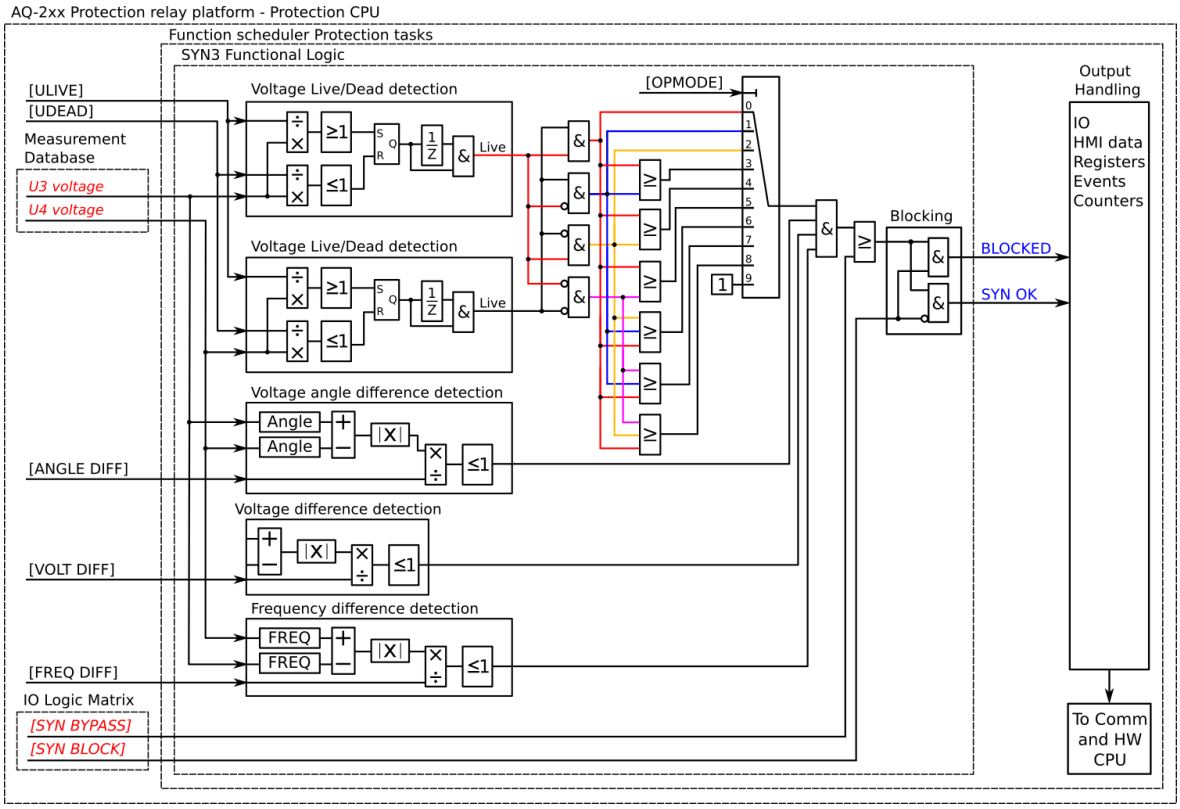
Figure. 5.5.10 - 172. Simplified function block diagram of the SYN1 and SYN2 function.






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Figure. 5.5.10 - 173. Simplified function block diagram of the SYN3 function.




## Measured input

The function block uses analog current measurement values. The monitored magnitude is equal to RMS values.

Table. 5.5.10 - 262. Measurement inputs of the synchrocheck function.

| Signal | Description | Time base |
|---|---|---|
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |
| $U_4$RMS | RMS measurement of voltage $U_4$/V | 5ms |

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.10 - 263. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| dV / da / df LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of SYN block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |

| Name | Range | Step | Description |
|---|---|---|---|
| SYN condition | 0: SYN1 Blocked<br>1: SYN1 Ok<br>2: SYN1 Bypass<br>3: SYN1 Vcond Ok<br>4: SYN1 Vdiff Ok<br>5: SYN1 Adiff Ok<br>6: SYN1 fdiff Ok | - | Displays status of the control function. |
| SYN volt status | 0: Dead Dead<br>1: Live Dead<br>2: Dead Live<br>3: Live Live<br>4: Undefined<br>5: Not monitored | - | Displays the voltage status of both sides. |
| SYN Mag diff | -120...120%Un | 0.01%Un | Displays voltage difference between the two measured voltages. |
| SYN Ang diff | -360'...360deg | 0.01deg | Displays angle difference between the two measured voltages. |
| SYN Freq diff | -75...75Hz | 0.001Hz | Displays frequency difference between the two measured voltages. |
| SYN Switch status | 0: Still<br>1: Departing<br>2: Enclosing | - | Displays the synchroswitching status.<br>This parameter is visible when "SYN1 Switching" parameter has been set to "Use SynSW". |
| Estimated BRK closing time | 0...360s | 0.005s | Estimated time left to breaker closing. |
| Networks rotating time | 0...360s | 0.005s | Estimated time how long it takes for the network to rotate fully. |
| Networks placement atm | -360...360deg | 0.001deg | Networks placement in degrees. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the synchronization is OK, a SYN OK signal is generated.

If the blocking signal is active when the SYN OK activates, a BLOCKED signal is generated and the function does not process the situation further. If the SYN OK function has been activated before the blocking signal, it resets.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup voltage values and its fault type to be issued.

The blocking signal can also be tested in the commissioning phase by a software switch signal when the relay's testing mode "Enable stage forcing" is activated (*General → Device*). The variables the user can set are binary signals from the system.

## Setting parameters

**NOTE!** Before these settings can be accessed, a voltage channel (U3 or U4) must be set into the synchrocheck mode ("SS") in the voltage transformer settings (*Measurements → VT Module*).


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The general settings can be found at the synchrocheck function's *INFO* tab, while the synchrocheck stage settings can be found in the *Settings* tab (*Control → Control functions → Synchrocheck*).

Table. 5.5.10 - 264. General settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| dV / da / df LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | 1: On | Set mode of SYN block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| SYN(1,2,3) Status Force to | 0: Normal<br>1: SYN1 Blocked<br>2: SYN1 Ok<br>3: SYN2 Blocked<br>4: SYN2 Ok<br>5: SYN3 Blocked<br>6: SYN3 Ok | - | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Use SYNx | 0: No<br>1: Yes | - | 0: No | Activated/de-activates the individual stages (SYN1, 2, and 3) of the synchrocheck function. Activating a stage reveals the parameter settings for the configuration. |
| SYNx V Start check | 0: Always<br>1: On start | - | 0: Always | Selects synchrocheck start behaviour. If "On start" is selected "SYNx START" input must be active for synchrochecking to begin. "SYNx START" input signal can be defined at *IO → Input control* menu. If "Always" is selected "SYNx START" input is not needed for synchrochecking to start. |
| SYN1 V Reference | 0: Not in use<br>1: UL12<br>2: UL23<br>3: UL31<br>4: UL1<br>5: UL2<br>6: UL3 | - | 0: Not in use | Selects the reference voltage of the stage. Please note that the available references depend on the selected mode.<br><br>All references available:<br>- 3LN+U4(SS)<br>- 2LL+U3(U0)+U4(SS)<br>- 2LL+U3(SS)+U4(U0)<br><br>Reference options 0...3 available:<br>- 3LL+U4(SS)<br>- 2LL+U3(Not in use)+U4(SS)<br>- 2LL+U3(SS)+U4(Not in use) |
| SYN1 Switching | 0: Not in use<br>1: Use SynSW | - | 0: Not in use | Disables or enables synchroswitching. Synchroswitching is available only for SYN1. When synchroswitching is used, the function automatically closes the breaker when both sides of the breaker are synchronized.<br><br>This setting is only visible when "Use SYN1" is activated. |
| SYN1 Switch bk time | 0.000...1800.000s | 0.005s | 0.05s | Estimated time between a close command given to a breaker and the breaker entering the closed state. This setting is used to time the closing of the breaker so that both sides are as synchronized as possible when the breaker is actually closed.<br><br>This setting is only visible when "SYN1 switching" is activated. |
| SYN1 Switching object | 0: Object 1<br>1: Object 2<br>2: Object 3<br>3: Object 4<br>4: Object 5 | - | 0: Object 1 | When synchroswitching is enabled, this parameter defines which object receives the breaker's closing command.<br><br>This setting is only visible when "SYN1 switching" is activated. |
| Estimated BRK closing time | 0.000…360.000s | 0.005s | - | Displays the estimated time until networks are synchronized. |
| Networks rotating time | 0.000…360.000s | 0.005s | - | Displays the time it takes for both sides of the network to fully rotate. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Networks placement atm | -360.000…360.000deg | 0.001deg | - | Indicates the angle difference between the two sides of the breaker at the moment. |
| SYN2 V Reference | 0: Not in use<br>1: UL12<br>2: UL23<br>3: UL31 | - | 0: Not in use | Selects the reference voltage of the stage.<br><br>SYN2 is available when both U3 and U4 have been set to SS mode. |
| SYN3 V Reference | 0: Not in use<br>1: U3–U4 | - | 0: Not in use | Enables and disables the SYN3 stage. Operable in the 2LL+U3+U4 mode, with references UL12, UL23 and UL31 can be connected to the channels.. |

Table. 5.5.10 - 265. Synchrocheck stage settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| SYNx U conditions | 0: LL only<br>1: LD only<br>2: DL only<br>3: LL & LD<br>4: LL & DL<br>5: LL & DD<br>6: LL & LD & DL<br>7: LL & LD & DD<br>8: LL & DL & DD<br>9: Bypass | - | 0: LL only | Determines the allowed states of the supervised systems.<br><br>L = Live<br>D = Dead |
| SYNx U live > | 0.10…100.00%Un | 0.01%Un | 20%Un | The voltage limit of the live state. |
| SYNx U dead < | 0.00…100.00%Un | 0.01%Un | 20%Un | The voltage limit of the dead state. |
| SYNx U diff < | 2.00…50.00%Un | 0.01%Un | 2.00%Un | The maximum allowed voltage difference between the systems. |
| SYNx angle diff < | 3.00…90.00deg | 0.01deg | 3deg | The maximum allowed angle difference between the systems. |
| SYNx freq diff < | 0.05…0.50Hz | 0.01Hz | 0.1Hz | The maximum allowed frequency difference between the systems. |

## Events and registers

The synchrocheck function (abbreviated "SYN" in event block names) generates events and registers from status changes such as SYN OK, BYPASS, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers three (3) independent stages; the events are segregated for each stage operation.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.5.10 - 266. Event messages.

| Event block name | Event names |
|---|---|
| SYN1 | SYN1 Blocked On |
| SYN1 | SYN1 Blocked OFF |
| SYN1 | SYN1 Ok ON |
| SYN1 | SYN1 Ok OFF |
| SYN1 | SYN1 Bypass ON |
| SYN1 | SYN1 Bypass OFF |
| SYN1 | SYN1 Volt condition OK |



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| Event block name | Event names |
|---|---|
| SYN1 | SYN1 Volt cond not match |
| SYN1 | SYN1 Volt diff Ok |
| SYN1 | SYN1 Volt diff out of setting |
| SYN1 | SYN1 Angle diff Ok |
| SYN1 | SYN1 Angle diff out of setting |
| SYN1 | SYN1 Frequency diff Ok |
| SYN1 | SYN1 Frequency diff out of setting |
| SYN1 | SYN2 Blocked ON |
| SYN1 | SYN2 Blocked OFF |
| SYN1 | SYN2 Ok ON |
| SYN1 | SYN2 Ok OFF |
| SYN1 | SYN2 Bypass ON |
| SYN1 | SYN2 Bypass OFF |
| SYN1 | SYN2 Volt condition OK |
| SYN1 | SYN2 Volt cond not match |
| SYN1 | SYN2 Volt diff Ok |
| SYN1 | SYN2 Volt diff out of setting |
| SYN1 | SYN2 Angle diff Ok |
| SYN1 | SYN2 Angle diff out of setting |
| SYN1 | SYN2 Frequency diff Ok |
| SYN1 | SYN2 Frequency diff out of setting |
| SYN1 | SYN3 Blocked ON |
| SYN1 | SYN3 Blocked OFF |
| SYN1 | SYN3 Ok ON |
| SYN1 | SYN3 Ok OFF |
| SYN1 | SYN3 Bypass ON |
| SYN1 | SYN3 Bypass OFF |
| SYN1 | SYN3 Volt condition OK |
| SYN1 | SYN3 Volt cond not match |
| SYN1 | SYN3 Volt diff Ok |
| SYN1 | SYN3 Volt diff out of setting |
| SYN1 | SYN3 Angle diff Ok |
| SYN1 | SYN3 Angle diff out of setting |
| SYN1 | SYN3 Frequency diff Ok |
| SYN1 | SYN3 Frequency diff out of setting |
| SYN1 | SYN1 Switch ON |
| SYN1 | SYN1 Switch OFF |
| SYN1 | SYN2 Switch ON |

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| Event block name | Event names |
|---|---|
| SYN1 | SYN2 Switch OFF |
| SYN1 | SYN3 Switch ON |
| SYN1 | SYN3 Switch OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.5.10 - 267. Register content.

| Name | Range |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| SYNx Ref1 voltage | The reference voltage of the selected stage. |
| SYNx Ref2 voltage | The reference voltage of the selected stage. |
| SYNx Volt Cond | The voltage condition of the selected stage. |
| SYNx Volt status | The voltage status of the selected stage. |
| SYNx Vdiff | The voltage difference of the selected stage. |
| SYNx Vdiff cond | The set condition of the voltage difference of the selected stage. |
| SYNx Adiff | The angle difference of the selected stage. |
| SYNx Adiff cond | The set condition of the angle difference of the selected stage. |
| SYNx fdiff | The frequency difference of the selected stage. |
| SYNx fdiff cond | The set condition of the frequency difference of the selected stage. |
| Setting group in use | Setting group 1...8 active. |

## 5.5.11 Milliampere output control

The milliamp current loop is the prevailing process control signal in many industries. It is an ideal method of transferring process information because a current does not change as it travels from a transmitter to a receiver. It is also much more simple and cost-effective.

The benefits of 4...20 mA loops:

- the dominant standard in many industries
- the simplest option to connect and configure
- uses less wiring and connections than other signals, thus greatly reducing initial setup costs
- good for travelling long distances, as current does not degrade over long connections like voltage does
- less sensitive to background electrical noise
- detects a fault in the system incredibly easily since 4 mA is equal to 0 % output.

### Milliampere (mA) outputs

AQ-200 series supports up to two (2) independent mA option cards. Each card has four (4) mA output channels and one (1) mA input channel. If the device has an mA option card, enable mA outputs at *Control → Device IO → mA outputs*. The outputs are activated in groups of two: channels 1 and 2 are activated together, as are channels 3 and 4.


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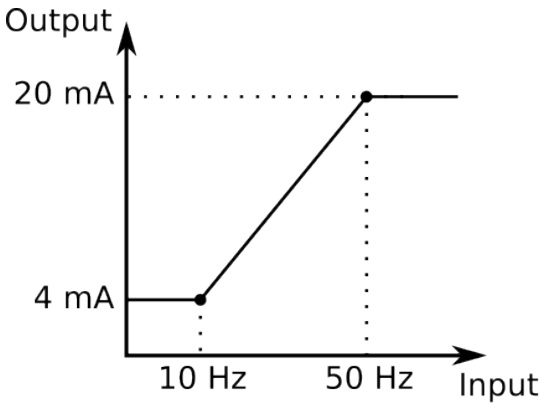
Table. 5.5.11 - 268. Main settings (output channels).

| Name | | Range | Default | Description |
|---|---|---|---|---|
| mA option card 1 | Enable mA output channels 1 and 2 | 0: Disabled<br>1: Enabled | 0: Disabled | Enables and disables the outputs of the mA output card 1. |
| | Enable mA output channels 3 and 4 | | | |
| mA option card 2 | Enable mA output channels 5 and 6 | 0: Disabled<br>1: Enabled | 0: Disabled | Enables and disables the outputs of the mA output card 2. |
| | Enable mA output channels 7 and 8 | | | |

Table. 5.5.11 - 269. Settings for mA output channels.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable mA output channel | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables and disables the selected mA output channel. If the channel is disabled, the channel settings are hidden. |
| Magnitude selection for mA output channel | 0: Currents<br>1: Voltages<br>2: Powers<br>3: Impedance and admittance<br>4: Other | - | 0: Currents | Defines the measurement category that is used for mA output control. |
| Magnitude of mA output channel | (dependent on the measurement category selection) | - | (dependent on the measurement category selection) | Defines the measurement magnitude used for mA output control. The available measurements depend on the selection of the "Magnitude selection for mA output channel" parameter. |
| Input value 1 | $-10^7 \ldots 10^7$ | 0.001 | 0 | The first input point in the mA output control curve. |
| Scaled mA output value 1 | 0.0000…24.0000mA | 0.0001mA | 0mA | The mA output value when the measured value is equal to or less than Input value 1. |
| Input value 2 | $-10^7 \ldots 10^7$ | 0.001 | 1 | The second input point in the mA output control curve. |
| Scaled mA output value 2 | 0.0000…24.0000mA | 0.0001mA | 0mA | The mA output value when the measured value is equal to or greater than Input value 2. |

Figure. 5.5.11 - 174. Example of the effects of mA output channel settings.



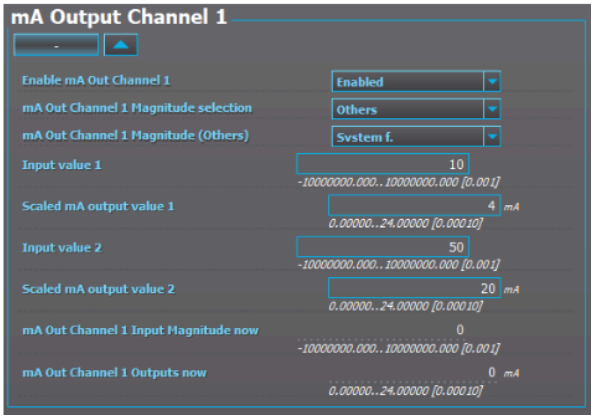



Table. 5.5.11 - 270. Hardware indications.

| Name | Range | Step | Description |
|---|---|---|---|
| Hardware in mA output channels 1...4 | 0: None<br>1: Slot A<br>2: Slot B<br>3: Slot C<br>4: Slot D<br>5: Slot E<br>6: Slot F<br>7: Slot G<br>8: Slot H<br>9: Slot I<br>10: Slot J<br>11: Slot K<br>12: Slot L<br>13: Slot M<br>14: Slot N<br>15: Too many cards installed | - | Indicates the option card slot where the mA output card is located. |
| Hardware in mA output channels 5...8 | | | |

Table. 5.5.11 - 271. Measurement values reported by mA output cards.

| Name | Range | Step | Description |
|---|---|---|---|
| mA in Channel 1 | 0.0000…24.0000mA | 0.0001mA | Displays the measured mA value of the selected input channel. |
| mA in Channel 2 | | | |
| mA Out Channel Input Magnitude now | $-10^7 \ldots 10^7$ | 0.001 | Displays the input value of the selected mA output channel at that moment. |
| mA Out Channel Outputs now | 0.0000…24.0000mA | 0.0001mA | Displays the output value of the selected mA output channel at that moment. |

## 5.5.12 Synchronizer (ΔV/Δa/Δf; 25)

The synchronizer function is used to automatically synchronize generators to power grids. Proper synchronizing is essential to avoid inrush currents, power system oscillations as well as thermal and mechanical stress on the generator when connecting a synchronous generator to a grid.

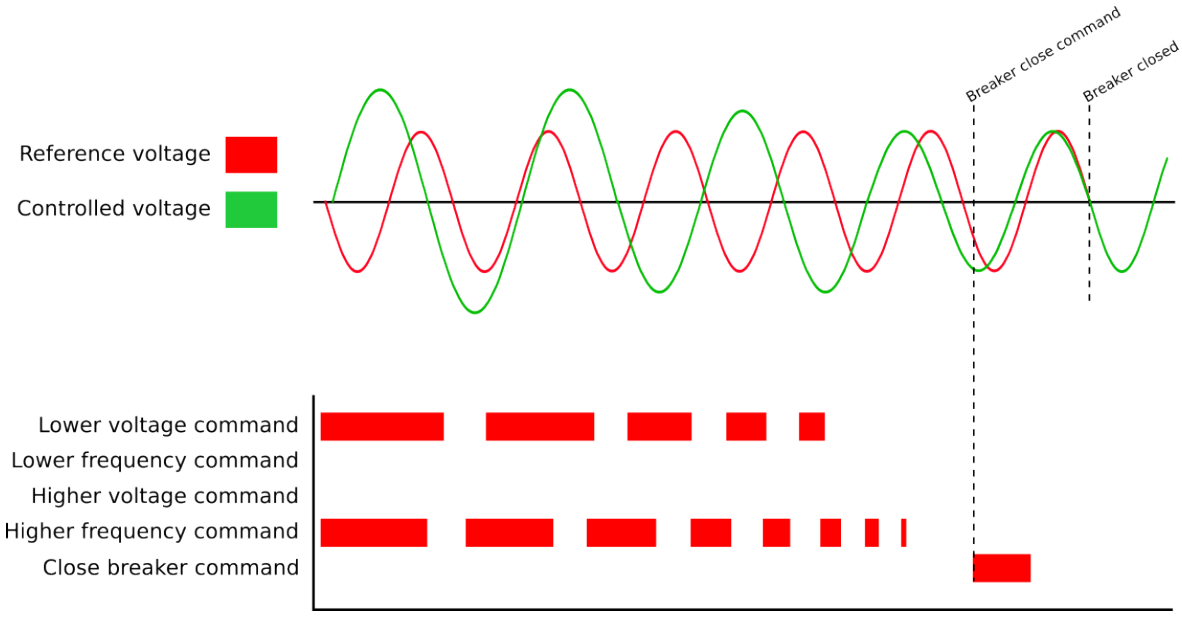
The user can synchronize up to eight (8) circuit breakers with the same synchronizing function by using different setting groups and the logic editor. The synchrocheck function is used to parallel or energize power lines.






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Figure. 5.5.12 - 175. Simplified presentation of synchronizer operation




The synchronizing function uses voltage signals from each side of the circuit breaker to be closed.

- The amplitude difference between the two voltages is used to send "Increase" and "Decrease" commands to the generator's voltage regulator. The pulse length for these commands can be set, and it is automatically adjusted depending on the difference between the two measured signals.
- The frequency difference between the two voltages (the slip frequency) is used to send "Increase" and "Decrease" commands to the turbine's speed governor. The pulse length for these commands can be adjusted individually to take into account turbine governors with different speeds. The pulse length is automatically adjusted depending on the difference between the two measured signals.
- Settings can be adjusted to only allow positive slip to avoid reverse power at synchronizing.
- When the amplitude, the speed, and the phase-angle between the two voltages match (within pre-set limits), a "Close" command signal is sent to the generator's circuit breaker.

Pre-closing time can be used to allow for delay time in a circuit breaker and any auxiliary relays. The pre-closing angle is adjusted automatically depending on the slip frequency.

The outputs of the function are the following signals:

- Voltage Magnitude Difference Ok
- Voltage Frequency Difference Ok
- Voltage Angle Difference Ok
- Blocked
- Running
- Increase Voltage
- Decrease Voltage
- Increase Frequency
- Decrease Frequency
- Breaker Close Pulse
- Long Sync Time
- Nets Standstill
- Nets Departing
- Nets Enclosing

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The time stamp resolution is 1 ms.

## Measured input

The function block uses analog voltage measurement values. The monitored magnitude is equal to RMS values.

Table. 5.5.12 - 272. Measurement inputs of the synchronizer function.

| Signal | Description | Time base |
|---|---|---|
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |
| $U_4$RMS | RMS measurement of voltage $U_4$/V | 5ms |

## Setting parameters

Table. 5.5.12 - 273. General setting parameters.

| Name | Range | Step | Default |
|---|---|---|---|
| Voltage difference calculation mode | 0: System is reference<br>1: U3/U4 input is reference | - | 0: System is reference |
| Synchronizer voltage reference | 0: UL12<br>1: UL23<br>2: UL31<br>3: UL1<br>4: UL2<br>5: UL3 | - | 0: UL12 |
| Synchronizer measurement settings | 0: Meas.Conf.Incorrect<br>1: PP and PE voltages<br>2: PP Voltages | - | - |
| Synchronizer status | 0: Conf.Error<br>1: Idle Ready<br>2: Synchronizing<br>3: Blocked | - | - |
| Synchroswitch status | 0: Standstill<br>1: Departing<br>2: Enclosing | - | - |
| Force control signals on | 0: None<br>1: Blocked On<br>2: Running On<br>3: Increase U On<br>4: Decrease U On<br>5: Increase F On<br>6: Decrease F On<br>7: CB Close On<br>8: LongSyncTime On | - | 0: None |
| Enable on-screen synchronizer view | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Magnitude difference | -200.000...200.000%Un | 0.001%Un | 0%Un |


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| Name | Range | Step | Default |
|---|---|---|---|
| Frequency difference | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference | -360.000...360.000deg | 0.001deg | 0deg |
| Magnitude difference on closing BRK | -200.000...200.000%Un | 0.001%Un | 0%Un |
| Frequency difference on closing BRK | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference on closing BRK | -360.000...360.000deg | 0.001deg | 0deg |
| Estimated BRK Closing time | 0.000...360.000s | 0.005s | 0s |
| Networks rotating time | 0.000...360.000s | 0.005s | 0s |
| Networks placement atm | -360.000...360.000deg | 0.001deg | 0deg |
| Synchronizing time left | 0.000...1800.000s | 0.005s | 0s |
| Get measurement errors for fine tuning | 0: -<br>1: Get errors | - | 0: - |
| Magnitude difference fine tune | -200.000...200.000% | 0.001% | 0% |
| Frequency difference fine tune | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference fine tune | -360.000...360.000deg | 0.001deg | 0deg |

Table. 5.5.12 - 274. Synchronizing settings.

| Name | Range | Step | Default |
|---|---|---|---|
| Maximum allowed voltage difference | 0.10...50.00%Un | 0.01%Un | 2.00%Un |
| Maximum allowed overfrequency difference to allow synchronizing | 0.00...2.00Hz | 0.01Hz | 0.2Hz |
| Maximum allowed underfrequency difference to allow synchronizing | 0.00...2.00Hz | 0.01Hz | 0Hz |
| Maximum time for synchronizing | 0.000...1800.000s | 0.005s | 300.000s |
| Maximum allowed angular disposition to allow synchronizing | -25.00...25.00deg | 0.01deg | 10.00deg |
| Adjustment for measurement inaccuracy or set of desired volt. offset | -95.0000...95.0000%Un | 0.0001%Un | 0%Un |
| Adjustment for measurement inaccuracy or set of desired angular offset | -60.0000...60.0000deg | 0.0001deg | 0deg |
| Adjustment for measurement inaccuracy or set of desired freq. offset | -0.5000...2.0000Hz | 0.0001Hz | -0.1000Hz |
| Voltage adjustment slope | 0.00...25.00%/s | 0.01%/s | 0.20%/s |
| Volt. Max. adjustment pulse length | 0.000...1800.000s | 0.005s | 3.000s |
| Volt. Min. adjustment pulse length | 0.000...1800.000s | 0.005s | 0.100s |
| Volt. Min. Resting time between pulses | 0.000...1800.000s | 0.005s | 2.500s |
| Freq. Max. adjustment pulse length | 0.000...1800.000s | 0.005s | 3.000s |
| Freq. Min. adjustment pulse length | 0.000...1800.000s | 0.005s | 0.100s |
| Freq. Min. Resting time between pulses | 0.000...1800.000s | 0.005s | 2.500s |
| Frequency adjustment slope when increasing | 0.00...10.00Hz/s | 0.01Hz/s | 0.10Hz/s |
| Frequency adjustment slope when decreasing | -10.00...0.00Hz/s | 0.01Hz/s | -0.10Hz/s |
| Circuit breaker pre-closing time incl auxiliary relays | 0.000...1800.000s | 0.005s | 0.100s |
| Lenght of circuit breaker closing pulse | 0.000...1800.000s | 0.005s | 0.250s |

| Name | Range | Step | Default |
|---|---|---|---|
| Multiple On pulses | 0: Single On pulse<br>1: Multiple pulses | - | 0: Single On pulse |

Table. 5.5.12 - 275. Synchronizer internal parameters.

| Name | Range | Step | Default |
|---|---|---|---|
| Maximum allowed voltage difference to start synchronizing | 0.00...50.00%Un | 0.01%Un | 20.00%Un |
| Block voltage up commands over | 0.00...50.00%Un | 0.01%Un | 20.00%Un |
| Block voltage down commands under | -50.00...50.00%Un | 0.01%Un | -20.00%Un |
| Integrator sum when voltage adjustment pulse is generated | 0.00...50.00% | 0.01% | 10.00% |
| Voltage adjustment pulse length constant | 0.00...5000.00 | 0.01 | 1000.00 |
| Maximum allowed frequency difference to start synchronizing | 0.00...25.00Hz | 0.01Hz | 5.00Hz |
| Integrator sum when frequency adjustment pulse is generated | 0.00...50.00Hz | 0.01Hz | 1.00Hz |
| Frequency adjustment pulse length constant | 0.00...5000.00 | 0.01 | 1000.00 |
| Filter time for angle derivative | 0.000...1800.000s | 0.005s | 1.000s |
| Circuit breaker pre-closing adjustment constant | 0.00...10.00 | 0.01 | 0.10 |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a BREAKER CLOSE PULSE signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events

The synchronizing function (abbreviated "GSYN" in event block names) generates events and registers from the status changes in the following: VOLTAGE MAG/FREQ/ANG DIFFERENCE OK, RUNNING, DECREASE/INCREASE VOLTAGE/FREQUENCY, BREAKER CLOSE PULSE, LONG SYNC TIME, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.5.12 - 276. Event messages.

| Event block name | Event names |
|---|---|
| GSYN | Synchronizing Blocked ON |
| GSYN | Synchronizing Blocked OFF |
| GSYN | Synchronizing Running ON |
| GSYN | Synchronizing Running OFF |



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| Event block name | Event names |
|---|---|
| GSYN | Synchr. Increase Voltage ON |
| GSYN | Synchr. Increase Voltage OFF |
| GSYN | Synchr. Decrease Voltage ON |
| GSYN | Synchr. Decrease Voltage OFF |
| GSYN | Synchr. Increase Frequency ON |
| GSYN | Synchr. Increase Frequency OFF |
| GSYN | Synchr. Decrease Frequency ON |
| GSYN | Synchr. Decrease Frequency OFF |
| GSYN | Synchronizer BRK Close ON |
| GSYN | Synchronizer BRK Close OFF |
| GSYN | Synchronizer Long Sync. Time ON |
| GSYN | Synchronizer Long Sync. Time OFF |
| GSYN | Synchroswitch Close fail Re-init ON |
| GSYN | Synchroswitch Close fail Re-init OFF |
| GSYN | Synchroswitching requested ON |
| GSYN | Synchroswitching requested OFF |

### 5.5.13 Vector jump (Δφ; 78)

Distribution systems may include different kinds of distributed power generation sources, such as wind farms and diesel or fuel generators. When a fault occurs in the distribution system, it is usually detected and isolated by the protection system closest to the faulty point, resulting in the electrical power system shutting dow either partially or completely. The remaining distributed generators try to deliver the power to the part of the distribution system that has been disconnected from the grid, and usually an overload condition can be expected. Under such overload conditions, it is normal to have a drop in voltage and frequency. This overload results in the final system disconnection from the islanding generator(s). The disconnection depends greatly on the ratio between the power generation and the demand of the islanded system. When any power is supplied to a load only from distributed generators, (due to the opening of the main switch), the situation is called an isolated island operation or an islanded operation of the electrical distribution network.

The vector jump control function is suitable to detect most islanding situations and to switch off the mains breaker in order to let the generator only supply loads according to their rated power value. Therefore, an overload does not cause any mechanical stress to the generator unit(s). The vector jump relay should be located either on the mains side of the operated breaker or on the islanding generator side.

The vector jump function is used for instant tripping and has only one operating stage. The function has an algorithm which follows the samples of chosen measured voltages (64 samples/cycle). The reference voltage used can be all or any of the phase-to-phase or phase-to-neutral voltages.

The outputs of the function are the ALARM, TRIP and BLOCKED signals. Both ALARM and TRIP signals have an individual pick-up setting. The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running. The vector jump function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude selection
- input magnitude processing
- threshold comparator
- two block signal checks (undervoltage block or stage external signal)
- time delay characteristics
- output processing.

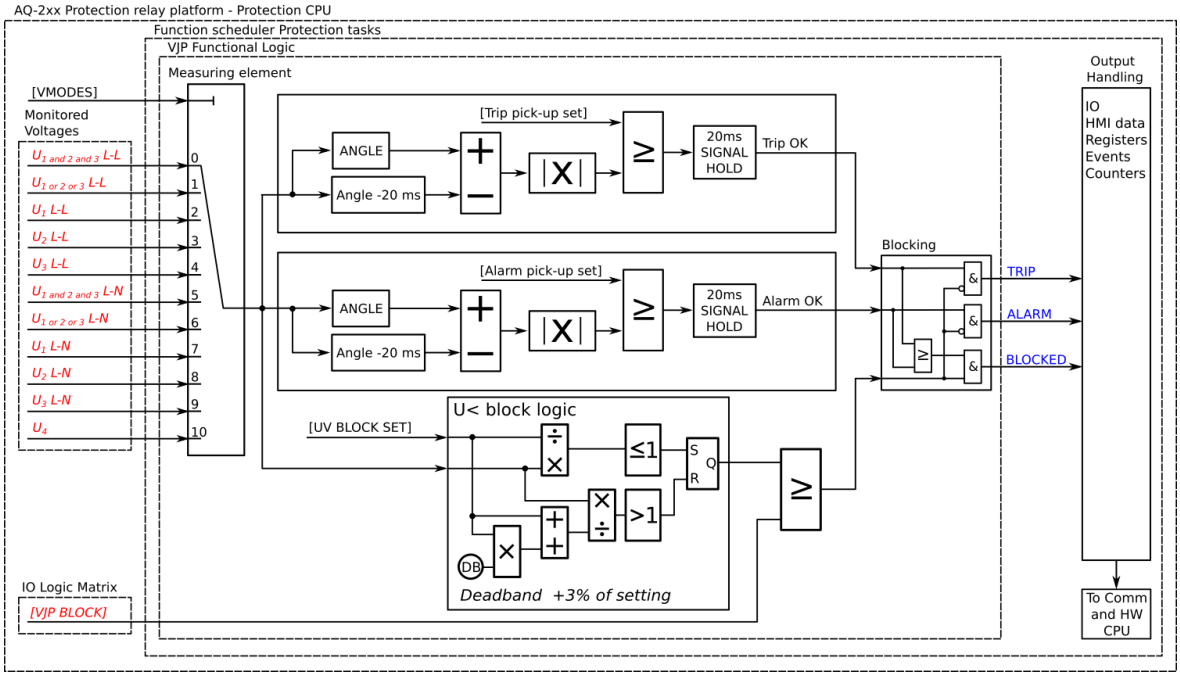
The inputs for the function are the following:

- available stages
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's outputs are ALARM, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. When tripping, the function outputs ALARM and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the ALARM, TRIP and BLOCKED events.

The following figure presents a simplified function block diagram of the vector jump function.

Figure. 5.5.13 - 176. Simplified function block diagram of the Δφ function.




## Measured input

The function block uses analog voltage measurement values and always uses complex measurement from samples. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.5.13 - 277. Measurement inputs of the vector jump function.

| Signal | Description | Time base |
|---|---|---|
| $U_1$L-L | Measured line-to-line voltage $U_1$/V | 5ms |



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IM00015

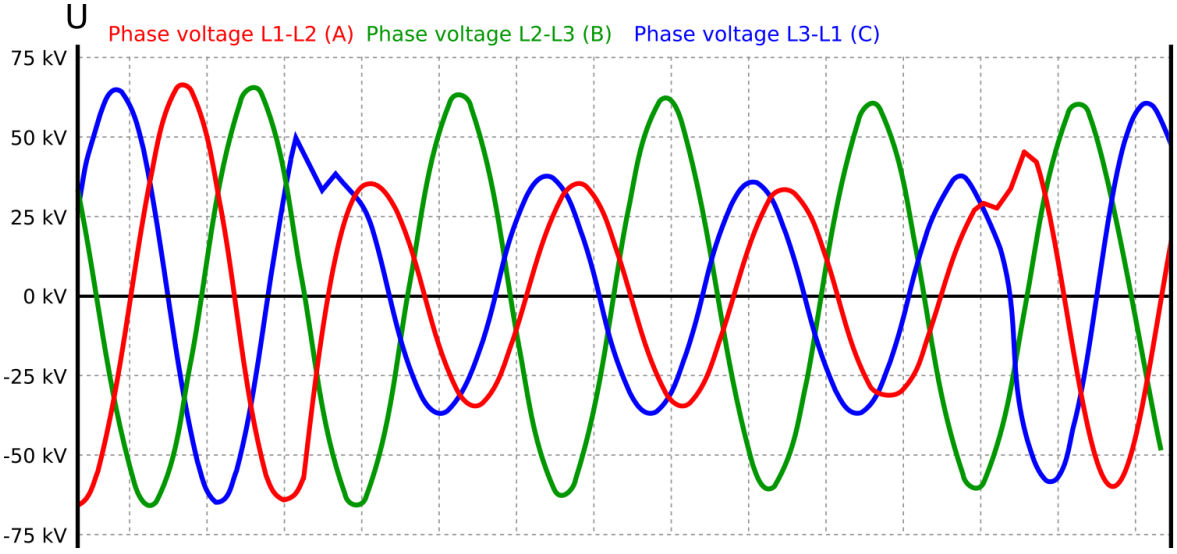
| Signal | Description | Time base |
|---|---|---|
| $U_2$L-L | Measured line-to-line voltage $U_2$/V | 5ms |
| $U_3$L-L | Measured line-to-line voltage $U_3$/V | 5ms |
| $U_1$L-N | Measured line-to-neutral voltage $U_1$/V | 5ms |
| $U_2$L-N | Measured line-to-neutral voltage $U_2$/V | 5ms |
| $U_3$L-N | Measured line-to-neutral voltage $U_3$/V | 5ms |
| $U_4$ | Measured voltage $U_4$/V | 5ms |

The selection of the used AI channel is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from ALARM or TRIP event.

## Pick-up

When a fault appears in the power system and some areas are disconnected, normally the remaining generators connected to the network must supply the area disconnected from the utility side supply. This results in an instantaneous demand of power that the generators must tackle. The excitation and the mechanical systems cannot answer such a huge demand of power quickly even if there were enough reserve power. The worst of the situation is received by the rotors of the generator units: they suffer a torsion torque that can even break the rotor and cause subsequent damage not only for the generator but for the entire power plant too.

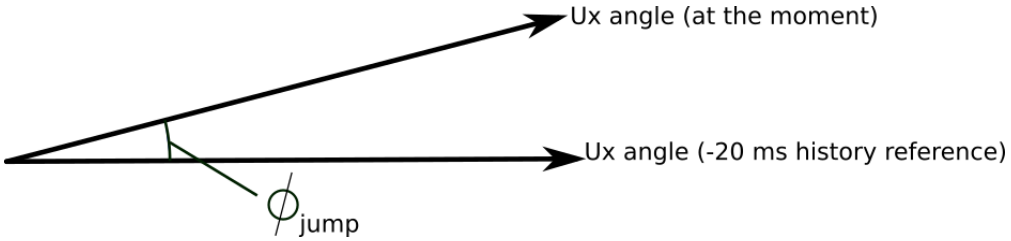
Figure. 5.5.13 - 177. Generator islanding.




As can be seen in the example above, only phase-to-phase voltages L1-L2 and L3-L1 have been reduced, while voltage L2-L3 remains the same. This means that the problem occured in phase L1 of the network. The voltage level is not reduced to zero, nor is the voltage in any phase is totally lost. The phases without the fault condition remain normal with the same value. On the other hand, the frequency can sag as can be seen in the figure above.

The *Δα* setting parameter controls the pick-up of the vector jump function. This defines the minimum allowed rapid measured voltage angle change before action from the function. The function constantly calculates the ratio between the $\Delta\alpha_{set}$ and the measured magnitude ($\Delta\alpha_m$) for each of the selected voltages. The function's stage trip signal lasts for 20 ms and automatically resets after that time has passed. The setting value is common for all measured amplitudes.

Figure. 5.5.13 - 178. Vector jump from the relay's point of view.




The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.5.13 - 278. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| Δα LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | 0: On | Set mode of VJP block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Δα force status to | 0: Normal<br>1: Blocked<br>2: Trip<br>3: Alarm | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Available stages | 0: Trip<br>1: Trip and alarm | 0: Trip | Defines if alarm is included with trip or not. |
| Monitored voltages | 0: System all P-P Voltages<br>1: System any P-P Voltage<br>2: System L12 Voltage<br>3: System L23 Voltage<br>4: System L31 Voltage<br>5: System all P-E voltages<br>6: System any P-E voltage<br>7: System L1 Voltage<br>8: System L2 Voltage<br>9: System L3 Voltage<br>10: U4 Voltage | 1: System any P-P Voltage | Defines the monitored voltage channel(s) |

Table. 5.5.13 - 279. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Pick-up setting Δα (lead or lag) Trip | 0.05…30.00° | 0.01° | 5° | Pick-up setting for trip signal |
| Pick-up setting Δα (lead or lag) Alarm | 0.05…30.00° | 0.01° | 5° | Pick-up setting for alarm signal |
| Undervoltage block limit % < Un | 0.01…100.00%$U_n$ | 0.01%$U_n$ | 95%$U_n$ | Block setting. When measured voltage is below this setting the function is blocked. |

The pick-up activation of the function is not directly equal to the START or TRIP signal generation of the function. The START signal is allowed if the blocking condition is not active.



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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.5.13 - 280. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| Δα > LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of UEX block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Δα > condition | 0: Normal<br>1: Blocked<br>2: Trip<br>3: Alarm | - | Displays status of the protection function. |
| Voltage meas selected | 0: Selection Ok<br>1: Selection not available | - | Displays validity of the voltage channel(s) selected in "Monitored voltages" parameter. |
| Δα > U1 Angle difference | -360...360deg | 0.01deg | Displays the angle difference between present time and 20 ms ago. |
| Δα > U2 Angle difference | | | |
| Δα > U3 Angle difference | | | |
| Δα > U1meas/set | -360...360p.u. | 0.01p.u. | Displays the ratio between the measured voltage and undervoltage block limit setting. |
| Δα > U2meas/set | | | |
| Δα > U3meas/set | | | |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a ALARM or TRIP signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events and registers

The vector jump function (abbreviated "VJP" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

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Table. 5.5.13 - 281. Event messages.

| Event block name | Event names |
|---|---|
| VJP1 | Block ON |
| VJP1 | Block OFF |
| VJP1 | Trip ON |
| VJP1 | Trip OFF |
| VJP1 | Alarm ON |
| VJP1 | Alarm OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.5.13 - 282. Register content.

| Date and time | Event | Fault type | Trip Δα meas / dataset | Alarm Δα meas / dataset | Used SG |
|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1(2), L2(3), L3(1) and U4 | Trip angle difference | Alarm angle difference | Setting group 1...8 active |

## 5.5.14 Synchronizer (ΔV/Δa/Δf; 25)

The synchronizer function is used to automatically synchronize generators to power grids. Proper synchronizing is essential to avoid inrush currents, power system oscillations as well as thermal and mechanical stress on the generator when connecting a synchronous generator to a grid.

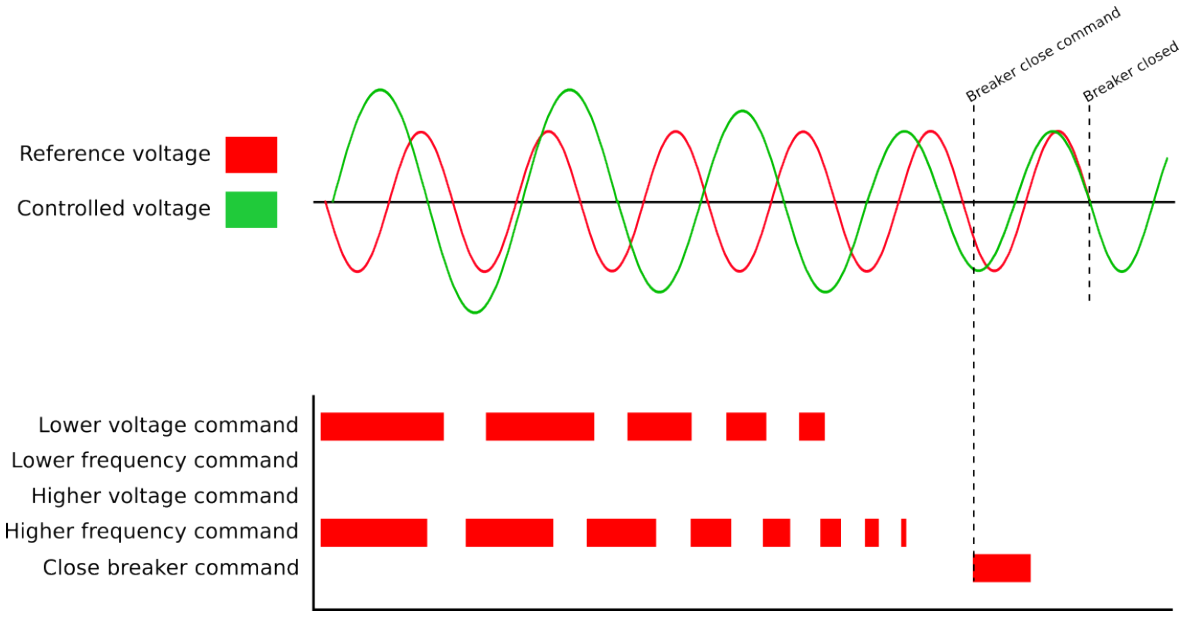
The user can synchronize up to eight (8) circuit breakers with the same synchronizing function by using different setting groups and the logic editor. The synchrocheck function is used to parallel or energize power lines.






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IM00015

Figure. 5.5.14 - 179. Simplified presentation of synchronizer operation




The synchronizing function uses voltage signals from each side of the circuit breaker to be closed.

- The amplitude difference between the two voltages is used to send "Increase" and "Decrease" commands to the generator's voltage regulator. The pulse length for these commands can be set, and it is automatically adjusted depending on the difference between the two measured signals.
- The frequency difference between the two voltages (the slip frequency) is used to send "Increase" and "Decrease" commands to the turbine's speed governor. The pulse length for these commands can be adjusted individually to take into account turbine governors with different speeds. The pulse length is automatically adjusted depending on the difference between the two measured signals.
- Settings can be adjusted to only allow positive slip to avoid reverse power at synchronizing.
- When the amplitude, the speed, and the phase-angle between the two voltages match (within pre-set limits), a "Close" command signal is sent to the generator's circuit breaker.

Pre-closing time can be used to allow for delay time in a circuit breaker and any auxiliary relays. The pre-closing angle is adjusted automatically depending on the slip frequency.

The outputs of the function are the following signals:

- Voltage Magnitude Difference Ok
- Voltage Frequency Difference Ok
- Voltage Angle Difference Ok
- Blocked
- Running
- Increase Voltage
- Decrease Voltage
- Increase Frequency
- Decrease Frequency
- Breaker Close Pulse
- Long Sync Time
- Nets Standstill
- Nets Departing
- Nets Enclosing

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes.

The function's output signals can be used for direct I/O controlling and user logic programming. The time stamp resolution is 1 ms.

## Measured input

The function block uses analog voltage measurement values. The monitored magnitude is equal to RMS values.

Table. 5.5.14 - 283. Measurement inputs of the synchronizer function.

| Signal | Description | Time base |
|---|---|---|
| $U_1$RMS | RMS measurement of voltage $U_1$/V | 5ms |
| $U_2$RMS | RMS measurement of voltage $U_2$/V | 5ms |
| $U_3$RMS | RMS measurement of voltage $U_3$/V | 5ms |
| $U_4$RMS | RMS measurement of voltage $U_4$/V | 5ms |

## Setting parameters

Table. 5.5.14 - 284. General setting parameters.

| Name | Range | Step | Default |
|---|---|---|---|
| Voltage difference calculation mode | 0: System is reference<br>1: U3/U4 input is reference | - | 0: System is reference |
| Synchronizer voltage reference | 0: UL12<br>1: UL23<br>2: UL31<br>3: UL1<br>4: UL2<br>5: UL3 | - | 0: UL12 |
| Synchronizer measurement settings | 0: Meas.Conf.Incorrect<br>1: PP and PE voltages<br>2: PP Voltages | - | - |
| Synchronizer status | 0: Conf.Error<br>1: Idle Ready<br>2: Synchronizing<br>3: Blocked | - | - |
| Synchroswitch status | 0: Standstill<br>1: Departing<br>2: Enclosing | - | - |
| Force control signals on | 0: None<br>1: Blocked On<br>2: Running On<br>3: Increase U On<br>4: Decrease U On<br>5: Increase F On<br>6: Decrease F On<br>7: CB Close On<br>8: LongSyncTime On | - | 0: None |
| Enable on-screen synchronizer view | 0: Disabled<br>1: Enabled | - | 0: Disabled |
| Magnitude difference | -200.000...200.000%Un | 0.001%Un | 0%Un |


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| Name | Range | Step | Default |
|---|---|---|---|
| Frequency difference | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference | -360.000...360.000deg | 0.001deg | 0deg |
| Magnitude difference on closing BRK | -200.000...200.000%Un | 0.001%Un | 0%Un |
| Frequency difference on closing BRK | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference on closing BRK | -360.000...360.000deg | 0.001deg | 0deg |
| Estimated BRK Closing time | 0.000...360.000s | 0.005s | 0s |
| Networks rotating time | 0.000...360.000s | 0.005s | 0s |
| Networks placement atm | -360.000...360.000deg | 0.001deg | 0deg |
| Synchronizing time left | 0.000...1800.000s | 0.005s | 0s |
| Get measurement errors for fine tuning | 0: -<br>1: Get errors | - | 0: - |
| Magnitude difference fine tune | -200.000...200.000% | 0.001% | 0% |
| Frequency difference fine tune | -100.000...100.000Hz | 0.001Hz | 0Hz |
| Angle difference fine tune | -360.000...360.000deg | 0.001deg | 0deg |

Table. 5.5.14 - 285. Synchronizing settings.

| Name | Range | Step | Default |
|---|---|---|---|
| Maximum allowed voltage difference | 0.10...50.00%Un | 0.01%Un | 2.00%Un |
| Maximum allowed overfrequency difference to allow synchronizing | 0.00...2.00Hz | 0.01Hz | 0.2Hz |
| Maximum allowed underfrequency difference to allow synchronizing | 0.00...2.00Hz | 0.01Hz | 0Hz |
| Maximum time for synchronizing | 0.000...1800.000s | 0.005s | 300.000s |
| Maximum allowed angular disposition to allow synchronizing | -25.00...25.00deg | 0.01deg | 10.00deg |
| Adjustment for measurement inaccuracy or set of desired volt. offset | -95.0000...95.0000%Un | 0.0001%Un | 0%Un |
| Adjustment for measurement inaccuracy or set of desired angular offset | -60.0000...60.0000deg | 0.0001deg | 0deg |
| Adjustment for measurement inaccuracy or set of desired freq. offset | -0.5000...2.0000Hz | 0.0001Hz | -0.1000Hz |
| Voltage adjustment slope | 0.00...25.00%/s | 0.01%/s | 0.20%/s |
| Volt. Max. adjustment pulse length | 0.000...1800.000s | 0.005s | 3.000s |
| Volt. Min. adjustment pulse length | 0.000...1800.000s | 0.005s | 0.100s |
| Volt. Min. Resting time between pulses | 0.000...1800.000s | 0.005s | 2.500s |
| Freq. Max. adjustment pulse length | 0.000...1800.000s | 0.005s | 3.000s |
| Freq. Min. adjustment pulse length | 0.000...1800.000s | 0.005s | 0.100s |
| Freq. Min. Resting time between pulses | 0.000...1800.000s | 0.005s | 2.500s |
| Frequency adjustment slope when increasing | 0.00...10.00Hz/s | 0.01Hz/s | 0.10Hz/s |
| Frequency adjustment slope when decreasing | -10.00...0.00Hz/s | 0.01Hz/s | -0.10Hz/s |
| Circuit breaker pre-closing time incl auxiliary relays | 0.000...1800.000s | 0.005s | 0.100s |
| Lenght of circuit breaker closing pulse | 0.000...1800.000s | 0.005s | 0.250s |

| Name | Range | Step | Default |
|---|---|---|---|
| Multiple On pulses | 0: Single On pulse<br>1: Multiple pulses | - | 0: Single On pulse |

Table. 5.5.14 - 286. Synchronizer internal parameters.

| Name | Range | Step | Default |
|---|---|---|---|
| Maximum allowed voltage difference to start synchronizing | 0.00...50.00%Un | 0.01%Un | 20.00%Un |
| Block voltage up commands over | 0.00...50.00%Un | 0.01%Un | 20.00%Un |
| Block voltage down commands under | -50.00...50.00%Un | 0.01%Un | -20.00%Un |
| Integrator sum when voltage adjustment pulse is generated | 0.00...50.00% | 0.01% | 10.00% |
| Voltage adjustment pulse length constant | 0.00...5000.00 | 0.01 | 1000.00 |
| Maximum allowed frequency difference to start synchronizing | 0.00...25.00Hz | 0.01Hz | 5.00Hz |
| Integrator sum when frequency adjustment pulse is generated | 0.00...50.00Hz | 0.01Hz | 1.00Hz |
| Frequency adjustment pulse length constant | 0.00...5000.00 | 0.01 | 1000.00 |
| Filter time for angle derivative | 0.000...1800.000s | 0.005s | 1.000s |
| Circuit breaker pre-closing adjustment constant | 0.00...10.00 | 0.01 | 0.10 |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a BREAKER CLOSE PULSE signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events

The synchronizing function (abbreviated "GSYN" in event block names) generates events and registers from the status changes in the following: VOLTAGE MAG/FREQ/ANG DIFFERENCE OK, RUNNING, DECREASE/INCREASE VOLTAGE/FREQUENCY, BREAKER CLOSE PULSE, LONG SYNC TIME, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.5.14 - 287. Event messages.

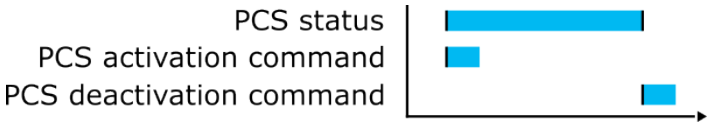
| Event block name | Event names |
|---|---|
| GSYN | Synchronizing Blocked ON |
| GSYN | Synchronizing Blocked OFF |
| GSYN | Synchronizing Running ON |
| GSYN | Synchronizing Running OFF |


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| Event block name | Event names |
|---|---|
| GSYN | Synchr. Increase Voltage ON |
| GSYN | Synchr. Increase Voltage OFF |
| GSYN | Synchr. Decrease Voltage ON |
| GSYN | Synchr. Decrease Voltage OFF |
| GSYN | Synchr. Increase Frequency ON |
| GSYN | Synchr. Increase Frequency OFF |
| GSYN | Synchr. Decrease Frequency ON |
| GSYN | Synchr. Decrease Frequency OFF |
| GSYN | Synchronizer BRK Close ON |
| GSYN | Synchronizer BRK Close OFF |
| GSYN | Synchronizer Long Sync. Time ON |
| GSYN | Synchronizer Long Sync. Time OFF |
| GSYN | Synchroswitch Close fail Re-init ON |
| GSYN | Synchroswitch Close fail Re-init OFF |
| GSYN | Synchroswitching requested ON |
| GSYN | Synchroswitching requested OFF |

### 5.5.15 Programmable control switch

The programmable control switch is a control function that controls its binary output signal. This output signal can be controlled locally from the relay's mimic (displayed as a box in the mimic) or remotely from the RTU. The main purpose of programmable control switches is to block or enable function and to change function properties by changing the setting group. However, this binary signal can also be used for any number of other purposes, just like all other binary signals. Once a programmable control switch has been activated or disabled, it remains in that state until given a new command to switch to the opposite state (see the image below). The switch cannot be controlled by an auxiliary input, such as digital inputs or logic signals; it can only be controlled locally (mimic) or remotely (RTU).




## Settings.

These settings can be accessed at *Control → Device I/O → Programmable control switch*.

Table. 5.5.15 - 288. Settings.

| Name | Range | Default | Description |
|---|---|---|---|
| Switch name | - | Switchx | The user-settable name of the selected switch. The name can be up to 32 characters long. |
| Access level for Mimic control | 0: User<br>1: Operator<br>2: Configurator<br>3: Super user | 2: Configurator | Determines which access level is required to be able to control the programmable control switch via the Mimic. |

### Events

The programmable control switch function (abbreviated "PCS" in event block names) generates events from status changes. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function offers five (5) independent switches.

Table. 5.5.15 - 289. Event messages.

| Event block name | Event names |
|---|---|
| PCS | Switch 1 ON |
| PCS | Switch 1 OFF |
| PCS | Switch 2 ON |
| PCS | Switch 2 OFF |
| PCS | Switch 3 ON |
| PCS | Switch 3 OFF |
| PCS | Switch 4 ON |
| PCS | Switch 4 OFF |
| PCS | Switch 5 ON |
| PCS | Switch 5 OFF |

## 5.5.16 User buttons

AQ-250 IEDs have twelve (12) physical user buttons in the front panel of the device. The main purpose of user buttons is to block or enable functions and to change function properties by changing the setting group. However, this binary signal can also be used for any number of other purposes, just like all other binary signals. Push buttons have two operation modes: "Press release" and "Toggle On/Off". In "Press release" mode the push button status is active while the button is pressed down. In "Toggle On/Off" mode push button status toggles between "On" and "Off". Each button has a user configurable LED at the top left corner of the button. The LED can be configured to activate red, orange or green color from button status or any other logical binary signal.

General user button settings can be set at *Control → Device IO → User-button Settings*.

NOTE!

Status of push button output can only be controlled from the AQ-200 device front panel i.e. can't be controlled remotely. Therefore it is recommended to use "a virtual button" (programmable control switches or logical inputs) if a toggleable signal must be controlled both locally and remotely.

## 5.5.17 Analog input scaling curves

Sometimes when measuring with RTD inputs, milliampere inputs and digital inputs the measurement might be inaccurate because the signal coming from the source is inaccurate. One common example of this is tap changer location indication signal not changing linearly from step to step. If the output difference between the steps are not equal to each other, measuring the incoming signal accurately is not enough. "Analog input scaling curves" menu can be used to take these inaccuracies into account.

Analog input scaling curve settings can be found at *Measurement → AI(mA, DI volt) scaling* menu.

Currently following measurements can be scaled with analog input scaling curves:

- RTD inputs and mA inputs in "RTD & mA input" option cards


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- mA inputs in "mA output & mA input" option cards
- Digital input voltages

Table. 5.5.17 - 290. Main settings (input channel).

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Analog input scaling | 0: Disabled<br>1: Activated | - | 0: Disabled | Enables and disables the input. |
| Scaling curve 1...4 | 0: Disabled<br>1: Activated | - | 0: Disabled | Enables and disables the scaling curve and the input measurement. |
| Curve 1...4 input signal select | 0: S7 mA Input<br>1: S8 mA Input<br>2: S15 mA Input<br>3: S16 mA Input<br>4: DI1 Voltage<br>...<br>23: DI20 Voltage<br>24: RTD S1 Resistance<br>...<br>39: RTD S16 Resistance<br>40: mA In 1 (I card 1)<br>41: mA In 2 (I card 2) | - | 0: S7 mA Input | Defines the measurement used by scaling curve. |
| Curve 1...4 input signal filtering | 0: No<br>1: Yes | - | 0: No | Enables calculation of the average of received signal. |
| Curve 1...4 input signal filter time constant | 0.005...3800.000 s | 0.005 s | 1 s | Time constant for input signal filtering.<br><br>This parameter is visible when "Curve 1...4 input signal filtering" has been set to "Yes". |
| Curve 1...4 input signal out of range set | 0: No<br>1: Yes | - | 0: No | Enables out of range signals. If input signal is out of minimum and maximum limits, "ASC1...4 input out of range" signal is activated. |
| Curve1...4 input minimum | -1 000 000.00...1 000 000.00 | 0.00001 | 0 | Defines the minimum input of the curve. If input is below the set limit, "ASC1...4 input out of range" is activated. |
| Curve 1...4 input | -1 000 000.00...1 000 000.00 | 0.00001 | - | Displays the input measurement received by the curve. |
| Curve1...4 input maximum | -1 000 000.00...1 000 000.00 | 0.00001 | 0 | Defines the maximum input of the curve. If input is above the set limit, "ASC1...4 input out of range" is activated. |
| Curve1...4 output | -1 000 000.00...1 000 000.00 | 0.00001 | - | Displays the output of the curve. |

The input signal filtering parameter calculates the average of received signals according to the set time constant. This is why rapid changes and disturbances (such as fast spikes) are smothered. The Nyquist rate states that the filter time constant must be at least double the period time of the disturbance process signal. For example, the value for the filter time constant is 2 seconds for a 1 second period time of a disturbance oscillation.

$$H(s) = \frac{Wc}{S+Wc} = \frac{1}{1+s/Wc}$$

When the curve signal is out of range, it activates the "ASC1...4 input out of range" signal, which can be used inside logic or with other relay functions. The signal can be assigned directly to an output relay or to an LED in the I/O matrix. The "Out of range" signal is activated, when the measured signal falls below the set input minimum limit, or when it exceeds the input maximum limit.

If for some reason the input signal is lost, the value is fixed to the last actual measured cycle value. The value does not go down to the minimum if it has been something else at the time of the signal breaking.

Table. 5.5.17 - 291. Output settings and indications.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Curve 1...4 update cycle | 5...10 000ms | 5ms | 150ms | Defines the length of the input measurement update cycle. If the user wants a fast operation, this setting should be fairly low. |
| Scaled value handling | 0: Floating point<br>1: Integer out (Floor)<br>2: Integer (Ceiling)<br>3: Integer (Nearest) | - | 0: Floating point | Rounds the milliampere signal output as selected. |
| Input value 1 | 0...4000 | 0.000 01 | 0 | The measured input value at Curve Point 1. |
| Scaled output value 1 | $-10^7...10^7$ | 0.000 01 | 0 | Scales the measured milliampere signal at Point 1. |
| Input value 2 | 0...4000 | 0.000 01 | 1 | The measured input value at Curve Point 2. |
| Scaled output value 1 | $-10^7...10^7$ | 0.000 01 | 0 | Scales the measured milliampere signal at Point 2. |
| Add curvepoint 3...20 | 0: Not used<br>1: Used | - | 0: Not used | Allows the user to create their own curve with up to twenty (20) curve points, instead of using a linear curve between two points. |

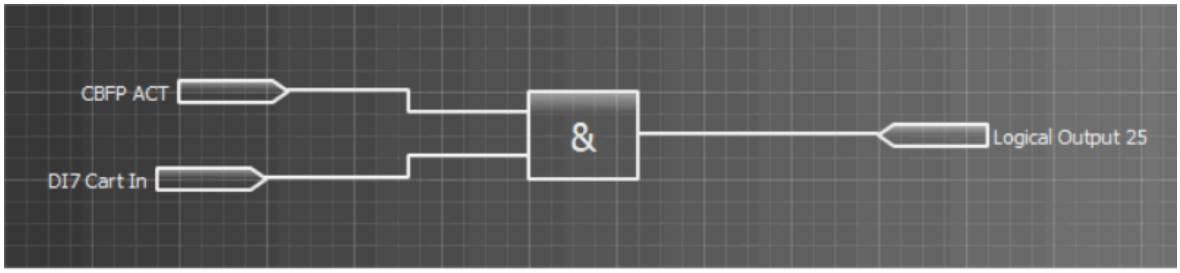
## 5.5.18 Logical outputs

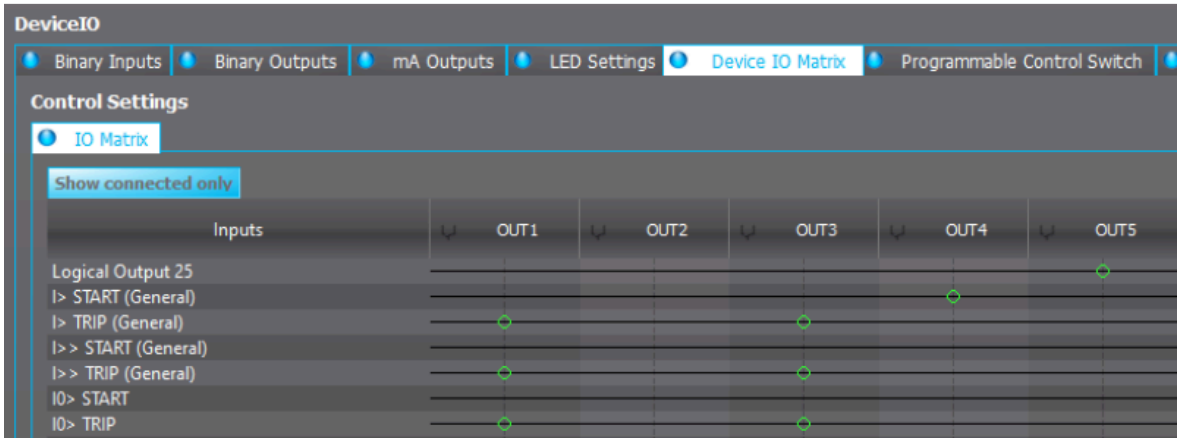
Logical outputs are used for sending binary signals out from a logic that has been built in the logic editor. Logical signals can be used for blocking functions, changing setting groups, controlling digital outputs, activating LEDs, etc. The status of logical outputs can also be reported to a SCADA system. 64 logical outputs are available. The figure below presents a logic output example where a signal from the circuit breaker failure protection function controls the digital output relay number 5 ("OUT5") when the circuit breaker's cart status is "In".



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Figure. 5.5.18 - 180. Logic output example. Logical output is connected to an output relay in matrix.




## Logical output descriptions

Logical outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 5.5.18 - 292. Logical output user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description LOx | 1...31 characters | Logical output x | Description of the logical output. This description is used in several menu types for easier identification. |

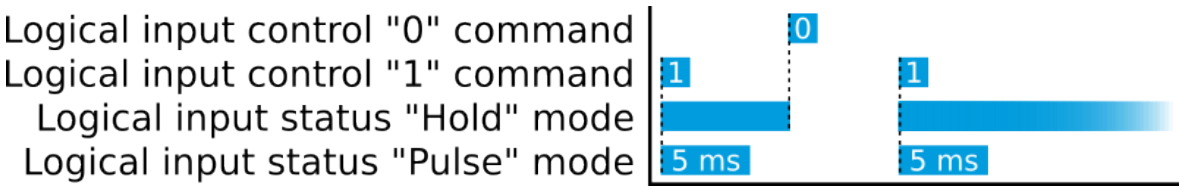
## 5.5.19 Logical inputs

Logical inputs are binary signals that a user can control manually to change the behavior of the AQ-200 unit or to give direct control commands. Logical inputs can be controlled with a virtual switch built in the mimic and from a SCADA system (IEC 61850, Modbus, IEC 101, etc.). Logical inputs are volatile signals: their status will always return to "0" when the AQ-200 device is rebooted. 32 logical inputs are available.

Logical inputs have two modes available: Hold and Pulse. When a logical input which has been set to "Hold" mode is controlled to "1", the input will switch to status "1" and it stays in that status until it is given a control command to go to status "0" or until the device is rebooted. When a logical input which has been set to "Pulse" mode is controlled to "1", the input will switch to status "1" and return back to "0" after 5 ms.

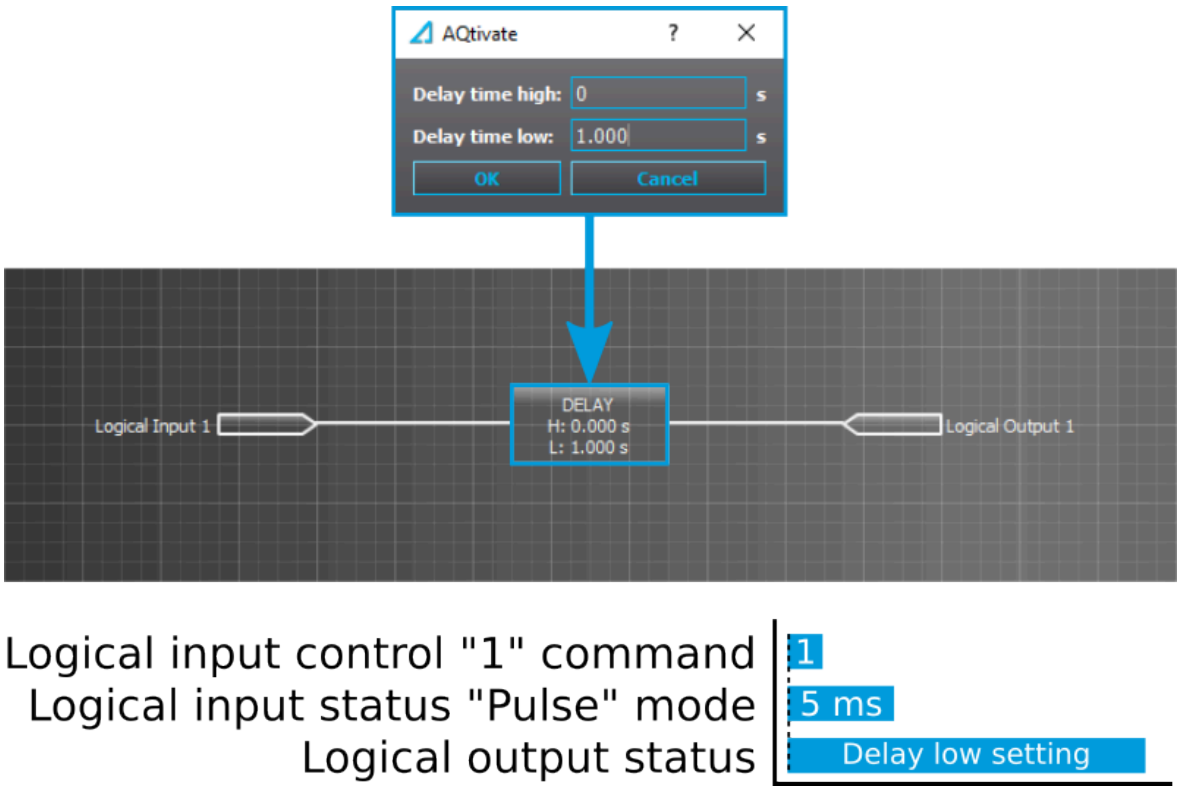
The figure below presents the operation of a logical input in Hold mode and in Pulse mode.

Figure. 5.5.19 - 181. Operation of logical input in "Hold" and "Pulse" modes.




A logical input pulse can also be extended by connecting a DELAY-low gate to a logical output, as has been done in the example figure below.

Figure. 5.5.19 - 182. Extending a logical input pulse.




## Logical input descriptions

Logical inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 5.5.19 - 293. Logical input user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description LIx | 1...31 characters | Logical input x | Description of the logical input. This description is used in several menu types for easier identification. |



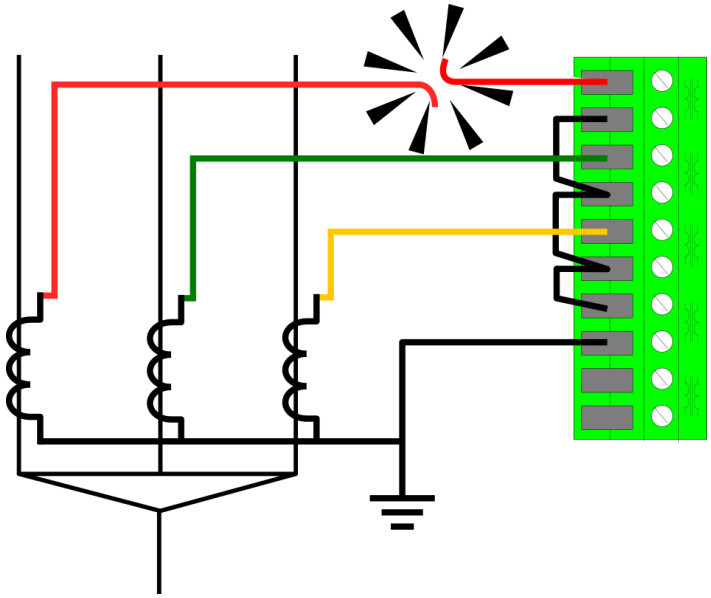
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# 5.6 Monitoring functions

## 5.6.1 Current transformer supervision

The current transformer supervision function (abbreviated CTS in this document) is used for monitoring the CTs as well as the wirings between the device and the CT inputs for malfunctions and wire breaks. An open CT circuit can generate dangerously high voltages into the CT secondary side, and cause unintended activations of current balance monitoring functions.

Figure. 5.6.1 - 183. Secondary circuit fault in phase L1 wiring.



The function constantly monitors the instant values and the key calculated magnitudes of the phase currents. Additionally, the residual current circuit can be monitored if the residual current is measured from a dedicated residual current CT. The user can enable and disable the residual circuit monitoring at will.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running.

The function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The following conditions have to met simultaneously for the function alarm to activate:

- None of the three-phase currents exceeds the $I_{set}$ *high limit* setting.
- At least one of the three-phase currents exceeds the $I_{set}$ *low limit* setting.
- At least one of the three-phase currents are below the $I_{set}$ *low limit* setting.
- The ratio between the calculated minum and maximum of the three-phase currents is below the $I_{set}$ *ratio* setting.

- The ratio between the negative sequence and the positive sequence exceeds the *I2/I1 ratio* setting.
- The calculated difference (IL1+IL2+IL3+I0) exceeds the $I_{sum}$ *difference* setting (optional).
- The above-mentioned condition is met until the set time delay for alarm.

The inputs of the function are the following:

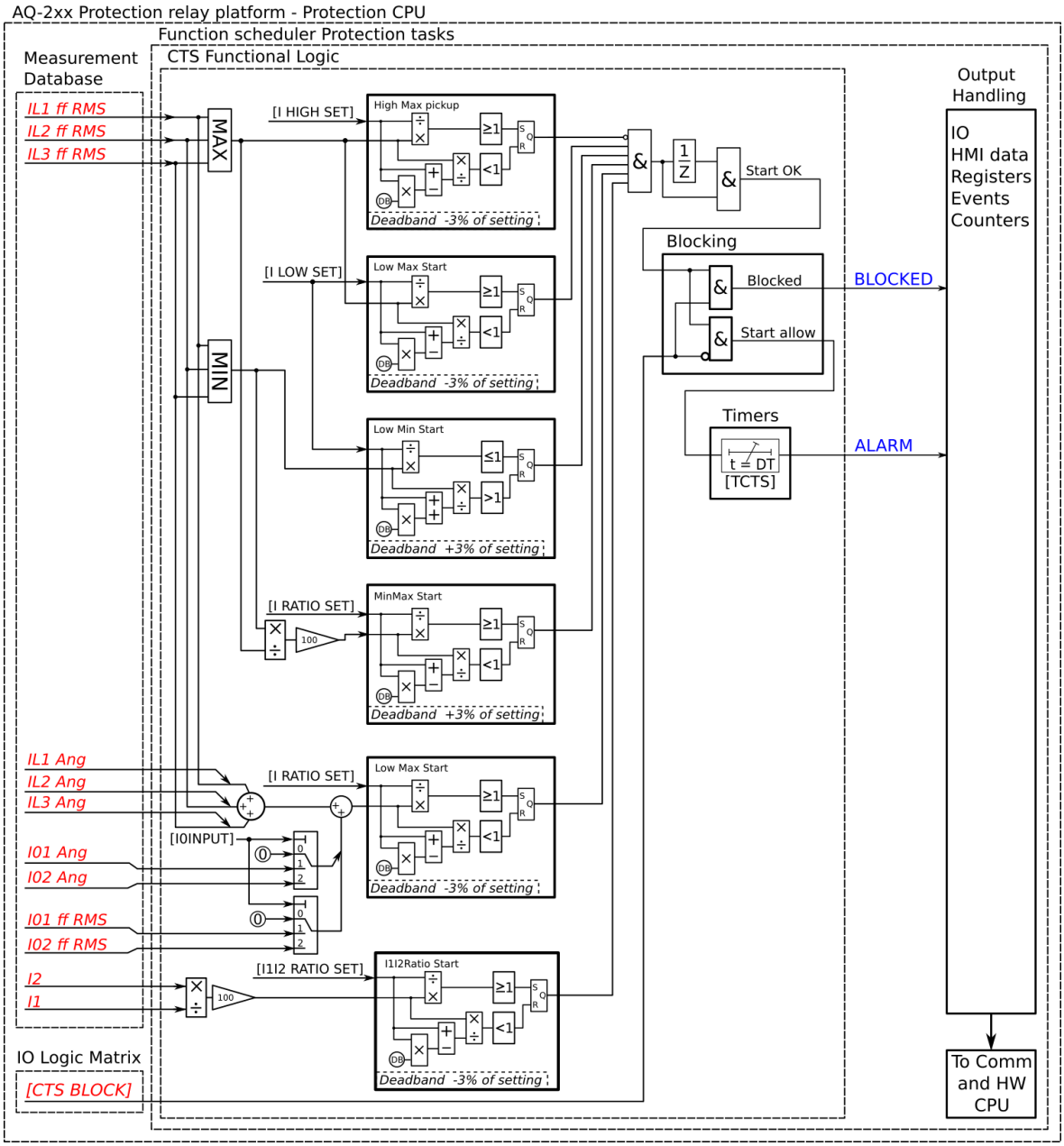
- setting parameters
- measured and pre-processed current magnitudes.

The function's outputs are CTS ALARM and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the CTS ALARM and BLOCKED events.

The following figure presents a simplified function block diagram of the current transformer supervision function.


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Figure. 5.6.1 - 184. Simplified function block diagram of the CTS function.




## Measured input

The function block uses analog current measurement values, the RMS magnitude of the current measurement inputs, and the calculated positive and negative sequence currents. The user can select what is used for the residual current measurement: nothing, the I01 RMS measurement, or the I02 RMS measurement.

Table. 5.6.1 - 294. Measured inputs of the CTS function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |
| I01RMS | RMS measurement of residual input I01 | 5ms |

| Signal | Description | Time base |
|---|---|---|
| I02RMS | RMS measurement of residual input I02 | 5ms |
| I1 | Phase current's positive sequence component | 5ms |
| I2 | Phase current's negative sequence component | 5ms |
| IL1Ang | Angle of phase L1 (A) current | 5ms |
| IL2 Ang | Angle of phase L2 (B) current | 5ms |
| IL3 Ang | Angle of phase L3 (C) current | 5ms |
| I01 Ang | Angle of residual input I01 | 5ms |
| I02 Ang | Angle of residual input I02 | 5ms |

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.6.1 - 295. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| CTS LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of CTS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CTS force status to | 0: Normal<br>1: Alarm<br>2: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| I0 input selection | 0: Not in use<br>1: I01<br>2: I02 | 0: Not in use | Selects the measurement input for the residual current. If the residual current is measured with a separate CT, the residual current circuit can be monitored with the CTS function as well. However, this does not apply to summing connections (Holmgren, etc.). If the phase current CT is summed with I01 or I02, this selection should be set to "Not in use". |
| I0 direction | 0: Add<br>1: Subtract | 0: Add | Defines the polarity of residual current channel connection. |
| Compensate natural unbalance | 0: -<br>1: Comp | 0: - | When activated while the line is energized, the currently present calculated residual current is compensated to 0. |

## Pick-up

The $I_{set}$ and $I0_{set}$ setting parameters control the current-dependent pick-up and activation of the current transformer supervision function. They define the minimum and maximum allowed measured current before action from the function. The function constantly calculates the ratio between the setting values and the measured magnitude ($I_m$) for each of the three phases and for the selected residual current input. The reset ratio of 97 % and 103% are built into the function and is always relative to the $I_{set}$ value. The setting value is common for all measured amplitudes, and when the $I_m$ exceeds the $I_{set}$ value (in single, dual or all currents) it triggers the pick-up operation of the function.


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Table. 5.6.1 - 296. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| $I_{set}$ high limit | 0.01…40.00×$I_n$ | 0.01×$I_n$ | 1.20×$I_n$ | Determines the pick-up threshold for phase current measurement. This setting limit defines the upper limit for the phase current's pick-up element.<br><br>If this condition is met, it is considered as fault and the function is not activated. |
| $I_{set}$ low limit | 0.01…40.00×$I_n$ | 0.01×$I_n$ | 0.10×$I_n$ | Determines the pick-up threshold for phase current measurement. This setting limit defines the lower limit for the phase current's pick-up element.<br><br>This condition has to be met for the function to activate. |
| $I_{set}$ ratio | 0.01…100.00% | 0.01% | 10.00% | Determines the pick-up ratio threshold between the minimum and maximum values of the phase current.<br><br>This condition has to be met for the function to activate. |
| I2/I1 ratio | 0.01…100.00% | 0.01% | 49.00% | Determines the pick-up ratio threshold for the negative and positive sequence currents calculated from the phase currents.<br><br>This condition has to be met for the function to activate.<br><br>The ratio is 50 % for a full single-phasing fault (i.e. when one of the phases is lost entirely). Setting this at 49 % allows a current of 0.01 × $I_n$ to flow in one phase, wile the other two are at nominal current. |
| $I_{sum}$ difference | 0.01…40.00×$I_n$ | 0.01×$I_n$ | 0.10×$I_n$ | Determines the pick-up ratio threshold for the calculated residual phase current and the measured residual current. If the measurement circuit is healthy, the sum of these two currents should be 0. |
| Time delay for alarm | 0.000…1800.000s | 0.005s | 0.5s | Determines the delay between the activation of the function and the alarm. |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active. When the activation of the pick-up is based on binary signals, the activation happens immediately after the monitored signal is activated.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.6.1 - 297. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| CTS LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of CTS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Uncompensated residual unbalance Pri | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays the natural unbalance of current after compensating it with *Compensate natural unbalance* parameter. |
| Natural unbalance ang | -360.00...360.00 deg | 0.01 deg | Displays the natural unbalance of angle after compensating it with *Compensate natural unbalance* parameter. |
| Measured current difference Isum, I0 | 0.00...50.00 xIn | 0.01 xIn | Current difference between summed phases and residual current. |

| Name | Range | Step | Description |
|---|---|---|---|
| Measured angle difference Isum, I0 | -360...360 deg | 0.01 deg | Angle difference between summed phases and residual current. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

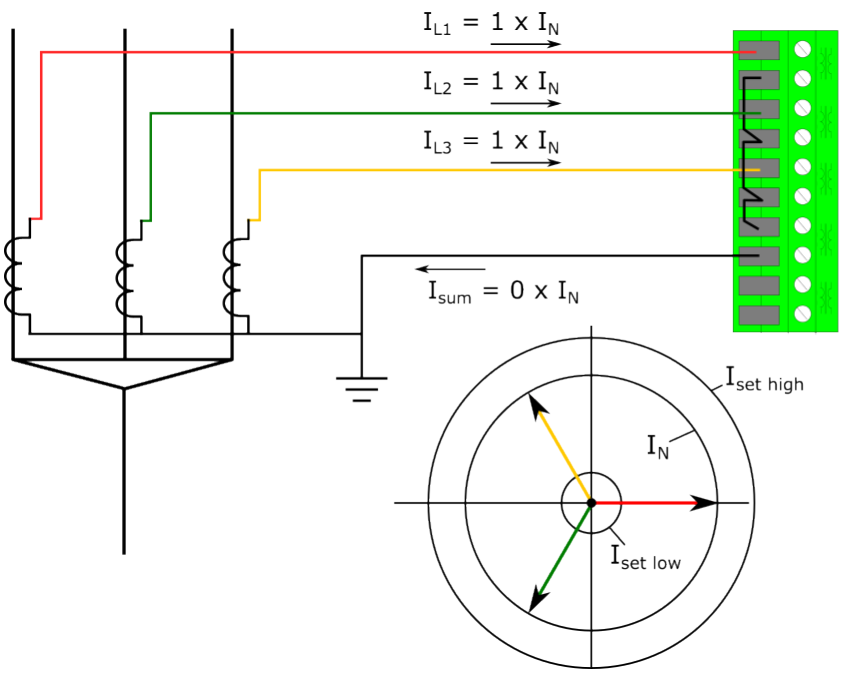
## Operating time characteristics

This function supports definite time delay (DT). For detailed information on this delay type please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Typical cases of current transformer supervision

The following nine examples present some typical cases of the current transformer supervision and their setting effects.

Figure. 5.6.1 - 185. All works properly, no faults.



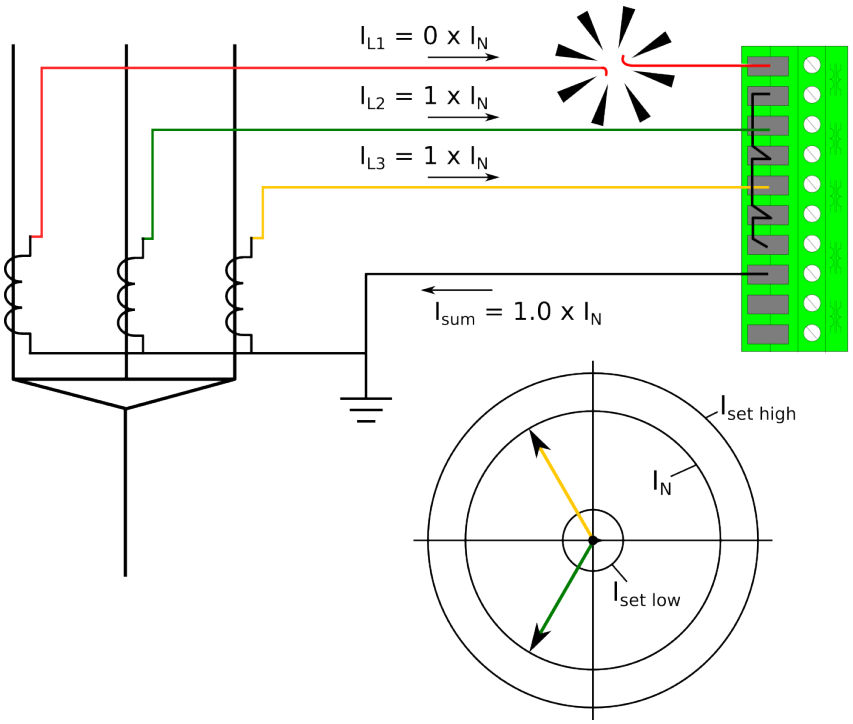

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**Measurements:**
$I_{min}$ = 1 x $I_N$
$I_{max}$ = 1 x $I_N$
I1 = 1 x $I_N$
I2 = 0 x $I_N$
$I_{min}/I_{max}$ = 1
I2/I1 = 0%

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 0
$I_{set}$ Low limit high > = 1
I ratio < = 0
$I_{unbalance}$ ratio > = 0


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Figure. 5.6.1 - 186. Secondary circuit fault in phase L1 wiring.



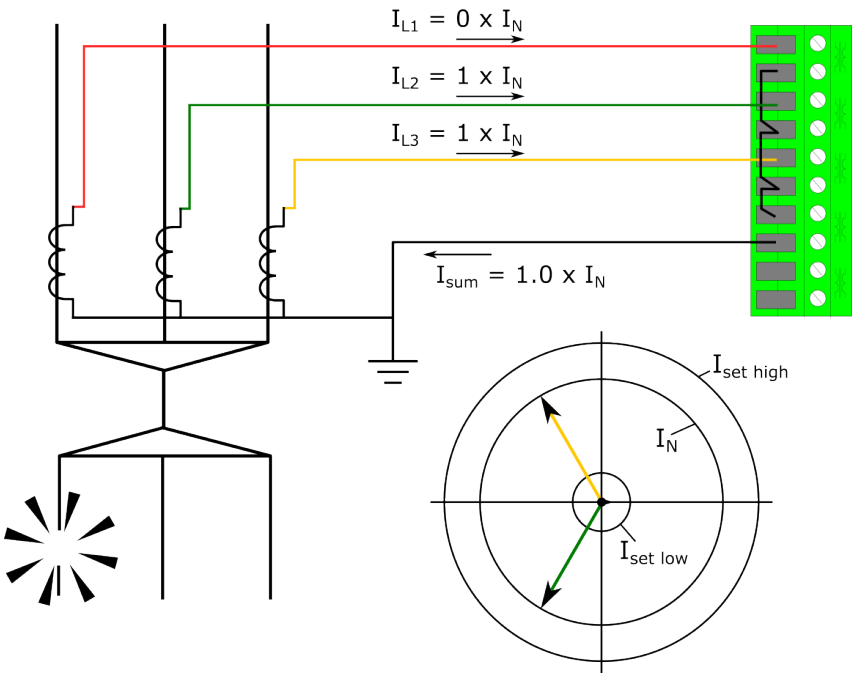

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**Measurements:**
$I_{min}$ = 0 x $I_N$
$I_{max}$ = 1 x $I_N$
I1 = 0.67 x $I_N$
I2 = 0.33 x $I_N$
$I_{min}/I_{max}$ = 0
I2/I1 = 50%

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1

When a fault is detected and all conditions are met, the CTS timer starts counting. If the situation continues until the set time has passed, the function issues an alarm.

Figure. 5.6.1 - 187. Primary circuit fault in phase L1 wiring.



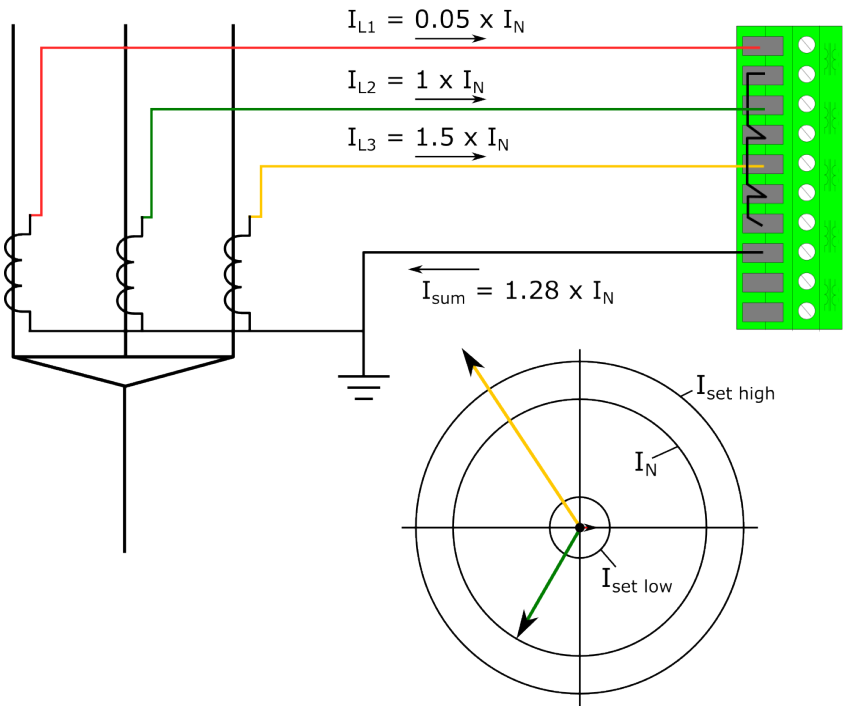

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**Measurements:**
$I_{min}$ = 0 x $I_N$
$I_{max}$ = 1 x $I_N$
I1 = 0.67 x $I_N$
I2 = 0.33 x $I_N$
$I_{min}/I_{max}$ = 0
I2/I1 = 50%

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1

In this example, distinguishing between a primary fault and a secondary fault is impossible. However, the situation meets the function's activation conditions, and if this state (secondary circuit fault) continues until the set time has passed, the function issues an alarm. This means that the function supervises both the primary and the secondary circuit.

Figure. 5.6.1 - 188. No wiring fault but heavy unbalance.



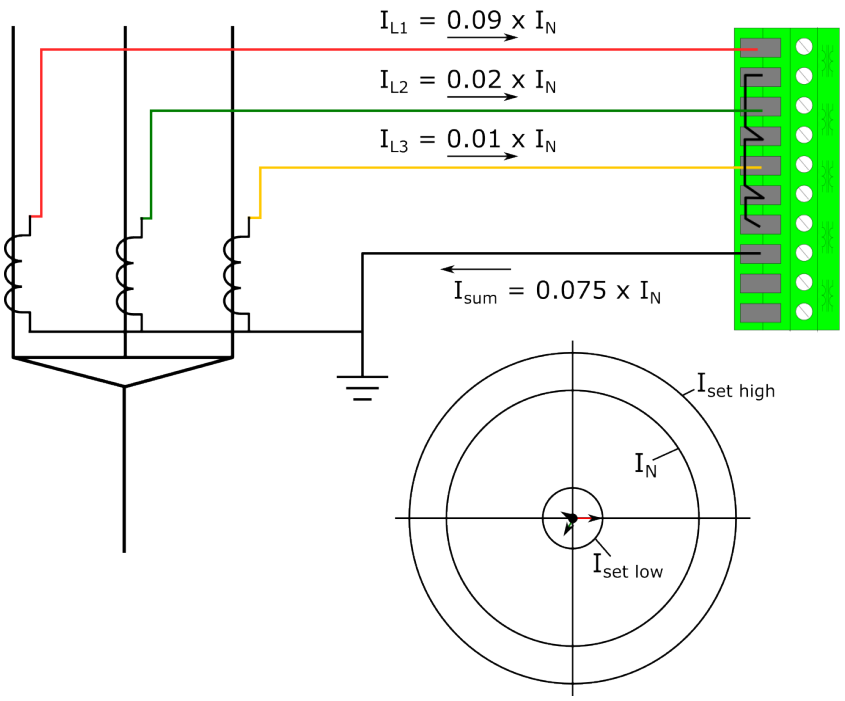

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**Measurements:**
$I_{min}$ = 0.05 x $I_N$
$I_{max}$ = 1.50 x $I_N$
I1 = 0.85 x $I_N$
I2 = 0.43 x $I_N$
$I_{min}/I_{max}$ = 0.7 %
I2/I1 = 50.03 %

**CTS conditions:**
$I_{set}$ High limit < = 0
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1

If any of the phases exceed the *$I_{set}$ high limit* setting, the operation of the function is not activated. This behavior is applied to short-circuits and earth faults even when the fault current exceeds the *$I_{set}$ high limit* setting.

Figure. 5.6.1 - 189. Low current and heavy unbalance.




**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**Measurements:**
$I_{min}$ = 0.01 x $I_N$
$I_{max}$ = 0.09 x $I_N$
I1 = 0.04 x $I_N$
I2 = 0.03 x $I_N$
$I_{min}/I_{max}$ = 11.0 %
I2/I1 = 62.92 %

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 0
I ratio < = 1
$I_{unbalance}$ ratio > = 1

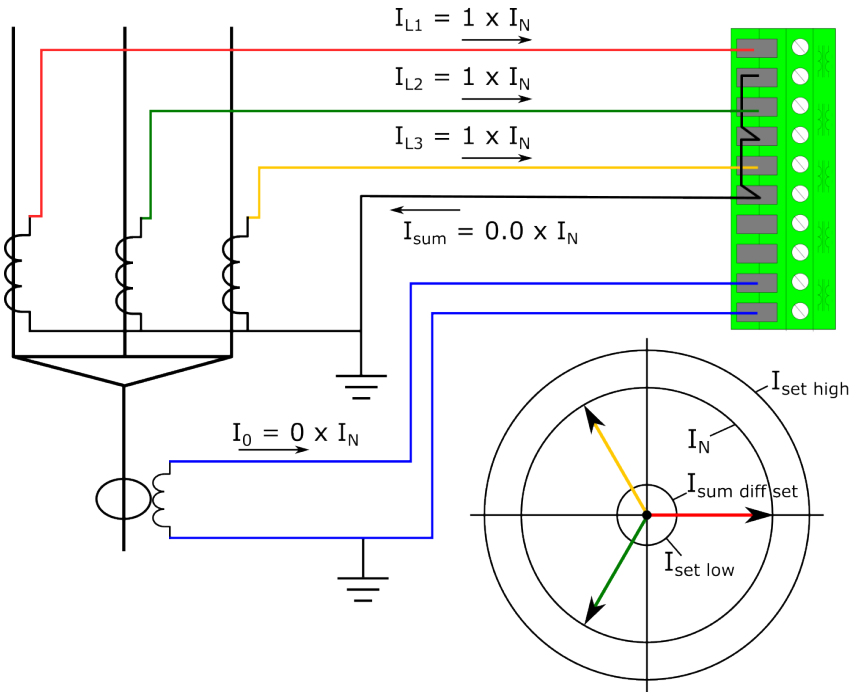
If all of the measured phase magnitudes are below the *$I_{set}$ low limit* setting, the function is not activated even when the other conditions (inc. the unbalance condition) are met.



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If the *$I_{set}$ high limit* and *$I_{set}$ low limit* setting parameters are adjusted according to the application's normal behavior, the operation of the function can be set to be very sensitive for broken circuit and conductor faults.

Figure. 5.6.1 - 190. Normal situation, residual current also measured.



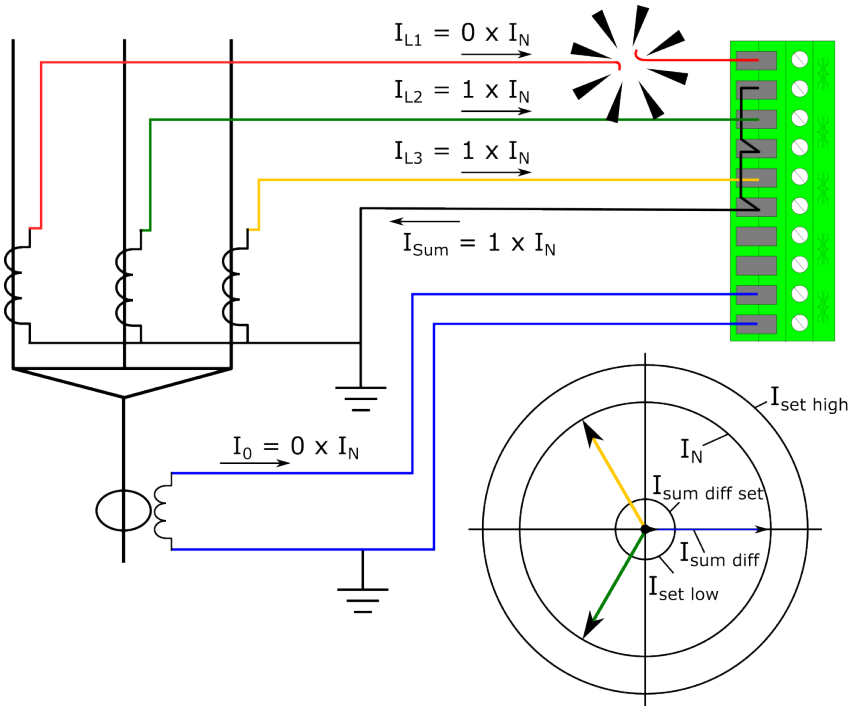

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**Measurements:**
$I_{min}$ = 1 x $I_N$
$I_{max}$ = 1 x $I_N$
I1 = 1 x $I_N$
I2 = 0 x $I_N$
$I_{min}/I_{max}$ = 1
I2/I1 = 0
$I_{sum}$ Difference= 0.0 x $I_N$

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 0
$I_{set}$ Low limit high > = 1
I ratio < = 0
$I_{unbalance}$ ratio > = 0

When the residual condition is added with the "I0 input selection", the sum of the current and the residual current are compared against each other to verify the wiring condition.

Figure. 5.6.1 - 191. Broken secondary phase current wiring.



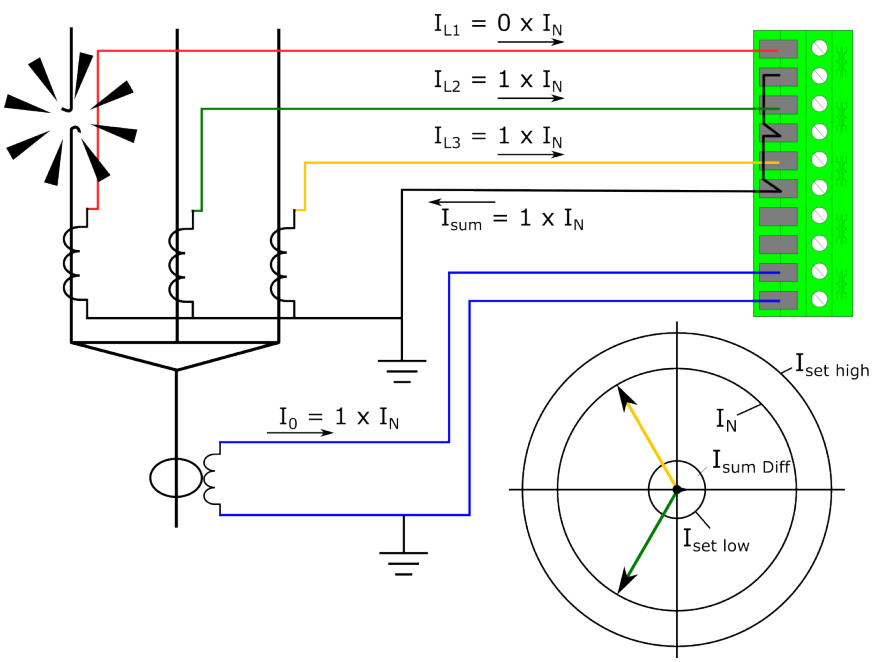

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**Measurements:**
$I_{min}$ = 1 x $I_N$
$I_{max}$ = 0 x $I_N$
I1 = 0.67 x $I_N$
I2 = 0.33 x $I_N$
$I_{min}/I_{max}$ = 0
I2/I1 = 50 %
$I_{sum}$ Difference= 1.0 x $I_N$

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1
$I_{sum}$ Difference > = 1

When phase current wire is broken all of the conditions are met in the CTS and alarm shall be issued in case if the situation continues until the set alarming time is met.

Figure. 5.6.1 - 192. Broken primary phase current wiring.



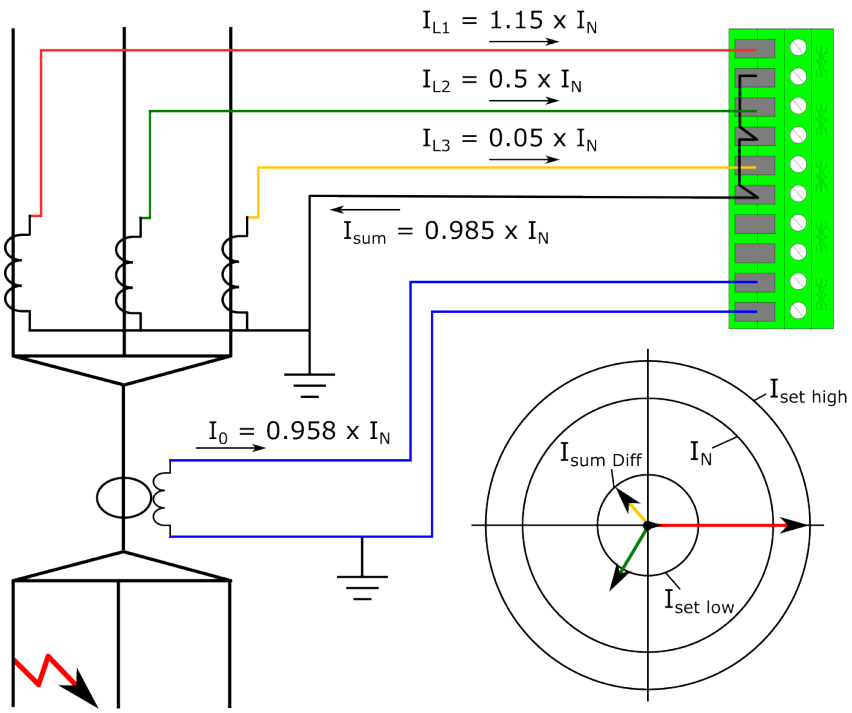

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**Measurements:**
$I_{min}$ = 0 x $I_N$
$I_{max}$ = 1 x $I_N$
I1 = 0.67 x $I_N$
I2 = 0.33 x $I_N$
$I_{min}/I_{max}$ = 0
I2/I1 = 50 %
$I_{sum}$ Difference= 0.0 x $I_N$

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1
$I_{sum}$ Difference > = 0

In this example, all other condition are met except the residual difference. That is now 0 × $I_n$, which indicates a primary side fault.

Figure. 5.6.1 - 193. Primary side high-impedance earth fault.




**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**Measurements:**
$I_{min}$ = 1 x $I_N$
$I_{max}$ = 0 x $I_N$
I1 = 0.57 x $I_N$
I2 = 0.32 x $I_N$
$I_{min}/I_{max}$ = 0.04
I2/I1 = 56.34 %
$I_{sum}$ Difference= 0.0 x $I_N$

**CTS conditions:**
$I_{set}$ High limit < = 1
$I_{set}$ Low limit low < = 1
$I_{set}$ Low limit high > = 1
I ratio < = 1
$I_{unbalance}$ ratio > = 1
$I_{sum}$ Difference > = 0

In this example there is a high-impedance earth fault. It does not activate the function, if the measurement conditions are met, while the calculated and measured residual current difference does not reach the limit. The *$I_{sum}$ difference* setting should be set according to the application in order to reach maximum security and maximum sensitivity for the network earthing.



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### Events and registers

The current transformer supervision function (abbreviated "CTS" in event block names) generates events and registers from the status changes in ALARM ACTIVATED and BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.6.1 - 298. Event messages.

| Event block name | Event names |
|---|---|
| CTS1 | Alarm ON |
| CTS1 | Alarm OFF |
| CTS1 | Block ON |
| CTS1 | Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers; this information is available for all provided instances separately. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.6.1 - 299. Register content.

| Date and time | Event | Trigger currents | Time to CTSact | Fault type | Used SG |
|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | The phase currents (L1, L2 & L3), the residual currents (I01 & I02), and the sequence currents (I1 & I2) on trigger time. | Time remaining before alarm activation. | The status code of the monitored current. | Setting group 1...8 active. |

## 5.6.2 Voltage transformer supervision (60)

Voltage transformer supervision is used to detect errors in the secondary circuit of the voltage transformer wiring and during fuse failure. This signal is mostly used as an alarming function or to disable functions that require adequate voltage measurement.

The function uses a total of eight (8) separate setting groups which can be selected from one common source. Also, the operating mode of the function can be changed via setting group selection.

The operational logic consists of the following:

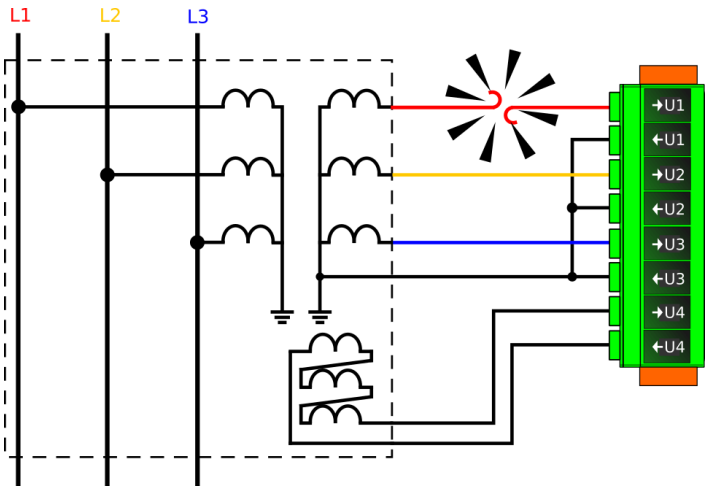
- input magnitude processing
- threshold comparator
- block signal check
- time delay characteristics
- output processing.

The inputs of the function are the following:

- setting parameters
- measured and pre-processed voltage magnitudes.

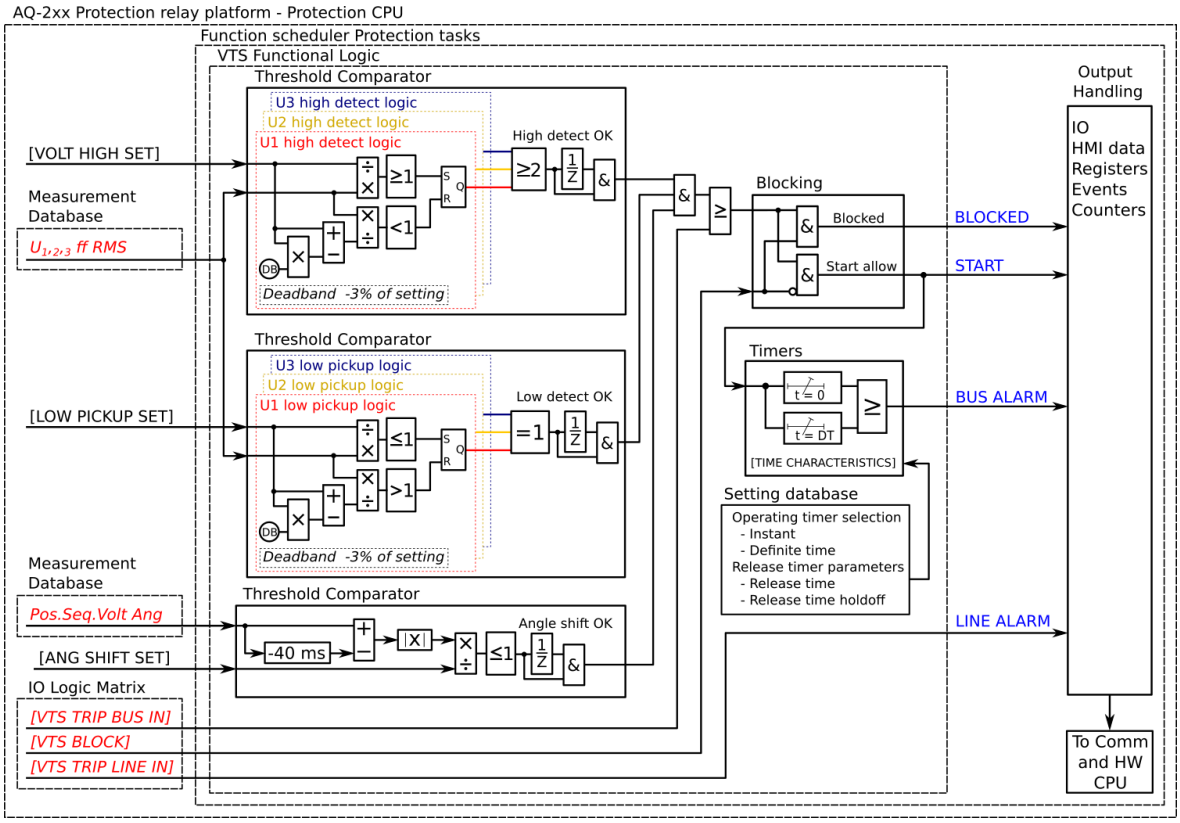
The function's outputs are START, ALARM BUS, ALARM LINE and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, ALARM BUS, ALARM LINE and BLOCKED events.

Figure. 5.6.2 - 194. Secondary circuit fault in phase L1 wiring.




The following figure presents a simplified function block diagram of the voltage transformer supervision function.

Figure. 5.6.2 - 195. Simplified function block diagram of the VTS function.




## Measured input

The function block uses analog voltage measurement values. Function uses the RMS value of the voltage measurement inputs and the calculated (positive, negative and zero) sequence currents.


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Table. 5.6.2 - 300. Measurement inputs of the voltage transformer supervision function.

| Signal | Description | Time base |
|---|---|---|
| $U_{L12}$RMS | RMS measurement of voltage $U_{L12}$/V | 5ms |
| $U_{L23}$RMS | RMS measurement of voltage $U_{L23}$/V | 5ms |
| $U_{L31}$RMS | RMS measurement of voltage $U_{L31}$/V | 5ms |
| $U_{L1}$RMS | RMS measurement of voltage $U_{L1}$/V | 5ms |
| $U_{L2}$RMS | RMS measurement of voltage $U_{L2}$/V | 5ms |
| $U_{L3}$RMS | RMS measurement of voltage $U_{L3}$/V | 5ms |
| U1P | Positive sequence voltage | 5ms |
| U2N | Negative sequence voltage | 5ms |
| UZ0 | Zero sequence voltage | 5ms |
| $U_{L12}$Ang | Angle of $U_{L12}$ voltage | 5ms |
| $U_{L23}$Ang | Angle of $U_{L23}$ voltage | 5ms |
| $U_{L31}$Ang | Angle of $U_{L31}$ voltage | 5ms |
| $U_{L1}$Ang | Angle of $U_{L1}$ voltage | 5ms |
| $U_{L2}$Ang | Angle of $U_{L2}$ voltage | 5ms |
| $U_{L3}$Ang | Angle of $U_{L3}$ voltage | 5ms |

The selection of the AI channel in use is made with a setting parameter. In all possible input channel variations the pre-fault condition is presented with a 20 ms averaged history value from -20 ms from START or TRIP event.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.6.2 - 301. General settings of the function.

| Name | Range | Default | Description |
|---|---|---|---|
| VTS LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of VTS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| VTS force status to | 0: Normal<br>1: Start<br>2: VTLinefail<br>3: VTBusfail<br>4: Blocked | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Pick-up

The *Voltage low pick-up* and *Voltage high detect* setting parameters control the voltage-dependent pick-up and activation of the voltage transformer supervision function. The function's pick-up activates, if at least one of the three voltages is under the set *Voltage low pick-up* value, or if at least two of the three voltages exceed the set *Voltage high detect* value. The function constantly calculates the ratio between the setting values and the measured magnitude for each of the three phases.

Table. 5.6.2 - 302. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Voltage low pickup | 0.05…0.50×$U_n$ | 0.01×$U_n$ | 0.05×$U_n$ | If one the measured voltages is below low pickup value and two of the measured voltages exceed high detect value the function's pick-up activates. |
| Voltage high detect | 0.01…1.10×$U_n$ | 0.01×$U_n$ | 0.80×$U_n$ | |
| Angle shift limit | 2.00…90.00deg | 0.10deg | 5.00deg | If the difference between the present angle and the angle 40 ms before is below the set value, the function's pick-up is blocked. |
| Bus fuse fail check | 0: No<br>1: Yes | - | 1: Yes | Selects whether or not the state of the bus fuse is supervised. The supervised signal is determined the "VTS MCB Trip bus" setting (*I/O → Fuse failure inputs*). |
| Line fuse fail check | 0: No<br>1: Yes | - | 1: Yes | Selects whether or not the state of the line fuse is supervised. The supervised signal is determined by the "VTS MCB Trip line" setting (*I/O → Fuse failure inputs*). |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active. When the activation of the pick-up is based on binary signals, the activation happens immediately after the monitored signal is activated.

The voltage transformer supervision can also report several different states of the measured voltage. These can be seen in the function's *INFO* menu.

| Name | Description |
|---|---|
| Bus dead | No voltages. |
| Bus Live VTS Ok | All of the voltages are within the set limits. |
| Bus Live VTS Ok SEQ Rev | All of the voltages are within the set limits BUT the voltages are in a reversed sequence. |
| Bus Live VTS Ok SEQ Undef | Voltages are within the set limits BUT the sequence cannot be defined. |
| Bus Live VTS problem | Any of the VTS pick-up conditions are met. |

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.



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Table. 5.6.2 - 303. Information displayed by the function.

| Name | Range | Step | Description |
|---|---|---|---|
| VTS<br>LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | Displays the mode of VTS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| VTS<br>condition | 0: Normal<br>1: Start<br>2: VTLinefail<br>3: VTBusfail<br>4: Blocked | - | Displays status of the monitoring function. |
| Bus voltages | 0: Bus dead<br>1: Bus Live VTS Ok SEQ Ok<br>2: Bus Live VTS Ok SEQ Rev<br>3: Bus Live VTS Ok SEQ Undef<br>4: Bus Live VTS problem | - | Displays the status of bus voltages. |
| Expected operating time | 0.000...1800.000s | 0.005s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | -1800.000...1800.000s | 0.005s | When the function has detected a fault and counts down time towards a operation, this displays how much time is left before operation occurs. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for activation

This function supports definite time delay (DT). For detailed information on this delay type please refer to the chapter "General properties of a protection function" and its section "Operating time characteristics for trip and reset".

## Events and registers

The voltage transformer supervision function (abbreviated "VTS" in event block names) generates events and registers from the status changes in ALARM ACTIVATED and BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.6.2 - 304. Event messages.

| Event block name | Event names |
|---|---|
| VTS1 | Bus VT fail Start ON |
| VTS1 | Bus VT fail Start OFF |
| VTS1 | Bus VT fail Trip ON |
| VTS1 | Bus VT fail Trip OFF |
| VTS1 | Bus VT fail Block ON |
| VTS1 | Bus VT fail Block OFF |
| VTS1 | Line VT fail ON |
| VTS1 | Line VT fail OFF |
| VTS1 | Bus Fuse fail ON |
| VTS1 | Bus Fuse fail OFF |
| VTS1 | Line Fuse fail ON |
| VTS1 | Line Fuse fail OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for ACTIVATED, BLOCKED, etc. The table below presents the structure of the function's register content.

Table. 5.6.2 - 305. Register content.

| Date and time | Event | Volt 1, 2, 3, 4 status | System status | Input A, B, C, D angle diff | Trip time remaining | Used SG |
|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | 0: No voltage<br>1: Voltage OK<br>2: Low voltage | 0: Bus dead<br>1: Bus live, VTS OK, Seq. OK<br>2: Bus live, VTS OK, Seq. reversed<br>3: Bus live, VTS OK, Seq. undefined<br>4: Bus live, VTS fault | 0.00...360.00deg | Time remaining to alarm<br><br>0...1800s | Setting group 1...8 active |

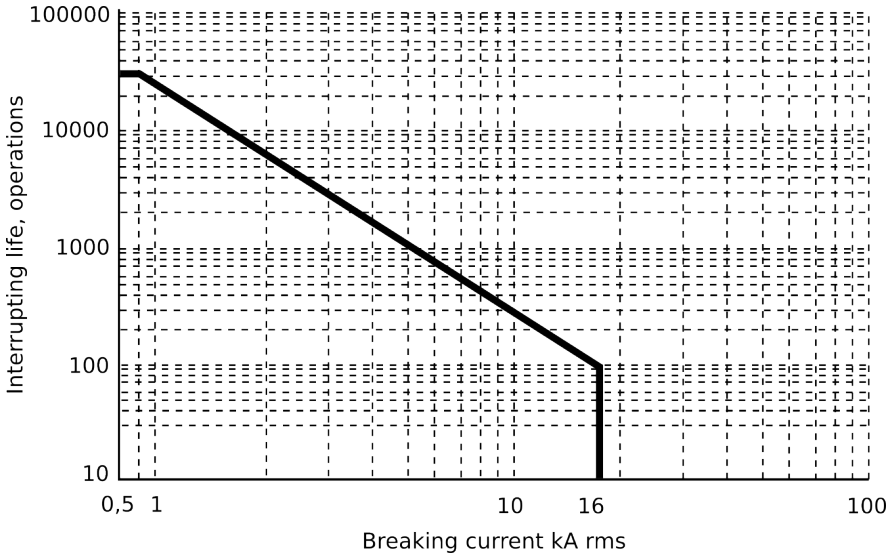
## 5.6.3 Circuit breaker wear monitoring

The circuit breaker wear function is used for monitoring the circuit breaker's lifetime and its maintenance needs caused by interrupting currents and mechanical wear. The function uses the circuit breaker's manufacturer-supplied data for the breaker operating cycles in relation to the interrupted current magnitudes.



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Figure. 5.6.3 - 196. Example of the circuit breaker interrupting life operations.




The function is triggered from the circuit breaker's "Open" command output and it monitors the three-phase current values in both the tripping moment and the normal breaker opening moment. The maximum value of interrupting life operations for each phase is calculated from these currents. The value is cumulatively deducted from the starting operations starting value. The user can set up two separate alarm levels, which are activated when the value of interrupting life operations is below the setting limit. The "Trip contact" setting defines the output that triggers the current monitoring at the breaker's "Open" command.

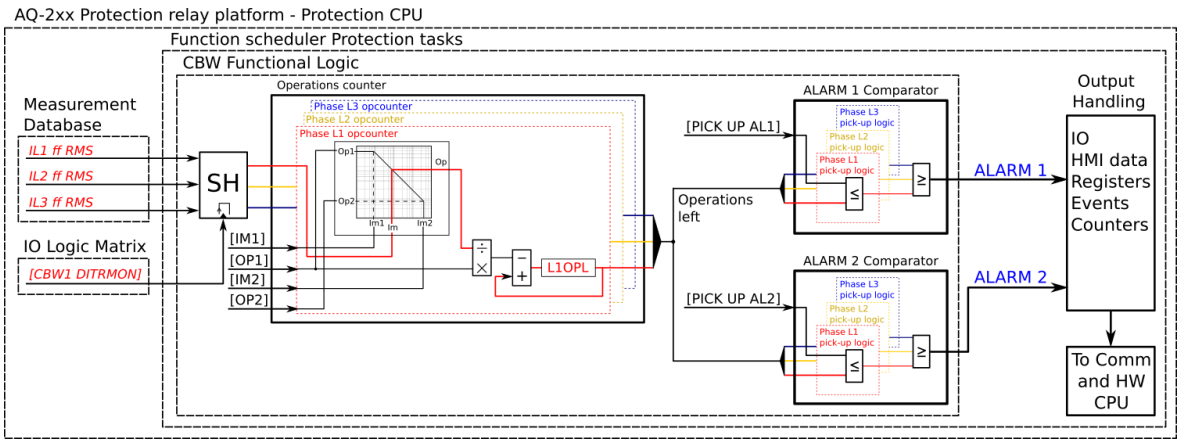
The inputs for the function are the following:

- setting parameters
- binary output signals
- measured and pre-processed current magnitudes.

The function's outputs are ALARM 1 and ALARM 2 signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the "Open" operations as well as the ALARM 1 and ALARM 2 events. The function can also monitor the operations left for each phase.

The following figure presents a simplified function block diagram of the circuit breaker wear function.

Figure. 5.6.3 - 197. Simplified function block diagram of the circuit breaker wear function.



## Measured input

The function block uses analog current measurement values and always uses the RMS magnitude of the current measurement input.

Table. 5.6.3 - 306. Measurement inputs of the circuit breaker wear function.

| Signal | Description | Time base |
|---|---|---|
| IL1RMS | RMS measurement of phase L1 (A) current | 5ms |
| IL2RMS | RMS measurement of phase L2 (B) current | 5ms |
| IL3RMS | RMS measurement of phase L3 (C) current | 5ms |

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by switching the setting group.

Table. 5.6.3 - 307. General settings.

| Name | Range | Default | Description |
|---|---|---|---|
| CBW LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of CBW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CBW force status to | 0: Normal<br>1: Alarm1 On<br>2: Alarm2 On | 0: Normal | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |

## Circuit breaker characteristics settings

The circuit breaker characteristics are set by two operating points, defined by the nominal breaking current, the maximum allowed breaking current and their respective operation settings. This data is provided by the circuit breaker's manufacturer.

Table. 5.6.3 - 308. Settings for circuit breaker characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Operations 1 | 0…200 000 | 1 | 50 000 | The number of interrupting life operations at the nominal current (Close - Open). |
| Operations 2 | 0…200 000 | 1 | 100 | The number of interrupting life operations at the rated breaking current (Open). |
| Current 1 ($I_{nom}$) | 0…100.00kA | 0.01kA | 1kA | The rated normal current (RMS). |
| Current 2 ($I_{max}$) | 0…100.00kA | 0.01kA | 20kA | The rated short-circuit breaking current (RMS). |

## Pick-up for alarming

For the alarm stages Alarm 1 and Alarm 2, the user can set the pick-up level for the number of operations left. The pick-up setting is common for all phases and the alarm stage picks up if any of the phases goes below this setting.


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Table. 5.6.3 - 309. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Alarm 1 | 0: Disabled 1: Enabled | - | 0: Disabled | Enable and disable the Alarm 1 stage. |
| Alarm 1 Set | 0…200 000 | 1 | 1 000 | Defines the pick-up threshold for remaining operations. When the number of remaining operations is below this setting, the ALARM 1 signal is activated. |
| Alarm 2 | 0: Disabled 1: Enabled | - | 0: Disabled | Enable and disable the Alarm 2 stage. |
| Alarm 2 Set | 0…200 000 | 1 | 100 | Defines the pick-up threshold for remaining operations. When the number of remaining operations is below this setting, the ALARM 2 signal is activated. |

## Setting example

Let us examine the settings, using a low-duty vacuum circuit breaker as an example. The image below presents the technical specifications provided by the manufacturer, with the data relevant to our settings highlighted in red:

| | |
|---|---|
| Rated voltage, kV | 24 |
| Rated current, A | 800 |
| Rated power frequency test voltage, kV | 50 |
| Rated frequency, Hz | 50/60 |
| Rated impulse test voltage, kV peak | 125 |
| Partial discharge level at 1,1 rated voltage kV, pC | <10 |
| Rated short-circuit breaking current, kA | 16 |
| Rated short-circuit making current, kA peak | 41.5 |
| Short time withstand current, 4s, kA | 16 |
| Mechanical life, CO cycles, not less than | 30,000 |
| Interrupting life operations, not less than | |
| at rated current | 30,000 |
| at breaking current | 100 |
| at other currents | see Fig.41 |
| Closing time, ms, not more than | 35 |
| Opening time, ms, not more than | 15 |
| Breaking time, ms, not more than | 25 |
| Main contact resistance, µOhm, not more than | 40 |
| Maximum ambient temperature, C° | +55 |
| Minimum ambient temperature, C° | -40 |
| Design class (according to IEC 60932) | 1 |
| Electrical endurance class at rated IEEE/IEC duty | E2 |
| Mechanical endurance class at rated IEEE/IEC duty | M2 |
| Capacitive current switching class | C2 |
| "Mechanical vibration and shock withstand capability, IEC 60721, IEC 60068" | Class 4M4 |
| Maximum altitude above sea level, m | 3000* |
| Maximum humidity, non condensing | 98 % |
| Weight, kg - LD_1 | 35 |
| Weight, kg - LD_6 | 55 |

Now, we set the stage as follows:

| Parameter | Setting |
|---|---|
| Current 1 | 0.80 kA |
| Operation 1 | 30 000 operations |
| Current 2 | 16.00 kA |
| Operations 2 | 100 operations |
| Enable Alarm 1 | 1: Enabled |
| Alarm 1 Set | 1000 operations |
| Enable Alarm 2 | 1: Enabled |
| Alarm 2 Set | 100 operations |

With these settings, Alarm 1 is issued when the cumulative interruption counter for any of the three phases dips below the set 1000 remaining operations ("Alarm 1 Set"). Similarly, when any of the counters dips below 100 remaining operations, Alarm 2 is issued.



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## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.6.3 - 310. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| CBW LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of CBW block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| CBW condition | 0: Normal<br>1: Alarm1 On<br>2: Alarm2 On | Displays the status of the function. |
| Breaker operations | - | Cumulative counter of "open" operations. |
| Alarm 1 counter | - | Alarm 1 operation counter. |
| Alarm 2 counter | - | Alarm 2 operation counter. |
| L1 Operations left | - | Operations left for phase L1. |
| L2 Operations left | - | Operations left for phase L2. |
| L3 Operations left | - | Operations left for phase L3. |

## Events and registers

The circuit breaker wear function (abbreviated "CBW" in event block names) generates events and registers from the status changes in Triggered, Alarm 1 and Alarm 2 signals as well as in internal pick-up comparators. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.6.3 - 311. Event messages.

| Event block name | Event names |
|---|---|
| CBW1 | CBWEAR1 Triggered |
| CBW1 | CBWEAR1 Alarm 1 ON |
| CBW1 | CBWEAR1 Alarm 1 OFF |
| CBW1 | CBWEAR1 Alarm 2 ON |
| CBW1 | CBWEAR1 Alarm 2 OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data. The table below presents the structure of the function's register content.

Table. 5.6.3 - 312. Register content.

| Date and time | Event | Trigger current | Deducted Op | Operations left |
|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Phase currents on trigger time | L1/L2/L3 Deducted operations from the cumulative sum | L1/L2/L3 Operations left |

## 5.6.4 Current total harmonic distortion (THD)

The total harmonic distortion (THD) function is used for monitoring the content of the current harmonic. The THD is a measurement of the harmonic distortion present, and it is defined as the ratio between the sum of all harmonic components' powers and the power of the fundamental frequency (RMS).

Harmonics can be caused by different sources in electric networks such as electric machine drives, thyristor controls, etc. The function's monitoring of the currents can be used to alarm of the harmonic content rising too high; this can occur when there is an electric quality requirement in the protected unit, or when the harmonics generated by the process need to be monitored.

The function constantly measures the phase and residual current magnitudes as well as the harmonic content of the monitored signals up to the 31$^{st}$ harmonic component. When the function is activated, the measurements are also available for the mimic and the measurement views in the HMI carousel. The user can also set the alarming limits for each measured channel if the application so requires.

The monitoring of the measured signals can be selected to be based either on an amplitude ratio or on the above-mentioned power ratio. The difference is in the calculation formula (as shown below):

Figure. 5.6.4 - 198. THD calculation formulas.

$$THD_P = \frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \dots {I_{x31}}^2}{{I_{x1}}^2}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \dots {I_{x31}}^2}{{I_{x1}}^2}}$$

, where
I = measured current,
x= measurement input,
n = harmonic number

While both of these formulas exist, the power ratio (*THD$_P$*) is recognized by the IEEE, and the amplitude ratio (*THD$_A$*) is recognized by the IEC.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running. This only applies if the alarming is activated.

The outputs of the function are the START and ALARM signals for the phase current ("THDPH") and the residual currents ("THDI01" and "THDI02") as well as BLOCKED signals. The function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal chec
- time delay characteristics
- output processing.

The inputs of the function are the following:

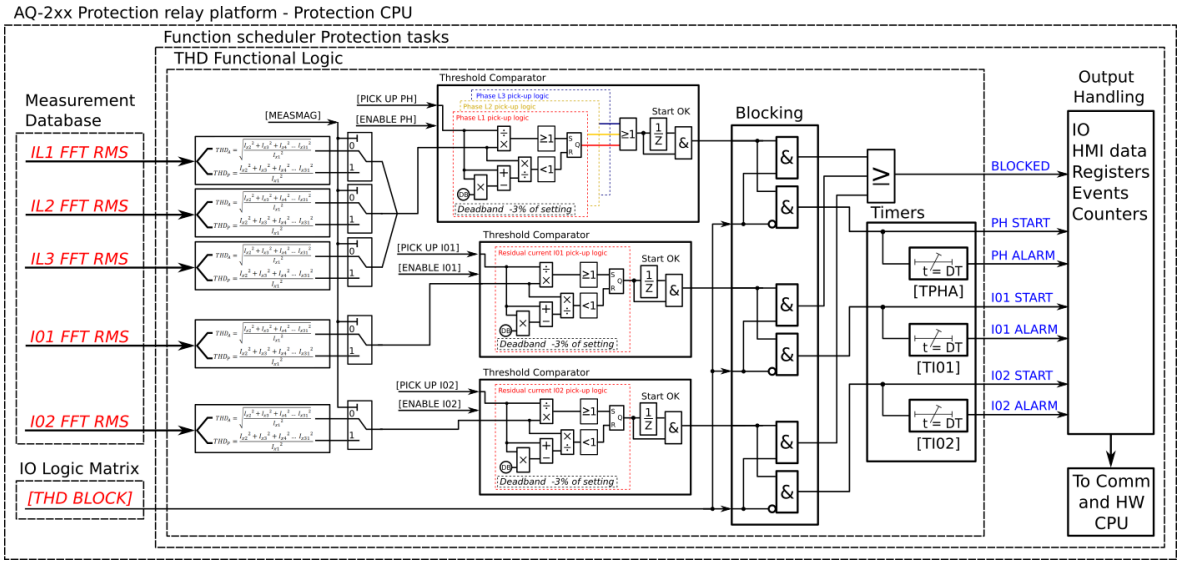

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- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes

The function's outputs are START, ALARM and BLOCKED signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, ALARM and BLOCKED events.

The following figure presents a simplified function block diagram of the total harmonic distortion monitor function.

Figure. 5.6.4 - 199. Simplified function block diagram of the total harmonic distortion monitor function.




## Measured input

The function block uses analog current measurement values. The function always uses FFT measurement of the whole harmonic specter of 32 components from each measured current channel. From these measurements the function calculates either the amplitude ratio or the power ratio. A -20 ms averaged value of the selected magnitude is used for pre-fault data registering.

Table. 5.6.4 - 313. Measurement inputs of the total harmonic distortion monitor function.

| Signal | Description | Time base |
|---|---|---|
| IL1FFT | FFT measurement of phase L1 (A) current | 5ms |
| IL2FFT | FFT measurement of phase L2 (B) current | 5ms |
| IL3FFT | FFT measurement of phase L3 (C) current | 5ms |
| I01FFT | FFT measurement of residual I01 current | 5ms |
| I02FFT | FFT measurement of residual I02 current | 5ms |

The selection of the calculation method is made with a setting parameter (common for all measurement channels).

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.6.4 - 314. General settings.

| Name | Range | Default | Description |
|---|---|---|---|
| THD> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of THD block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Measurement magnitude | 1: Amplitude<br>2: Power | 1: Amplitude | Defines which available measured magnitude the function uses. |

## Pick-up

The $Phase_{THD}$, $I01_{THD}$and $I02_{THD}$ setting parameters control the the pick-up and activation of the function. They define the maximum allowed measured current THD before action from the function. Before the function activates alarm signals, their corresponding pick-up elements need to be activated with the setting parameters *Enable phase THD alarm*, *Enable I01 THD alarm* and *Enable I02 THD alarm*. The function constantly calculates the ratio between the setting values and the calculated THD for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the calculated THD exceeds the pick-up value (in single, dual or all phases), it triggers the pick-up operation of the function.

Table. 5.6.4 - 315. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable phase THD alarm | 0: Enabled<br>1: Disabled | - | 0: Enabled | Enables and disables the THD alarm function from phase currents. |
| Enable I01 THD alarm | 0: Enabled<br>1: Disabled | - | 0: Enabled | Enables and disables the THD alarm function from residual current input I01. |
| Enable I02 THD alarm | 0: Enabled<br>1: Disabled | - | 0: Enabled | Enables and disables the THD alarm function from residual current input I02. |
| Phase THD pick-up | 0.10…100.00% | 0.01% | 10.00% | The pick-up setting for the THD alarm element from the phase currents. At least one of the phases' measured THD value has to exceed this setting in order for the alarm signal to activate. |
| I01 THD pick-up | 0.10…100.00% | 0.01% | 10.00% | The pick-up setting for the THD alarm element from the residual current I01. The measured THD value has to exceed this setting in order for the alarm signal to activate. |
| I02 THD pick-up | 0.10…100.00% | 0.01% | 10.00% | The pick-up setting for the THD alarm element from the residual current I02. The measured THD value has to exceed this setting in order for the alarm signal to activate. |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.



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Table. 5.6.4 - 316. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| THD> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of THD block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| THD condition | 0: Normal<br>1: Start<br>2: Alarm<br>3: Blocked | Displays status of the monitoring function. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for activation and reset

This function supports definite time delay (DT). The following table presents the setting parameters for the function's time characteristics.

Table. 5.6.4 - 317. Settings for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Phase THD alarm delay | 0.000…1800.000s | 0.005s | 10.000s | Defines the delay for the alarm timer from the phase currents' measured THD. |
| I01 THD alarm delay | 0.000…1800.000s | 0.005s | 10.000s | Defines the delay for the alarm timer from the residual current I01's measured THD. |
| I02 THD alarm delay | 0.000…1800.000s | 0.005s | 10.000s | Defines the delay for the alarm timer from the residual current I02's measured THD. |

## Events and registers

The total harmonic distortion monitor function (abbreviated "THD" in event block names) generates events and registers from the status changes in the alarm function when it is activated. The recorded signals are START and ALARM signals for the monitoring elements as well as common BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

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Table. 5.6.4 - 318. Event messages.

| Event block name | Event names |
|---|---|
| THD1 | THD Start Phase ON |
| THD1 | THD Start Phase OFF |
| THD1 | THD Start I01 ON |
| THD1 | THD Start I01 OFF |
| THD1 | THD Start I02 ON |
| THD1 | THD Start I02 OFF |
| THD1 | THD Alarm Phase ON |
| THD1 | THD Alarm Phase OFF |
| THD1 | THD Alarm I01 ON |
| THD1 | THD Alarm I01 OFF |
| THD1 | THD Alarm I02 ON |
| THD1 | THD Alarm I02 OFF |
| THD1 | Blocked ON |
| THD1 | Blocked OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, ALARM and BLOCKED. The table below presents the structure of the function's register content.

Table. 5.6.4 - 319. Register content.

| Date and time | Event | L1h, L2h, L3h Fault THD | Used SG |
|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Alarm THD of each phase. | Setting group 1...8 active. |

## 5.6.5 Voltage total harmonic distortion (THD)

The voltage total harmonic distortion (THD) function is used for monitoring the content of the voltage harmonic. The THD is a measurement of the harmonic distortion present, and it is defined as the ratio between the sum of all harmonic components' powers and the power of the fundamental frequency (RMS).

Harmonics can be caused by different sources in electric networks such as electric machine drives, thyristor controls, etc. The function's monitoring of the voltage can be used to alarm of the harmonic content rising too high; this can occur when there is an electric quality requirement in the protected unit, or when the harmonics generated by the process need to be monitored.

The function constantly measures the phase voltage magnitudes as well as the harmonic content of the monitored signals up to the 31$^{st}$ harmonic component. The user can set the alarming limits if the application so requires.

The monitoring of the measured signals can be selected to be based either on an amplitude ratio or on the above-mentioned power ratio. The difference is in the calculation formula (as shown below):



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Figure. 5.6.5 - 200. THD calculation formulas.

$$THD_P = \frac{{U_{x2}}^2 + {U_{x3}}^2 + {U_{x4}}^2 \dots {U_{x31}}^2}{{U_{x1}}^2}$$

, where
U = measured voltage,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{U_{x2}}^2 + {U_{x3}}^2 + {U_{x4}}^2 \dots {U_{x31}}^2}{{U_{x1}}^2}}$$

, where
U = measured voltage,
x= measurement input,
n = harmonic number

While both of these formulas exist, the power ratio (*THDP*) is recognized by the IEEE, and the amplitude ratio (*THDA*) is recognized by the IEC.

The blocking signal and the setting group selection control the operating characteristics of the function during normal operation, i.e. the user or user-defined logic can change function parameters while the function is running. This only applies if the alarming is activated.

The outputs of the function are the START and ALARM ACT signals for the phase voltages ("THDV") as well as BLOCKED signals. The function uses a total of eight (8) separate setting groups which can be selected from one common source.

The operational logic consists of the following:

- input magnitude processing
- threshold comparator
- block signal chec
- time delay characteristics
- output processing.

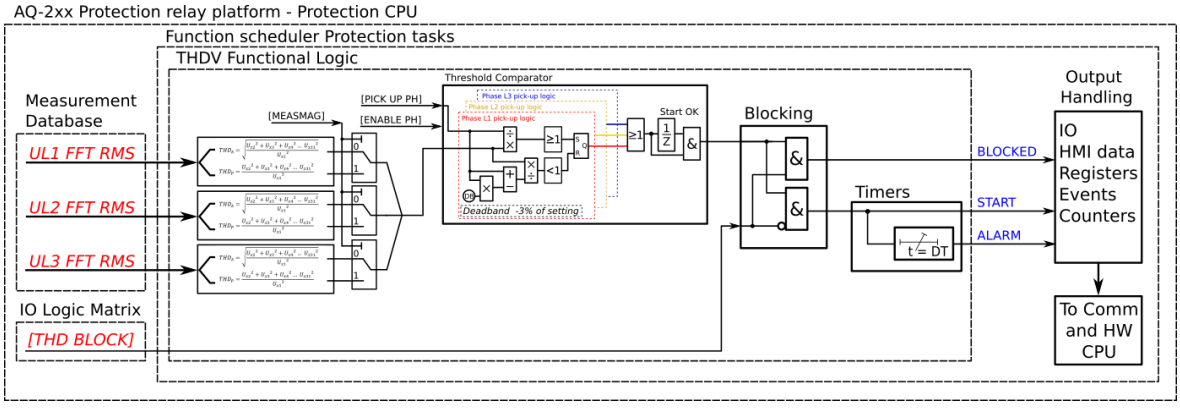
The inputs of the function are the following:

- setting parameters
- digital inputs and logic signals
- measured and pre-processed voltage magnitudes

The function's outputs are START, ALARM and BLOCKED signals can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, ALARM and BLOCKED events.

The following figure presents a simplified function block diagram of the total harmonic distortion monitor function.

Figure. 5.6.5 - 201. Simplified function block diagram of the total harmonic distortion monitor function.



## Measured input

The function block uses analog voltage measurement values. The function always uses FFT measurement of the whole harmonic specter of 32 components from each measured voltage channel. From these measurements the function calculates either the amplitude ratio or the power ratio.

Table. 5.6.5 - 320. Measurement inputs of the total harmonic distortion monitor function.

| Signal | Description | Time base |
|---|---|---|
| UL1FFT | FFT measurement of phase L1 (A) voltage | 5ms |
| UL2FFT | FFT measurement of phase L2 (B) voltage | 5ms |
| UL3FFT | FFT measurement of phase L3 (C) voltage | 5ms |

The selection of the calculation method is made with a setting parameter (common for all measurement channels).

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.6.5 - 321. General settings.

| Name | Range | Default | Description |
|---|---|---|---|
| THDV> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of THDV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Measurement magnitude | 1: Amplitude<br>2: Power | 1: Amplitude | Defines which available measured magnitude the function uses. |

## Pick-up

The THDV pick-up setting parameter controls the the pick-up and activation of the function. They define the maximum allowed measured voltage THD before action from the function. Before the function activates alarm signals, their corresponding pick-up elements need to be activated with the setting parameter *Enable THD alarm*. The function constantly calculates the ratio between the setting values and the calculated voltage THD. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the calculated THD exceeds the pick-up value (in single, dual or all phases), it triggers the pick-up operation of the function.

Table. 5.6.5 - 322. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable THDV alarm | 0: Enabled<br>1: Disabled | - | 0: Enabled | Enables and disables the THD alarm function. |
| THDV pick-up | 0.10…100.00% | 0.01% | 10.00% | The pick-up setting for the THD alarm element from the phase voltages. At least one of the phases' measured THD value has to exceed this setting in order for the alarm signal to activate. |



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The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.6.5 - 323. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| THDV> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Displays the mode of THDV block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| THDV condition | 0: Normal<br>1: Start<br>2: Alarm<br>3: Blocked | Displays status of the monitoring function. |

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Operating time characteristics for activation and reset

This function supports definite time delay (DT). The following table presents the setting parameters for the function's time characteristics.

Table. 5.6.5 - 324. Settings for operating time characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| THDV alarm delay | 0.000…1800.000s | 0.005s | 10.000s | Defines the delay for the alarm timer from the phase voltages' measured THD. |

### Events and registers

The voltage total harmonic distortion monitor function (abbreviated "THDV" in event block names) generates events and registers from the status changes in the alarm function when it is activated. The recorded signals are START and ALARM signals for the monitoring elements as well as common BLOCKED signals. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.6.5 - 325. Event messages.

| Event block name | Event names |
|---|---|
| THDV1 | Voltage THD Start ON |
| THDV1 | Voltage THD Start OFF |
| THDV1 | Voltage THD Alarm ON |
| THDV1 | Voltage THD Alarm OFF |
| THDV1 | Voltage Blocked ON |
| THDV1 | Voltage Blocked OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, ALARM and BLOCKED. The table below presents the structure of the function's register content.

Table. 5.6.5 - 326. Register content.

| Date and time | Event | UL1, UL2, UL3 THDV | Used SG |
|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | Start/Alarm Voltage THD of each phase. | Setting group 1...8 active. |

## 5.6.6 Fault locator (21FL)

The fault locator function is used for recording an estimated distance to the point where a fault has occurred. It is mostly used in directional overcurrent protection or distance protection applications but can be also triggered by other protections. The function can be used if all three phase currents and three phase voltages have been connected to the relay. The triggering signals, the triggering current and "Reactance per km" must be set in the configuration.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes.

The function generates general time-stamped ON/OFF events to the common event buffer from each of the output signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the fault locator triggering events.

### Measured input

Function block uses analog current and voltage measurements and calculated phase-to-phase or phase-to-ground loop impedances.


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Table. 5.6.6 - 327. Measurement inputs of the 21FL function.

| Signals | Description | Time base |
|---|---|---|
| VT1 U1, U2, U3 | The line-to-neutral or line-to-line voltages of the first voltage transformer module. | 5ms |
| CT1 IL1, IL2, IL3 | The measurements of the phase currents L1 (A), L2 (B) and L3 (C). | 5ms |

## Fault locator triggering

The "Trig fault locator" input defines which signal triggers the fault locator. This can be any binary signal generated by the unit. Typically, a TRIP signal of a protection function or the "Open" status of the breaker is used as the triggering input.

Several conditions have to be met before the fault locator can trigger and record the distance to a fault. First, when receiving a triggering signal, the function checks if the calculation is blocked. The calculation blocking signals are determined by the "Block calculation" matrix set by the user. Next, the function checks if any phase-to-earth voltages are available. If there are no available voltages, the function can only record phase-to-phase impedance loops. If there are available voltages, the function can also record phase-to-neutral impedance loops. Depending on the measured phase currents at the moment the triggering signal was received, the recorded impedance loop is selected from the available options. See the table "Required current conditions" for more information on which conditions have to be met to trigger impedance recording.

Table. 5.6.6 - 328. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Trigger current> | 0.0…40.0×$I_n$ | 0.1×$I_n$ | 1×$I_n$ | Sets the trigger current. Affects which impedance loop is recorded, if anything is recorded at all (see the table below). |
| Reactance per km | 0.000…5.000Ω/km | 0.001Ω/km | 0.125Ω/km | This setting helps calculate the distance to a fault. |

Table. 5.6.6 - 329. Required current conditions.

| Currents over limit | P-E voltages available | P-E voltages not available |
|---|---|---|
| | Recorded impedance | |
| IL1, IL2, IL3 | XL12 | XL12 |
| IL1, IL2 | XL12 | XL12 |
| IL2, IL3 | XL23 | XL23 |
| IL1, IL3 | XL31 | XL31 |
| IL1 | XL1 | No trigger |
| IL2 | XL2 | No trigger |
| IL3 | XL3 | No trigger |

If no current measurement requirements are fulfilled when the function receives a triggering signal, the function will not record impedance at all.

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup voltage values and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

### Events

The fault locator function (abbreviated "FLX" in event block names) generates events and registers from the status changes in triggering and calculation. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.6.6 - 330. Event messages.

| Event block name | Event names |
|---|---|
| FLX1 | Flocator triggered ON |
| FLX1 | Flocator triggered OFF |
| FLX1 | Flocator Calculation ON |
| FLX1 | Flocator Calculation OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The table below presents the structure of the function's register content.

Table. 5.6.6 - 331. Register content.

| Date and time | Event | Fault type | Fault direction | Fault reactance | Fault current | Fault current | Fault distance | Setting group in use |
|---|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | L1-L2; L2-L3; L3-L1; L1-N; L2-N; L3-N; L1-L2-L3 | Not detected; Forward; Reverse | In ohms (Ω) | In per-unit value | In primary value | In kilometers (km) | Setting group 1...8 active |

## 5.6.7 Disturbance recorder (DR)

The disturbance recorder is a high-capacity (64 MB permanent flash memory) and fully digital recorder integrated to the protection relay. The maximum sample rate of the recorder's analog channels is 64 samples per cycle. The recorder also supports 95 digital channels simultaneously with the twenty (20) measured analog channels. Maximum capacity of recordings is 100.

The recorder provides a great tool to analyze the performance of the power system during network disturbance situations. The recorder's output is in general COMTRADE format and it is compatible with most viewers and injection devices. The files are based on the IEEE standard C37.111-1999. Captured recordings can be injected as playback with secondary testing tools that support the COMTRADE file format. Playback of files might help to analyze the fault, or can be simply used for educational purposes.

### Analog and digital recording channels

Up to 20 analog recording channels and 95 digital channels are supported. The available analog channels vary according to the device type.



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Table. 5.6.7 - 332. Analog recording channels.

| Signal | Description |
|---|---|
| IL1 | Phase current $I_{L1}$ |
| IL2 | Phase current $I_{L2}$ |
| IL3 | Phase current $I_{L3}$ |
| I01c | Residual current $I_{01}$ coarse* |
| I01f | Residual current $I_{01}$ fine* |
| I02c | Residual current $I_{02}$ coarse* |
| I02f | Residual current $I_{02}$ fine* |
| IL1” | Phase current $I_{L1}$ (CT card 2) |
| IL2” | Phase current $I_{L2}$ (CT card 2) |
| IL3” | Phase current $I_{L3}$ (CT card 2) |
| I01”c | Residual current $I_{01}$ coarse* (CT card 2) |
| I01”f | Residual current $I_{01}$ fine* (CT card 2) |
| I02”c | Residual current $I_{02}$ coarse* (CT card 2) |
| I02”f | Residual current $I_{02}$ fine* (CT card 2) |
| U1(2)VT1 | Line-to-neutral $U_{L1}$ or line-to-line voltage $U_{12}$ (VT card 1) |
| U2(3)VT1 | Line-to-neutral $U_{L2}$ or line-to-line voltage $U_{23}$ (VT card 1) |
| U3(1)VT1 | Line-to-neutral $U_{L3}$ or line-to-line voltage $U_{31}$ (VT card 1) |
| U0(ss)VT1 | Zero sequence voltage $U_0$ or synchrocheck voltage $U_{SS}$ (VT card 1) |
| F tracked 1 | Tracked frequency of reference 1 |
| F tracked 2 | Tracked frequency of reference 2 |
| F tracked 3 | Tracked frequency of reference 3 |
| ISup | Current measurement module voltage supply supervision (CT card 1) |
| ISup" | Current measurement module voltage supply supervision (CT card 2) |
| USup | Voltage measurement module voltage supply supervision (VT card 2) |
| IL1'" | Phase current $I_{L1}$ (CT card 3) |
| IL2'" | Phase current $I_{L2}$ (CT card 3) |
| IL3'" | Phase current $I_{L3}$ (CT card 3) |
| I01'"c | Residual current $I_{01}$ coarse* (CT card 3) |
| I01'"f | Residual current $I_{01}$ fine* (CT card 3) |
| I02'"c | Residual current $I_{02}$ coarse* (CT card 3) |
| I02'"f | Residual current $I_{02}$ fine* (CT card 3) |
| ISup_3 | Current measurement module voltage supply supervision (CT card 3) |
| UL1(2)VT2 | Line-to-neutral $U_{L1}$ or line-to-line voltage $U_{12}$ (VT card 2) |
| UL2(3)VT2 | Line-to-neutral $U_{L2}$ or line-to-line voltage $U_{23}$ (VT card 2) |
| UL3(1)VT2 | Line-to-neutral $U_{L3}$ or line-to-line voltage $U_{31}$ (VT card 2) |
| U0(SS)VT2 | Zero sequence voltage $U_0$ or synchrocheck voltage $U_{SS}$ (VT card 2) |

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| Signal | Description |
|---|---|
| USup_2 | Voltage measurement module voltage supply supervision (VT card 2) |

*NOTE: There are two signals for each residual current channel in the disturbance recorder: coarse and fine. A coarse signal is capable of sampling in the full range of the current channel but suffers a loss of accuracy at very low currents. A fine signal is capable of sampling at very low currents and with high accuracy but cuts off at higher currents. Table below lists performance of both channels with fine and coarse gain.

Table. 5.6.7 - 333. Residual current channel performance with coarse or residual gain.

| Channel | Coarse gain range | Fine gain range | Fine gain peak |
|---|---|---|---|
| I01 | 0...150 A | 0...10 A | 15 A |
| I02 | 0...75 A | 0...5 A | 8 A |

Table. 5.6.7 - 334. Digital recording channels – Measurements.

| Signal | Description | Signal | Description |
|---|---|---|---|
| Currents | | | |
| Pri.Pha.curr.ILx | Primary phase current ILx (IL1, IL2, IL3) | Pha.curr.ILx TRMS Pri | Primary phase current TRMS (IL1, IL2, IL3) |
| Pha.angle ILx | Phase angle ILx (IL1, IL2, IL3) | Pos./Neg./Zero seq.curr. | Positive/Negative/Zero sequence current |
| Pha.curr.ILx | Phase current ILx (IL1, IL2, IL3) | Sec.Pos./Neg./Zero seq.curr. | Secondary positive/negative/zero sequence current |
| Sec.Pha.curr.ILx | Secondary phase current ILx (IL1, IL2, IL3) | Pri.Pos./Neg./Zero seq.curr. | Primary positive/negative/zero sequence current |
| Pri.Res.curr.I0x | Primary residual current I0x (I01, I02) | Pos./Neg./Zero seq.curr.angle | Positive/Negative/Zero sequence current angle |
| Res.curr.angle I0x | Residual current angle I0x (I01, I02) | Res.curr.I0x TRMS | Residual current TRMS I0x (I01, I02) |
| Res.curr.I0x | Residual current I0x (I01, I02) | Res.curr.I0x TRMS Sec | Secondary residual current TRMS I0x (I01, I02) |
| Sec.Res.curr.I0x | Secondary residual current I0x (I01, I02) | Res.curr.I0x TRMS Pri | Primary residual current TRMS I0x (I01, I02) |
| Pri.cal.I0 | Primary calculated I0 | Pha.Lx ampl. THD | Phase Lx amplitude THD (L1, L2, L3) |
| Sec.calc.I0 | Secondary calculated I0 | Pha.Lx pow. THD | Phase Lx power THD (L1, L2, L3) |
| calc.I0 | Calculated I0 | Res.I0x ampl. THD | Residual I0x amplitude THD (I01, I02) |
| calc.I0 Pha.angle | Calculated I0 phase angle | Res.I0x pow. THD | Residual I0x power THD (I01, I02) |
| Pha.curr.ILx TRMS | Phase current TRMS ILx (IL1, IL2, IL3) | P-P curr.ILx | Phase-to-phase current ILx (IL1, IL2, IL3) |
| Pha.curr.ILx TRMS Sec | Secondary phase current TRMS (IL1, IL2, IL3) | P-P curr.I0x | Phase-to-phase current I0x (I01, I02) |
| Voltages | | | |
| Ux Volt p.u. | Ux voltage in per-unit values (U1, U2, U3, U4) | System volt ULxx mag | Magnitude of the system voltage ULxx (UL12, UL23, UL31) |
| Ux Volt pri | Primary Ux voltage (U1, U2, U3, U4) | System volt ULxx mag(kV) | Magnitude of the system voltage ULxx in kilovolts (UL12, UL23, UL31) |
| Ux Volt sec | Secondary Ux voltage (U1, U2, U3, U4) | System volt ULxx ang | Angle of the system voltage ULxx (UL12, UL23, UL31) |


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| Signal | Description | Signal | Description |
|---|---|---|---|
| Ux Volt TRMS p.u. | Ux voltage TRMS in per-unit values (U1, U2, U3, U4) | System volt ULx mag | Magnitude of the system voltage ULx (U1, U2, U3, U4) |
| Ux Volt TRMS pri | Primary Ux voltage TRMS (U1, U2, U3, U4) | System volt ULx mag(kV) | Magnitude of the system voltage ULx in kilovolts (U1, U2, U3, U4) |
| Ux Volt TRMS sec | Secondary Ux voltage TRMS (U1, U2, U3, U4) | System volt ULx ang | Angle of the system voltage ULx (U1, U2, U3, U4) |
| Pos/Neg./Zero seq.Volt.p.u. | Positive/Negative/ Zero sequence voltage in per-unit values | System volt U0 mag | Magnitude of the system voltage U0 |
| Pos./Neg./Zero seq.Volt.pri | Primary positive/negative/ zero sequence voltage | System volt U0 mag(kV) | Magnitude of the system voltage U0 in kilovolts |
| Pos./Neg./Zero seq.Volt.sec | Secondary positive/ negative/zero sequence voltage | System volt U0 mag(%) | Magnitude of the system voltage U0 in percentages |
| Ux Angle | Ux angle (U1, U2, U3, U4) | System volt U0 ang | Angle of the system voltage U0 |
| Pos./Neg./Zero Seq volt.Angle | Positive/Negative/Zero sequence voltage angle | Ux Angle difference | Ux angle difference (U1, U2, U3) |
| Resistive and reactive currents | | | |
| ILx Resistive Current p.u. | ILx resistive current in per-unit values (IL1, IL2, IL3) | Pos.seq. Resistive Current Pri. | Primary positive sequence resistive current |
| ILx Reactive Current p.u. | ILx reactive current in per-unit values (IL1, IL2, IL3) | Pos.seq. Reactive Current Pri. | Primary positive sequence reactive current |
| Pos.Seq. Resistive Current p.u. | Positive sequence resistive current in per-unit values | I0x Residual Resistive Current Pri. | Primary residual resistive current I0x (I01, I02) |
| Pos.Seq. Reactive Current p.u. | Positive sequence reactive current in per-unit values | I0x Residual Reactive Current Pri. | Primary residual reactive current I0x (I01, I02) |
| I0x Residual Resistive Current p.u. | I0x residual resistive current in per-unit values (I01, I02) | ILx Resistive Current Sec. | Secondary resistive current ILx (IL1, IL2, IL3) |
| I0x Residual Reactive Current p.u. | I0x residual ractive current in per-unit values (I01, I02) | ILx Reactive Current Sec. | Secondary reactive current ILx (IL1, IL2, IL3) |
| ILx Resistive Current Pri. | Primary resistive current ILx (IL1, IL2, IL3) | I0x Residual Resistive Current Sec. | Secondary residual resistive current I0x (I01, I02) |
| ILx Reactive Current Pri. | Primary reactive current ILx (IL1, IL2, IL3) | I0x Residual Reactive Current Sec. | Secondary residual reactive current I0x (I01, I02) |
| Power, GYB, frequency | | | |
| Lx PF | Lx power factor (L1, L2, L3) | Curve x Input | Input of Curve x (1, 2, 3, 4) |
| POW1 3PH Apparent power (S) | Three-phase apparent power | Curve x Output | Output of Curve x (1, 2, 3, 4) |
| POW1 3PH Apparent power (S MVA) | Three-phase apparent power in megavolt-amperes | Enablefbasedfunctions(VT1) | Enable frequency-based functions |
| POW1 3PH Active power (P) | Three-phase active power | Track.sys.f. | Tracked system frequency |
| POW1 3PH Active power (P MW) | Three-phase active power in megawatts | Sampl.f. used | Used sample frequency |

| Signal | Description | Signal | Description |
|---|---|---|---|
| POW1 3PH Reactive power (Q) | Three-phase reactive power | Tr f CH x | Tracked frequency (channels A, B, C) |
| POW1 3PH Reactive power (Q MVar) | Three-phase reactive power in megavars | Alg f Fast | Fast frequency algorithm |
| POW1 3PH Tan(phi) | Three-phase tangent phi | Alg f avg | Average frequency algorithm |
| POW1 3PH Cos(phi) | Three-phase cosine phi | Frequency based protections blocked | When true ("1"), all frequency-based protections are blocked. |
| 3PH PF | Three-phase power factor | f atm. Protections (when not measurable returns to nominal) | Frequency at the moment. If the system nominal is set to 50 Hz, this will show "50 Hz". |
| Neutral conductance G (Pri) | Primary neutral conductance | f atm. Display (when not measurable is 0 Hz) | Frequency at the moment. If the frequency is not measurable, this will show "0 Hz". |
| Neutral susceptance B (Pri) | Primary neutral susceptance | f meas qlty | Quality of tracked frequency |
| Neutral admittance Y (Pri) | Primary neutral admittance | f meas from | Indicates which of the three voltage or current channel frequencies is used by the relay. |
| Neutral admittance Y (Ang) | Neutral admittace angle | SS1.meas.frqs | Synchrocheck – the measured frequency from voltage channel 1 |
| I01 Resistive component (Pri) | Primary resistive component I01 | SS2.meas.frqs | Synchrocheck – the measured frequency from voltage channel 2 |
| I01 Capacitive component (Pri) | Primary capacitive component I01 | Enable f based functions | Status of this signal is active when frequency-based protection functions are enabled. |

Table. 5.6.7 - 335. Digital recording channels – Binary signals.

| Signal | Description | Signal | Description |
|---|---|---|---|
| DIx | Digital input 1...11 | Timer x Output | Output of Timer 1...10 |
| Open/close control buttons | Active if buttons I or 0 in the unit's front panel are pressed. | Internal Relay Fault active | If the unit has an internal fault, this signal is active. |
| Status PushButton x On | Status of Push Button 1...12 is ON | (Protection, control and monitoring event signals) | (see the individual function description for the specific outputs) |
| Status PushButton x Off | Status of Push Button 1...12 is OFF | Always True/False | "Always false" is always "0". Always true is always "1". |
| Forced SG in use | Stage forcing in use | OUTx | Output contact statuses |
| SGx Active | Setting group 1...8 active | GOOSE INx | GOOSE input 1...64 |
| Double Ethernet LinkA down | Double ethernet communication card link A connection is down. | GOOSE INx quality | Quality of GOOSE input 1...64 |
| Double Ethernet LinkB down | Double ethernet communication card link B connection is down. | Logical Input x | Logical input 1...32 |



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| Signal | Description | Signal | Description |
|---|---|---|---|
| MBIO ModA Ch x Invalid | Channel 1...8 of MBIO Mod A is invalid | Logical Output x | Logical output 1...64 |
| MBIO ModB Ch x Invalid | Channel 1...8 of MBIO Mod B is invalid | NTP sync alarm | If NTP time synchronization is lost, this signal will be active. |
| MBIO ModB Ch x Invalid | Channel 1...8 of MBIO Mod C is invalid | Ph.Rotating Logic control 0=A-B-C, 1=A-C-B | Phase rotating order at the moment. If true ("1") the phase order is reversed. |

NOTE!

Digital channels are measured every 5 ms.

## Recording settings and triggering

Disturbance recorder can be triggered manually or automatically by using the dedicated triggers. Every signal listed in "Digital recording channels" can be selected to trigger the recorder.

The device has a maximum limit of 100 for the number of recordings. Even when the recordings are very small, their number cannot exceed 100. The number of analog and digital channels together with the sample rate and the time setting affect the recording size. See calculation examples below in the section titled "Estimating the maximum length of total recording time".

Table. 5.6.7 - 336. Recorder control settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Recorder enabled | 0: Enabled<br>1: Disabled | - | 0: Enabled | Enables and disables the disturbance recorder function. |
| Recorder status | 0: Recorder ready<br>1: Recording triggered<br>2: Recording and storing<br>3: Storing recording<br>4: Recorder full<br>5: Wrong config | - | - | Indicates the status of recorder. |
| Clear record+ | 0…$2^{32}$-1 | 1 | - | Clears selected recording. If "1" is inserted, first recording will be cleared from memory. If "10" is inserted, tenth (10th) recording will be cleared from memory. |
| Manual trigger | 0: -<br>1: Trig | - | 0: - | Triggers disturbance recording manually. This parameter will return back to "-" automatically. |
| Clear all records | 0: -<br>1: Clear | - | 0: - | Clears all disturbance recordings. |
| Clear newest record | 0: -<br>1: Clear | - | 0: - | Clears the newest stored disturbance recording. |
| Clear oldest record | 0: -<br>1: Clear | - | 0: - | Clears the oldest stored disturbance recording. |
| Max. number of recordings | 0…100 | 1 | - | Displays the maximum number of recordings that can be stored in the device's memory with settings currently in use. The maximum number of recordings can go up to 100. |
| Max. length of a recording | 0.000...1800.000s | 0.001s | - | Displays the maximum length of a single recording. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Max. location of the pre-trigger | 0.000...1800.000s | 0.001s | - | Displays the highest pre-triggering time that can be set with the settings currently in use. |
| Recordings in memory | 0…100 | 1 | - | Displays how many recordings are stored in the memory. |

Table. 5.6.7 - 337. Recorder trigger setting.

| Name | Description |
|---|---|
| Recorder trigger | Selects the trigger input(s). Clicking the "Edit" button brings up a pop-up window, and checking the boxes enable the selected triggers. |

Table. 5.6.7 - 338. Recorder settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Recording length | 0.100...1800.000s | 0.01s | 1s | Sets the length of a recording. |
| Recording mode | 0: FIFO<br>1: Keep olds | - | 0: FIFO | Selects what happens when the memory is full.<br><br>"FIFO" (= first in, first out) replaces the oldest stored recording with the latest one. "Keep olds" does not accept new recordings. |
| Analog channel samples | 0: 64s/c<br>1: 32s/c<br>2: 16s/c<br>3: 8s/c | - | 0: 64s/c | Selects the sample rate of the disturbance recorder in samples per cycle. The samples are saved from the measured wave according to this setting. |
| Digital channel samples | 5ms (fixed) | - | 5 ms(fixed) | The fixed sample rate of the recorded digital channels. |
| Pretriggering time | 0.2...30.0s | 0.1s | 0.2s | Sets the recording length before the trigger. |
| Analog recording CH1...CH20 | 0…8 freely selectable channels | - | - | Selects the analog channel for recording. Please see the list of all available analog channels in the section titled "Analog and digital recording channels". |
| Automatically get recordings | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables and disables the automatic transfer of recordings. The recordings are taken from the relay's protection CPU and transferred to the relay's FTP directory in the communication CPU; the FTP client then automatically loads the recordings from the relay and transfers them further to the SCADA system.<br><br>Please note that when this setting is enabled, all new disturbance recordings will be pushed to the FTP server of the relay. Up to six (6) recordings can be stored in the FTP at once. Once those six recordings have been retrieved and removed, more recordings will then be pushed to the FTP.<br><br>When a recording has been sent to the FTP server of the relay, it is no longer accessible through setting tools *Disturbance recorder → Get DR files* command. |
| Recorder digital channels | 0…95 freely selectable channels | - | - | Selects the digital channel for recording. Please see the list of all available digital channels in the section titled "Analog and digital recording channels". |

NOTE!

The disturbance recorder is not ready unless the "Max. length of a recording" parameter is showing some value other than zero. At least one trigger input has to be selected in the "Recorder Trigger" setting to fulfill this term.



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## Estimating the maximum length of total recording time

Once the disturbance recorder's settings have been made and loaded to the relay, the device automatically calculates and displays the total length of recordings. However, if the user wishes to confirm this calculation, they can do so with the following formula. Please note that the formula assumes there are no other files in the FTP that share the 64 MB space.

$$\frac{\text{Total sample reserve}}{(f_n * (Ch_{an} + 1) * SR) + (200\ Hz * Ch_{dig})}$$

Where:

- total sample reserve = the number of samples available in the FTP when no other files are saved; calculated by dividing the total number of available bytes by 4 bytes (=the size of one sample); e.g. 64 306 588 bytes/4 bytes = 16 076 647 samples.
- $f_n$ = the nominal frequency (Hz).
- $Ch_{an}$ = the number of analog channels recorded; "+ 1" stands for the time stamp for each recorded sample.
- $SR$ = the selected sample rate (s/c).
- 200 Hz = the rate at which digital channels are always recorded, i.e. 5 ms.
- $Ch_{dig}$ = the number of digital channels recorded.

For example, let us say the nominal frequency is 50 Hz, the selected sample rate is 64 s/c, nine (9) analog channels and two (2) digital channels record. The calculation is as follows:

$$\frac{16\ 076\ 647\ \text{samples}}{(50\ \text{Hz} * (9 + 1) * 64) + (200\ \text{Hz} * 2)} \approx 496\ \text{s}$$

Therefore, the maximum recording length in our example is approximately 496 seconds.

## Application example

This chapter presents an application example of how to set the disturbance recorder and analyze its output. The recorder is configured by using the setting tool software or relay HMI, and the results are analyzed with the AQviewer software (is automatically downloaded and installed with AQtivate). Registered users can download the latest tools from the Arcteq website (arcteq.fi./downloads/).

In this example, we want the recordings to be made according to the following specifications:

- the recording length is 6.0 s
- the sample rate is 64 s/c (therefore, with a 50 Hz system frequency a sample is taken every 312.5 µs)
- the analog channels 1...8 are used
- digital channels are tracked every 5 ms
- the first activation of the overcurrent stage trip (I> TRIP) triggers the recorder
- the pre-triggering time is 5 (ie. how long is recorded before the I> TRIP signal) and the post-triggering time is 1 s

The image below shows how these settings are placed in the setting tool.

Figure. 5.6.7 - 202. Disturbance recorder settings.

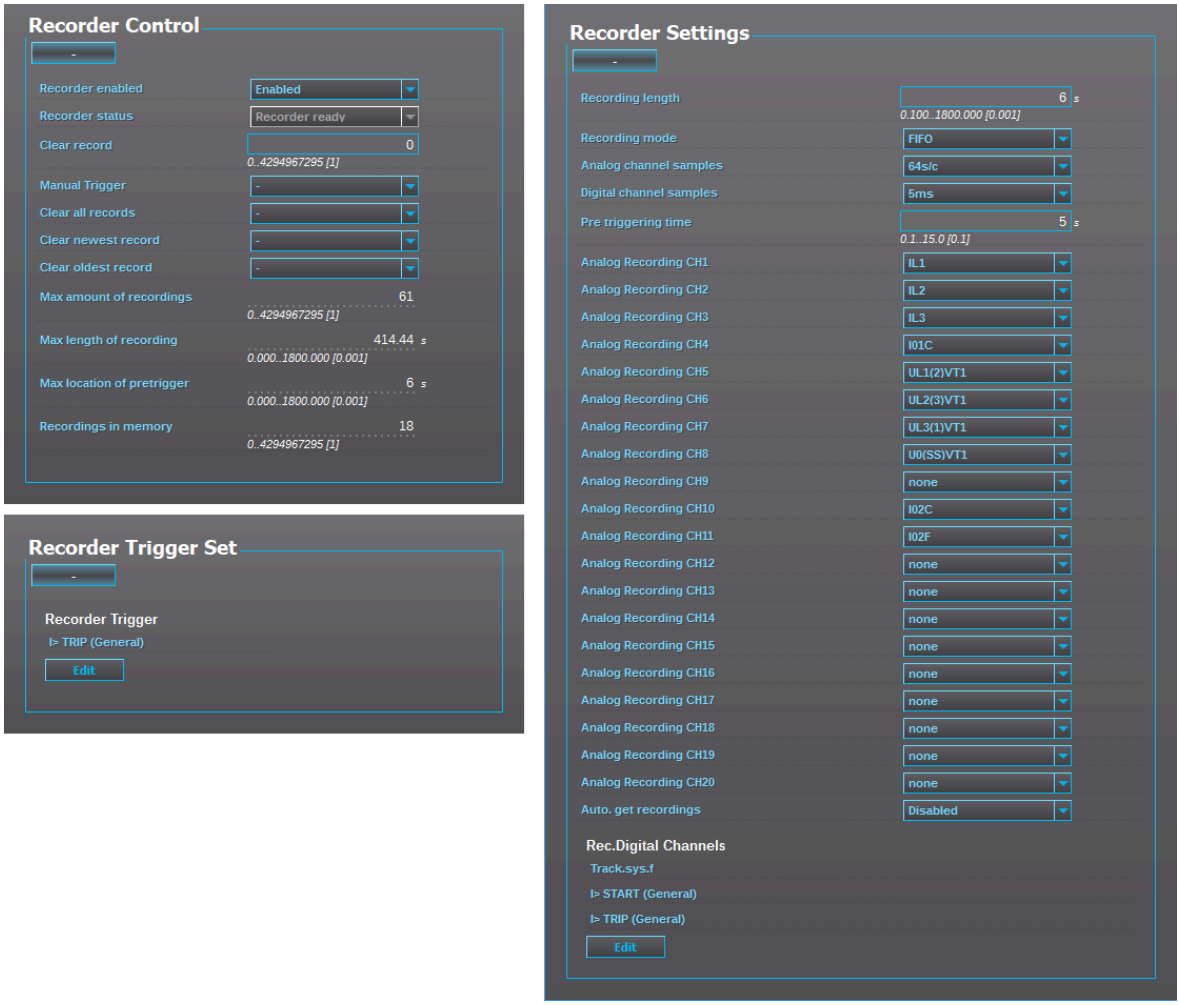
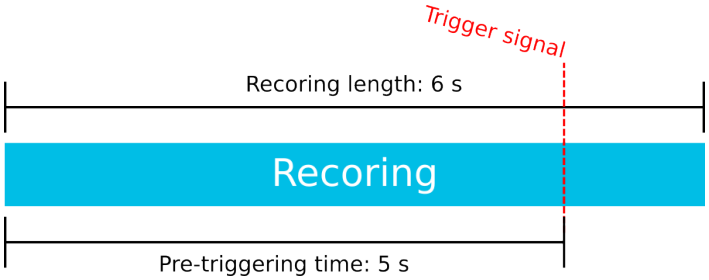
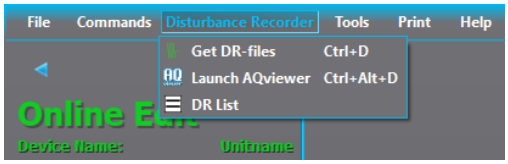



Figure. 5.6.7 - 203. Effects of recording length and pre-triggering time signals. This example is based on the settings shown above.




When there is at least one recording in the device's memory, that recording can be analyzed by using the AQviewer software (see the image below). However, the recording must first be made accessible to AQViewer. The user can read it from the device's memory (*Disturbance recorder → Get DR-files*). Alternatively, the user can load the recordings individually (*Disturbance recorder → DR List*) from a folder in the PC's hard disk drive; the exact location of the folder is described in *Tools → Settings → DR path*.






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The user can also launch the AQviewer software from the *Disturbance recorder* menu. AQviewer software instructions can be found in AQtivate 200 Instruction manual (arcteq.fi./downloads/).

### Events

The disturbance recorder function (abbreviated "DR" in event block names) generates events and registers from the status changes of the function: the recorder generates an event each time it is triggered (manually or by dedicated signals). Events cannot be masked off. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

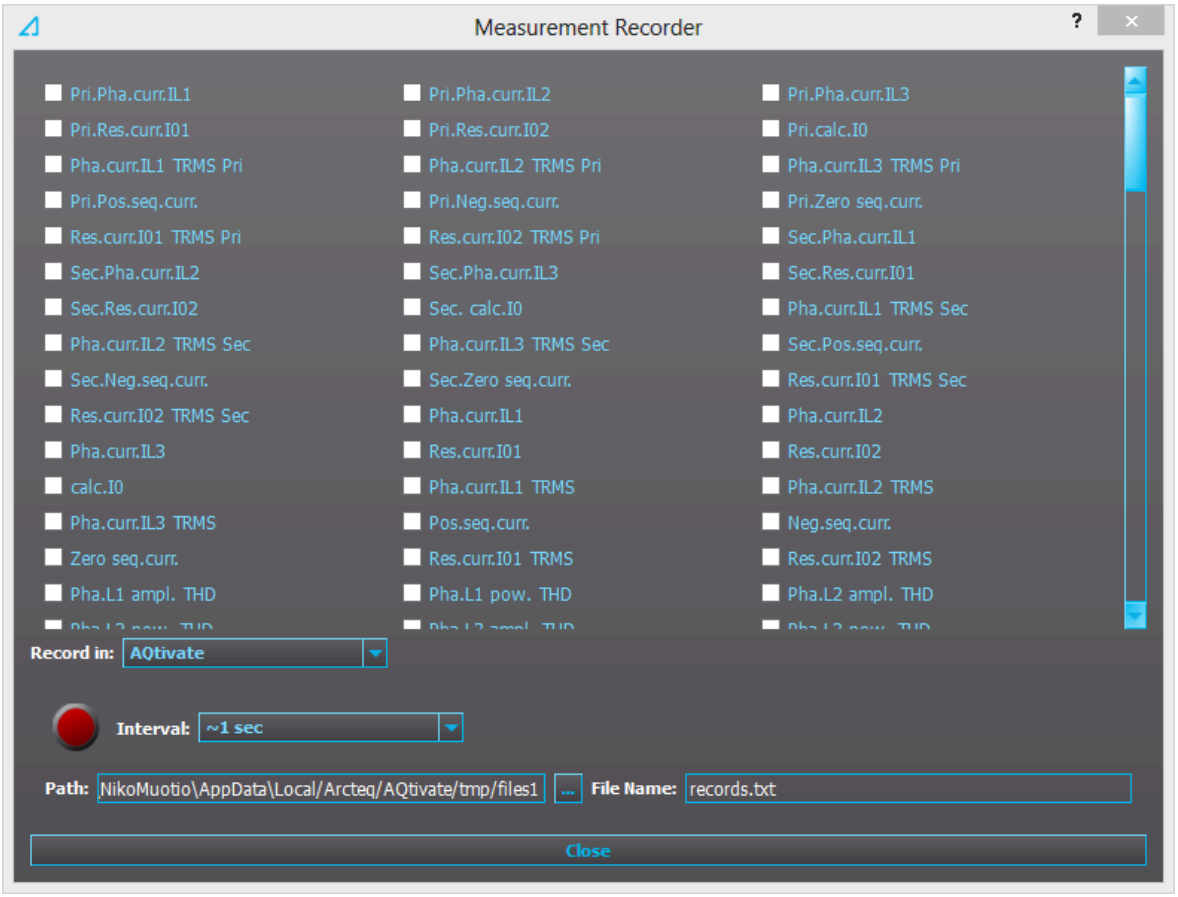
Table. 5.6.7 - 339. Event messages.

| Event block name | Event names |
|---|---|
| DR1 | Recorder triggered ON |
| DR1 | Recorder triggered OFF |
| DR1 | Recorder memory cleared |
| DR1 | Oldest record cleared |
| DR1 | Recorder memory full ON |
| DR1 | Recorder memory full OFF |
| DR1 | Recording ON |
| DR1 | Recording OFF |
| DR1 | Storing recording ON |
| DR1 | Storing recording OFF |
| DR1 | Newest record cleared |

## 5.6.8 Event logger

Event logger records status changes of protection functions, digital inputs, logical signals etc. Events are recorded with a timestamp. The time stamp resolution is 1 ms. Up to 15 000 events can be stored at once. When 15 000 events have been recorded, the event history will begin to remove the oldest events to make room for new events. You can find more information about event masks in the selected function's "Events" tab. Event masks determine what is recorded into the event history; they are configured in each function's individual settings in the *Protection*, *Control* and *Monitoring* menu. Event history is accessible with PC setting tool (*Tools → Events and Logs → Event history*) and from the device HMI if "Events" view has been configured with Carousel designer in PC setting tool.

### 5.6.9 Measurement recorder




Measurements can be recorded to a file with the measurement recorder. The chosen measurements are recorded at selected intervals. In the "Measurement recorder" window, the measurements the user wants to be recorded can be selected by checking their respective check boxes. In order for the measurement recorder to activate, a connection to a relay must be established via the setting tool software and its Live Edit mode must be enabled (see the AQtivate 200 manual for more information). Navigate to the measurement recorder through *Tools → Miscellaneous tools → Measurement recorder*. The recording interval can be changed from the "Interval" drop-down menu. From the "Record in" drop-down menu the user can also choose whether the measurements are recorded in the setting tool or in the relay.

If the recording is done in the setting tool, both the setting tool software and its Live Edit mode have to be activated. The user can change the recording file location by editing the "Path" field. File names can also be changed with the "File name" field. Hitting the "Record" button (the big red circle) starts the recorder. Please note that closing the "Measurement recorder" window does not stop the recording; that can only be done by hitting the "Stop" button (the big blue circle).

If the recording is done in the relay, only the recording interval needs to be set before recording can be started. The setting tool estimates the maximum recording time, which depends on the recording interval. When the measurement recorder is running, the measurements can be viewed in graph form with the AQtivate PRO software (see the image below).


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Figure. 5.6.9 - 204. Measurement recorder values viewed with AQtivate PRO.

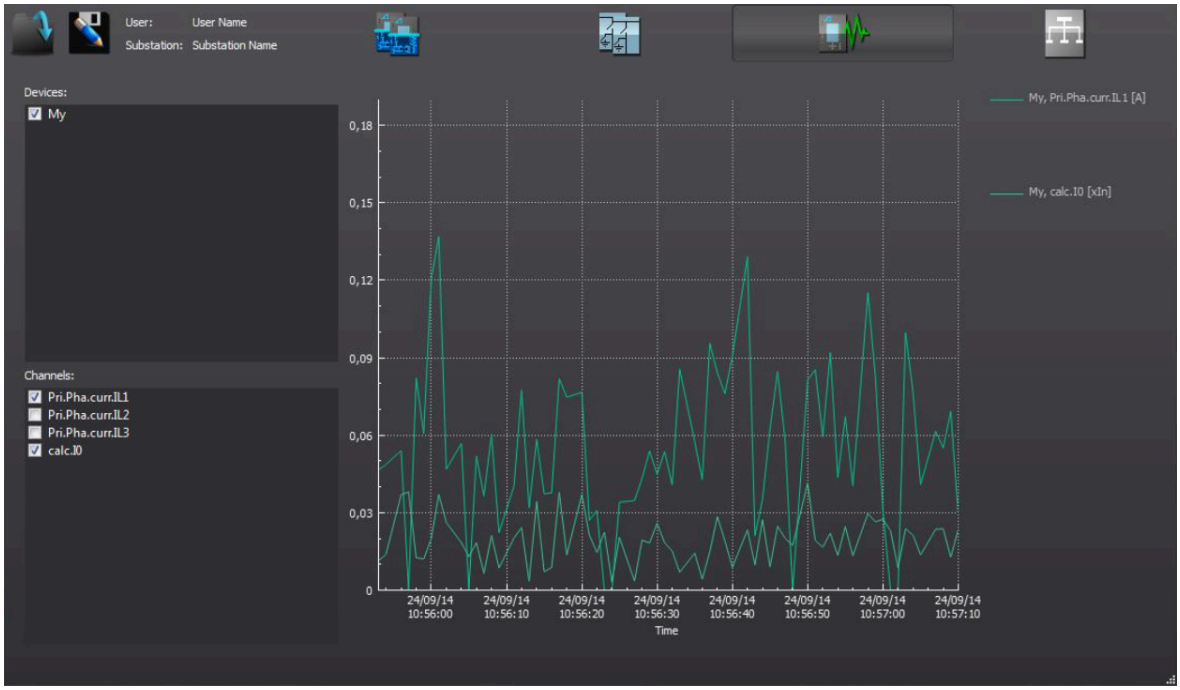



Table. 5.6.9 - 340. Available analog signals.

| | | |
|---|---|---|
| Current measurements | P-P Curr.I"L3 | L1 Imp.React.Ind.E.Mvarh |
| Pri.Pha.Curr.IL1 | P-P Curr.I"01 | L1 Imp.React.Ind.E.kvarh |
| Pri.Pha.Curr.IL2 | P-P Curr.I"02 | L1 Exp/Imp React.Ind.E.bal.Mvarh |
| Pri.Pha.Curr.IL3 | Pha.angle I"L1 | L1 Exp/Imp React.Ind.E.bal.kvarh |
| Pri.Res.Curr.I01 | Pha.angle I"L2 | L2 Exp.Active Energy MWh |
| Pri.Res.Curr.I02 | Pha.angle I"L3 | L2 Exp.Active Energy kWh |
| Pri.Calc.I0 | Res.Curr.angle I"01 | L2 Imp.Active Energy MWh |
| Pha.Curr.IL1 TRMS Pri | Res.Curr.angle I"02 | L2 Imp.Active Energy kWh |
| Pha.Curr.IL2 TRMS Pri | Calc.I"0.angle | L2 Exp/Imp Act. E balance MWh |
| Pha.Curr.IL3 TRMS Pri | I" Pos.Seq.Curr.angle | L2 Exp/Imp Act. E balance kWh |
| Pri.Pos.Seq.Curr. | I" Neg.Seq.Curr.angle | L2 Exp.React.Cap.E.Mvarh |
| Pri.Neg.Seq.Curr. | I" Zero.Seq.Curr.angle | L2 Exp.React.Cap.E.kvarh |
| Pri.Zero.Seq.Curr. | Voltage measurements | L2 Imp.React.Cap.E.Mvarh |
| Res.Curr.I01 TRMS Pri | U1Volt Pri | L2 Imp.React.Cap.E.kvarh |
| Res.Curr.I02 TRMS Pri | U2Volt Pri | L2 Exp/Imp React.Cap.E.bal.Mvarh |
| Sec.Pha.Curr.IL1 | U3Volt Pri | L2 Exp/Imp React.Cap.E.bal.kvarh |
| Sec.Pha.Curr.IL2 | U4Volt Pri | L2 Exp.React.Ind.E.Mvarh |
| Sec.Pha.Curr.IL3 | U1Volt Pri TRMS | L2 Exp.React.Ind.E.kvarh |
| Sec.Res.Curr.I01 | U2Volt Pri TRMS | L2 Imp.React.Ind.E.Mvarh |
| Sec.Res.Curr.I02 | U3Volt Pri TRMS | L2 Imp.React.Ind.E.kvarh |
| Sec.Calc.I0 | U4Volt Pri TRMS | L2 Exp/Imp React.Ind.E.bal.Mvarh |
| Pha.Curr.IL1 TRMS Sec | Pos.Seq.Volt.Pri | L2 Exp/Imp React.Ind.E.bal.kvarh |

| | | |
|---|---|---|
| Pha.Curr.IL2 TRMS Sec | Neg.Seq.Volt.Pri | L3 Exp.Active Energy MWh |
| Pha.Curr.IL3 TRMS Sec | Zero.Seq.Volt.Pri | L3 Exp.Active Energy kWh |
| Sec.Pos.Seq.Curr. | U1Volt Sec | L3 Imp.Active Energy MWh |
| Sec.Neg.Seq.Curr. | U2Volt Sec | L3 Imp.Active Energy kWh |
| Sec.Zero.Seq.Curr. | U3Volt Sec | L3 Exp/Imp Act. E balance MWh |
| Res.Curr.I01 TRMS Sec | U4Volt Sec | L3 Exp/Imp Act. E balance kWh |
| Res.Curr.I02 TRMS Sec | U1Volt Sec TRMS | L3 Exp.React.Cap.E.Mvarh |
| Pha.Curr.IL1 | U2Volt Sec TRMS | L3 Exp.React.Cap.E.kvarh |
| Pha.Curr.IL2 | U3Volt Sec TRMS | L3 Imp.React.Cap.E.Mvarh |
| Pha.Curr.IL3 | U4Volt Sec TRMS | L3 Imp.React.Cap.E.kvarh |
| Res.Curr.I01 | Pos.Seq.Volt.Sec | L3 Exp/Imp React.Cap.E.bal.Mvarh |
| Res.Curr.I02 | Neg.Seq.Volt.Sec | L3 Exp/Imp React.Cap.E.bal.kvarh |
| Calc.I0 | Zero.Seq.Volt.Sec | L3 Exp.React.Ind.E.Mvarh |
| Pha.Curr.IL1 TRMS | U1Volt p.u. | L3 Exp.React.Ind.E.kvarh |
| Pha.Curr.IL2 TRMS | U2Volt p.u. | L3 Imp.React.Ind.E.Mvarh |
| Pha.Curr.IL3 TRMS | U3Volt p.u. | L3 Imp.React.Ind.E.kvarh |
| Pos.Seq.Curr. | U4Volt p.u. | L3 Exp/Imp React.Ind.E.bal.Mvarh |
| Neg.Seq.Curr. | U1Volt TRMS p.u. | L3 Exp/Imp React.Ind.E.bal.kvarh |
| Zero.Seq.Curr. | U2Volt TRMS p.u. | Exp.Active Energy MWh |
| Res.Curr.I01 TRMS | U3Volt p.u. | Exp.Active Energy kWh |
| Res.Curr.I02 TRMS | U4Volt p.u. | Imp.Active Energy MWh |
| Pha.L1 ampl. THD | Pos.Seq.Volt. p.u. | Imp.Active Energy kWh |
| Pha.L2 ampl. THD | Neg.Seq.Volt. p.u. | Exp/Imp Act. E balance MWh |
| Pha.L3 ampl. THD | Zero.Seq.Volt. p.u. | Exp/Imp Act. E balance kWh |
| Pha.L1 pow. THD | U1Volt Angle | Exp.React.Cap.E.Mvarh |
| Pha.L2 pow. THD | U2Volt Angle | Exp.React.Cap.E.kvarh |
| Pha.L3 pow. THD | U3Volt Angle | Imp.React.Cap.E.Mvarh |
| Res.I01 ampl. THD | U4Volt Angle | Imp.React.Cap.E.kvarh |
| Res.I01 pow. THD | Pos.Seq.Volt. Angle | Exp/Imp React.Cap.E.bal.Mvarh |
| Res.I02 ampl. THD | Neg.Seq.Volt. Angle | Exp/Imp React.Cap.E.bal.kvarh |
| Res.I02 pow. THD | Zero.Seq.Volt. Angle | Exp.React.Ind.E.Mvarh |
| P-P Curr.IL1 | System Volt UL12 mag | Exp.React.Ind.E.kvarh |
| P-P Curr.IL2 | System Volt UL12 mag (kV) | Imp.React.Ind.E.Mvarh |
| P-P Curr.IL3 | System Volt UL23 mag | Imp.React.Ind.E.kvarh |
| P-P Curr.I01 | System Volt UL23 mag (kV) | Exp/Imp React.Ind.E.bal.Mvarh |
| P-P Curr.I02 | System Volt UL31 mag | Exp/Imp React.Ind.E.bal.kvarh |
| Pha.angle IL1 | System Volt UL31 mag (kV) | Other measurements |
| Pha.angle IL2 | System Volt UL1 mag | TM> Trip expect mode |
| Pha.angle IL3 | System Volt UL1 mag (kV) | TM> Time to 100% T |



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| | | |
|---|---|---|
| Res.Curr.angle I01 | System Volt UL2 mag | TM> Reference T curr. |
| Res.Curr.angle I02 | System Volt UL2 mag (kV) | TM> Active meas curr. |
| Calc.I0.angle | System Volt UL3 mag | TM> T est.with act. curr. |
| Pos.Seq.Curr.angle | System Volt UL3 mag (kV) | TM> T at the moment |
| Neg.Seq.Curr.angle | System Volt U0 mag | TM> Max.Temp.Rise All. |
| Zero.Seq.Curr.angle | System Volt U0 mag (kV) | TM> Temp.Rise atm. |
| Pri.Pha.Curr.I"L1 | System Volt U1 mag | TM> Hot Spot estimate |
| Pri.Pha.Curr.I"L2 | System Volt U1 mag (kV) | TM> Hot Spot Max. All |
| Pri.Pha.Curr.I"L3 | System Volt U2 mag | TM> Used k for amb.temp |
| Pri.Res.Curr.I"01 | System Volt U2 mag (kV) | TM> Trip delay remaining |
| Pri.Res.Curr.I"02 | System Volt U3 mag | TM> Alarm 1 time to rel. |
| Pri.Calc.I"0 | System Volt U3 mag (kV) | TM> Alarm 2 time to rel. |
| Pha.Curr.I"L1 TRMS Pri | System Volt U4 mag | TM> Inhibit time to rel. |
| Pha.Curr.I"L2 TRMS Pri | System Volt U4 mag (kV) | TM> Trip time to rel. |
| Pha.Curr.I"L3 TRMS Pri | System Volt UL12 ang | S1 Measurement |
| I" Pri.Pos.Seq.Curr. | System Volt UL23 ang | S2 Measurement |
| I" Pri.Neg.Seq.Curr. | System Volt UL31 ang | S3 Measurement |
| I" Pri.Zero.Seq.Curr. | System Volt UL1 ang | S4 Measurement |
| Res.Curr.I"01 TRMS Pri | System Volt UL2 ang | S5 Measurement |
| Res.Curr.I"02 TRMS Pri | System Volt UL3 ang | S6 Measurement |
| Sec.Pha.Curr.I"L1 | System Volt U0 ang | S7 Measurement |
| Sec.Pha.Curr.I"L2 | System Volt U1 ang | S8 Measurement |
| Sec.Pha.Curr.I"L3 | System Volt U2 ang | S9 Measurement |
| Sec.Res.Curr.I"01 | System Volt U3 ang | S10 Measurement |
| Sec.Res.Curr.I"02 | System Volt U4 ang | S11 Measurement |
| Sec.Calc.I"0 | Power measurements | S12 Measurement |
| Pha.Curr.I"L1 TRMS Sec | L1 Apparent Power (S) | Sys.meas.frqs |
| Pha.Curr.I"L2 TRMS Sec | L1 Active Power (P) | f atm. |
| Pha.Curr.I"L3 TRMS Sec | L1 Reactive Power (Q) | f meas from |
| I" Sec.Pos.Seq.Curr. | L1 Tan(phi) | SS1.meas.frqs |
| I" Sec.Neg.Seq.Curr. | L1 Cos(phi) | SS1f meas from |
| I" Sec.Zero.Seq.Curr. | L2 Apparent Power (S) | SS2 meas.frqs |
| Res.Curr.I"01 TRMS Sec | L2 Active Power (P) | SS2f meas from |
| Res.Curr.I"02 TRMS Sec | L2 Reactive Power (Q) | L1 Bias current |
| Pha.Curr.I"L1 | L2 Tan(phi) | L1 Diff current |
| Pha.Curr.I"L2 | L2 Cos(phi) | L1 Char current |
| Pha.Curr.I"L3 | L3 Apparent Power (S) | L2 Bias current |
| Res.Curr.I"01 | L3 Active Power (P) | L2 Diff current |
| Res.Curr.I"02 | L3 Reactive Power (Q) | L2 Char current |

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| | | |
|---|---|---|
| Calc.I"0 | L3 Tan(phi) | L3 Bias current |
| Pha.Curr.I"L1 TRMS | L3 Cos(phi) | L3 Diff current |
| Pha.Curr.I"L2 TRMS | 3PH Apparent Power (S) | L3 Char current |
| Pha.Curr.I"L3 TRMS | 3PH Active Power (P) | HV I0d> Bias current |
| I" Pos.Seq.Curr. | 3PH Reactive Power (Q) | HV I0d> Diff current |
| I" Neg.Seq.Curr. | 3PH Tan(phi) | HV I0d> Char current |
| I" Zero.Seq.Curr. | 3PH Cos(phi) | LV I0d> Bias current |
| Res.Curr.I"01 TRMS | Energy measurements | LV I0d> Diff current |
| Res.Curr.I"02 TRMS | L1 Exp.Active Energy MWh | LV I0d> Char current |
| Pha.IL"1 ampl. THD | L1 Exp.Active Energy kWh | Curve1 Input |
| Pha.IL"2 ampl. THD | L1 Imp.Active Energy MWh | Curve1 Output |
| Pha.IL"3 ampl. THD | L1 Imp.Active Energy kWh | Curve2 Input |
| Pha.IL"1 pow. THD | L1 Exp/Imp Act. E balance MWh | Curve2 Output |
| Pha.IL"2 pow. THD | L1 Exp/Imp Act. E balance kWh | Curve3 Input |
| Pha.IL"3 pow. THD | L1 Exp.React.Cap.E.Mvarh | Curve3 Output |
| Res.I"01 ampl. THD | L1 Exp.React.Cap.E.kvarh | Curve4 Input |
| Res.I"01 pow. THD | L1 Imp.React.Cap.E.Mvarh | Curve4 Output |
| Res.I"02 ampl. THD | L1 Imp.React.Cap.E.kvarh | Control mode |
| Res.I"02 pow. THD | L1 Exp/Imp React.Cap.E.bal.Mvarh | Motor status |
| P-P Curr.I"L1 | L1 Exp/Imp React.Cap.E.bal.kvarh | Active setting group |
| P-P Curr.I"L2 | L1 Exp.React.Ind.E.Mvarh | |
| | L1 Exp.React.Ind.E.kvarh | |

### 5.6.10 Measurement value recorder

The measurement value recorder function records the value of the selected magnitudes at the time of a pre-defined trigger signal. A typical application is the recording of fault currents or voltages at the time of the breaker trips; it can also be used to record the values from any trigger signal set by the user. The user can select whether the function records per-unit values or primary values. Additionally, the user can set the function to record overcurrent fault types or voltage fault types. The function operates instantly from the trigger signal.

The measurement value recorder function has an integrated fault display which shows the current fault values when the tripped by one of the following functions:

- I> (non-directional overcurrent)
- I2> (current unbalance)
- Idir> (directional overcurrent)
- I0> (non-directional earth fault)
- I0dir> (directional earth fault)
- f<(underfrequency)
- f> (overfrequency)
- U< (undervoltage)
- U> (overvoltage)
- U1/U2 >/< (sequence voltage)
- U0> (residual voltage)
- P> (over power)


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- P< (under power)
- Prev> (reverse power)
- T> (thermal overload)

## Measured input

The function block uses analog current and voltage measurement values. Based on these values, the relay calculates the primary and secondary values of currents, voltages, powers, and impedances as well as other values.

The user can set up to eight (8) magnitudes to be recorded when the function is triggered. An overcurrent fault type, a voltage fault type, and a tripped stage can be recorded and reported straight to SCADA.

NOTE!

The available measurement values depend on the relay type. If only current analog measurements are available, the recorder can solely use signals which only use current. The same applies, if only voltage analog measurements are available.

| Currents | Description |
|---|---|
| IL1 (ff), IL2 (ff), IL3 (ff), I01 (ff), I02 (ff) | The fundamental frequency current measurement values (RMS) of phase currents and of residual currents. |
| IL1TRMS, IL2TRMS, IL3TRMS, I01TRMS, I02TRMS | The TRMS current measurement values of phase currents and of residual currents. |
| IL1,2,3 & I01/I02 $2^{nd}$ h., $3^{rd}$ h., $4^{th}$ h., $5^{th}$ h., $7^{th}$ h., $9^{th}$ h., $11^{th}$ h., $13^{th}$ h., $15^{th}$ h., $17^{th}$ h., $19^{th}$ h. | The magnitudes of phase current components: Fundamental, $2^{nd}$ harmonic, $3^{rd}$ harmonic, $4^{th}$ harmonic, $5^{th}$ harmonic $7^{th}$, harmonic $9^{th}$, harmonic $11^{th}$, harmonic $13^{th}$, harmonic $15^{th}$, harmonic $17^{th}$, harmonic $19^{th}$ harmonic current. |
| I1, I2, I0Z | The positive sequence current, the negative sequence current and the zero sequence current. |
| I0CalcMag | The residual current calculated from phase currents. |
| IL1Ang, IL2Ang, IL3Ang, I01Ang, I02Ang, I0CalcAng, I1Ang, I2Ang | The angles of each measured current. |
| **Voltages** | **Description** |
| UL1Mag, UL2Mag, UL3Mag, UL12Mag, UL23Mag, UL31Mag<br><br>U0Mag, U0CalcMag | The magnitudes of phase voltages, of phase-to-phase voltages, and of residual voltages. |
| U1 Pos.seq V mag, U2 Neg.seq V mag | The positive sequence voltage and the negative sequence voltage. |
| UL1Ang, UL2Ang, UL3Ang, UL12Ang, UL23Ang, UL31Ang<br><br>U0Ang, U0CalcAng | The angles of phase voltages, of phase-to-phase voltages, and of residual voltages. |
| U1 Pos.seq V Ang, U2 Neg.seq V Ang | The positive sequence angle and the negative sequence angle. |
| **Powers** | **Description** |
| S3PH, P3PH, Q3PH | The three-phase apparent, active and reactive powers. |
| SL1, SL2, SL3, PL1, PL2, PL3, QL1, QL2, QL3 | The phase apparent, active and reactive powers. |
| tanfi3PH, tanfiL1, tanfiL2, tanfiL3 | The tan (φ) of three-phase powers and phase powers. |

| Currents | Description |
|---|---|
| cosfi3PH, cosfiL1, cosfiL2, cosfiL3 | The cos (φ) of three-phase powers and phase powers. |
| **Impedances and admittances** | **Description** |
| RL12, RL23, RL31<br>XL12, XL23, XL31,<br>RL1, RL2, RL3<br>XL1, XL2, XL3<br>Z12, Z23, Z31<br>ZL1, ZL2, ZL3 | The phase-to-phase and phase-to-neutral resistances, reactances and impedances. |
| Z12Ang, Z23Ang, Z31Ang,<br>ZL1Ang, ZL2Ang, ZL3Ang | The phase-to-phase and phase-to-neutral impedance angles. |
| Rseq, Xseq, Zseq<br>RseqAng, XseqAng, ZseqAng | The positive sequence resistance, reactance and impedance values and angles. |
| GL1, GL2, GL3, G0<br>BL1, BL2, BL3, B0<br>YL1, YL2, YL3, Y0 | The conductances, susceptances and admittances. |
| YL1angle, YL2angle, YL3angle<br>Y0angle | The admittance angles. |
| **Others** | **Description** |
| System f. | The tracking frequency in use at that moment. |
| Ref f1 | The reference frequency 1. |
| Ref f2 | The reference frequency 2. |
| M thermal T | The motor thermal temperature. |
| F thermal T | The feeder thermal temperature. |
| T thermal T | The transformer thermal temperature. |
| RTD meas 1…16 | The RTD measurement channels 1…16. |
| Ext RTD meas 1…8 | The external RTD measurement channels 1…8 (ADAM module). |

## Reported values

When triggered, the function holds the recorded values of up to eight channels, as set. In addition to this tripped stage, the overcurrent fault type and the voltage fault types are reported to SCADA.



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Table. 5.6.10 - 341. Reported values.

| Name | Range | Step | Description |
|---|---|---|---|
| Tripped stage | 0: -<br>1: I> Trip<br>2: I>> Trip<br>3: I>>> Trip<br>4: I>>>> Trip<br>5: IDir> Trip<br>6: IDir>> Trip<br>7: IDir>>> Trip<br>8: IDir>>>> Trip<br>9: U> Trip<br>10: U>> Trip<br>11: U>>> Trip<br>12: U>>>> Trip<br>13: U< Trip<br>14: U<< Trip<br>15: U<<< Trip<br>16: U<<<< Trip<br>17: I0> TRIP<br>18: I0>> Trip<br>19: I0>>> Trip<br>20: I0>>>> Trip<br>21: I0Dir> Trip<br>22: I0Dir>> Trip<br>23: I0Dir>>> Trip<br>24: I0Dir>>>> Trip<br>25: f> Trip<br>26: f>> Trip<br>27: f>>> Trip<br>28: f>>>> Trip<br>29: f< Trip<br>30: f<< Trip<br>31: f<<< Trip<br>32: f<<<< Trip<br>33: P> Trip<br>34: P< Trip<br>35: Prev> Trip<br>36: T> Trip<br>37: I2> Trip<br>38: I2>> Trip<br>39: I2>>> Trip<br>40: I2>>>> Trip<br>41: U1/2 > Trip<br>42: U1/2 >> Trip<br>43: U1/2 >>> Trip<br>44: U1/2 >>>> Trip<br>45: U0> Trip<br>46: U0>> Trip<br>47: U0>>> Trip<br>48: U0>>>> Trip | - | The tripped stage. |
| Overcurrent fault type | 0: -<br>1: A-G<br>2: B-G<br>3: A-B<br>4: C-G<br>5: A-C<br>6: B-C<br>7: A-B-C | - | The overcurrent fault type. |

| Name | Range | Step | Description |
|---|---|---|---|
| Voltage fault type | 0: -<br>1: A(AB)<br>2: B(BC)<br>3: A-B(AB-BC)<br>4: C(CA)<br>5: A-C(AB-CA)<br>6: B-C(BC-CA)<br>7: A-B-C<br>8: -<br>9: Overfrequency<br>10: Underfrequency<br>11: Overpower<br>12: Underpower<br>13: Reversepower<br>14: Thermal overload<br>15: Unbalance<br>16: Harmonic overcurrent<br>17: Residual overvoltage | - | The voltage fault type. |
| Magnitude 1…8 | 0.000…1800.000 A/V/p.u. | 0.001 A/V/p.u. | The recorded value in one of the eight channels. |

### Events

The measurement value recorder function (abbreviated "VREC" in event block names) generates events from the function triggers. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 5.6.10 - 342. Event messages.

| Event block name | Event name |
|---|---|
| VREC1 | Recorder triggered ON |
| VREC1 | Recorder triggered OFF |

## 5.7 Programmable stage (PGx>/<; 99)

The programmable stage is a stage that the user can program to create more advanced applications, either as an individual stage or together with programmable logic. The relay has ten programmable stages, and each can be set to follow one to three analog measurements. The programmable stages have three available pick up terms options: overX, underX and rate-of-change of the selected signal. Each stage includes a definite time delay to trip after a pick-up has been triggered.

The programmable stage cycle time is 5 ms. The pick-up delay depends on which analog signal is used as well as its refresh rate (typically under a cycle in a 50 Hz system).

The number of programmable stages to be used is set in the *INFO* tab. When this function has been set as "Activated", the number of programmable stages can be set anywhere between one (1) and ten (10) depending on how many the application needs. In the image below, the number of programmable stages have been set to two which makes PS1 and PS2 to appear. Inactive stages are hidden until they are activated.

Please note that setting the number of available stages does not activate those stages, as they also need to be enabled individually with the *PSx >/< Enabled* parameter. When enabled an active stage shows its current state (condition), the expected operating time and the time remaining to trip under the activation parameters. If a stage is not active the *PSx>/< condition* parameter will merely display “Disabled”.

The function's outputs are START, TRIP and BLOCKED signals. The programmable stage function uses a total of eight (8) separate setting groups which can be selected from one common source.


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The function can operate on instant or time-delayed mode. Definite time (DT) delay can be selected in the In time-delayed mode.

The inputs for the function are the following:

- operating mode selections
- setting parameters
- digital inputs and logic signals
- measured and pre-processed magnitudes.

The function's outputs are START, TRIP and BLOCKED signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the three (3) output signals. In the instant operating mode the function outputs START and TRIP events simultaneously with an equivalent time stamp. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

## General settings

The following general settings define the general behavior of the function. These settings are static i.e. it is not possible to change them by editing the setting group.

Table. 5.7 - 343. General settings of the function.

| Name | Range | Description |
|---|---|---|
| PSx >/< LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Set mode of PGS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| PSx >/< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Displays the mode of PGS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| PSx >/< Available stages | 1...10 | Defines the available amount of stages. |
| PSx >/< Enabled | 0: Disabled<br>1: Enabled | Enables the stage. |
| PSx >/< Force status to | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| PSx >/< Measurement setting | 0: One magnitude comp<br>1: Two magnitude comp<br>2: Three magnitude comp | Defines how many measurement magnitudes are used by the stage. |
| PSx >/< Magnitude handling ("Two magnitude comp" selected) | 0: Mag1 x Mag2 | Multiplies Signal 1 by Signal 2. The comparison uses the product of this calculation. |
| | 1: Mag1 / Mag2 | Divides Signal 1 by Signal 2. The comparison uses the product of this calculation. |
| | 2: Max (Mag1, Mag2) | The bigger value of the chosen signals is used in the comparison. |
| | 3: Min (Mag1, Mag2) | The smaller value of the chosen signals is used in the comparison. |

| Name | Range | Description |
|---|---|---|
| | 4: Mag1 OR Mag2 | Either of the chosen signals has to fulfill the pick-up condition. Both signals have their own pick-up setting. |
| | 5: Mag1 AND Mag2 | Both of the chosen signals have to fulfill the pick-up condition. Both signals have their own pick-up setting. |
| | 6: Mag1 – Mag2 | Subtracts Signal 2 from Signal 1. The comparison uses the product of this calculation. |
| PSx >/< Magnitude handling ("Three magnitude comp" selected) | 0: Mag1 x Mag2 x Mag3 | Multiplies Signals 1, 2 and 3. The comparison uses the product of this calculation. |
| | 1: Max (Mag1, Mag2, Mag3); | The biggest value of the chosen signals is used in the comparison. |
| | 2: Min (Mag1, Mag2, Mag3) | The smallest value of the chosen signals is used in the comparison. |
| | 3: Mag1 OR Mag2 OR Mag3 | Any of the signals fulfills the pick-up condition. Each signal has their own pick-up setting. |
| | 4: Mag1 AND Mag2 AND Mag3 | All of the signals need to fulfill the pick-up condition. Each signal has their own pick-up setting. |
| | 5: (Mag1 OR Mag2) AND Mag3 | Signals 1 OR 2 AND 3 need to fulfill the pick-up condition. Each signal has their own pick-up setting. |
| PSx Magnitude selection | 0: Currents<br>1: Voltages<br>2: Powers<br>3: Impedances and admittances<br>4: Others | Defines the measurement type used by the stage |
| PSx MagnitudeX | See table below. | Defines the measurement used by the stage. Available parameters depend on selected measurement type. |
| PSx MagnitudeX multiplier | -5 000 000...5 000 000 | Multiplies the selected measurement. 1 by default (no multiplication). See section "Magnitude multiplier" for more information. |

## Analog values

The numerous analog signals have been divided into categories to help the user find the desired value.

Table. 5.7 - 344. Phase and residual current measurements (IL1, IL2, IL3, Io1 and Io2)

| Name | Description |
|---|---|
| ILx ff (p.u.) | Fundamental frequency RMS value (in p.u.) |
| ILx 2$^{nd}$ h. | ILx 2$^{nd}$ harmonic value (in p.u.) |
| ILx 3$^{rd}$ h. | ILx 3$^{nd}$ harmonic value (in p.u.) |
| ILx 4$^{th}$ h. | ILx 4$^{nd}$ harmonic value (in p.u.) |
| ILx 5$^{th}$ h. | ILx 5$^{nd}$ harmonic value (in p.u.) |
| ILx 7$^{th}$ h. | ILx 7$^{nd}$ harmonic value (in p.u.) |
| ILx 9$^{th}$ h. | ILx 9$^{nd}$ harmonic value (in p.u.) |
| ILx 11$^{th}$ h. | ILx 11$^{nd}$ harmonic value (in p.u.) |
| ILx 13$^{th}$ h. | ILx 13$^{nd}$ harmonic value (in p.u.) |
| ILx 15$^{th}$ h. | ILx 15$^{nd}$ harmonic value (in p.u.) |


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| Name | Description |
|---|---|
| ILx 17th h. | ILx 17nd harmonic value (in p.u.) |
| ILx 19th h. | ILx 19nd harmonic value (in p.u.) |
| ILx TRMS | ILx TRMS value (in p.u.) |
| ILx Ang | ILx Angle (degrees) |

Table. 5.7 - 345. Other current measurements

| Name | Description |
|---|---|
| I0Z Mag | Zero sequence current value (in p.u.) |
| I0CALC Mag | Calculated I0 value (in p.u.) |
| I1 Mag | Positive sequence current value (in p.u.) |
| I2 Mag | Negative sequence current value (in p.u.) |
| I0CALC Ang | Angle of calculated residual current (degrees) |
| I1 Ang | Angle of positive sequence current (degrees) |
| I2 Ang | Angle of negative sequence current (degrees) |
| I01ResP | I01 primary current of a current-resistive component |
| I01CapP | I01 primary current of a current-capacitive component |
| I01ResS | I01 secondary current of a current-resistive component |
| I01CapS | I01 secondary current of a current-capacitive component |
| I02ResP | I02 primary current of a current-resistive component |
| I02CapP | I02 primary current of a current-capacitive component |
| I02ResS | I02 secondary current of a current-resistive component |
| I02CapS | I02 secondary current of a current-capacitive component |

Table. 5.7 - 346. Voltage measurements

| Name | Description |
|---|---|
| UL12Mag | UL12 Primary voltage V |
| UL23Mag | UL23 Primary voltage V |
| UL31Mag | UL31 Primary voltage V |
| UL1Mag | UL1 Primary voltage V |
| UL2Mag | UL2 Primary voltage V |
| UL3Mag | UL3 Primary voltage V |
| UL12Ang | UL12 angle (degrees) |
| UL23Ang | UL23 angle (degrees) |
| UL31Ang | UL31 angle (degrees) |
| UL1Ang | UL1 angle (degrees) |
| UL2Ang | UL2 angle (degrees) |
| UL3Ang | UL3 angle (degrees) |
| U0Ang | UL0 angle (degrees) |
| U0CalcMag | Calculated residual voltage |

| Name | Description |
|---|---|
| U1 pos.seq.V Mag | Positive sequence voltage |
| U2 neg.seq.V Mag | Negative sequence voltage |
| U0CalcAng | Calculated residual voltage angle (degrees) |
| U1 pos.seq.V Ang | Positive sequence voltage angle (degrees) |
| U2 neg.seq.V Ang | Negative sequence voltage angle (degrees) |

Table. 5.7 - 347. Power measurements

| Name | Description |
|---|---|
| S3PH | Three-phase apparent power S (kVA) |
| P3PH | Three-phase active power P (kW) |
| Q3PH | Three-phase reactive power Q (kvar) |
| tanfi3PH | Three-phase active power direction |
| cosfi3PH | Three-phase reactive power direction |
| SLx | Phase apparent power L1 / L2 / L3 S (kVA) |
| PLx | Phase active power L1 / L2 / L3 P (kW) |
| QLx | Phase reactive power L1 / L2 / L3 Q (kVar) |
| tanfiLx | Phase active power direction L1 / L2 / L3 |
| cosfiLx | Phase reactive power direction L1 / L2 / L3 |

Table. 5.7 - 348. Phase-to-phase and phase-to-neutral impedances, resistances and reactances

| Name | Description |
|---|---|
| RLxPri | Resistance R L12, L23, L31, L1, L2, L3 primary (Ω) |
| XLxPri | Reactance X L12, L23, L31, L1, L2, L3 primary (Ω) |
| ZLxPri | Impedance Z L12, L23, L31, L1, L2, L3 primary (Ω) |
| RLxSec | Resistance R L12, L23, L31, L1, L2, L3 secondary (Ω) |
| XLxSec | Reactance X L12, L23, L31, L1, L2, L3 secondary (Ω) |
| ZLxSec | Impedance Z L12, L23, L31, L1, L2, L3 secondary (Ω) |
| ZLxAngle | Impedance Z L12, L23, L31, L1, L2, L3 angle |

Table. 5.7 - 349. Other impedances, resistances and reactances

| Name | Description |
|---|---|
| RSeqPri | Positive Resistance R primary (Ω) |
| XSeqPri | Positive Reactance X primary (Ω) |
| RSeqSec | Positive Resistance R secondary (Ω) |
| XSeqSec | Positive Reactance X secondary (Ω) |
| ZSeqPri | Positive Impedance Z primary (Ω) |
| ZSeqSec | Positive Impedance Z secondary (Ω) |
| ZSeqAngle | Positive Impedance Z angle |



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Table. 5.7 - 350. Conductances, susceptances and admittances (L1, L2, L3)

| Name | Description |
|---|---|
| GLxPri | Conductance G L1, L2, L3 primary (mS) |
| BLxPri | Susceptance B L1, L2, L3 primary (mS) |
| YLxPriMag | Admittance Y L1, L2, L3 primary (mS) |
| GLxSec | Conductance G L1, L2, L3 secondary (mS) |
| BLxSec | Susceptance B L1, L2, L3 secondary (mS) |
| YLxSecMag | Admittance Y L1, L2, L3 secondary (mS) |
| YLxAngle | Admittance Y L1, L2, L3 angle (degrees) |

Table. 5.7 - 351. Other conductances, susceptances and admittances

| Name | Description |
|---|---|
| G0Pri | Conductance G0 primary (mS) |
| B0Pri | Susceptance B0 primary (mS) |
| G0Sec | Conductance G0 secondary (mS) |
| B0Sec | Susceptance B0 secondary (mS) |
| Y0Pri | Admittance Y0 primary (mS) |
| Y0Sec | Admittance Y0 secondary (mS) |
| Y0Angle | Admittance Y0 angle |

Table. 5.7 - 352. Other measurements

| Name | Description |
|---|---|
| System f. | System frequency |
| Ref f1 | Reference frequency 1 |
| Ref f2 | Reference frequency 2 |
| M Thermal T | Motor thermal temperature |
| F Thermal T | Feeder thermal temperature |
| T Thermal T | Transformer thermal temperature |
| RTD meas 1…16 | RTD measurement channels 1…16 |
| Ext RTD meas 1…8 | External RTD measurement channels 1…8 (ADAM) |
| mA input 7,8,15,16 | mA input channels 7, 8, 15, 16 |
| ASC 1…4 | Analog scaled curves 1…4 |

## Magnitude multiplier

Programmable stages can be set to follow one, two or three analog measurements with the *PSx >/< Measurement setting* parameter. The user must choose a measurement signal value to be compared to the set value, and possibly also set a scaling for the signal. The image below is an example of scaling: a primary neutral voltage has been scaled to a percentage value for easier handling when setting up the comparator.

The scaling factor was calculated by taking the inverse value of a 20 kV system:

$$k = \frac{1}{20\,000\ \text{V}/\sqrt{3}} = 0.008\ 66$$

When this multiplier is in use, the full earth fault neutral voltage is 11 547 V primary which is then multiplied with the above-calculated scaling factor, inversing the final result to 100%. This way a pre-processed signal is easier to set, although it is also possible to just use the scaling factor of 1.0 and set the desired pick-up limit as the primary voltage. Similarly, any chosen measurement value can be scaled to the desired form.

## Read-only parameters

The relay's *Info* page displays useful, real-time information on the state of the protection function. It is accessed either through the relay's HMI display, or through the setting tool software when it is connected to the relay and its Live Edit mode is active.

Table. 5.7 - 353. Information displayed by the function.

| Name | Range | Description |
|---|---|---|
| PSx >/< LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | Displays the mode of PGS block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | Displays status of the function. |
| Expected operating time | -1800.000...1800.000s | Displays the expected operating time when a fault occurs. |
| Time remaining to trip | 0.000...1800.000s | When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs. |
| PSx Scaled magnitude X | -5 000 000...5 000 000 | Displays measurement value after multiplying it the value set to *PSx Magnitude multiplier*. |
| PSx >/< MeasMag1/ MagSet1 at the moment | -5 000 000...5 000 000 | The ratio between measured magnitude and the pick-up setting. |
| PSx >/< MeasMag2/ MagSet2 at the moment | -5 000 000...5 000 000 | The ratio between measured magnitude and the pick-up setting. |
| PSx >/< MeasMag3/ MagSet3 at the moment | -5 000 000...5 000 000 | The ratio between measured magnitude and the pick-up setting. |
| PSx >/< CalcMeasMag/ MagSet at the moment | -5 000 000...5 000 000 | The ratio between calculated magnitude and the pick-up setting. |

## Pick-up

The *Pick-up setting Mag* setting parameter controls the pick-up of the PGx>/< function. This defines the maximum or minimum allowed measured magnitude before action from the function. The function constantly calculates the ratio between the set and the measured magnitudes. The user can set the reset hysteresis in the function (by default 3 %). It is always relative to the *Pick-up setting Mag* value.


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Table. 5.7 - 354. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| PS# Pick-up term Mag# | 0: Over > 1: Over (abs) > 2: Under < 3: Under (abs) < 4: Delta set (%) +/- > 5: Delta abs (%) > 6: Delta +/- measval 7: Delta abs measval | - | 0: Over | Comparator mode for the magnitude. See "Comparator modes" section below for more information. |
| PS# Pick-up setting Mag#/calc >/< | -5 000 000.0000…5 000 000.0000 | 0.0001 | 0.01 | Pick-up magnitude |
| PS# Setting hysteresis Mag# | 0.0000…50.0000% | 0.0001% | 3% | Setting hysteresis |
| Definite operating time delay | 0.000…1800.000s | 0.005s | 0.04s | Delay setting |
| Release time delays | 0.000…1800.000s | 0.005s | 0.06s | Pick-up release delay |

The pick-up activation of the function is not directly equal to the START signal generation of the function. The START signal is allowed if the blocking condition is not active.

## Comparator modes

When setting the comparators, the user must first choose a comparator mode.

Table. 5.7 - 355. Comparator modes

| Mode | Description |
|---|---|
| 0: Over > | **Greater than**. If the measured signal is greater than the set pick-up level, the comparison condition is fulfilled. |
| 1: Over (abs) > | **Greater than (absolute)**. If the absolute value of the measured signal is greater than the set pick-up level, the comparison condition is fulfilled. |
| 2: Under < | **Less than**. If the measured signal is less than the set pick-up level, the comparison condition is fulfilled. The user can also set a blocking limit: the comparison is not active when the measured value is less than the set blocking limit. |
| 3: Under (abs) < | **Less than (absolute)**. If the absolute value of the measured signal is less than the set pick-up level, the comparison condition is fulfilled. The user can also set a blocking limit: the comparison is not active when the measured value is less than the set blocking limit. |
| 4: Delta set (%) +/- > | **Relative change over time**. If the measured signal changes more than the set relative pick-up value in 20 ms, the comparison condition is fulfilled. The condition is dependent on direction. |
| 5: Delta abs (%) > | **Relative change over time (absolute)**. If the measured signal changes more than the set relative pick-up value in 20 ms in either direction, the comparison condition is fulfilled. The condition is not dependent on direction. |
| 6: Delta +/- measval | **Change over time**. If the measured signal changes more than the set pick-up value in 20 ms, the comparison condition is fulfilled. The condition is dependent on direction. |
| 7: Delta abs measval | **Change over time (absolute)**. If the measured signal changes more than the set pick-up value in 20 ms in either direction, the comparison condition is fulfilled. The condition is not dependent on direction. |

The pick-up level is set individually for each comparison. When setting up the pick-up level, the user needs to take into account the modes in use as well as the desired action. The pick-up limit can be set either as positive or as negative. Each pick-up level has a separate hysteresis setting which is 3 % by default.

The user can set the operating and releasing time delays for each stage.

## Function blocking

The block signal is checked in the beginning of each program cycle. The blocking signal is received from the blocking matrix in the function's dedicated input. If the blocking signal is not activated when the pick-up element activates, a START signal is generated and the function proceeds to the time characteristics calculation.

If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the START function has been activated before the blocking signal, it resets and the release time characteristics are processed similarly to when the pick-up signal is reset.

The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup values of the selected signal and its fault type to be issued.

The variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

## Events and registers

The programmable stage function (abbreviated "PGS" in event block names) generates events and registers from the status changes in START, TRIP, and BLOCKED. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

The events triggered by the function are recorded with a time stamp and with process data values.

Table. 5.7 - 356. Event messages.

| Event block name | Event names |
|---|---|
| PGS1 | PS1 >/< Start ON |
| PGS1 | PS1 >/< Start OFF |
| PGS1 | PS1 >/< Trip ON |
| PGS1 | PS1 >/< Trip OFF |
| PGS1 | PS1 >/< Block ON |
| PGS1 | PS1 >/< Block OFF |
| PGS1 | PS2 >/< Start ON |
| PGS1 | PS2 >/< Start OFF |
| PGS1 | PS2 >/< Trip ON |
| PGS1 | PS2 >/< Trip OFF |
| PGS1 | PS2 >/< Block ON |
| PGS1 | PS2 >/< Block OFF |
| PGS1 | PS3 >/< Start ON |
| PGS1 | PS3 >/< Start OFF |


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| Event block name | Event names |
|---|---|
| PGS1 | PS3 >/< Trip ON |
| PGS1 | PS3 >/< Trip OFF |
| PGS1 | PS3 >/< Block ON |
| PGS1 | PS3 >/< Block OFF |
| PGS1 | PS4 >/< Start ON |
| PGS1 | PS4 >/< Start OFF |
| PGS1 | PS4 >/< Trip ON |
| PGS1 | PS4 >/< Trip OFF |
| PGS1 | PS4 >/< Block ON |
| PGS1 | PS4 >/< Block OFF |
| PGS1 | PS5 >/< Start ON |
| PGS1 | PS5 >/< Start OFF |
| PGS1 | PS5 >/< Trip ON |
| PGS1 | PS5 >/< Trip OFF |
| PGS1 | PS5 >/< Block ON |
| PGS1 | PS5 >/< Block OFF |
| PGS1 | reserved |
| PGS1 | reserved |
| PGS1 | PS6 >/< Start ON |
| PGS1 | PS6 >/< Start OFF |
| PGS1 | PS6 >/< Trip ON |
| PGS1 | PS6 >/< Trip OFF |
| PGS1 | PS6 >/< Block ON |
| PGS1 | PS6 >/< Block OFF |
| PGS1 | PS7 >/< Start ON |
| PGS1 | PS7 >/< Start OFF |
| PGS1 | PS7 >/< Trip ON |
| PGS1 | PS7 >/< Trip OFF |
| PGS1 | PS7 >/< Block ON |
| PGS1 | PS7 >/< Block OFF |
| PGS1 | PS8 >/< Start ON |
| PGS1 | PS8 >/< Start OFF |
| PGS1 | PS8 >/< Trip ON |
| PGS1 | PS8 >/< Trip OFF |
| PGS1 | PS8 >/< Block ON |
| PGS1 | PS8 >/< Block OFF |
| PGS1 | PS9 >/< Start ON |
| PGS1 | PS9 >/< Start OFF |

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| Event block name | Event names |
|---|---|
| PGS1 | PS9 >/< Trip ON |
| PGS1 | PS9 >/< Trip OFF |
| PGS1 | PS9 >/< Block ON |
| PGS1 | PS9 >/< Block OFF |
| PGS1 | PS10 >/< Start ON |
| PGS1 | PS10 >/< Start OFF |
| PGS1 | PS10 >/< Trip ON |
| PGS1 | PS10 >/< Trip OFF |
| PGS1 | PS10 >/< Block ON |
| PGS1 | PS10 >/< Block OFF |

The function registers its operation into the last twelve (12) time-stamped registers. The register of the function records the ON event process data for START, TRIP or BLOCKED. The table below presents the structure of the function's register content.

Table. 5.7 - 357. Register content.

| Date and time | Event | >/< Mag# | Mag#/Set# | Trip time remaining | Used SG |
|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | The numerical value of the magnitude | Ratio between the measured magnitude and the pick-up setting | 0 ms...1800s | Setting group 1...8 active |



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# 6 Communication

## 6.1 Connections menu

"Connections" menu is found under "Communication" menu. It contains all basic settings of ethernet port and RS-485 serial port included with every AQ-200 device as well as settings of communication option cards.

Table. 6.1 - 358. Ethernet settings.

| Name | Range | Description |
|---|---|---|
| IP address | 0.0.0.0...255.255.255.255 | Set IP address of the ethernet port in the back of the AQ-200 series device. |
| Netmask | 0.0.0.0...255.255.255.255 | Set netmask of the ethernet port in the back of the AQ-200 series device. |
| Gateway | 0.0.0.0...255.255.255.255 | Set gateway of the ethernet port in the back of the AQ-200 series device. |
| MAC-Address | 00-00-00-00-00-00...FF-FF-FF-FF-FF-FF | Indication of MAC address of the AQ-200 series device. |
| Double Ethernet card mode | 1: Switch<br>2: HSR<br>3: PRP | If the device has a double ethernet option card it is possible to choose its mode. |
| COM A and Ethernet option card connection | 1: Block all<br>2: Allow both directions<br>3: Allow COM A to option card<br>4: Allow option card to COM A | If the device has ethernet option card it is possible to determine the allowed direction of data. |
| Double Ethernet link events | 1: Disable<br>2: Enable | Disables or enables "Double Ethernet Link A down" and "Double Ethernet Link B down" logic signals and events. |

Virtual Ethernet enables the device to be connected to multiple different networks simultaneously via one physical Ethernet connection. Virtual Ethernet has its own separate IP address and network configurations. All Ethernet-based protocol servers listen for client connections on the IP addresses of both the physical Ethernet and the Virtual Ethernet.

Table. 6.1 - 359. Virtual Ethernet settings.

| Name | Description |
|---|---|
| Enable virtual adapter (No / Yes) | Enable virtual adapter. Off by default. |
| IP address | Set IP address of the virtual adapter. |
| Netmask | Set netmask of the virtual adapter. |
| Gateway | Set gateway of the virtual adapter. |

AQ-200 series devices are always equipped with an RS-485 serial port. In the software it is identified as "Serial COM1" port.

Table. 6.1 - 360. Serial COM1 settings.

| Name | Range | Description |
|---|---|---|
| Bitrate | 0: 9600bps<br>1: 19200bps<br>2: 38400bps | Bitrate used by RS-485 port. |

| Name | Range | Description |
|---|---|---|
| Databits | 7...8 | Databits used by RS-485 port. |
| Parity | 0: None<br>1: Even<br>2: Odd | Paritybits used by RS-485 port. |
| Stopbits | 1...2 | Stopbits used by RS-485 port. |
| Protocol | 0: None<br>1: ModbutRTU<br>2: ModbusIO<br>3: IEC103<br>4: SPA<br>5: DNP3<br>6: IEC101 | Communication protocol used by RS-485 port. |

AQ-200 series supports communication option card type that has serial fiber ports (Serial COM2) an RS-232 port (Serial COM3).

Table. 6.1 - 361. Serial COM2 settings.

| Name | Range | Description |
|---|---|---|
| Bitrate | 0: 9600bps<br>1: 19200bps<br>2: 38400bps | Bitrate used by serial fiber channels. |
| Databits | 7...8 | Databits used by serial fiber channels. |
| Parity | 0: None<br>1: Even<br>2: Odd | Paritybits used by serial fiber channels. |
| Stopbits | 1...2 | Stopbits used by serial fiber channels. |
| Protocol | 0: None<br>1: ModbutRTU<br>2: ModbusIO<br>3: IEC103<br>4: SPA<br>5: DNP3<br>6: IEC101 | Communication protocol used by serial fiber channels. |
| Echo | 0: Off<br>1: On | Enable or disable echo. |
| Idle Light | 0: Off<br>1: On | Idle light behaviour. |

Table. 6.1 - 362. Serial COM3 settings.

| Name | Range | Description |
|---|---|---|
| Bitrate | 0: 9600bps<br>1: 19200bps<br>2: 38400bps | Bitrate used by RS-232 port. |
| Databits | 7...8 | Databits used by RS-232 port. |
| Parity | 0: None<br>1: Even<br>2: Odd | Paritybits used by RS-232 port. |
| Stopbits | 1...2 | Stopbits used by RS-232 port. |



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| Name | Range | Description |
|---|---|---|
| Protocol | 0: None<br>1: ModbutRTU<br>2: ModbusIO<br>3: IEC103<br>4: SPA<br>5: DNP3<br>6: IEC101 | Communication protocol used by RS-232 port. |

## 6.2 Time synchronization

Time synchronization source can be selected with "Time synchronization" parameter at *Communication → Synchronization → General*.

Table. 6.2 - 363. General time synchronization source settings.

| Name | Range | Description |
|---|---|---|
| Time synchronization source | 0: Internal<br>1: External NTP<br>2: External serial<br>3: IRIG-B<br>4: PTP | Selection of time synchronization source. |

### 6.2.1 Internal

If no external time synchronization source is available the mode should be set to "internal". This means that the AQ-200 device clock runs completely on its own. Time can be set to the device with AQtivate setting tool with *Commands → Sync Time* command or in the clock view from the HMI. When using *Sync time* command AQtivate sets the time to device the connected computer is currently using. Please note that the clock doesn't run when the device is powered off.

### 6.2.2 NTP

When enabled, the NTP (Network Time Protocol) service can use external time sources to synchronize the device's system time. The NTP client service uses an Ethernet connection to connect to the NTP time server. NTP can be enabled by setting the primary time server and the secondary time server parameters to the address of the system's NTP time source(s).

Table. 6.2.2 - 364. Server settings.

| Name | Range | Description |
|---|---|---|
| Primary time server address | 0.0.0.0...255.255.255.255 | Defines the address of the primary NTP server. Setting this parameter at "0.0.0.0" means that the server is not in use. |
| Secondary time server address | 0.0.0.0...255.255.255.255 | Defines the address of the secondary (or backup) NTP server. Setting this parameter at "0.0.0.0" means that the server is not in use. |

Table. 6.2.2 - 365. Status.

| Name | Range | Description |
|---|---|---|
| NTP quality for events | 0: No sync<br>1: Synchronized | Displays the status of the NTP time synchronization at the moment.<br>NOTE: This indication is not valid if another time synchronization method is used (external serial). |
| NTP-processed message count | 0...4294967295 | Displays the number of messages processed by the NTP protocol. |

Additionally, the time zone of the relay can be set by connecting to the relay and the selecting the time zone at *Commands → Set time zone* in AQtivate setting tool.

### 6.2.3 PTP

PTP, Precision Time Protocol, is a higher accuracy synchronization protocol for Ethernet networks. Accuracy of microsecond level can be achieved.

In a PTP network the devices can have different roles. There is a Grandmaster clock that is the clock source, normally connected to GPS. Most devices take the role of an Ordinary clock which receive synchronization from the Grandmaster clock. In the PTP network there can also be Boundary and Transparent clock roles, these are most often PTP enabled switches that can redistribute time or compensate for their delays.

BMCA, Best Master Clock Algorithm, is an algorithm that PTP devices use to determine the best clock source. This is utilized in network segments where there are 2 Grandmaster clocks or in situations where there are no Grandmaster available. In these situations the devices make a selection which device will act as the clock source. In these cases without GPS synchronized clock source, the accuracy between the devices is still high.

#### Settings

Select PTP as the time synchronization source from *Communication → Synchronization → General* menu.

The following settings are available in *Communication → Synchronization → PTP* menu.

Table. 6.2.3 - 366. PTP time synchronization settings.

| Name | Range | Description |
|---|---|---|
| Role | 0: Auto (Default)<br>1: Master<br>2: Slave | In Auto mode, the device can take both the role of a clock source and clock consumer. In Master mode the device is forced to concider itself to be a clock source. In Slave mode the device is forced to be a clock consumer. |
| Mechanism | 0: P2P (Default)<br>1: E2E | Delay measurement mechanism used. Peer-to-peer can utilize the PTP enabled switches as transparent ro boundary clocks while End-to-end must be used if non-PTP enabled switches are found in the network. |
| Domain number | 0...255 | PTP devices can be set to belong to a grouping called domain. Devices in same domain is primearly being synchronized together. |

#### Status indications

The following status indications are available in *Communication → Synchronization → PTP* menu.

Table. 6.2.3 - 367. PTP status indications

| Name | Description |
|---|---|
| State | State of the PTP application (Master, Slave, Listening). |
| Best master | Identification of best master in network. Id consist of MAC address plus id number. |
| Last receive | Time when last synchronization frame was received. |
| Message sent | Diagnostic message counter. |
| Message receive | Diagnostic message counter. |
| PTP timesource | Diagnostic number describing the current time source. |


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## 6.3 Communication protocols

### 6.3.1 IEC 61850

The user can enable the IEC 61850 protocol in device models that support this protocol at *Communication → Protocols → IEC61850*. AQ-21x frame units support Edition 1 of IEC 61850. AQ-25x frame units support both Edition 1 and 2 of IEC 61850. The following services are supported by IEC 61850 in Arcteq devices:

- Up to six data sets (predefined data sets can be edited with the IEC 61850 tool in AQtivate)
- Report Control Blocks (both buffered and unbuffered reporting)
- Control ('Direct operate with normal security', 'Select before operate with normal security, 'Direct with enhanced security' and 'Select before operate with enhanced sequrity' control sequences)
- Disturbance recording file transfer
- GOOSE
- Time synchronization

The device's current IEC 61850 setup can be viewed and edited with the IEC61850 tool (*Tools → Communication → IEC 61850*).

### Settings.

The general setting parameters for the IEC 61850 protocol are visible both in AQtivate and in the local HMI. The settings are described in the table below.

Table. 6.3.1 - 368. General settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable IEC 61850 | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables and disables the IEC 61850 communication protocol. |
| Reconfigure IEC 61850 | 0: -<br>1: Reconfigure | - | 0: - | Reconfigures IEC 61850 settings. |
| IP port | 0…65 535 | 1 | 102 | Defines the IP port used by the IEC 61850 protocol.<br><br>The standard (and default) port is 102. |
| IEC61850 edition | 0: Ed1<br>0: Ed2 | - | - | Displays the IEC61850 edition used by the device. Edition can be chosen by loading a new CID file at *Tools → Communication → IEC 61850* with *Open* button. |
| Control Authority switch | 0: Remote Control<br>1: Station Level Control | - | 0: Remote Control | The device can be set to allow object control via IEC 61850 only from clients that are of category Station level control. This would mean that other Remote control clients would not be allowed to control. In Remote control mode all IEC 61850 clients of both remote and station level category are allowed to control objects. |
| Ethernet port | 0: All<br>1: COM A<br>2: Double ethernet card | - | 0: All | Determines which ports use IEC61850. Parameter is visible if double ethernet option card is found in the device. |
| Configure GOOSE Subscriber from CID file allowed | 0: Disabled<br>1: Allowed | - | 0: Disabled | In edition 2 of IEC 61850 GOOSE subscriber configuration is a part of the CID file. Determines if it is possible to import published GOOSE settings of another device with a CID file and set them to GOOSE input at *Tools → Communication → IEC 61850 → GOOSE subscriptions*. |
| General deadband | 0.1…10.0 % | 0.1 % | 2 % | Determines the general data reporting deadband settings. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Active energy deadband | 0.1…1000.0 kWh | 0.1 kWh | 2 kWh | Determines the data reporting deadband settings for this measurement. |
| Reactive energy deadband | 0.1…1000.0 kVar | 0.1 kVar | 2 kVar | Determines the data reporting deadband settings for this measurement. |
| Active power deadband | 0.1…1000.0 kW | 0.1 kW | 2 kW | Determines the data reporting deadband settings for this measurement. |
| Reactive power deadband | 0.1…1000.0 kVar | 0.1 kVar | 2 kVar | Determines the data reporting deadband settings for this measurement. |
| Apparent power deadband | 0.1…1000.0 kVA | 0.1 kVA | 2 kVA | Determines the data reporting deadband settings for this measurement. |
| Power factor deadband | 0.01…0.99 | 0.01 | 0.05 | Determines the data reporting deadband settings for this measurement. |
| Frequency deadband | 0.01…1.00 Hz | 0.01 Hz | 0.1 Hz | Determines the data reporting deadband settings for this measurement. |
| Current deadband | 0.01…50.00 A | 0.01 A | 5 A | Determines the data reporting deadband settings for this measurement. |
| Residual current deadband | 0.01…50.00 A | 0.01 A | 0.2 A | Determines the data reporting deadband settings for this measurement. |
| Voltage deadband | 0.01…5000.00 V | 0.01 V | 200 V | Determines the data reporting deadband settings for this measurement. |
| Residual voltage deadband | 0.01…5000.00 V | 0.01 V | 200 V | Determines the data reporting deadband settings for this measurement. |
| Angle measurement deadband | 0.1…5.0 deg | 0.1 deg | 1 deg | Determines the data reporting deadband settings for this measurement. |
| Integration time | 0…10 000 ms | 1 ms | 0 ms | Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use. |
| GOOSE Ethernet port | 0: All<br>1: COM A<br>2: Double ethernet card | - | 0: All | Determines which ports can use GOOSE communication. Visible if double ethernet option card is found in the device. |

For more information on the IEC 61850 communication protocol support, please refer to the conformance statement documents (www.arcteq.fi/downloads/ → AQ-200 series → Resources).

#### 6.3.1.1 Logical device mode and logical node mode

Every protection block has its own behavior (LNBeh). This behavior is determined using a combination of the protection block's mode (LNMod) and the device's mode (LDMod).

In IEC68150 mode,

- LNMod can be reported and controlled through Mod data object in all logical nodes.
- LNBeh can be reported through Beh data object in all logical nodes.
- LDMod is only visible through logical node zero's Mod data object (LLN0.Mod).

#### Mode and behavior values

There are 5 values defined for mode and behavior: On, Blocked, Test, Test / Blocked and Off.



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Table. 6.3.1.1 - 369. Behavior descriptions.

| LNBeh | On | Blocked | Test | Test / Blocked | Off |
|---|---|---|---|---|---|
| Function working | Yes | Yes | Yes | Yes | No |
| Data quality | Relevant to data | Relevant to data | q.test = True | q.test = True | q.validity = Invalid |
| Output to process | Yes | No | Yes | No | No |
| Accept normal control | Yes | Yes | No | No | No |
| Accept test control | No | No | Yes | Yes | No |

The communication services for the data object Mod do not care about the status of the LNBeh. Mod will always accept commands with q.test = False.

Data objects Mod, Beh and Health will always have q.validity = Good. Regardless of the status of LNBeh, the quality test attribute of Mod, Beh and Health shall be q.test = False.

## Behavior determination

The values for LDMod and LNMod are settable by the user by using HMI, setting tool, or IEC 61850 client. The value for LNBeh are then determined using following rules.

- If either LDMod or LNMod is Off, LNBeh is Off.
- Otherwise,
    - If either LDMod or LNMod is set to either "Test" or "Test / Blocked" mode, LNBeh is in Test mode.
    - If either LDMod or LNMod is set to either "Blocked" or "Test / Blocked" mode, LNBeh is in Blocked mode.
    - If LNBeh still doesn't have anything, LNBeh is "On".

All the possible combinations are laid out in the following table.

Table. 6.3.1.1 - 370. All possible logical device and logical node combinations.

| LDMod | LNMod | LNBeh |
|---|---|---|
| Off | Off | Off |
| | Test / Blocked | Off |
| | Test | Off |
| | Blocked | Off |
| | On | Off |
| Test / Blocked | Off | Off |
| | Test / Blocked | Test / Blocked |
| | Test | Test / Blocked |
| | Blocked | Test / Blocked |
| | On | Test / Blocked |
| Test | Off | Off |
| | Test / Blocked | Test / Blocked |
| | Test | Test |
| | Blocked | Test / Blocked |
| | On | Test |

| LDMod | LNMod | LNBeh |
|---|---|---|
| Blocked | Off | Off |
| | Test / Blocked | Test / Blocked |
| | Test | Test / Blocked |
| | Blocked | Blocked |
| | On | Blocked |
| On | Off | Off |
| | Test / Blocked | Test / Blocked |
| | Test | Test |
| | Blocked | Blocked |
| | On | On |

## Processing of incoming data in different behaviors

This part only applies to incoming data with quality information.

The table below gives the functional processing of the data in different behavior states as defined by the standard. Logical nodes should process receiving data according to their quality information:

- Processed as valid - Reacts according to the quality.
- Processed as invalid - Reacts as if the quality of the data had been invalid.
- Processed as questionable - The application decides how to consider the status value.
- Not processed - Do not belong to communication services, no quality bit can be evaluated.

Table. 6.3.1.1 - 371. Processing of incoming data in different behaviors as defined by the standard.

| | On | Blocked | Test | Test / Blocked | Off |
|---|---|---|---|---|---|
| q.validity = Good<br>q.test = False | Processed as valid | Processed as valid | Processed as valid | Processed as valid | Not processed |
| q.validity = Questionable<br>q.test = False | Processed as questionable | Processed as questionable | Processed as questionable | Processed as questionable | Not processed |
| q.validity = Good<br>q.test = True | Processed as invalid | Processed as invalid | Processed as valid | Processed as valid | Not processed |
| q.validity = Questionable<br>q.test = True | Processed as invalid | Processed as invalid | Processed as questionable | Processed as questionable | Not processed |
| q.validity = Invalid<br>q.test = True/False | Processed as invalid | Processed as invalid | Processed as invalid | Processed as invalid | Not processed |

Arcteq's implementation treats “Processed as questionable” and “Processed as invalid” in the same way with “Not processed”. Only "Processed as valid" is passed to the application.



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Table. 6.3.1.1 - 372. Arcteq's implementation of processing of incoming data in different behaviors.

| | On | Blocked | Test | Test / Blocked | Off |
|---|---|---|---|---|---|
| q.validity = Good<br>q.test = False | Processed as valid | Processed as valid | Processed as valid | Processed as valid | |
| q.validity = Questionable<br>q.test = False | | | | | |
| q.validity = Good<br>q.test = True | | | Processed as valid | Processed as valid | |
| q.validity = Questionable<br>q.test = True | | | | | |
| q.validity = Invalid<br>q.test = True/False | | | | | |

## Using mode and behavior

Enabling LDMod and LNMod changing can be done at *General → Device info*.

Table. 6.3.1.1 - 373. Parameters to allow changing of LNMod and LDMod.

| Name | Range | Default | Description |
|---|---|---|---|
| Allow setting of device mode | 0: Prohibited<br>1: From HMI/setting tool only<br>2: Allowed | 0: Prohibited | Allows global mode to be modified from setting tool, HMI and IEC61850.<br><br>Prohibited: Cannot be changed.<br><br>From HMI/setting tool only: Can only be changed from the setting tool or HMI.<br><br>Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client. |
| Allow setting of individual LN mode | 0: Prohibited<br>1: From HMI/setting tool only<br>2: Allowed | 0: Prohibited | Allow local modes to be modified from setting tool, HMI and IEC61850.<br><br>This parameter is visible only when "Allow setting of device mode" is enabled.<br><br>Prohibited: Cannot be changed.<br><br>From HMI/setting tool only: Can only be changed from the setting tool or HMI<br><br>Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client. |

When enabled it is possible to change LDMod at *Communication → Protocols → IEC61850*.

Table. 6.3.1.1 - 374. Parameter for changing logical device mode.

| Name | Range | Default | Description |
|---|---|---|---|
| Allow setting of device mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 0: On | Set mode of logical device.<br><br>This parameter is visible only when *Allow setting of device mode* is enabled in *General* menu. |

Each protection, control and monitoring function has its own logical node mode which can be changed individually. This parameter is found in the functions *Info*-menu. Each function also reports its behavior. Behavior of the function is influenced by the status of the device mode setting and the functions mode setting.

Table. 6.3.1.1 - 375. LNMod parameters.

| Name | Range | Default | |
|---|---|---|---|
| LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of function logical node.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| LN behavior | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Displays the mode of the function logical node.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |

### 6.3.1.2 GOOSE

Arcteq relays support both GOOSE publisher and GOOSE subscriber. GOOSE subscriber is enabled with the "GOOSE subscriber enable" parameter at *Communication → Protocols → IEC 61850/ GOOSE*. The GOOSE inputs are configured using either the local HMI or the AQtivate software.

There are up to 64 GOOSE inputs available for use. Each of the GOOSE inputs also has a corresponding input quality signal which can also be used in internal logic. The quality is good, when the input quality status is "low" (that is, when the quality is marked as "0"). The value of the input quality can switch on as a result of a GOOSE time-out or a configuration error, for example. The status and quality of the various logical input signals can be viewed at the *GOOSE IN status* and *GOOSE IN quality* tabs at *Control → Device I/O → Logical signals*.

#### General GOOSE setting

The table below presents general settings for GOOSE publisher.

Table. 6.3.1.2 - 376. General GOOSE publisher settings.

| Name | Range | Description |
|---|---|---|
| GOOSE control block 1 simulation bit | 0: Disabled (Default)<br>1: Enabled | The publisher will publish frames with simulation bit active if enabled. For GOOSE simulation testing purposes. |
| GOOSE control block 2 simulation bit | | |

The table below presents general settings for GOOSE subscriber

Table. 6.3.1.2 - 377. General GOOSE subscriber settings.

| Name | Range | Description |
|---|---|---|
| GOOSE subscriber enable | 0: Disabled (Default)<br>1: Enabled | Enables or disables GOOSE subscribing for the device. |



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| Name | Range | Description |
|---|---|---|
| Not used GOOSE input Quality | 1: Bad quality (1)<br>2: Good quality (0) | Defines what state should GOOSE input quality signal to be in the logic if the input has been set as "disabled". |
| Subscriber checks GoCBRef | 0: No (Default)<br>1: Yes | When subscriber sees GOOSE frame it checks APPID and Conf. Rev but can also check if GoCBRef or SqNum match. |
| Subscriber checks SqNum | | |
| Subscriber process simulation messages | 0: No (Default)<br>1: Yes | Subscriber can be set to process frames which are published with simulation bit high if enabled.<br><br>The subscriber can still subscribe to non-simulated frames from a publisher until that a simulated frame is received from a publisher. From that point on, only simulated frames are accepted from that publisher.<br><br>For other publishers, non-simulated frames are accepted normally (given no simulated frame is received from that publisher).<br><br>This behavior ends when the setting is set back to No. |

## GOOSE input settings

The table below presents the different settings available for all 64 GOOSE inputs.

These settings can be found from *Communication → Protocols → IEC61850/GOOSE → GOOSE Input Settings*.

Table. 6.3.1.2 - 378. GOOSE input settings.

| Name | Range | Description |
|---|---|---|
| In use | 0: No (Default)<br>1: Yes | Enables and disables the GOOSE input in question. |
| Application ID ("AppID") | 0×0…0×3FFF | Defines the application ID that will be matched with the publisher's GOOSE control block. |
| Configuration revision ("ConfRev") | 1…$2^{32}$-1 | Defines the configuration revision that will be matched with the publisher's GOOSE control block. |
| Data index ("DataIdx") | 0…99 | Defines the data index of the value in the matched published frame. It is the status of the GOOSE input. |
| NextIdx is quality | 0: No (Default)<br>1: Yes | Selects whether or not the next received input is the quality bit of the GOOSE input. |
| Data type | 0: Boolean (Default)<br>1: Integer<br>2: Unsigned<br>3: Floating point | Selects the data type of the GOOSE input. |
| Control block reference | - | GOOSE subscriber can be set to check the GCB reference of the published GOOSE frame. This setting is automatically filled when Ed2 GOOSE configuration is done by importing cid file of the publisher. |

## GOOSE input descriptions

Each of the GOOSE inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

These settings can be found from *Control → Device IO → Logical Signals → GOOSE IN Description*.

Table. 6.3.1.2 - 379. GOOSE input user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description GI x | 1...31 characters | GOOSE IN x | Description of the GOOSE input. This description is used in several menu types for easier identification. |

## GOOSE input values

Each of the GOOSE subscriber inputs (1...64) have indications listed in the following table. These indications can be found from *Communication → Protocols → IEC61850/GOOSE → GOOSE input values*.

Table. 6.3.1.2 - 380. GOOSE input indications

| Name | Range | Description |
|---|---|---|
| Subscription status | 0: Not Active<br>1: Active | When active correct data received and passed to application. |
| Processing simulation message | 0: False<br>1: True | When true subscriber is processing simulation frames for this input (and rejecting non-simulated frames). |
| Needs commissioning | 0: False<br>1: True | When true configuration doesn't match the received frame (goCBRef, confRev). |
| Last received state number | 0...4294967295 | Status number (stNum) of the last data passed to application. |
| GOOSE IN X boolean value | 0...1 | GOOSE input 1...64 boolean value. |
| GOOSE IN X analog value | -3.4E+38...3.4E+38 | GOOSE input 1...64 analog value. |


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| Name | Range | Description |
|---|---|---|
| GOOSE IN X quality | 0: Old data<br>1: Failure<br>2: Oscillatory<br>3: Bad reference<br>4: Out of range<br>5: Overflow<br>6: Invalid<br>7: Reserved/ Questionable<br>8: Reserved<br>9: Reserved<br>10: Reserved<br>11: Operator blocked<br>12: Test<br>13: Substituted<br>14: Inaccurate<br>15: Inconsistent | GOOSE input quality indication. |
| GOOSE IN X time | DD/MM/YYYY HH:MM:SS | Time when publisher sent GOOSE frame. |
| GOOSE IN X time fraction | 0...4294967295 µs | Microseconds of the publisher GOOSE frame. |

### GOOSE events

GOOSE signals generate events from status changes. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The events triggered by the function are recorded with a time stamp and with process data values. The time stamp resolution is 1 ms.

Table. 6.3.1.2 - 381. GOOSE event

| Event block name | Event name | Description |
|---|---|---|
| GOOSE1...GOOSE2 | GOOSE IN 1...64 ON/OFF | Status change of GOOSE input. |
| GOOSE3...GOOSE4 | GOOSE IN 1...64 quality Bad/Good | Status change of GOOSE inputs quality. |
| GOOSE5...GOOSE6 | GOOSE Subscription status 1...64 Active/Not active | When active correct data received and passed to application. |
| GOOSE7...GOOSE8 | GOOSE Processing simulated messages 1...64 True/False | When true subscriber is processing simulation frames for this input (and rejecting non-simulated frames). |
| GOOSE9...GOOSE10 | GOOSE Subscription needs commissioning 1...64 True/False | When true configuration doesn't match the received frame (goCBRef, confRev). |

### Setting the publisher

The configuration of the GOOSE publisher is done using the IEC 61850 tool in AQtivate (*Tools → Communication → IEC 61850*). Refer to *AQtivate-200 Instruction manual* for more information on how to set up GOOSE publisher.

## 6.3.2 Modbus/TCP and Modbus/RTU

The device supports both Modbus/TCP and Modbus/RTU communication. Modbus/TCP uses the Ethernet connection to communicate with Modbus/TCP clients. Modbus/RTU is a serial protocol that can be selected for the available serial ports.

The following Modbus function types are supported:

- Read multiple holding registers (function code 3)

- Write single holding register (function code 6)
- Write multiple holding registers (function code 16)
- Read/Write multiple registers (function code 23)

The following data can be accessed using both Modbus/TCP and Modbus/RTU:

- Device measurements
- Device I/O
- Commands
- Events
- Time

Once the configuration file has been loaded, the user can access the Modbus map of the relay via the AQtivate software (*Tools → Communication → Modbus Map*). Please note that holding registers start from 1. Some masters might begin numbering holding register from 0 instead of 1; this will cause an offset of 1 between the relay and the master. Modbus map can be edited with Modbus Configurator (*Tools → Communication → Modbus Configurator*).

Table. 6.3.2 - 382. Modbus/TCP settings.

| Parameter | Range | Description |
|---|---|---|
| Enable Modbus/ TCP | 0: Disabled<br>1: Enabled | Enables and disables the Modbus/TCP on the Ethernet port. |
| IP port | 0…65 535 | Defines the IP port used by Modbus/TCP. The standard port (and the default setting) is 502. |
| Ethernet port | 0: All<br>1: COM A<br>2: Double Ethernet card | Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device. |
| Event read mode | 0: Get oldest available<br>1: Continue previous connection<br>2: New events only | 0: Get oldest event possible (Default)<br><br>1: Continue with the event idx from previous connection<br><br>2: Get only new events from connection time and forward. |

Table. 6.3.2 - 383. Modbus/RTU settings.

| Parameter | Range | Description |
|---|---|---|
| Slave address | 1…247 | Defines the Modbus/RTU slave address for the unit. |

## Reading events

Modbus protocol does not support time-stamped events by standard definition. This means that every vendor must come up with their own definition how to transfer events from the device to the client. In AQ-200 series devices events can be read from HR17...HR22 holding registers. HR17 contains the event-code, HR18...20 contains the time-stamp in UTC, HR21 contains a sequential index and HR22 is reserved for future expansion. See the Modbus Map for more information. The event-codes and their meaning can be found from Event list (*Tools → Events ang Logs → Event list* in setting tool). The event-code in HR17 is 0 if no new events can be found in the device event-buffer. Every time HR17 is read from client the event in event-buffer is consumed and on following read operation the next un-read event information can be found from event registers. HR11…HR16 registers contains a back-up of last read event. This is because some users want to double-check that no events were lost


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### 6.3.3 IEC 103

IEC 103 is the shortened form of the international standard IEC 60870-5-103. The AQ-200 series units are able to run as a secondary (slave) station. The IEC 103 protocol can be selected for the serial ports that are available in the device. A primary (master) station can then communicate with the AQ-200 device and receive information by polling from the slave device. The transfer of disturbance recordings is not supported.

NOTE: Once the configuration file has been loaded, the IEC 103 map of the relay can be found in the AQtivate software (*Tools → IEC 103 map*).

The following table presents the setting parameters for the IEC 103 protocol.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Slave address | 1…254 | 1 | 1 | Defines the IEC 103 slave address for the unit. |
| Measurement interval | 0…60 000 ms | 1 ms | 2000 ms | Defines the interval for the measurements update. |

### 6.3.4 IEC 101/104

The standards IEC 60870-5-101 and IEC 60870-5-104 are closely related. Both are derived from the IEC 60870-5 standard. On the physical layer the IEC 101 protocol uses serial communication whereas the IEC 104 protocol uses Ethernet communication. The IEC 101/104 implementation works as a slave in the unbalanced mode.

For detailed information please refer to the IEC 101/104 interoperability document (www.arcteq.fi/downloads/ → AQ-200 series → Resources → "AQ-200 IEC101 & IEC104 interoperability").

#### IEC 101 settings

Table. 6.3.4 - 384. IEC 101 settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Common address of ASDU | 0…65 534 | 1 | 1 | Defines the common address of the application service data unit (ASDU) for the IEC 101 communication protocol. |
| Common address of ASDU size | 1…2 | 1 | 2 | Defines the size of the common address of ASDU. |
| Link layer address | 0…65 534 | 1 | 1 | Defines the address for the link layer. |
| Link layer address size | 1…2 | 1 | 2 | Defines the address size of the link layer. |
| Information object address size | 2…3 | 1 | 3 | Defines the address size of the information object. |
| Cause of transmission size | 1…2 | 1 | 2 | Defines the cause of transmission size. |

#### IEC 104 settings

Table. 6.3.4 - 385. IEC 104 settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| IEC 104 enable | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enables and disables the IEC 104 communication protocol. |
| IP port | 0…65 535 | 1 | 2404 | Defines the IP port used by the protocol. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Ethernet port | 0: All<br>1: COM A<br>2: Double Ethernet card | - | 0: All | Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device. |
| Common address of ASDU | 0…65 534 | 1 | 1 | Defines the common address of the application service data unit (ASDU) for the IEC 104 communication protocol. |

## Measurement scaling coefficients

The measurement scaling coefficients are available for the following measurements, in addition to the general measurement scaling coefficient:

Table. 6.3.4 - 386. Measurements with scaling coefficient settings.

| Name | Range |
|---|---|
| Active energy | 0: No scaling<br>1: 1/10<br>2: 1/100<br>3: 1/1000<br>4: 1/10 000<br>5: 1/100 000<br>6: 1/1 000 000<br>7: 10<br>8: 100<br>9: 1000<br>10: 10 000<br>11: 100 000<br>12: 1 000 000 |
| Reactive energy | |
| Active power | |
| Reactive power | |
| Apparent power | |
| Power factor | |
| Frequency | |
| Current | |
| Residual current | |
| Voltage | |
| Residual voltage | |
| Angle | |

## Deadband settings.

Table. 6.3.4 - 387. Analog change deadband settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| General deadband | 0.1…10.0% | 0.1% | 2% | Determines the general data reporting deadband settings. |
| Active energy deadband | 0.1…1000.0kWh | 0.1kWh | 2kWh | Determines the data reporting deadband settings for this measurement. |
| Reactive energy deadband | 0.1…1000.0kVar | 0.1kVar | 2kVar | |
| Active power deadband | 0.1…1000.0kW | 0.1kW | 2kW | |
| Reactive power deadband | 0.1…1000.0kVar | 0.1kVar | 2kVar | |
| Apparent power deadband | 0.1…1000.0kVA | 0.1kVA | 2kVA | |
| Power factor deadband | 0.01…0.99 | 0.01 | 0.05 | |
| Frequency deadband | 0.01…1.00Hz | 0.01Hz | 0.1Hz | |
| Current deadband | 0.01…50.00A | 0.01A | 5A | |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Residual current deadband | 0.01…50.00A | 0.01A | 0.2A | |
| Voltage deadband | 0.01…5000.00V | 0.01V | 200V | |
| Residual voltage deadband | 0.01…5000.00V | 0.01V | 200V | |
| Angle measurement deadband | 0.1…5.0deg | 0.1deg | 1deg | |
| Integration time | 0…10 000ms | 1ms | - | Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use. |

### 6.3.5 SPA

The device can act as a SPA slave. SPA can be selected as the communication protocol for the RS-485 port (Serial COM1). When the device has a serial option card, the SPA protocol can also be selected as the communication protocol for the serial fiber (Serial COM2) ports or RS-232 (Serial COM3) port. Please refer to the chapter "Construction and installation" in the device manual to see the connections for these modules.

The data transfer rate of SPA is 9600 bps, but it can also be set to 19 200 bps or 38 400 bps. As a slave the device sends data on demand or by sequenced polling. The available data can be measurements, circuit breaker states, function starts, function trips, etc. The full SPA signal map can be found in AQtivate (*Tools → SPA map*).

The SPA event addresses can be found at *Tools → Events and logs → Event list*.

Table. 6.3.5 - 388. SPA setting parameters.

| Name | Range | Description |
|---|---|---|
| SPA address | 1...899 | SPA slave address. |
| UTC time sync | 0: Disabled 1: Enabled | Determines if UTC time is used when synchronizing time. When disabled it is assumed time synchronization uses local time. If enabled it is assumed that UTC time is used. When UTC time is used the timezone must be set at *Commands → Set time zone*. |

NOTE!

To access SPA map and event list, an .aqs configuration file should be downloaded from the relay.

### 6.3.6 DNP3

DNP3 is a protocol standard which is controlled by the DNP Users Group (www.dnp.org). The implementation of a DNP3 slave is compliant with the DNP3 subset (level) 2, but it also contains some functionalities of the higher levels. For detailed information please refer to the DNP3 Device Profile document (www.arcteq.fi/downloads/ → AQ-200 series → Resources).

#### Settings

The following table describes the DNP3 setting parameters.

Table. 6.3.6 - 389. Settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable DNP3 TCP | 0: Disabled 1: Enabled | - | 0: Disabled | Enables and disables the DNP3 TCP communication protocol when the Ethernet port is used for DNP3. If a serial port is used, the DNP3 protocol can be enabled from *Communication → DNP3*. |
| IP port | 0…65 535 | 1 | 20 000 | Defines the IP port used by the protocol. |
| Ethernet port | 0: All 1: COM A 2: Double Ethernet card | - | 0: All | Defines which ethernet ports are available for Modbus connection. Visible if any double ethernet option card is installed in the device. |
| Slave address | 1…65 519 | 1 | 1 | Defines the DNP3 slave address of the unit. |
| Master address | 1…65 534 | 1 | 2 | Defines the address for the allowed master. |
| Link layer time-out | 0…60 000ms | 1ms | 0ms | Defines the length of the time-out for the link layer. |
| Link layer retries | 1…20 | 1 | 1 | Defines the number of retries for the link layer. |
| Diagnostic - Error counter | $0…2^{32}-1$ | 1 | - | Counts the total number of errors in received and sent messages. |
| Diagnostic - Transmitted messages | $0…2^{32}-1$ | 1 | - | Counts the total number of transmitted messages. |
| Diagnostic - Received messages | $0…2^{32}-1$ | 1 | - | Counts the total number of received messages. |

## Default variations

Table. 6.3.6 - 390. Default variations.

| Name | Range | Default | Description |
|---|---|---|---|
| Group 1 variation (BI) | 0: Var 1 1: Var 2 | 0: Var 1 | Selects the variation of the binary signal. |
| Group 2 variation (BI change) | 0: Var 1 1: Var 2 | 1: Var 2 | Selects the variation of the binary signal change. |
| Group 3 variation (DBI) | 0: Var 1 1: Var 2 | 0: Var 1 | Selects the variation of the double point signal. |
| Group 4 variation (DBI change) | 0: Var 1 1: Var 2 | 1: Var 2 | Selects the variation of the double point signal. |
| Group 20 variation (CNTR) | 0: Var 1 1: Var 2 2: Var 5 3: Var 6 | 0: Var 1 | Selects the variation of the control signal. |
| Group 22 variation (CNTR change) | 0: Var 1 1: Var 2 2: Var 5 3: Var 6 | 2: Var 5 | Selects the variation of the control signal change. |



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| Name | Range | Default | Description |
|---|---|---|---|
| Group 30 variation (AI) | 0: Var 1<br>1: Var 2<br>2: Var 3<br>3: Var 4<br>4: Var 5 | 4: Var 5 | Selects the variation of the analog signal. |
| Group 32 variation (AI change) | 0: Var 1<br>1: Var 2<br>2: Var 3<br>3: Var 4<br>4: Var 5<br>5: Var 7 | 4: Var 5 | Selects the variation of the analog signal change. |

## Setting the analog change deadbands

Table. 6.3.6 - 391. Analog change deadband settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| General deadband | 0.1…10.0% | 0.1% | 2% | Determines the general data reporting deadband settings. |
| Active energy deadband | 0.1…1000.0kWh | 0.1kWh | 2kWh | Determines the data reporting deadband settings for this measurement. |
| Reactive energy deadband | 0.1…1000.0kVar | 0.1kVar | 2kVar | |
| Active power deadband | 0.1…1000.0kW | 0.1kW | 2kW | |
| Reactive power deadband | 0.1…1000.0kVar | 0.1kVar | 2kVar | |
| Apparent power deadband | 0.1…1000.0kVA | 0.1kVA | 2kVA | |
| Power factor deadband | 0.01…0.99 | 0.01 | 0.05 | |
| Frequency deadband | 0.01…1.00Hz | 0.01Hz | 0.1Hz | |
| Current deadband | 0.01…50.00A | 0.01A | 5A | |
| Residual current deadband | 0.01…50.00A | 0.01A | 0.2A | |
| Voltage deadband | 0.01…5000.00V | 0.01V | 200V | |
| Residual voltage deadband | 0.01…5000.00V | 0.01V | 200V | |
| Angle measurement deadband | 0.1…5.0deg | 0.1deg | 1deg | |
| Integration time | 0…10 000ms | 1ms | 0ms | Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use. |

## 6.3.7 Modbus I/O

The Modbus I/O protocol can be selected to communicate on the available serial ports. The Modbus I/O is actually a Modbus/RTU master implementation that is dedicated to communicating with serial Modbus/RTU slaves such as RTD input modules. Up to three (3) Modbus/RTU slaves can be connected to the same bus polled by the Modbus I/O implementation. These are named I/O Module A, I/O Module B and I/O Module C. Each of the modules can be configured using parameters in the following two tables.

Table. 6.3.7 - 392. Module settings.

| Name | Range | Description |
|---|---|---|
| I/O module X address | 0…247 | Defines the Modbus unit address for the selected I/O Module (A, B, or C). If this setting is set to "0", the selected module is not in use. |
| Module x type | 0: ADAM-4018+<br>1: ADAM-4015 | Selects the module type. |
| Channels in use | Channel 0…Channel 7 (or None) | Selects the number of channels to be used by the module. |

Table. 6.3.7 - 393. Channel settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Thermocouple type | 0: +/- 20mA<br>1: 4…20mA<br>2: Type J<br>3: Type K<br>4: Type T<br>5: Type E<br>6: Type R<br>7: Type S | - | 1: 4…20mA | Selects the thermocouple or the mA input connected to the I/O module.<br><br>Types J, K, T and E are nickel-alloy thermocouples, while Types R and S are platinum/rhodium-alloy thermocouples. |
| Input value | -101.0…2 000.0 | 0.1 | - | Displays the input value of the selected channel. |
| Input status | 0: Invalid<br>1: OK | - | - | Displays the input status of the selected channel. |

## 6.4 Analog fault registers

At *Communication → General I/O → Analog fault registers* the user can set up to twelve (12) channels to record the measured value when a protection function starts or trips. These values can be read in two ways: locally from this same menu, or through a communication protocol if one is in use.

The following table presents the setting parameters available for the 12 channels.

Table. 6.4 - 394. Fault register settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Select record source | Not in use<br><br>I>, I>>, I>>>, I>>>> (IL1, IL2, IL3)<br><br>Id>, Id>>, Id>>>, Id>>>> (IL1, IL2, IL3)<br><br>I0>, I0>>, I0>>>, I0>>>> (I0)<br><br>I0d>, I0d>>, I0d>>>, I0d>>>> (I0)<br><br>FLX (Fault locator) | - | Not in use | Selects the protection function and its stage to be used as the source for the fault register recording.<br><br>The user can choose between non-directional overcurrent, directional overcurrent, non-directional earth fault, directional earth fault, and fault locator functions. |
| Select record trigger | TRIP signal<br><br>START signal<br><br>START and TRIP signals | - | 0: TRIP signal | Selects what triggers the fault register recording: the selected function's TRIP signal, its START signal, or either one. |
| Recorded fault value | - 1000 000.00…1 000 000.00 | 0.01 | - | Displays the recorded measurement value at the time of the selected fault register trigger. |



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## 6.5 Real-time measurements to communication

With the *Real-time signals to communication* menu the user can report measurements to SCADA in a faster interval. The real measurement update delay depends on the used communication protocol and equipment used. Up to eight (8) magnitudes can be selected. The recorded value can be either a per-unit value or a primary value (set by the user).

### Measurable values

Function block uses analog current and voltage measurement values. The relay uses these values as the basis when it calculates the primary and secondary values of currents, voltages, powers, impedances and other values.

Table. 6.5 - 395. Available measured values.

| Signals | Description |
|---|---|
| Currents | |
| IL1 (ff), IL2 (ff), IL3 (ff), I01 (ff), I02 (ff) | Fundamental frequency (RMS) current measurement values of phase currents and residual currents. |
| IL1 (TRMS), IL2 (TRMS), IL3 (TRMS), I01 (TRMS), I02 (TRMS) | TRMS current measurement values of phase currents and residual currents. |
| IL1, IL2, IL3, I01, I02 & $2^{nd}$ h., $3^{rd}$ h., $4^{th}$ h., $5^{th}$ h., $7^{th}$ h., $9^{th}$ h., $11^{th}$ h., $13^{th}$ h., $15^{th}$ h., $17^{th}$ h., $19^{th}$ h. | Magnitudes of the phase current components: $2^{nd}$ harmonic, $3^{rd}$ harmonic, $4^{th}$ harmonic, $5^{th}$ harmonic $7^{th}$, harmonic $9^{th}$, harmonic $11^{th}$, harmonic $13^{th}$, harmonic $15^{th}$, harmonic $17^{th}$, harmonic $19^{th}$ harmonic current. |
| I1, I2, I0Z | Positive sequence current, negative sequence current and zero sequence current. |
| I0CalcMag | Residual current calculated from phase currents. |
| IL1Ang, IL2Ang, IL3Ang,<br>I01Ang, I02Ang, I0CalcAng<br>I1Ang, I2Ang | Angles of each measured current. |
| Voltages | |
| UL1Mag, UL2Mag, UL3Mag,<br>UL12Mag, UL23Mag, UL31Mag,<br>U0Mag, U0CalcMag | Magnitudes of phase voltages, phase-to-phase voltages and residual voltages. |
| U1 Pos.seq V mag, U2 Neg.seq V mag | Positive and negative sequence voltages. |
| UL1Ang, UL2Ang, UL3Ang,<br>UL12Ang, UL23Ang, UL31Ang,<br>U0Ang, U0CalcAng | Angles of phase voltages, phase-to-phase voltages and residual voltages. |
| U1 Pos.seq V Ang, U2 Neg.seq V Ang | Positive and negative sequence angles. |
| Powers | |
| S3PH<br>P3PH<br>Q3PH | Three-phase apparent, active and reactive power. |
| SL1, SL2, SL3,<br>PL1, PL2, PL3,<br>QL1, QL2, QL3 | Phase apparent, active and reactive powers. |
| tanfi3PH<br>tanfiL1<br>tanfiL2<br>tanfiL3 | Tan (φ) of three-phase powers and phase powers. |
| cosfi3PH<br>cosfiL1<br>cosfiL2<br>cosfiL3 | Cos (φ) of three-phase powers and phase powers. |

| Signals | Description |
|---|---|
| Impedances and admittances | |
| RL12, RL23, RL31<br>XL12, XL23, XL31<br>RL1, RL2, RL3<br>XL1, XL2, XL3<br>Z12, Z23, Z31<br>ZL1, ZL2, ZL3 | Phase-to-phase and phase-to-neutral resistances, reactances and impedances. |
| Z12Ang, Z23Ang, Z31Ang,<br>ZL1Ang, ZL2Ang, ZL3Ang | Phase-to-phase and phase-to-neutral impedance angles. |
| Rseq, Xseq, Zseq<br>RseqAng, XseqAng, ZseqAng | Positive sequence resistance, reactance and impedance values and angles. |
| GL1, GL2, GL3, G0<br>BL1, BL2, BL3, B0<br>YL1, YL2, YL3, Y0 | Conductances, susceptances and admittances. |
| YL1angle, YL2angle, YL3angle,<br>Y0angle | Admittance angles. |
| Others | |
| System f. | Used tracking frequency at the moment. |
| Ref f1 | Reference frequency 1. |
| Ref f2 | Reference frequency 2. |
| M thermal T | Motor thermal temperature. |
| F thermal T | Feeder thermal temperature. |
| T thermal T | Transformer thermal temperature. |
| RTD meas 1…16 | RTD measurement channels 1…16. |
| Ext RTD meas 1…8 | External RTD measurement channels 1…8 (ADAM module). |

## Settings

Table. 6.5 - 396. Settings.

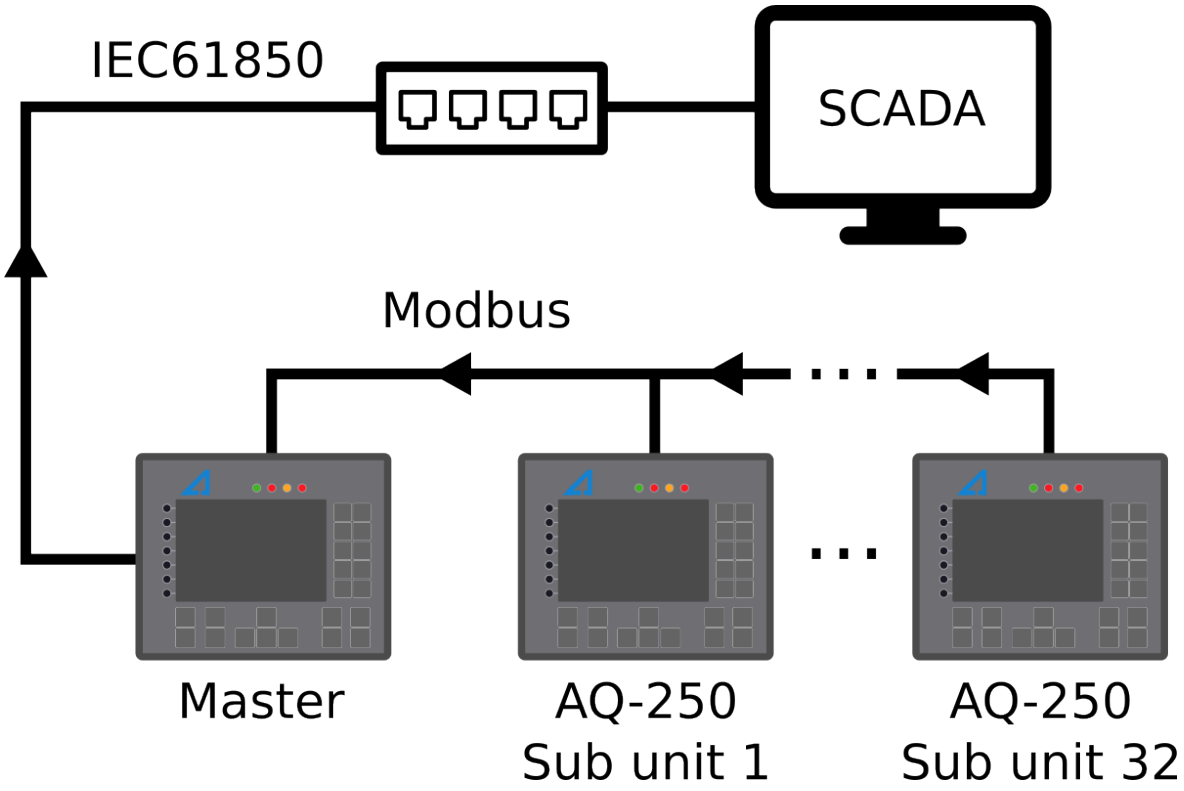
| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Measurement value recorder mode | 0: Disabled<br>1: Activated | - | 0: Disabled | Activates and disables the real-time signals to communication. |
| Scale current values to primary | 0: No<br>1: Yes | - | 0: No | Selects whether or not values are scaled to primary. |
| Slot X magnitude selection | 0: Currents<br>1: Voltages<br>2: Powers<br>3: Impedance (ZRX) and admittance (YGB)<br>4: Others | - | 0: Currents | Selects the measured magnitude catecory of the chosen slot. |
| Slot X magnitude | Described in table above ("Available measured values") | - | - | Selects the magnituge in the previously selected category. |
| Magnitude X | -10 000 000.000…10 000 000.000 | 0.001 | - | Displays the measured value of the selected magnitude of the selected slot.<br><br>The unit depends on the selected magnitude (either amperes, volts, or per-unit values). |



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## 6.6 Modbus Gateway

Figure. 6.6 - 205. Example setup of Modbus Gateway application.




Any AQ-250 device can be setup as a Modbus Gateway (i.e. master). Modbus Gateway device can import messages (measurements, status signals etc.) from external Arcteq and third-party devices. RS-485 serial communication port. Up to 32 sub units can be connected to an AQ-200 master unit. These messages can then be used for controlling logic in the master device, display the status in user created mimic. Binary signals can be reported forward to SCADA with IEC61850, IEC101, IEC103, IEC104, Modbus, DNP3 or SPA.

Arc protection relays AQ-103 and AQ-103 LV Modbus variant is designed to work as a sub unit with Modbus Gateway master. More details about AQ-103 and AQ-103 LV capabilities and how to set them up can be found in *AQ-103 Instruction manual* (arcteq.fi./downloads/). Also see application example at the end of this chapter.

Modbus Gateway and its basic settings can be found from *Communication → Modbus Gateway*. General settings-menu displays the health of connection to each sub unit.

Table. 6.6 - 397. General settings

| Name | Range | Description |
|---|---|---|
| Modbus Gateway mode | 0: Disabled (Default)<br>1: Enabled | Enables or disables Modbus Gateway. |
| Modbus Gateway reconfigure | 0: -<br>1: Reconfigure | Setting this parameter to "Reconfigure" takes new settings into use. Parameter returns back to "-" automatically. |
| Quality of Modbus Sub unit 1...32 | 0: OK<br>1: Old data<br>2: Data questionable<br>3: Modbus error<br>4: Send fail<br>5: Receive fail | Quality of each connected sub unit. |

## Imported signals

Modbus Gateway supports importing of measurements, bits, double bits, counters and integer signals. Up to 128 signals can be imported of each signal type with the exception of double bits (32).

Table. 6.6 - 398. Imported signals

| Name | Range |
|---|---|
| Imported measurement 1-128 | -3.4E+38...3.4E+38 |
| Imported bit signal 1-128 | 0...1 |
| Imported double bit data 1-32 | 0...3 |
| Imported counter data 1-128 | 0...4294967295 |
| Imported integer signal 1-128 | -2147483648...2147483647 |

To assign the signals use Modbus Gateway editor (*Tools → Communication → Modbus Gateway*). Detailed description of this tool can be found in *AQtivate 200 Instruction manual* (arcteq.fi./downloads/).

All imported signals can be given a description. The description will be displayed in most of menus with the signal (logic editor, matrix, block settings etc.).

Table. 6.6 - 399. Imported signal user description.

| Name | Range | Default | Description |
|---|---|---|---|
| Describe measurement x | 1...31 characters | Acq. Meas x | User settable description for the signal. This description is used in several menu types for easier identification. |
| Describe bit signal x | | Acq. Bit x | |
| Describe doube bit signal x | | Acq. Binary x | |
| Describe counter signal x | | Acq. Counter x | |
| Describe integer signal x | | Acq. Integer x | |

## Events

The Modbus Gateway generates events the status changes in imported bits and double bits. The user can select which event messages are stored in the main event buffer: ON, OFF, or both.

Table. 6.6 - 400. Event messages

| Event block name | Event names |
|---|---|
| MGWB1 | Bit 1...Bit 32 (ON, OFF) |
| MGWB2 | Bit 33...Bit 64 (ON, OFF) |
| MGWB3 | Bit 65...Bit 96 (ON, OFF) |
| MGWB4 | Bit 97...Bit 128 (ON, OFF) |
| MGWD1 | Double Bit 1... Double bit 16 (ON/ON, OFF/OFF, ON/OFF, OFF/ON) |
| MGWD2 | Double Bit 17... Double bit 32 (ON/ON, OFF/OFF, ON/OFF, OFF/ON) |

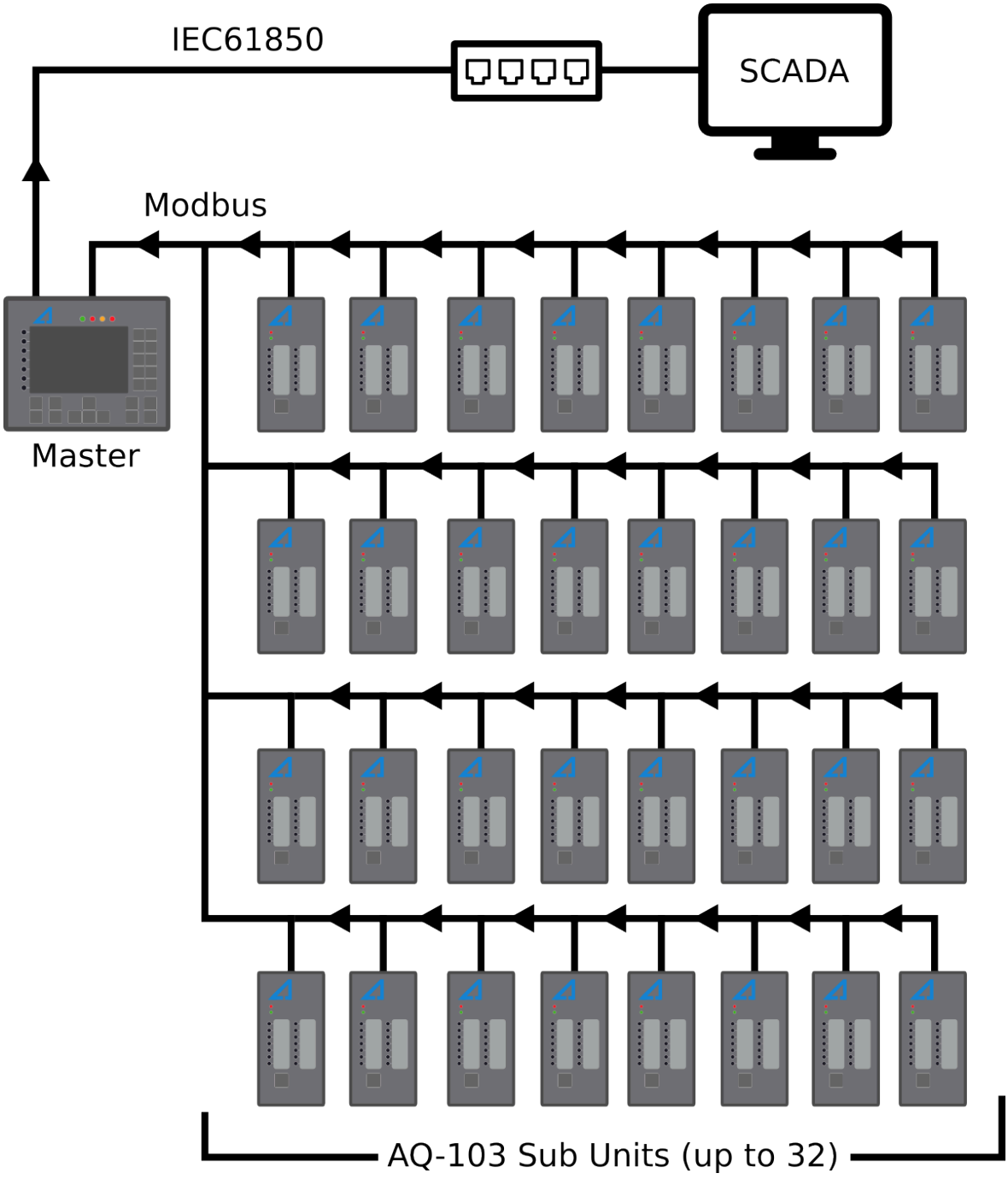

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## Connect AQ-103 devices to Modbus Gateway device

AQ-103 is a sophisticated microprocessor-based arc flash protection unit for arc light detection. AQ-103 acts as a sub-unit to AQ-110P (or, AQ-110F) in an AQ-100 arc protection system. It can also function as a stand-alone unit in light-only systems. AQ-103 provides communication through RS-485 and Modbus protocol as ordering options. Through the Modbus communication AQ-103 connects to an AQ-250 device for indication of exact fault location and to a SCADA system either trough a AQ-250 device or RTU.

AQ-103 Modbus variant is able to report various signals like number of installed sensors, sensor activations, I/O activations etc. Holding registers of each signal can be found in the AQ-103 instruction manual.

Figure. 6.6 - 206. AQ-250 device can receive signals through modbus and use them to control logic of the device, create mimics and report the values to IEC 61850.



The signals received from AQ-103 device can be used for fault indications on AQ-200 device and for reporting the signals forward with IEC 61850 or other communication protocol. Fault indication can be done by setting up an alarm display for each incoming signal or by building a mimic.

Figure. 6.6 - 207. To report imported bit signals to SCADA the signals must be connected to a logical output.

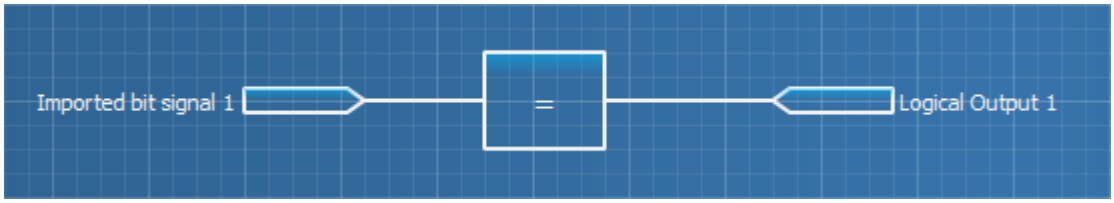
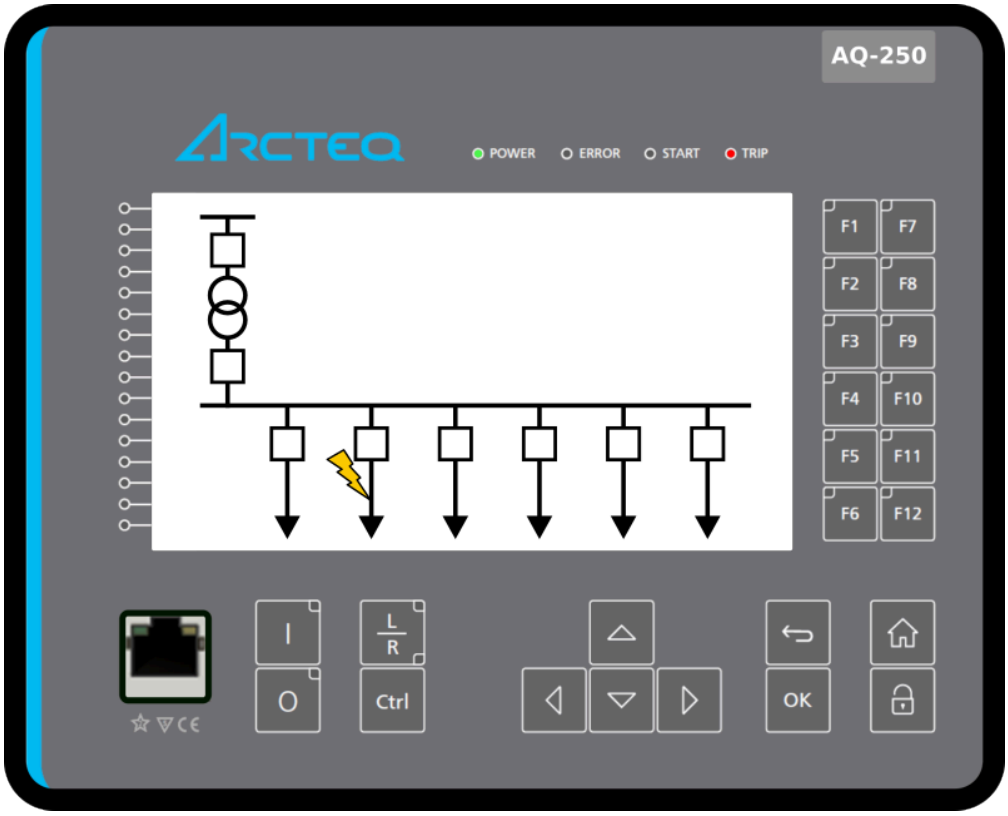


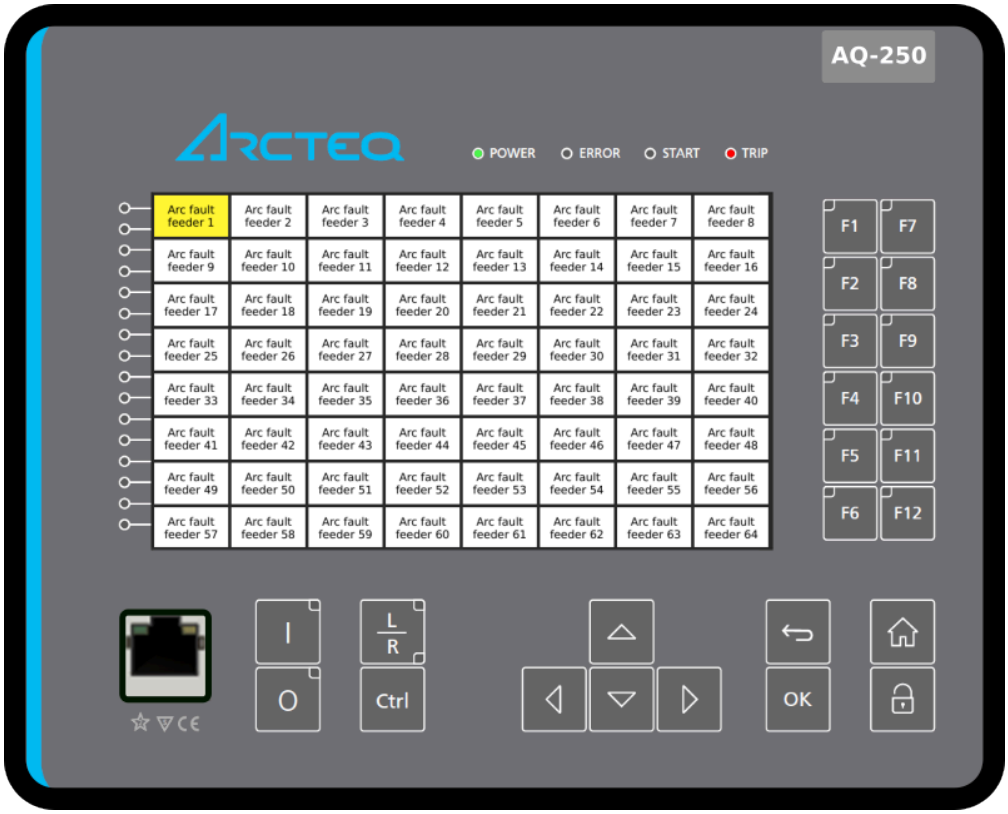

Figure. 6.6 - 208. Example mimic where sensor activation location is indicated with a symbol.






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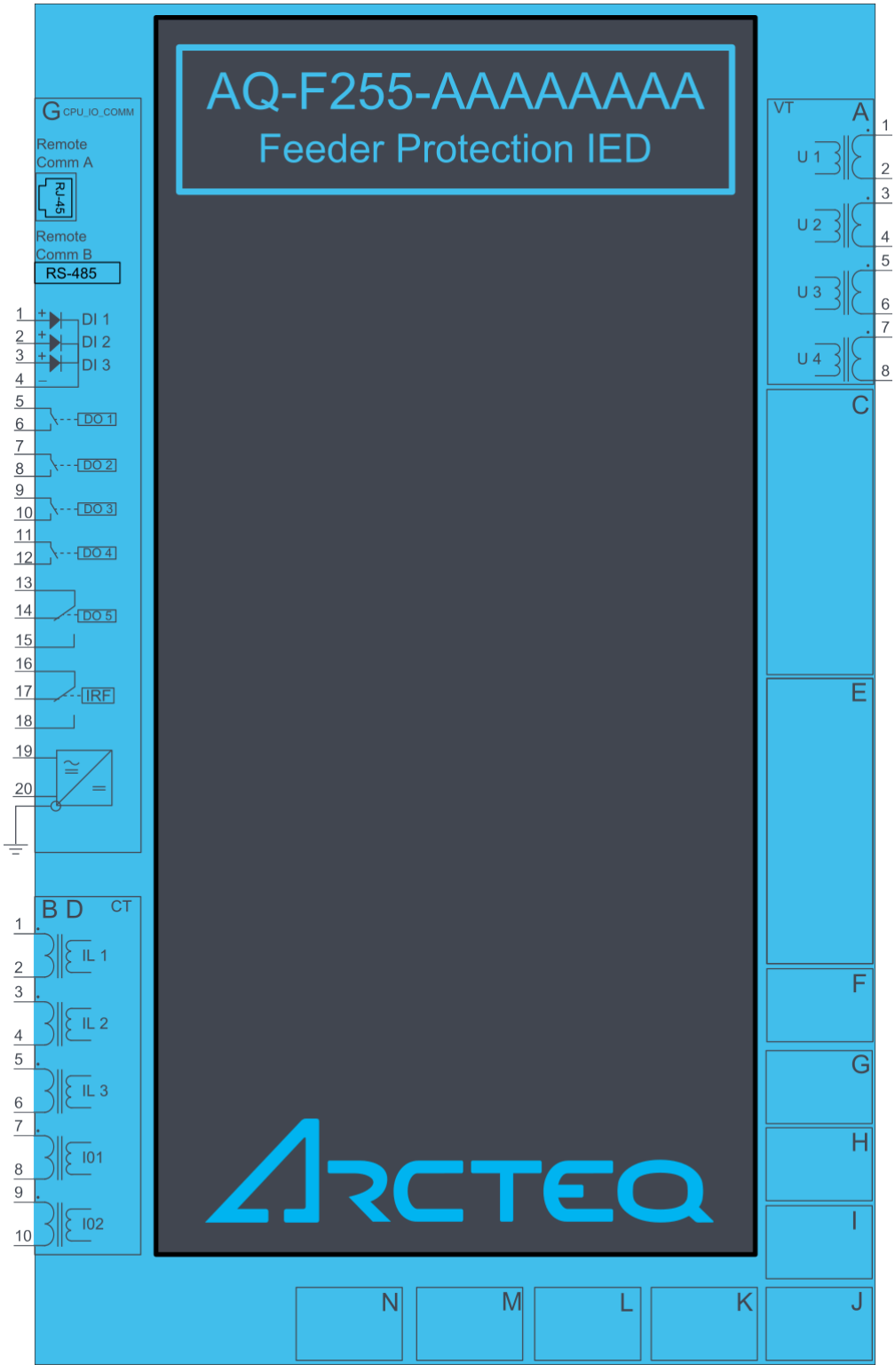
Figure. 6.6 - 209. In AQ-S254 it is possible to set up the display to show sensor activations in alarm display.



# 7 Connections and application examples

## 7.1 Connections of AQ-F255

Figure. 7.1 - 210. AQ-F255 variant without add-on modules.






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Figure. 7.1 - 211. AQ-F255 variant with digital input and output modules.

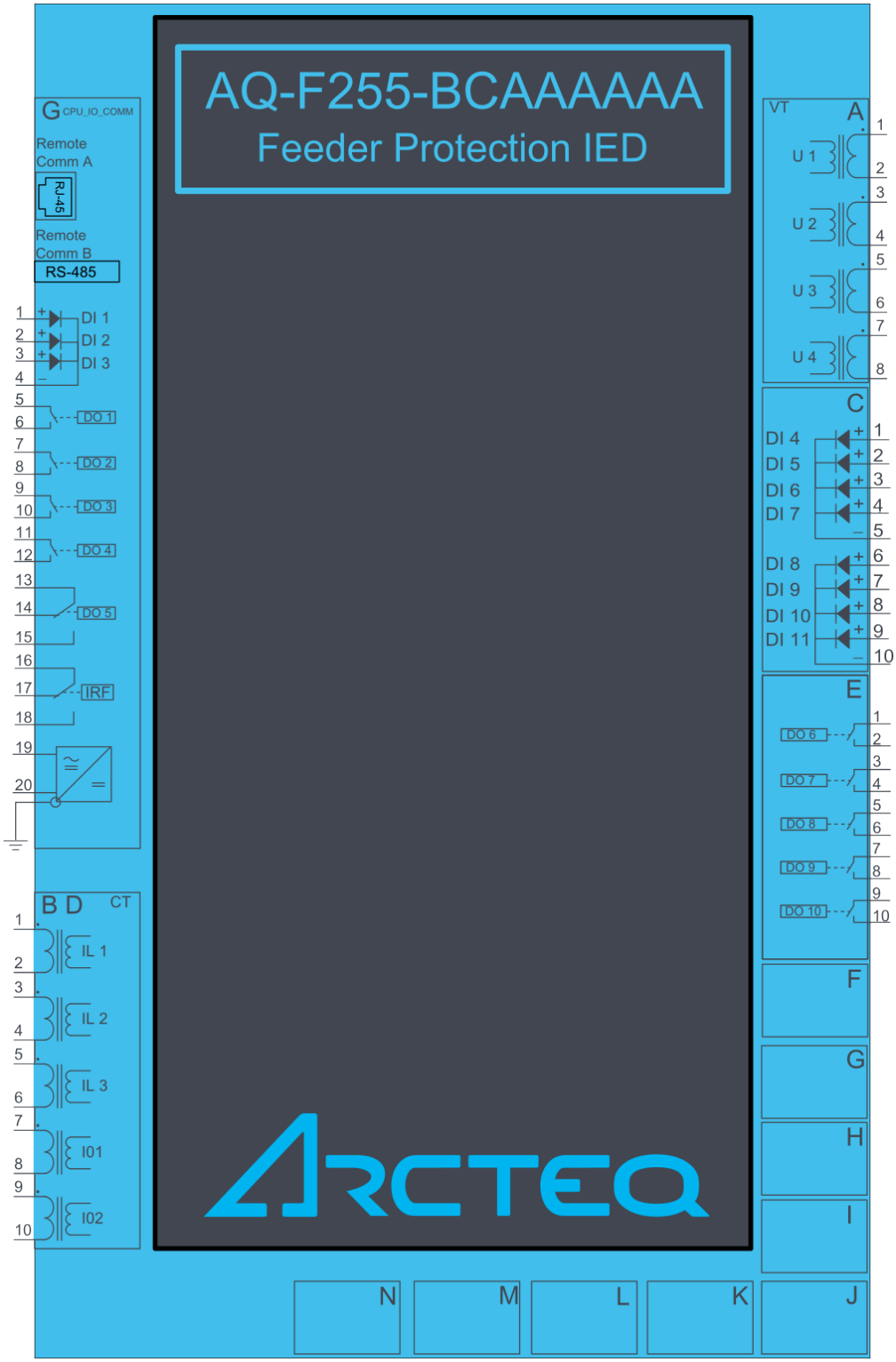
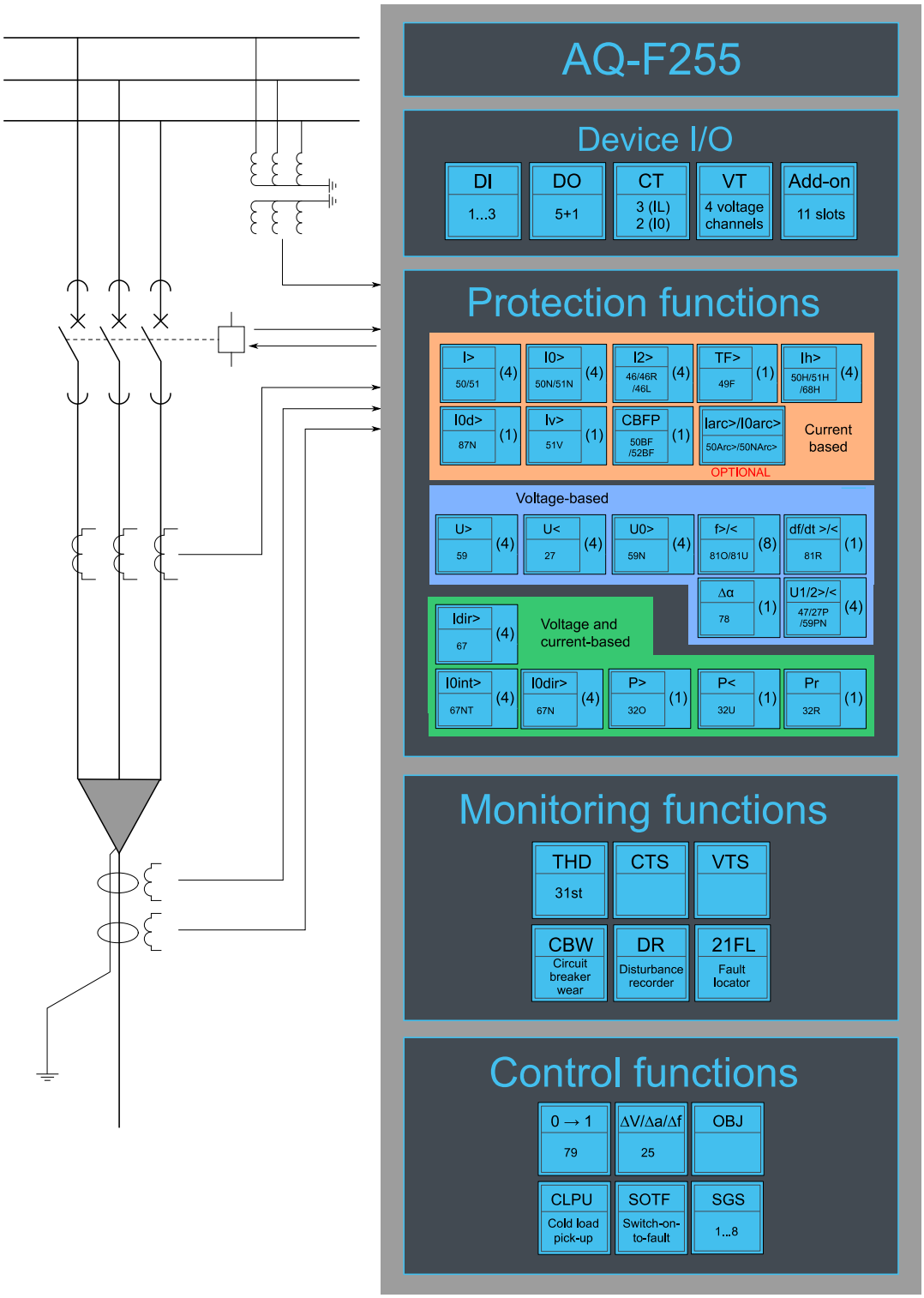


Figure. 7.1 - 212. AQ-F255 application example with function block diagram.




## 7.2 Application example and its connections

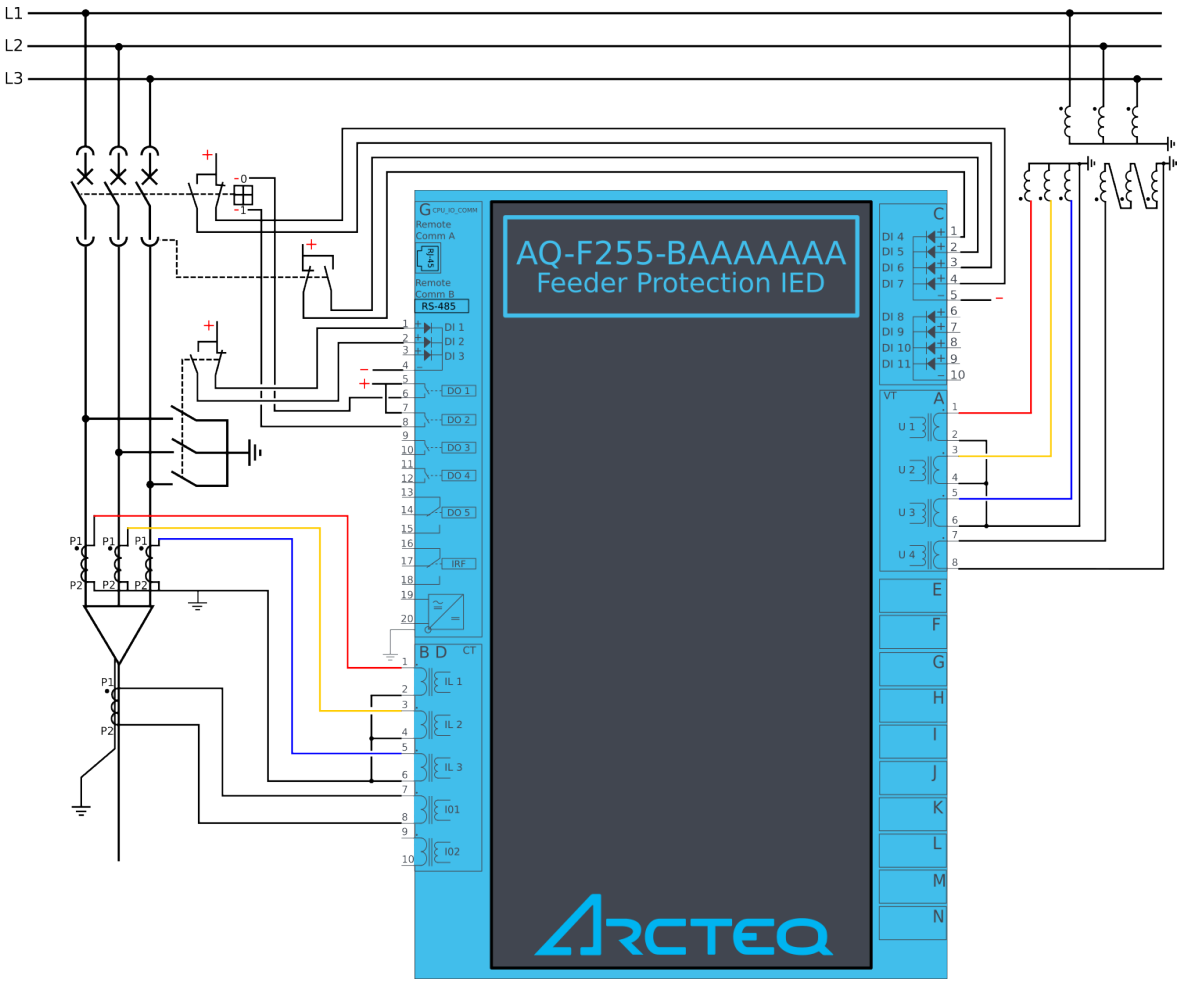
This chapter presents an application example for the feeder protection IED.



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Since three line-to-neutral voltages and the zero sequence voltage (U4) are connected, this application uses the voltage measurement mode "3LN+U0" (see the image below). Additionally, the three phase currents and the residual current (I01) are also connected. The digital inputs are connected to indicate the breaker status, while the digital outputs are used for breaker control.

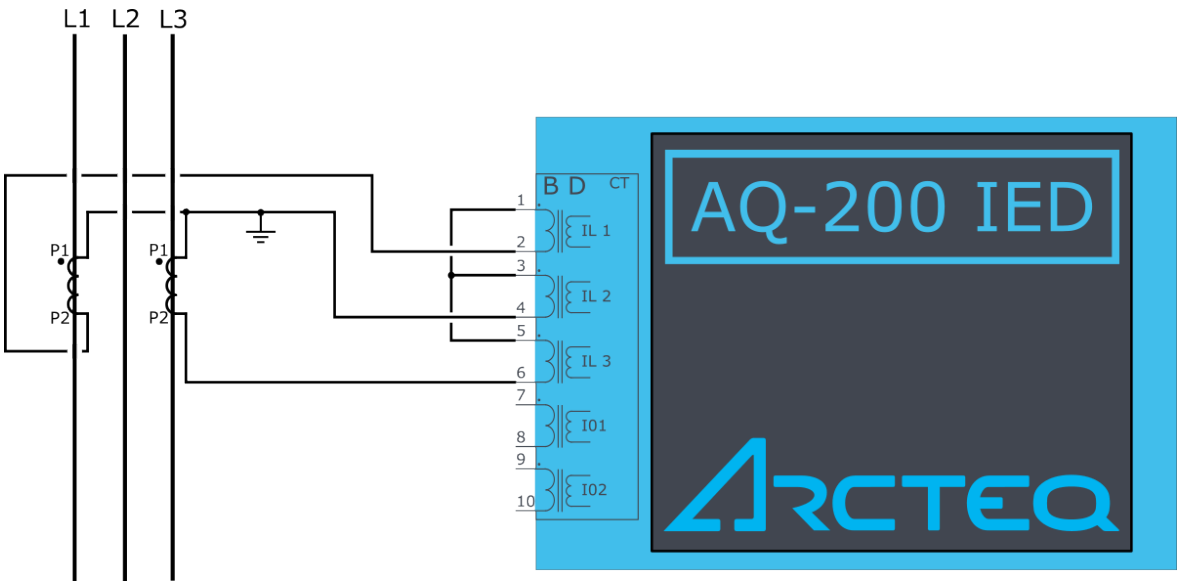
Figure. 7.2 - 213. Application example and its connections.




## 7.3 Two-phase, three-wire ARON input connection

This chapter presents the two-phase, three-wire ARON input connection for any AQ-200 series IED with a current transformer. The example is for applications with protection CTs for just two phases. The connection is suitable for both motor and feeder applications.

Figure. 7.3 - 214. ARON connection.




The ARON input connection can measure the load symmetrically despite the fact that one of the CTs is missing from the installation. Normally, Phase 2 does not have a current transformer installed as an external fault is much more likely to appear on Lines 1 or 3.

A fault between Line 2 and the earth cannot be detected when the ARON input connection is used. In order to detect an earth fault in Phase 2, a cable core CT must be used.

## 7.4 Trip circuit supervision (95)

Trip circuit supervision is used to monitor the wiring from auxiliary power supply, through the IED's digital output, and all the way to the open coil of the breaker. It is recommended to supervise the health of the trip circuit when breaker is closed.

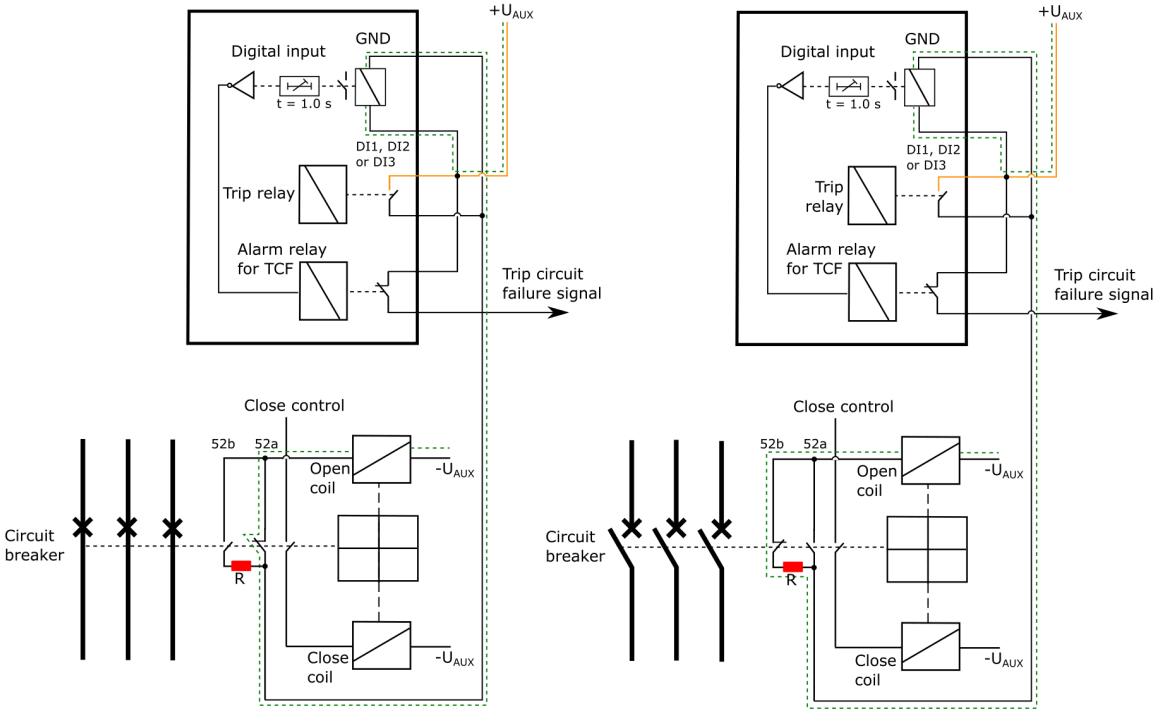
### Trip circuit supervision with one digital input and one non-latched trip output

The figure below presents an application scheme for trip circuit supervision with one digital input and a non-latched trip output. With this connection the current keeps flowing to the open coil of the breaker via the breaker's closing auxiliary contacts (52b) even after the circuit breaker is opened. This requires a resistor which reduces the current: this way the coil is not energized and the relay output does not need to cut off the coil's inductive current.



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Figure. 7.4 - 215. Trip circuit supervision with one DI and one non-latched trip output.

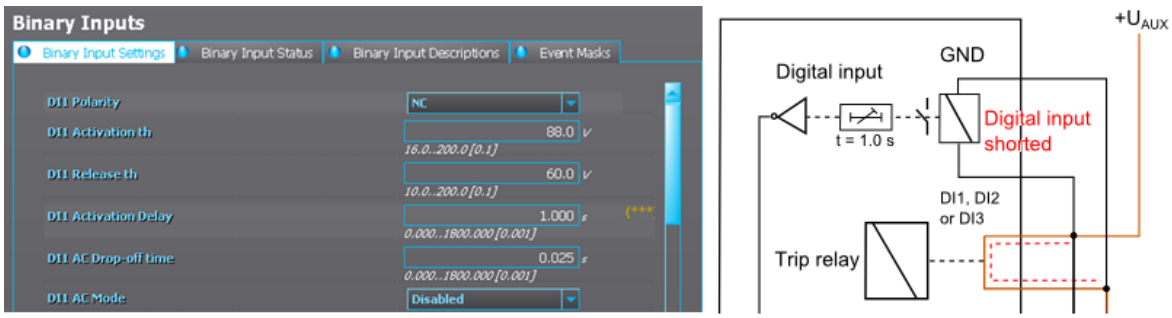



Note that the digital input that monitors the circuit is normally closed, and the same applies to the alarm relay if one is used. For monitoring and especially trip circuit supervision purposes it is recommended to use a normally closed contact to confirm the wiring's condition. An active digital input generates a less than 2 mA current to the circuit, which is usually small enough not to make the breaker's open coil operate.

When the trip relay is controlled and the circuit breaker is opening, the digital input is shorted by the trip contact as long as the breaker opens. Normally, this takes about 100 ms if the relay is non-latched. A one second activation delay should, therefore, be added to the digital input. An activation delay that is slightly longer than the circuit breaker's operations time should be enough. When circuit breaker failure protection (CBFP) is used, adding its operation time to the digital input activation time is useful. The whole digital input activation time is, therefore, $t_{DI} = t_{CB} + t_{IEDrelease} + t_{CBFP}$.

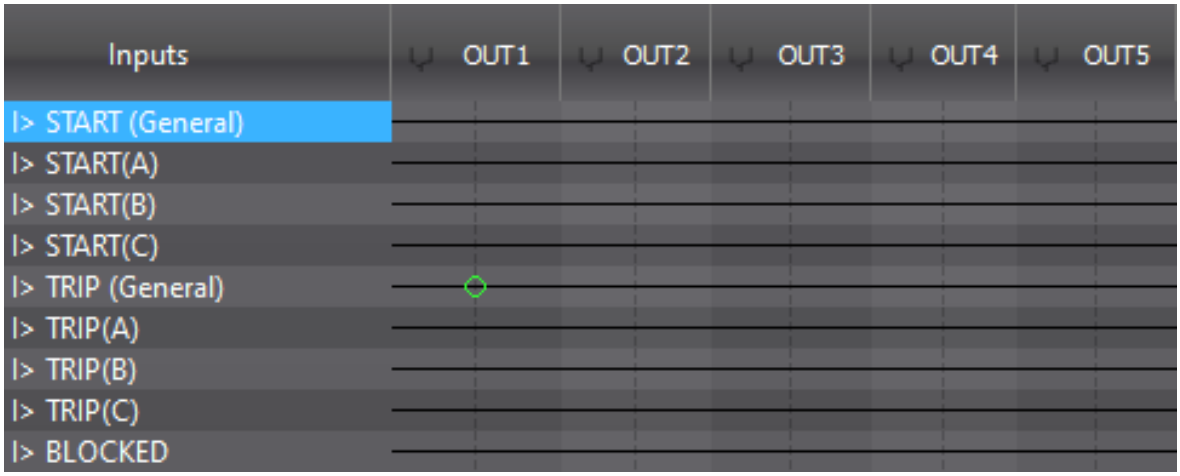
The image below presents the necessary settings when using a digital input for trip circuit supervision. The input's polarity must be NC (normally closed) and a one second delay is needed to avoid nuisance alarm while the circuit breaker is controlled open.

Figure. 7.4 - 216. Settings for a digital input used for trip circuit supervision.




Non-latched outputs are seen as hollow circles in the output matrix, whereas latched contacts are painted. See the image below of an output matrix where a non-latched trip contact is used to open the circuit breaker.

Figure. 7.4 - 217. Non-latched trip contact.




When the auto-reclosing function is used in feeder applications, the trip output contacts must be non-latched. Trip circuit supervision is generally easier and more reliable to build with non-latched outputs.

The open coil remains energized only as long as the circuit breaker is opened and the IED output releases. This takes approximately 100 ms depending on the size and type of the breaker. When the breaker opens, the auxiliary contacts open the inductive circuit; however, the trip contact does not open at the same time. The IED's output relay contact opens in under 50 ms or after a set release delay that takes place after the breaker is opened. This means that the open coil is energized for a while after the breaker has already opened. The coil could even be energized a moment longer if the circuit breaker failure protection has to be used and the incomer performs the trip.

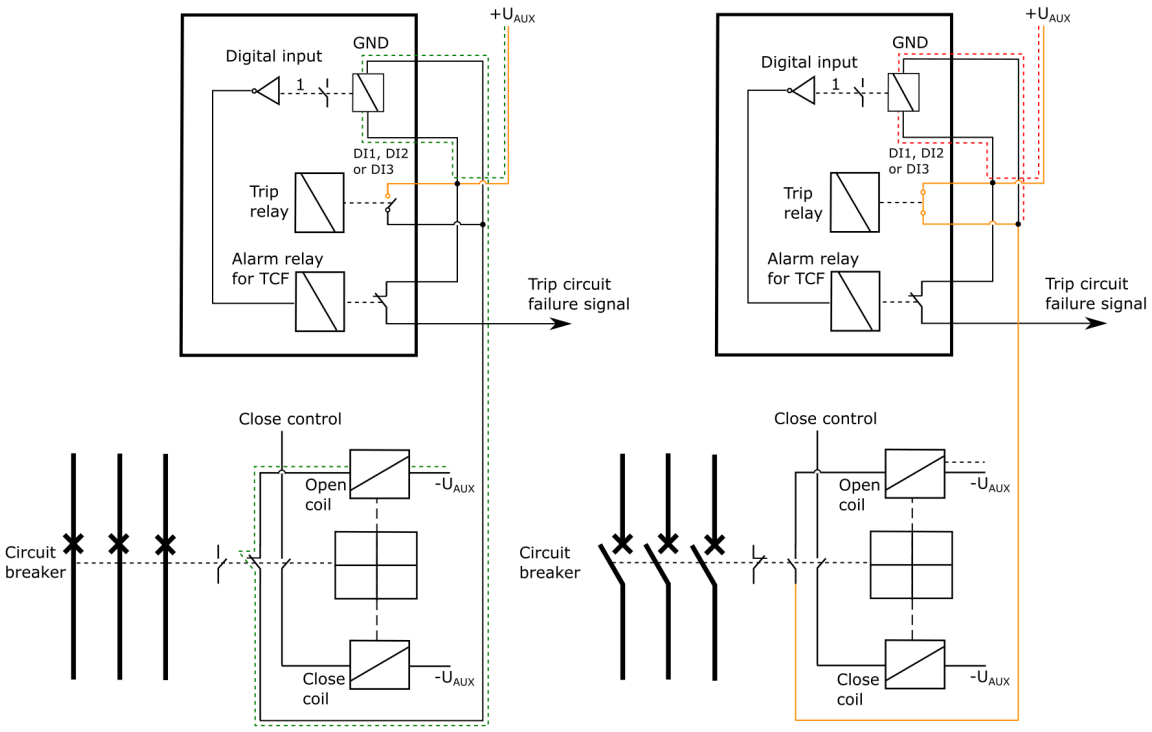
## Trip circuit supervision with one digital input and one connected, non-latched trip output

There is one main difference between non-latched and latched control in trip circuit supervision: when using the latched control, the trip circuit (in an open state) cannot be monitored as the digital input is shorted by the IED's trip output.



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Figure. 7.4 - 218. Trip circuit supervision with one DI and one latched output contact.

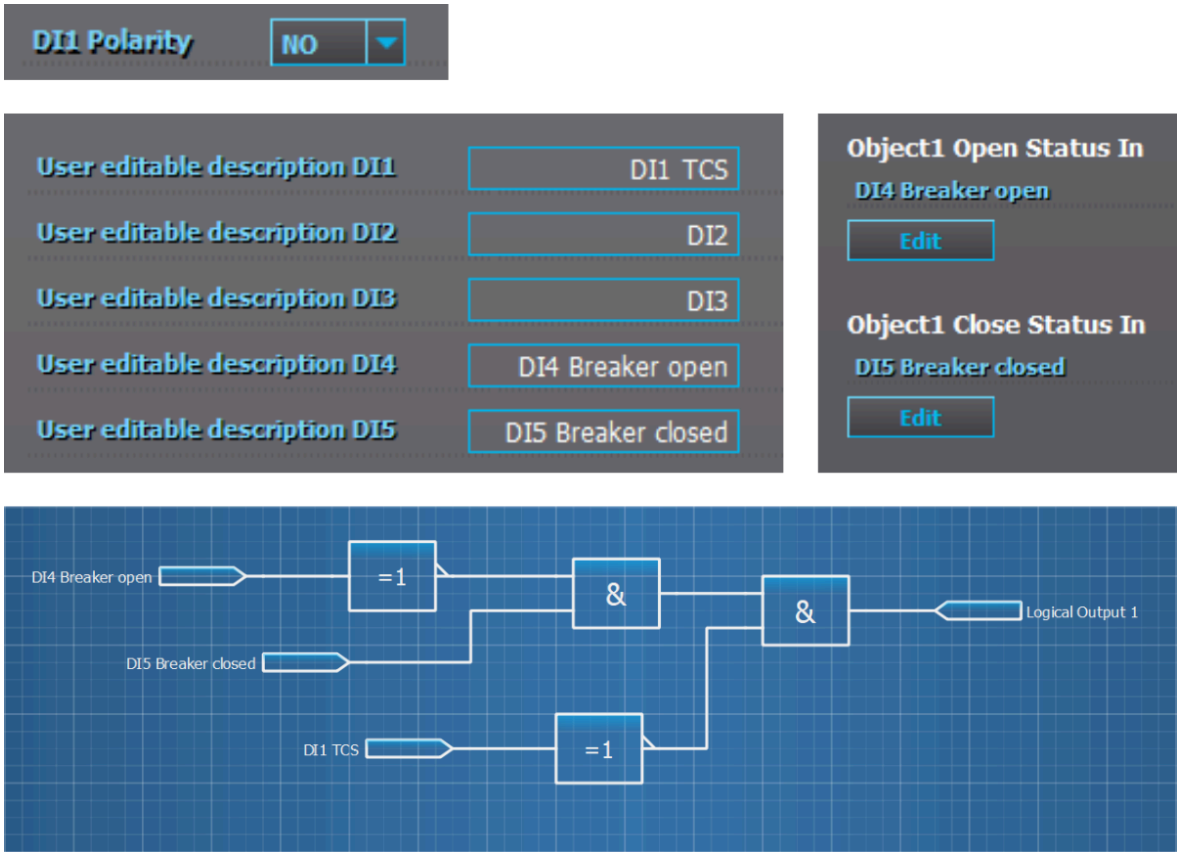



The trip circuit with a latched output contact can be monitored, but only when the circuit breaker's status is "Closed". Whenever the breaker is open, the supervision is blocked by an internal logic scheme. Its disadvantage is that the user does not know whether or not the trip circuit is intact when the breaker is closed again.

The following logic scheme (or similar) blocks the supervision alarm when the circuit breaker is open. The alarm is issued whenever the breaker is closed and whenever the inverted digital input signal ("TCS") activates. A normally closed digital input activates only when there is something wrong with the trip circuit and the auxiliary power goes off. Logical output can be used in the output matrix or in SCADA as the user wants.

The image below presents a block scheme when a non-latched trip output is not used.

Figure. 7.4 - 219. Example block scheme.






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# 8 Construction and installation

## 8.1 Construction

AQ-X255 is a member of the modular and scalable AQ-200 series, and it includes eleven (11) configurable and modular add-on card slots. As a standard configuration the device includes the CPU module (which consists of the CPU, a number of inputs and outputs, and the power supply) as well as one separate voltage measurement module and one separate current measurement module.

The images below present the modules of both the non-optioned model (AQ-X255-XXXXXXX-AAAAAAAAAAA) and a partially optioned model (AQ-X255-XXXXXXX-BBBBBCAAAAJ).

Figure. 8.1 - 220. Modular construction of AQ-X255-XXXXXXX-AAAAAAAAAAA

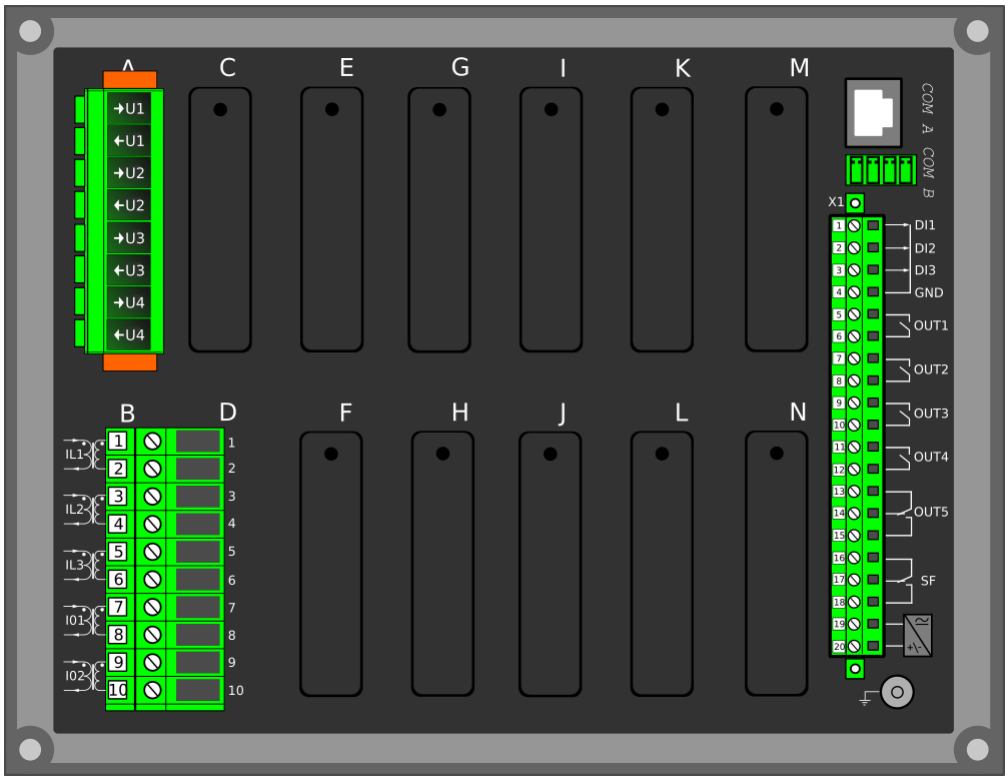
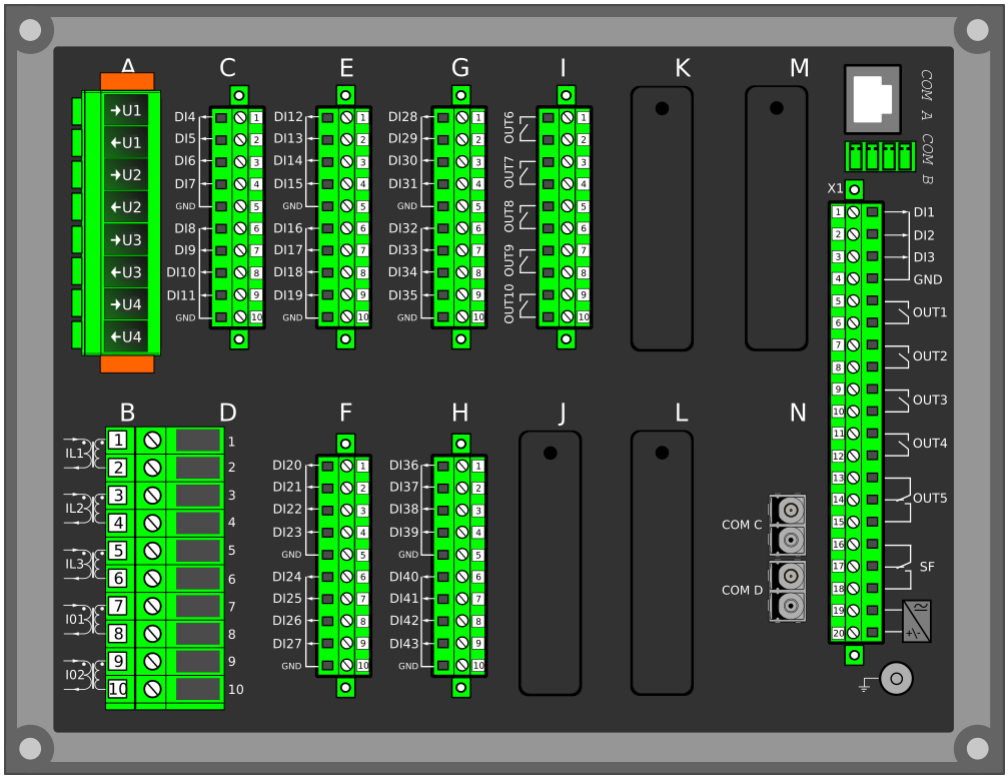


Figure. 8.1 - 221. Modular construction of AQ-X255-XXXXXXX-BBBBBCAAAAJ




The modular structure of AQ-X255 allows for scalable solutions for different application requirements. In non-standard configurations slots from C to N accept all available add-on modules, such as digital I/O modules, integrated arc protection and other special modules. The only difference between the slots affecting device scalability is that Slots M and N both also support communication options.

Start-up scan searches for modules according to their type designation code. If the module content is not what the device expects, the IED issues a hardware configuration error message. In field upgrades, therefore, add-on modules must be ordered from Arcteq Relays Ltd. or its representative who can then provide the module with its corresponding unlocking code to allow the device to operate correctly once the hardware configuration has been upgraded.

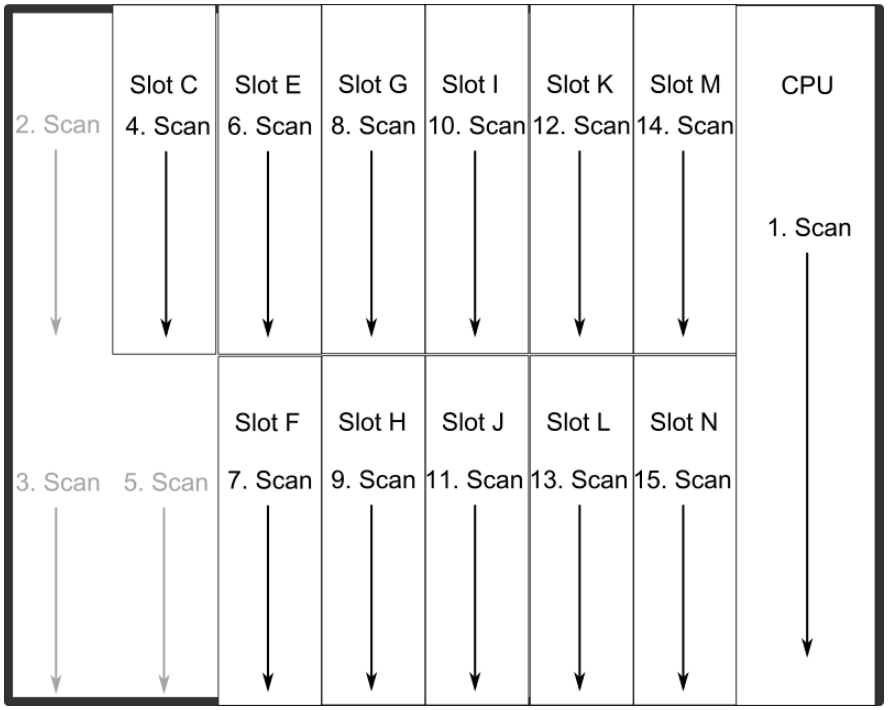
When an I/O module is inserted into the device, the module location affects the naming of the I/O. The I/O scanning order in the start-up sequence is as follows: the CPU module I/O, Slot C, Slot E, Slot F, and so on. This means that the digital input channels DI1, DI2 and DI3 as well as the digital output channels OUT1, OUT2, OUT3, OUT4 and OUT5 are always located in the CPU module. If additional I/O cards are installed, their location and card type affect the I/O naming.

The figure below presents the start-up hardware scan order of the device as well as the I/O naming principles.



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Figure. 8.1 - 222. AQ-X255 hardware scanning and I/O naming principles.




1. Scan
   The start-up system; detects and self-tests the CPU module, voltages, communication and the I/O; finds and assigns "DI1", "DI2", "DI3", "OUT1", "OUT2", "OUT3", "OUT4" and "OUT5".
2. Scan
   Scans Slot A and finds the four channels of the VT module (fixed for AQ-X255). If the VTM is not found, the device issues an alarm.
3. Scan
   Scans Slot B, which should always remain empty in AQ-X255 devices. If it is not empty, the device issues an alarm.
4. Scan
   Scans Slot C, and moves to the next slot if Slot C is empty. If the scan finds an 8DI module (that is, a module with eight digital inputs), it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If the scan finds a DO5 module (that is, a module with five digital outputs), it reserves the designations "OUT6", "OUT7", "OUT8", "OUT9" and "OUT10" to this slot. The I/O is then added if the type designation code (e.g. AQ-P215-PH0AAAA-BBC) matches with the existing modules in the device. If the code and the modules do not match, the device issues and alarm. An alarm is also issued if the device expects to find a module here but does not find one.
5. Scan
   Scans Slot D and finds the five channels of the CT module (fixed for AQ-X255). If the CTM is not found, the device issues an alarm.
6. Scan
   Scans Slot E, and moves to the next slot if Slot E is empty. If the scan finds an 8DI module, it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If Slot C also has an 8DI module (and therefore has already reserved these designations), the device reserves the designations "DI12", "DI13", "DI14", "DI15", "DI16", "DI17", "DI18" and "DI19" to this slot. If the scan finds a 5DO module, it reserves the designations "OUT6", "OUT7", "OUT8", "OUT9" and "OUT10" to this slot. Again, if Slot C also has a 5DO and has therefore already reserved these designations, the device reserves the designations "OUT11", "OUT12", "OUT13", "OUT14" and "OUT15" to this slot. If the scan finds the arc protection module, it reserves the sensor channels ("S1", "S2", "S3", "S4"), the high-speed outputs ("HSO1", "HSO2"), and the digital input channel ("ArcBI") to this slot.

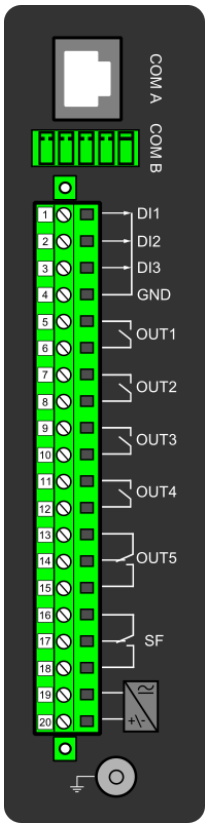
7. –15. Scan
   A similar operation to Scan 6 (checks which designations have been reserved by modules in previous slots and numbers the new ones accordingly).

Thus far this chapter has only explained the installation of I/O add-on cards to the option module slots. This is because all other module types are treated in a same way. For example, when an additional communication port is installed into the upper port of the communication module, its designation is Communication port 3 or higher, as Communication ports 1 and 2 already exist in the CPU module (which is scanned, and thus designated, first). After a communication port is detected, it is added into the device's communication space and its corresponding settings are enabled.

The partially optioned example case of AQ-X255-XXXXXXX-BBBBBCAAAAJ (the first image pair, on the right) has a total of 43 digital input channels available: three (DI1…DI3) in the CPU module, and the rest in Slots C…H in groups of eight. It also has a total of 10 digital output channels available: five (DO1…DO5) in the CPU module, and five (DO6…DO10) in Slot I. Additionally, there is a double (LC) fiber Ethernet communication option card installed in Slot N. These same principles apply to all non-standard configurations in the AQ-X255 IED family.

## 8.2 CPU module

Figure. 8.2 - 223. CPU module.




| Connector | Description |
|---|---|
| COM A | Communication port A, or the RJ-45 port. Used for the setting tool connection and for IEC 61850, Modbus/TCP, IEC 104, DNP3 and station bus communications. |
| COM B | Communication port B, or the RS-485 port. Used for the SCADA communications for the following protocols: Modbus/RTU, Modbus I/O, SPA, DNP3, IEC 101 and IEC 103. The pins have the following designations: Pin 1 = DATA +, Pin 2 = DATA –, Pin 3 = GND, Pins 4 & 5 = Terminator resistor enabled by shorting. |
| X1-1 | Digital input 1, nominal threshold voltage 24 V, 110 V or 220 V. |
| X1-2 | Digital input 2, nominal threshold voltage 24 V, 110 V or 220 V. |


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| Connector | Description |
|---|---|
| X1-3 | Digital input 3, nominal threshold voltage 24 V, 110 V or 220 V. |
| X1-4 | Common GND for digital inputs 1, 2 and 3. |
| X1-5:6 | Output relay 1, with a normally open (NO) contact. |
| X1-7:8 | Output relay 2, with a normally open (NO) contact. |
| X1-9:10 | Output relay 3, with a normally open (NO) contact. |
| X1-11:12 | Output relay 4, with a normally open (NO) contact. |
| X1-13:14:15 | Output relay 5, with a changeover contact. |
| X1-16:17:18 | System fault's output relay, with a changeover contact. Pins 16 and 17 are closed when the unit has a system fault or is powered OFF. Pins 16 and 18 are closed when the unit is powered ON and there is no system fault. |
| X1-19:20 | Power supply IN. Either 85…265 VAC/DC (model A; order code "H") or 18…75 DC (model B; order code "L"). Positive side (+) to Pin 20. |
| GND | The relay's earthing connector. |

By default, the CPU module (combining the CPU, the I/O and the power supply) includes two standard communication ports and the relay's basic digital I/O.

The current consumption of the digital inputs is 2 mA when activated, while the range of the operating voltage is 24 V/110 V/220 V depending on the ordered hardware. All digital inputs are scannced in 5 ms program cycles. Their pick-up and release thresholds depend on the selection of the order code. Their delays and NO/NC selection, however, can be set with software. The digital output controls are also set by the user with software. By default, the digital outputs are controlled in 5 ms program cycles. All output contacts are mechanical. The rated voltage of the NO/NC outputs is 250 VAC/DC.

The auxiliary voltage is defined in the ordering code: the available power supply models available are A (85…265 VAC/DC) and B (18…75 DC). The power suppy's minimum allowed bridging time for all voltage levels is above 150 ms. The power supply's maximum power consumption is 15 W. The power supply allows a DC ripple of below 15 % and the start-up time of the power supply is below 5 ms. For further details, please refer to the "Auxiliary voltage" chapter in the "Technical data" section of this document.

## Digital input settings

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the relay settings.

Table. 8.2 - 401. Digital input settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| DIx Polarity | 0: NO (Normally open)<br>1: NC (Normally closed) | - | 0: NO | Selects whether the status of the digital input is 1 or 0 when the input is energized. |
| DIx Activation delay | 0.000…1800.000 s | 0.001 s | 0.000 s | Defines the delay for the status change from 0 to 1. |
| DIx Drop-off time | 0.000…1800.000 s | 0.001 s | 0.000 s | Defines the delay for the status change from 1 to 0. |
| DIx AC mode | 0: Disabled<br>1: Enabled | - | 0: Disabled | Selects whether or not a 30-ms deactivation delay is added to account for alternating current. |

### Digital input and output descriptions

CPU card digital inputs and outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 8.2 - 402. Digital input and output user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description DIx | 1...31 characters | DIx | Description of the digital input. This description is used in several menu types for easier identification. |
| User editable description OUTx | | OUTx | Description of the digital output. This description is used in several menu types for easier identification. |

### Scanning cycle

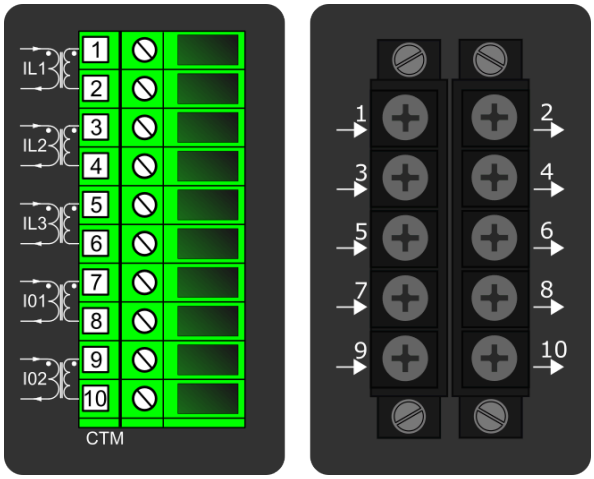
All digital inputs are scanned in a 5 ms cycle, meaning that the state of an input is updated every 0…5 milliseconds. When an input is used internally in the device (either in group change or logic), it takes additional 0…5 milliseconds to operate. Theoretically, therefore, it takes 0…10 milliseconds to change the group when a digital input is used for group control or a similar function. In practice, however, the delay is between 2…8 milliseconds about 95 % of the time. When a digital input is connected directly to a digital output (T1…Tx), it takes an additional 5 ms round. Therefore, when a digital input controls a digital output internally, it takes 0…15 milliseconds in theory and 2…13 milliseconds in practice.

NOTE!

The mechanical delay of the relay is not included in these approximations!

## 8.3 Current measurement module

Figure. 8.3 - 224. Module connections with standard and ring lug terminals.




| Connector | Description |
|---|---|
| CTM 1-2 | Phase current measurement for phase L1 (A). |


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| Connector | Description |
|---|---|
| CTM 3-4 | Phase current measurement for phase L2 (B). |
| CTM 5-6 | Phase current measurement for phase L3 (C). |
| CTM 7-8 | Coarse residual current measurement I01. |
| CTM 9-10 | Fine residual current measurement I02. |

A basic current measurement module with five channels includes three-phase current measurement inputs as well as coarse and fine residual current inputs. The CT module is available with either standard or ring lug connectors.

The current measurement module is connected to the secondary side of conventional current transformers (CTs). The nominal current for the phase current inputs is 5 A. The input nominal current can be scaled for secondary currents of 1…10 A. The secondary currents are calibrated to nominal currents of 1 A and 5 A, which provide ±0.5 % inaccuracy when the range is 0.005…4 × $I_n$.

The measurement ranges are as follows:

- Phase currents 25 mA…250 A (RMS)
- Coarse residual current 5 mA…150 A (RMS)
- Fine residual current 1 mA…75 A (RMS)

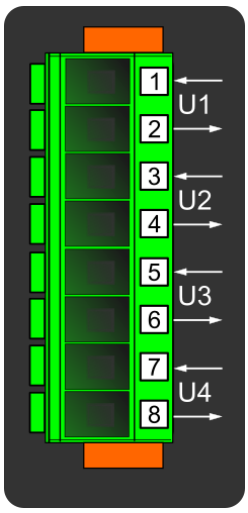
The characteristics of phase current inputs are as follows:

- The angle measurement inaccuracy is less than ± 0.2 degrees with nominal current.
- The frequency measurement range of the phase current inputs is 6…1800 Hz with standard hardware.
- The quantization of the measurement signal is applied with 18-bit AD converters, and the sample rate of the signal is 64 samples/cycle when the system frequency ranges from 6 Hz to 75 Hz.

For further details please refer to the "Current measurement" chapter in the “Technical data” section of this document.

## 8.4 Voltage measurement module

Figure. 8.4 - 225. Voltage measurement module.




| Connector | Description |
|---|---|
| VTM 1-2 | Configurable voltage measurement input U1. |

| Connector | Description |
|---|---|
| VTM 3-4 | Configurable voltage measurement input U2. |
| VTM 5-6 | Configurable voltage measurement input U3. |
| VTM 7-8 | Configurable voltage measurement input U4. |

A basic voltage measurement module with four channels includes four voltage measurement inputs that can be configured freely.

The voltage measurement module is connected to the secondary side of conventional voltage transformers (VTs) or directly to low-voltage systems secured by fuses. The nominal voltage can be set between 100…400 V. Voltages are calibrated in a range of 0…240 V, which provides ± 0.2 % inaccuracy in the same range.

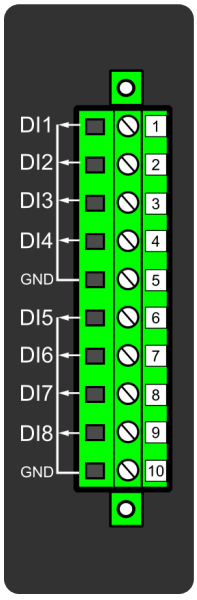
The voltage input characteristics are as follows:

- The measurement range is 0.5…480.0 V per channel.
- The angle measurement inaccuracy is less than ± 0.5 degrees within the nominal range.
- The frequency measurement range of the voltage inputs is 6…1800 Hz with standard hardware.
- The quantization of the measurement signal is applied with 18-bit AD converters, and the sample rate of the signal is 64 samples/cycle when the system frequency ranges from 6 Hz to 75 Hz.

For further details please refer to the "Voltage measurement" chapter in the “Technical data” section of this document.

## 8.5 Digital input module (optional)

Figure. 8.5 - 226. Digital input module (DI8) with eight add-on digital inputs.




| Connector | Description (x = the number of digital inputs in other modules that preceed this one in the configuration) |
|---|---|
| X 1 | DIx + 1 |
| X 2 | DIx + 2 |
| X 3 | DIx + 3 |


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| Connector | Description (x = the number of digital inputs in other modules that preceed this one in the configuration) |
|---|---|
| X 4 | DIx + 4 |
| X 5 | Common earthing for the first four digital inputs. |
| X 6 | DIx + 5 |
| X 7 | DIx + 6 |
| X 8 | DIx + 7 |
| X 9 | DIx + 8 |
| X 10 | Common earthing for the other four digital inputs. |

The DI8 module is an add-on module with eight (8) galvanically isolated digital inputs. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. The properties of the inputs in this module are the same as those of the inputs in the main processor module. The current consumption of the digital inputs is 2 mA when activated, while the range of the operating voltage is from 0…265 VAC/DC. The activation and release thresholds are set in the software and the resolution is 1 V. All digital inputs are scannced in 5 ms program cycles, and their pick-up and release delays as well as their NO/NC selection can be set with software.

For the naming convention of the digital inputs provided by this module please refer to the chapter titled "Construction and installation".

For technical details please refer to the chapter titled "Digital input module" in the "Technical data" section of this document.

## Setting up the activation and release delays

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the relay settings.

Table. 8.5 - 403. Digital input settings of DI8 module.

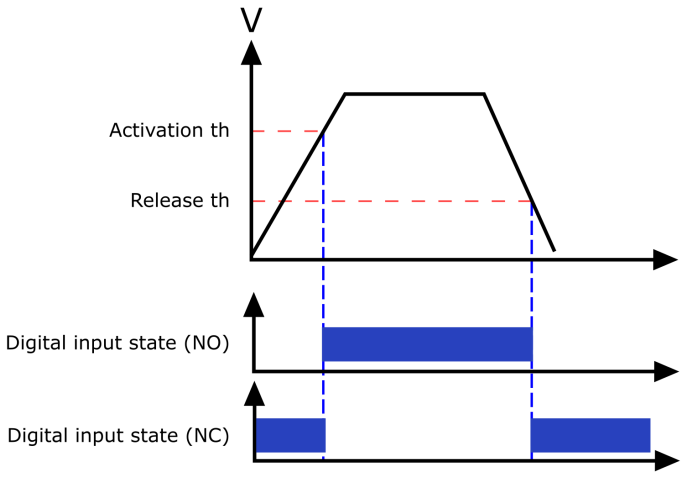
| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| DIx Polarity | 0: NO (Normally open)<br>1: NC (Normally closed) | - | 0: NO | Selects whether the status of the digital input is 1 or 0 when the input is energized. |
| DIx Activation threshold | 16.0…200.0 V | 0.1 V | 88 V | Defines the activation threshold for the digital input.<br><br>When "NO" is the selected polarity, the measured voltage exceeding this setting activates the input. When "NC" is the selected polarity, the measured voltage exceeding this setting deactivates the input. |
| DIx Release threshold | 10.0…200.0 V | 0.1 V | 60V | Defines the release threshold for the digital input.<br><br>When "NO" is the selected polarity, the measured voltage below this setting deactivates the input. When "NC" is the selected polarity, the measured voltage below this setting activates the input. |
| DIx Activation delay | 0.000…1800.000 s | 0.001 s | 0.000 s | Defines the delay when the status changes from 0 to 1. |
| DIx Drop-off time | 0.000…1800.000 s | 0.001 s | 0.000 s | Defines the delay when the status changes from 1 to 0. |
| DIx AC Mode | 0: Disabled<br>1: Enabled | - | 0: Disabled | Selects whether or not a 30-ms deactivation delay is added to take the alternating current into account. The "DIx Release threshold" parameter is hidden and forced to 10 % of the set "DIx Activation threshold" parameter. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| DIx Counter | 0…$2^{32}$–1 | 1 | 0 | Displays the number of times the digital input has changed its status from 0 to 1. |
| DIx Clear counter | 0: -<br>1: Clear | - | 0: - | Resets the DIx counter value to zero. |

The user can set the activation threshold individually for each digital input. When the activation and release thresholds have been set properly, they will result in the digital input states to be activated and released reliably. The selection of the normal state between normally open (NO) and normally closed (NC) defines whether or not the digital input is considered activated when the digital input channel is energized.

The diagram below depicts the digital input states when the input channels are energized and de-energized.

Figure. 8.5 - 227. Digital input state when energizing and de-energizing the digital input channels.




## Digital input descriptions

Option card inputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 8.5 - 404. Digital input user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description DIx | 1...31 characters | DIx | Description of the digital input. This description is used in several menu types for easier identification. |

## Digital input voltage measurements

Digital input option card channels measure voltage on each channel. The measured voltage can be seen at *Control → Device IO → Digital inputs → Digital input voltages*.

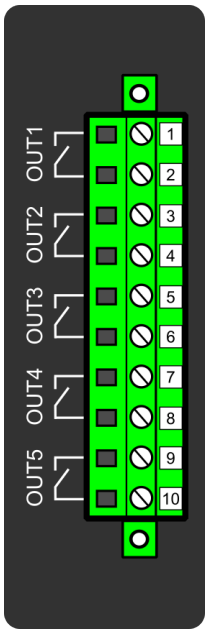

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Table. 8.5 - 405. Digital input channel voltage measurement.

| Name | Range | Step | Description |
|---|---|---|---|
| DIx Voltage now | 0.000...275.000 V | 0.001 V | Voltage measurement of a digital input channel. |

## 8.6 Digital output module (optional)

Figure. 8.6 - 228. Digital output module (DO5) with five add-on digital outputs.




| Connector | Description |
|---|---|
| X 1–2 | OUTx + 1 (1st and 2nd pole NO) |
| X 3–4 | OUTx + 2 (1st and 2nd pole NO) |
| X 5–6 | OUTx + 3 (1st and 2nd pole NO) |
| X 7–8 | OUTx + 4 (1st and 2nd pole NO) |
| X 9–10 | OUTx + 5 (1st and 2nd pole NO) |

The DO5 module is an add-on module with five (5) digital outputs. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. The properties of the outputs in this module are the same as those of the outputs in the main processor module. The user can set the digital output controls with software. All digital outputs are scanned in 5 ms program cycles, and their contacts are mechanical in type. The rated voltage of the NO/NC outputs is 250 VAC/DC.

For the naming convention of the digital inputs provided by this module please refer to the chapter titled "Construction and installation".

For technical details please refer to the chapter titled "Digital output module" in the "Technical data" section of this document.

### Digital output descriptions

Option card outputs can be given a description. The user defined description are displayed in most of the menus:

- logic editor
- matrix
- block settings
- event history
- disturbance recordings
- etc.

Table. 8.6 - 406. Digital output user description.

| Name | Range | Default | Description |
|---|---|---|---|
| User editable description OUTx | 1...31 characters | OUTx | Description of the digital output. This description is used in several menu types for easier identification. |

## 8.7 Point sensor arc protection module (optional)

Figure. 8.7 - 229. Arc protection module.

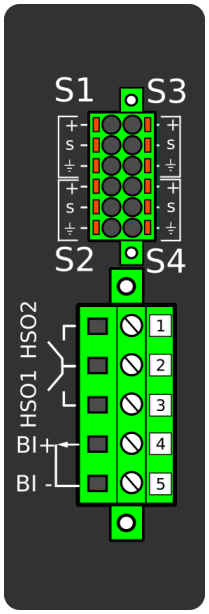



Table. 8.7 - 407. Module connections.

| Connector | Description |
|---|---|
| S1 | Light sensor channels 1…4 with positive ("+"), sensor ("S") and earth connectors. |
| S2 | |
| S3 | |
| S4 | |
| X 1 | HSO2 (+, NO) |
| X 2 | Common battery positive terminal (+) for the HSOs. |
| X 3 | HSO1 (+, NO) |
| X 4 | Binary input 1 (+ pole) |
| X 5 | Binary input 1 ( – pole) |


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The arc protection module is an add-on module with four (4) light sensor channels, two (2) high-speed outputs and one (1) binary input. This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required. If even one of the sensor channels is connected incorrectly, the channel does not work. Each channel can have up to three (3) light sensors serially connected to it. The user can choose how many of the channels are in use.

The high-speed outputs (HSO1 and HSO2) operate only with a DC power supply. The battery's positive terminal (+) must be wired according to the drawing. The NO side of the outputs 1 or 2 must be wired through trip coil to the battery's negative terminal (–). The high-speed outputs can withstand voltages up to 250 VDC. The operation time of the high-speed outputs is less than 1 ms. For further information please refer to the chapter titled "Arc protection module" in the "Technical data" section of this manual.

The rated voltage of the binary input is 24 VDC. The threshold picks up at ≥16 VDC. The binary input can be used for external light information or for similar applications. It can also be used as a part of various ARC schemes. Please note that the binary input's delay is 5…10ms.

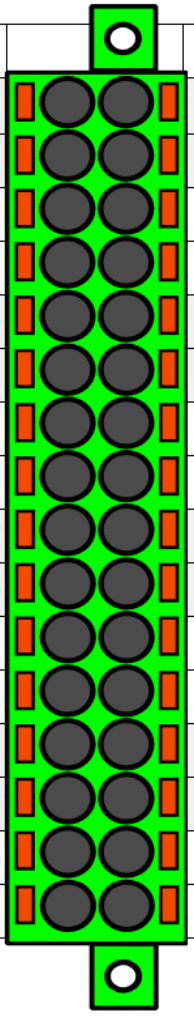
NOTE!

BI1, HSO1 and HSO2 are not visible in the *Binary inputs* and *Binary outputs* menus (*Control → Device I/O*), they can only be programmed in the arc matrix menu (*Protection → Arc protection → I/O → Direct output control* and *HSO control*).

## 8.8 RTD input module (optional)

Figure. 8.8 - 230. RTD input module connectors.

| Channel | Connector | | | Connector |
|---|---|---|---|---|
| 1 | RTD1-1 | 1 | 2 | RTD1-2 |
| | RTD1-3 | 3 | 4 | RTD1-4 |
| 2 | RTD2-1 | 5 | 6 | RTD2-2 |
| | RTD2-3 | 7 | 8 | RTD2-4 |
| 3 | RTD3-1 | 9 | 10 | RTD3-2 |
| | RTD3-3 | 11 | 12 | RTD3-4 |
| 4 | RTD4-1 | 13 | 14 | RTD4-2 |
| | RTD4-3 | 15 | 16 | RTD4-4 |
| 5 | RTD5-1 | 17 | 18 | RTD5-2 |
| | RTD5-3 | 19 | 20 | RTD5-4 |
| 6 | RTD6-1 | 21 | 22 | RTD6-2 |
| | RTD6-3 | 23 | 24 | RTD6-4 |
| 7 | RTD7-1 | 25 | 26 | RTD7-2 |
| | RTD7-3 | 27 | 28 | RTD7-4 |
| 8 | RTD8-1 | 29 | 30 | RTD8-2 |
| | RTD8-3 | 31 | 32 | RTD8-4 |

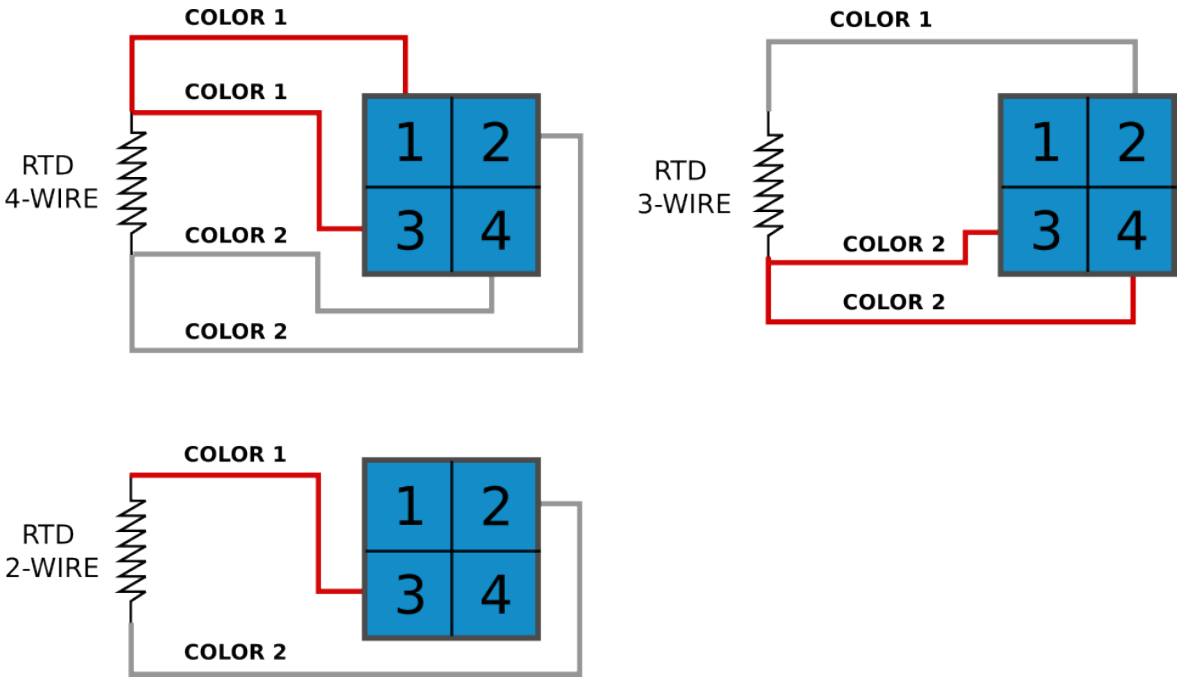


The RTD input module is an add-on module with eight (8) RTD input channels. Each input supports 2-wire, 3-wire and 4-wire RTD sensors. The sensor type can be selected with software for two groups, four channels each. The card supports Pt100 and Pt1000 sensors



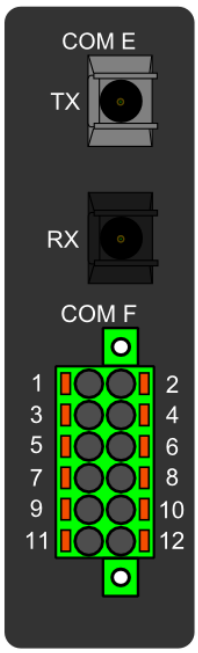
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Figure. 8.8 - 231. RTD sensor connection types.




## 8.9 Serial RS-232 communication module (optional)

Figure. 8.9 - 232. Serial RS-232 module connectors.



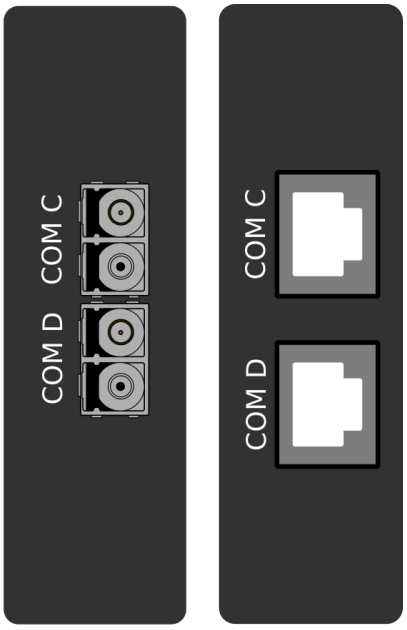

| Connector | Name | Description |
|---|---|---|
| COM E | Serial fiber (GG/ PP/GP/PG) | • Serial-based communications<br>• Wavelength 660 nm<br>• Compatible with 50/125 µm, 62.5/125 µm, 100/140 µm, and 200 µm Plastic-Clad Silica (PCS) fiber<br>• Compatible with ST connectors |

| Connector | Name | Description |
|---|---|---|
| COM F – Pin 1 | +24 V input | Optional external auxiliary voltage for serial fiber |
| COM F – Pin 2 | GND | Optional external auxiliary voltage for serial fiber |
| COM F – Pin 3 | - | - |
| COM F – Pin 4 | - | - |
| COM F – Pin 5 | RS-232 RTS | Serial based communications |
| COM F – Pin 6 | RS-232 GND | Serial based communications |
| COM F – Pin 7 | RS-232 TX | Serial based communications |
| COM F – Pin 8 | RS-232 RX | Serial based communications |
| COM F – Pin 9 | - | - |
| COM F – Pin 10 | +3.3 V output (spare) | Spare power source for external equipment (45 mA) |
| COM F – Pin 11 | Clock sync input | Clock synchronization input |
| COM F – Pin 12 | Clock sync GND | Clock synchronization input |

The option card includes two serial communication interfaces: COM E is a serial fiber interface with glass/plastic option, COM F is an RS-232 interface.

## 8.10 LC or RJ45 100 Mbps Ethernet communication module (optional)

Figure. 8.10 - 233. LC and RJ45 100 Mbps Ethernet module connectors.





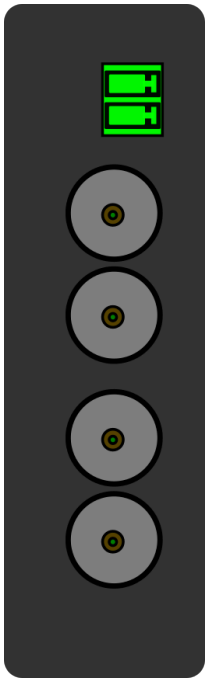

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| Connector | Description (LC ports) | Description (RJ45) |
|---|---|---|
| COM C: | • Communication port C, 100 MbpsLC fiber connector.<br>• 62.5/125 µm or 50/125 µm multimode (glass).<br>• Wavelength 1300 nm. | • RJ-45 connectors<br>• 10BASE-T and 100BASE-TX |
| COM D: | • Communication port D, 100 Mbps LC fiber connector.<br>• 62.5/125 µm or 50/125 µm multimode (glass).<br>• Wavelength 1300 nm. | • RJ-45 connectors<br>• 10BASE-T and 100BASE-TX |

Both cards support both HSR and PRP protocols.

## 8.11 Double ST 100 Mbps Ethernet communication module (optional)

Figure. 8.11 - 234. Double ST 100 Mbps Ethernet communication module connectors.



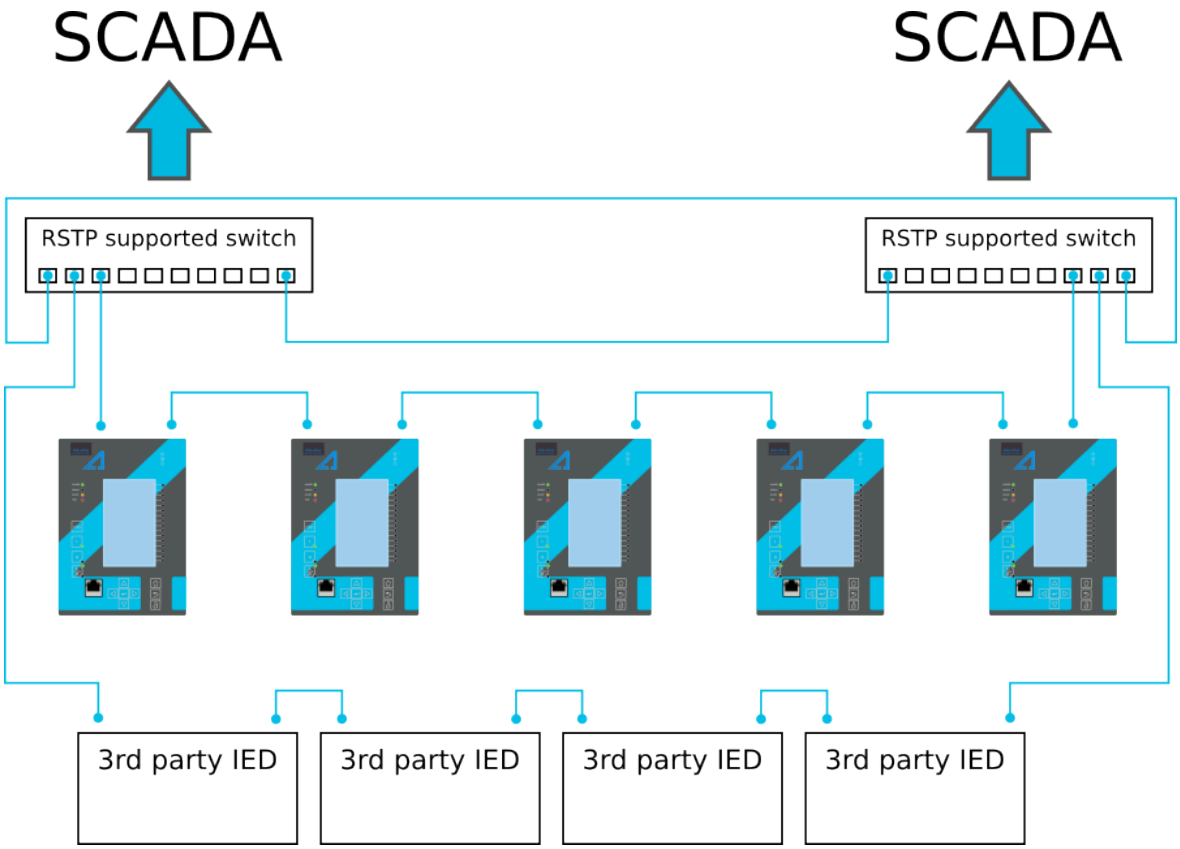
| Connector | Description |
|---|---|
| Two-pin connector | • IRIG-B input |
| ST connectors | • Duplex ST connectors<br>• 62.5/125 µm or 50/125 µm multimode fiber<br>• Transmitter wavelength: 1260…1360 nm (nominal: 1310 nm)<br>• Receiver wavelength: 1100…1600 nm<br>• 100BASE-FX<br>• Up to 2 km |

This option cards supports redundant ring configuration and multidrop configurations. Please note that each ring can only contain AQ-200 series devices, and any third party devices must be connected to a separate ring.

For other redundancy options, please refer to the option card "LC 100 Mbps Ethernet communication module".

The images below present two example configurations: the first displays a ring configuration (note how the third party devices are connected in a separate ring), while the second displays a multidrop configuration.

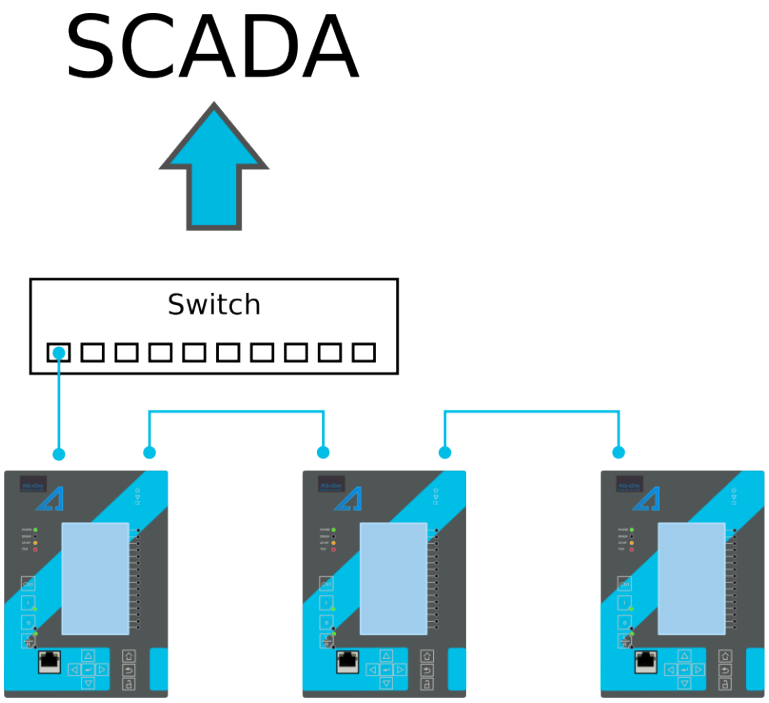
Figure. 8.11 - 235. Example of a ring configuration.





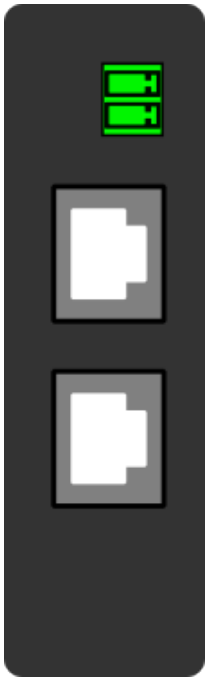

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Figure. 8.11 - 236. Example of a multidrop configuration.




## 8.12 Double RJ45 10/100 Mbps Ethernet communication module (optional)

Figure. 8.12 - 237. Double RJ-45 10/100 Mbps Ethernet communication module.



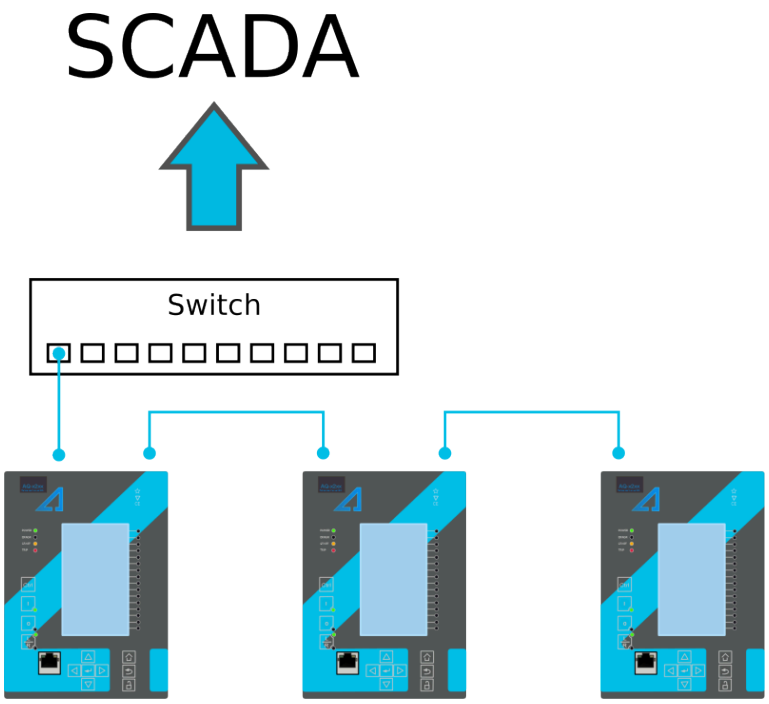
| Connector | Description |
|---|---|
| Two-pin connector | • IRIG-B input |

| Connector | Description |
|---|---|
| RJ-45 connectors | • Two Ethernet ports<br>• RJ-45 connectors<br>• 10BASE-T and 100BASE-TX |

This option card supports multidrop configurations.

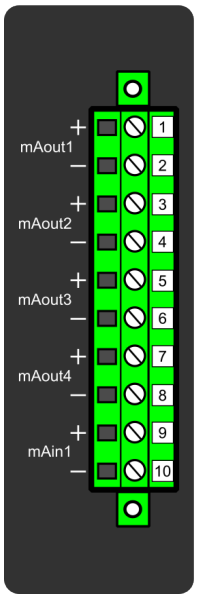
For other redundancy options, please refer to the option card "LC 100 Mbps Ethernet communication module".

Figure. 8.12 - 238. Example of a multidrop configuration.




## 8.13 Milliampere (mA) I/O module (optional)

Figure. 8.13 - 239. Milliampere (mA) I/O module connections.






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| Connector | Description |
|---|---|
| Pin 1 | mA OUT 1 + connector (0…24 mA) |
| Pin 2 | mA OUT 1 – connector (0…24 mA) |
| Pin 3 | mA OUT 2 + connector (0…24 mA) |
| Pin 4 | mA OUT 2 – connector (0…24 mA) |
| Pin 5 | mA OUT 3 + connector (0…24 mA) |
| Pin 6 | mA OUT 3 – connector (0…24 mA) |
| Pin 7 | mA OUT 4 + connector (0…24 mA) |
| Pin 8 | mA OUT 4 – connector (0…24 mA) |
| Pin 9 | mA IN 1 + connector (0…33 mA) |
| Pin 10 | mA IN 1 – connector (0…33 mA) |

The milliampere (mA) I/O module is an add-on module with four (4) mA outputs and one (1) mA input. Both the outputs and the input are in two galvanically isolated groups, with one pin for the positive (+) connector and one pin for the negative (–) connector.

This module can be ordered directly to be installed into the device in the factory, or it can be upgraded in the field after the device's original installation when required.

The user sets the mA I/O with the mA outputs control function. This can be done at *Control → Device I/O → mA outputs* in the relay configuration settings.

## 8.14 Dimensions and installation

The device can be installed either to a standard 19” rack or to a switchgear panel with cutouts. The desired installation type is defined in the order code. When installing to a rack, the device takes a half (½) of the rack's width, meaning that a total of two devices can be installed to the same rack next to one another.

The figures below describe the device dimensions (first figure), the device installation (second), and the panel cutout dimensions and device spacing (third).

Figure. 8.14 - 240. Device dimensions.

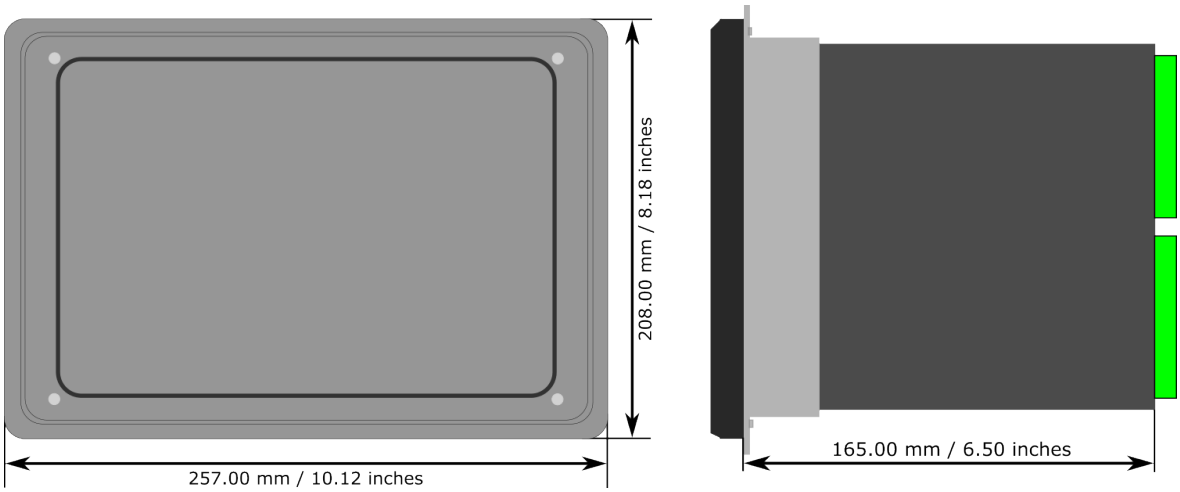
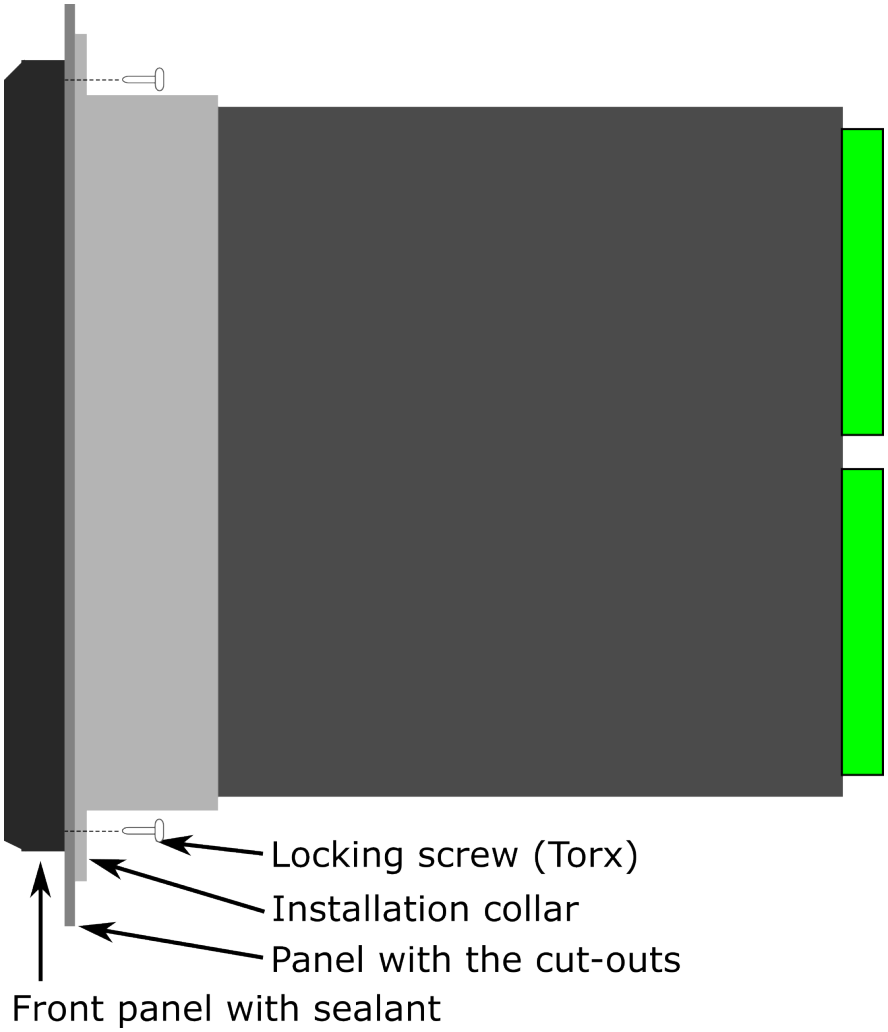


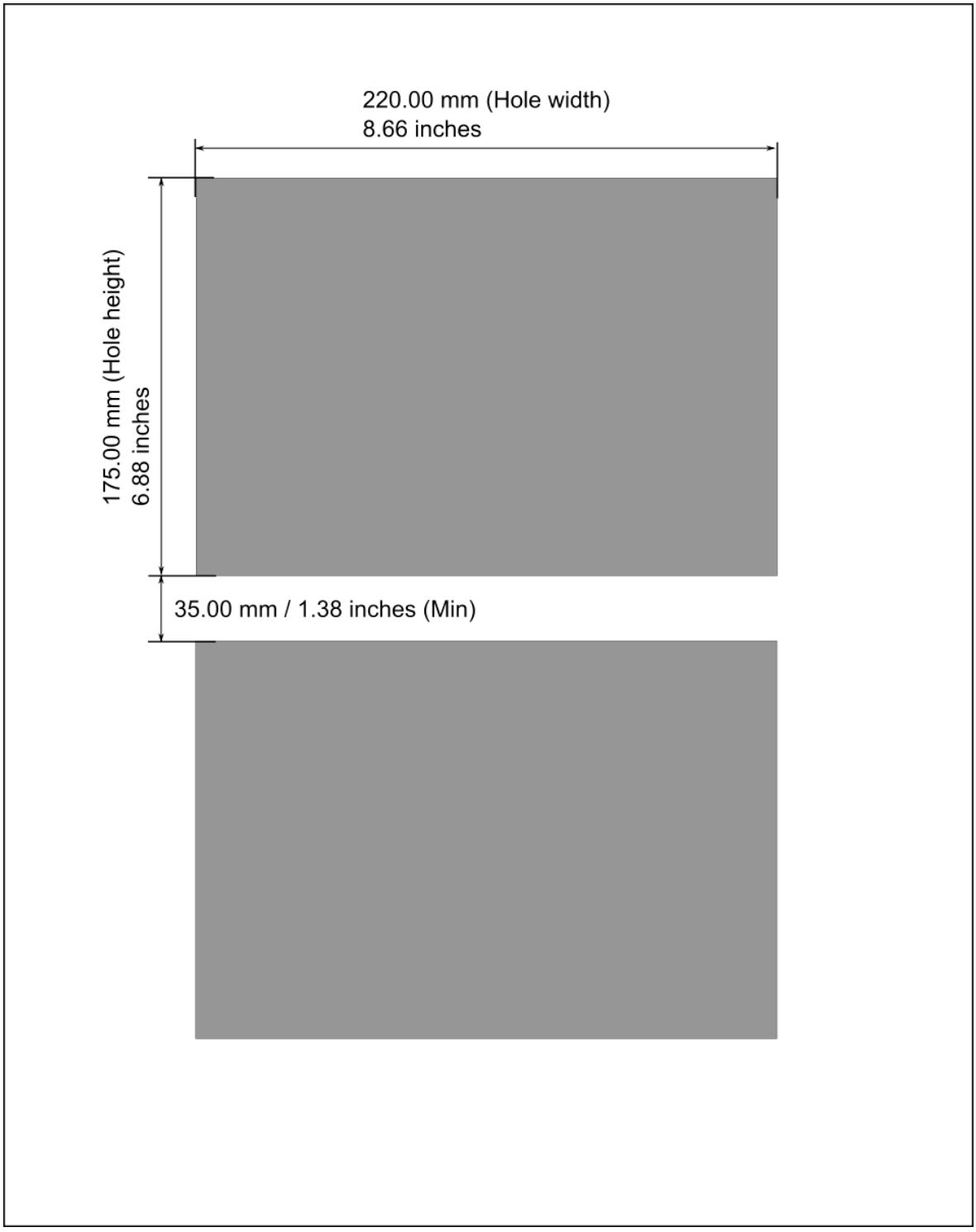
Figure. 8.14 - 241. Device installation.






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Figure. 8.14 - 242. Panel cut-out and spacing of the IED.



# 9 Technical data

## 9.1 Hardware

### 9.1.1 Measurements

#### 9.1.1.1 Current measurement

Table. 9.1.1.1 - 408. Technical data for the current measurement module.

| | |
|---|---|
| **General information** | |
| Spare part code | #SP-2XX-CM |
| Compatibility | AQ-210 and AQ-250 series models |
| **Connections** | |
| Measurement channels/CT inputs | Three phase current inputs: IL1 (A), IL2 (B), IL3 (C)<br>Two residual current inputs: Coarse residual current input I01, Fine residual current input I02 |
| **Phase current inputs (A, B, C)** | |
| Sample rate | 64 samples per cycle in frequency range 6...75Hz |
| Rated current $I_N$ | 5 A (configurable 0.2…10 A) |
| Thermal withstand | 20 A (continuous)<br>100 A (for 10 s)<br>500 A (for 1 s)<br>1250 A (for 0.01 s) |
| Frequency measurement range | From 6…75Hz fundamental, up to the 31$^{st}$ harmonic current |
| Current measurement range | 25 mA…250 A (RMS) |
| Current measurement inaccuracy | 0.005…4.000 × $I_N$ < ±0.5 % or < ±15 mA<br>4…20 × $I_N$ < ±0.5 %<br>20…50 × $I_N$ < ±1.0 % |
| Angle measurement inaccuracy | < ±0.2° (I> 0.1 A)<br>< ±1.0° (I≤ 0.1 A) |
| Burden (50/60 Hz) | <0.1 VA |
| Transient overreach | <8 % |
| **Coarse residual current input (I01)** | |
| Rated current $I_N$ | 1 A (configurable 0.1…10 A) |
| Thermal withstand | 25 A (continuous)<br>100 A (for 10 s)<br>500 A (for 1 s)<br>1250 A (for 0.01 s) |
| Frequency measurement range | From 6…75 Hz fundamental, up to the 31$^{st}$ harmonic current |
| Current measurement range | 5 mA…150 A (RMS) |


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| | |
|---|---|
| Current measurement inaccuracy | 0.002…10.000 × $I_N$ < ±0.5 % or < ±3 mA<br>10…150 × $I_N$ < ±0.5 % |
| Angle measurement inaccuracy | < ±0.2° (I> 0.05 A)<br>< ±1.0° (I≤ 0.05 A) |
| Burden (50/60Hz) | <0.1 VA |
| Transient overreach | <5 % |
| Fine residual current input (I02) | |
| Rated current $I_N$ | 0.2 A (configurable 0.001…10 A) |
| Thermal withstand | 25 A (continuous)<br>100 A (for 10 s)<br>500 A (for 1 s)<br>1250 A (for 0.01 s) |
| Frequency measurement range | From 6…75 Hz fundamental, up to the 31$^{st}$ harmonic current |
| Current measurement range | 1 mA…75 A (RMS) |
| Current measurement inaccuracy | 0.002…25.000 × $I_N$ < ±0.5 % or < ±0.6 mA<br>25…375 × $I_N$ < ±1.0 % |
| Angle measurement inaccuracy | < ±0.2° (I> 0.01 A)<br>< ±1.0° (I≤ 0.01 A) |
| Burden (50/60Hz) | <0.1 VA |
| Transient overreach | <5 % |
| Terminal block connection | |
| Terminal block | Phoenix Contact FRONT 4-H-6,35 |
| Solid or stranded wire<br>Maximum wire diameter | 4 mm$^2$ |

NOTE!

Current measurement accuracy has been verified with 50/60 Hz.

The amplitude difference is 0.2 % and the angle difference is 0.5 degrees higher at 16.67 Hz and other frequencies.

### 9.1.1.2 Voltage measurement

Table. 9.1.1.2 - 409. Technical data for the voltage measurement module.

| | |
|---|---|
| General information | |
| Spare part code | #SP-2XX-VT |
| Compatibility | AQ-200 series & AQ-250 series models |
| Connection | |
| Measurement channels/VT inputs | 4 independent VT inputs (U1, U2, U3 and U4) |
| Measurement | |
| Sample rate | 64 samples per cycle in frequency range 6...75Hz |

| | |
|---|---|
| Voltage measuring range | 0.50…480.00 V (RMS) |
| Voltage measurement inaccuracy | 1…2 V ±1.5 %<br>2…10 V ±0.5 %<br>10…480 V ±0.35 % |
| Angle measurement inaccuracy | ±0.2 degrees (15…300 V)<br>±1.5 degrees (1…15 V) |
| Voltage measurement bandwidth (freq.) | 7…75 Hz fundamental, up to the 31$^{st}$ harmonic voltage |
| Terminal block connection | |
| Terminal block | Phoenix Contact PC 5/8-STCL1-7.62 |
| Solid or stranded wire<br>Maximum wire diameter | 6 mm$^2$ |
| Input impedance | 24.5…24.6 MΩ |
| Burden (50/60 Hz) | <0.02 VA |
| Thermal withstand | 630 $V_{RMS}$ (continuous) |

NOTE!

Voltage measurement accuracy has been verified with 50/60 Hz.

The amplitude difference is 0.2 % and the angle difference is 0.5 degrees higher at 16.67 Hz and other frequencies.

### 9.1.1.3 Power and energy measurement

Table. 9.1.1.3 - 410. Power and energy measurement accuracy

| Power measurement P, Q, S | Frequency range 6…75 Hz |
|---|---|
| Inaccuracy | 0.3 % <1.2 × $I_N$ or 3 VA secondary<br>1.0 % >1.2 × $I_N$ or 3 VA secondary |
| Energy measurement | Frequency range 6…75 Hz |
| Energy and power metering inaccuracy | 0.5% down to 1A RMS (50/60Hz) as standard<br>0.2% down to 1A RMS (50/60Hz) option available (see the order code for details) |

### 9.1.1.4 Frequency measurement

Table. 9.1.1.4 - 411. Frequency measurement accuracy.

| Frequency measurement performance | |
|---|---|
| Frequency measuring range | 6…75 Hz fundamental, up to the 31$^{st}$ harmonic current or voltage |
| Inaccuracy | 10 mHz |

## 9.1.2 CPU & Power supply

Table. 9.1.2 - 412. General information for the CPU module.

| General information |
|---|



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| | |
|---|---|
| Spare part code | #SP-250-CPU |
| Compatibility | AQ-250 series models |

### 9.1.2.1 Auxiliary voltage

Table. 9.1.2.1 - 413. Power supply model A

| Rated values | |
|---|---|
| Rated auxiliary voltage | 85…265 V (AC/DC) |
| Power consumption | < 20 W<br>< 40 W |
| Maximum permitted interrupt time | < 40 ms with 110 VDC |
| DC ripple | < 15 % |
| **Terminal block connection** | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br>Maximum wire diameter | 2.5 $mm^2$ |
| **Other** | |
| Minimum recommended fuse rating | MCB C2 |

Table. 9.1.2.1 - 414. Power supply model B

| Rated values | |
|---|---|
| Rated auxiliary voltage | 18…72 VDC |
| Power consumption | < 20 W<br>< 40 W |
| Maximum permitted interrupt time | < 40 ms with 24 VDC |
| DC ripple | < 15 % |
| **Terminal block connection** | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br>Maximum wire diameter | 2.5 $mm^2$ |
| **Other** | |
| Minimum recommended fuse rating | MCB C2 |

### 9.1.2.2 CPU communication ports

Table. 9.1.2.2 - 415. Front panel local communication port.

| Port | |
|---|---|
| Port media | Copper Ethernet RJ-45 |
| Number of ports | 1 |

| | |
|---|---|
| Port protocols | PC-protocols<br>FTP<br>Telnet |
| Features | |
| Data transfer rate | 100 MB |
| System integration | Cannot be used for system protocols, only for local programming |

Table. 9.1.2.2 - 416. Rear panel system communication port A.

| Port | |
|---|---|
| Port media | Copper Ethernet RJ-45 |
| Number of ports | 1 |
| Features | |
| Port protocols | IEC 61850<br>IEC 104<br>Modbus/TCP<br>DNP3<br>FTP<br>Telnet |
| Data transfer rate | 100 MB |
| System integration | Can be used for system protocols and for local programming |

Table. 9.1.2.2 - 417. Rear panel system communication port B.

| Port | |
|---|---|
| Port media | Copper RS-485 |
| Number of ports | 1 |
| Features | |
| Port protocols | Modbus/RTU<br>IEC 103<br>IEC 101<br>DNP3<br>SPA |
| Data transfer rate | 65 580 kB/s |
| System integration | Can be used for system protocols |

### 9.1.2.3 CPU digital inputs

Table. 9.1.2.3 - 418. CPU model-isolated digital inputs, with thresholds defined by order code.

| Rated values | |
|---|---|
| Rated auxiliary voltage | 265 V (AC/DC) |
| Nominal voltage | Order code defined: 24, 110, 220 V (AC/DC) |



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| | |
|---|---|
| Pick-up threshold<br>Release threshold | Order code defined: 19, 90,170 V<br>Order code defined: 14, 65, 132 V |
| Scanning rate | 5 ms |
| Settings | |
| Pick-up delay | Software settable: 0…1800 s |
| Polarity | Software settable: Normally On/Normally Off |
| Current drain | 2 mA |
| Terminal block connection | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br><br>Maximum wire diameter | <br><br>2.5 $mm^2$ |

## 9.1.2.4 CPU digital outputs

Table. 9.1.2.4 - 419. Digital outputs (Normally Open)

| | |
|---|---|
| Rated values | |
| Rated auxiliary voltage | 265 V (AC/DC) |
| Continuous carry | 5 A |
| Make and carry 0.5 s<br>Make and carry 3 s | 30 A<br>15 A |
| Breaking capacity, DC (L/R = 40 ms)<br>at 48 VDC<br>at 110 VDC<br>at 220 VDC | <br>1 A<br>0.4 A<br>0.2 A |
| Control rate | 5 ms |
| Settings | |
| Polarity | Software settable: Normally On/Normally Off |
| Terminal block connection | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br>Maximum wire diameter | <br>2.5 $mm^2$ |

Table. 9.1.2.4 - 420. Digital outputs (Change-Over)

| | |
|---|---|
| Rated values | |
| Rated auxiliary voltage | 265 V (AC/DC) |
| Continuous carry | 5 A |
| Make and carry 0.5 s<br>Make and carry 3 s | 30 A<br>15 A |
| Breaking capacity, DC (L/R = 40 ms)<br>at 48 VDC<br>at 110 VDC<br>at 220 VDC | <br>1 A<br>0.4 A<br>0.2 A |
| Control rate | 5 ms |
| Settings | |
| Polarity | Software settable: Normally On/Normally Off |

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| Terminal block connection | |
|---|---|
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br>Maximum wire diameter | <br>2.5 $mm^2$ |

### 9.1.3 Option cards

#### 9.1.3.1 Digital input module

Table. 9.1.3.1 - 421. Technical data for the digital input module.

| General information | |
|---|---|
| Spare part code | #SP-250-DI8 |
| Compatibility | AQ-250 series models |
| **Rated values** | |
| Rated auxiliary voltage | 5…265 V (AC/DC) |
| Current drain | 2 mA |
| Scanning rate<br>Activation/release delay | 5 ms<br>5...11 ms |
| **Settings** | |
| Pick-up threshold<br>Release threshold | Software settable: 16…200 V, setting step 1 V<br>Software settable: 10…200 V, setting step 1 V |
| Pick-up delay | Software settable: 0…1800 s |
| Drop-off delay | Software settable: 0…1800 s |
| Polarity | Software settable: Normally On/Normally Off |
| **Terminal block connection** | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br><br>Maximum wire diameter | <br>2.5 $mm^2$ |

#### 9.1.3.2 Digital output module

Table. 9.1.3.2 - 422. Technical data for the digital output module.

| General information | |
|---|---|
| Spare part code | #SP-250-DO5 |
| Compatibility | AQ-250 series models |
| **Rated values** | |
| Rated auxiliary voltage | 265 V (AC/DC) |
| Continuous carry | 5 A |
| Make and carry 0.5 s<br>Make and carry 3 s | 30 A<br>15 A |
| Breaking capacity, DC (L/R = 40 ms)<br>at 48 VDC<br>at 110 VDC<br>at 220 VDC | <br>1 A<br>0.4 A<br>0.2 A |
| Control rate | 5 ms |


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| Settings | |
|---|---|
| Polarity | Software settable: Normally On/Normally Off |
| **Terminal block connection** | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br><br>Maximum wire diameter | <br><br>2.5 $mm^2$ |

### 9.1.3.3 Point sensor arc protection module

Table. 9.1.3.3 - 423. Technical data for the point sensor arc protection module.

| General information | |
|---|---|
| Spare part code | #SP-2XX-ARC |
| Compatibility | AQ-200 series & AQ-250 series models |
| **Connections** | |
| Input arc point sensor channels | S1, S2, S3, S4 (pressure and light, or light only) |
| Sensors per channel | 3 |
| **Performance** | |
| Pick-up light intensity | 8, 25 or 50 kLx (the sensor is selectable in the order code) |
| Point sensor detection radius | 180 degrees |
| Start and instant operating time (light only) | Typically <5 ms with dedicated semiconductor outputs (HSO)<br>Typically <10 ms regular output relays |

Table. 9.1.3.3 - 424. High-Speed Outputs (HSO1…2)

| Rated values | |
|---|---|
| Rated auxiliary voltage | 250 VDC |
| Continuous carry | 2 A |
| Make and carry 0.5 s<br>Make and carry 3 s | 15 A<br>6 A |
| Breaking capacity, DC (L/R = 40 ms) | 1 A/110 W |
| Control rate | 5 ms |
| Operation delay | <1 ms |
| Polarity | Normally Off |
| Contact material | Semiconductor |
| **Terminal block connection** | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br><br>Maximum wire diameter | <br><br>2.5 $mm^2$ |

Table. 9.1.3.3 - 425. Binary input channel

| Rated values | |
|---|---|
| Voltage withstand | 265 VDC |

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| | |
|---|---|
| Nominal voltage<br>Pick-up threshold<br>Release threshold | 24 VDC<br>≥16 VDC<br>≤15 VDC |
| Scanning rate | 5 ms |
| Polarity | Normally Off |
| Current drain | 3 mA |
| Terminal block connection | |
| Terminal block | Phoenix Contact MSTB 2,5/5-ST-5,08 |
| Solid or stranded wire<br><br>Maximum wire diameter | <br><br>2.5 $mm^2$ |

NOTE! Polarity has to be correct.

### 9.1.3.4 Milliampere module (mA out & mA in)

Table. 9.1.3.4 - 426. Technical data for the milliampere module.

| | |
|---|---|
| General information | |
| Spare part code | #SP-2XX-MA |
| Compatibility | AQ-200 series & AQ-250 series models |
| Signals | |
| Output magnitudes | 4 × mA output signal (DC) |
| Input magnitudes | 1 × mA input signal (DC) |
| mA input | |
| Range (hardware) | 0...33 mA |
| Range (measurement) | 0...24 mA |
| Inaccuracy | ±0.1 mA |
| Update cycle | 5...10 000 ms, setting step 5 ms |
| Response time @ 5 ms cycle | ~ 15 ms (13...18 ms) |
| Update cycle time inaccuracy | Max. +20 ms above the set cycle |
| mA input scaling range | 0...4000 mA |
| Output scaling range | -1 000 000.0000…1 000 000.0000, setting step 0.0001 |
| mA output | |
| Inaccuracy @ 0...24 mA | ±0.01 mA |
| Response time @ 5 ms cycle [fixed] | < 5 ms |
| mA output scaling range | 0...24 mA, setting step 0.001 mA |
| Source signal scaling range | -1 000 000.000…1 000 000.0000, setting step 0.0001 |

### 9.1.3.5 RTD input module

Table. 9.1.3.5 - 427. Technical data for the RTD input module.

| | |
|---|---|
| General information | |
| Spare part code | #SP-2xx-RTD |



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| | |
|---|---|
| Compatibility | AQ-200 series & AQ-250 series models |
| Channels 1-8 | |
| 2/3/4-wire RTD | |
| Pt100 or Pt1000 | |

### 9.1.3.6 RS-232 & serial fiber communication module

Table. 9.1.3.6 - 428. Technical data for the RS-232 & serial fiber communication module.

| | |
|---|---|
| General information | |
| PP Spare part code | #SP-2XX-232PP |
| PG Spare part code | #SP-2XX-232PG |
| GP Spare part code | #SP-2XX-232GP |
| GG Spare part code | #SP-2XX-232GG |
| Compatibility | AQ-200 series & AQ-250 series models |
| Ports | |
| RS-232 | |
| Serial fiber (GG/PP/GP/PG) | |
| Serial port wavelength | |
| 660 nm | |
| Cable type | |
| 1 mm plastic fiber | |

### 9.1.3.7 Double LC 100 Mbps Ethernet communication module

Table. 9.1.3.7 - 429. Technical data for the double LC 100 Mbps Ethernet communication module.

| | |
|---|---|
| General information | |
| Spare part code | #SP-2XX-2XLC |
| Compatibility | AQ-200 series & AQ-250 series models |
| Protocols | |
| Protocols | HSR and PRP |
| Ports | |
| Quantity of fiber ports | 2 |
| Communication port C & D | LC fiber connector<br>Wavelength 1300 nm |
| Fiber cable | 50/125 µm or 62.5/125 µm multimode (glass) |

### 9.1.3.8 Double ST 100 Mbps Ethernet communication module

Table. 9.1.3.8 - 430. Technical data for the double ST 100 Mbps Ethernet communication module.

| | |
|---|---|
| General information | |
| Spare part code | #SP-2XX-2XST |
| Compatibility | AQ-200 series & AQ-250 series models |

| | |
|---|---|
| Dimensions | 74 mm X 179 mm |
| Ports | ST connectors (2) and IRIG-B connector (1) |
| Protocols | |
| Protocols | IEC61850, DNP/TCP, Modbus/TCP, IEC104 & FTP |
| ST connectors | |
| Connector type | Duplex ST connectors<br>62.5/125 µm or 50/125 µm multimode fiber<br>100BASE-FX |
| Transmitter wavelength | 1260…1360 nm (nominal: 1310 nm) |
| Receiver wavelength | 1100…1600 nm |
| Maximum distance | 2 km |
| IRIG-B Connector | |
| Connector type | Phoenix Contact MC 1,5/ 2-ST-3,5 BD:1-2 |

### 9.1.4 Display

Table. 9.1.4 - 431. Technical data for the HMI TFT display.

| | |
|---|---|
| General information | |
| Spare part code | #SP-200-DISP |
| Compatibility | AQ-250 series models |
| Dimensions and resolution | |
| Number of dots/resolution | 800 x 480 |
| Size | 154.08 × 85.92 mm (6.06 × 3.38 in) |
| Display | |
| Type of display | TFT |
| Color | RGB color |

## 9.2 Functions

### 9.2.1 Protection functions

#### 9.2.1.1 Non-directional overcurrent protection (I>; 50/51)

Table. 9.2.1.1 - 432. Technical data for the non-directional overcurrent function.

| | |
|---|---|
| Measurement inputs | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS phase currents<br>TRMS phase currents<br>Peak-to-peak phase currents |
| Pick-up | |
| Pick-up current setting | 0.10…50.00 × $I_n$, setting step 0.01 × $I_n$ |
| Inrush 2nd harmonic blocking | 0.10…50.00 %$I_{fund}$, setting step 0.01 %$I_{fund}$ |



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| | |
|---|---|
| Inaccuracy:<br>- Current<br>- 2nd harmonic blocking | <br>±0.5 %$I_{set}$ or ±15 mA (0.10…4.0 × $I_{set}$)<br>±1.0 %-unit of the 2nd harmonic setting |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time: $I_m/I_{set}$ ratio > 3<br>- Definite time: $I_m/I_{set}$ ratio = 1.05…3 | <br>±1.0 % or ±20 ms<br>±1.0 % or ±30 ms |
| IDMT setting parameters:<br>- k Time dial setting for IDMT<br>- A IDMT constant<br>- B IDMT constant<br>- C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| Retardation time (overshoot) | <30 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio = 2<br>- $I_m/I_{set}$ ratio = 5<br>- $I_m/I_{set}$ ratio = 10 | <br>Typically 25 ms<br>Typically 16 ms<br>Typically 12 ms |
| Reset | |
| Reset ratio | 97 % of the pick-up current setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±50 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- The release delay does not apply to phase-specific tripping.

### 9.2.1.2 Non-directional earth fault protection (I0>; 50N/51N)

Table. 9.2.1.2 - 433. Technical data for the non-directional earth fault function.

| | |
|---|---|
| Measurement inputs | |
| Current input (selectable) | Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine)<br>Calculated residual current: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS residual current ($I_{01}$, $I_{02}$ or calculated $I_0$)<br>TRMS residual current ($I_{01}$ or $I_{02}$)<br>Peak-to-peak residual current ($I_{01}$ or $I_{02}$) |
| Pick-up | |
| Used magnitude | Measured residual current I01 (1 A)<br>Measured residual current I02 (0.2 A)<br>Calculated residual current I0Calc (5 A) |
| Pick-up current setting | 0.0001…40.00 × $I_n$, setting step 0.0001 × $I_n$ |
| Inaccuracy:<br>- Starting I01 (1 A)<br>- Starting I02 (0.2 A)<br>- Starting I0Calc (5 A) | <br>±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 × $I_{set}$)<br>±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 × $I_{set}$)<br>±1.0 %$I0_{set}$ or ±15 mA (0.005…4.0 × $I_{set}$) |
| Operating time | |

| | |
|---|---|
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time: $I_m/I_{set}$ ratio > 3<br>- Definite time: $I_m/I_{set}$ ratio = 1.05…3 | <br>±1.0 % or ±20 ms<br>±1.0 % or ±30 ms |
| IDMT setting parameters:<br>- k Time dial setting for IDMT<br>- A IDMT constant<br>- B IDMT constant<br>- C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| Retardation time (overshoot) | <30 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio > 3.5<br>- $I_m/I_{set}$ ratio = 1.05…3.5 | <br><50 ms (typically 35 ms)<br><55 ms |
| Reset | |
| Reset ratio | 97 % of the pick-up current setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±50 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- The operation and reset time accuracy does not apply when the measured secondary current in I02 is 1…20 mA. The pick-up is tuned to be more sensitive and the operation times vary because of this.

### 9.2.1.3 Directional overcurrent protection (Idir>; 67)

Table. 9.2.1.3 - 434. Technical data for the directional overcurrent function.

| | |
|---|---|
| Input signals | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS phase currents<br>TRMS phase currents<br>Peak-to-peak phase currents |
| Current input calculations | Positive sequence current angle |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ + U0 |
| Voltage input calculations | Positive sequence voltage angle |
| Pick-up | |
| Characteristic direction | Directional, non-directional |
| Operating sector center | -180.0…180.0 deg, setting step 0.1 deg |
| Operating sector size (+/-) | 1.00…170.00 deg, setting step 0.10 deg |
| Pick-up current setting | 0.10…40.00 × $I_n$, setting step 0.01 × $I_n$ |
| Inaccuracy:<br>- Current<br>- U1/I1 angle (U > 15 V)<br>- U1/I1 angle (U = 1…15 V) | <br>±0.5 %$I_{set}$ or ±15 mA (0.10…4.0 × $I_{set}$)<br>±0.20°<br>±1.5° |


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| Operation time | |
|---|---|
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time: $I_m/I_{set}$ ratio > 3<br>- Definite time: $I_m/I_{set}$ ratio = 1.05…3 | <br>±1.0 % or ±20 ms<br>±1.0 % or ±35 ms |
| IDMT setting parameters:<br>- k Time dial setting for IDMT<br>- A IDMT constant<br>- B IDMT constant<br>- C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio > 3<br>- $I_m/I_{set}$ ratio = 1.05…3 | <br><40 ms (typically 30 ms)<br><50 ms |
| **Reset** | |
| Reset ratio:<br>- Current<br>- U1/I1 angle | <br>97 % of the pick-up current setting<br>2.0° |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±50 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- The minimum voltage for direction solving is 1.0 V secondary. During three-phase short-circuits the angle memory is active for 0.5 seconds in case the voltage drops below 1.0 V.

### 9.2.1.4 Directional earth fault protection (I0dir>; 67N/32N)

Table. 9.2.1.4 - 435. Technical data for the directional earth fault function.

| Measurement inputs | |
|---|---|
| Current input (selectable) | Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine)<br>Calculated residual current: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS residual current ($I_{01}$, $I_{02}$ or calculated $I_0$)<br>TRMS residual current ($I_{01}$ or $I_{02}$)<br>Peak-to-peak residual current ($I_{01}$ or $I_{02}$) |
| Voltage input (selectable) | Residual voltage from U3 or U4 voltage channel<br>Residual voltage calculated from $U_{L1}$, $U_{L2}$, $U_{L3}$ |
| Voltage input magnitudes | RMS residual voltage $U_0$<br>Calculated RMS residual voltage $U_0$ |
| **Pick-up** | |
| Characteristic direction | Unearthed (Varmetric 90°)<br>Petersen coil GND (Wattmetric 180°)<br>*Earthed* (Adjustable sector) |
| When the *earthed* mode is active:<br>- Tripping area center<br>- Tripping area size (+/-) | <br>0.00…360.00 deg, setting step 0.10 deg<br>45.00…135.00 deg, setting step 0.10 deg |
| Pick-up current setting<br>Pick-up voltage setting | 0.005…40.00 × $I_n$, setting step 0.001 × $I_n$<br>1.00…75.00 %$U0_n$, setting step 0.01 %$U0_n$ |

| | |
|---|---|
| Inaccuracy:<br>- Starting I01 (1 A)<br>- Starting I02 (0.2 A)<br>- Starting I0Calc (5 A)<br>- Voltage U0 and U0Calc<br>- U0/I0 angle (U > 15 V)<br>- U0/I0 angle (U = 1…15 V) | <br>±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 × $I_{set}$)<br>±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 × $I_{set}$)<br>±1.5 %$I0_{set}$ or ±15 mA (0.005…4.0 × $I_{set}$)<br>±1.0 %$U0_{set}$ or ±30 mV<br>±0.2° (I0Calc ±1.0°)<br>±1.0° |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br><br>- Definite time ($I_m/I_{set}$ ratio 1.05→) | <br>±1.0 % or ±45 ms |
| IDMT setting parameters:<br>- k Time dial setting for IDMT<br>- A IDMT constant<br>- B IDMT constant<br>- C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br><br>- IDMT operating time<br>- IDMT minimum operating time | <br><br>±1.5 % or ±25 ms<br>±20 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio > 3<br>- $I_m/I_{set}$ ratio = 1.05…3 | <br><55 ms (typically 45 ms)<br><65 ms |
| Reset | |
| Current and voltage reset<br>U0/I0 angle | 97 % of the pick-up current and voltage setting<br>2.0° |
| Reset time setting<br>Inaccuracy: Reset time | 0.000…150.000 s, step 0.005 s<br>±1.0 % or ±45 ms |
| Instant reset time and start-up reset | <50 ms |

### 9.2.1.5 Intermittent earth fault protection (I0int>; 67NT)

Table. 9.2.1.5 - 436. Technical data for the intermittent earth fault function.

| | |
|---|---|
| Measurement inputs | |
| Current inputs (selectable) | Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| Current input magnitudes | Residual current samples |
| Voltage inputs (selectable) | Residual voltage from U3 or U4 voltage channel |
| Voltage input magnitude | Zero sequence voltage samples |
| Pick-up settings | |
| Spikes to trip | 1…50, setting step 1 |
| Pick-up current setting<br>Pick-up voltage setting | 0.05…40.00 × $I_n$, setting step 0.001 × $I_n$<br>1.00…100.00 %$U0_n$, setting step 0.01 %$U0_n$ |
| Pick-up inaccuracy | |
| Starting I01 (1 A)<br>Starting I02 (0.2 A)<br>Voltage U0 | ±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 x $I_{set}$)<br>±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 x $I_{set}$)<br>±1.0 %$U0_{set}$ or ±30 mV |
| Operation time setting | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |


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| Operation time inaccuracy | |
|---|---|
| Definite time: $I_m/I_{set}$ ratio 1.05→ | ±1.0 % or ±30 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio 1.05→ | <15 ms |
| **Reset time** | |
| Reset time setting (FWD and REV)<br>Inaccuracy: Reset time | 0.000…1800.000 s, step 0.005 s<br>±1.0 % or ±35 ms |
| Instant reset time and start-up reset | <50 ms |

### 9.2.1.6 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L)

Table. 9.2.1.6 - 437. Technical data for the current unbalance function.

| Measurement inputs | |
|---|---|
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input calculations | Positive sequence current (I1)<br>Negative sequence current (I2) |
| **Pick-up** | |
| Used magnitude | Negative sequence component I2pu<br>Relative unbalance I2/I1 |
| Pick-up setting | 0.01…40.00 × $I_n$, setting step 0.01 × $I_n$ (I2pu)<br>1.00…200.00 %, setting step 0.01 % (I2/I1) |
| Minimum phase current (at least one phase above) | 0.01…2.00 × $I_n$, setting step 0.01 × $I_n$ |
| Inaccuracy:<br>- Starting I2pu<br>- Starting I2/I1 | <br>±1.0 %-unit or ±100 mA (0.10…4.0 × $I_n$)<br>±1.0 %-unit or ±100 mA (0.10…4.0 × $I_n$) |
| **Operating time** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_m/I_{set}$ ratio > 1.05) | <br>±1.5 % or ±60 ms |
| IDMT setting parameters:<br>- k Time dial setting for IDMT<br>- A IDMT Constant<br>- B IDMT Constant<br>- C IDMT Constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±2.0 % or ±30 ms<br>±20 ms |
| Retardation time (overshoot) | <5 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $I_m/I_{set}$ ratio > 1.05 | <br><70 ms |
| **Reset** | |
| Reset ratio | 97 % of the pick-up setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.5 % or ±60 ms |
| Instant reset time and start-up reset | <55 ms |

### 9.2.1.7 Harmonic overcurrent protection (Ih>; 50H/51H/68H)

Table. 9.2.1.7 - 438. Technical data for the harmonic overcurrent function.

| | |
|---|---|
| **Measurement inputs** | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| **Pick-up** | |
| Harmonic selection | $2^{nd}$, $3^{rd}$, $4^{th}$, $5^{th}$, $6^{th}$ $7^{th}$, $9^{th}$, $11^{th}$, $13^{th}$, $15^{th}$, $17^{th}$ or $19^{th}$ |
| Used magnitude | Harmonic per unit (× $I_N$)<br>Harmonic relative (Ih/IL) |
| Pick-up setting | 0.05…2.00 × $I_N$, setting step 0.01 × $I_N$ (× $I_N$)<br>5.00…200.00 %, setting step 0.01 % (Ih/IL) |
| Inaccuracy:<br>- Starting × $I_N$<br>- Starting × Ih/IL | <br><0.03 × $I_N$ ($2^{nd}$, $3^{rd}$, $5^{th}$)<br><0.03 × $I_N$ tolerance to Ih ($2^{nd}$, $3^{rd}$, $5^{th}$) |
| **Operation time** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_M/I_{SET}$ ratio >1.05) | <br>±1.0 % or ±35 ms |
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>$I_M/I_{SET}$ ratio >1.05 | <br><50 ms |
| **Reset** | |
| Reset ratio | 95 % of the pick-up setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±35 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- Harmonics generally: The amplitude of the harmonic content has to be least 0.02 × $I_N$ when the relative mode (Ih/IL) is used.
- Blocking: To achieve fast activation for blocking purposes with the harmonic overcurrent stage, note that the harmonic stage may be activated by a rapid load change or fault situation. An intentional activation lasts for approximately 20 ms if a harmonic component is not present. The harmonic stage stays active if the harmonic content is above the pick-up limit.
- Tripping: When using the harmonic overcurrent stage for tripping, please ensure that the operation time is set to 20 ms (DT) or longer to avoid nuisance tripping caused by the above-mentioned reasons.


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### 9.2.1.8 Circuit breaker failure protection (CBFP; 50BF/52BF)

Table. 9.2.1.8 - 439. Technical data for the circuit breaker failure protection function.

| | |
|---|---|
| **Measurement inputs** | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| Current input magnitudes | RMS phase currents<br>RMS residual current ($I_{01}$, $I_{02}$ or calculated $I_0$) |
| **Pick-up** | |
| Monitored signals | Digital input status, digital output status, logical signals |
| Pick-up current setting:<br>- IL1…IL3<br>- I01, I02, I0Calc | <br>0.10…40.00 × $I_N$, setting step 0.01 × $I_N$<br>0.005…40.00 × $I_N$, setting step 0.005 × $I_N$ |
| Inaccuracy:<br>- Starting phase current (5A)<br>- Starting I01 (1 A)<br>- Starting I02 (0.2 A)<br>- Starting I0Calc (5 A) | <br>±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$)<br>±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × $I_{SET}$)<br>±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × $I_{SET}$)<br>±1.0 %$I0_{SET}$ or ±15 mA (0.005…4.0 × $I_{SET}$) |
| **Operation time** | |
| Definite time function operating time setting | 0.050…1800.000 s, setting step 0.005 s |
| Inaccuracy:<br>- Current criteria ($I_M/I_{SET}$ ratio 1.05→)<br>- DO or DI only | <br>±1.0 % or ±55 ms<br>±15 ms |
| **Reset** | |
| Reset ratio | 97 % of the pick-up current setting |
| Reset time | <50 ms |

### 9.2.1.9 Low-impedance or high-impedance restricted earth fault/ cable end differential protection (I0d>; 87N)

Table. 9.2.1.9 - 440. Technical data for the restricted earth fault/cable end differential function.

| | |
|---|---|
| **Measurement inputs** | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| Current input calculations | Calculated bias and residual differential currents |
| **Pick-up** | |
| Operating modes | Restricted earth fault<br>Cable end differential |
| Characteristics | Biased differential with 3 settable sections and 2 slopes |
| Pick-up current sensitivity setting<br>Slope 1<br>Slope 2<br>Bias (Turnpoint 1 & 2) | 0.01…50.00 % ($I_N$), setting step 0.01 %<br>0.00…150.00 %, setting step 0.01 %<br>0.00…250.00 %, setting step 0.01 %<br>0.01…50.00 × $I_N$, setting step 0.01 × $I_N$ |
| Inaccuracy<br>- Starting | ±3% of the set pick-up value > 0.5 × $I_N$ setting.<br>±5 mA < 0.5 × $I_N$ setting |
| **Operation time** | |

| | |
|---|---|
| Instant operation time<br>1.05 x $I_{SET}$ | <30 ms |
| Reset | |
| Reset ratio | No hysteresis |
| Reset time | <40 ms |

## 9.2.1.10 Overvoltage protection (U>; 59)

Table. 9.2.1.10 - 441. Technical data for the overvoltage function.

| | |
|---|---|
| Measurement inputs | |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ (+ $U_0$) |
| Voltage input magnitudes | RMS line-to-line or line-to-neutral voltages |
| Pick-up | |
| Pick-up terms | 1 voltage<br>2 voltages<br>3 voltages |
| Pick-up setting | 50.00…150.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Voltage | ±1.5 %$U_{SET}$ |
| Operating time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($U_M/U_{SET}$ ratio 1.05→) | ±1.0 % or ±35 ms |
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $U_M/U_{SET}$ ratio 1.05→ | <50 ms |
| Reset | |
| Reset ratio | 97 % of the pick-up voltage setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±45 ms |
| Instant reset time and start-up reset | <50 ms |

## 9.2.1.11 Undervoltage protection (U<; 27)

Table. 9.2.1.11 - 442. Technical data for the undervoltage function.

| | |
|---|---|
| Measurement inputs | |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ (+ $U_0$) |
| Voltage input magnitudes | RMS line-to-line or line-to-neutral voltages |


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| Pick-up | |
|---|---|
| Pick-up terms | 1 voltage<br>2 voltages<br>3 voltages |
| Pick-up setting | 0.00…120.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Voltage | ±1.5 %$U_{SET}$ or ±30 mV |
| **Low voltage block** | |
| Pick-up setting | 0.00…80.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Voltage | ±1.5 %$U_{SET}$ or ±30 mV |
| **Operation time** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($U_M/U_{SET}$ ratio 1.05→) | ±1.0 % or ±35 ms |
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $U_M/U_{SET}$ ratio 1.05→ | <br><65 ms |
| Retardation time (overshoot) | <30 ms |
| **Reset** | |
| Reset ratio | 103 % of the pick-up voltage setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±45 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- The low-voltage block is not in use when its pick-up setting is set to 0 %. The undervoltage function is in trip stage when the LV block is disabled and the device has no voltage injection.
- After the low voltage blocking condition, the undervoltage stage does not trip unless the voltage exceeds the pick-up setting first.

### 9.2.1.12 Neutral overvoltage protection (U0>; 59N)

Table. 9.2.1.12 - 443. Technical data for the neutral overvoltage function.

| Measurement inputs | |
|---|---|
| Voltage input (selectable) | Residual voltage from U3 or U4 voltage channel<br>Residual voltage calculated from $U_{L1}$, $U_{L2}$, $U_{L3}$ |
| Voltage input magnitudes | RMS residual voltage $U_0$<br>Calculated RMS residual voltage $U_0$ |
| **Pick-up** | |

| | |
|---|---|
| Pick-up voltage setting | 1.00…50.00 % $U0_N$, setting step 0.01 × $I_N$ |
| Inaccuracy:<br>- Voltage U0<br>- Voltage U0Calc | <br>±1.5 %$U0_{SET}$ or ±30 mV<br>±150 mV |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($U0_M/U0_{SET}$ ratio 1.05→) | <br>±1.0 % or ±45 ms |
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $U0_M/U0_{SET}$ ratio 1.05→ | <br><50 ms |
| Reset | |
| Reset ratio | 97 % of the pick-up voltage setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.000 … 150.000 s, step 0.005 s<br>±1.0 % or ±50 ms |
| Instant reset time and start-up reset | <50 ms |

## 9.2.1.13 Sequence voltage protection (U1/U2>/<; 47/27P/59NP)

Table. 9.2.1.13 - 444. Technical data for the sequence voltage function.

| | |
|---|---|
| Measurement inputs | |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ (+ $U_0$) |
| Voltage input calculations | Positive sequence voltage (I1)<br>Negative sequence voltage (I2) |
| Pick-up | |
| Pick-up setting | 5.00…150.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Voltage | <br>±1.5 %$U_{SET}$ or ±30 mV |
| Low voltage block | |
| Pick-up setting | 1.00…80.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>-Voltage | <br>±1.5 %$U_{SET}$ or ±30 mV |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy<br>-Definite Time ($U_M/U_{SET}$ ratio 1.05→) | <br>±1.0 % or ±35 ms |



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| | |
|---|---|
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $U_M/U_{SET}$ ratio <0.95/1.05→ | <65 ms |
| Reset | |
| Reset ratio | 97 or 103 % of the pick-up voltage setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±1.0 % or ±35 ms |
| Instant reset time and start-up reset | <50 ms |

## 9.2.1.14 Overfrequency and underfrequency protection (f>/<; 81O/81U)

Table. 9.2.1.14 - 445. Technical data for the overfrequency and underfrequency function.

| | |
|---|---|
| Input signals | |
| Sampling mode | Fixed<br>Tracking |
| Frequency reference 1<br>Frequency reference 2<br>Frequency reference 3 | CT1IL1, CT2IL1, VT1U1, VT2U1<br>CT1IL2, CT2IL2, VT1U2, VT2U2<br>CT1IL3, CT2IL3, VT1U3, VT2U3 |
| Pick-up | |
| f> pick-up setting<br>f< pick-up setting | 10.00…70.00 Hz, setting step 0.01 Hz<br>7.00…65.00 Hz, setting step 0.01 Hz |
| Inaccuracy (sampling mode):<br>- Fixed<br>- Tracking | <br>±20 mHz (50/60 Hz fixed frequency)<br>±20 mHz (U > 30 V secondary)<br>±20 mHz (I > 30 % of rated secondary) |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_M/I_{SET}$ ratio +/- 50 mHz) | <br>±1.5 % or ±50 ms (max. step size: 100 mHz) |
| Instant operation time | |
| Start time and instant operation time (trip):<br>- $I_M/I_{SET}$ ratio +/- 50 mHz (Fixed)<br>- $I_M/I_{SET}$ ratio +/- 50 mHz (Tracking) | <br><70 ms (max. step size: 100 mHz)<br><3 cycles or <60 ms (max. step size: 100 mHz) |
| Reset | |
| Reset ratio | 0.020 Hz |
| Instant reset time and start-up reset:<br>- $I_M/I_{SET}$ ratio +/- 50 mHz (Fixed)<br>- $I_M/I_{SET}$ ratio +/- 50 mHz (Tracking) | <br><110 ms (max. step size: 100 mHz)<br><3 cycles or <70 ms (max. step size: 100 mHz) |

Note!

- The secondary voltage must exceed 2 volts or the current must exceed 0.25 amperes (peak-to peak) in order for the function to measure frequency.

- The frequency is measured two seconds after a signal is received.
- The fixed frequency mode: When the fixed mode is used, the system's nominal frequency should be set to 50 or 60 Hz.
- The tracked frequency mode: When tracked mode is used, the system's nominal frequency can be anything between 7...75 Hz.

### 9.2.1.15 Rate-of-change of frequency protection (df/dt>/<; 81R)

Table. 9.2.1.15 - 446. Technical data for the rate-of-change of frequency function.

| Input signals | |
|---|---|
| Sampling mode | Fixed<br>Tracking |
| Frequency reference 1<br>Frequency reference 2<br>Frequency reference 3 | CT1IL1, CT2IL1, VT1U1, VT2U1<br>CT1IL2, CT2IL2, VT1U2, VT2U2<br>CT1IL3, CT2IL3, VT1U3, VT2U3 |
| Pick-up | |
| df/dt >/< pick-up setting | 0.15…1.00 Hz/s, setting step 0.01 Hz |
| f> limit | 10.00…70.00 Hz, setting step 0.01 Hz |
| f< limit | 7.00…65.00 Hz, setting step 0.01 Hz |
| Pick-up inaccuracy | |
| - df/dt | ±5.0 %$I_{SET}$ or ±20 mHz/s |
| - frequency | ±15 mHz (U > 30 V secondary)<br>±20 mHz (I > 30 % of rated secondary) |
| Operation time | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_M/I_{SET}$ ratio +/- 50 mHz) | ±1.5 % or ±110 ms (max. step size: 100 mHz) |
| Start time and instant operation time (trip): | |
| - $f_M/f_{SET}$ ratio +/- 20 mHz (overreach) | <200 ms |
| - $f_M/f_{SET}$ ratio +/- 200 mHz (overreach) | <90 ms |
| Reset | |
| f< and f> frequency limit | ±0.020 Hz |
| df/dt | ±10.0 % of pick-up or 50 mHz/s |
| Instant reset time and start-up reset:<br><br>- $f_M/f_{SET}$ ratio +/- 50 mHz | <325 ms (max. step size: 100 mHz) |

Note!

- Frequency is measured two seconds after a signal is received.

### 9.2.1.16 Line thermal overload protection (TF>; 49F)

Table. 9.2.1.16 - 447. Technical data for the line thermal overload protection function.

| Measurement inputs | |
|---|---|
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | TRMS phase currents (up to the 31$^{st}$ harmonic) |


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| Settings | |
|---|---|
| Time constants τ | 1 |
| Time constant value | 0.0…500.00 min, step 0.1 min |
| Service factor (maximum overloading) | 0.01…5.00 × $I_N$, step 0.01 × $I_N$ |
| Thermal model biasing | - Ambient temperature (Set –60.0…500.0 deg, step 0.1 deg and RTD)<br>- Negative sequence current |
| Thermal replica temperature estimates | Selectable between °C and °F |
| **Outputs** | |
| - Alarm 1<br>- Alarm 2<br>- Thermal trip<br>- Trip delay<br>- Restart inhibit | 0…150 %, step 1 %<br>0…150 %, step 1 %<br>0…150 %, step 1 %<br>0.000…3600.000 s, step 0.005 s<br>0…150 %, step 1 % |
| **Inaccuracy** | |
| - Starting<br>- Operating time | ±0.5 % of the set pick-up value<br>±5 % or ± 500 ms |

## 9.2.1.17 Overpower (P>; 32O), underpower (P<; 32U) and reverse power (Pr; 32R) protection

Table. 9.2.1.17 - 448. Technical data for the power protection functions.

| Measurement inputs | |
|---|---|
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ (+ $U_0$) |
| Calculated measurement | Three-phase active power |
| **Pick-up** | |
| P><br>Prev> | 0.10…150 000.00 kW, setting step 0.01 kW<br>-15 000.00…-1.00 kW, setting step 0.01 kW |
| P<<br>Low-power blocking $P_{SET}$< | 0.00…150 000.00 kW, setting step 0.01 kW<br>0.00…100 000.00 kW, setting step 0.01 kW |
| Inaccuracy:<br>- Active power | Typically <1.0 %$P_{SET}$ |
| **Operation time** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($P_M$/$P_{SET}$ ratio 1.05→) | ±1.0 % or ±35 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $P_M$/$P_{SET}$ ratio 1.05→ | <50 ms |
| **Reset** | |
| Reset ratio | 97 or 103 %$P_{SET}$ |
| Reset time setting<br>Inaccuracy: Reset time | 0.000…150.000 s, step 0.005 s<br>±1.0 % or ±35 ms |
| Instant reset time and start-up reset | <50 ms |

Note!

- Voltage measurement starts from 0.5 V and current measurement from 50 mA. In case either or both are missing the power measurement is forced to 0 kW. If the settings allow it (low-power blocking = 0 kW), the P< might be in the trip state during this condition. The trip is released when the function begins to measure the voltage and the current again.
- When the low-power blocking is set to zero, it is not in use. Also, all power measurements below 1.00 kW are forced to zero ("P< blocked").

### 9.2.1.18 Voltage-restrained overcurrent protection (Iv>; 51V)

Table. 9.2.1.18 - 449. Technical data for the voltage-restrained overcurrent protection function.

| Measurement inputs | |
|---|---|
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS phase currents |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ + $U_0$ |
| Voltage input calculation | Positive sequence voltage |
| **Pick-up** | |
| Pick-up current setting (point 1 & 2) | 0.10…40.00 × $I_N$, setting step 0.01 × $I_N$ |
| Pick-up voltage setting (point 1 & 2) | 0.05…150.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Current<br>- Voltage | <br>±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$)<br>±1.5 %$U_{SET}$ or ±30 mV |
| **Operation time** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_M/I_{SET}$ ratio 1.05→) | <br>±1.0 % or ±25 ms |
| IDMT setting parameters:<br>k Time dial setting for IDMT<br>A IDMT constant<br>B IDMT constant<br>C IDMT constant | <br>0.01…25.00, step 0.01<br>0…250.0000, step 0.0001<br>0…5.0000, step 0.0001<br>0…250.0000, step 0.0001 |
| Inaccuracy:<br>- IDMT operating time<br>- IDMT minimum operating time | <br>±1.5 % or ±20 ms<br>±20 ms |
| **Instant operation time** | |
| Start time and instant operation time (trip):<br>- $I_M/I_{SET}$ ratio 1.05→ | <br><40 ms |
| **Reset** | |
| Reset ratio:<br>- Current | <br>97 % of the pick-up current setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.000…150.000 s, step 0.005 s<br>±1.0 % or ±25 ms |
| Instant reset time and start-up reset | <45 ms |

### 9.2.1.19 Resistance temperature detectors

Table. 9.2.1.19 - 450. Technical data of the resistance temperature detectors.

| Inputs | |
|---|---|
| Resistance input magnitudes | Measured temperatures measured by RTD sensors |


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| | |
|---|---|
| Alarm channels | 12 individual alarm channels |
| Settable alarms | 24 alarms available (two per each alarm channel) |
| Pick-up | |
| Alarm setting range<br>Inaccuracy<br>Reset ratio | 101.00…2000.00 deg, setting step 0.1 deg (either < or > setting)<br>±3 % of the set pick-up value<br>97 % of the pick-up setting |
| Operation | |
| Operating time | Typically <500 ms |

## 9.2.1.20 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional)

Table. 9.2.1.20 - 451. Technical data for the arc fault protection function.

| | |
|---|---|
| Measurement inputs | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| Current input magnitudes | Sample-based phase current measurement<br>Sample-based residual current measurement |
| Arc point sensor inputs | Channels S1, S2, S3, S4 (pressure and light sensor, or light-only sensor)<br>Up to four (4) sensors per channel |
| System frequency operating range | 6.00…75.00 Hz |
| Pick-up | |
| Pick-up current setting (phase current)<br>Pick-up current setting (residual current)<br>Pick-up light intensity | 0.50…40.00 × $I_N$, setting step 0.01 × $I_N$<br>0.10…40.00 × $I_N$, setting step 0.01 × $I_N$<br>8, 25 or 50 kLx (the sensor is selected in the order code) |
| Starting inaccuracy (IArc> and I0Arc>) | ±3 % of the set pick-up value > 0.5 × $I_N$ setting. 5 mA < 0.5 × $I_N$ setting. |
| Point sensor detection radius | 180 degrees |
| Operation time | |
| Light only:<br>- Semiconductor outputs HSO1 and HSO2<br>- Regular relay outputs | <br>Typically 7 ms (3…12 ms)<br>Typically 10 ms (6.5…15 ms) |
| Light + current criteria (zone 1…4):<br>- Semiconductor outputs HSO1 and HSO2<br>- Regular relay outputs | <br>Typically 10 ms (6.5…14 ms)<br>Typically 14 ms (10…18 ms) |
| Arc BI only:<br>- Semiconductor outputs HSO1 and HSO2<br>- Regular relay outputs | <br>Typically 7 ms (2…12 ms)<br>Typically 10 ms (6.5…15 ms) |
| Reset | |
| Reset ratio for current | 97 % of the pick-up setting |
| Reset time | <35 ms |

Note!

- The maximum length of the arc sensor cable is 200 meters.

## 9.2.1.21 Voltage memory

Table. 9.2.1.21 - 452. Technical data for the voltage memory function.

| |
|---|
| Measurement inputs |

| | |
|---|---|
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ + $U_0$ |
| Current inputs (back-up frequency) | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Pick-up | |
| Pick-up voltage setting<br>Pick-up current setting (optional) | 2.00…50.00 %$U_N$, setting step 0.01 x %$U_N$<br>0.01…50.00 × $I_N$, setting step 0.01 × $I_N$ |
| Inaccuracy:<br>- Voltage<br>- Current | <br>±1.5 %$U_{SET}$ or ±30 mV<br>±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$) |
| Operation time | |
| Angle memory activation delay | <20 ms (typically 5 ms) |
| Maximum active time | 0.020…50.000 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($U_M$/$U_{SET}$ ratio >1.05) | <br>±1.0 % or ±35 ms |
| Angle memory | |
| Angle drift while voltage is absent | ±1.0° per 1 second |
| Reset | |
| Reset ratio:<br>- Voltage memory (voltage)<br>- Voltage memory (current) | <br>103 % of the pick-up voltage setting<br>97 % of the pick-up current setting |
| Reset time | <50 ms |

Note!

- Voltage memory is activated only when all line voltages fall below set pick-up value.
- Voltage memory activation captures healthy situation voltage angles, one cycle before actual activation (50Hz/20ms before “bolted” fault)

## 9.2.2 Control functions

### 9.2.2.1 Setting group selection

Table. 9.2.2.1 - 453. Technical data for the setting group selection function.

| | |
|---|---|
| Settings and control modes | |
| Setting groups | 8 independent, control-prioritized setting groups |
| Control scale | Common for all installed functions which support setting groups |
| Control mode | |
| Local | Any digital signal available in the device |
| Remote | Force change overrule of local controls either from the setting tool, HMI or SCADA |
| Operation time | |
| Reaction time | <5 ms from receiving the control signal |

### 9.2.2.2 Object control and monitoring

Table. 9.2.2.2 - 454. Technical data for the object control and monitoring function.

| |
|---|
| Signals |



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| | |
|---|---|
| Input signals | Digital inputs<br>Software signals |
| Output signals | Close command output<br>Open command output |
| Operation time | |
| Breaker traverse time setting | 0.02…500.00 s, setting step 0.02 s |
| Max. close/open command pulse length | 0.02…500.00 s, setting step 0.02 s |
| Control termination time out setting | 0.02…500.00 s, setting step 0.02 s |
| Inaccuracy:<br>- Definite time operating time | <br>±0.5 % or ±10 ms |
| Breaker control operation time | |
| External object control time | <75 ms |
| Object control during auto-reclosing | See the technical sheet for the auto-reclosing function. |

### 9.2.2.3 Auto-reclosing (0 → 1; 79)

Table. 9.2.2.3 - 455. Technical data for the auto-reclosing function.

| | |
|---|---|
| Input signals | |
| Input signals | Software signals (protection, logics, etc.)<br>Binary inputs |
| Requests | |
| REQ1-5 | 5 priority request inputs; can be set parallel as signals to each request |
| Shots | |
| 1-5 shots | 5 independent or scheme-controlled shots in each AR request |
| Operation time | |
| Operating time settings:<br>- Lockout after successful AR<br>- Object close reclaim time<br>- AR shot starting delay<br>- AR shot dead time delay<br>- AR shot action time<br>- AR shot specific reclaim time | <br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s |
| Inaccuracy | |
| AR starting (from a protection stage's START signal) | ±1.0 % or ±30 ms (AR delay) |
| AR starting (from a protection stage's TRIP signal) | Trip delay inaccuracy +25 ms (Protection + AR delay) |
| Dead time | ±1.0 % or ±35 ms (AR delay) |
| Action time | ±1.0 % or ±30 ms (AR delay) |
| Instant starting time | |
| Instant operation time | Protection activation delay + 15 ms (Protection + AR delay) |

### 9.2.2.4 Cold load pick-up (CLPU)

Table. 9.2.2.4 - 456. Technical data for the cold load pick-up function.

| | |
|---|---|
| Measurement inputs | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | RMS phase currents |

| Pick-up | |
|---|---|
| Pick-up current setting<br>- $I_{LOW}/I_{HIGH}/I_{OVER}$ | 0.01…40.00 × $I_N$, setting step 0.01 × $I_N$ |
| Reset ratio | 97 % of the pick-up current setting |
| Inaccuracy:<br>- Current | ±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$) |
| **Operation time** | |
| Definite time function operating time settings:<br>- $t_{SET}$<br>- $t_{MAX}$<br>- $t_{MIN}$ | <br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s<br>0.000…1800.000 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($I_M/I_{SET}$ ratio = 1.05/0.95) | ±1.0 % or ±45 ms |
| **Instant operation time** | |
| CLPU activation and release | <45 ms (measured from the trip contact) |

Note!

- A single-phase current (IL1, IL2 or IL3) is enough to prolong or release the blocking during an overcurrent condition.

### 9.2.2.5 Switch-on-to-fault (SOTF)

Table. 9.2.2.5 - 457. Technical data for the switch-on-to-fault function.

| Initialization signals | |
|---|---|
| SOTF activate input | Any IED blocking input signal (Object closed signal, etc.) |
| **Pick-up** | |
| SOTF function input | Any IED blocking input signal (I> or similar) |
| **SOTF activation time** | |
| Activation time | <40 ms (measured from the trip contact) |
| **SOTF release time** | |
| Release time setting | 0.000…1800.000 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time | ±1.0 % or ±30 ms |
| SOTF instant release time | <40 ms (measured from the trip contact) |

### 9.2.2.6 Vector jump (Δφ; 78)

Table. 9.2.2.6 - 458. Technical data for the vector jump protection function.

| Measurement inputs | |
|---|---|
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ + $U_0$ |
| Monitored voltages | Any or all system line-to-line voltage(s)<br>Any or all system line-to-neutral voltage(s)<br>Specifically chosen line-to-line or line-to-neutral voltage<br>U4 channel voltage |
| **Pick-up** | |
| Pick-up setting | 0.05…30.00°, setting step 0.01° |


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| | |
|---|---|
| Inaccuracy:<br>- Voltage angle | ±30% overreach or 1.00 ° |
| Low-voltage blocking | |
| Pick-up setting | 0.01…100.00 %$U_N$, setting step 0.01 %$U_N$ |
| Inaccuracy:<br>- Voltage | ±1.5 %$U_{SET}$ or ±30 mV |
| Instant operation time | |
| Alarm and trip operation time:<br>- (Im/Iset ratio > ±30% overreach or 1.00 °) | <40 ms (typically 30 ms) 50/60 Hz<br><50 ms (typically 40 ms) 16.67 Hz |
| Reset | |
| Trip pulse | ~5-10ms |

## 9.2.2.7 Synchrocheck (ΔV/Δa/Δf; 25)

Table. 9.2.2.7 - 459. Technical data for the synchrocheck function.

| | |
|---|---|
| Input signals | |
| Voltage inputs | U1, U2, U3 or U4 voltage channel |
| Voltage input magnitudes | RMS line-to-line or line-to-neutral voltages<br>U3 or U4 voltage channel RMS |
| Pick-up | |
| U diff < setting | 2.00…50.00 %$U_N$, setting step 0.01 %$U_N$ |
| Angle diff < setting | 3.0…90.0 deg, setting step 0.10 deg |
| Freq diff < setting | 0.05…0.50 Hz, setting step 0.01 Hz |
| Inaccuracy:<br>- Voltage<br>- Frequency<br>- Angle | ±3.0 %$U_{SET}$ or ±0.3 %$U_N$<br>±25 mHz (U> 30 V secondary)<br>±1.5° (U> 30 V secondary) |
| Reset | |
| Reset ratio:<br>- Voltage<br>- Frequency<br>- Angle | 99 % of the pick-up voltage setting<br>20 mHz<br>±2.0° |
| Activation time | |
| Activation (to LD/DL/DD)<br>Activation (to Live Live) | <35 ms<br><60 ms |
| Reset | <40 ms |
| Bypass modes | |
| Voltage check mode (excluding LL) | LL+LD, LL+DL, LL+DD, LL+LD+DL, LL+LD+DD, LL+DL+DD, bypass |
| U live > limit<br>U dead < limit | 0.10…100.00 %$U_N$, setting step 0.01 %$U_N$<br>0.00…100.00 %$U_N$, setting step 0.01 %$U_N$ |

Note!

- Voltage is scaled to the primary amplitude; therefore, the different sized PT secondaries are possible.
- The minimum voltage for direction and frequency solving is 20.0 %$U_N$.
- U< dead limit is not in use when set to 0 %$U_N$.
- When SYN3 is used, SYN1 and SYN2 must have the same reference voltage.

- In 3LN mode the synchronization to the L-N and L-L voltages is possible. In 3LL/2LL modes the synchronization is only supported to the L-L voltage.

## 9.2.3 Monitoring functions

### 9.2.3.1 Current transformer supervision

Table. 9.2.3.1 - 460. Technical data for the current transformer supervision function.

| | |
|---|---|
| **Measurement inputs** | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse) (optional)<br>Residual current channel $I_{02}$ (Fine) (optional) |
| Current input magnitudes | RMS phase currents<br>RMS residual current ($I_{01}$, $I_{02}$) (optional) |
| **Pick-up** | |
| Pick-up current settings:<br>- $I_{SET}$ high limit<br>- $I_{SET}$ low limit<br>- $I_{SUM}$ difference<br>- $I_{SET}$ ratio<br>- I2/I1 ratio | <br>0.10…40.00 × $I_N$, setting step 0.01 × $I_N$<br>0.10…40.00 × $I_N$, setting step 0.01 × $I_N$<br>0.10…40.00 × $I_N$, setting step 0.01 × $I_N$<br>0.01…100.00 %, setting step 0.01 %<br>0.01…100.00 %, setting step 0.01 % |
| Inaccuracy:<br>- Starting IL1, IL2, IL3<br>- Starting I2/I1<br>- Starting I01 (1 A)<br>- Starting I02 (0.2 A) | <br>±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$)<br>±1.0 %$I2_{SET}$ / $I1_{SET}$ or ±100 mA (0.10…4.0 × $I_N$)<br>±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × $I_{SET}$)<br>±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × $I_{SET}$) |
| **Time delay for alarm** | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy_<br>- Definite time ($I_M/I_{SET}$ ratio > 1.05) | <br>±2.0 % or ±80 ms |
| Instant operation time (alarm):<br>- $I_M/I_{SET}$ ratio > 1.05 | <br><80 ms (<50 ms in differential protection relays) |
| **Reset** | |
| Reset ratio | 97/103 % of the pick-up current setting |
| Instant reset time and start-up reset | <80 ms (<50 ms in differential protection relays) |

### 9.2.3.2 Voltage transformer supervision (60)

Table. 9.2.3.2 - 461. Technical data for the voltage transformer supervision function.

| | |
|---|---|
| **Measurement inputs** | |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ |
| Voltage input magnitudes | RMS line-to-line or line-to-neutral voltages |
| **Pick-up** | |
| Pick-up settings:<br>- Voltage (low pick-up)<br>- Voltage (high pick-up)<br>- Angle shift limit | <br>0.05…0.50 × $U_N$, setting step 0.01 × $U_N$<br>0.50…1.10 × $U_N$, setting step 0.01 × $U_N$<br>2.00…90.00 deg, setting step 0.10 deg |
| Inaccuracy:<br>- Voltage<br>- U angle (U> 1 V) | <br>±1.5 %$U_{SET}$<br>±1.5° |


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| | |
|---|---|
| External line/bus side pick-up (optional) | 0 → 1 |
| Time delay for alarm | |
| Definite time function operating time setting | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time ($U_M/U_{SET}$ ratio > 1.05/0.95) | ±1.0 % or ±35 ms |
| Instant operation time (alarm):<br>- $U_M/U_{SET}$ ratio > 1.05/0.95 | <80 ms |
| VTS MCB trip bus/line (external input) | <50 ms |
| Reset | |
| Reset ratio | 97/103 % of the pick-up voltage setting |
| Reset time setting<br>Inaccuracy: Reset time | 0.010…10.000 s, step 0.005 s<br>±2.0 % or ±80 ms |
| Instant reset time and start-up reset | <50 ms |
| VTS MCB trip bus/line (external input) | <50 ms |

Note!

- When turning on the auxiliary power of an IED, the normal condition of a stage has to be fulfilled before tripping.

### 9.2.3.3 Circuit breaker wear monitoring

Table. 9.2.3.3 - 462. Technical data for the circuit breaker wear monitoring function.

| | |
|---|---|
| Pick-up | |
| Breaker characteristics settings:<br>- Nominal breaking current<br>- Maximum breaking current<br>- Operations with nominal current<br>- Operations with maximum breaking current | <br>0.00…100.00 kA, setting step 0.001 kA<br>0.00…100.00 kA, setting step 0.001 kA<br>0…200 000 operations, setting step 1 operation<br>0…200 000 operations, setting step 1 operation |
| Pick-up setting for Alarm 1 and Alarm 2 | 0…200 000 operations, setting step 1 operation |
| Inaccuracy | |
| Inaccuracy for current/operations counter:<br>- Current measurement element<br>- Operation counter | <br>0.1× $I_N$ > I < 2 × $I_N$ ±0.2 % of the measured current, rest 0.5 %<br>±0.5 % of operations deducted |

### 9.2.3.4 Total harmonic distortion

Table. 9.2.3.4 - 463. Technical data for the total harmonic distortion function.

| | |
|---|---|
| Input signals | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C)<br>Residual current channel $I_{01}$ (Coarse)<br>Residual current channel $I_{02}$ (Fine) |
| Current input magnitudes | Current measurement channels (FFT result) up to the 31$^{st}$ harmonic component. |
| Pick-up | |
| Operating modes | Power THD<br>Amplitude THD |
| Pick-up setting for all comparators | 0.10…200.00 % , setting step 0.01 % |

| | |
|---|---|
| Inaccuracy | ±3 % of the set pick-up value > 0.5 × $I_N$ setting; 5 mA < 0.5 × $I_N$ setting. |
| **Time delay** | |
| Definite time function operating time setting for all timers | 0.00…1800.00 s, setting step 0.005 s |
| Inaccuracy:<br>- Definite time operating time<br>- Instant operating time, when $I_M/I_{SET}$ ratio > 3<br>- Instant operating time, when $I_M/I_{SET}$ ratio 1.05 < $I_M/I_{SET}$ < 3 | ±0.5 % or ±10 ms<br>Typically <20ms<br>Typically <25 ms |
| **Reset** | |
| Reset time | Typically <10 ms |
| Reset ratio | 97 % |

## 9.2.3.5 Fault locator (21FL)

Table. 9.2.3.5 - 464. Technical data for the fault locator function.

| | |
|---|---|
| **Input signals** | |
| Current inputs | Phase current inputs: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Voltage inputs | $U_{L1}$, $U_{L2}$, $U_{L3}$<br>$U_{L12}$, $U_{L23}$, $U_{L31}$ + $U_0$ |
| Calculated reactance magnitudes when line-to-neutral voltages available | XL12, XL23, XL31, XL1, XL2, XL3 |
| Calculated reactance magnitudes when line-to-line voltages available | XL12, XL23, XL31 |
| **Pick-up** | |
| Trigger current > | 0.00…40.00 × $I_N$, setting step 0.01 × $I_N$ |
| Inaccuracy:<br>- Triggering | ±0.5 %$I_{SET}$ or ±15 mA (0.10…4.0 × $I_{SET}$) |
| **Reactance** | |
| Reactance per kilometer | 0.000…5.000 s, setting step 0.001 Ω/km |
| Inaccuracy:<br>- Reactance | ±5.0 % (typically) |
| **Operation (Triggering)** | |
| Activation | From the trip signal of any protection stage |
| Minimum operation time | At least 0.040 s of stage operation time required |

## 9.2.3.6 Disturbance recorder

Table. 9.2.3.6 - 465. Technical data for the disturbance recorder function.

| | |
|---|---|
| **Recorded values** | |
| Recorder analog channels | 0…20 channels<br>Freely selectable |
| Recorder digital channels | 0…95 channels<br>Freely selectable analog and binary signals<br>5 ms sample rate (FFT) |
| **Performance** | |
| Sample rate | 8, 16, 32 or 64 samples/cycle |



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| | |
|---|---|
| Recording length | 0.000…1800.000 s, setting step 0.001 s<br>The maximum length is determined by the chosen signals. |
| Number of recordings | 0…100, 60 MB of shared flash memory reserved<br>The maximum number of recordings according to the chosen signals and operation time setting combined |

### 9.2.3.7 Event logger

Table. 9.2.3.7 - 466. Technical data for the event logger function.

| General information | |
|---|---|
| Event history capacity | 15 000 events |
| Event timestamp resolution | 1 ms |

## 9.3 Tests and environmental

### Electrical environment compatibility

Table. 9.3 - 467. Disturbance tests.

| All tests | CE-approved and tested according to EN 60255-26 |
|---|---|
| Emissions | |
| Conducted emissions:<br>EN 60255-26 Ch. 5.2, CISPR 22 | 150 kHz…30 MHz |
| Radiated emissions:<br>EN 60255-26 Ch. 5.1, CISPR 11 | 30…1 000 MHz |
| Immunity | |
| Electrostatic discharge (ESD):<br>EN 60255-26, IEC 61000-4-2 | Air discharge 15 kV<br>Contact discharge 8 kV |
| Electrical fast transients (EFT):<br>EN 60255-26, IEC 61000-4-4 | Power supply input 4 kV, 5/50 ns, 5 kHz<br>Other inputs and outputs 4 kV, 5/50 ns, 5 kHz |
| Surge:<br>EN 60255-26, IEC 61000-4-5 | Between wires: 2 kV, 1.2/50 µs<br>Between wire and earth: 4 kV, 1.2/50 µs |
| Radiated RF electromagnetic field:<br>EN 60255-26, IEC 61000-4-3 | f = 80…1 000 MHz, 10 V/m |
| Conducted RF field:<br>EN 60255-26, IEC 61000-4-6 | f = 150 kHz…80 MHz, 10 V (RMS) |

Table. 9.3 - 468. Voltage tests.

| Dielectric voltage test | |
|---|---|
| EN 60255-27, IEC 60255-5, EN 60255-1 | 2 kV, 50 Hz, 1 min |
| Impulse voltage test | |
| EN 60255-27, IEC 60255-5 | 5 kV, 1.2/50 µs, 0.5 J |

## Physical environment compatibility

Table. 9.3 - 469. Mechanical tests.

| Vibration test | |
|---|---|
| EN 60255-1, EN 60255-27, IEC 60255-21-1 | 2…13.2 Hz, ± 3.5 mm<br>13.2…100 Hz, ± 1.0 g |
| **Shock and bump test** | |
| EN 60255-1, EN 60255-27, IEC 60255-21-2 | 20 g, 1 000 bumps/dir. |

Table. 9.3 - 470. Environmental tests.

| Damp heat (cyclic) | |
|---|---|
| EN 60255-1, IEC 60068-2-30 | Operational: +25…+55 °C, 93…97 % (RH), 12+12h |
| **Dry heat** | |
| EN 60255-1, IEC 60068-2-2 | Storage: +70 °C, 16 h<br>Operational: +55 °C, 16 h |
| **Cold test** | |
| EN 60255-1, IEC 60068-2-1 | Storage: –40 °C, 16 h<br>Operational: –20 °C, 16 h |

Table. 9.3 - 471. Environmental conditions.

| IP classes | |
|---|---|
| Casing protection class | IP54 (front)<br>IP21 (rear) |
| **Temperature ranges** | |
| Ambient service temperature range | –35…+70 °C |
| Transport and storage temperature range | –40…+70 °C |
| **Other** | |
| Altitude | <2000 m |
| Overvoltage category | III |
| Pollution degree | 2 |

## Casing and package

Table. 9.3 - 472. Dimensions and weight.

| Without packaging (net) | |
|---|---|
| Dimensions | Height: 208 mm<br>Width: 257 mm (½ rack)<br>Depth: 165 mm (no cards or connectors) |
| Weight | 1.5 kg |
| **With packaging (gross)** | |
| Dimensions | Height: 250 mm<br>Width: 343 mm<br>Depth: 256 mm |


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| | |
|---|---|
| Weight | 2.0 kg |

# 10 Ordering information

AQ - F 2 5 5 X - P X X X A X A - X X X X X X X X X X X X

**Model**
F Feeder protection

**Device size**
5 1/2 of 19" rack

**Analog measurement**
5 5 Current measurement channels and 4 voltage measurement channels

**Functionality package**
A Standard feeder protection package
R Standard feeder protection package + phase-wise circuit breaker control
S Standard feeder protection package + synchronizer function

**Mounting**
P Panel mounted

**Auxiliary voltage**
H 80...265 VAC/DC
L 18...72 VDC

**Measurement accuracy**
0 Power/Energy measurement accuracy 0.5%
2 Power/Energy measurement accuracy 0.2%

**Terminals**
A Standard
B Ring lug terminals

**Reserved for future use**
A N/A

**Digital inputs on power supply module**
A 3 Digital inputs, 24 V nominal threshold
B 3 Digital inputs, 110 V nominal threshold
C 3 Digital inputs, 220 V nominal threshold

**Reserved for future use**
A N/A

**Slots C, E, F, G, H, I, J, K, L, M, N (11 pcs)**
A Empty
B 8 Digital inputs
C 5 Output relays ****
D Arc protection with 4 sensor channels, 2 x HSO, 1 x BI
F 2 x mA input - 8 x RTD input **
G 2 x RJ-45 100Mb Ethernet & IRIG-B */***
H 2 x ST 100Mb Ethernet & IRIG-B */***
I 4 x mA outputs - 1 x mA input **
J Double LC 100Mb Ethernet (HSR, PRP redundant protocols) */***
K Double RJ45 100Mb Ethernet (HSR, PRP redundant protocols) *
L RS-232 - Serial fiber (Plastic-Plastic) */***
M RS-232 - Serial fiber (Plastic-Glass) */***
N RS-232 - Serial fiber (Glass-Plastic) */***
O RS-232 - Serial fiber (Glass-Glass) */***

* One card at most per IED
** Two cards at most per IED
*** Can only be applied to the last slot
**** Six cards at most per IED

## Accessories

| Order code | Description | Note | Manufacturer |
|---|---|---|---|
| ADAM-4015-CE | External 6-channel 2 or 3 wires RTD Input module, pre-configured | Requires an external power module | Advanced Co. Ltd. |



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| | | | |
|---|---|---|---|
| ADAM-4018+-BE | External 8-ch Thermocouple mA Input module, pre-configured | Requires an external power module | Advanced Co. Ltd. |
| AQX121 | Raising frame 120mm | | Arcteq Ltd. |
| AQX122 | Raising frame 40mm | | Arcteq Ltd. |
| AQX098 | Wall mounting bracket | | Arcteq Ltd. |
| AQ-01A | Light point sensor unit (8,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |
| AQ-01B | Light point sensor unit (25,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |
| AQ-01C | Light point sensor unit (50,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |
| AQ-02A | Pressure and light point sensor unit (8,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |
| AQ-02B | Pressure and light point sensor unit (25,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |
| AQ-02C | Pressure and light point sensor unit (50,000 lux threshold) | Max. cable length 200 m | Arcteq Ltd. |

# 11 Contact and reference information

## Manufacturer

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## Visiting and postal address

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