ARCTEQ®
RELAYABLE POWER

# AQ-T256

## Transformer protection IED

# Instruction manual

# Table of contents

1 Document information ..... 6
1.1 Version 2 revision notes ..... 6
1.2 Version 1 revision notes ..... 9
2 Abbreviations ..... 10
3 General ..... 12
4 IED user interface ..... 13
4.1 Panel structure ..... 13
4.1.1 Local panel structure ..... 13
4.2 Configuring user levels and their passwords ..... 14
5 Functions ..... 16
5.1 Functions included in AQ-T256 ..... 16
5.2 Measurements ..... 17
5.2.1 Current measurement and scaling in differential applications ..... 17
5.2.2 Frequency tracking and scaling ..... 28
5.3 General menu ..... 31
5.4 Protection functions ..... 33
5.4.1 General properties of a protection function ..... 33
5.4.2 Non-directional overcurrent protection (I>; 50/51) ..... 42
5.4.3 Non-directional earth fault protection (I0>; 50N/51N) ..... 50
5.4.4 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L) ..... 55
5.4.5 Harmonic overcurrent protection (Ih>; 50H/51H/68H) ..... 60
5.4.6 Circuit breaker failure protection (CBFP; 50BF/52BF) ..... 68
5.4.7 Low-impedance or high-impedance restricted earth fault/ cable end differential protection (I0d>; 87N) ..... 83
5.4.8 Transformer status monitoring ..... 92
5.4.9 Transformer thermal overload protection (TT>; 49T) ..... 98
5.4.10 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G) ..... 107
5.4.11 Resistance temperature detectors (RTD) ..... 148
5.4.12 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) ..... 154
5.5 Control functions ..... 163
5.5.1 Common signals ..... 163
5.5.2 Setting group selection ..... 164
5.5.3 Object control and monitoring ..... 172
5.5.4 Indicator object monitoring ..... 182
5.5.5 Milliampere output control ..... 184
5.5.6 Programmable control switch ..... 186
5.5.7 User buttons ..... 187
5.5.8 Analog input scaling curves ..... 188
5.5.9 Logical outputs ..... 189
5.5.10 Logical inputs ..... 190
5.6 Monitoring functions ..... 192
5.6.1 Current transformer supervision ..... 192
5.6.2 Circuit breaker wear monitoring ..... 202
5.6.3 Current total harmonic distortion (THD) ..... 208
5.6.4 Disturbance recorder (DR) ..... 212
5.6.5 Event logger ..... 221
5.6.6 Measurement recorder ..... 222
5.6.7 Measurement value recorder ..... 226
5.7 Programmable stage (PGx>/<; 99) ..... 230
6 Communication ..... 241
6.1 Connections menu ..... 241
6.2 Time synchronization ..... 243
6.2.1 Internal ..... 243

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6.2.2 NTP ..... 243
6.2.3 PTP ..... 244
6.3 Communication protocols ..... 245
6.3.1 IEC 61850 ..... 245
6.3.1.1 Logical device mode and logical node mode ..... 246
6.3.1.2 GOOSE ..... 250
6.3.2 Modbus/TCP and Modbus/RTU ..... 253
6.3.3 IEC 103 ..... 255
6.3.4 IEC 101/104 ..... 255
6.3.5 SPA ..... 257
6.3.6 DNP3 ..... 257
6.3.7 Modbus I/O ..... 259
6.4 Analog fault registers ..... 260
6.5 Real-time measurements to communication ..... 261
6.6 Modbus Gateway ..... 263
7 Connections and application examples ..... 265
7.1 Connections of AQ-T256 ..... 265
7.2 Application example and its connections ..... 267
7.3 Trip circuit supervision (95) ..... 268
8 Construction and installation ..... 273
8.1 Construction ..... 273
8.2 CPU module ..... 276
8.3 Current measurement module ..... 279
8.4 Digital input module (optional) ..... 280
8.5 Digital output module (optional) ..... 283
8.6 Point sensor arc protection module (optional) ..... 284
8.7 RTD input module (optional) ..... 285
8.8 Serial RS-232 communication module (optional) ..... 286
8.9 LC or RJ45 100 Mbps Ethernet communication module (optional) ..... 287
8.10 Double ST 100 Mbps Ethernet communication module (optional) ..... 288
8.11 Double RJ45 10/100 Mbps Ethernet communication module (optional) ..... 290
8.12 Milliampere (mA) I/O module (optional) ..... 291
8.13 Dimensions and installation ..... 292
9 Technical data ..... 295
9.1 Hardware ..... 295
9.1.1 Measurements ..... 295
9.1.1.1 Current measurement ..... 295
9.1.1.2 Frequency measurement ..... 296
9.1.2 CPU & Power supply ..... 296
9.1.2.1 Auxiliary voltage ..... 296
9.1.2.2 CPU communication ports ..... 297
9.1.2.3 CPU digital inputs ..... 298
9.1.2.4 CPU digital outputs ..... 299
9.1.3 Option cards ..... 300
9.1.3.1 Digital input module ..... 300
9.1.3.2 Digital output module ..... 300
9.1.3.3 Point sensor arc protection module ..... 300
9.1.3.4 Milliampere module (mA out & mA in) ..... 301
9.1.3.5 RTD input module ..... 302
9.1.3.6 RS-232 & serial fiber communication module ..... 302
9.1.3.7 Double LC 100 Mbps Ethernet communication module ..... 302
9.1.3.8 Double ST 100 Mbps Ethernet communication module ..... 303
9.1.4 Display ..... 303
9.2 Functions ..... 303
9.2.1 Protection functions ..... 303
9.2.1.1 Non-directional overcurrent protection (I>; 50/51) ..... 303
9.2.1.2 Non-directional earth fault protection (I0>; 50N/51N) ..... 304
9.2.1.3 Negative sequence overcurrent/ phase current reversal/ current unbalance protection (I2>; 46/46R/46L) ..... 305


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9.2.1.4 Harmonic overcurrent protection (Ih>; 50H/51H/68H) ..... 306
9.2.1.5 Circuit breaker failure protection (CBFP; 50BF/52BF) ..... 307
9.2.1.6 Low-impedance or high-impedance restricted earth fault/ cable end differential protection (I0d>; 87N) ..... 308
9.2.1.7 Transformer thermal overload protection (TT>; 49T) ..... 308
9.2.1.8 Resistance temperature detectors ..... 309
9.2.1.9 Transformer status monitoring ..... 309
9.2.1.10 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G) ..... 309
9.2.1.11 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional) ..... 310
9.2.2 Control functions ..... 311
9.2.2.1 Setting group selection ..... 311
9.2.2.2 Object control and monitoring ..... 311
9.2.3 Monitoring functions ..... 312
9.2.3.1 Current transformer supervision ..... 312
9.2.3.2 Circuit breaker wear monitoring ..... 313
9.2.3.3 Total harmonic distortion ..... 313
9.2.3.4 Disturbance recorder ..... 313
9.2.3.5 Event logger ..... 314
9.3 Tests and environmental ..... 314
10 Ordering information ..... 317
11 Contact and reference information ..... 319

# Disclaimer

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 current measurement side selection description to functions with such feature.<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 |


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| | |
|---|---|
| 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: current unbalance<br><br>- Tech data updated: transformer differential<br><br>- Improvements to many drawings and formula images.<br><br>- Added 6th harmonic to harmonic overcurrent protection function.<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. |
| 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 |
| 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 | - Improved descriptions generally in many chapters.<br>- Improved readability of a lot of drawings and images.<br>- Order codes have been revised.<br>- Added LN mode parameters to all functions (On, Blocked, Test, Test/Blocked, Off).<br>- Added color themes parameter description.<br>- Improved color sleep mode description.<br>- Improved alarm function color behavior description and images.<br>- Added operation time with different measurement values vs setting ratio in instant operation mode to non-directional overcurrent function description.<br>- Fixed bias calculation formula for restricted earth fault function. Was correctly in the code, just written wrong in the manual.<br>- Added power measurement side selection to power functions.<br>- Added 30 s pretriggering time for disturbance recorder (AQ-250 devices only).<br>- Added new trip detections and fault types to measurement value recorder.<br>- Added user description parameter descriptions for digital inputs, digital outputs, logical inputs, logical outputs and GOOSE inputs.<br>- Arc point sensor HSO1 and HSO2 position fixed.<br>- Added spare part codes and compatibilities to option cards. |
| Revision | 2.07 |
| Date | 7.7.2022 |
| Changes | - Fixed logical input amounts.<br>- Added common signals function description.<br>- Added PTP time synchronization description.<br>- Added Modbus Gateway description.<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. |



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## 1.2 Version 1 revision notes

Table. 1.2 - 2. Version 1 revision notes

| Revision | 1.00 |
|---|---|
| Date | 13.4.2016 |
| Changes | - The first revision for AQ-T256, T257 and T259 IEDs. |
| Revision | 1.01 |
| Date | 10.2.2017 |
| Changes | - Order code updated<br>- Added programmable stage description |
| Revision | 1.02 |
| Date | 9.1.2018 |
| Changes | - Measurement value recorder description<br>- ZCT connection added to current measurement description<br>- Internal harmonics blocking to I>,I0> function descriptions<br>- Non-standard delay curves added<br>- Event lists revised on several functions<br>- RTD&mA card description improvements<br>- Ring-lug CT card option 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 |

# 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-T256 transformer 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-T256 transformer protection IED. For other AQ-200 series products please consult their respective device manuals.

AQ-T256 is a transformer protection IED with a sophisticated and easy-to-use differential protection function. The AQ-T256 transformer protection IED provides both low-side and high-side overcurrent, earth fault, negative sequence and two independent restricted earth fault instances. There are up to ten (10) option card slots available for additional I/O or communication cards for more comprehensive monitoring and control applications. AQ-T256 communicates using various protocols including the IEC 61850 substation communication standard.


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# 4 IED user interface

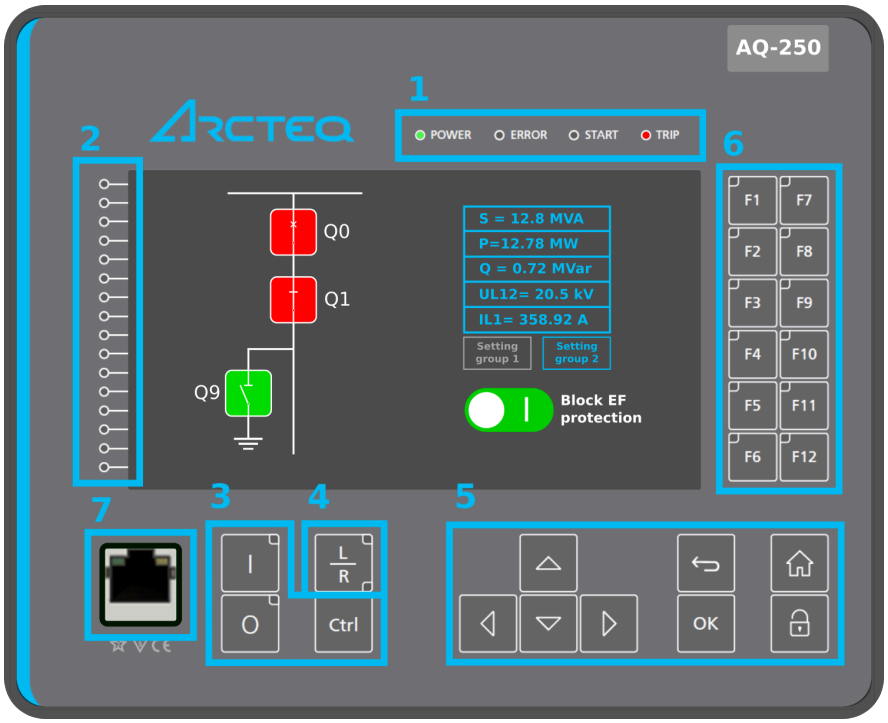
## 4.1 Panel structure

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.

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

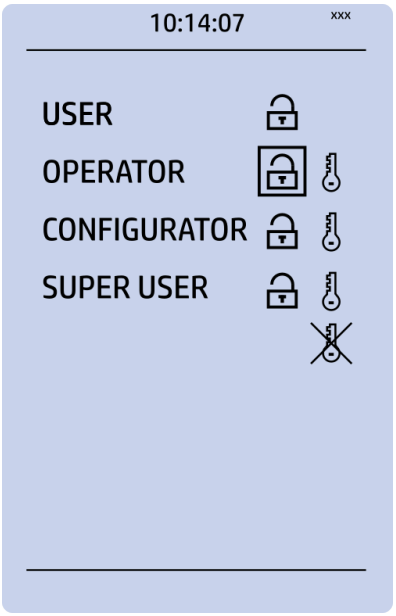
As a factory default, no user level is locked with a password in an IED. In order to activate the different user levels, click the Lock button in the device's HMI and set the desired passwords for the different user levels.

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 ( - )





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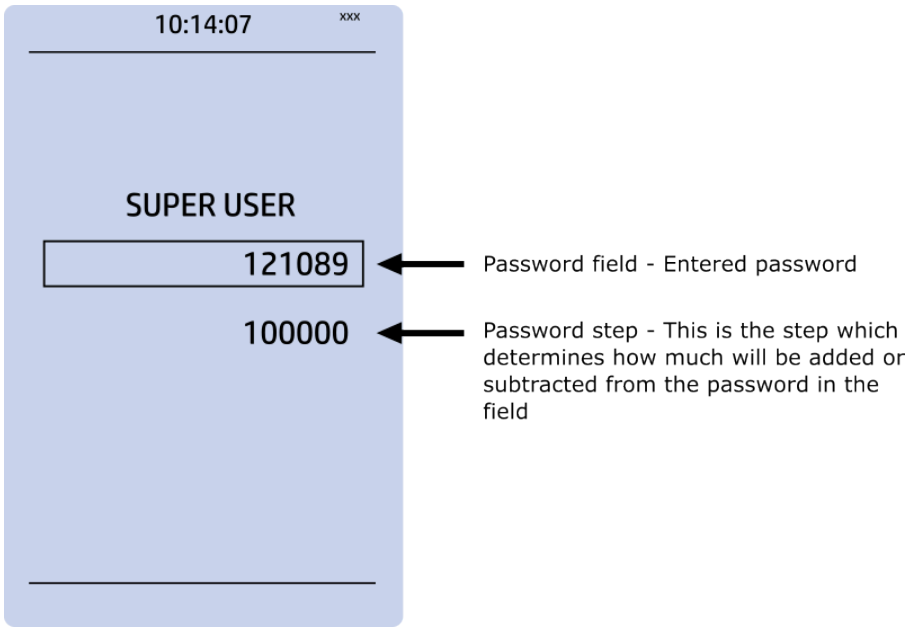


You can set a new password for a user level by selecting the key icon next to the user level's name. After this you can lock the user level by pressing the Return key while the lock is selected. If you need to change the password, you can select the key icon again and give a new password. Please note 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.

# 5 Functions

## 5.1 Functions included in AQ-T256

The AQ-T256 transformer protection relay includes the following functions as well as the number of stages in those functions.

Table. 5.1 - 3. Protection functions of AQ-T256.

| Name (number of stages) | IEC | ANSI | Description |
|---|---|---|---|
| NOC (4) | I><br>I>><br>I>>><br>I>>>> | 50/51 | Non-directional overcurrent protection |
| NEF (4) | I0><br>I0>><br>I0>>><br>I0>>>> | 50N/51N | Non-directional earth fault protection |
| CUB (4) | I2><br>I2>><br>I2>>><br>I2>>>> | 46/46R/46L | Negative sequence overcurrent/<br>phase current reversal/<br>current unbalance protection |
| HOC (4) | Ih><br>Ih>><br>Ih>>><br>Ih>>>> | 50H/51H/68H | Harmonic overcurrent protection |
| CBFP (1) | CBFP | 50BF/52BF | Circuit breaker failure protection |
| TRF | - | - | Transformer status monitoring |
| DIF (1) | Idb>/Idi>/I0dHV>/I0dLV> | 87T/87N/87G | Transformer differential protection with integrated restricted earth fault protection |
| TOLT (1) | TT> | 49T | Transformer thermal overload protection |
| RTD (1) | - | - | Resistance temperature detectors |
| PGS (1) | PGx>/< | 99 | Programmable stage |
| ARC (1) | IArc>/I0Arc> | 50Arc/50NArc | Arc fault protection (optional) |

Table. 5.1 - 4. Control functions of AQ-T256.

| Name | IEC | ANSI | Description |
|---|---|---|---|
| SGS | - | - | Setting group selection |
| OBJ | - | - | Object control and monitoring<br>(10 objects available) |
| CIN | - | - | Indicator object monitoring<br>(10 objects available) |

Table. 5.1 - 5. Monitoring functions of AQ-T256.

| Name | IEC | ANSI | Description |
|---|---|---|---|
| CTS (2) | - | - | Current transformer supervision |



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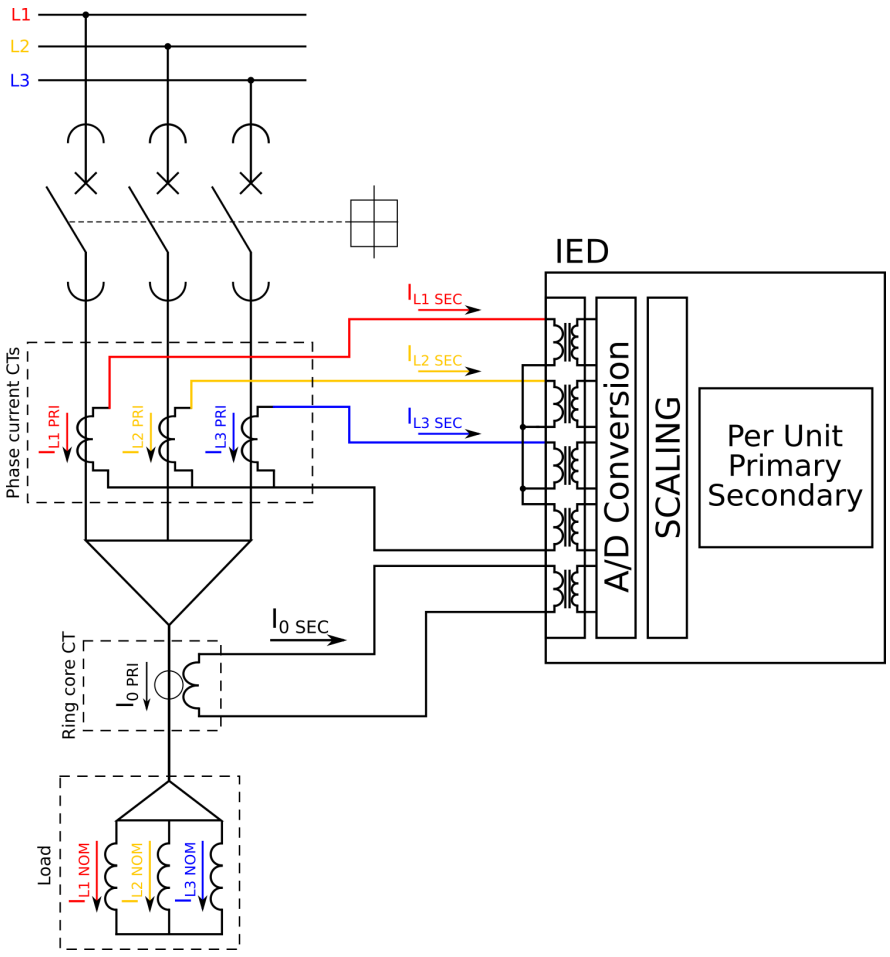
| Name | IEC | ANSI | Description |
|---|---|---|---|
| DR | - | - | Disturbance recorder |
| CBW | - | - | Circuit breaker wear monitor |
| THD | - | - | Total harmonic distortion |
| MR | - | - | Measurement recorder |
| VREC | - | - | Measurement value recorder |

## 5.2 Measurements

### 5.2.1 Current measurement and scaling in differential applications

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.

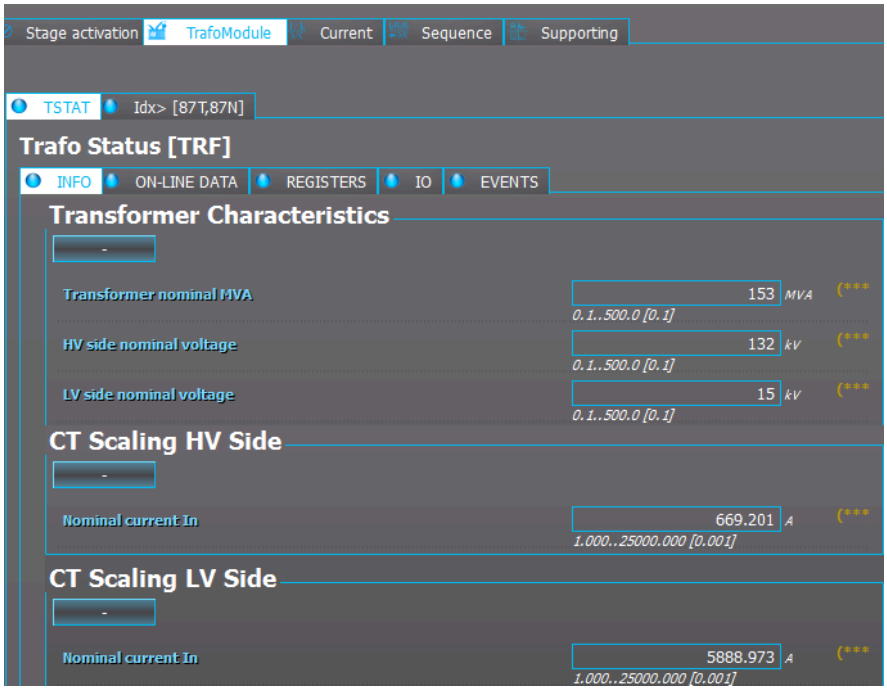
SEC: The secondary current, i.e. the current which the current transformer transforms according to its ratios. This current is measured by the device.

NOM: The nominal primary current of the protected transformer. The nominal current on the HV side differs from that on the LV side according to the transformer voltage ratio. The nominal current is calculated based on the transformer's MVA and the nominal voltage on each winding.

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 correctly, and that the scaling is set correctly.

The device calculates the scaling factors based on the set values of the CT primary, the CT secondary and the nominal current. 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. In power transformers, the protected unit's nominal current in both windings is calculated based on the given nominal power (MVA) and the nominal voltage. The settings can only give the apparatus nominal in p.u. (per-unit) when the nominal current is known. Also, knowing what the transformer's nominal current is makes the unit protection much easier and more straightforward to configure. In modern protection devices this scaling calculation is done internally after the current transformer's primary current, secondary current and machine nominal current are set.

Figure. 5.2.1 - 3. Nominal current calculation in differential protection relays.




Normally, the primary current ratings for phase current transformers are ten amperes to thousands of amperes and 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 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 device measurements for the selected current transformer and nominal load.

## Example of CT scaling (application 1)

The following figure presents how CTs are connected to the device's measurement inputs. It also shows the CT ratings and the transformer nominal current. Note that S1 is always connected to an odd connector regardless of the CT direction. The CT direction is selected in the settings of the transformer differential protection function.


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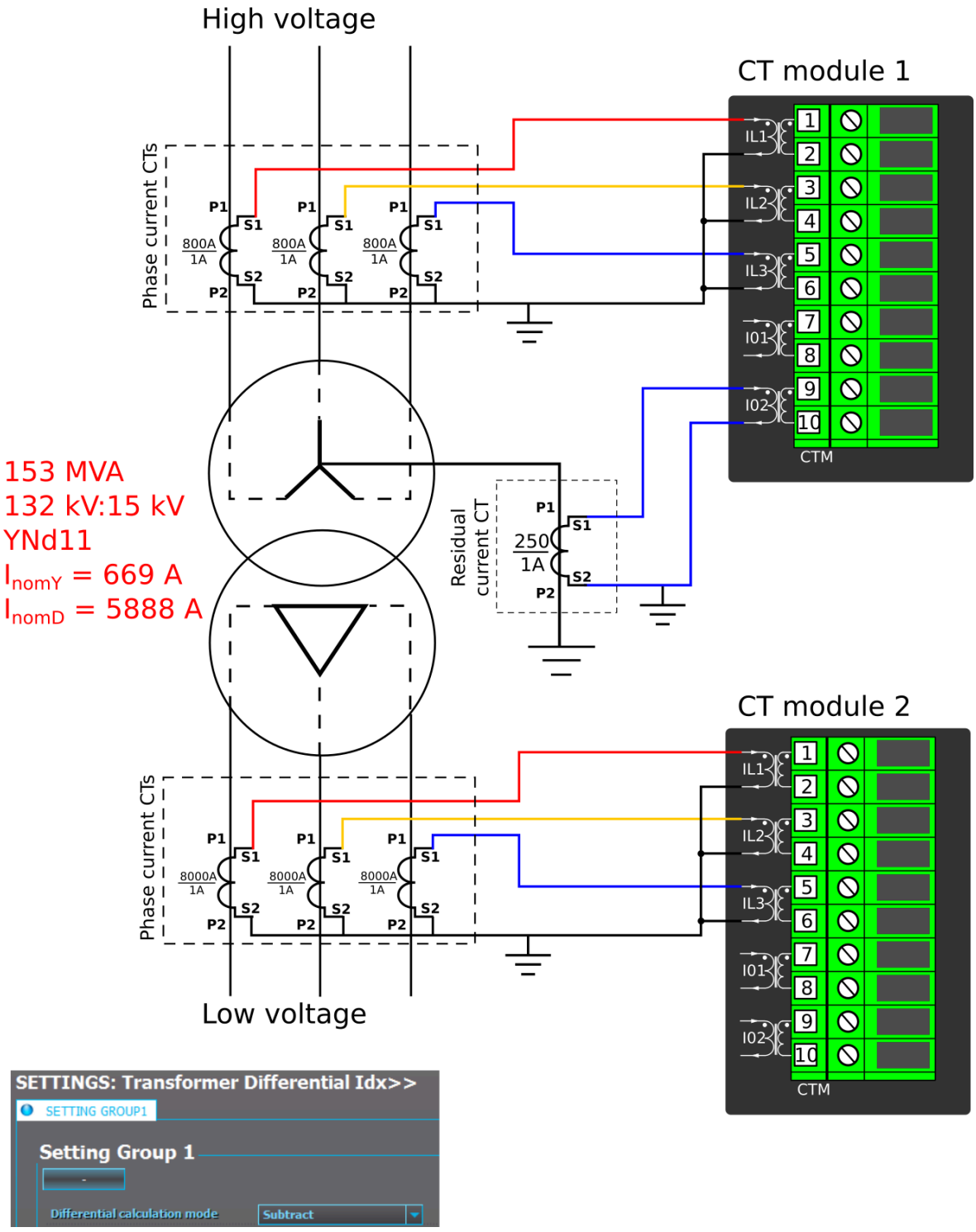
Figure. 5.2.1 - 4. Connections (application 1).







Because of the direction of the CTs and because the CTs' P1/S1 side is always wired to the modules's odd inputs, the "Differential calculation mode" setting has to be set to "Subtract" (*Protection → TrafoModule → Idx> [87T,87N] → Settings*). This way the direction of the measured currents are checked correctly from the device's perspective.

The following table presents the initial data of the connection as well as the ratings.

Table. 5.2.1 - 6. Initial data.

| | | |
|---|---|---|
| High-voltage side CT<br>- CT primary: 800 A<br>- CT secondary: 1 A<br>High-voltage side nominal current<br>669 A | Ring core CT in Input I02<br>- 3I0CT primary: 250 A<br>- 3I0CT secondary: 1 A | Low-voltage side CT<br>- CT primary: 8000 A<br>- CT secondary: 1 A<br>Low-voltage side nominal current<br>5888 A |
| - both CTs are pointing through the transformer (HV-S2 and LV-S2 are pointing in the same direction) | | |

The nominal current for both the HV and LV sides of the protected transformer are calculated based on the values set in the *Transformer characteristics* menu (*Protection → TrafoModule → TSTAT → INFO*). The ratio between the CT modules 1 and 2 can be set in their respective tabs at *Measurement → Transformers*. The per-unit scaling ("Scale meas. to In") is automatically set to "Object in p.u." in all machine protection devices and it cannot be changed.

Figure. 5.2.1 - 5. Phase CT scaling to machine nominal.

As seen in the image above, device calculates both the HV side nominal current (669.2 A) and the LV side nominal current (5 888.97 A). The nominal current calculations are done according to the following formulas:

$$\text{HV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{HV}/\sqrt{3}} = \frac{153\,000\,000/3}{132\,000/\sqrt{3}} \approx 669.201\ \text{A}$$

$$\text{LV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{LV}/\sqrt{3}} = \frac{153\,000\,000/3}{15\,000/\sqrt{3}} \approx 5888.97\ \text{A}$$

The HV and LV side nominal current can also be calculated in per unit values as follows:

$$\text{HV CT nom to TR nom factor} = \frac{HV\ side\ nominal\ current\ (pri)}{Phase\ CT\ primary} = \frac{669.2\ \text{A}}{800\ \text{A}} \approx 0.84\ \text{p.u.}$$

$$\text{LV CT nom to TR nom factor} = \frac{LV\ side\ nominal\ current\ (pri)}{Phase\ CT\ primary} = \frac{5888.97\ \text{A}}{8000\ \text{A}} \approx 0.74\ \text{p.u.}$$



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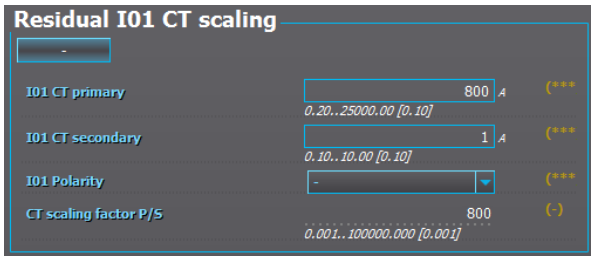
The secondary nominal current (in amperes) is the result of multiplying the per unit value with the phase CT secondary side current. This current can be used when the unit is commissioned and when the directions of CTs are checked. See the example calculation below:

$$\text{HV side nominal current (sec)} = HV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.84\ \text{p.u.} \times 1\ \text{A} = 0.84\ \text{A}$$

$$\text{LV side nominal current (sec)} = LV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.74\ \text{p.u.} \times 1\ \text{A} = 0.74\ \text{A}$$

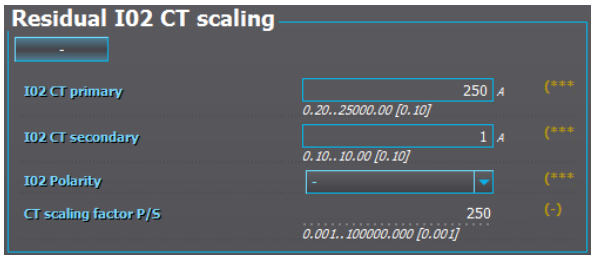
In case the phase current CTs are connected to the module via a Holmgren (summing) connection, the use of coarse residual current measurement settings is required: the "I01 CT" settings are set according to the phase current CTs' ratings (800/1 A).

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




The residual current CT is connected to the first CTM directly, which requires the use of sensitive residual current measurement settings: the "Residual I02 CT scaling" settings are set according to the residual current CT's ratings (250/1 A).

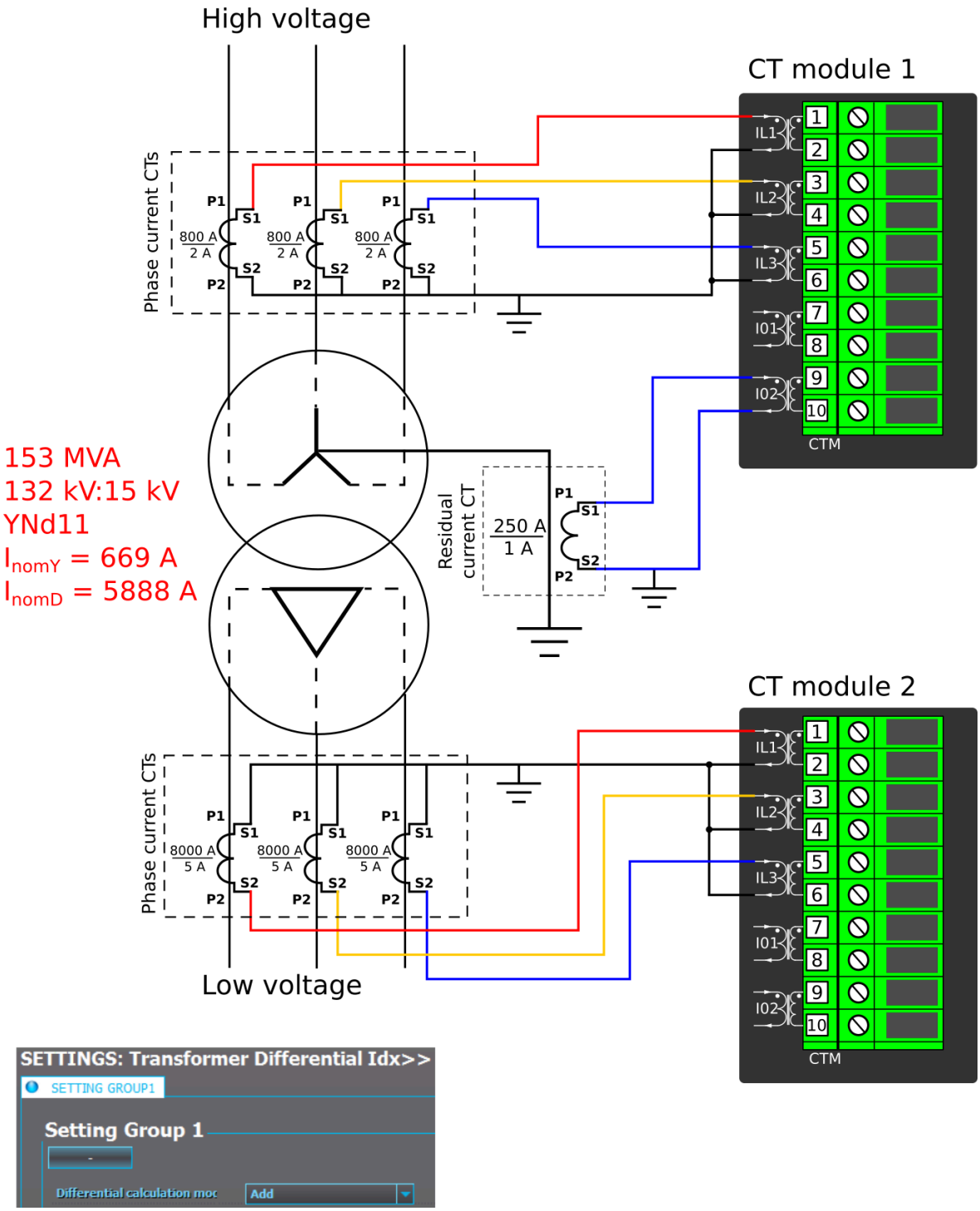
Figure. 5.2.1 - 7. Residual I02 CT scaling (sensitive).




## Example of CT scaling (application 2)

The following figure presents how the CTs are connected to the device's measurement inputs. It also shows the CT ratings and the transformer nominal current. Note that S1 is always connected to an odd connector regardless of the CT direction. The CT direction is selected in the settings of the transformer differential protection function.

Figure. 5.2.1 - 8. Connections (application 2).







Because of the direction of the CTs and because the CTs' P1/S1 side is always wired to the modules's odd inputs, the "Differential calculation mode" has to be set to "Add" (*Protection → TrafoModule → Idx> [87T,87N] → Settings*). The difference with the first application is that here the CTs point towards the protected object instead of pointing through it.

The following table presents the initial data of the connection as well as the ratings.



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Table. 5.2.1 - 7. Initial data.

| | | |
|---|---|---|
| Machine nominal power: 153 MVA<br>Machine high voltage side nominal amplitude: 132 kV<br>Machine low voltage side nominal amplitude: 15 kV | | |
| High voltage side CT<br>- CT primary: 800 A<br>- CT secondary: 2 A<br>High-voltage side nominal current<br>669 A | Residual current CT in Input I02<br>- 3I0CT primary: 250 A<br>- 3I0CT secondary: 1 A | Low voltage side CT<br>- CT primary: 8000 A<br>- CT secondary: 5 A<br>Low-voltage side nominal current<br>5 888 A |
| - both CTs are pointing towards the protected object (HV-S2 and LV-S2 are pointing at each other) | | |

The nominal currents on both the HV and the LV sides are the same as in Application 1. However, the CTs' secondary current levels have been changed to 2 A (on the HV side) and to 5 A (on the LV side). The nominal currents are still calculated the same way:

$$\text{HV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{HV}/\sqrt{3}} = \frac{153\,000\,000/3}{132\,000/\sqrt{3}} \approx 669.201 \text{ A}$$

$$\text{LV side nominal current (pri)} = \frac{trafo_{nom}/3}{U_{LV}/\sqrt{3}} = \frac{153\,000\,000/3}{15\,000/\sqrt{3}} \approx 5888.97 \text{ A}$$

The HV and LV side nominal current can also be calculated in per unit values as follows:

$$\text{HV CT nom to TR nom factor} = \frac{HV\ side\ nominal\ current\ (pri)}{Phase\ CT\ primary} = \frac{669.2 \text{ A}}{800 \text{ A}} \approx 0.84 \text{ p.u.}$$

$$\text{LV CT nom to TR nom factor} = \frac{LV\ side\ nominal\ current\ (pri)}{Phase\ CT\ primary} = \frac{5888.97 \text{ A}}{8000 \text{ A}} \approx 0.74 \text{ p.u.}$$

The secondary nominal current (in amperes) is the result of multiplying the per unit value with the phase CT secondary side current. This current can be used when the unit is commissioned and when the directions of CTs are checked. In Application 2 it is necessary to inject higher amplitudes to the CTs via the secondary injection tool in order to reach the nominal currents. See the example calculation below:

$$\text{HV side nominal current (sec)}$$
$$= HV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.84 \text{ p.u.} \times 2 \text{ A} = 1.68 \text{ A}$$

$$\text{LV side nominal current (sec)}$$
$$= LV\ CT\ nom\ to\ TR\ nom\ factor \times Phase\ CT\ secondary = 0.74 \text{ p.u.} \times 5 \text{ A} = 3.70 \text{ A}$$

## Settings

Table. 5.2.1 - 8. 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. (NOT APPLICBLE IN MACHINE PROTECTION!) |
| 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 meas. 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. |
| 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. |

Table. 5.2.1 - 9. 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 | 0.00001 | 1.0 | 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 - 10. Settings of the Residual I02 CT scaling.

| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| I02 CT primary | A | 1…25000 | 0.00001 | 100 | The rated primary current of the current transformer. |


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| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| 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 - 11. 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 | 0.000…1250.000 | 0.001 | 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 | 0.000…500.000 | 0.001 | The peak-to-peak current measurement (in p.u.) from each of the phase current channels. |

Table. 5.2.1 - 12. Primary phase current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary phase current ILx ("Pri.Pha.curr.ILx") | A | 0.000…1000000.000 | 0.001 | The primary RMS current measurement from each of the phase current channels. |
| Primary phase current ILx TRMS ("Pha.curr.ILx TRMS Pri") | A | 0.000…1000000.000 | 0.001 | The primary TRMS current (inc. harmonics up to 31$^{st}$) measurement from each of the phase current channels. |

Table. 5.2.1 - 13. Secondary phase current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary phase current ILx "Sec.Pha.curr.ILx") | A | 0.000…300.000 | 0.001 | The primary RMS current measurement from each of the phase current channels. |
| Secondary phase current ILx TRMS ("Pha.curr.ILx TRMS Sec") | A | 0.000…300.000 | 0.001 | The primary TRMS current (inc. harmonics up to 31$^{st}$) measurement from each of the phase current channels. |

Table. 5.2.1 - 14. Phase current angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Phase angle ILx ("Pha.angle ILx") | deg | 0.000…360.000 | 0.001 | The phase angle measurement from each of the three phase current inputs. |

Table. 5.2.1 - 15. Per-unit residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Residual current I0x ("Res.curr.I0x") | × In | 0.000…1250.000 | 0.001 | The RMS current measurement (in p.u.) from the residual current channel I01 or I02. |
| Calculated I0 | × In | 0.000…1250.000 | 0.001 | The RMS current measurement (in p.u.) from the calculated I0 current channel. |
| Phase current I0x TRMS ("Res.curr.I0x TRMS") | × In | 0.000…1250.000 | 0.001 | 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 | 0.000…500.000 | 0.001 | The peak-to-peak current measurement (in p.u.) from the residual current channel I01 or I02. |

Table. 5.2.1 - 16. Primary residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary residual current I01 ("Pri.Res.curr.I0x") | A | 0.000…1000000.000 | 0.001 | The primary RMS current measurement from the residual current channel I01 or I02. |
| Primary calculated I0 ("Pri.calc.I0") | A | 0.000…1000000.000 | 0.001 | The primary RMS current measurement from the calculated current channel I0. |
| Primary residual current I0x TRMS ("Res.curr.I01 TRMS Pri") | A | 0.000…1000000.000 | 0.001 | The TRMS current (inc. harmonics up to 31$^{st}$) measurement from the primary residual current channel I01 or I02. |

Table. 5.2.1 - 17. Secondary residual current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary residual current I0x ("Sec.Res.curr.I0x") | A | 0.000…300.000 | 0.001 | The secondary RMS current measurement from the residual current channel I01 or I02. |
| Secondary calculated I0 ("Sec.calc.I0") | A | 0.000…300.000 | 0.001 | The secondary RMS current measurement from the calculated current channel I0. |
| Secondary residual current I0x TRMS ("Res.curr.I0x TRMS Sec") | A | 0.000…300.000 | 0.001 | The secondary TRMS current (inc. harmonics up to 31$^{st}$) measurement from the secondary residual current channel I01 or I02. |

Table. 5.2.1 - 18. Residual current phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Residual current angle I0x ("Res.curr.angle I0x") | deg | 0.000…360.000 | 0.001 | The residual current angle measurement from the I01 or I02 current input. |
| Calculated I0 angle | deg | 0.000…360.000 | 0.001 | The calculated residual current angle measurement. |



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Table. 5.2.1 - 19. Per-unit sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence current ("Positive sequence curr.") | × In | 0.00…1250.0 | 0.001 | The measurement (in p.u.) from the calculated positive sequence current. |
| Negative sequence current ("Negative sequence curr.") | × In | 0.00…1250.0 | 0.001 | The measurement (in p.u.) from the calculated negative sequence current. |
| Zero sequence current ("Zero sequence curr.") | × In | 0.00…1250.0 | 0.001 | The measurement (in p.u.) from the calculated zero sequence current. |

Table. 5.2.1 - 20. Primary sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Primary positive sequence current ("Pri.Positive sequence curr.") | A | 0.00…1000000.0 | 0.001 | The primary measurement from the calculated positive sequence current. |
| Primary negative sequence current ("Pri.Negative sequence curr.") | A | 0.00…1000000.0 | 0.001 | The primary measurement from the calculated negative sequence current. |
| Primary zero sequence current ("Pri.Zero sequence curr.") | A | 0.00…1000000.0 | 0.001 | The primary measurement from the calculated zero sequence current. |

Table. 5.2.1 - 21. Secondary sequence current measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Secondary positive sequence current ("Sec.Positive sequence curr.") | A | 0.000…300.000 | 0.001 | The secondary measurement from the calculated positive sequence current. |
| Secondary negative sequence current ("Sec.Negative sequence curr.") | A | 0.000…300.000 | 0.001 | The secondary measurement from the calculated negative sequence current. |
| Secondary zero sequence current ("Sec.Zero sequence curr.") | A | 0.000…300.000 | 0.001 | The secondary measurement from the calculated zero sequence current. |

Table. 5.2.1 - 22. Sequence phase angle measurements.

| Name | Unit | Range | Step | Description |
|---|---|---|---|---|
| Positive sequence current angle ("Positive sequence curr.angle") | deg | 0.000…360.0 | 0.001 | The calculated positive sequence current angle. |
| Negative sequence current angle ("Negative sequence curr.angle") | deg | 0.000…360.0 | 0.001 | The calculated negative sequence current angle. |
| Zero sequence current angle ("Zero sequence curr.angle") | deg | 0.000…360.0 | 0.001 | The calculated zero sequence current angle. |

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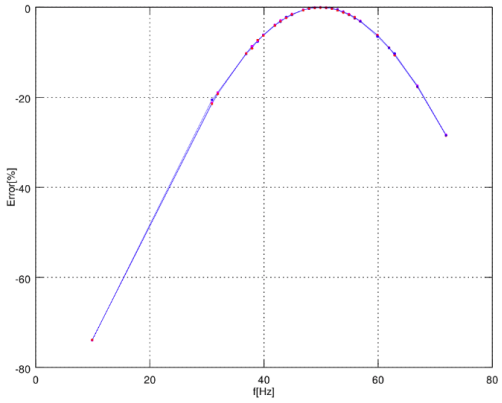
Table. 5.2.1 - 23. Harmonic current measurements.

| Name | Unit | Range | Step | Default | Description |
|---|---|---|---|---|---|
| Harmonics calculation values ("Harm Abs.pr Perc.") | - | 0: Percent<br>1: Absolute | - | 0: Percent | Defines whether the harmonics are calculated as percentage or absolute values. |
| Harmonics display | - | 0: Per unit<br>1: Primary A<br>2: Secondary A | - | 0: Per unit | Defines how the harmonics are displayed: in p.u. values, as primary current values, or as secondary current values. |
| Maximum harmonics value ("IxxMaximum harmonic") | A | 0.000…1000000.000 | 0.001 | - | Displays the maximum harmonics value of the selected current input ILx or I0x. |
| Fundamental frequency ("Ixx fundamental") | A | 0.000…1000000.000 | 0.001 | - | Displays the current value of the fundamental frequency measurement (RMS) from the selected current input ILx or I0x. |
| Ixx harmonics ($2^{nd}$…$31^{st}$ harmonic) | A | 0.000…1000000.000 | 0.001 | - | Displays the selected harmonic from the current input ILx or I0x. |

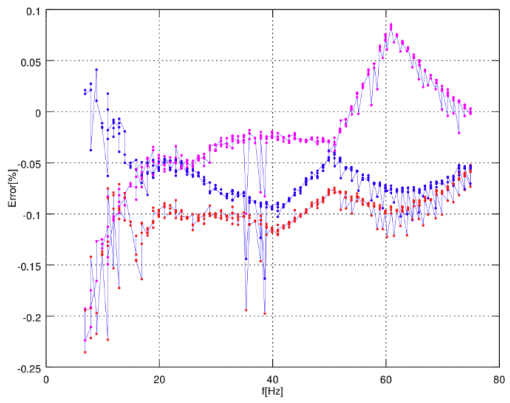
## 5.2.2 Frequency tracking and scaling

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.

Table. 5.2.2 - 24. 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.



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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./ 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. 5.2.2 - 25. 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. |
| 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. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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. |
| 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". |



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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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 - 26. 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 - 27. 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>Prohibited: Cannot be changed.<br>From HMI/setting tool only: Can only be changed from the setting tool or HMI<br>Allowed: Can be changed from the setting tool, HMI, and IEC 61850 client. |

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| Name | Range | Default | Description |
|---|---|---|---|
| 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. |
| 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*. |



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| Name | Range | Default | Description |
|---|---|---|---|
| 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. |

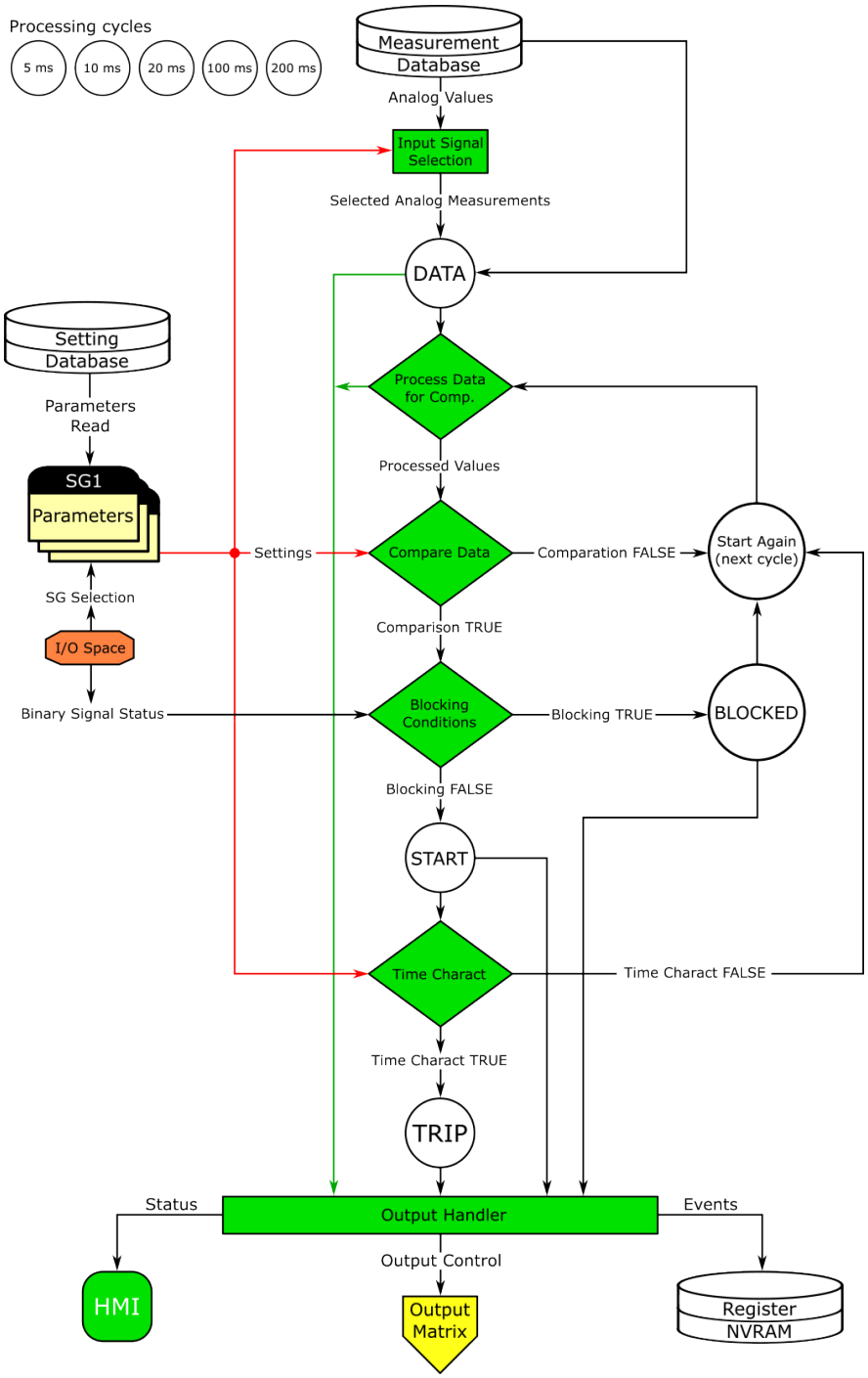
Table. 5.3 - 28. General menu logical inputs.

| 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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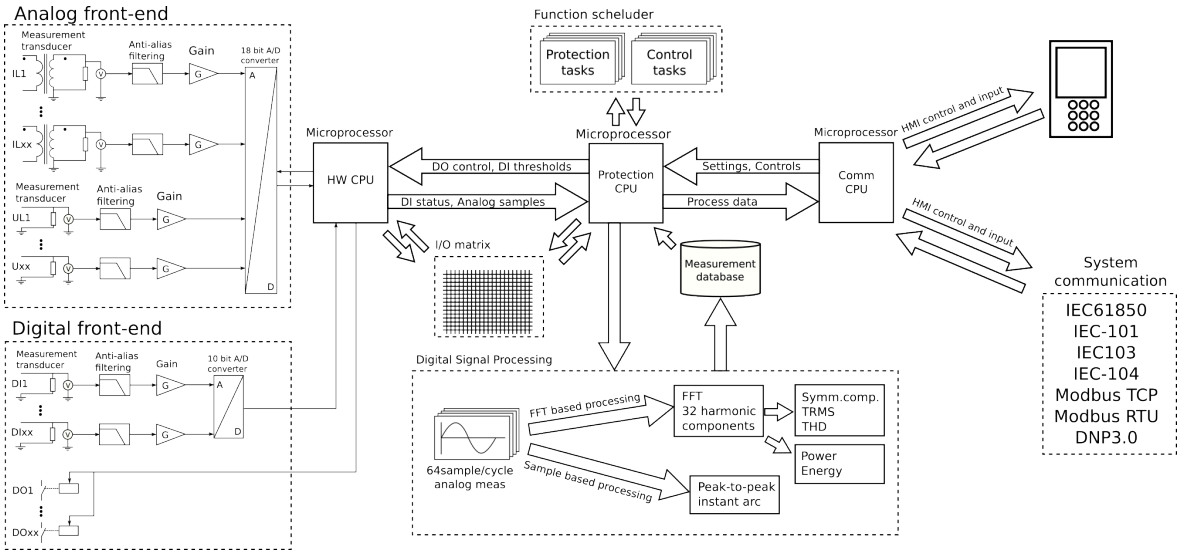
Figure. 5.4.1 - 9. Principle diagram of the protection relay platform.

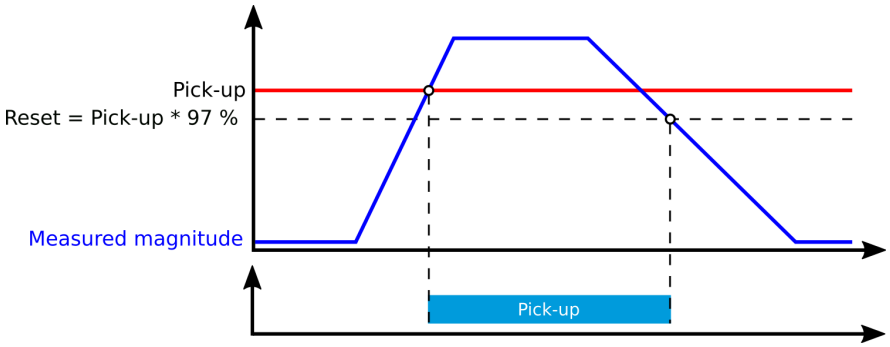



In the following chapters the common functionalities of protection functions are described. If a protection function deviates from this basic structure, the difference is described in the corresponding chapter of the manual.

## Pick-up

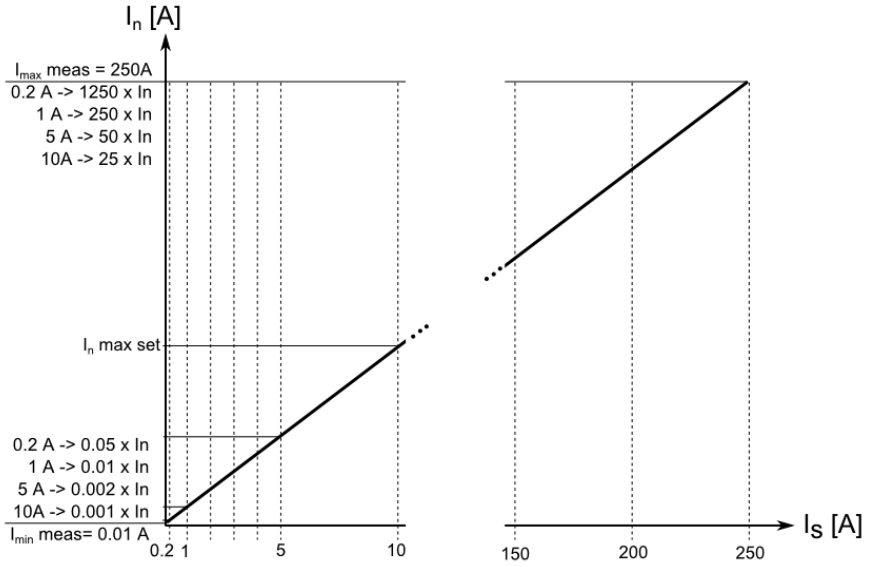
The $X_{set}$ parameter defines the pick-up level of the function, and this in turn defines the maximum or minimum allowed measured magnitude (in per unit, absolute or percentage value) before the function takes action. The function constantly calculates the ratio between the pick-up parameter set by 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 - 10. 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 - 11. 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 - 12. Operating time delay: *Definite (Min)* and the minimum for tripping.

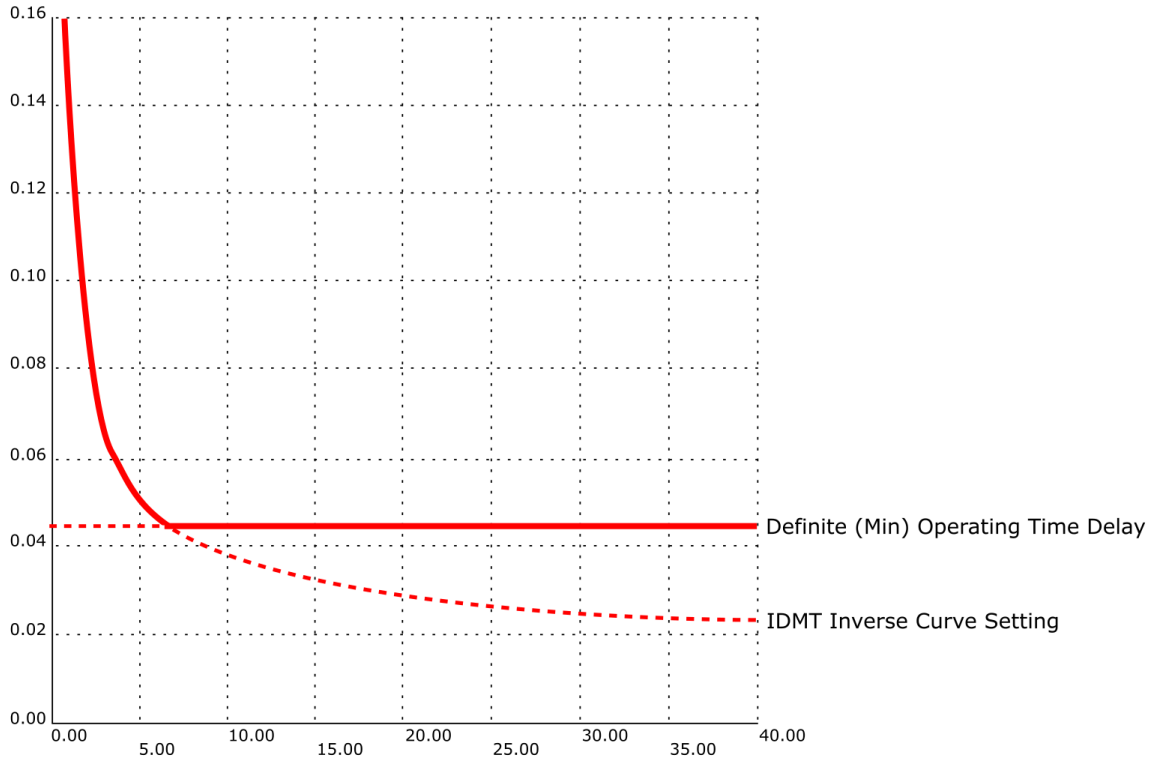


Table. 5.4.1 - 29. Operating time characteristics setting parameters (general).

| 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 - 13. 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 - 30. 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 - 31. 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 - 14. No delayed pick-up release.

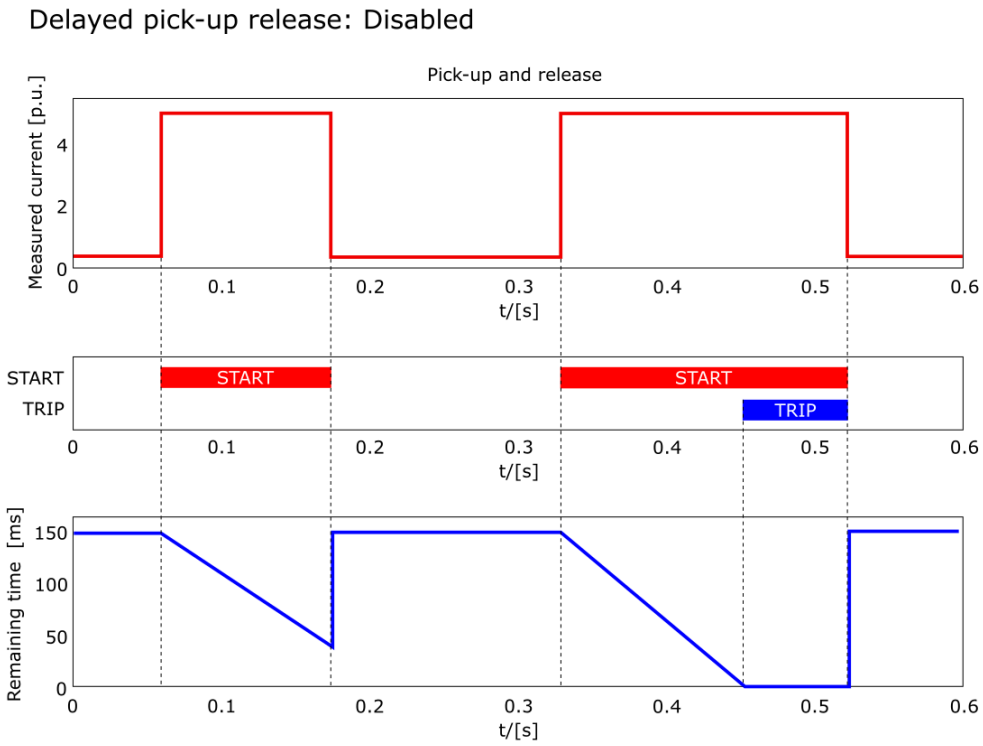




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Figure. 5.4.1 - 15. Delayed pick-up release, delay counter is reset at signal drop-off.

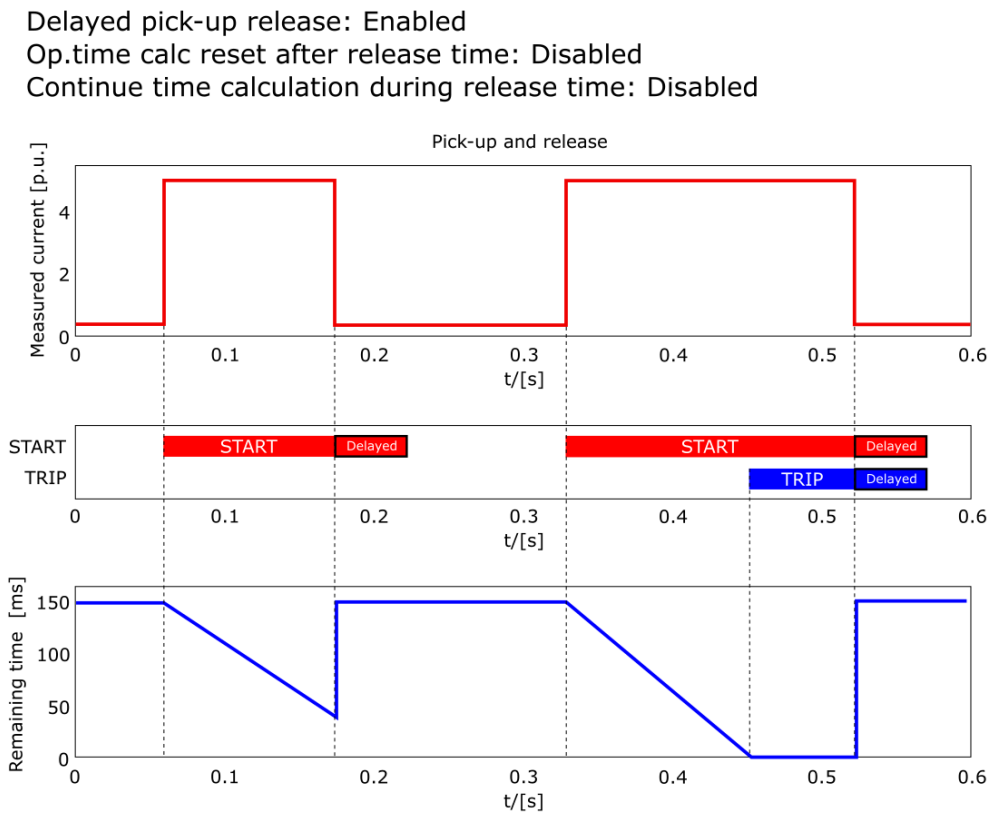



Figure. 5.4.1 - 16. Delayed pick-up release, delay counter value is held during the release time.

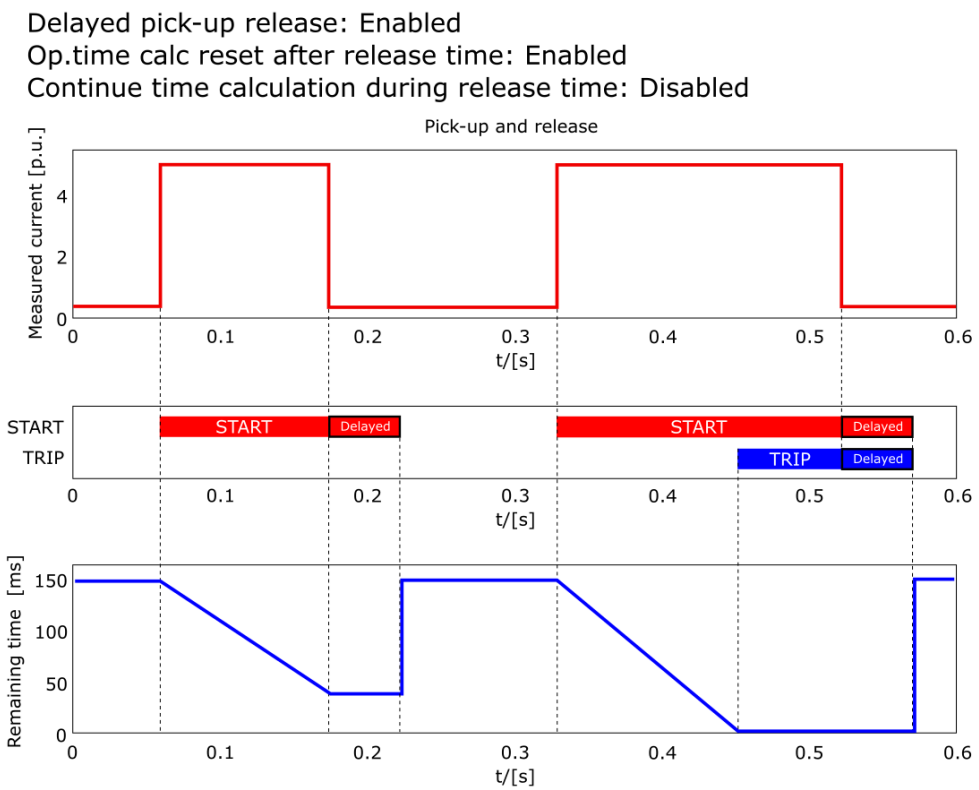
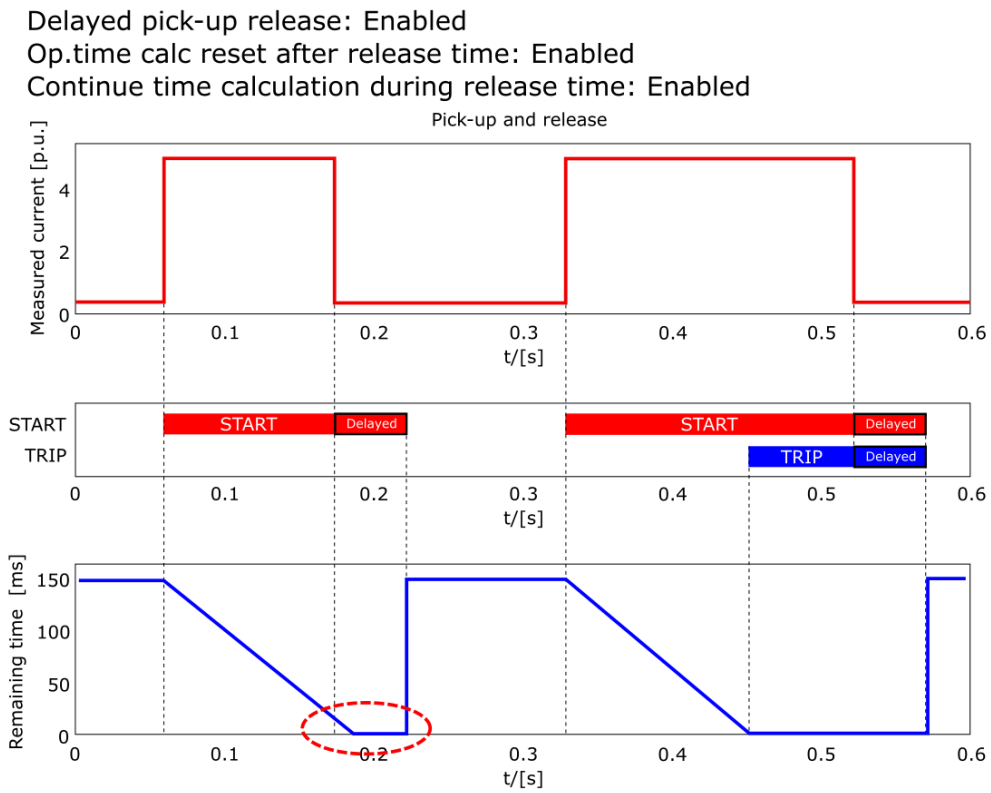


Figure. 5.4.1 - 17. Delayed pick-up release, delay counter value is decreasing during the release time.




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.

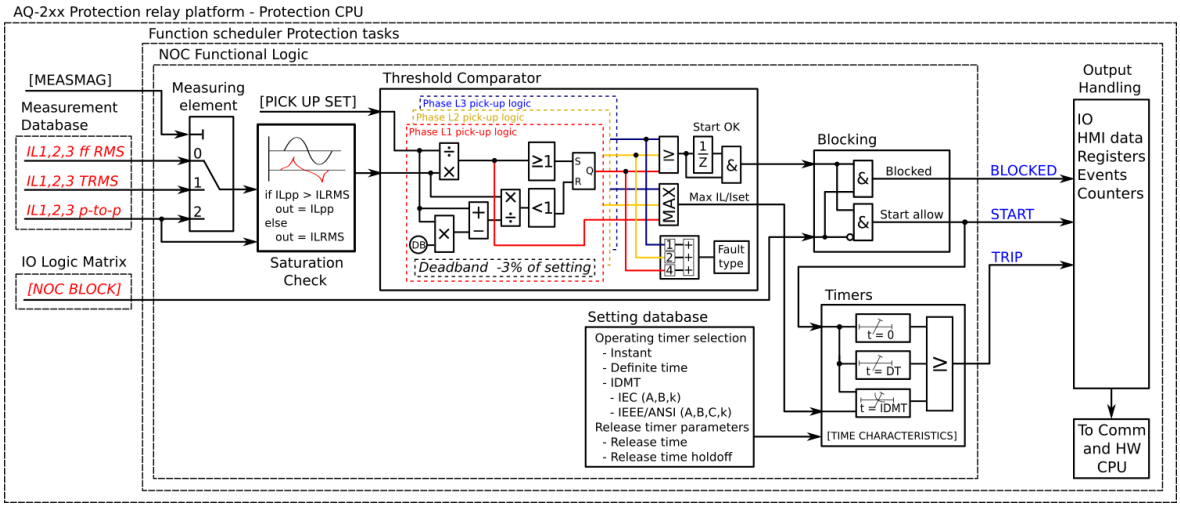
The inputs for the function are the following:

- 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 - 18. 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 - 32. 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 - 33. 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. |
| Measurement side | 1: Side 1<br>2: Side 2 | 1: Side 1 | Defines which current measurement module 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 - 34. 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 - 35. 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 - 36. 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 2nd harmonic blocking. |
| 2nd harmonic blocking limit (Iharm/Ifund) | 0.10…50.00%$I_{fund}$ | 0.01%$I_{fund}$ | 0.01%$I_{fund}$ | Defines the limit of the 2nd 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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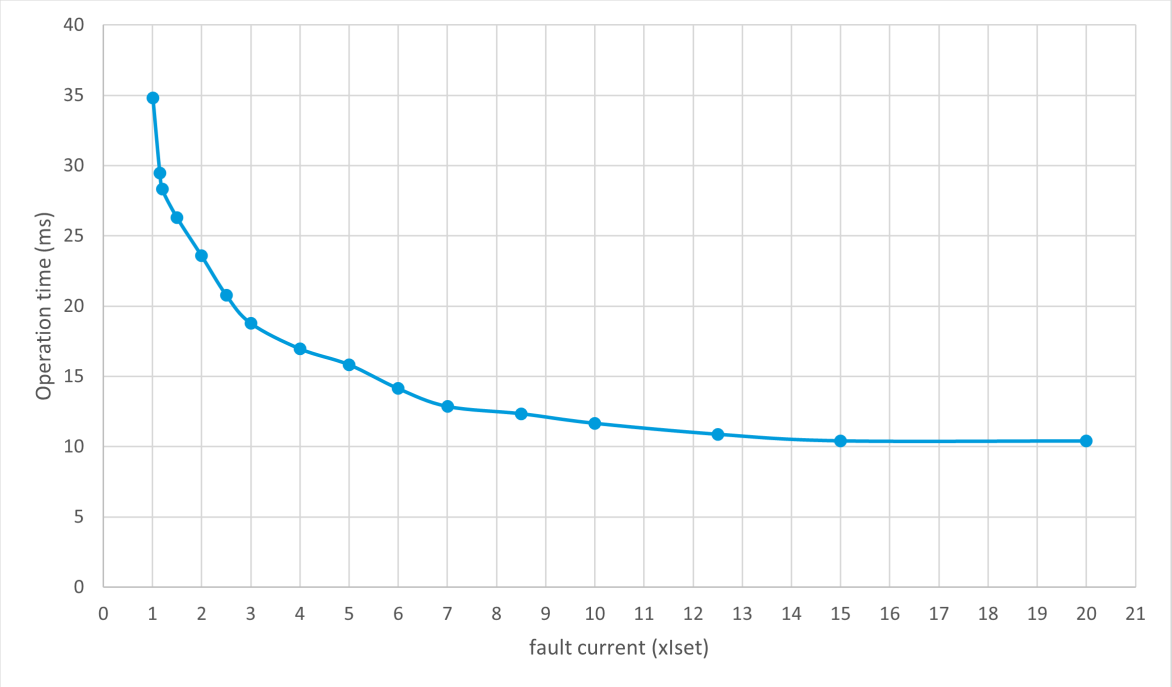
The blocking of the function causes an HMI display event and a-time stamped blocking event with information of the startup current values and its fault type to be issued.

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 - 19. 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 - 37. 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 - 38. 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 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.


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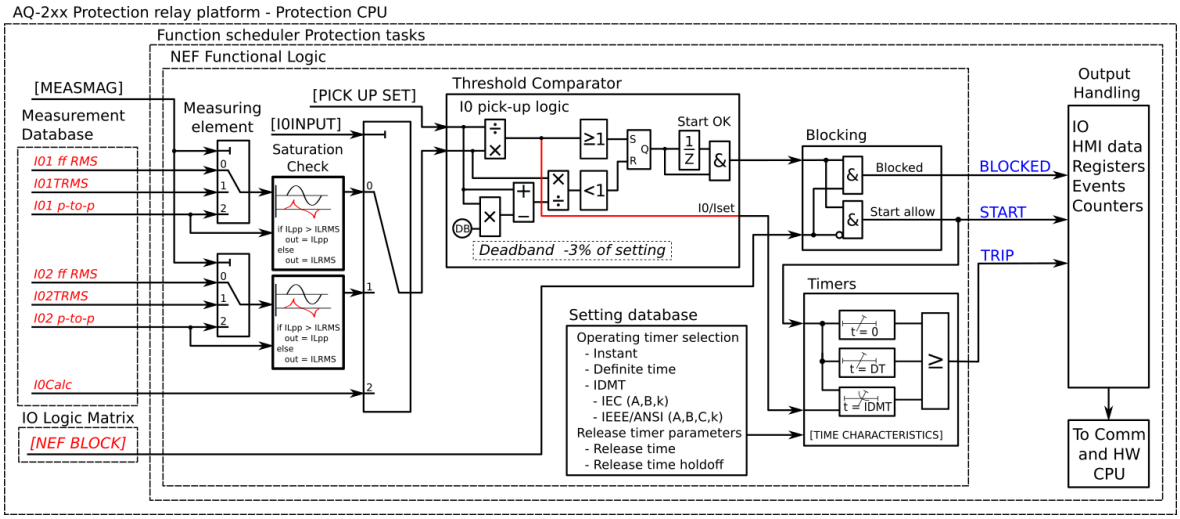
Figure. 5.4.3 - 20. Simplified function block diagram of the I0> fucntion.




## 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. 5.4.3 - 39. 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. 5.4.3 - 40. 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. |

| 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". |
| Measurement side | 1: Side 1<br><br>2: Side 2 | 1: Side 1 | Defines which current measurement module is used by the function. |
| 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. 5.4.3 - 41. 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. 5.4.3 - 42. 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. |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| Name | Range | Step | Description |
|---|---|---|---|
| I0> condition | 0: Normal<br>1: Start<br>2: Trip<br>3: Blocked | - | Displays status of the protection function. |
| 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. 5.4.3 - 43. 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".

## 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. 5.4.3 - 44. 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.


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Table. 5.4.3 - 45. 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 |

### 5.4.4 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
- block signal check
- time delay characteristics
- output processing.

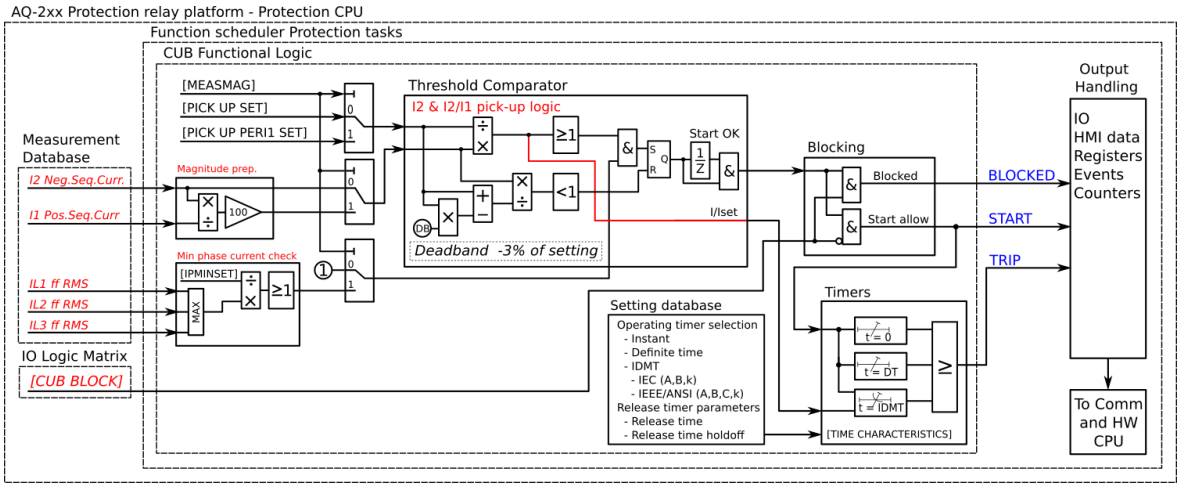
The inputs for the function are the following:

- 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. 5.4.4 - 21. 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. 5.4.4 - 46. 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 |
| 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. 5.4.4 - 47. 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><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 |
|---|---|---|---|
| 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. |
| Measurement side | 1: Side 1<br><br>2: Side 2 | 1: Side 1 | Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module. |
| 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. 5.4.4 - 48. 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.

Table. 5.4.4 - 49. 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


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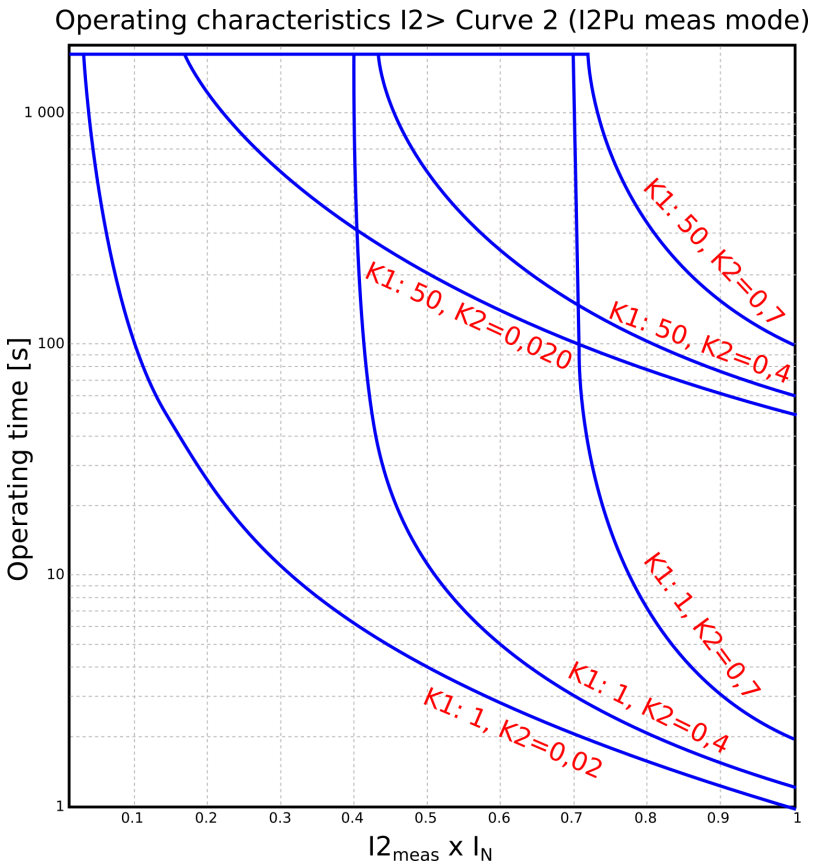
Figure. 5.4.4 - 22. Operation characteristics curve for I2> Curve2.




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.

Table. 5.4.4 - 50. Event messages.

| Event block name | Event names |
|---|---|
| CUB1 | Start ON |
| CUB1 | Start OFF |
| CUB1 | Trip ON |

| Event block name | Event names |
|---|---|
| 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. 5.4.4 - 51. 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 |

## 5.4.5 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.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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.

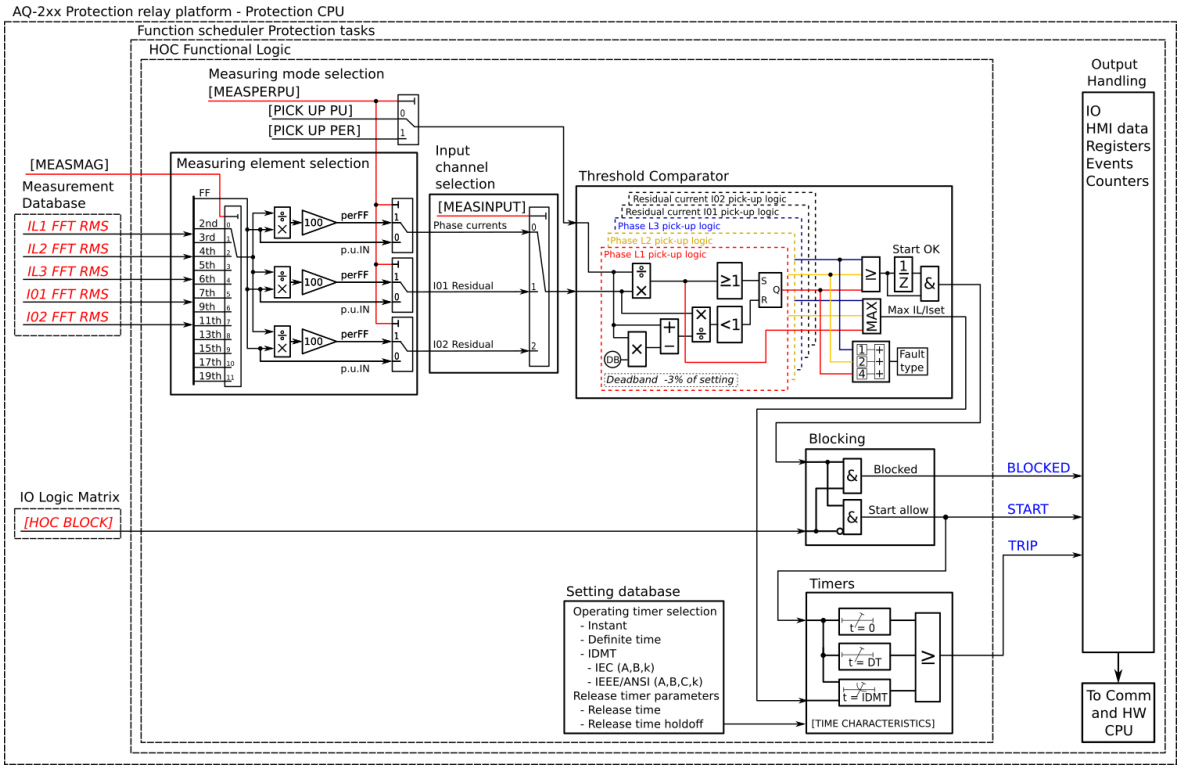
The inputs of the function are the following:

- 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.

Figure. 5.4.5 - 23. 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. 5.4.5 - 52. 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 |



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| 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 |

| 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. 5.4.5 - 53. 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. |
| Ih> measurement side | 1: Side 1<br><br>2: Side 2 | 1: Side 1 | Defines which current measurement module is used by the function. Visible if the unit has more than one current measurement module. |



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| 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. 5.4.5 - 54. 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.

## 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 - 55. 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".


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## 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. 5.4.5 - 56. 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.

Table. 5.4.5 - 57. 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 |

### 5.4.6 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.


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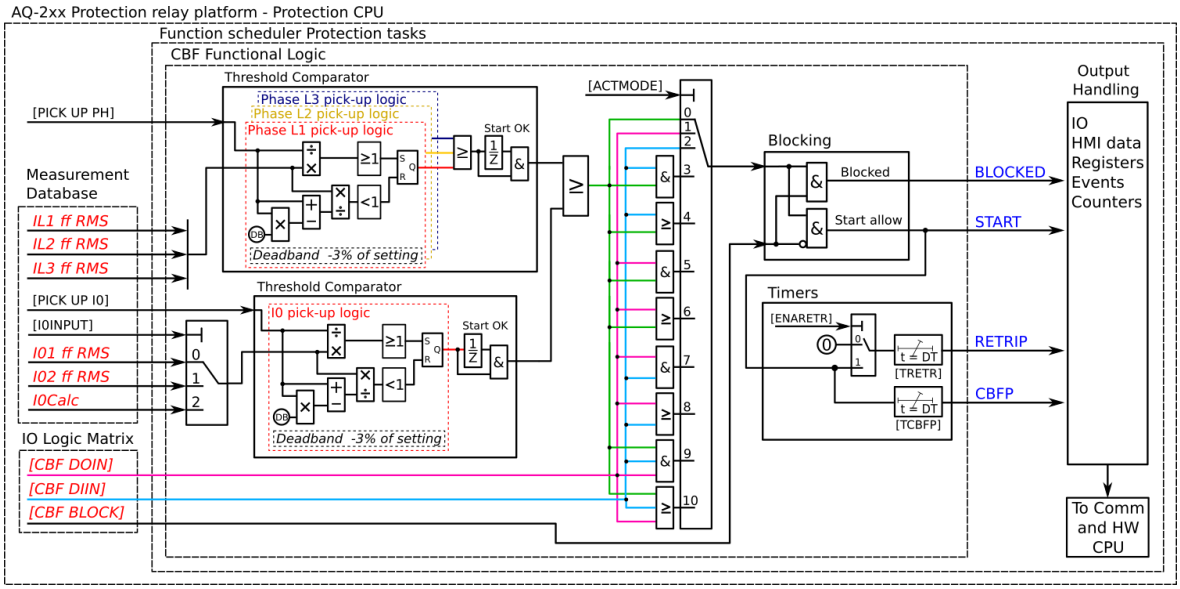
Figure. 5.4.6 - 24. Simplified function block diagram of the CBFP function.




## 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. 5.4.6 - 58. 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.

Table. 5.4.6 - 59. 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. 5.4.6 - 60. 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. |
| Measurement side | 1: Side 1<br><br>2: Side 2 | 1: Side 1 | Defines which current measurement module is used by the function. |

## 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. 5.4.6 - 61. 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. |



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| 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. 5.4.6 - 62. 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. 5.4.6 - 63. 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. |

## 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. 5.4.6 - 64. 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.


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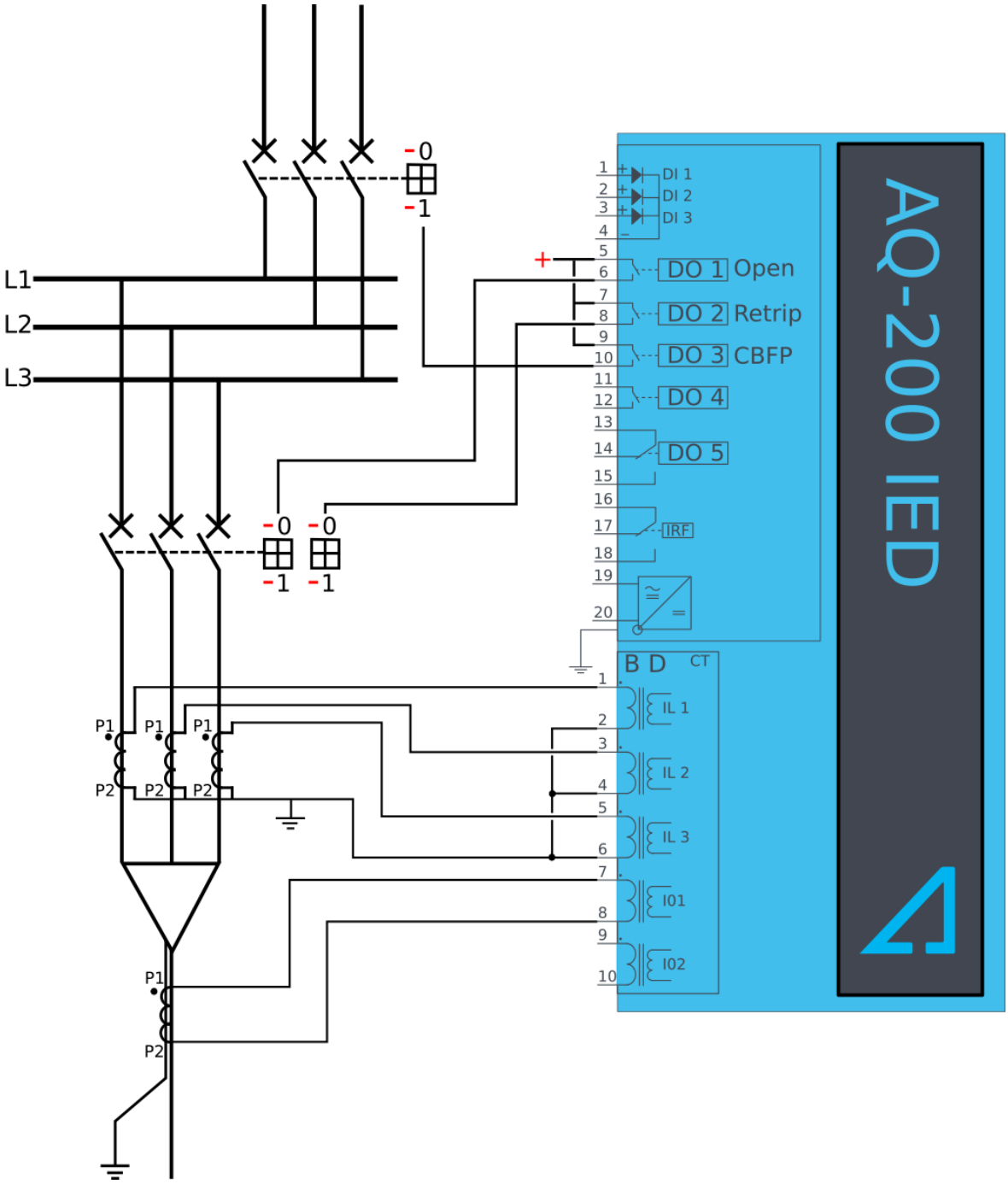
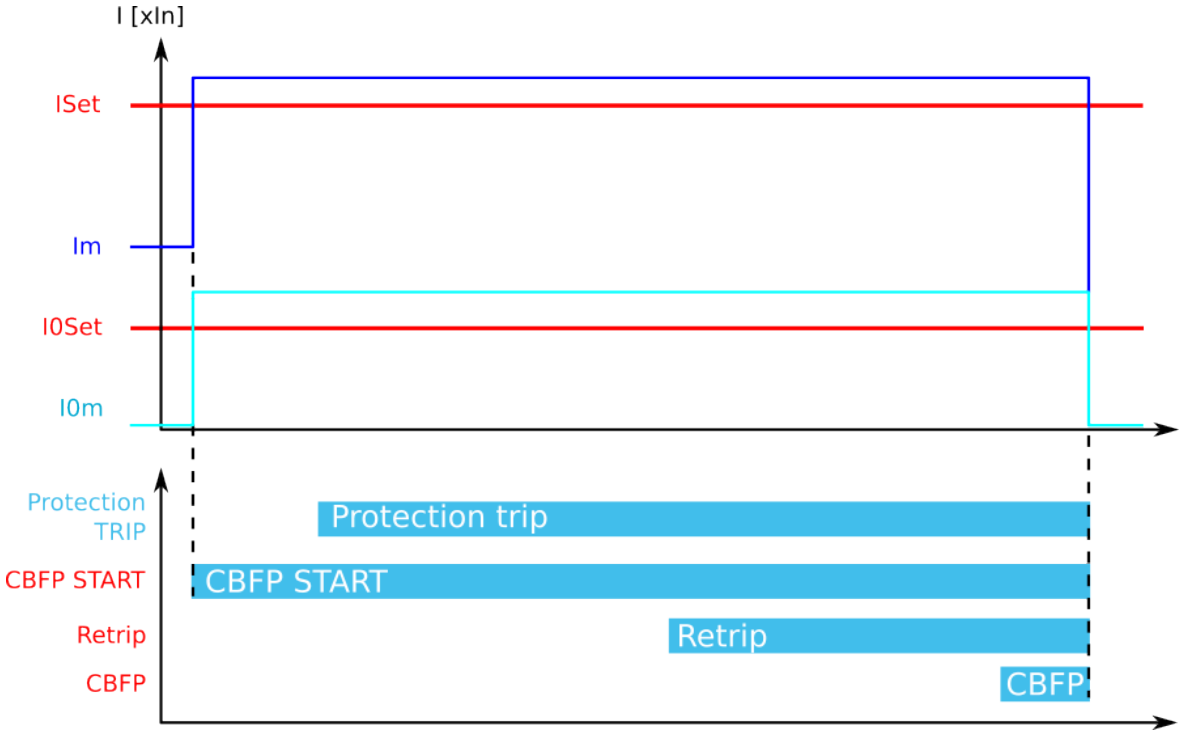
## Trip, Retrip and CBFP in the device configuration

Figure. 5.4.6 - 25. 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.

Figure. 5.4.6 - 26. 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.


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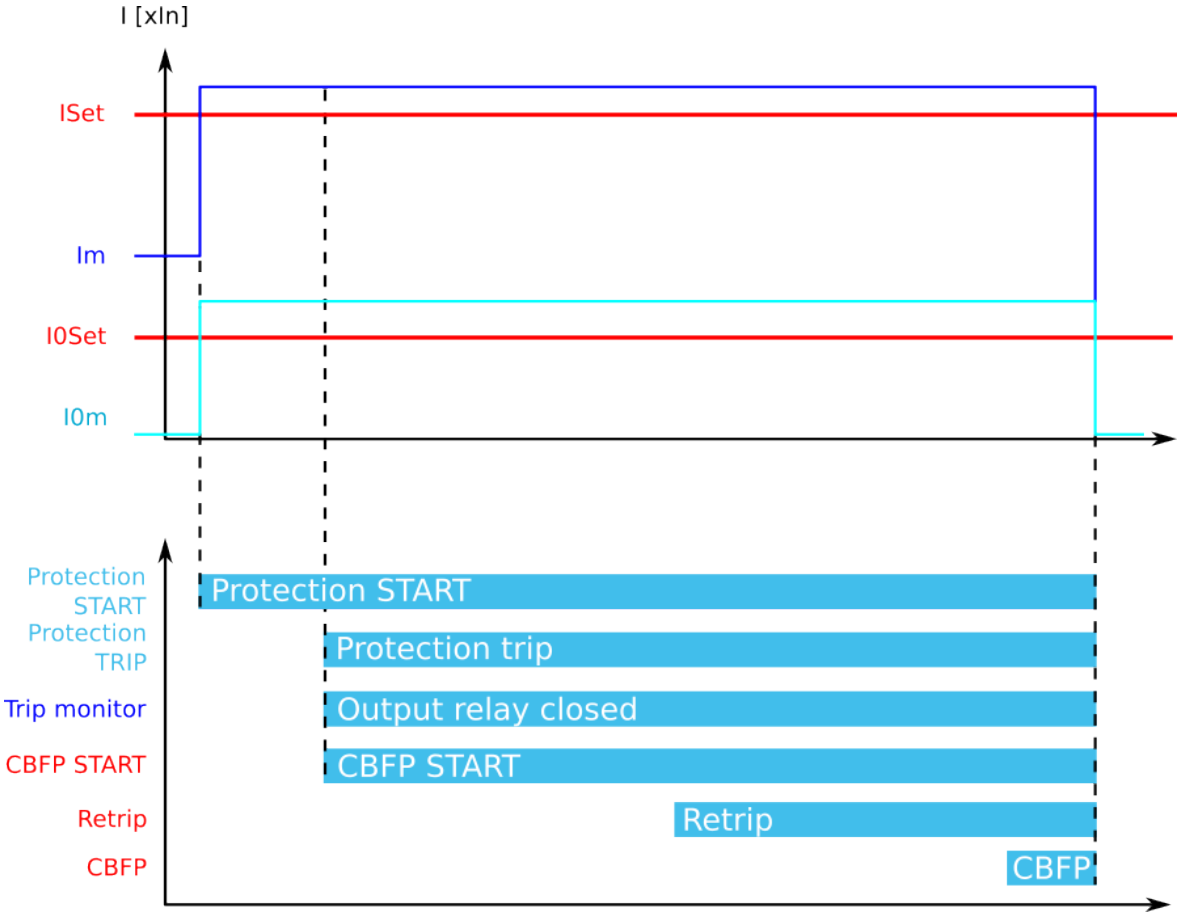
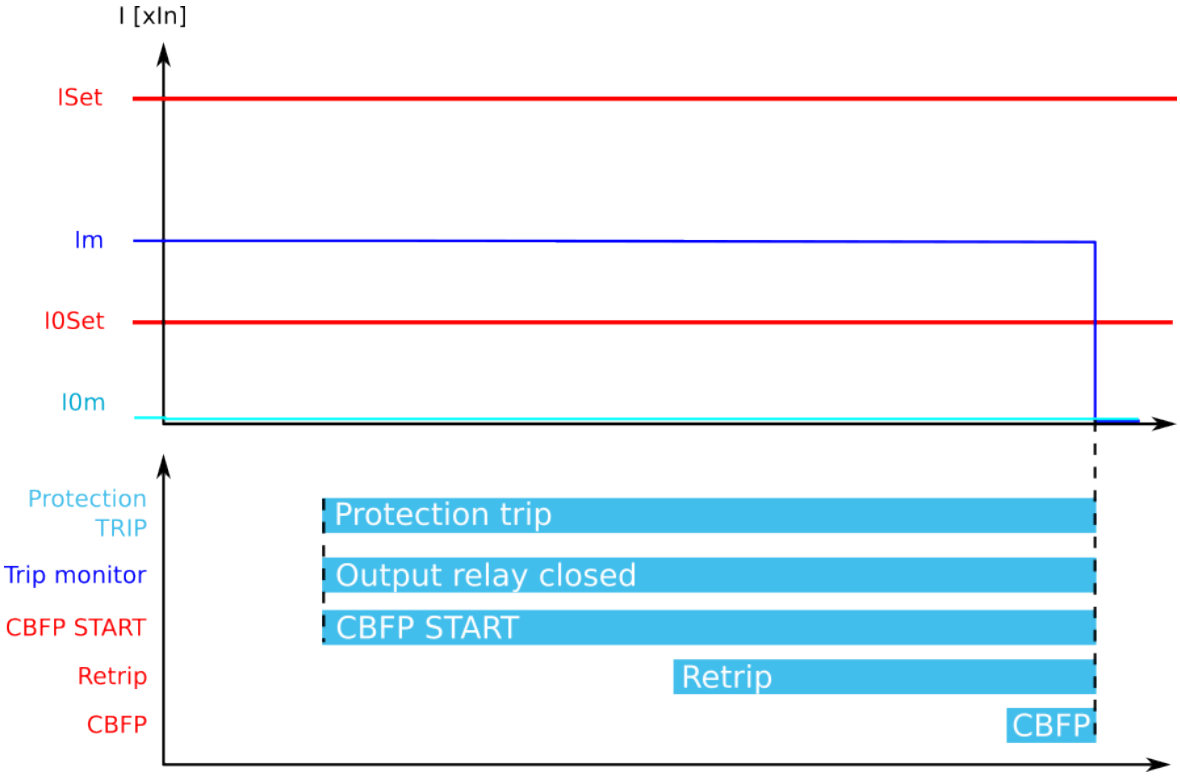
Figure. 5.4.6 - 27. Retrip and CBFP when "Current and DO" is the selected criterion.




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.

Figure. 5.4.6 - 28. 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.



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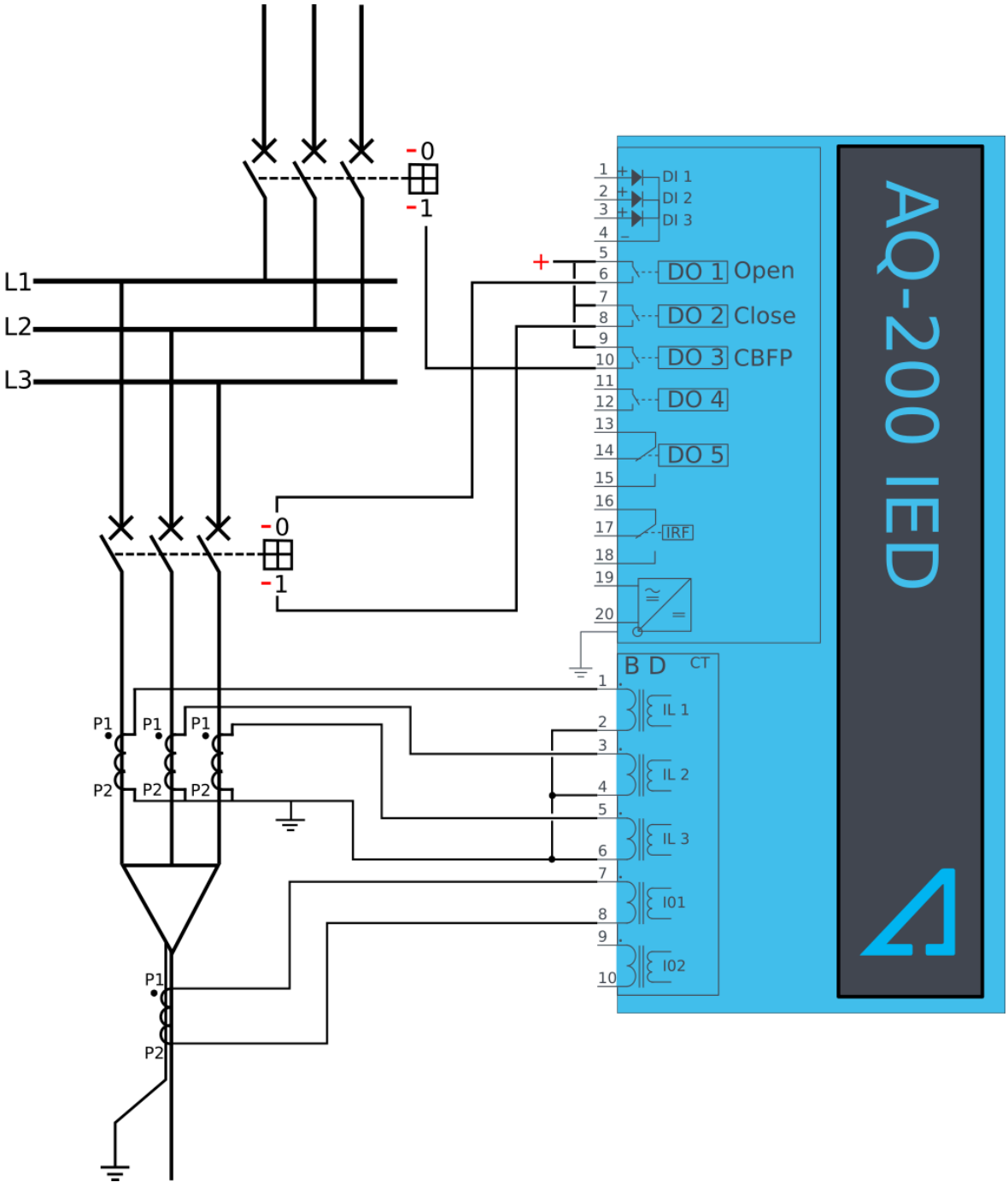
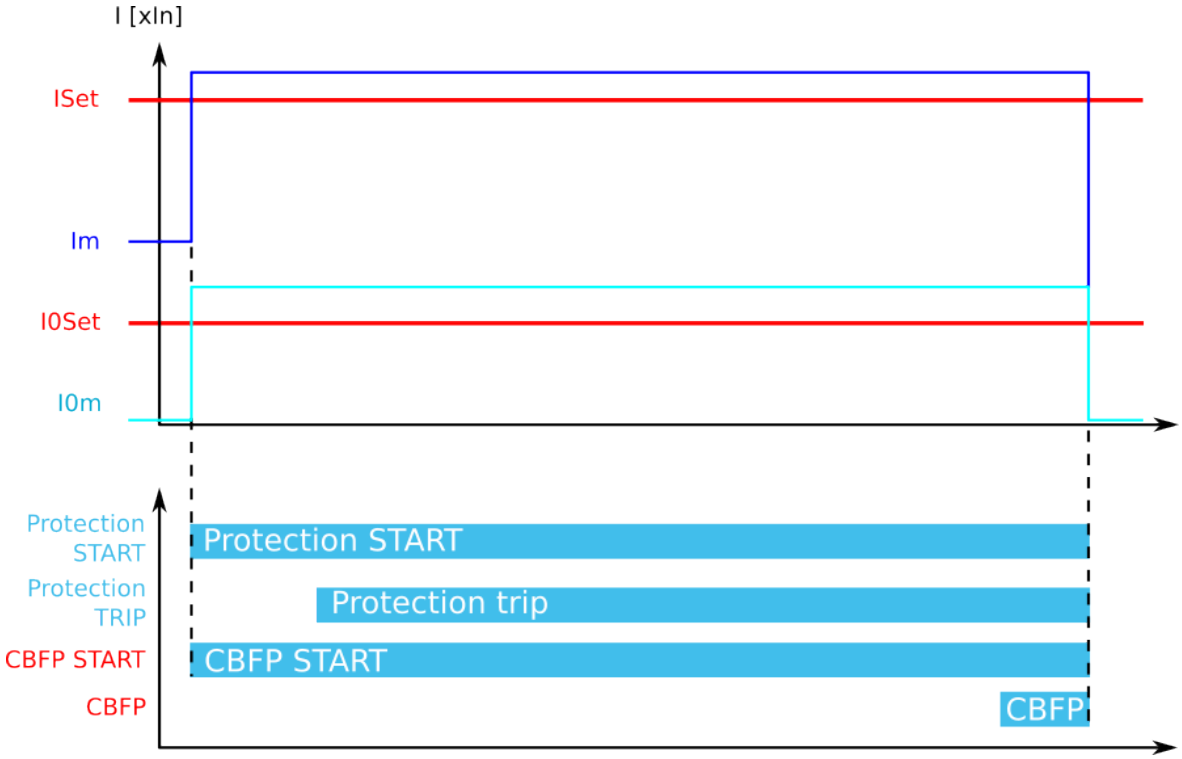
## Trip and CBFP in the device configuration

Figure. 5.4.6 - 29. 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.

Figure. 5.4.6 - 30. 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.



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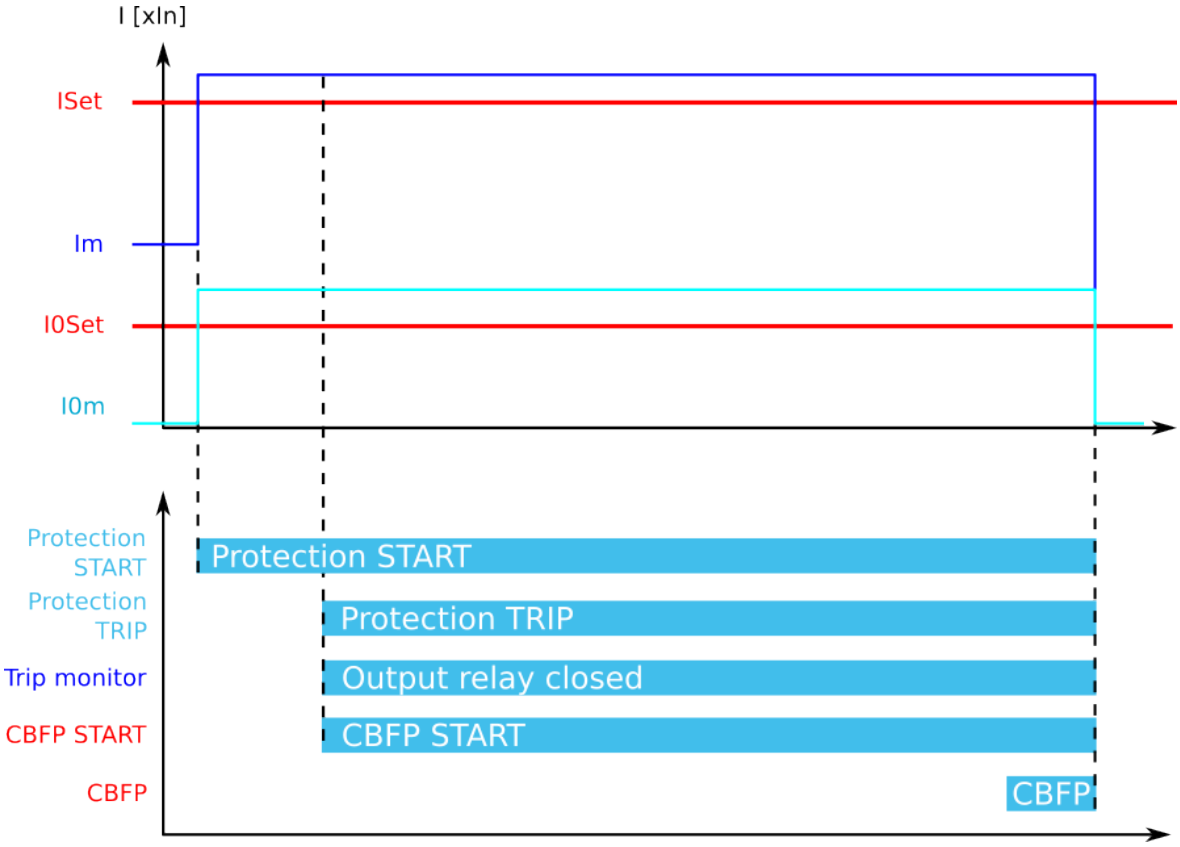
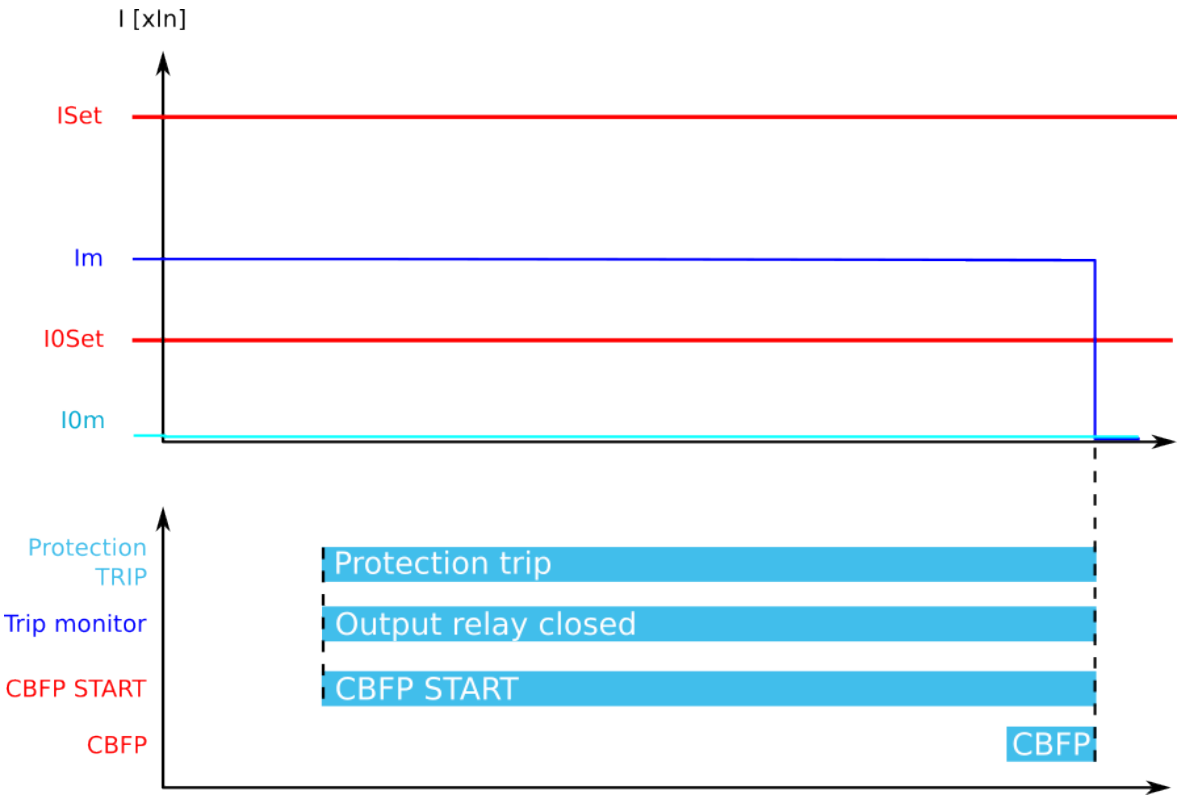
Figure. 5.4.6 - 31. CBFP when "Current and DO" is the selected criterion.




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.

Figure. 5.4.6 - 32. 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.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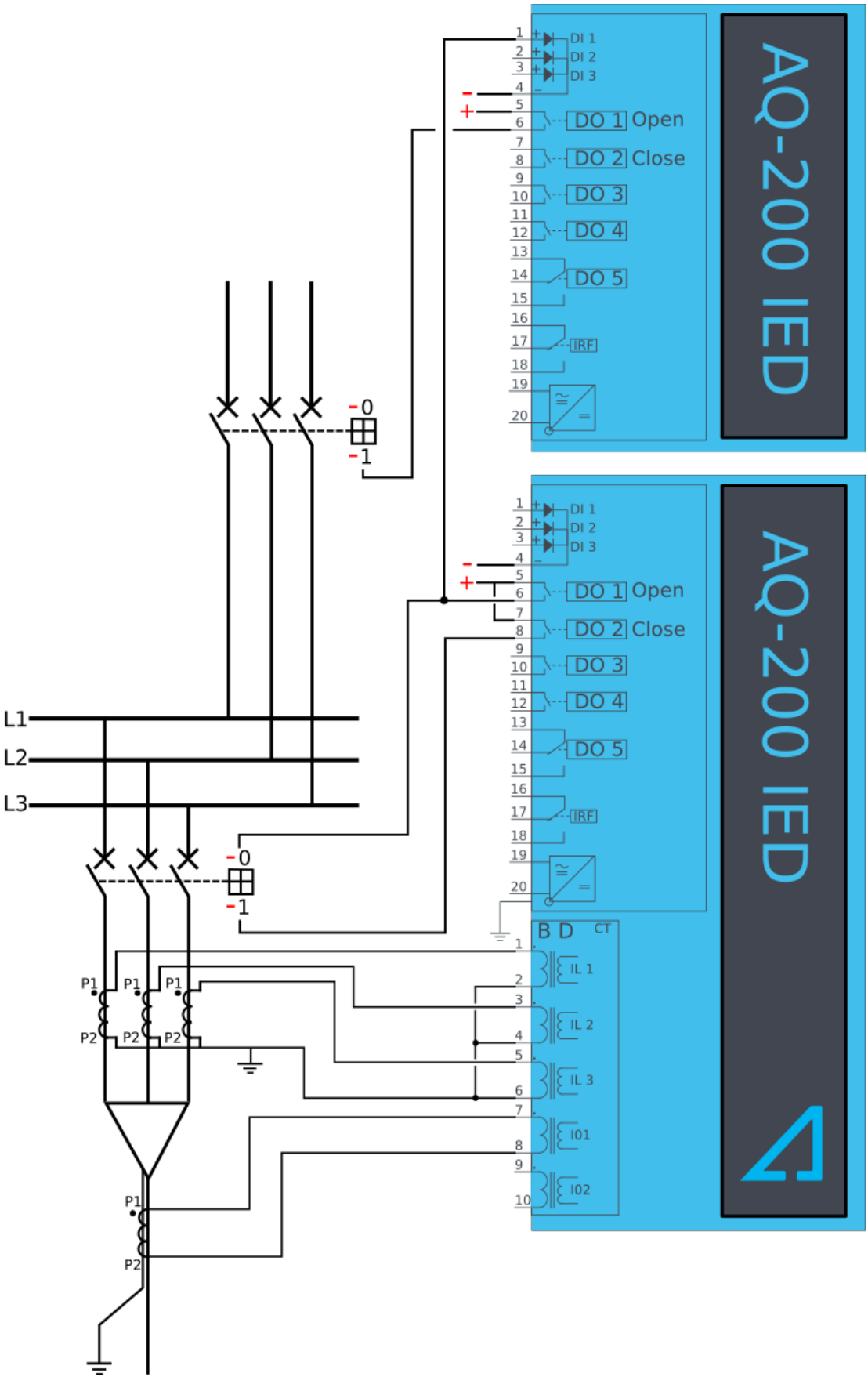
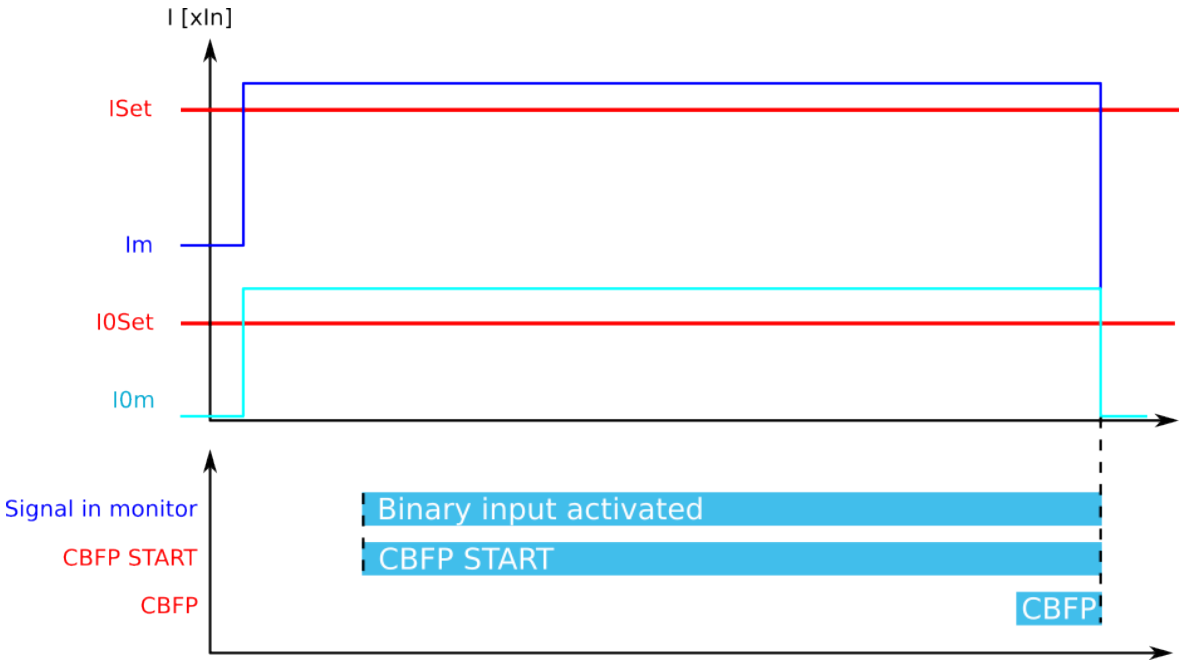
## Device configuration as a dedicated CBFP unit

Figure. 5.4.6 - 33. Wiring diagram when the device is configured as a dedicated CBFP unit.



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. 5.4.6 - 34. 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. 5.4.6 - 65. Event messages.

| Event block name | Event names |
|---|---|
| CBF1 | Start ON |
| CBF1 | Start OFF |
| CBF1 | Retrip ON |
| CBF1 | Retrip OFF |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| 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. 5.4.6 - 66. 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 |

## 5.4.7 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

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

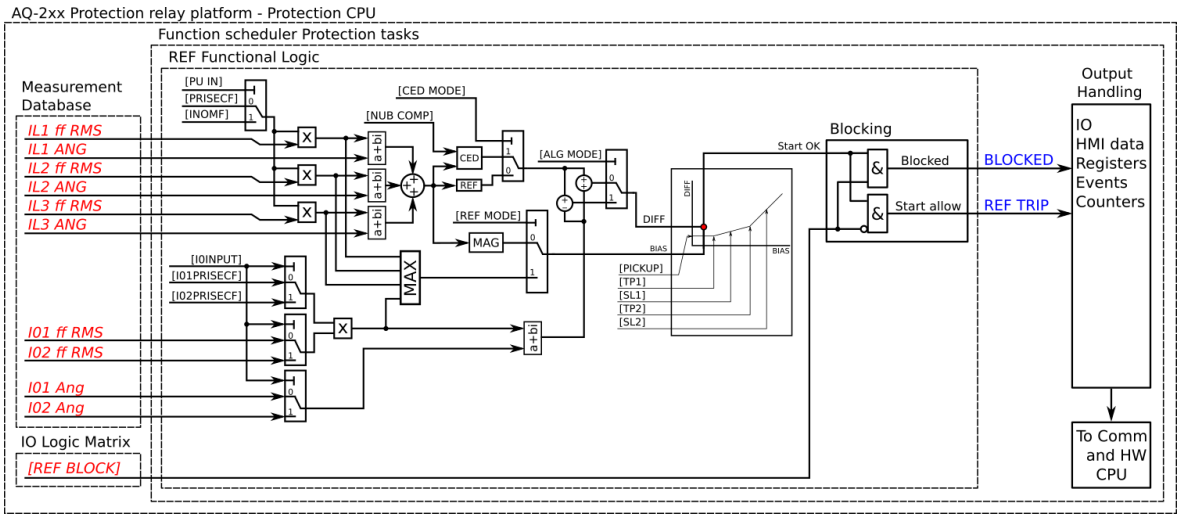
The inputs for the function are the following:

- 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. 5.4.7 - 35. 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. 5.4.7 - 67. 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 |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| 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. 5.4.7 - 68. 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. |
| I0d> in side | 1: Side 1<br><br>2: Side 2 | 1: Side 1 | Defines which current measurement module is used by the function. |
| 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. 5.4.7 - 69. Pick-up settings.

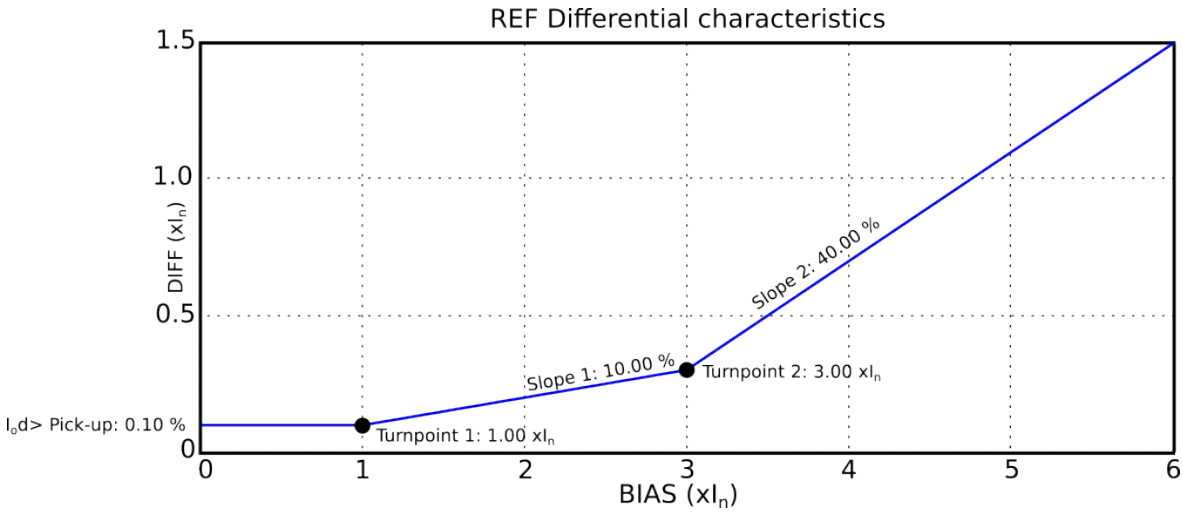
| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| I0 Input | 0: I01<br>1: I02 | - | 0: I01 | Selection of the used residual current measurement input. |
| I0 Direction | 0: Add<br>1: Subtract | - | 0: Add | Differential current calculation mode. This matches the directions of the 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. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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. |
| 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. 5.4.7 - 36. Differential characteristics for the I0d> function with default settings.




The equations for the differential characteristics are the following:

Figure. 5.4.7 - 37. Differential current (the calculation is based on user-selected inputs and direction).

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

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

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

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



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Figure. 5.4.7 - 38. 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. 5.4.7 - 39. 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. 5.4.7 - 70. 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.

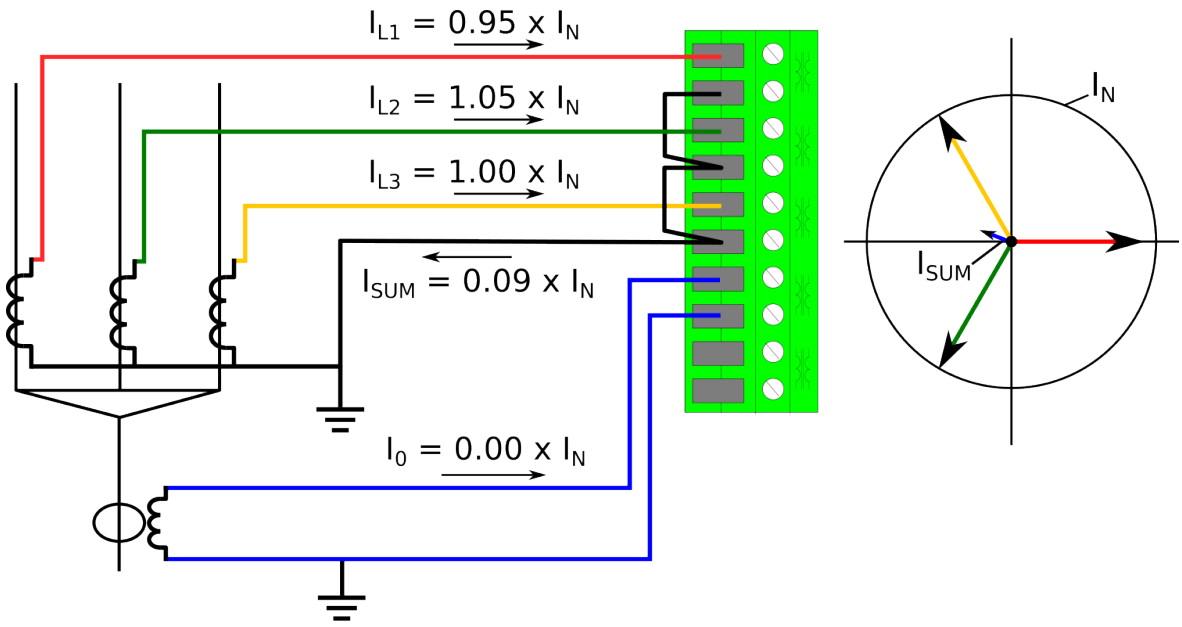
If the blocking signal is active when the pick-up element activates, a BLOCKED signal is generated and the function does not process the situation further. If the TRIP function has been activated before the blocking signal, it resets and processes the release time characteristics similarly to when the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

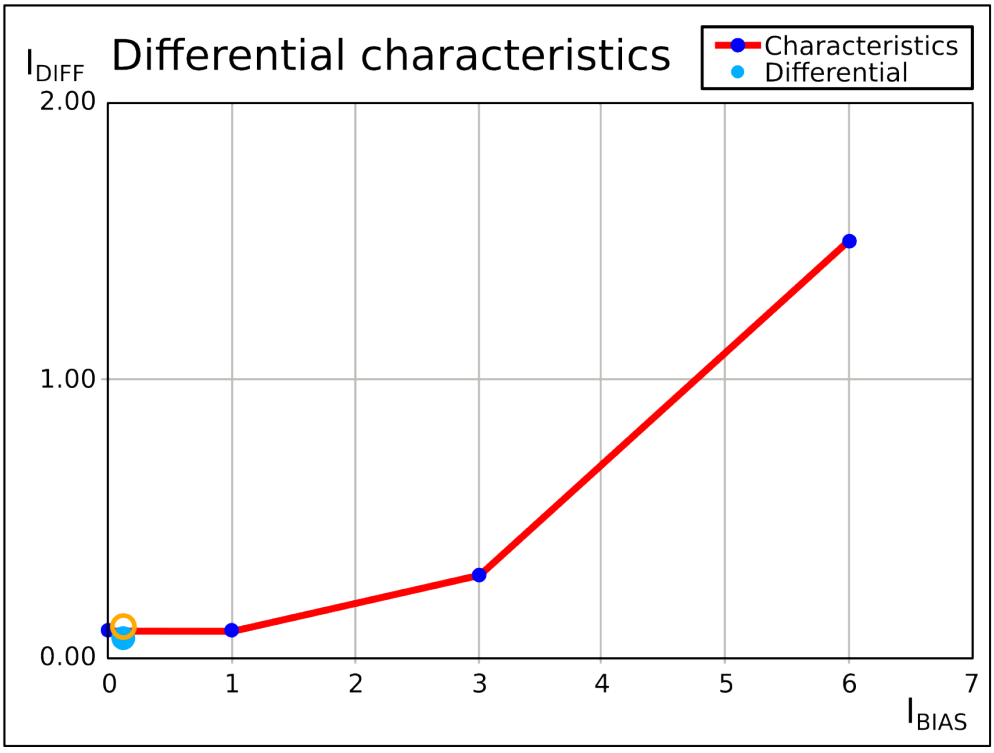
The blocking of the function causes an HMI display event and a time-stamped blocking event with information of the startup current values and its fault type to be issued.

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.

The following figures present some typical applications for this function.

Figure. 5.4.7 - 40. 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.



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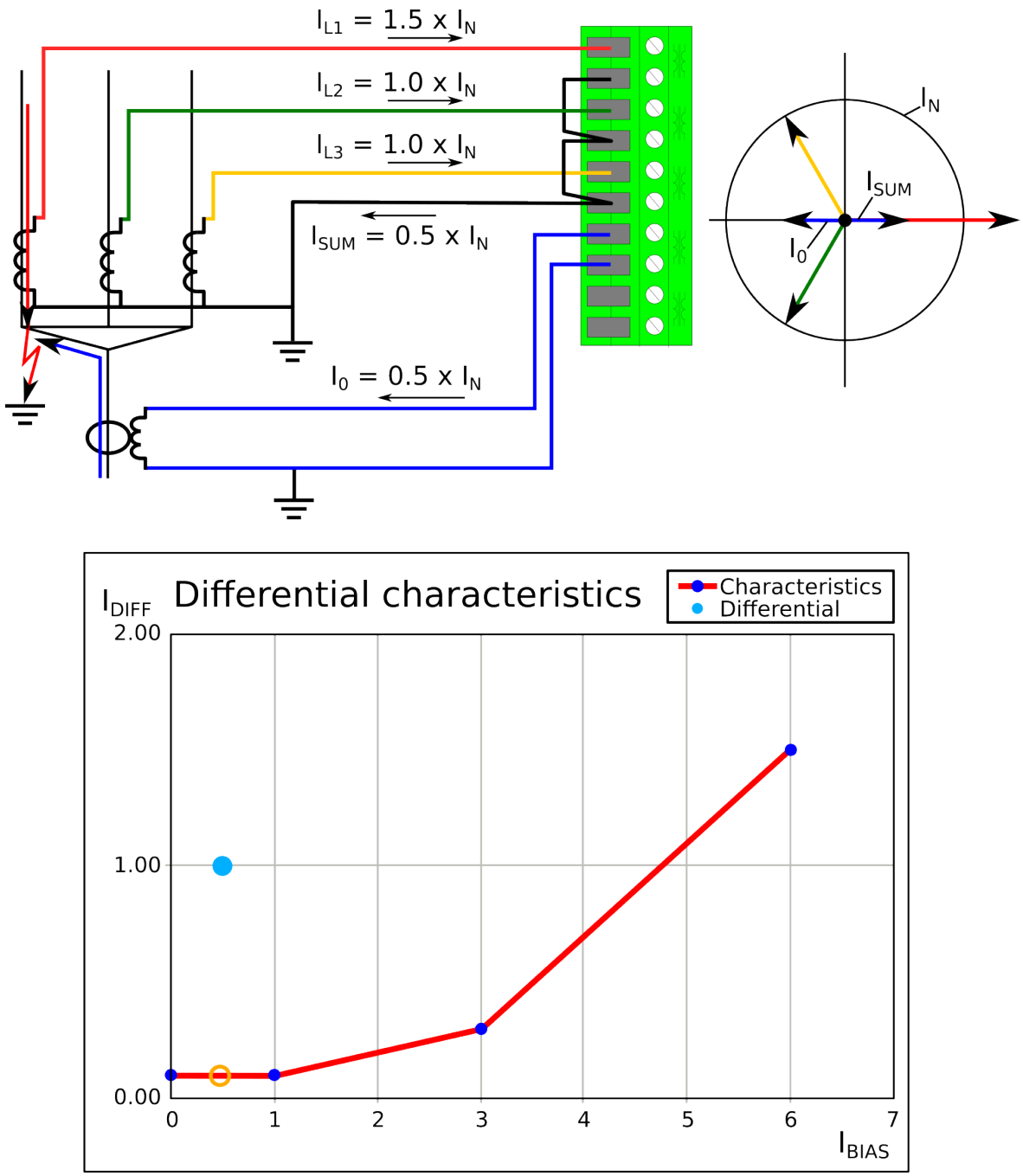
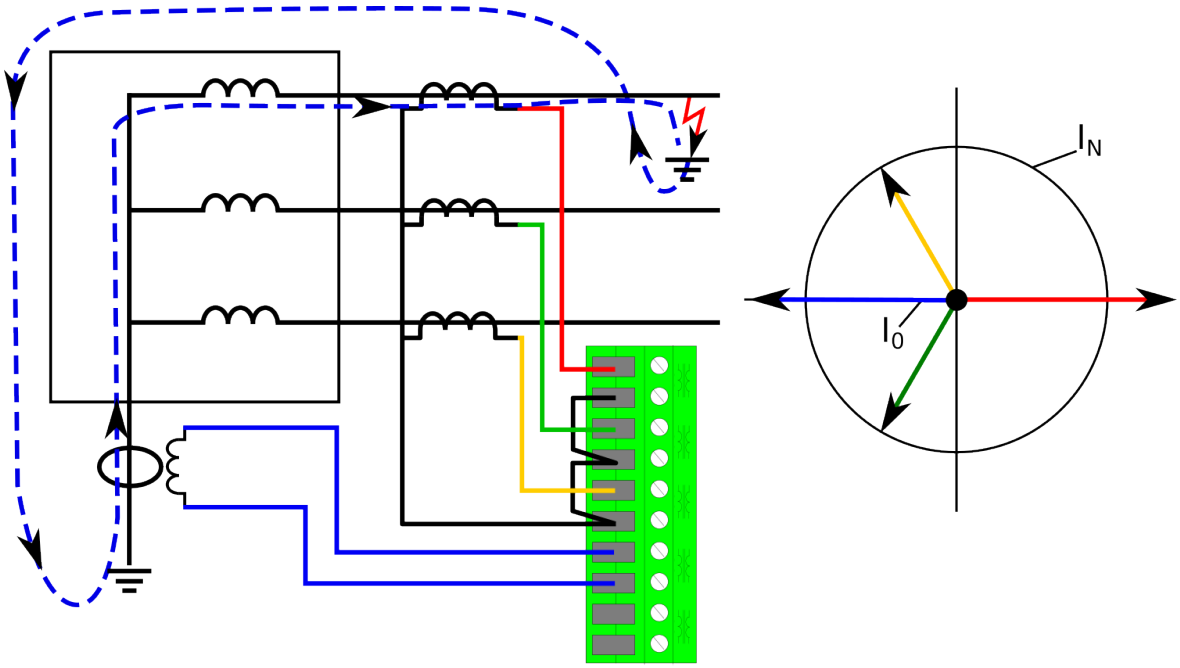
Figure. 5.4.7 - 41. Cable end differential when a fault occurs.

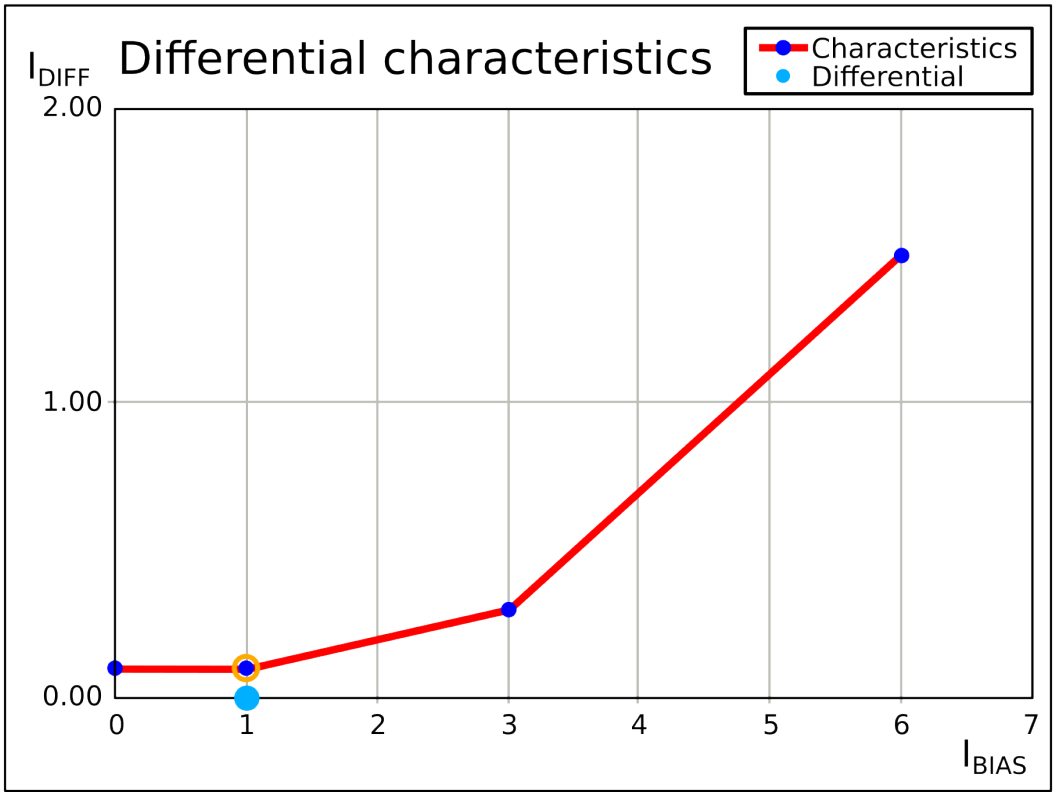



If a starting fault occurs in the cable end, the CED mode catches the difference between the ingoing and the outgoing residual currents. The resulting signal can be used for alarming or tripping purposes for the feeder with the failing cable end. The user can freely change both the settings and the sensitivity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

Figure. 5.4.7 - 42. 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.



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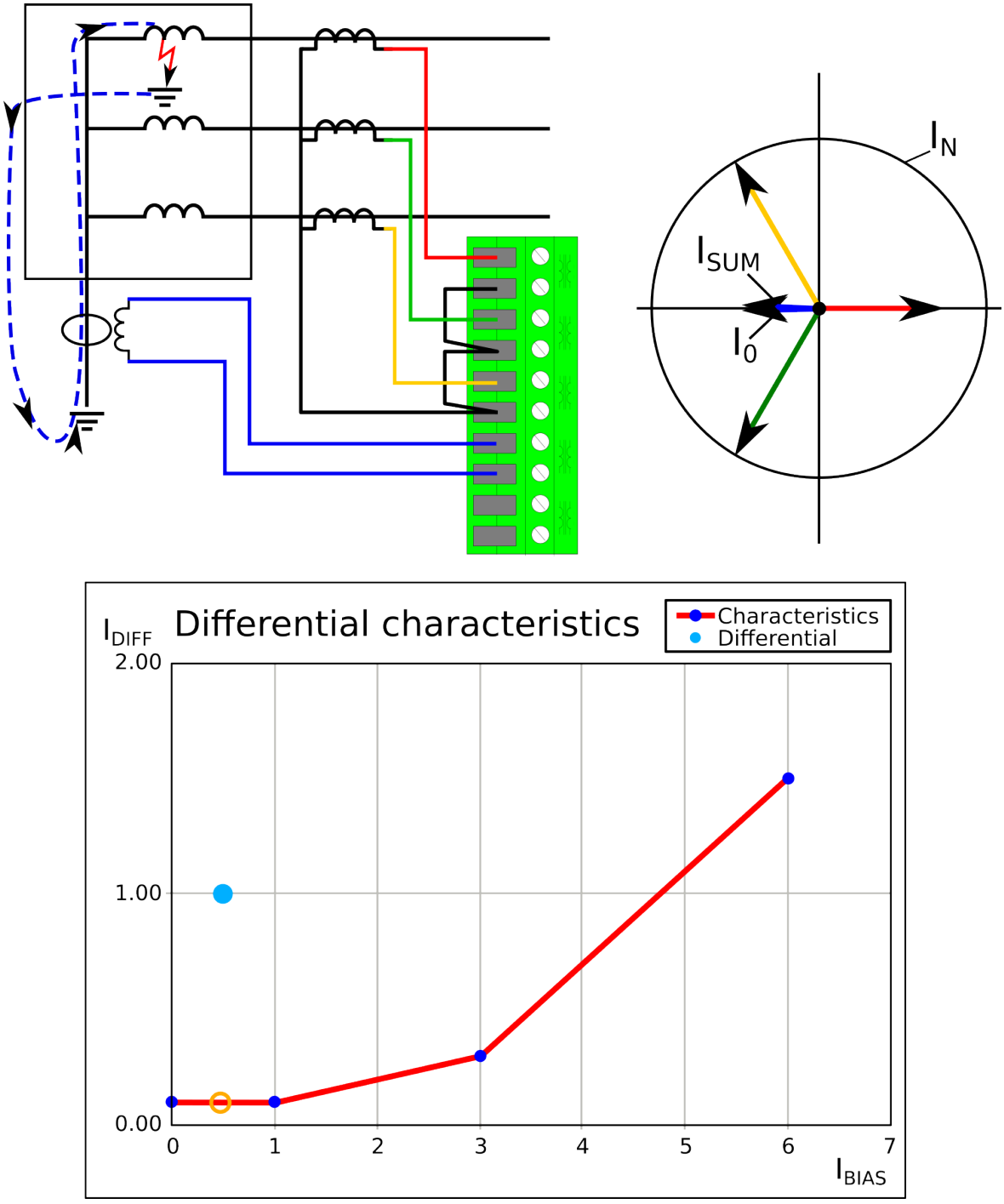
Figure. 5.4.7 - 43. Restricted earth fault inside a Y winding transformer.




## 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.

Table. 5.4.7 - 71. 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. 5.4.7 - 72. Register content.

| Date and time | Event | Trigger currents | Maximum trigger currents | Residual currents | Used SG |
|---|---|---|---|---|---|
| dd.mm.yyyy<br>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 |

## 5.4.8 Transformer status monitoring

The transformer status monitoring function is designed to be the one place where the user can set up all necessary transformer data and select the used transformer protection functions. Settings related to the protection functions can also be edited inside each function and any changes are updated into this function as well. The function calculates many transformer-related properties which are used in functions that protect and monitor the transformer. Standard transformers require only name plate data and CT scalings to get the relay automatically scale all measurement signals to the transfomer. In special transformers manually set values can be applied to cover the transformer properties that are rarely met. Additionally, the function counts a transformer's cumulative overloading and high overcurrent time.

The function can output the following signals:

- light/no load
- HV side inrush
- LV side inrush
- normal load
- overloading
- heavy overloading.

These signals can be used in indication or in logic programming, and they are the basis for the events the function generates (if so chosen).



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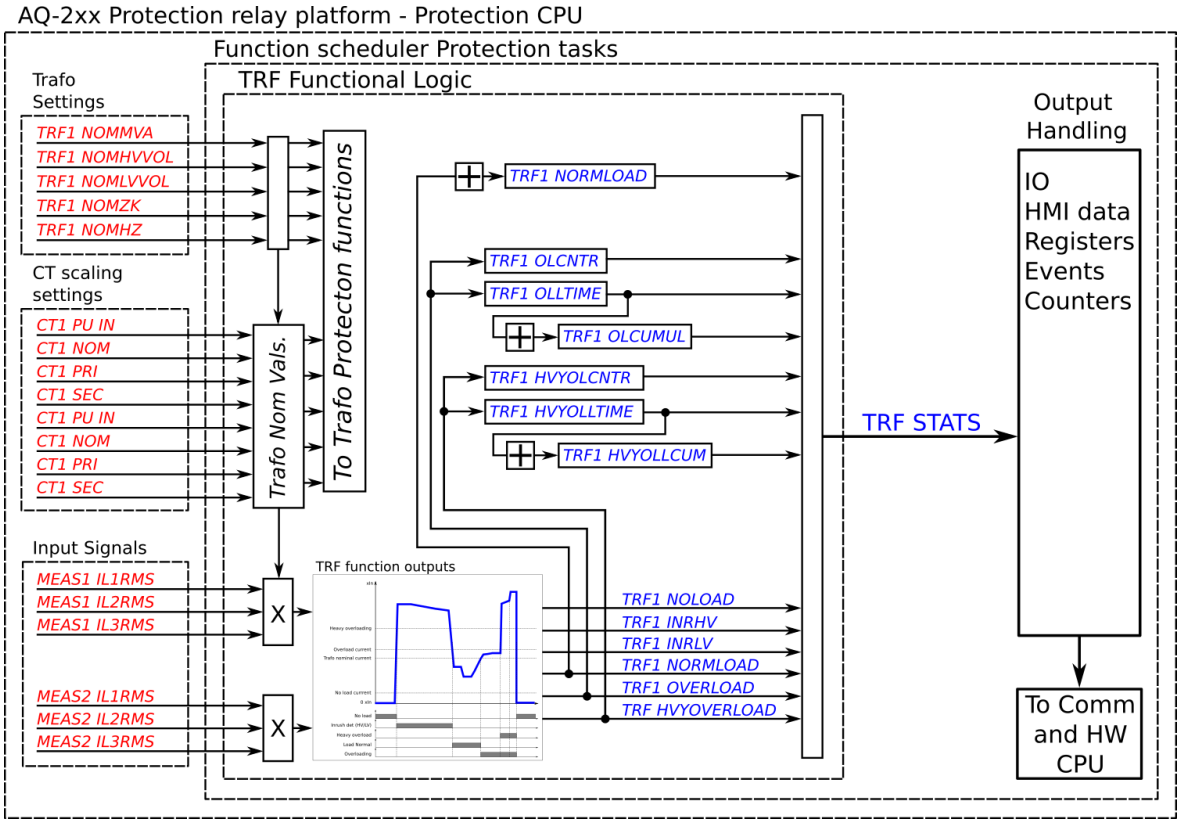
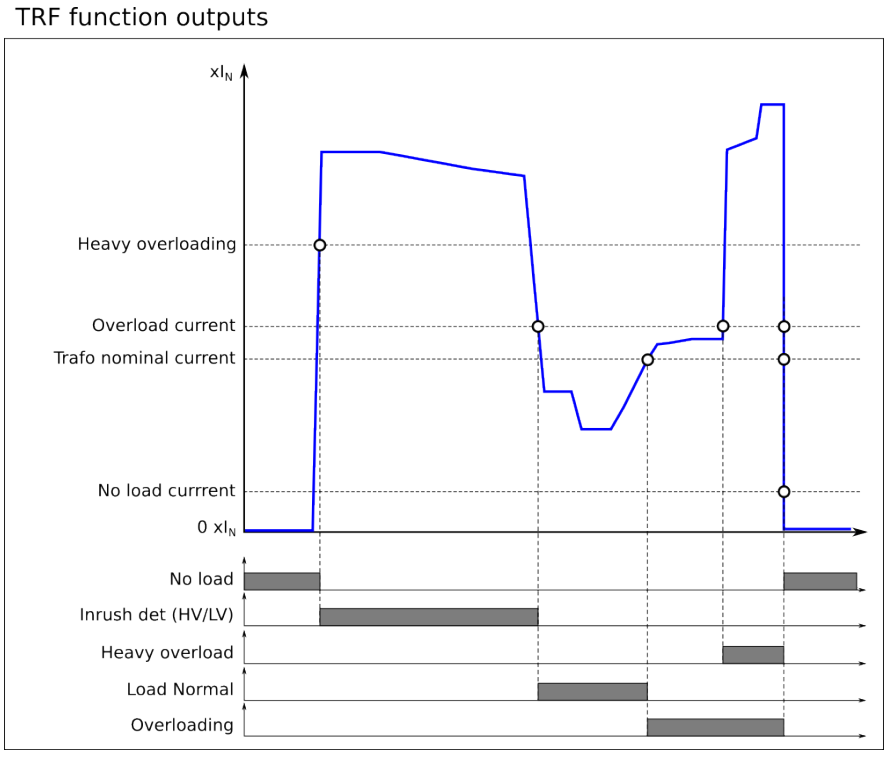
Figure. 5.4.8 - 44. Simplified function block diagram of the transformer status monitoring function.




The function's outputs are dependent on the set transformer data because the measured currents (in p.u.) are related to the transformer nominal values. The following diagram presents the function's outputs in various situations.

Figure. 5.4.8 - 45. Activation of the function's outputs.



The *No load* signal is activated when the current dips below the "No load current" limit (= 0.2 x $I_n$)" for longer than ten milliseconds. If the current increases from this situation up to the "Heavy overloading" limit (> 1.3 x $I_n$), the *HV inrush detection* and *LV inrush detection* signals are activated. If the measured current is between the "No load current" limit and the "Nominal current" limit, the *Load normal* signal is activated. If the measured current is between the "Nominal" and the "Heavy overloading" currents, the *Overloading* signal is activated.

These signals can be used for multiple purposes: information, transformer-related logics, and monitoring. A constant, long-lasting heavy overloading can cause oil ageing in the transformer, and thus more frequent maintenance is recommended to prevent possible problems in the transformer.

## Settings and signals

The settings of the transformer status monitoring function are mostly shared with other transformer protection functions in the transformer module of the device. The following table shows these other functions that also use these settings.

Table. 5.4.8 - 73. Settings of the transformer status monitoring function and how they are shared by other protection functions.

| Name | Range | Step | Default | Functions | Description |
|---|---|---|---|---|---|
| TRF LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | 1: On | - | Set mode of MST block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TRF LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | - | - | Displays the mode of MST block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TRF force status to | 0: NoForce<br>1: Light/Noload<br>1: HV inrush<br>2: LV inrush<br>3: Normload<br>4: Overload<br>5: High Overload | - | 0: NoForce | - | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Transformer nominal | 0.1...500.0MVA | 0.1MVA | 1.0MVA | All | The nominal MVA of the transformer. This value is used to calculate the nominal currents onf both the HV and the LV side. |
| HV side nominal voltage | 0.1…500.0kV | 0.1kV | 110.0kV | All | The HV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the HV side. |
| LV side nominal voltage | 0.1…500.0kV | 0.1kV | 110.0kV | All | The LV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the LV side. |
| Transformer Zk% | 0.01…25.00% | 0.01% | 3.00% | Info | The transformer's short-circuit impedance in percentages. Used for calculating short-circuit current. |
| Transformer nom. freq. | 10…75Hz | 1Hz | 50Hz | Info | The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance. |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| Name | Range | Step | Default | Functions | Description |
|---|---|---|---|---|---|
| Transf. vect. group | 0: Manual set<br>1: Yy0<br>2: Yyn0<br>3: YNy0<br>4: YNyn0<br>5: Yy6<br>6: Yyn6<br>7: YNy6<br>8: YNyn6<br>9: Yd1<br>10: YNd1<br>11: Yd7<br>12: YNd7<br>13: Yd11<br>14: YNd11<br>15: Yd5<br>16: YNd5<br>17: Dy1<br>18: Dyn1<br>19: Dy7<br>20: Dyn7<br>21: Dy11<br>22: Dyn11<br>23: Dy5<br>24: Dyn5<br>25: Dd0<br>26: Dd6 | - | 1: Yy0 | - transformer status monitoring<br>- transformer differential | The selection of the transformer's vector group. The selection values (1–26) are predefined so that the scaling and vector matching are applied in the relay automatically when the correct vector group is selected.<br><br>The predefinitions assume that the HV side is connected to the CT1 module and that the LV side is connected to the CT2 module.<br><br>If the protected transformer vector group is not found in the predefined list, it can be manually set by selecting the option "0: Manual set". |
| HV side Star or Zigzag / Delta | 0: Star/Zigzag<br>1: Delta | - | 0: Star/ Zigzag | - transformer status monitoring<br>- transformer differential | The selection of the HV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV side earthed | 0: Not earthed<br>1: Earthed | - | 0: Not earthed | - transformer status monitoring<br>- transformer differential | The selection of whether or not the zero sequence compensation is applied in the HV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV side lead or lag LV | 0: Lead<br>1: Lag | - | 0: Lead | - transformer status monitoring<br>- transformer differential | The selection of whether the HV side leads or lags the LV side. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side Star or Zigzag / Delta | 0: Star/Zigzag<br>1: Delta | - | 0: Star/ Zigzag | - transformer status monitoring<br>- transformer differential | The selection of the LV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side earthed | 0: Not earthed<br>1: Earthed | - | 0: Not earthed | - transformer status monitoring<br>- transformer differential | The selection of whether or not the zero sequence compensation is applied in the LV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side lead or lag HV | 0: Lead<br>1: Lag | - | 0: Lead | - transformer status monitoring<br>- transformer differential | The selection of whether the LV side leads or lags the HV side. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV-LV side phase angle | 0.0...360.00deg | 0.1deg | 0.0deg | - transformer status monitoring<br>- transformer differential | The angle correction factor for HV/LV sides, looked from the HV side. E.g. if the transformer is Dy1, this is set to 30 degrees. The selection is visible only if the option "Manual set" is selected for the vector group setting. |

| Name | Range | Step | Default | Functions | Description |
|---|---|---|---|---|---|
| HV-LV side mag correction | 0.0…100.0x$I_n$ | 0.1x$I_n$ | 0.0x$I_n$ | - transformer status monitoring<br>- transformer differential | The magnitude correction for the HV-LV side currents (in p.u.), if the currents are not directly matched through the calculations of the nominal values. The selection is visible only if the option "Manual set" for the vector group setting. |
| Check online HV-LV configuration | 0: -<br>1: Check | - | 0: - | - transformer status monitoring<br>- transformer differential | The selection of whether or not the function checks the current going through the transformer and then compares it to the settings. For this to work, the transformer needs to have a current flowing on both sides and "see" no faults. The selection is visible only if the option "Manual set" is selected for the vector group setting. |

Table. 5.4.8 - 74. Calculations of the transformer status monitoring function.

| Name | Range | Step | Default | Functions | Description |
|---|---|---|---|---|---|
| HV side nominal current (pri) | 0.01...50 000.00A | 0.01A | 0.00A | Info | The calculated primary current of the transformer's HV side primary current. |
| HV side nominal current (sec) | 0.01…250.00A | 0.01A | 0.00A | Info | The calculated primary current of the transformer's HV side secondary current. |
| HV CT nom. to TR nom. factor | 0.01…250.00p.u. | 0.01p.u. | 0.00p.u. | Info | The transformer's HV side calculated nominal to the CT primary rate. |
| LV side nominal current (pri) | 0.01…50 000.00A | 0.01A | 0.00A | Info | The calculated primary current of the transformer's LV side primary current. |
| LV side nominal current (sec) | 0.01…250.00A | 0.01A | 0.00A | Info | The calculated primary current of the transformer's LV side secondary current. |
| LV CT nom. to TR nom. factor | 0.01…250.00p.u. | 0.01p.u. | 0.00p.u. | Info | The transformer's LV side calculated nominal to the CT primary rate. |
| Transformer nom. impedance | 0.01…250.00Ω | 0.01Ω | 0.00Ω | Info | The calculated nominal impedance of the transformer. |
| Transformer nom. Zk | 0.01…250.00Ω | 0.01Ω | 0.00Ω | Info | The calculated nominal short-circuit impedance of the transformer. |
| Transformer nom. SC inductance | 0.001…250.000µH | 0.01µH | 0.000µH | Info | The calculated nominal short-circuit inductance of the transformer. |
| Transformer ratio | 0.01…250.00 | 0.01 | 0.00 | Info | The transformer's calculated ratio (= HV/LV). |
| LV side max. 3ph SC curr. | 0.001…500.000kA | 0.001kA | 0.000kA | Info | The calculated maximum three-phase short-circuit current in the LV poles of the transformer. |
| LV side 3ph SC to HV side | 0.001…500.000kA | 0.001kA | 0.000kA | Info | Shows how the calculated maximum three-phase short-circuit current in the LV side is seen in the HV side. |
| LV side max. 2ph SC curr. | 0.001…500.000kA | 0.001kA | 0.000kA | Info | The calculated maximum two-phase short-circuit current in the LV poles of the transformer. |
| LV side 2ph SC to HV side | 0.001...500.000kA | 0.001kA | 0.000kA | Info | Shows how the calculated maximum two-phase short-circuit current in the LV side is seen in the HV side. |



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Table. 5.4.8 - 75. Output signals of the transformer status monitoring function.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| No/Light load | 0: Not active 1: Active | 1 | 0: Not active | The signal is active, when the function detects a current below the "No load current" limit. This signal presents a situation where there is a very light load, or only one or no side of the transformer is energized. |
| HV side inrush detected | 0: Not active 1: Active | 1 | 0: Not active | The signal is active, when the detected current rises above the "High overcurrent" limit in the HV side. |
| LV side inrush detected | 0: Not active 1: Active | 1 | 0: Not active | The signal is active, when the detected current rises above the "High overcurrent" limit in the LV side. |
| Load normal | 0: Not active 1: Active | 1 | 0: Not active | The signal is active when the measured current is below the "Nominal current" but above the "No load current" limit. |
| Overloading | 0: Not active 1: Active | 1 | 0: Not active | The signal is active, when the measured current is between the "Nominal current" and the "High overcurrent" limits. |
| Heavy overloading (HVY overloading) | 0: Not active 1: Active | 1 | 0: Not active | The signal is active, when the measured current is above the "High overcurrent" limit. |

## Events

The transformer status monitoring function (abbreviated "TRF" in event block names) generates events from the detected transformer energizing status. The data register is available, based on the events.

Table. 5.4.8 - 76. Event messages.

| Event block name | Event names |
|---|---|
| TRF1 | Light/No load ON |
| TRF1 | Light/No load OFF |
| TRF1 | HV side inrush ON |
| TRF1 | HV side inrush OFF |
| TRF1 | LV side inrush ON |
| TRF1 | LV side inrush OFF |
| TRF1 | Load normal ON |
| TRF1 | Load normal OFF |
| TRF1 | Overloading ON |
| TRF1 | Overloading OFF |
| TRF1 | High overload ON |
| TRF1 | High overload OFF |
| TRF1 | Setting changes, calculating new transformer data |
| TRF1 | Calculation finished, possible restart |

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. 5.4.8 - 77. Register content.

| Date and time | Event | HV L1 current | HV L2 current | HV L3 current | LV L1 current | LV L2 current | LV L3 current |
|---|---|---|---|---|---|---|---|
| dd.mm.yyyy hh:mm:ss.mss | Event name | HV side's Phase L1 current x $I_n$ | HV side's Phase L2 current x $I_n$ | HV side's Phase L3 current x $I_n$ | LV side's Phase L1 current x $I_n$ | LV side's Phase L2 current x $I_n$ | LV side's Phase L3 current x $I_n$ |

## 5.4.9 Transformer thermal overload protection (TT>; 49T)

The transformer thermal overload protection function is used for monitoring and protecting thermal capacity in power transformers.

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:

$$\theta_{t\%} = \left( \left( \theta_{t-1} - \left( \frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \times e^{-\frac{t}{\tau_1/\tau_2}} \right) + \left( \frac{I_{MAX}}{I_N \times k_{SF} \times k_{AMB}} \right)^2 \right) \times 100\%$$

Where:

- $\theta_{t\%}$ = Thermal image status, percentage of the maximum available thermal capacity
- $\theta_{t-1}$ = Thermal image status, 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 (pick-up current in p.u., $t_{max}$ achieved in τ x 5)
- $k_{SF}$ = Loading factor (service factor), maximum allowed load current (in p.u.) value, dependent on the protected object or cable/line installation
- $k_{amb}$ = Temperature correction factor, either from a linear approximation or from a settable ten-point thermal capacity curve
- t = Calculation time step (0.005 s)
- e = Euler's number
- $\tau_1$ = Thermal heating time constant of the protected object (in minutes)
- $\tau_2$ = Thermal heating 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.


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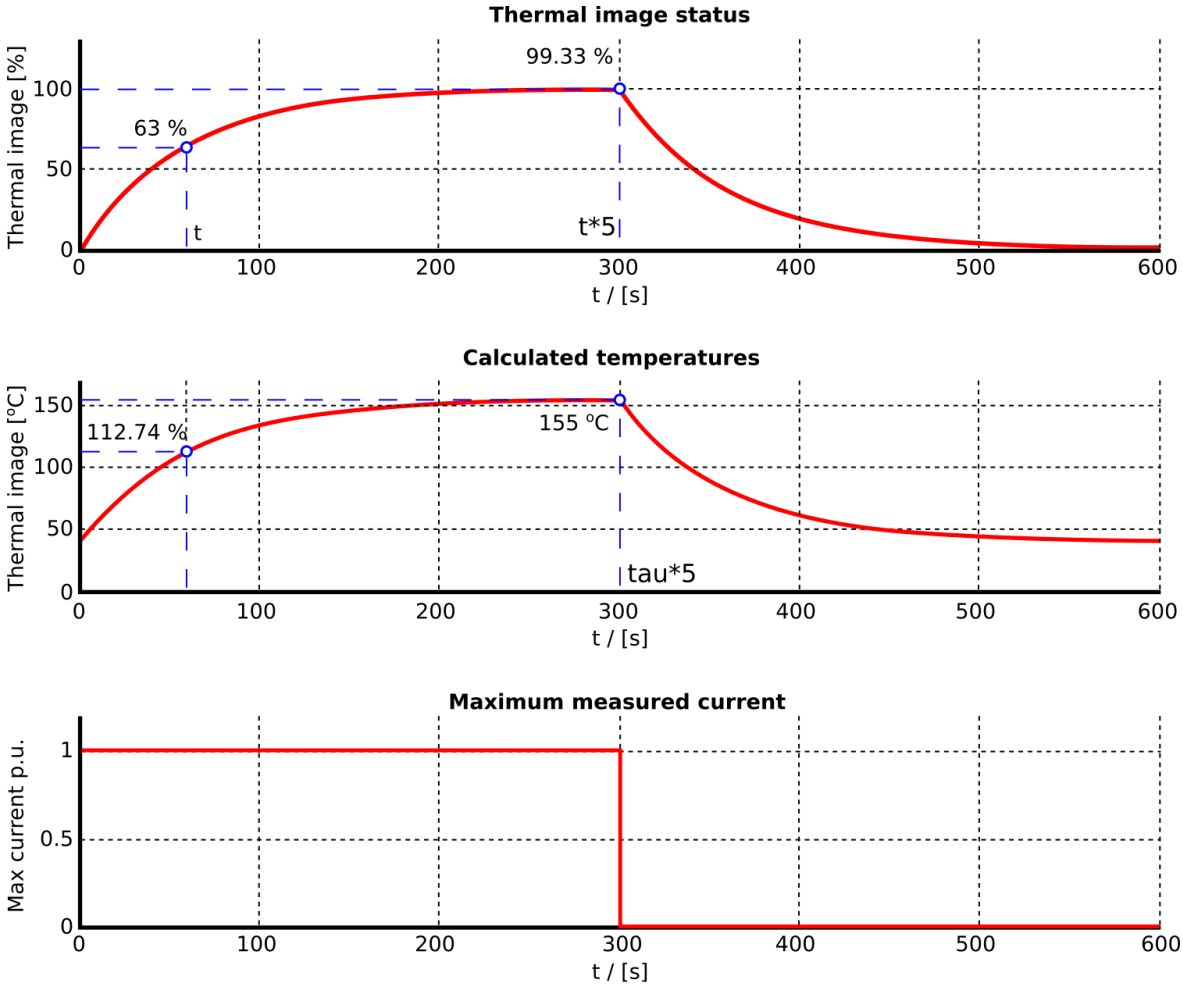
Figure. 5.4.9 - 46. Example of thermal image calculation with nominal conditions.




**Settings**

| | |
|---|---|
| $I_N$ = 1.00 p.u. | Max. temperature rise = 115 °C |
| Qt-1 = 0.01 % | Ambient temperature = 40 °C |
| tau = 1 minutet | Max end temperature = 155 °C |
| Service factor = 1.00 | Temperature k factor = 1.00 |

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:

$$t_{Amb<t_{min}} = k_{min}$$

$$t_{Amb<t_{ref}} = \left(\frac{1 - k_{min}}{t_{ref} - t_{min}} \times (t_{AMB} - t_{min})\right) + k_{min}$$

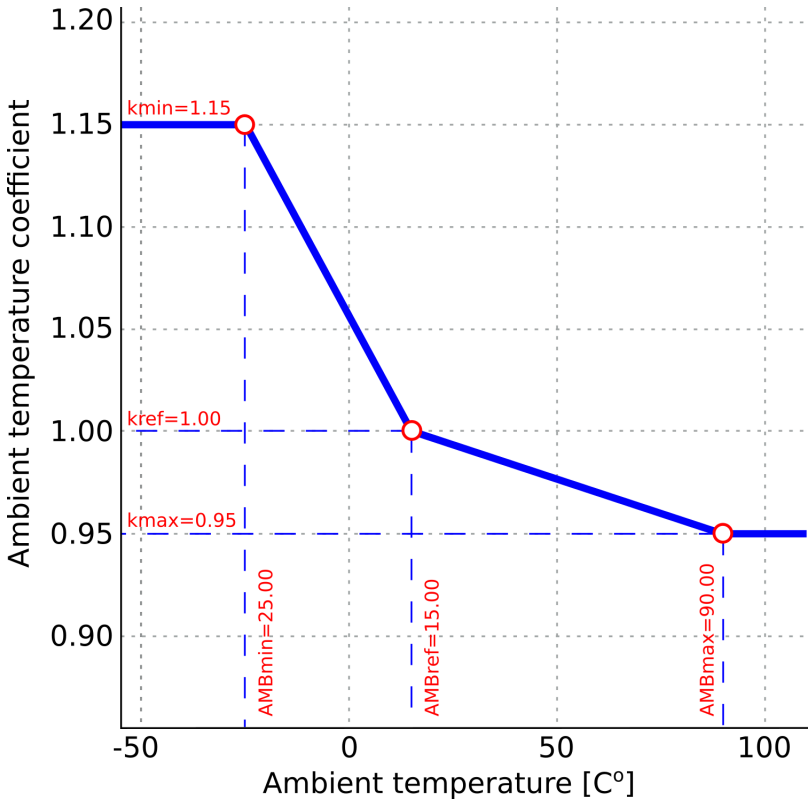
$$t_{Amb>t_{ref}} = \left(\frac{k_{max} - 1}{t_{max} - t_{ref}} \times (t_{AMB} - t_{ref})\right) + 1.0$$

$$t_{Amb>t_{max}} = k_{max}$$

Where:

- $t_{amb}$ = Measured (set) ambient temperature (can be set in ℃ or ℉)
- $t_{max}$ = Maximum temperature (can be set in ℃ or ℉) for the protected object
- $k_{max}$ = Ambient temperature correction factor for the maximum temperature
- $t_{min}$ = Minimum temperature (can be set in ℃ or ℉) for the protected object
- $k_{min}$ = Ambient temperature correction factor for the minimum temperature
- $t_{ref}$ = Ambient temperature reference (can be set in ℃ or ℉, the temperature in which the manufacturer's temperature presumptions apply, the temperature correction factor is 1.0)

Figure. 5.4.9 - 47. Ambient temperature coefficient calculation (a three-point linear approximation and a settable correction curve).




## 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.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The function's outputs are 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
- comparator
- block signal check
- output processing.

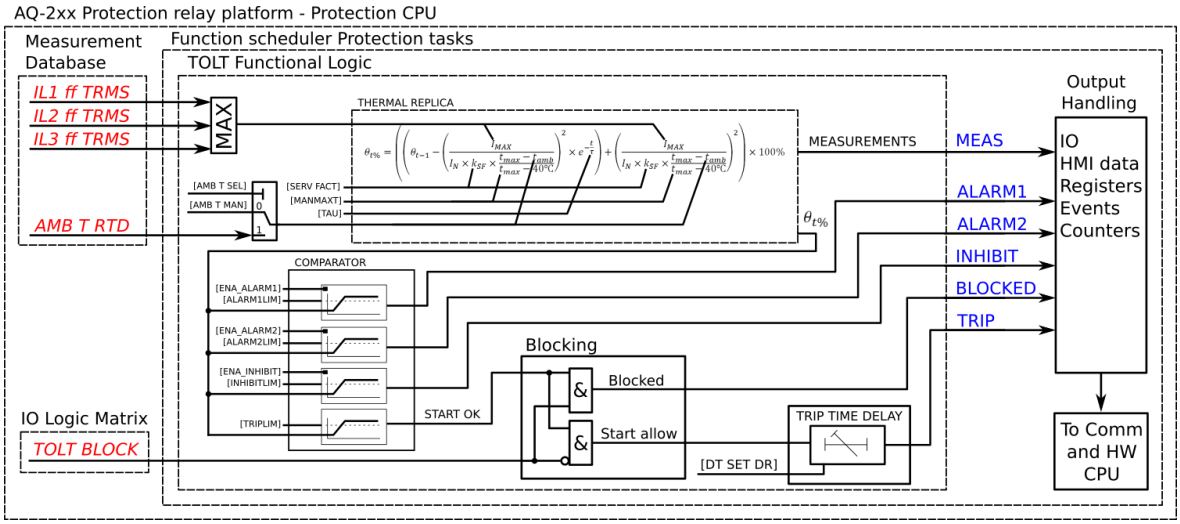
The inputs for the function are the following:

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

The function's 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 transformer thermal overload protection function.

Figure. 5.4.9 - 48. Simplified function block diagram of the TT> 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. 5.4.9 - 78. Measurement inputs of the TT> function.

| Signal | Description | Time base |
|---|---|---|
| IL1TRMS | TRMS measurement of phase L1 (A) current | 5 ms |
| IL2TRMS | TRMS measurement of phase L2 (B) current | 5 ms |
| IL3TRMS | TRMS measurement of phase L3 (C) current | 5 ms |
| RTD | Temperature measurement for the ambient correction | 5 ms |

Table. 5.4.9 - 79. General settings (not selectable under setting groups)

| Name | Range | Default | Description |
|---|---|---|---|
| TT> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | 1: On | Set mode of TOLT block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TT> 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. |
| TT> 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. 5.4.9 - 80. 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 $\tau$ x 5). |
| tau h (t const) | 0.1…500.0min | 0.1min | 10.0min | The $\tau_h$ time constant setting. This time constant is used for the heating of the protected object. |
| tau c (t const) | 0.1…500.0min | 0.1min | 10.0min | The $\tau_c$ time constant setting. This time constant is used for the cooling of the protected object. |
| $k_{SF}$ (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 or the device. 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. 5.4.9 - 81. 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. |



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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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.

Table. 5.4.9 - 82. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Enable TT> Alarm 1 | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 1 signal and the I/O. |
| TT> Alarm 1 level | 0.0…150.0% | 0.1% | 40% | ALARM 1 activation threshold. |
| Enable TT> Alarm 2 | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the ALARM 2 signal and the I/O. |
| TT> Alarm 2 level | 0.0…150.0% | 0.1% | 40% | ALARM 2 activation threshold. |
| Enable TT> Rest Inhibit | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the INHIBIT signal and the I/O. |
| TT> Inhibit level | 0.0…150.0% | 0.1% | 80% | INHIBIT activation threshold. |
| Enable TT> Trip | 0: Disabled<br>1: Enabled | - | 0: Disabled | Enabling/disabling the TRIP signal and the I/O. |
| TT> Trip level | 0.0…150.0% | 0.1% | 100% | TRIP activation threshold. |
| TT> 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. |

## Function blocking

he 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:


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Table. 5.4.9 - 83. General status codes.

| Name | Range | Description |
|---|---|---|
| TT> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/ Blocked<br>5: Off | Set mode of TOLT block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| TT> 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. |
| TT> 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. |
| TT> 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. |
| TT> 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. |
| TT> 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. 5.4.9 - 84. 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. |

| Name | Range | Description/values |
|---|---|---|
| Thermal image | 0: Thermal image calc. | - TT> Trip expect mode: No trip expected/Trip expected<br>- TT> Time to 100 % theta: Time to reach the 100 % thermal cap<br>- TT> Rreference T curr.: reference/pick-up value (IEQ)<br>- TT> Active meas. curr.: the measured maximum TRMS current at a given moment<br>- TT> T est. with act. curr.: estimation of the used thermal capacity including the current at a given moment<br>- TT> T at a given moment: the thermal capacity used at that moment |
| | 1: Temp. estimates | - TT> Used k for amb. temp: the ambient correction factor at a givenmoment<br>- TT> Max. temp. rise all.: the maximum allowed temperature rise<br>- TT> Temp. rise atm: the calculated temperature rise at a given moment<br>- TT> Hot spot estimate: the estimated hot spot temperature including the ambient temperature<br>- TT> Hot spot max. all.: the maximum allowed temperature for the object |
| | 2: Timing status | - TT> Trip delay remaining: the time to reach 100% theta<br>- TT> Trip time to rel.: the time to reach theta while staying below the trip limit during cooling<br>- TT> Alarm 1 time to rel.: the time to reach theta while staying below the Alarm 1 limit during cooling<br>- TT> Alarm 2 time to rel.: the time to reach theta while staying below the Alarm 2 limit during cooling<br>- TT> Inhibit time to rel.: the time to reach theta while staying below the Inhibit limit during cooling |

Table. 5.4.9 - 85. 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 "TOLT" 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. 5.4.9 - 86. Event messages.

| Event block name | Event names |
|---|---|
| TOLT1 | Alarm1 ON |
| TOLT1 | Alarm1 OFF |
| TOLT1 | Alarm2 ON |
| TOLT1 | Alarm2 OFF |
| TOLT1 | Inhibit ON |
| TOLT1 | Inhibit OFF |
| TOLT1 | Trip ON |
| TOLT1 | Trip OFF |
| TOLT1 | Block ON |


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| Event block name | Event names |
|---|---|
| TOLT1 | 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, BLOCKED, etc. signals. The table below presents the structure of the function's register content.

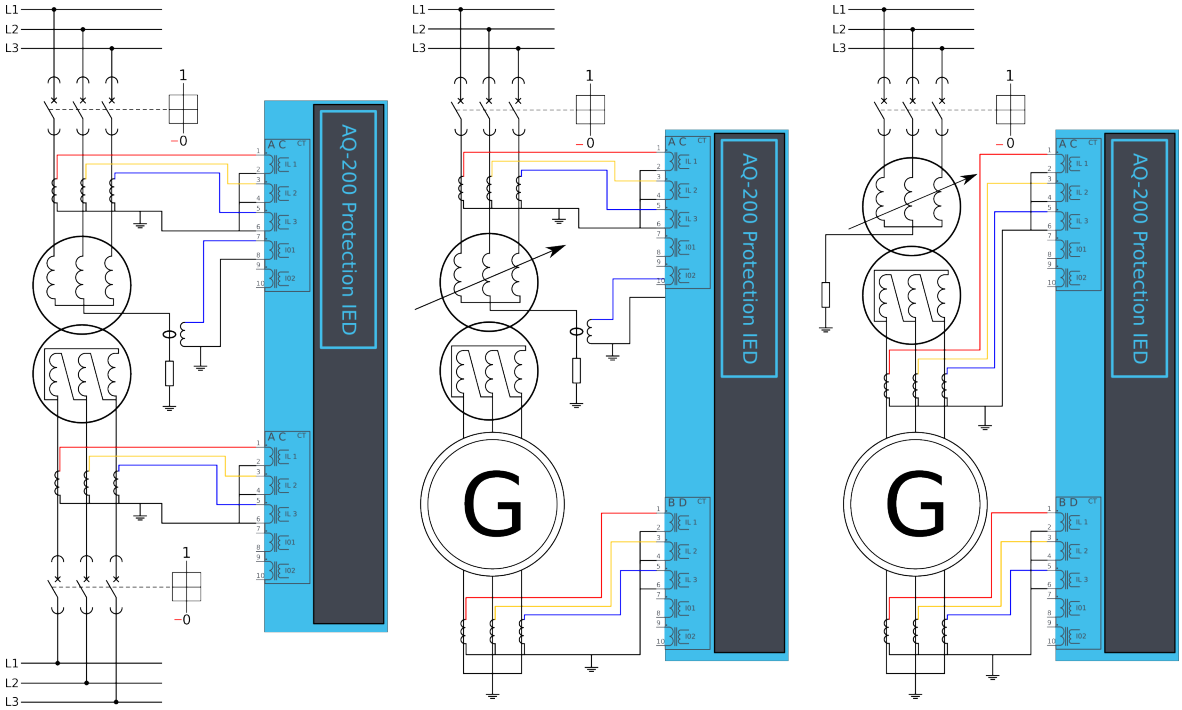
Table. 5.4.9 - 87. Register content.

| 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 |

## 5.4.10 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G)

The generator/transformer differential function is used for protecting the following power transformers: two-winding transformers, and to some extent three-winding and two-winding transformers that have double outputs and a summing application. This function can also be used for protecting generators.

Figure. 5.4.10 - 49. Differential protection function can be used for protecting transformers, generators and both at the same time.




Power transformers are seen in electric power generation, transmission, and distribution. They are also part of application networks for a wide range of purposes (eg. power and voltage levels). The most common use for a transformer is (as the name implies) to transform alternating voltage from one voltage level to another. What is common for all transformers is that they are a crucial and one of the most important single components in a network because a transformer's failure affects a wide area in the network. While transformers do not have many moving parts (apart from tap changers), their electric and mechanical properties are far from being simple.

When designing transformer protection it is usual to consider the transformer's usage as well as the power level it transforms. This is because the economical aspect becomes more significant as the size of the transformer increases, and the applied protection should be in line with the cost of the transformer. For example, there is little point in installing a high-level multifunction transformer device into a distribution transformer of a few kVA that feeds a handful of farms in a rural area network. Similarly, it is pointless to have nothing but fuses protecting a transmission transformer of a few hundred MVA that feeds entire cities.

When designing transformer protection one should consider which protection elements are needed to apply sufficient protection. The following table gives a rough idea what protection methods and elements as well as risks exist for the different types of transformers. Overlooking these points when designing transformers increase the risk of costly problems with the transformer.

| Transformer | Risk level | Protection |
|---|---|---|
| Pole-mounted <100 kVA transformer.<br><br>Distribution. | Risks are mostly environmental; the most common issue is a lightning hitting an overhead line. A broken device can be switched to a new one within hours. Relatively cheap. | Protection includes feeder overcurrent and earth fault protection. No separate protection devices are normally applied. |



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| Transformer | Risk level | Protection |
|---|---|---|
| <500 kVA transformer in industrial use, installation indoors.<br><br>Distribution, applications. | The biggest risk is overloading; cooling can be an issue if the environmental conditions are difficult. A broken device can be replaced with a new one within hours. Possible fault extension to other parts of the network or to building should be reduced. Relatively cheap. | Protection includes feeder overcurrent and earth fault protection. Fuses are used to limit the possible short-circuit current. |
| 500kVA...2 MVA<br><br>Distribution, applications, motors, small generators. | Risks include overloading, overvoltage, transients, and cooling. Replacing a broken device is costly, so fixing might be the better option if a fault occurs. It is important to monitor the device as the cost of fixing failures is probably higher than the cost of monitoring. | Protection includes overcurrent and earth fault protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with winding temperature monitors. Fuses could be considered for limiting the short-circuit current.<br><br>If the transformer is oil-insulated, oil level monitoring should be applied. |
| 2MVA...100 MVA<br><br>Distribution, generation, sub transmission <130 kV. | Risks include overloading, overvoltage, transients, cooling, and environmental issues. Replacing a broken device is problematic as the process is difficult and normally takes the network off-line for a long time. The device is relatively expensive. Its failure affects a wide area regardless of where it is installed (transmission, distribution, generation). Monitoring, clearing faults quickly, and limiting the device's internal fault time are all very important. | Includes the following protections: differential, overcurrent and earth fault protection, backup overcurrent and earth fault protection, tap changer protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with numerical and winding temperature monitors.<br><br>If the transformer is oil-insulated, oil level monitoring should be applied in addition to monitoring of loading and oil-ageing estimations.<br><br>If the transformer has forced cooling, monitoring and protection for cooling systems should be applied.<br><br>Multifunction relays need protections and monitoring; dedicated relays require backup overcurrent and earth fault protections. |
| >100 MVA<br><br>Transmission > 130 kV | Risks include overloading, overvoltage, transients, cooling, and environmental issues. Replacing a broken device is problematic as the process is difficult and normally takes the network off-line for a long time. The device is extremely expensive. Its failure affects a wide area regardless where it is installed (transmission, distribution, generation). Monitoring, clearing faults quickly, and limiting the device's internal fault time are all very important. | Includes the following protections: redundant differential overcurrent and earth fault protection, redundant backup overcurrent and earth fault protection, tap changer protection, a dedicated pressure guard (Buchholz gas relay), overloading protection with numerical and redundant winding temperature monitors.<br><br>Oil level monitor should be applied, as well as monitoring of loading and oil-ageing estimations.<br><br>If the transformer has forced cooling, monitoring and protection for cooling systems should be applied.<br><br>Separated relays for control, monitoring and protection. |

There are many transformer faults, e.g. dirty, watered or old transformer oil, oil leakage from the tank, as well as multiple, prolonged heavy overloading and other faults in the cooling systems. These can cause earth faults, interturn faults or even phase-to-phase faults in the windings of the transformer.

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## Why is differential protection needed in transformer protection?

The transformer differential function is based on calculating the difference between the ingoing and outgoing currents. If the operating status is normal, all power that comes in also goes out. If this is not the case, the transformer has an internal fault and the device should be de-energized as soon as possible to avoid extensive damage to the transformer. An operating differential function takes a faulty transformer off-line for a long time. A quick de-energizing of the fault saves money because in most cases the transformer can still be repaired which is significantly cheaper than replacing the broken device with a new one. However, there are some exceptions to this. Faults that occur within the differential protection zone but without the transformer itself (such as in the bus or in the cables connected to the transformer). Faults of this type are easily repaired and the transformer can be re-energized soon after the fault has bee cleared.

If a transformer is protected only by conventional overcurrent and earth-fault protections, the operating time should be set in coordination with the low-voltage side protection relays to ensure selectivity. Therefore, transformer protection should be set to delayed operation (not instant) so that the low-voltage side relays can operate before transformer protection. This is necessary because under normal conditions the transformer's energizing and its short-circuit supply to the high or low voltage side is seen directly on both sides of the transformer. An overcurrent protection with instant operation causes problems with timing coordination or sensitivity, especially if the instant protection is set on high-current starting criteria. However, this is not a significant issue with smaller transformers as the installation and maintenance of various differential protections is considered more expensive than not having full protection.

Differential protection is very sensitive and it is scaled internally to the loading and fault current flowing through the transformer. For example, an interturn fault in the transformer's windings could go entirely unnoticed by an overcurrent relay while a differential relay could trip it in the very first power cycle. The same goes for internal earth faults: they can be impossible for conventional earth fault protection to notice until the fault causes heavier fault currents (such as when the fault location is close to the neutral side inside the star winding).

These are the main arguments for using differential protection: they are sensitive, their operation in internal in-zone faults is fast, and they have a high stability for out-zone faults. These guarantee a minimum of unwanted power outages as well as minimized and reduced damage to the transformer itself. On the other hand, differential protection has its negative properties: it is not very easy to set up to operate correctly, and it requires a second set of current transformers which increases installation costs. However, this cost is marginal in larger scale power transformers.

The following chapter explains the principles of transformers. It also shows how how to set the differential protection correctly for the example application.

## Transformer properties and basic concepts for differential protection

Setting the differential protection requires some intial data of the transformer to be known. At minimum, the following data needs to be available:

- the transformer's nominal power
- the nominal voltages of both the HV and LV sides
- the transformer's special properties, such as tap changer and auxiliary windings
- the transformer's vector group (for matching the transformer vectors in p.u.)
- the ratios and properties of the transformers HV and LV sides.

This chapter shows the setting and the principle of transformer differential protection step by step.


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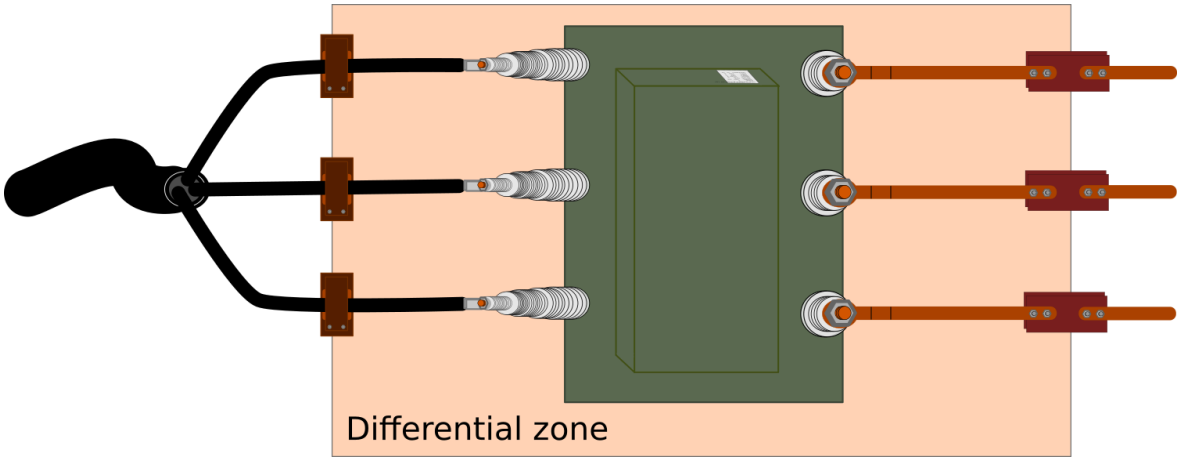
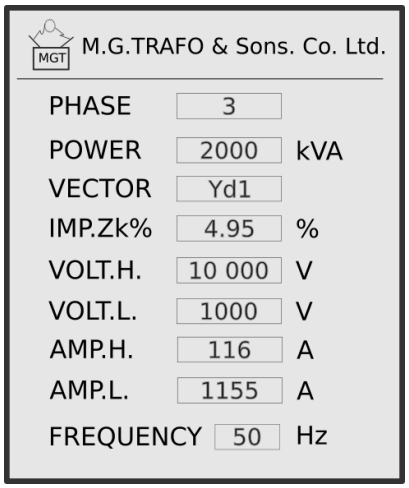
Figure. 5.4.10 - 50. Transformer and its components forming the differential zone.




The differential protection area is the area between the current transformers. This is called the differential zone which means that the currents going in from one side must come out from the other side. This is true whether the signal is scaled higher or lower, or whether the phase angle is shifted. Unless both side currents match there is a problem within the protected zone which either blocks or keeps the current inside the zone.

The image below shows what a typical transformer name plate looks like, what data it includes and what to do with it.

Figure. 5.4.10 - 51. Transformer name plate data.




According to the data on this example name plate, this transformer is designed for three-phase usage and therefore it has two windings. The nominal power of the transformer is 2 MVA. Its vector group is Yd1: this means that the high-voltage side is connected to the Y and the low-voltage side to the delta, resulting in the LV side having a 30-degree lag in relation to the HV side. Additionally, the HV side's nominal voltage is 10 kV and its amperage is 116 A, on the LV side the nominal voltage is 1kV and its amperage is 1.155 kA. The transformer's short-circuit impedance is 4.95 %; it is based on the transformer's final test and presents how much short-circuit current the transformer is able to feed. The transformer's frequency is 50 Hz. This kind of information is usually available in a transformer's name plate and documentation. If the transformer has a tap changer, its information is usually also available in the name plate data.

Nominal current matching is the first thing to consider in differential protection. Usually a modern numerical protection relay can calculate these factors itself as long as the transformer's nominal power and voltage levels are known. However, if one feels inclined to calculate the amplitude matching factor, they can do so with the formulas presented below.

For this example, let us say we want to do these calculation for the transformer whose name plate we have in the image above. Let us further say the HV side current transformers are 150/5 A and the LV side current transformers are 1200/5 A. The primary side factor (p.u.) and current are then calculated as follows:

$$I_{n,HV} = \frac{S_n}{\sqrt{3} \times U_{HV}} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times 10\ 000\ \text{V}} = 115.47\ \text{A}$$

$$I_{pu,pri,HV} = \frac{I_{n,HV}}{CT_{pri,HV}} = \frac{115.47\ \text{A}}{150\ \text{A}} = 0.77$$

$$I_{pu,sec,HV} = I_{pu,pri,HV} \times CT_{sec,HV} = 0.77 \times 5\ \text{A} = 3.85\ \text{A}$$

Then, the secondary side factor (p.u.) and current are calculated as follows:

$$I_{n,LV} = \frac{S_n}{\sqrt{3} \times U_{LV}} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times 1\ 000\ \text{V}} = 1154.7\ \text{A}$$

$$I_{pu,pri,LV} = \frac{I_{n,LV}}{CT_{pri,LV}} = \frac{1154.7\ \text{A}}{1200\ \text{A}} = 0.96$$

$$I_{pu,sec,LV} = I_{pu,pri,LV} \times CT_{sec,LV} = 0.96 \times 5\ \text{A} = 4.81\ \text{A}$$

The calculations show that if 2 MVA of power go through the transformer the CT's secondary current on the high-voltage side will be 3.85 A and the CT secondary current on the low-voltage side will be 4.81 A. The differential function uses these values to change them into measured currents in per unit. Therefore, it would show 1.0 · $I_n$ for both HV and LV side measurements, eventhough the measured currents are different. This is called amplitude matching of the HV and LV sides. In modern differential relays this is done automatically when the nominal values and CT ratings are set for the transformer. Thus, these calculations only have nice-to-know informational value.


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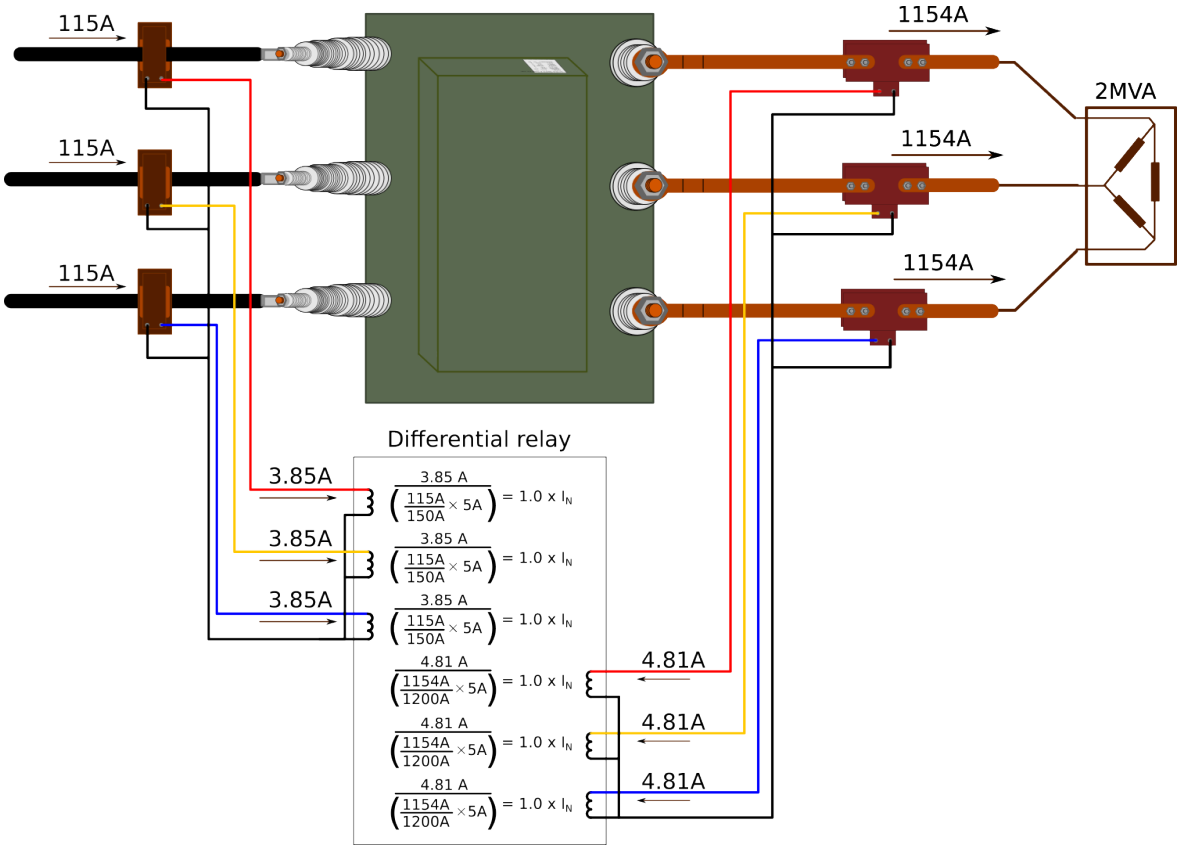
Figure. 5.4.10 - 52. Amplitude scaling to match the nominal currents and CTs in the differential relay.

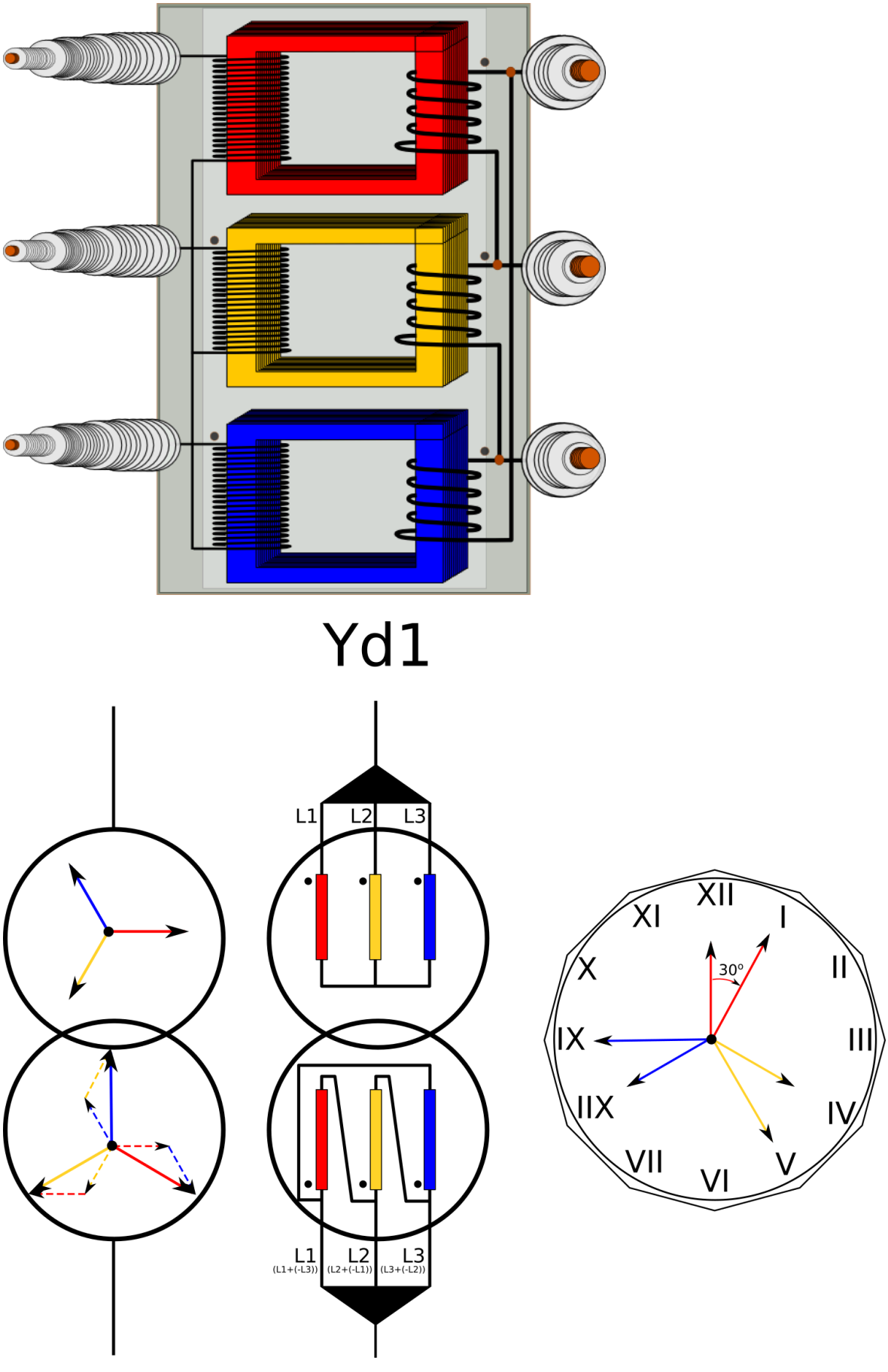



Nominal current matching is only part of the differential protection settings. The vector group of the transformer is also important, since the differential function is interested in the angle difference of the measured current vectors. In this example the transformer's vector group is Yd1, which means that the transformer's HV side is connected to the Y and the LV side to the delta. Therefore, the LV side is in 30-degree lag in relation to the HV side vectors.

The number '1' in the vector group's name comes from the angle in the phase current difference between the HV and the LV side. If one imagines the HV side current's Y placed upside down on the face of a clock (with the Y's leg pointing at 12), the LV side's delta would be pointing at 1. Likewise, '11' means that the LV side is leading 30 degrees; '5' and '7' are just the other ends of the windings thus causing a 180-degree difference between the '1' and '11' clock numbers.

The following example explains transformer current vectors and what a connection might look like.

Figure. 5.4.10 - 53. Yd1 transformer's internal connection (in theory).



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In modern relays these standard vector groups (Y or delta, lead or lag) are defined by a setting selection and there is no need for interposing transformers. Even if the transformer's vector group is not standard it should still be settable within the relay (such as with zigzag transformers).

In this example, the function translates the delta side currents. The correction applies not only to the angles but also to the amplitudes because the delta side (in p.u.) is relative to the amplitude difference with the Y-connected side.

$$\overline{IL1DS_{LV}} = \frac{(\overline{IL1_{LV}} - \overline{IL2_{LV}})}{\sqrt{3}}$$

$$\overline{IL2DS_{LV}} = \frac{(\overline{IL2_{LV}} - \overline{IL3_{LV}})}{\sqrt{3}}$$

$$\overline{IL3DS_{LV}} = \frac{(\overline{IL3_{LV}} - \overline{IL1_{LV}})}{\sqrt{3}}$$

This process is called vector group matching for the currents (in p.u.) of the transformer. This matching is necessary whenever one side is connected to the delta and another to the Y. Previously in non-numerical relays, this matching was done by interposing CTs which connected the power transformer's Y side to the delta, and the transformer's delta side to the Y. This got the HV and LV side vectors to match each other. Then the currents in the relay inputs are summed up. If there is no difference (as the HV and LV side currents negate each other), the pick-up is not triggered. If the currents do have a difference, the current flows to the relay input and with enough difference causes a pick-up and a trip. However, as modern differential relays do this transformation by calculating the corrected vector internally, this is also just nice-to-know information not related to the actual operation of the relay.

Figure. 5.4.10 - 54. Expected phase shifts from HV side to LV side (a symmetrical situation).

| | | Phase angles HV side | | | Phase angles LV side | | |
|---|---|---|---|---|---|---|---|
| | Shift(deg) | IL1 | IL2 | IL3 | IL1" | IL2" | IL3" |
| Yy0, Yyn0, YNy0, Dd0 | 0 | 0 | 240 | 120 | 0 | 240 | 120 |
| Yy6,Yyn6, YNy6, YNyn6, Dd6 | 180 | 0 | 240 | 120 | 180 | 60 | 300 |
| Yd1, YNd1, Dy1, Dyn1 | -30 | 0 | 240 | 120 | 330 | 210 | 90 |
| Yd11, YNd11, Dy11, Dyn11 | 30 | 0 | 240 | 120 | 30 | 270 | 150 |
| Yd5, YNd5, Dy5, Dyn5 | -150 | 0 | 240 | 120 | 210 | 90 | 330 |
| Yd7, YNd7, Dy7, Dyn7 | 150 | 0 | 240 | 120 | 150 | 30 | 270 |

The direction of the CTs' Y legs on the HV and LV sides affects how the differential calculation method is set. The setting options are "add" and "subtract" which is why the CTs' currenct direction has to be taken into account. The "add" mode is used when the CT's starpoints are either pointing towards each other or away from each other. The "subtract" mode is used when those points are pointing in the same direction. In this example the correct setting would be the "add" mode because the CTs in the main circuit are connected to the opposite and thus the measured currents from the CTs are also opposite. The user selects how they want the signals shown: the CTs' currents can be negated with the "subtract" option, resulting in a one Y-connected vector diagram.

The images below present the differential algorithm itself (one calculating formula for each phase difference); first the "subtract" formulas, then the "add" formulas. Selection is based on the CT connections.

Figure. 5.4.10 - 55. "Subtract" formula.

$$L1DIFF_{Subt} = |\overline{IL1_{HV}} - \overline{IL1_{LV}}|$$

$$L2DIFF_{Subt} = |\overline{IL2_{HV}} - \overline{IL2_{LV}}|$$

$$L3DIFF_{Subt} = |\overline{IL3_{HV}} - \overline{IL3_{LV}}|$$

Figure. 5.4.10 - 56. "Add" formula.

$$L1DIFF_{Add} = |\overline{IL1_{HV}} + \overline{IL1_{LV}}|$$

$$L2DIFF_{Add} = |\overline{IL2_{HV}} + \overline{IL2_{LV}}|$$

$$L3DIFF_{Add} = |\overline{IL3_{HV}} + \overline{IL3_{LV}}|$$

Figure. 5.4.10 - 57. CTs' starpoints requiring the "Add" mode.

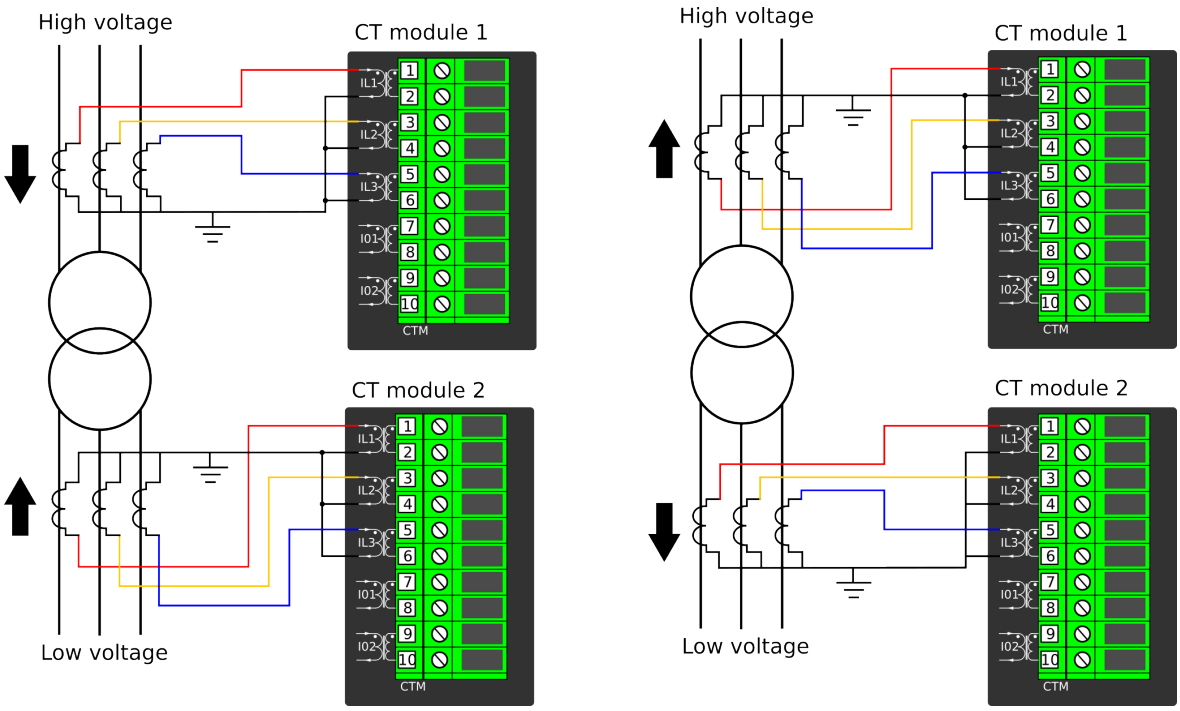




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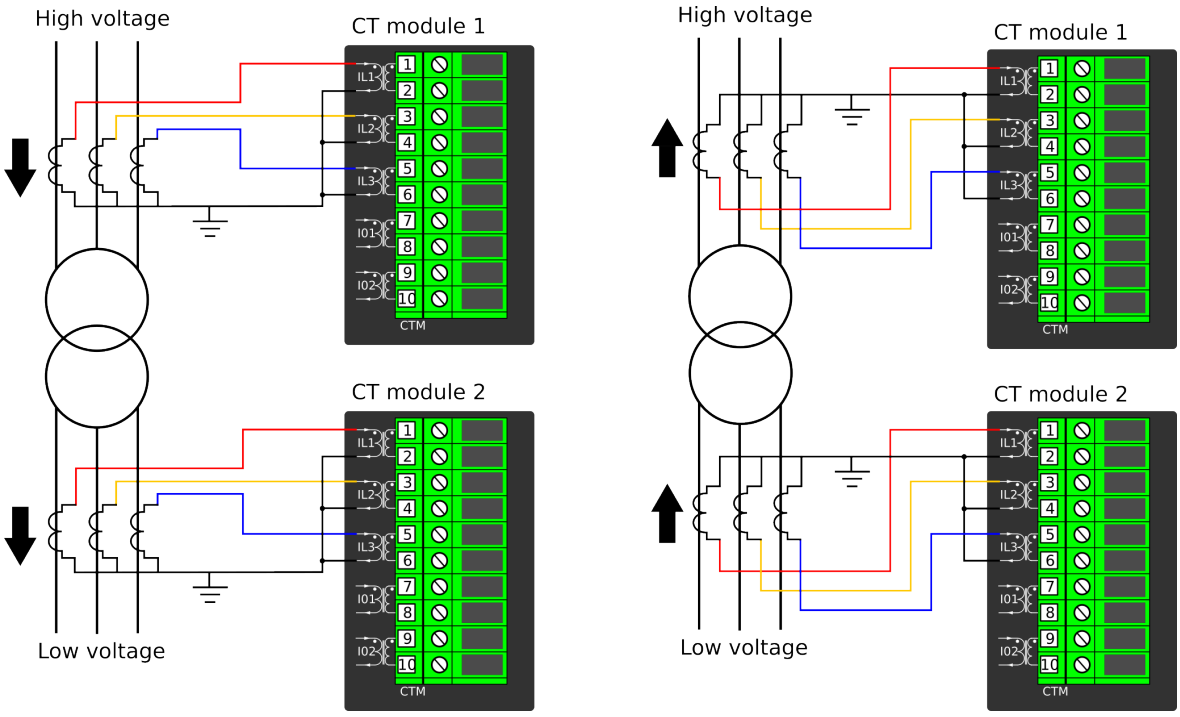
Figure. 5.4.10 - 58. CTs' starpoints requiring the "Subtract" mode.




The differential function has two (2) separate stages built into the function. Non-restraint characteristics use only the "Average mode and Max mode formulas (described below) as the comparison base. Restraint characteristics also make a so-called bias calculation for each of the phases in order to adjust the differential stage towards the measured currents. Bias calculation can be sensitive or coarse (see the following formulas).

Figure. 5.4.10 - 59. Average mode (sensitive biasing).

$$L1BIAS_{AVG} = \frac{|IL1_{HV}| + |IL1_{LV}|}{2}$$

$$L2BIAS_{AVG} = \frac{|IL2_{HV}| + |IL2_{LV}|}{2}$$

$$L3BIAS_{AVG} = \frac{|IL3_{HV}| + |IL3_{LV}|}{2}$$

Figure. 5.4.10 - 60. Max mode (coarse biasing).

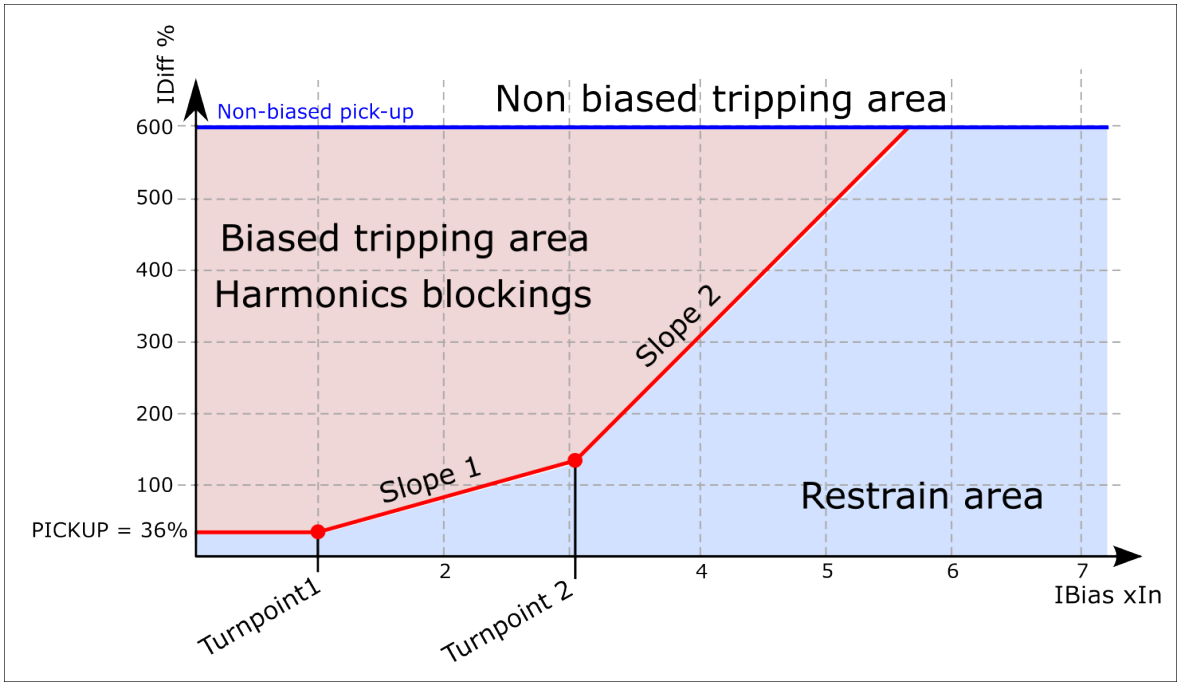
$$L1BIAS_{MAX} = \max\left(|\mathrm{IL1_{HV}}|, |\mathrm{IL1_{LV}}|\right)$$

$$L2BIAS_{MAX} = \max\left(|\mathrm{IL2_{HV}}|, |\mathrm{IL2_{LV}}|\right)$$

$$L3BIAS_{MAX} = \max\left(|\mathrm{IL3_{HV}}|, |\mathrm{IL3_{LV}}|\right)$$

Next, these two formulas are combined in a graph: the x-axis presents the measured differential current, and the y-axis presents the calculated bias current. The following graph shows the differential function characteristic, both biased and non-biased.

Figure. 5.4.10 - 61. Differential function characteristic, biased and non-biased.




The graph is the function of measured biasing current and the differential protection current. The red line presents the allowed differential current in percentages. In this example the non-biased pick-up is set lower than in a normal transformer application. The settings and the ranges of the differential protection function are presented in the "Settings and signals" section of this topic.

The biasing characteristic is formed with the following formulas:

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

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

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

These form a straight line from zero current to Turnpoint (TP1). From TP1 to TP2 is the first slope (Slope 1) which causes the set biasing to be coarser when the measured current amplitude increases. When the measured current is higher that the TP2 set value, the second slope (Slope 2) is used.

## Differential characteristics settings

*Characteristics parts*

One needs to understand what the various parts of the characteristics mean in order to set the characteristics for the transformer application.

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

This is the first straight line which represents the differential current created by the transformer's normal operation. It takes into account measurement errors, possible variations caused by the transformer's tap changer (if available), and the various reasons why the application might have caused a different load inside the protected differential zone. In differential relays this is known as the pick-up current ($I_{d>pick-up}$). It is the basic sensitivity limit: when the measured differential current is below this limit, the transformer still operates normally and the protection does not trigger. In other words, the pick-up current setting must be higher than the combination of all the normal operation factors that cause differential currents.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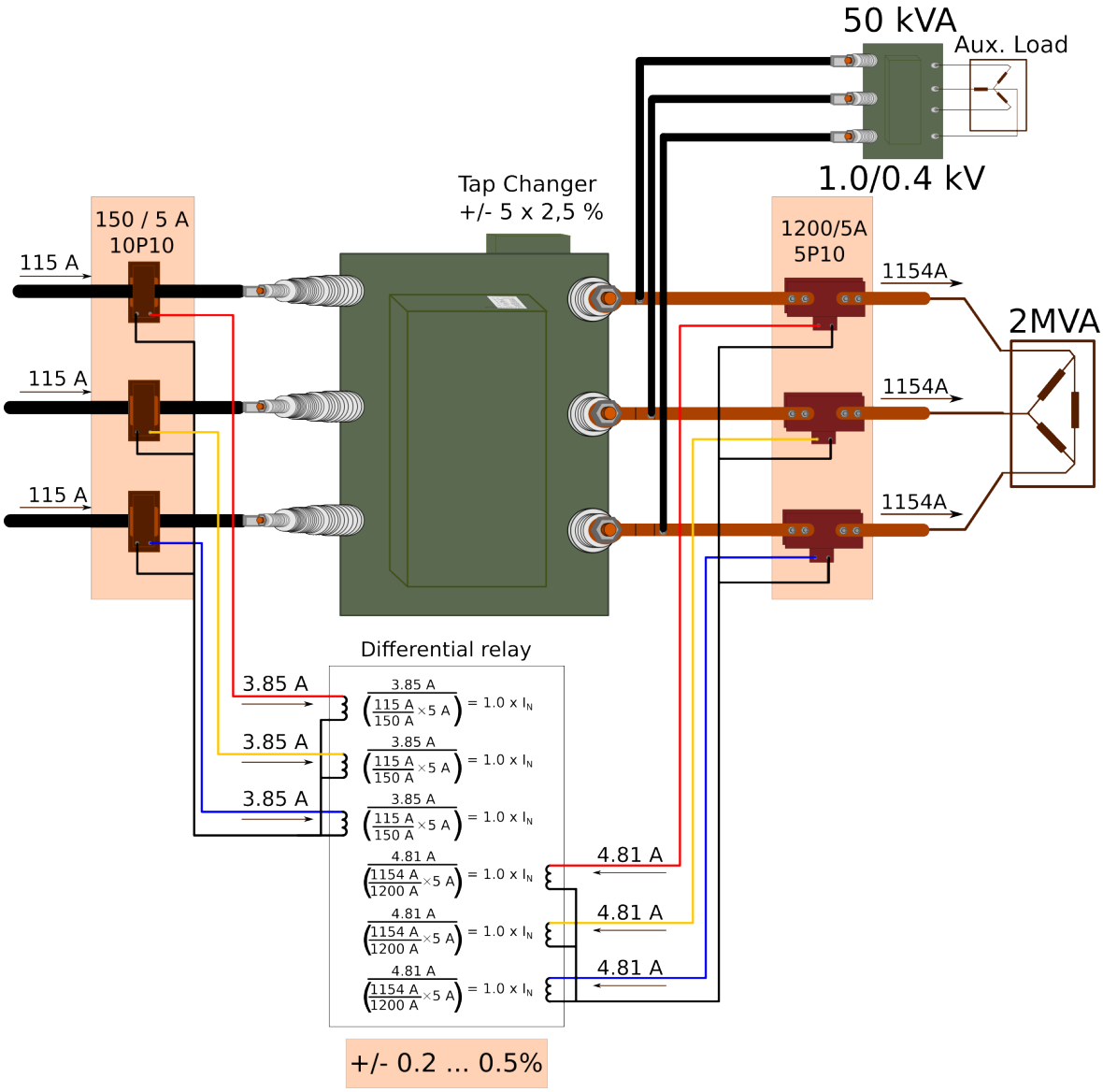
### Differential current sources (normal operation)

When calculating the differential current in a basic situation, it is strongly recommended to consider the following transformer component errors (the illustrated parts in the image below).

Figure. 5.4.10 - 62. Differential current sources (normal operation).




There seven (7) differential current sources for normal operation:

1) Primary side CT measurement accuracy ($CTE_{pri}$)
In this example the primary side CTs are Class 10P, which means the measurement error is 10 %.

2) Secondary side CT measurement accuracy ($CTE_{sec}$)
In this example the secondary side CTs are Class 5P, which means the measurement error is 5 %.

3) Relay measurement accuracy (primary and secondary) ($RE_m$)
The relay measurement error is below 0.5 %, its optional accuracy below 0.2 % per measurement channel: the combined value for both sides is either 1 % or 0.4 %.

4) Possible auxiliary transformer or auxiliary winding, currents not measured separately (AUTE)
In this example a 50 kVA auxiliary transformer is connected to the LV side output before the CTs, and this needs to be noted in the calculations. The same is true when the transformer itself is connected to auxiliary power output and those currents are not measured. The auxiliary power output's effect can be calculated by calculating the percentage of the auxiliary transformer/winding VA in relation to the transformer nominal VA (see formula below; assumes the auxiliary load to be nominal):

$$AUTE = \frac{AUX}{NOM} \times 100\ \% = \frac{50\ 000\ \text{VA}}{2\ 000\ 000\ \text{VA}} \times 100\ \% = 2.5\ \%$$

5) Transformer core magnetizing current (TME)
Transformer magnetizing current is the current which flows in the primary winding. Since it is running only in the primary side, this needs to be taken into account in the settings calculations. The approximate magnetizing current value can be calculated according to the following formula:

$$I_{TM} = \frac{U_{PRI}}{j\omega L_P}$$

When the primary inductance is known, the magnetizing current value is compared to the HV side's nominal current and the resulting percentage is directly the TME value. If the transformer's primary inductance is unknown, one can use a conservative estimate of 3 % as the TME value.

6) Safety margin (SME)
Conservative settings typically use a safety margin up to 5 %.

7) Tap changer on load side (TCE)
This example transformer has a tap changer with the rating of +/- 5 × 2.5 %. This means that the secondary side windings can be set +/- 5 × 2.5 % from the nominal center position, causing a maximum deviation of 5 × 2.5 % from the nominal conditions. Therefore the TCE is 12.5 % in this case. Please note that the tap position is not always in the nominal center position: check the application and calculate the maximum effect to the worst side.

Generally the tap changer means that the transformer transformation ratio can be adjusted in order to receive the nominal voltage more accurately to the secondary side of the transformer. There a multiple reasons for voltage variations, e.g. heavy or light loading in the HV side. In practice this means that if the secondary side needs more or less voltage, the secondary side uses more or less winding rounds. This causes a difference in the nominal current condition, which can be noticed as a differential current in the relay. Usually tap changer positions are presented as deviation steps for the secondary voltage to both positive and negative direction from the center (see the second image below).


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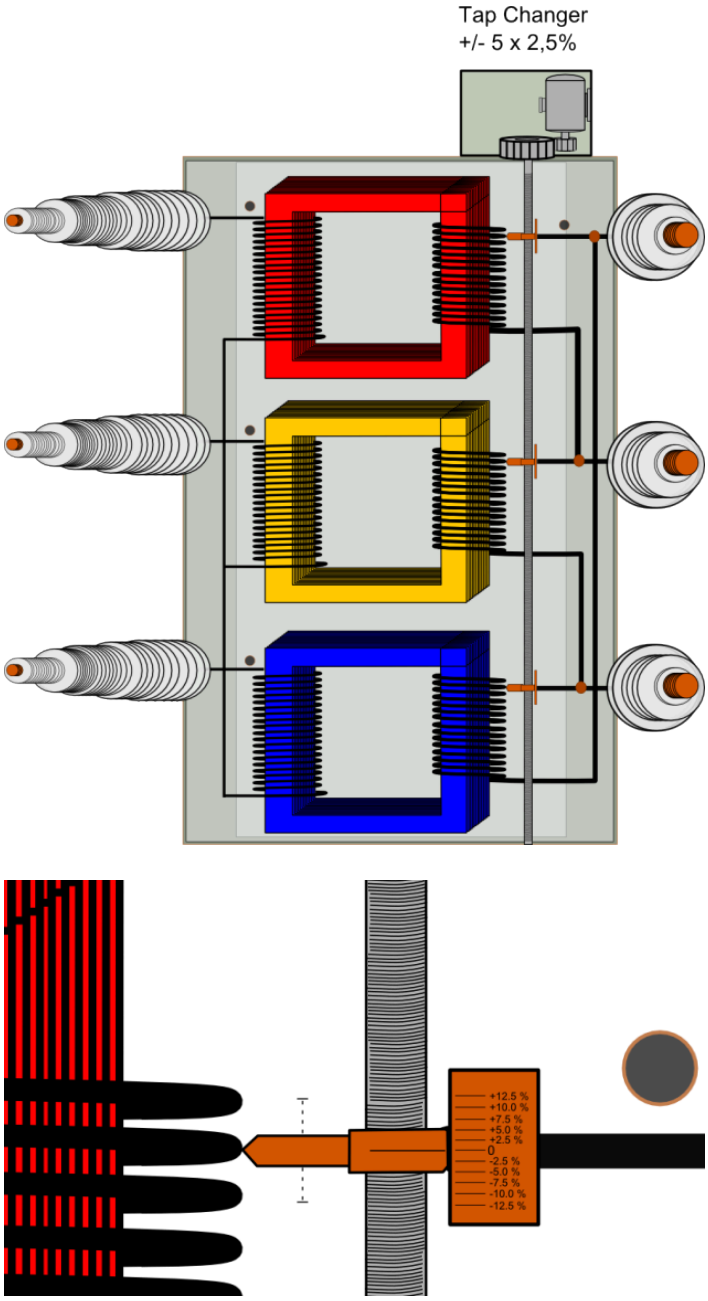
Figure. 5.4.10 - 63. Transformer tap changer.




*Calculating the generated differential current — The biased settings*

Now we have all the necessary data to calculate a naturally generated differential current based on the known errors and possible variables.

First we need to calculate the maximum uncertainty ($I_{meas,\ unc}$) from the various magnitudes inside the transformer. In this example, the transformer has a tap changer that affects the internal currents; however, its effects cannot be estimated reliably and the current's maximum uncertainty needs to be calculated. If there is no tap changer, the maximum uncertainty can be calculated sufficiently enough by summing the maximum inaccuracies of the CTs on the HV and LV sides.

$$I_{meas,unc} = \frac{absolute\ uncertainty}{absolute\ measurement} \times 100$$

Looking at the formula above, one can see that the absolute maximum uncertainty as well as the absolute measurement are needed. The former is the sum of the primary CT error ($CTE_{pri}$), the secondary CT error ($CTE_{sec}$), the tap changer maximum error (TCE) and the product of multiplying the secondary CT error with the tap changer maximum error ($CTE_{sec} \times TCE$). The latter is the sum of the so-called expected value ($1 \times I_n$) and the tap changer maximum error (TCE). The images below show the full formula (on the left) as well as the formula and its result when filled with the figures from our example configuration (on the right):

$$I_{meas,unc} = \frac{CTE_{pri} + CTE_{sec} + TCE + (CTE_{sec} + TCE)}{1 + TCE} \times 100 \qquad I_{meas,unc} = \frac{0.1 + 0.05 + 0.125 + (0.05 \times 0.125)}{1 + 0.125} \times 100 = 25\ \%$$

The calculation result (25 %) presents the maximum caused differential current to nominal that can be caused by the transformer's properties. If we know other uncertainties, they can now be added to $I_{meas,\ unc}$ to get the following operation:

$$I_{db>pick-up} = I_{meas,unc} + (2 \times RE_m) + AUTE + TME = 25\ \% + (2 \times 0.5\ \%) + 2.5\ \% + 3\ \% = 31.5\ \%$$

This means that in the worst case scenario, the differential current flows while the transformer's operation is normal. This is why the final result usually gets an added safety margin: the stable operation of the differential protection must be ensured and possible calculation errors negated. The following image shows the base sensitivity (i.e. the minimum setting for the differential current that the relay operation requires) given to the differential protection characteristics:

$$I_{db>\ pick-up} = \left(\frac{CTE_{pri} + CTE_{sec} + TCE + CTE_{sec} \times TCE}{1 + TCE} \times 100\right) + 2 \times RE_m + AUTE + TME + SME = 36\ \%$$

Now the base sensitivity takes into account the starting situation (no load to Turnpoint 1) in the characteristics. Next, it needs to be decided where to set Turnpoint 1. In most of differential relays this point is either fixed or automatically defined based on the base sensitivity and Slope 1; however, in this type of differential relay this point can be set by the user. If the user wants a high sensitivity, TP1 can be set to $1 \times I_n$ since the calculated base sensitivity already factors in the tap changer effect and all other differential current sources that normal operating causes. If the user prefers coarse settings, TP1 can be set to $0.5 \times I_n$, even $0.01 \times I_n$. The limit is determined by the sum of the protection principle the user wants. A smaller value results in a conservative and stable operation, while a larger value results in a highly sensitive but possibly unstable protection.

Please note that if TP 1 is set to $0.01 \times I_n$, Slope 1 starts directly from the setting and no unbiased sensitive section is available. This is useful when the user does not want base sensitivity to include the tap changer effect, but instead have it be accounted for in Slope 1 directly. This can lead to optimal sensitivity and stable settings for a differential relay even if there are no non-biased sensitive section in the characteristics. In this case, the formula to calculate the base sensitivity is as follows:

$$I_{db>\ pick-up} = CTE_{pri} + CTE_{sec} + 2 \times RE_m + AUTE + TME + SME$$

$$I_{db>\ pick-up} = 10\ \% + 5\ \% + 2 \times 0.5\ \% + 2.5\ \% + 3\ \% + 5\ \% = 26\ \%$$

Next are the Slope 1 settings, which present the relay's restrain characteristics over the transformer's load current range. This slope should be effective up to the maximum transformer loading. This value for power transformers is usually around 1.0 to $2.0 \times I_n$; for large power transformer a typical value is $1.5 \times I_n$. The purpose is to compensate the measurement errors caused by a relatively high current, including the tap changer effect. Slope 1 is calculated by using the transformer and CT nominal values in the maximum full load (Turnpoint 2) of the transformer with highest possible differential current causing tap position. Generally the Slope 1 setting is calculated as follows: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$$Slope\ 1 = \frac{I_{diff}\ TP2}{I_{bias}\ TP2} \times 100\ \%$$

Now the calculation of the maximum differential current in Turnpoint 2 includes the previously calculated correction factors for the HV and LV side CTs.

$$I_{pu\ PRI\ HV} = \frac{In_{HV}}{CT_{PRI\ HV}} = \frac{115.47\ \text{A}}{150\ \text{A}} = 0.77$$

$$I_{pu\ PRI\ LV} = \frac{In_{LV}}{CT_{PRI\ LV}} = \frac{1154.7\ \text{A}}{1200\ \text{A}} = 0.96$$

Also is needed the corrected transformation ratio effect ($TR_{corr}$) due to the tap changer position on the maximum voltage position (usually this generates the highest differential current).

$$TR_{CORR} = \frac{U_{HV\ VOLTS\ MIN}}{U_{HV}} \times \left(\frac{U_{HV}}{U_{LV}}\right)$$

To get the HV volts minimum value the user needs to apply the calculation on a situation when the tap changer on the secondary side is at maximum output voltage and the output is nominal. In this example we had a maximum of +12.5% increasing effect from the tap changer, resulting in the following calculation:

$$TR_{CORR} = \frac{10\ 000\ \text{V} \times (1.0 - 0.125)}{10\ 000\ \text{V}} \times \left(\frac{10\ 000\ \text{V}}{1\ 000\ \text{V}}\right) = 8.75$$

Next we calculate the the currents that flow in the HV and LV sides, when the loading of the transformer is e.g. 1.5 times its rated power.

Therefore, the LV side currents are as follows:

$$I_{LV} = \frac{I_{N\ LV} \times 1.5}{CT_{LV\ SEC} \times I_{pu\ PRI\ LV} \times \left(\frac{CT_{LV\ PRI}}{CT_{LV\ SEC}}\right)} = \frac{1154.7\ \text{A} \times 1.5}{5\ \text{A} \times 0.96 \times \left(\frac{1200\ \text{A}}{5\ \text{A}}\right)} = 1.5\ \text{x In}$$

The currents of the HV side are as follows:

$$I_{HV} = \frac{\left(\frac{I_{N\ LV} \times 1.5}{TR_{CORR}}\right)}{CT_{HV\ SEC} \times I_{pu\ PRI\ HV} \times \left(\frac{CT_{HV\ PRI}}{CT_{HV\ SEC}}\right)} = \frac{\left(\frac{1154.7\ \text{A} \times 1.5}{8.75}\right)}{5\ A \times 0.77 \times \left(\frac{150\ \text{A}}{5\ \text{A}}\right)} = 1.7\ x\ In$$

These currents present the worst-case scenario that the tap changer effect can cause to the differential relay's measured currents.

Next, we need to calculate the differential current. In theory there are two ways to use biasing calculation to do this, but in practice only one: the results of add and subtract modes are the same because they just compensate the connected CTs differently (starpoint towards or away from the transformer). Thus, the differential current is always calculated as follows:

$$|I_{HV} - I_{LV}|$$

This gives the absolute difference in the measured currents.

If the user wants more sensitive settings, the Average mode is selected and the Slope 1 calculation is as follows:

$$L_{x\ BIAS\ AVG} = \frac{|I_{Lx\ HV}| + |I_{Lx\ LV}|}{2}$$

$$Slope\ 1 = \frac{I_{diff\ TP2}}{L_{x\ BIAS\ AVG}} \times 100\ \% = \frac{|I_{LV} - I_{HV}|}{\left(\frac{I_{LV} + I_{HV}}{2}\right)} \times 100\ \% = \frac{1.5 - 1.7}{\left(\frac{1.5 + 1.7}{2}\right)} \times 100\ \% = 12.5\ \%$$

If the user wants more stable settings, the Maximum mode is selected and the Slope 1 calculation is as follows:

$$L_{x\ BIAS\ MAX} = \max\left(|I_{Lx\ HV}|, |I_{Lx\ LV}|\right)$$

$$Slope\ 1 = \frac{I_{diff\ TP2}}{L_{x\ BIAS\ max}} \times 100\ \% = \frac{|I_{LV} - I_{HV}|}{\max\left(|I_{LV}|, |I_{HV}|\right)} \times 100\ \% = \frac{1.5 - 1.7}{1.7} \times 100\ \% = 11.7\ \%$$

If the user wants to be on the safe side, yet another safety margin (in addition to the 5 % already in the base sensitivity settings) can be added to ensure stability.

At this point the only setting still missing is that of Slope 2. This setting is used for biasing the differential characteristics against heavy faults outside the differential zone that can cause heavy saturation on one or both sides of the CTs causing heavy differential current in the measurements even though the transformer itself does not have a fault. Please note that if there is a heavy end fault causing the biasing current to increase, this setting should not be set to maximum as the biasing may block the differential characteristics. This makes the trip not applicable even if there is an end fault.

When the transformer is fed from the HV side and the differential current is direct, the fault that feeds the end current can be accounted in the Slope 2 setting.

If the Average mode is used for biasing (due to a single end fault), the bias current is calculated as follows:

$$L_{x\ BIAS\ AVG} = \frac{|I_{Lx\ HV}| + |0|}{2}$$

Therefore, the differential current is the following:

$$|I_{Lx\ HV}|$$

$$Slope\ 2 = \frac{|I_{Lx\ HV}|}{\frac{|I_{Lx\ HV}|}{2}} \times 100\ \% = \frac{|1|}{\left(\frac{1}{2}\right)} \times 100\ \% = 200\ \%$$

If the Maximum mode is used for biasing (due to a single end fault), the bias current is the same as the differential current. Therefore, the Slope 2 setting is calculated as follows:


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$$Slope\ 2 = \frac{|I_{Lx\ HV}|}{|I_{Lx\ HV}|} \times 100\ \% = \frac{|1|}{|1|} \times 100\ \% = 100\ \%$$

*Calculating the generated differential current — The non-biased settings*

Now that the biased characteristic is set, we consider the settings for the non-biased stage $I_{di>Pick\text{-}up}$.

The purpose of this stage is to ensure fast and selective tripping of faults inside the differential zone, and also to ensure a stable operation on heavy outside faults. This stage operates only on the measured absolute differential current and is not blocked by harmonics or bias restraints. The setting of the stage should be based on the weakest full saturation of the CT under worst-case fault conditions because then only the other side current is measured and all current seen is differential current.

Let us calculate the maximum three-phase short-circuit current on the LV side in our example case from earlier:

$$I_{3ph\ SC\ LV} = \frac{S_N}{\sqrt{3} \times Z_k} = \frac{S_N}{\sqrt{3} \times \left(\frac{{U_{LV}}^2}{S_N} \times \frac{Z_{k\%}}{100\ \%}\right)} = \frac{2\ 000\ 000\ \text{VA}}{\sqrt{3} \times \left(\frac{10\ 000\ \text{V}^2}{2\ 000\ 000\ \text{VA}} \times \frac{4.95\ \%}{100\ \%}\right)} = 23327\ \text{A}$$

On the HV side this current is seen as:

$$I_{3ph\ SC\ LV \rightarrow HV} = \frac{I_{3ph\ SC\ LV}}{\left(\frac{U_{HV}}{U_{LV}}\right)} = \frac{23\ 327\ \text{A}}{\left(\frac{10\ 000\ \text{V}}{1\ 000\ \text{V}}\right)} = 2\ 332\ \text{A}$$

Next, let us remind ourselves of the given CT ratings for our example:
$CT_{pri,HV}$ = 150/5A (10P10)
$CT_{pri,LV}$ = 1200/5A (5P10)

Now we can calculate the secondary currents:

$$I_{HV\ MAX} = \frac{I_{3ph\ SC\ LV \rightarrow HV}}{CT_{HV\ PRI}} = \frac{2\ 332\ \text{A}}{\frac{150\ \text{A}}{5\ \text{A}}} = 77.7\ \text{A}_{SEC}\ (20.18\ x\ In)$$

$$I_{LV\ MAX} = \frac{I_{3ph\ SC\ LV}}{CT_{HV\ PRI}} = \frac{23\ 327\ \text{A}}{\frac{1\ 200\ \text{A}}{5\ \text{A}}} = 97.2\ \text{A}_{SEC}\ (20.2\ x\ In)$$

This is the theoretical maximum of the current flowing in the CTs, when a bolted and symmetrical three-phase fault occurs in the LV side of the transformer. Based on the previous calculations, we can see that the HV side maximum current is approximately 15 times higher than the CT rating, and the LV side appr. 19 times higher. No full CT saturation should be seen in either side even though the accuracy limit factor for both CTs is ten times the nominal. The protection class information in the CT ratings tell us that the CT output is for both CTs ten times the rated current in their given measurement class (5 % and 10 %, respectively). However, this is related to the nominal burden that is normally very high compared to the CT input in modern protection relays.

Next, the real CT accuracy limit factor needs to be checked in both CTs, in both sides. This check has much important initial data: the VA of the CTs on both sides, the length of the wiring between the relay and the CTs, the connection between the CTs, as well as the cross-section and material of the wires. Let us begin with the burden the wiring causes to the relay, and calculate the resistance in a conductor:

$R_{Cond} = \frac{\rho \times l}{A}$, where

$R_{Cond}$ = resistance of conductor (Ω)
$\rho$ = resistivity of the conductor material (Ω /m)
$l$ = length of the wire in meters (m)
A = cross-section of the conductor ($m^2$)

When designing the CTs and their wiring, please keep in mind the following: the resistance of the wire doubles when the length is doubled, and the resistance halves when the wire's cross-section are doubles. When 1 A secondary is used (instead of 5 A secondary), all burdens drop to a level smaller to portion of $5A^2$ , e.g. 1/25.

Although copper cables are normally used to connect CTs to a relay, the table below also presents the resistivity (rho) and conductivity (sigma) properties of aluminum (at +20 °C):

| Material | ρ (Ω•m) at 20 °C (68 °F, 293 K) | σ (S/m) at 20 °C | Temperature coefficient (K–1) |
|---|---|---|---|
| Copper | $1.68\times10^{-8}$ | $5.96\times10^{7}$ | 0.003862 |
| Aluminum | $2.82\times10^{-8}$ | $3.5\times10^{7}$ | 0.0039 |

You can use the following formula to calculate the resistivity in temperatures other than +20 °C:

$\Delta_\rho = ((\alpha \times \Delta T) \times \rho_0$, where

$\Delta_\rho$ = change of resistivity (Ω / m)
$\alpha$ = temperature coefficient (K-1)
$\Delta T$ = temperature change ($t_1$-$t_0$)
$\rho_0$ = resistivity in given temperature (°C)

For example, the resistivity of copper at +75 °C is calculated like this:

$$\rho_0 + \Delta_\rho = \rho_0 + (\alpha \times \Delta T \times \rho_0)$$

$$1.68 \times 10^{-8} + \left((0.003862 \times (75\,°C - 20\,°C)) \times 1.68 \times 10^{-8}\right) = 0.0203\ \mu\Omega / m$$

With this value we can calculate the resistances (per meter) of the most commonly used copper wires given value most common used copper wires at +75 °C by using the above-mentioned formula for $R_{cond}$:

| Cross-section ($mm^2$) | Resistance (Ω/m) |
|---|---|
| 1.5 | 0.0135 |
| 2.5 | 0.00812 |
| 4.0 | 0.00508 |
| 6.00 | 0.00338 |

It is recommended that you use the worst-case scenario as the basis for calculating the CT burden. In most cases these +75 °C values are sufficient. If the ambient temperature in your application is higher than +75 °C, the resistance should be calculated for that specific temperature.


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It is also Important to know the wiring of the CTs: do the CTs have a common return wire or are both ends of both CTs wired to the terminal connector? Usually there are four wires coming from the CTs to the terminal: in these cases the length per phase is the sum of the distance from the CT to the relay and the distance from the relay OR from the CTs to the common coupling point. When both sides of all CTs are wired to the relay or to the terminal, the length of the wiring is double the distance from the CTs to the relay. If the connection is a combination of these two wiring types, the length can be estimated by increasinf the distance in proportion to the six-wire or four-wire connection. For example, if six wires connecting the CTs to the terminal account for 30 % of the wiring (in addition to the four wires connecting the and the terminal), the estimated length of the wire is 1.3 times the distance between the relay and the CTs.

The next loading factor is the resistance of the relay's measuring input. In this relay type the resistance is 0.0005 for the current input, which gives approximately 0.001 VA with a current of 1 A. Then we need to calculate the accuracy limit factor (ALF). This requires the CT nominal ALF value and we can get that from the above-mentioned CT rating: the figure after P gives the current overload as a factor of the nominal rated value and therefore gives the ALF applicable at that overload of the CT. The actual ALF can be calculated with the following common method:

$$ALF_{act} = ALF_{rated} \times \left| \frac{S_{ctrn} + S_{rated}}{S_{ctrn} + S_{actual}} \right|$$

, where
$ALF_{rated}$ = the rated accuracy limit factor, the “factor after P”
$S_{ctrn}$ = internal burden of the CT secondary (VA)
$S_{rated}$ = the rating of the CT (VA)
$S_{actual}$ = the actual power taken from the CT (VA)

The main issue with this equation is the $S_{CTRN}$, the internal burden of the CT secondary. The internal resistance is related to the CT rating, to the winding length as well as to the dimensions of the wire used in the winding. Some CT manufacturers include the SCTRN value in their product documentation. However, as the value is only a small portion of the CT burden as a whole (the wirings cause most of it in typical relay applications), one should not worry if the value is unknown.

For example, let us assume that the internal resistance of the CT's HV side is 0.05 Ω and is rated 5 VA, and that the internal resistance of the CT's LV side 0.09 Ω, also rated 5 VA. The wiring from the HV side to the relay is 10 m and from the LV side to the relay 5 m; both sides have 30% of the wiring made with a six-wire connection and 70% of the wiring with a four-wire connection. The wirings on both sides are made with 4 $mm^2$ wires. The HV side is 150/5 A, with the protection class 10P10; the LV side is 1200/5 A, with the protection class 5P10. Therefore, the actual accuracy limit factor on both sides is as follows (the HV side on the left, the LV side on the right):

| | |
|---|---|
| $ALF_{rated} = 10$ | $ALF_{rated} = 10$ |
| $S_{rated} = 5\ \text{VA}$ | $S_{rated} = 5\ \text{VA}$ |
| $S_{ctrn} = {I_{NS}}^2 \times CT_{RS} = 5^2\ \text{A} \times 0.05\ \Omega = 1.25\ \text{VA}$ | $S_{ctrn} = {I_{NS}}^2 \times CT_{RS} = 5^2 A \times 0.09\ \Omega = 2.25\ \text{VA}$ |
| $R_{wire} = (10\ m \times 1.3) \times\ 0.00508\ \frac{\Omega}{\text{m}} = 0.066\ \Omega$ | $R_{wire} = (5\ m \times 1.3) \times\ 0.00508 \frac{\Omega}{\text{m}} = 0.033\ \Omega$ |
| $S_{actual} = {I_{NS}}^2 \times \left(R_{wire} + R_{relay}\right) = 5^2\ \text{A} \times (0.066\ \Omega + 0.0005\ \Omega) = 1.65\ \text{VA}$ | $S_{actual} = {I_{NS}}^2 \times \left(R_{wire} + R_{relay}\right) = 5^2\ A \times (0.033\ \Omega + 0.0005\ \Omega) = 0.838\ \text{VA}$ |
| $ALF_{act} = ALF_{rated} \times \left\|\frac{S_{ctrn} + S_{rated}}{S_{ctrn} + S_{actual}}\right\| = 10 \times \left\|\frac{1.25\ \text{VA} + 5\ \text{VA}}{1.25\ \text{VA} + 1.65\ \text{VA}}\right\| = 21.55$ | $ALF_{act} = ALF_{rated} \times \left\|\frac{S_{ctrn} + S_{rated}}{S_{ctrn} + S_{actual}}\right\| = 10 \times \left\|\frac{2.25\ VA + 5\ \text{VA}}{2.25\ VA + 0.838\ VA}\right\| = 23.5$ |

When comparing the corrected CT accuracy limit factors to the estimated maximum through fault currents, we can see that the current will not saturate the CTs. The HV side can repeat the current 21.6 × $I_n$, while the calculated HV through fault current is at maximum 20.2 × $I_n$. The same is true for the LV side where the maximum output is 20.2 × $I_n$ when the LV side CT is able to repeat 23.5 × $I_n$. From this we can expect that through faults will not cause problems with this power transformer and CT combination. It also shows us that the non-biased differential stage can be set to operate sensitively during in-zone faults. If the CTs have the possibility to saturate (that is, the calculated through fault current is bigger than the ALF on either CT side), the setting of the instant stage must be set high enough so that it does not operate on through fault saturation.

The inrush peak current should also be considered when setting the instant stage. In normal-power transformers the energizing inrush current may be 10 × $I_n$, while the measured current is FFT-filtered for the fundamental frequency which is used for differential calculation. Typically, the found differential current is half of the maximum peak current. The instant stage should be 5 × $I_n$ if the setting should be according to the theoretical maximum and the margin. Conservative settings should use the 10 × $I_n$. The setting value should never cause trips for energizing, but still operate fast during energizing fault cases. This stage is usually never blocked in applications, and therefore the stage settings should consider the absolute differential current that is possible in normal operations while keeping the settings sensitive enough for inrush currents (especially in energiszing cases).

Thus, the setting suggestion for this $I_{di>Pick\text{-}up}$ stage is 6.0 × $I_n$…10 × $I_n$ for sensitive and conservative operations respectively.

*Finalising the settings*

Now the basic settings for the differential stages are applied and the differential protection is ready to operate. Our example transformer is very small but the formulas presented in this manual can be applied to transformers of all sizes. If so selected, the relay automatically calculates these settings (using these same formulas) in the Transformer status monitoring (TRF) module. When everything is set up correctly in the relay and when the transformer is feeding the load with nominal power, the result should look like the following example configuration when the example settings and transformer are used.


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Figure. 5.4.10 - 64. Example configuration for the transformer differential function.

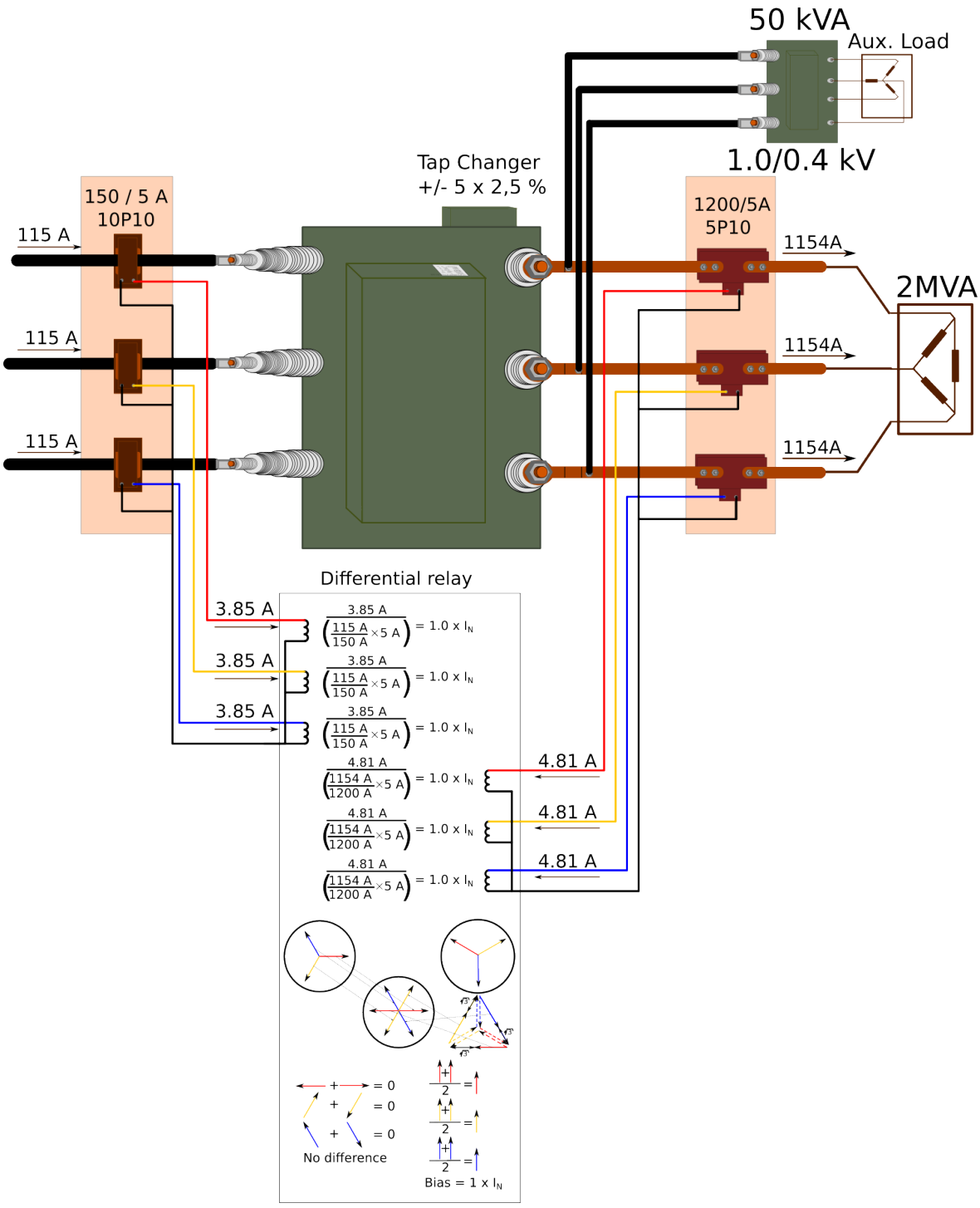
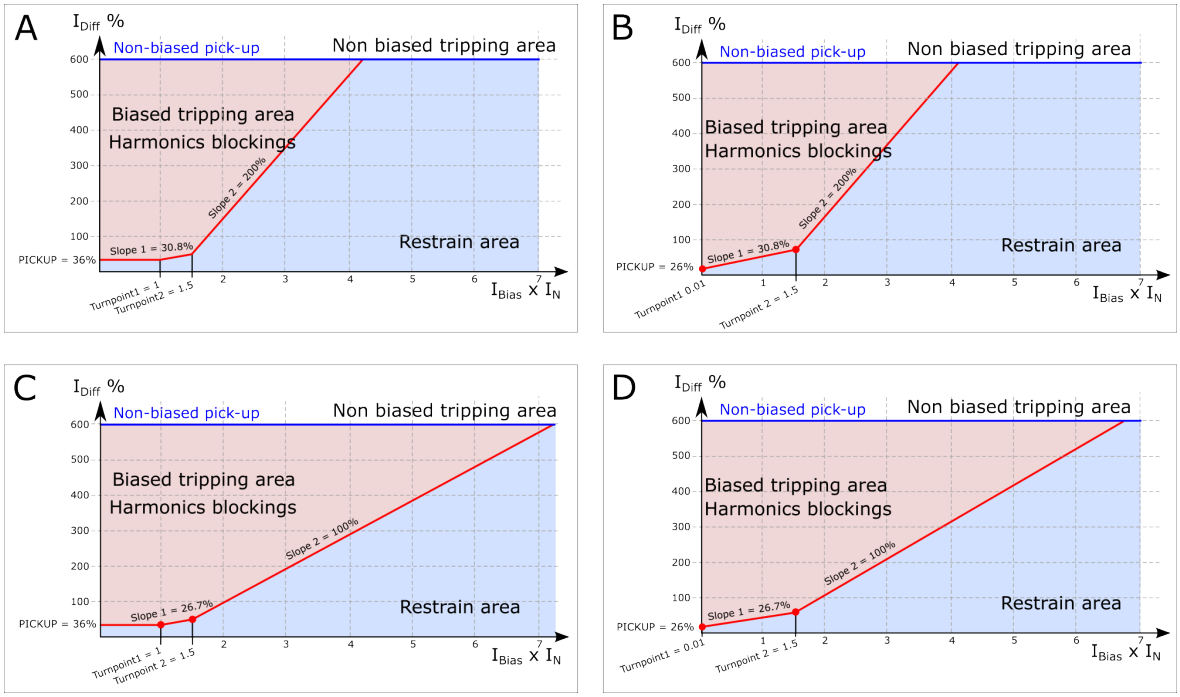


Figure. 5.4.10 - 65. Example differential characteristics




The four characteristics (the image above) present the setting variations based to the Average restraint calculation mode (figures A and B) and the Maximum restraint calculation modes (figures C and D). The characteristics are set to be equally sensitive in each of them. You can also see the variations in Turnpoint 1 settings: in Figures A and C it is set at 1.0 × $I_n$, whereas in Figures B and D it is set at 0.01 × $I_n$.

## Zero sequence compensation for external earth faults

Our example presented only one type of transformer and its properties. Another very common variation is the type of transformer where the star side (HV, LV, or both) is earthed and thus forms a route outside the differential zone (see the image below).



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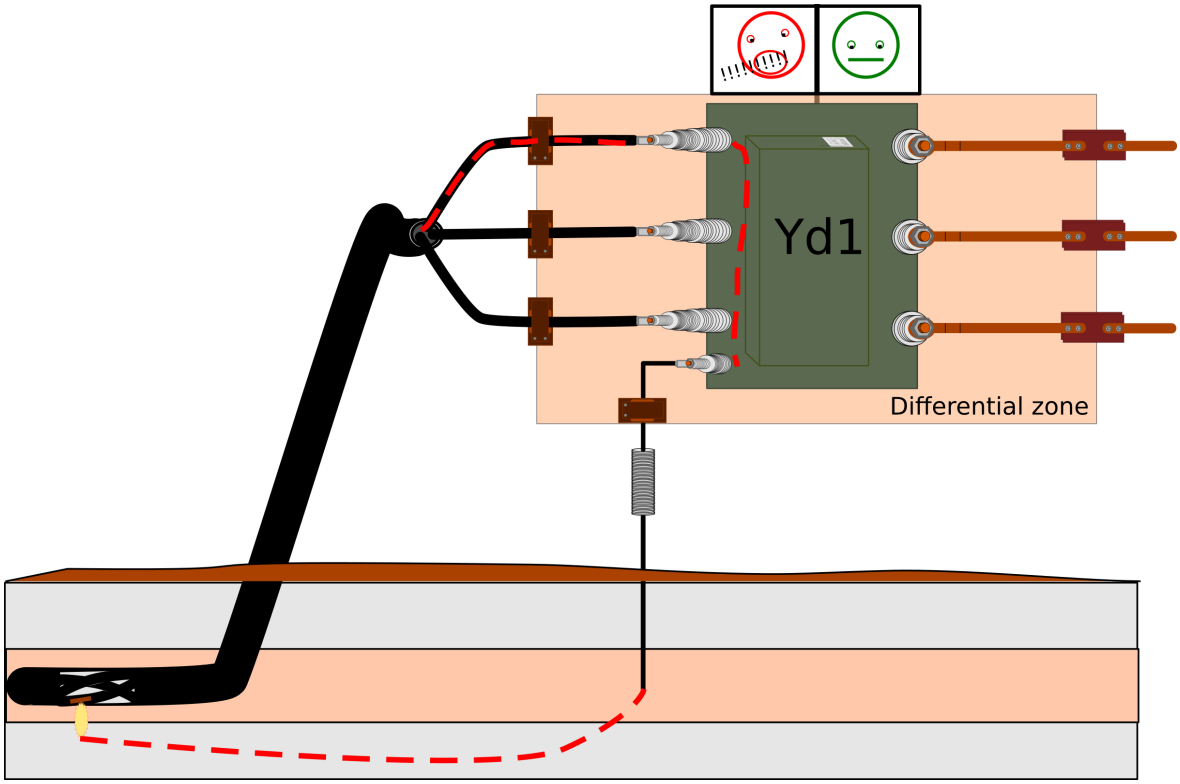
Figure. 5.4.10 - 66. Transformer earthing settings that do not compensate for external earth faults.




The differential relay looks at this situation and sees a fault inside the differential zone. This is because the other side is not affected at all by the fault (or only very little), and the relay sees a high current entering but not exiting the zone.

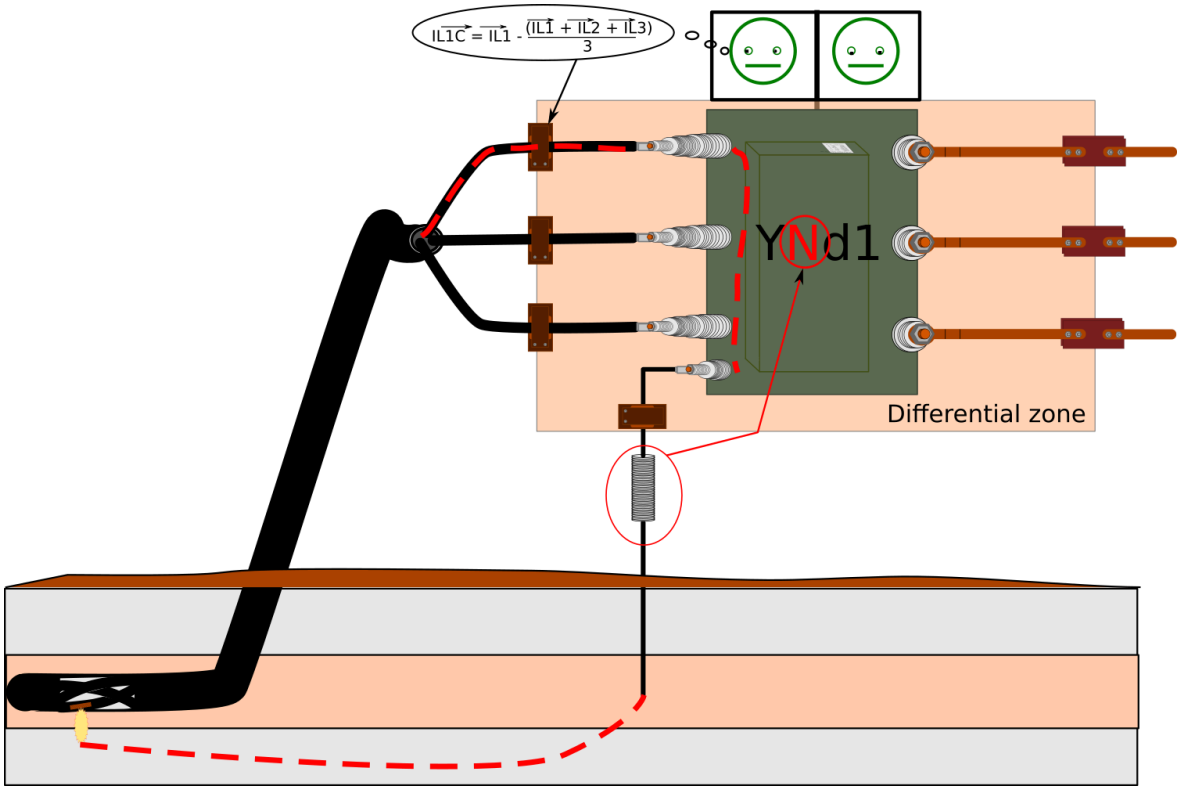
In many cases the zero sequence current is monitored by the CT in the earthing.

Earthing (directly or via a resistor) forms a route outside the differential zone.

When an external earth fault happens, only the earthed side of the transformer is involved in the fault.

The differential earthing requires the earthing to be known: if not compensated, any low-impedance earth fault outside the differential zone causes a differential current and possibly trips the differential protection. This is why the calculated zero sequence compensation is used. The vector group selection has either "N" or "n" to signify either HV side or LV side earthing. The selection then deducts the calculated zero sequence current from the currents (in p.u.) before differential calculation and thus negates the effect of an external earth fault. Correctly selected transformer settings prevent the differential function from being tripped by out-of-zone earth faults (see the image below).

Figure. 5.4.10 - 67. Transformer earthing settings that compensates for external earth faults.




When the transformer settings are correct, the differential relay compensates the zero sequence current and does not trip due to earth faults outside the differential zone.

Earthing (directly or via a resistor) forms a route outside the differential zone.

When an external earth fault happens, only the earthed side of the transformer is involved in the fault.

The "N" or "n" selection applies the correction and eliminates the zero sequence effect with the following formulas:

$$\overrightarrow{IL1}_{corr} = \overrightarrow{IL1} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL2}_{corr} = \overrightarrow{IL2} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

$$\overrightarrow{IL3}_{corr} = \overrightarrow{IL3} - \frac{\overrightarrow{IL1} + \overrightarrow{IL2} + \overrightarrow{IL3}}{3}$$

Note! When you enable the zero sequence compensation by selecting the "N" or "n" in the transformer vector group, the sensitivity to single-phase one end fault decreases by a third simultaneously. This is why restricted earth fault protection (I0>, REF) should be enabled for the side where the zero sequence is compensated. However, enabling the REF protection requires that both the phase current measurements and the starpoint current are available and can be connected to the relay's residual current channel on the corresponding (HV/LV) side measurement.



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## Restricted earth fault

When the transformer's earthed side is compensated with afore-mentioned zero sequence compensation, that side will be a third (appr. 33 %) less sensitive in detecting single-phase faults inside the differential zone. For this reason it is advised that the restricted earth fault (REF) stage is activated on the transformer side that compensates the zero sequence current. Additionally, it should be enabled whenever the Y side of the starpoint is earthed; normal phase differential protection cannot be set to provide the maximum sensitivity to detect single-phase (earth) faults within the differential are because the properties dependant on the transformer and the application that were described in the previous section. This differential stage monitors the incoming calculated residual current and compares it to the outgoing starpoint current. If the single-phase (earth) fault occurs outside the differential zone, this function does not operate; if the fault occurs inside the differential zone, this function operates quickly. This protection's sensitivity to earth faults only within the protection zone is referred to as the "restricted earth fault protection".

The transformer differential functions offers two stages of low-impedance, restricted earth fault protection.

The operating characters of the restricted earth fault function (I0d>) on both the high voltage and the low voltage side are more similar to each other than to the percentage characteristics presented by the Idb> function, even though both sides are independent and can be set freely. The calculation of differential and biasing currents on both sides is as follows (the HV side on the left, the LV side on the right).

| | |
|---|---|
| $HV_{I0d\ bias\ avg} = \frac{\lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HV\ meas}\rvert}{2}$ | $LV_{I0d\ bias\ avg} = \frac{\lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LV\ meas}\rvert}{2}$ |
| $HV_{I0d\ bias\ max} = \max\left((\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}), \overrightarrow{I0}_{HV\ meas}\right)$ | $LV_{I0d\ bias\ max} = \max\left((\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}), \overrightarrow{I0}_{LV\ meas}\right)$ |
| $HV_{I0d>\ diff\ add} = \lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) + \overrightarrow{I0}_{HV\ meas}\rvert$ | $LV_{I0d>\ diff\ add} = \lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) + \overrightarrow{I0}_{LV\ meas}\rvert$ |
| $HV_{I0d>\ diff\ substract} = \lvert(\overrightarrow{IL1}_{HV} + \overrightarrow{IL2}_{HV} + \overrightarrow{IL3}_{HV}) - \overrightarrow{I0}_{HV\ meas}\rvert$ | $LV_{I0d>\ diff\ subtract} = \lvert(\overrightarrow{IL1}_{LV} + \overrightarrow{IL2}_{LV} + \overrightarrow{IL3}_{LV}) - \overrightarrow{I0}_{LV\ meas}\rvert$ |

Similarly to the phase differential stages, both sides with the restricted earth fault stages have options between the average and the maximum bias current calculation, as well as the option between the add and the subtract current calculation. The use of these stages depends on the CTs' installation directions and the desired sensitivity for bias calculation.

In the transformer differential stage the reference current for the REF protection is always the protected side nominal current, which is calculated in the relay's Transformer status monitoring (TRF) module.

The transformer REF stage (regardless of the side) may be set to be a lot more sensitive than the phase differential. The setting sensitivity should be defined by whether or not one expects CT saturation (transformer's maximum single-phase output compared to the neutral point CT ratings). The tripping characteristics may be set differently when the network is earthed either directly or through impedance, and therefore the fault current may be expected to saturate the CTs even during external faults. For this reason there are three sections also in the REF function characteristics (non-biased, slightly biased, and heavily biased). For high-impedance or close-to-neutral winding faults the first (non-biased) section should consider the CTs' possible measurement errors as well as the desired sensitivity for internal faults close-to-neutral. The Turnpoint 1 setting should be twice the CT's nominal current. Normally the setting calculation is guided by the primary-to-maximum current rating because the CTs' neutral point has a lower primary current rating than the phase current. The first biased section (that is, Slope 1) should consider how a possible saturation in the CTs' neutral point affects normal (external) earth faults, and the how a heavy fault going fully through the second biased section (Slope 2) can cause saturation in the CTs' phase currents.

The recommended base settings:

- Pick-up (base sensitivity): typically 5 % to 10 % of the phase current CT error (Px)

- Turnpoint 1: double the neutral current CT nominal primary to transformer nominal current ratio
- Slope 1: calculate the maximum single-phase through fault overcurrent to nominal ratio and used biasing mode ratio
- Turnpoint2: set to maximum accuracy limit factor to transformer nominal ratio of the neutral point CT (typically 5 or 10); if the single-phase overcurrent fault exceeds this value, set Turnpoint 2 to that value
- Slope 2: set the maximum restraint calculation mode to 100 % and the average mode to 200 %.

## Blockings from harmonics ($2^{nd}$ and $5^{th}$)

In transformer protection harmonics are always present in energizing situations: they are generated by the high current in the transformer inductances when the coils are energized. They are also preent in the currents during overfluxing and overvoltage situations. Energizing situations generate even harmonics: the $2^{nd}$ harmonic is the most commonly used harmonic in inrush blocking. Overvoltage (and overexcitation) situations generate odd harmonics: the $5^{th}$ harmonic is mainly used for blocking (the $3^{rd}$ harmonic is also present in Y windings but absent in delta windings which is why the $5^{th}$ harmonic has been chosen for overfluxing and excitation detection). In this chapter 'blocking' refers to the Idb> (the biased differential) stage and it has both these blocking ($2^{nd}$ and $5^{th}$) applied internally. If the Idi> stage (the non-biased differential) needs to be blocked, external blocking must be used.

## $2^{nd}$ harmonic for magnetizing inrush blocking (principle and usage)

When the primary side of a power transformer is energized (secondary side open), the transformer acts as a simple inductance. During normal operation the flux produced in the transformer core lags behind the fed voltage by 1.58 radians (90 degrees). This means that when the voltage is in zero crossing, the steady state value of the flux is in its negative or positive maximum value. In energizing situations there is no flux available at the instant the winding is energized because there is no (live) magnetic flux linked to the transformer core prior to switching on the supply (however, remanence flux may still exist). The flux reaches its steady state operation some time after energization (depends on the transformer's properties such as its size, its R/X ratio, etc.). In practice this means that the flux in the transformer core starts from zero, as does the voltage in the winding; when energizing the transformer's primary side, the flux ends up 90 degrees behind the winding voltage and the system is in a steady state.

This start-up transition in the transformer has the effect of making the flux value be double the nominal flux value in the first half of the cycle after energization. The transformer core is generally saturated just above the steady state value of the flux and because of this the transformer core is decreasingly saturated during the transition time. During this saturation time the transformer's primary side draws a very high current with a heavy amount of even harmonics (the highest being the $2^{nd}$). This current is called the "magnetizing inrush current in transformer". The inrush current can be up to ten times higher than the nominal rated current of a transformer. The energizing characteristics of a transformer depend on the ratings of the transformer as well on the transformer's design (limb constructions, etc.).

The differential relay sees the energization current as a differential current since it only flows through the primary side winding only. The saturation of the transformer core generates the $2^{nd}$ harmonic component which can be used to block the biased sensitive differential stage during energization.


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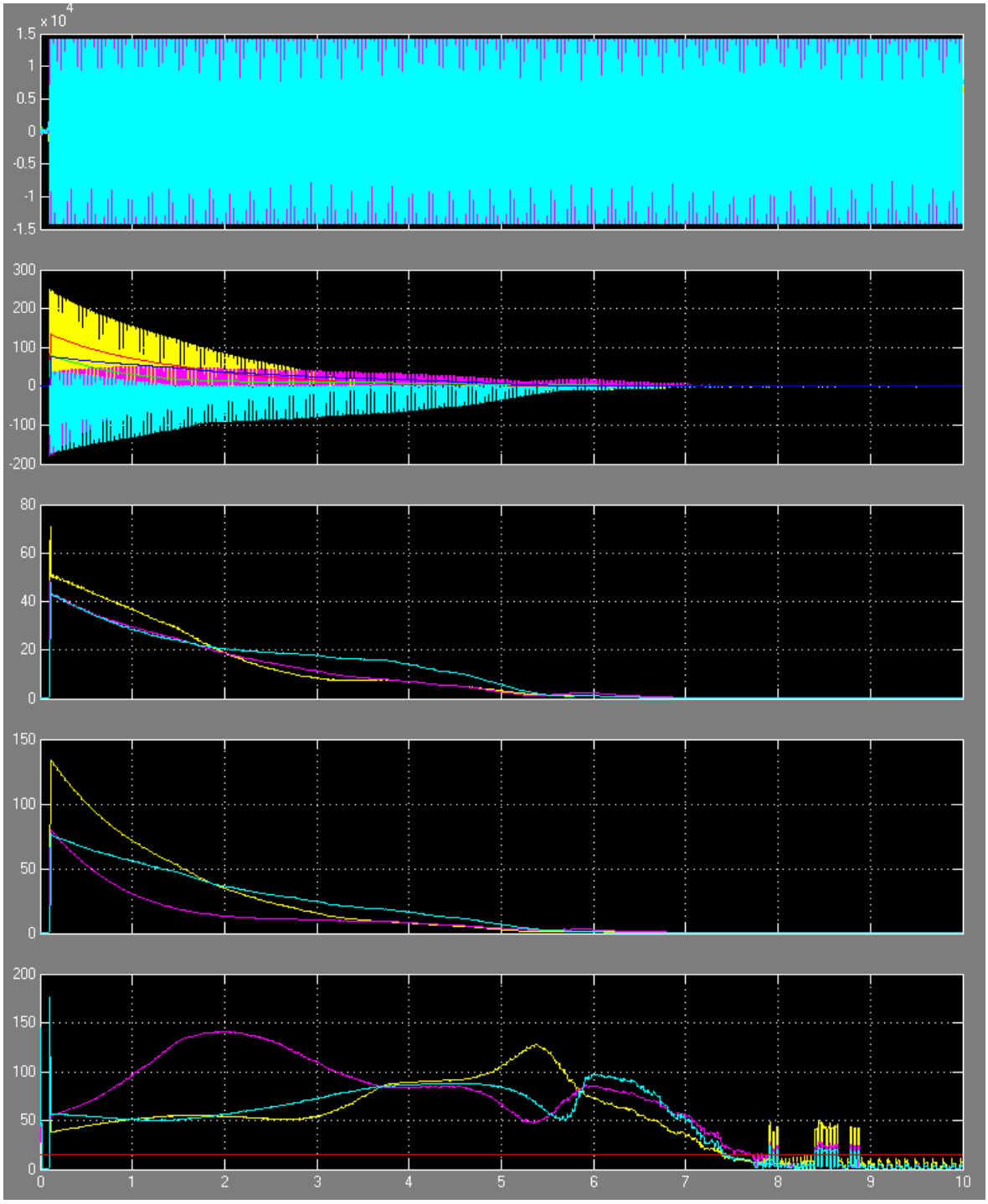
Figure. 5.4.10 - 68. Energizing behavior of a small transformer.




The figure above presents the energizing behavior of a small transformer. The first graph depicts the applied voltage, the second graph depicts the phase currents' peak and FFT values (as mentioned earlier, the calculated FFT value is about 50% of the peak value), the third graph depicts the 2$^{nd}$ harmonic absolute values (in amperes), the fourth graph depicts the fundamental (50 Hz) FFT-calculated currents (in amperes), and fifth graph depicts the 2$^{nd}$ harmonic components relative to the corresponding fundamental component currents (with the 15 % setting limit).

The magnetizing inrush current in a 2 MVA transformer is over quickly, in about seven seconds. Afterwards there is still the nominal measurable current (seen only in the transformer's primary side) which would cause the differential relay to trip if energized without magnetizing the inrush blocking. Looking at the currents more closely one can see that the input values of the fundamental frequency currents (used for differential calculations) are roughly as follows:

$$I_{L1\,peak} = 140\text{ A} = 1.2\ x\ In$$

$$I_{L2\,peak} = 75\text{ A} = 0.65\ x\ In$$

$$I_{L3\,peak} = 70\text{ A} = 0.60\ x\ In$$

In our previous example the transformer's nominal current on the HV (primary) side was 115.5 A; with it we can count the following:

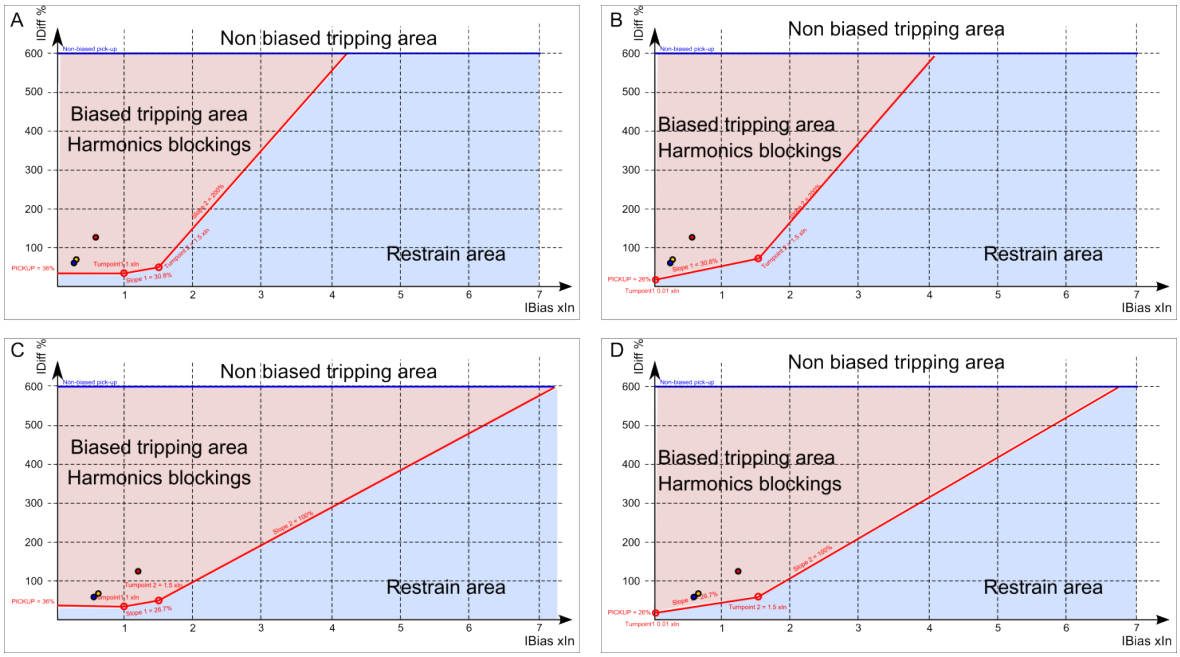
$$I_{L1\,diff} = 120\ \%,\ I_{L1\,bias\,avg} = \frac{1.2\ x\ In}{2} = 0.6\ x\ In,\ I_{L1\,bias\,max} = 1.2\ x\ In$$

$$I_{L2\,diff} = 65\ \%,\ I_{L2\,bias\,avg} = \frac{0.65\ x\ In}{2} = 0.33\ x\ In,\ I_{L2\,bias\,max} = 0.65\ x\ In$$

$$I_{L3\,diff} = 60\ \%,\ I_{L3\,bias\,avg} = \frac{0.60\ x\ In}{2} = 0.30\ x\ In,\ I_{L3\,bias\,max} = 0.60\ x\ In$$

The graph below shows how the differential currents look like when used in the set characteristics.

Figure. 5.4.10 - 69. Differential currents in the energization of a 2 MVA transformer.




While the results are very low compared to the magnetizing inrush current magnitudes, the differential relay would still definitely trip without the 2nd harmonic blocking. The situation is the same with all of the calculted setting variations.



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The following figure presents the principle operation of the harmonic blocking in the transformer differential. When the transformer is energized, both the fundamental frequency and the 2nd harmonic increase significantly. In this example the harmonic blocking limit was set to 15 % (the ratio between the 2nd harmonic and the fundamental frequency, all phases), which seems more than sufficient for this transformer. The pick-up in the example is set to 30 %. Now, when the flux in the transformer core starts to catch up, the saturation in the core is reduced and the current for magnetizing is reduced as well. The blocking remains active until the setting is reached after which the blocking is released for each phase separately. With our example transformer the harmonic blocking limit could be set to 30 % and the energizing would still be successful because the 2nd harmonic is still heavily present by the time the fundamental currents are reduced below the differential stage's pick-up limit.

Figure. 5.4.10 - 70. Inrush blocking by using the 2nd harmonic (relative to fundamental frequency).

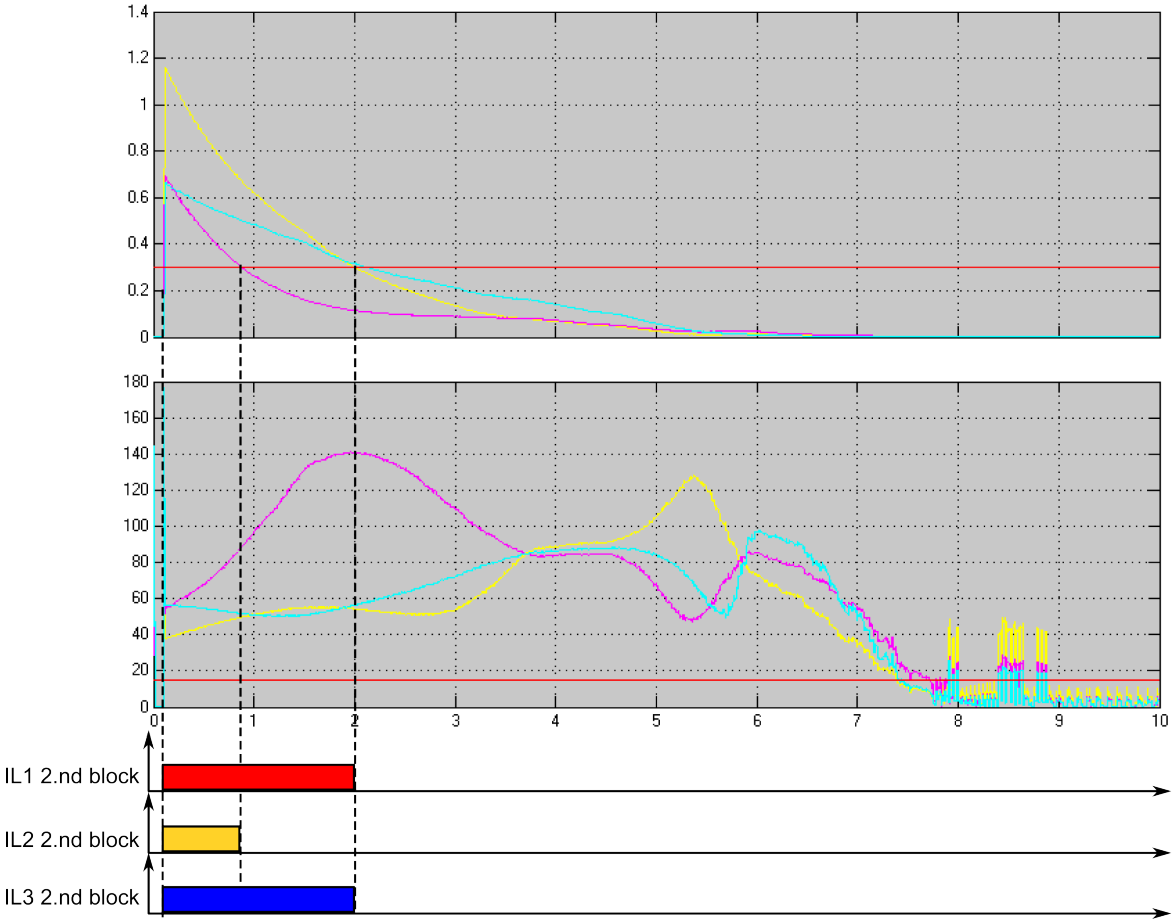
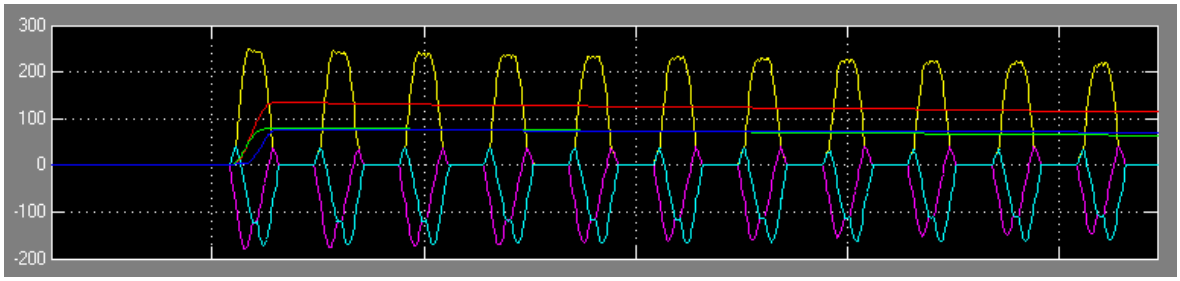



Figure. 5.4.10 - 71. Example of transformer magnetizing inrush currents.




A conservative setting recommendation for standard type transformers:

- enabling the 2nd harmonic blocking

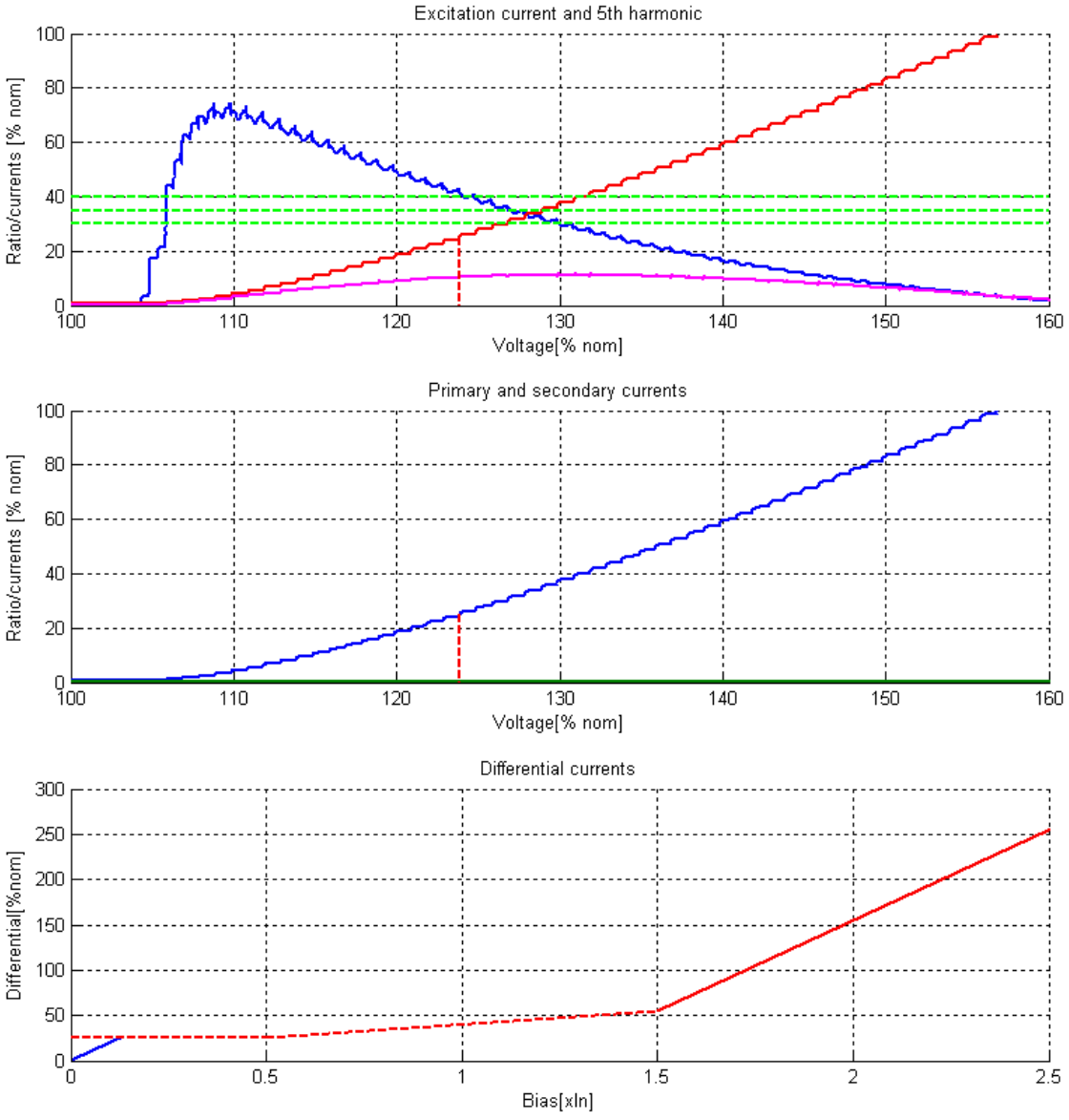
- sensitivity appr. 15...20 %
- harmonic content compared to the fundamental frequency.

The user can fine-tune the transformer settings during the commissioning phase if there are any issues with the transformer energization.

## 5th harmonic for overexcitation blocking (principle and usage)

When the transformer's primary side voltage increases for some reason, the voltage-frequency (V/f) ratio exceeds the desing limits and the transformer overexcited very quickly. This may be caused by two things: a fault in the LV side can throw off the loading and cause a temporary overvoltage, or the frequency in the network decreases for some reason (e.g. overloading or generation drop). The differential relay should not trip in either of these cases even though the overexcitation in the transformer's core result in the primary side measured currents being higher than those on the secondary side.

Figure. 5.4.10 - 72. Transformer behavior in case of overvoltage caused by overexcitation.



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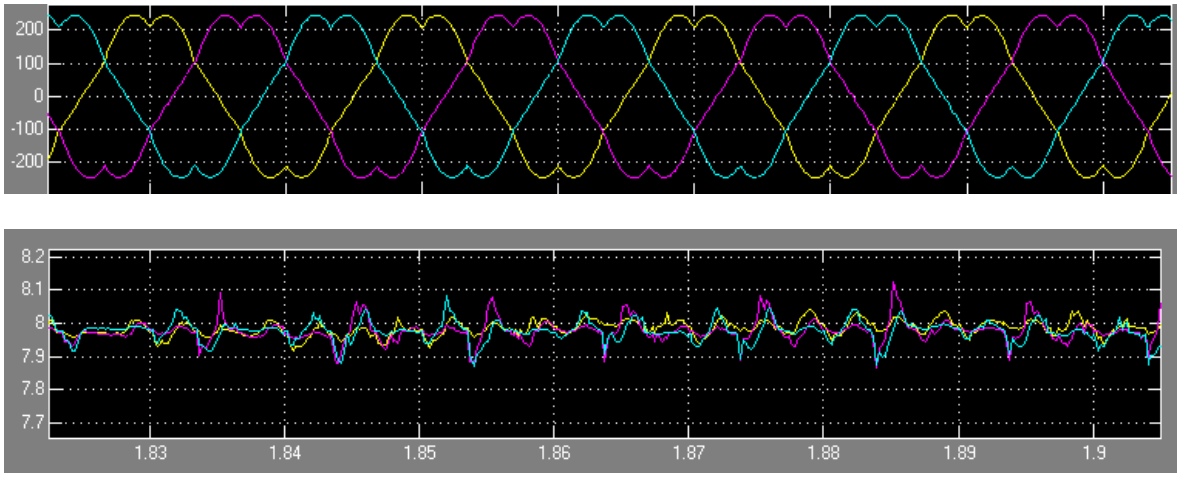
The figure above presents the simulated behavior of a power transformer when overvoltage occurs. In the simulation the transformer was unloaded on the secondary side while the voltage on the primary side was increased with a ramp. The first graph depicts the excitation current, the 5$^{th}$ harmonic component and their relation (which is used in the blocking); the green lines represents the suggested setting limits for 5$^{th}$ harmonic detection (30 %, 35 %, and 40 %). The second graph depicts the primary and secondary currents, plotted as a function of the voltage. The third graph depicts the differential characteristics as well as the differential and bias currents.

As can be noted from the first graph, the 5$^{th}$ harmonic component begins increasing rapidly (compared to the fundamental) in the start situation when the voltage is about 120 % of the nominal (depends entirely on the transformer properties and its saturation characteristics). This behavior is common to all transformers: when the core starts to be saturated there is a heavy amount of the 5$^{th}$ harmonic in the magnetizing current. When the overvoltage exceeds a certain point in the magnetizing characteristics, the 5$^{th}$ harmonic remains; however, the fundamental component of the current starts to grow very rapidly and as a result the relation of the 5$^{th}$ harmonic to fundamental decreases rapidly as a function of the primary side voltage. The growing magnetizing current is only seen on the transformer's primary side and the differential relay sees it as pure differential current. From the third graph we can see that the differential pick-up setting is reached when the voltage is approximately 125 % of the nominal value. This means that the differential current generated by the overexcitation could trip the transformer, as the ratio between the 5th harmonic and the fundamental magnitude decreases. If the overvoltage were, for example, 130 % of the nominal value, no blocking would be available; even the differential current would be greatly over the setting limit (appr. 40 % vs. the set 25 %). Nevertheless, this behavior can still be considered to be correct for the power transformer because an overvoltage like this can cause many serious problems and therefore tripping is desired.

The figures below present example waveforms of a transformer that is running with a 200 % rated voltage with the corresponding ratio between the 5$^{th}$ harmonic and the fundamental frequency component.

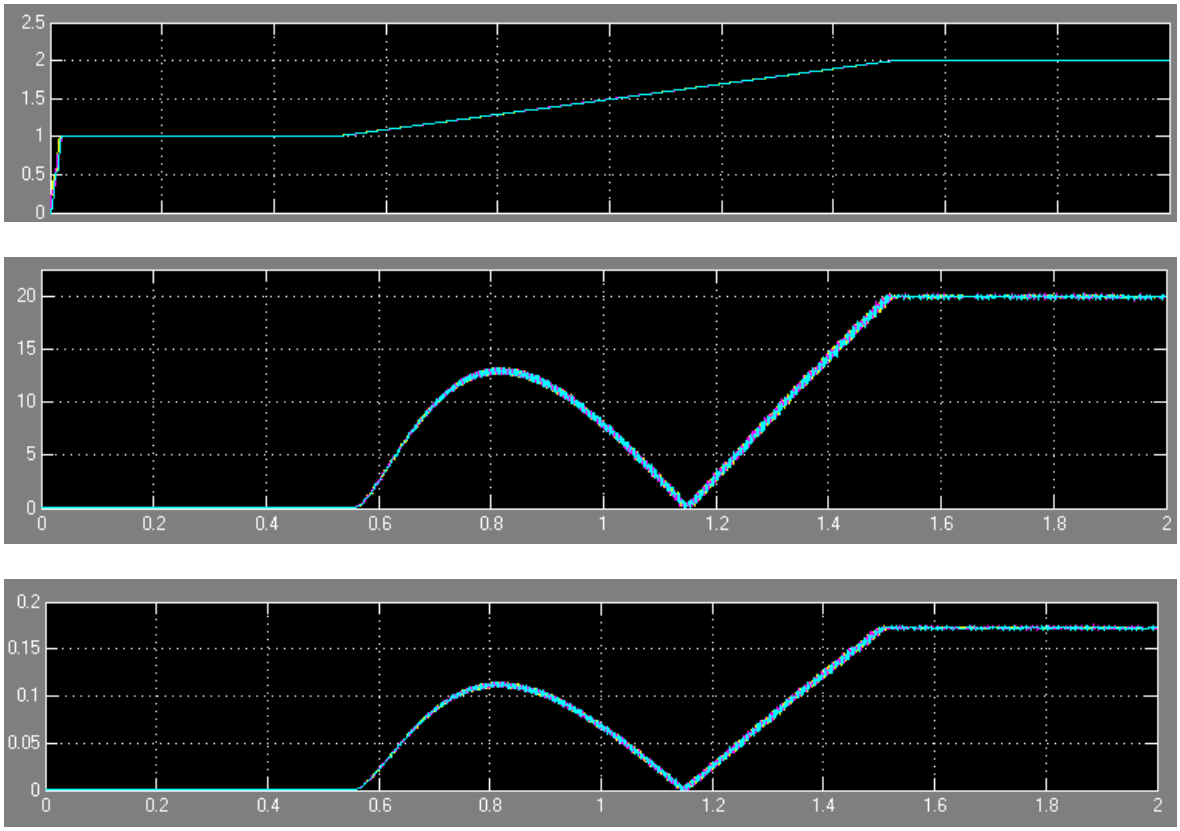
Figure. 5.4.10 - 73. Example waveforms.




Traditionally, the ratio between the 5$^{th}$ harmonic and the fundamental frequency component has been used in blocking the differential relay from tripping in overvoltage and overexcitation situations. However, the ratio is not a reliable method because you need to know the magnetizing properties and the hysteresis values exactly in order to set it correctly and for it to be of any use.

The figures below present the system voltage and the magnitude of the 5$^{th}$ harmonic component (both in per-unit), absolute and scaled to the transformer nominal.

Figure. 5.4.10 - 74. System voltage and magnitude of the 5th harmonic component.




As can be seen in the figure above, the 5th harmonic component first increases, then decreases and then increases again as the system voltage rises. In this case the 5th harmonic seems to disappear completely when around an overvoltage of 160 %. When the harmonic behaves this way, the previously mentioned blocking can be used as it automatically blocks on a smaller overvoltage (in case there is any differential current) and releases when the overvoltage is too heavy and the differential current is most probably over the tripping limit.

However, one should note that the behavior of this blocking is very unpredictable if the exact saturation characteristic and the transformer design are not known. If there is a chance that the overexcitation can cause problems (that is, no overvoltage relays are available), this blocking can be enabled with the setting of 30...40 % with the disturbance recorder enabled. If a trip occurs as a result of overexcitation, the settings can be adjusted based on the data captured by the disturbance recorder.



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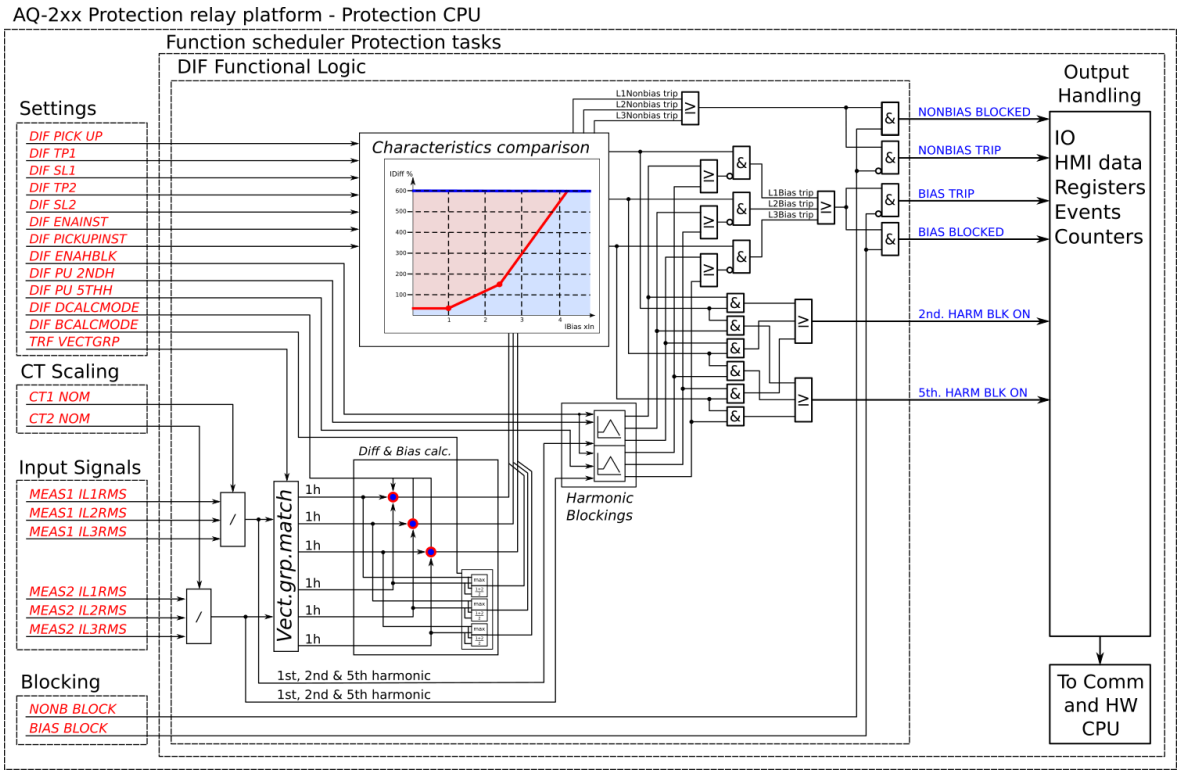
## Differential function details

Figure. 5.4.10 - 75. Simplified function block diagram of the transformer differential function.




The transformer differential function outputs TRIP and BLOCKED signals from the biased and non-biased functions as well as the 2nd and 5th harmonic block activation signals. These signals can be used in protection applications.

## Settings and signals

The settings of the differential function are a combination of transformer monitor and differential stage function settings. The following table shows the function's settings, including the general settings (in p.u.) used for pre-calculations.

Table. 5.4.10 - 88. Settings related to the differential function's pre-calculation.

| Name | Range | Step | Default | Function | Description |
|---|---|---|---|---|---|
| Idx> LN mode | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | 1: On | - | Set mode of DIF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |

| Name | Range | Step | Default | Function | Description |
|---|---|---|---|---|---|
| Idx> force status to | 0: Normal<br>1: Idb Blocked<br>2: Idb Trip<br>3: Idi Blocked<br>4: Idi Trip<br>5: H2block On<br>6: H5block On<br>7: HV I0d> Block On<br>8: HV I0d> Trip On<br>9: LV I0d> Block On<br>10: LV I0d> Trip On | - | 0: Normal | - | Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu. |
| Idx> LN behaviour | 1: On<br>2: Blocked<br>3: Test<br>4: Test/Blocked<br>5: Off | - | - | - | Displays the mode of DIF block.<br><br>This parameter is visible only when *Allow setting of individual LN mode* is enabled in *General* menu. |
| Transformer nominal | 0.1...500.0MVA | 0.1MVA | 1.0MVA | All | The nominal MVA of the transformer. This value is used to calculate the nominal currents onf both the HV and the LV side. |
| HV side nominal voltage | 0.1…500.0kV | 0.1kV | 110.0kV | All | The HV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the HV side. |
| LV side nominal voltage | 0.1…500.0kV | 0.1kV | 110.0kV | All | The LV side nominal voltage of the transformer. This value is used to calculate the nominal currents of the LV side. |
| Transformer Zk% | 0.01…25.00% | 0.01% | 3.00% | Info | The transformer's short-circuit impedance in percentages. Used for calculating short-circuit current. |
| Transformer nom. freq. | 10…75Hz | 1Hz | 50Hz | Info | The transformer's nominal frequency. Used for calculating the transformer's nominal short-circuit inductance. |
| Transf. vect. group | 0: Manual<br>1: Yy0<br>2: Yyn0<br>3: YNy0<br>4: YNyn0<br>5: Yy6<br>6: Yyn6<br>7: YNy6<br>8: YNyn6<br>9: Yd1<br>10: YNd1<br>11: Yd7<br>12: YNd7<br>13: Yd11<br>14: YNd11<br>15: Yd5<br>16: YNd5<br>17: Dy1<br>18: Dyn1<br>19: Dy7<br>20: Dyn7<br>21: Dy11<br>22: Dyn11<br>23: Dy5<br>24: Dyn5<br>25: Dd0<br>26: Dd6 | - | 1: Yy0 | - transformer status monitoring<br>- transformer differential | The selection of the transformer's vector group. The selection values (1–26) are predefined so that the scaling and vector matching are applied in the relay automatically when the correct vector group is selected.<br><br>The predefinitions assume that the HV side is connected to the CT1 module and that the LV side is connected to the CT2 module.<br><br>If the protected transformer vector group is not found in the predefined list, it can be manually set by selecting the option "0: Manual set". |



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| Name | Range | Step | Default | Function | Description |
|---|---|---|---|---|---|
| HV side Star or Zigzag/ Delta | 0: Star/Zigzag<br>1: Delta | - | 0: Star/ Zigzag | - transformer status monitoring<br>- transformer differential | The selection of the HV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV side grounded | 0: Not grounded<br>1: Grounded | - | 0: Not grounded | - transformer status monitoring<br>- transformer differential | The selection of whether or not the zero sequence compensation is applied in the HV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV side lead or lag LV | 0: Lead<br>1: Lag | - | 0: Lead | - transformer status monitoring<br>- transformer differential | The selection of whether the HV side leads or lags the LV side. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side Star/ Zigzag or Delta | 0: Star/Zigzag<br>1: Delta | - | 0: Star/ Zigzag | - transformer status monitoring<br>- transformer differential | The selection of the LV side connection. Can be selected between star or zigzag and delta. This selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side grounded | 0: Not grounded<br>1: Grounded | - | 0: Not grounded | - transformer status monitoring<br>- transformer differential | The selection of whether or not the zero sequence compensation is applied in the LV side current calculation. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| LV side lead or lag HV | 0: Lead<br>1: Lag | - | 0: Lead | - transformer status monitoring<br>- transformer differential | The selection of whether the LV side leads or lags the HV side. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV-LV side phase angle | 0.0...360.00deg | 0.1deg | 0.0deg | - transformer status monitoring<br>- transformer differential | The angle correction factor for HV/LV sides, looked from the HV side. E.g. if the transformer is Dy1, this is set to 30 degrees. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| HV-LV side mag correction | 0.0...100.0×$I_n$ | 0.1×$I_n$ | 0.0×$I_n$ | - transformer status monitoring<br>- transformer differential | The magnitude correction for the HV-LV side currents (in p.u.), if the currents are not directly matched through the calculations of the nominal values. The selection is visible only if the option "Manual set" for the vector group setting. |
| Check online HV-LV configuration | 0: -<br>1: Check | - | 0: - | - transformer status monitoring<br>- transformer differential | The selection of whether or not the function checks the current going through the transformer and then compares it to the settings. For this to work, the transformer needs to have a current flowing on both sides and "see" no faults. The selection is visible only if the option "Manual set" is selected for the vector group setting. |
| Enable I0d> (REF) HV side | 0: Disabled<br>1: Enabled | - | 0: Disabled | - transformer status monitoring<br>- transformer differential | The selection of whether the restricted earth fault stage on the HV side is enabled or disabled. |
| HV side starpoint meas. | 0: IO1<br>1: IO2 | - | 0: IO1 | - transformer status monitoring<br>- transformer differential | The selection of the starpoint measurement channel for the restricted earth fault protection on the HV side. This setting is only visible if the option "Enabled" is selected for the "Enable I0d> (REF) HV side" setting. |
| Enable I0d> (REF) LV side | 0: Disabled<br>1: Enabled | - | 0: Disabled | - transformer status monitoring<br>- transformer differential | The selection of whether the restricted earth fault stage on the LV side is enabled or disabled. |

| Name | Range | Step | Default | Function | Description |
|---|---|---|---|---|---|
| LV side starpint meas. | 0: IO1<br>1: IO2 | - | 0: IO1 | - transformer status monitoring<br>- transformer differential | The selection of the starpoint measurement channel for the restricted earth fault protection on the LV side. This setting is only visible if the option "Enabled" is selected for the "Enable I0d> (REF) LV side" setting. |

Table. 5.4.10 - 89. Settings for the operating characteristics.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Differential calculation mode | 0: Add<br>1: Subtract | - | 1: Subtract | The calculation mode of the differential current. The mode selection depends on the CTs' installation direction and the desired current directions. If the current flow on both sides is in the same direction, the differential current is subtracted. If the current flows are in the opposite directions, the differential current is added. |
| Bias calculation mode | 0: Average<br>1: Maximum | - | 0: Average | The calculation mode of the biasing current. With the average mode the operation may be set to be more sensitive. With the maximum mode the bias is always higher and thus provides a more stable operation. |
| Idb> Pick-up | 0.01…100.00% | 0.01% | 10.00% | The base sensitivity for the differential characteristics. |
| Turnpoint 1 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 1.00×$I_n$ | Turnpoint 1 for the differential characteristics. |
| Slope 1 | 0.01…250.00% | 0.01% | 10.00% | Slope 1 for the differential characteristics. |
| Turnpoint 2 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 3.00×$I_n$ | Turnpoint 2 for the differential characteristics. |
| Slope 2 | 0.01…250.00% | 0.01% | 200.00% | Slope 2 of the differential characteristics- |
| Enable harmonic blocking | 0: No harmonic blocking<br>1: 2nd harmonic blocking<br>2: 5th harmonic blocking<br>3: 2nd and 5th harmonic blocking | - | 1: 2nd harmonic blocking | The selection of the internal blockings to be used for the detection of transformer normal operations that cause differential currents. |
| 2nd harmonic blocking pick-up | 0.01…50.00% | 0.01% | 15.00% | The pick-up detection for the 2nd harmonic blocking stage. This setting is only visible if the "Enable harmonic blocking" setting is set to "1" or "3". |
| 5th harmonic blocking pick-up | 0.01…50.00% | 0.01% | 35.00% | The pick-up detection for the 5th harmonic blocking stage. This setting is only visible if the "Enable harmonic blocking" setting is set to "2" or "3". |
| Enable Idi> stage | 0: Disabled<br>1: Enabled | - | 1: Enabled | The selection of whether the non-biased and the non-blocked differential stage is enabled or disabled. |
| Idi> Non-biased pick-up | 200.00…1500.00% | 0.01% | 600.00% | The pick-up setting for the non-biased and non-blocked differential stage. This setting is only visible if the "Enable Idi> stage" is disabled. |
| HV I0d> Pick-up | 0.01…100.00% | 0.01% | 10.00% | The base sensitivity for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled. |
| HV I0d> Turnpoint 1 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 1.00×$I_n$ | Turnpoint 1 for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled. |
| HV I0d> Slope 1 | 0.01…250.00% | 0.01% | 10.00% | Slope 1 of the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| HV I0d> Turnpoint 2 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 3.00×$I_n$ | Turnpoint 2 for the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled. |
| HV I0d> Slope 2 | 0.01…250.00% | 0.01% | 200.00% | Slope 2 of the HV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) HV side" setting is enabled. |
| LV I0d> Pick-up | 0.01…100.00% | 0.01% | 10.00% | The base sensitivity for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled. |
| LV I0d> Turnpoint 1 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 1.00×$I_n$ | Turnpoint 1 for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled. |
| LV I0d> Slope 1 | 0.01…250.00% | 0.01% | 10.00% | Slope 1 of the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled. |
| LV I0d> Turnpoint2 | 0.01…50.00×$I_n$ | 0.01×$I_n$ | 3.00×$I_n$ | Turnpoint 2 for the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled. |
| LV I0d> Slope 2 | 0.01…250.00% | 0.01% | 200.00% | Slope 2 of the LV side restricted earth fault differential characteristics. This setting is only visible if the "Enable I0d> (REF) LV side" setting is enabled. |

Table. 5.4.10 - 90. Calculations of the transformer differential function.

| Name | Description |
|---|---|
| L1Bias | The calculated phase L1 bias current |
| L2Bias | The calculated phase L2 bias current |
| L3Bias | The calculated phase L3 bias current |
| L1Diff | The calculated phase L1 differential current |
| L2Diff | The calculated phase L2 differential current |
| L3Diff | The calculated phase L3 differential current |
| L1Char | The calculated phase L1 maximum differential current allowed with current bias level |
| L2Char | The calculated phase L1 maximum differential current allowed with current bias level |
| L3Char | The calculated phase L1 maximum differential current allowed with current bias level |
| HV I0d> Bias current | The calculated HV side restricted earth fault bias current |
| HV I0d> Diff current | The calculated HV side restricted earth fault differential current |
| HV I0d> Char current | The calculated HV side restricted earth fault differential current allowed with current bias level |
| LV I0d> Bias current | The calculated LV side restricted earth fault bias current |
| LV I0d> Diff current | The calculated LV side restricted earth fault differential current |
| LV I0d> Char current | The calculated LV side restricted earth fault differential current allowed with current bias level |

Table. 5.4.10 - 91. Output signals of the transformer differential function.

| Name | Description |
|---|---|
| Idb> Bias Trip | The TRIP output signal from the biased differential stage |
| Idi> Nobias Trip | The TRIP output signal from the non-biased and non-blocked differential stage |
| Idb> Bias Blocked | The BLOCKED output from the biased differential stage (external blocking) |

| Name | Description |
|---|---|
| Idi> Bias Blocked | The BLOCKED output from the non-biased and non-blocked differential stage (external blocking) |
| Idb> 2nd harm block on | The output of the 2nd harmonic activation signal |
| Idb> 5th harm block on | The output of the 5th harmonic activation signal |
| HV I0d> Trip | The TRIP output signal from the biased restricted earth fault differential stage on the HV side |
| HV I0d> Trip | The BLOCKED output signal from the biased restricted earth fault differential stage on the HV side |
| LV I0d> Trip | The TRIP output signal from the biased restricted earth fault differential stage on the LV side |
| LV I0d> Trip | The BLOCKED output signal from the biased restricted earth fault differential stage on the LV side |

## Events and registers

The transformer differential function (abbreviated "DIF" in event block names) generates events from internal status changes. The data register is available, based on the changes in the tripping events.

Table. 5.4.10 - 92. Event messages.

| Event block name | Event names |
|---|---|
| DIF1 | Idb> Trip ON |
| DIF1 | Idb> Trip OFF |
| DIF1 | Idb> Blocked (ext) ON |
| DIF1 | Idb> Blocked (ext) OFF |
| DIF1 | Idi> Trip ON |
| DIF1 | Idi> Trip OFF |
| DIF1 | Idi> Blocked (ext) ON |
| DIF1 | Idi> Blocked (ext) OFF |
| DIF1 | 2nd Harmonic Block ON |
| DIF1 | 2nd Harmonic Block OFF |
| DIF1 | 5th Harmonic Block ON |
| DIF1 | 5th Harmonic Block OFF |
| DIF1 | L1 2nd harmonic ON |
| DIF1 | L1 2nd harmonic OFF |
| DIF1 | L2 2nd harmonic ON |
| DIF1 | L2 2nd harmonic OFF |
| DIF1 | L3 2nd harmonic ON |
| DIF1 | L3 2nd harmonic OFF |
| DIF1 | L1 5th harmonic ON |
| DIF1 | L1 5th harmonic OFF |
| DIF1 | L2 5th harmonic ON |
| DIF1 | L2 5th harmonic OFF |


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| Event block name | Event names |
|---|---|
| DIF1 | L3 5th harmonic ON |
| DIF1 | L3 5th harmonic OFF |
| DIF1 | HV I0d> Block ON |
| DIF1 | HV I0d> Block OFF |
| DIF1 | HV I0d> Trip ON |
| DIF1 | HV I0d> Trip OFF |
| DIF1 | LV I0d> Block ON |
| DIF1 | LV I0d> Block OFF |
| DIF1 | LV I0d> Trip ON |
| DIF1 | LV I0d> Trip 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.

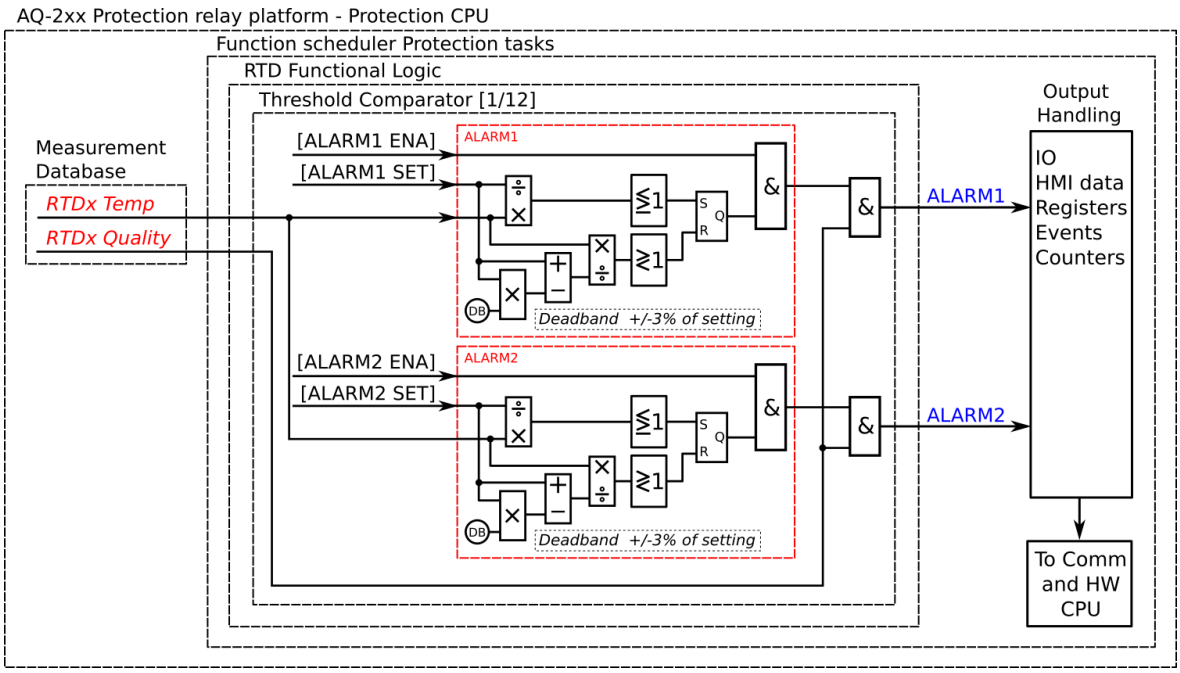
Table. 5.4.10 - 93. Register content.

| Name | Description |
|---|---|
| Date and time | dd.mm.yyyy hh:mm:ss.mss |
| Event | Event name |
| L1 bias current | Phase L1 bias current |
| L1 diff. current | Phase L1 maximum differential current |
| L1 char. current | Phase L1 maximum differential current with bias |
| L2 bias current | Phase L2 bias current |
| L2 diff. current | Phase L2 maximum differential current |
| L2 char. current | Phase L2 maximum differential current with bias |
| L3 bias current | Phase L3 bias current |
| L3 diff. current | Phase L3 maximum differential current |
| L3 char. current | Phase L3 maximum differential current with bias |
| HV I0d> bias current | HV side REF bias current |
| HV I0d> differential current | HV side REF differential current |
| HV I0d> characteristics current | HV side REF maximum differential current with bias |
| LV I0d> bias current | LV side REF bias current |
| LV I0d> differential current | LV side REF differential current |
| LV I0d> characteristics current | LV side REF maximum differential current with bias |
| Used SG | Setting group in use |
| Ftype | Detected fault type (faulty phases) |

### 5.4.11 Resistance temperature detectors (RTD)

Resistance temperature detectors (or RTDs) can be used to measure both temperatures of motors/ generators and ambient temperatures. Typically an RTD is a thermocouple or of type PT100. Up to three (3) separate RTD modules based on an external Modbus are supported; each can hold up to eight (8) measurement elements. Up to two (2) separate RTD option cards are supported by this function. Sixteen (16) individual element monitors can be set for this alarm function, and each of those can be set to alarm two (2) separate alarms from one selected input. The user can set alarms and measurements to be either in degrees Celsius or Fahrenheit.

The following figure shows the principal structure of the resistance temperature detection function.




Setting up an RTD measurement, the user first needs to set the measurement module to scan the wanted RTD elements. A multitude of Modbus-based modules are supported. Communication requires bitrate, databits, parity, stopbits and Modbus I/O protocol to be set; this is done at *Communication → Connections*. Once communication is set, the wanted channels are selected at *Communication → Protocols → ModbusIO*. Then the user selects the measurement module from the three (3) available modules (A, B and C), as well as the poll address. Additionally, both the module type and the polled channels need to be set. When using a thermocouple module, the thermo element type also needs to be set for each of the measurement channels. Once these settings are done the RTDs are ready for other functions.


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Figure. 5.4.11 - 76. RTD alarm setup.

Function can be set to monitor the measurement data from previously set RTD channels. A single channel can be set to have several alarms if the user sets the channel to multiple sensor inputs. In each sensor setting the user can select the monitored module and channel, as well as the monitoring and alarm setting units (°C or °F). The alarms can be enabled, given a setting value (in degrees), and be set to trigger either above or below the setting value. There are sixteen (16) available sensor inputs in the function. An active alarm requires a valid channel measurement. It can be invalid if communication is not working or if a sensor is broken.

## Settings

Table. 5.4.11 - 94. General settings of the function.

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

Table. 5.4.11 - 95. Function settings for Channel x (Sx).

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| S1...S16 enable | 0: No<br>1: Yes | - | 0: No | Enables/disables the selecion of sensor measurements and alarms. |
| S1...S16 module | 0: InternalRTD1<br>1: InternalRTD2<br>2: ExtModuleA<br>3: ExtModuleB<br>4: ExtModuleC | - | 0: InternalRTD1 | Selects the measurement module. Internal RTD modules are option cards installed to the relay. External modules are Modbus based external devices. |
| S1...S16 channel | 0: Channel 0<br>1: Channel 1<br>3: Channel 2<br>4: Channel 3<br>5: Channel 4<br>6: Channel 5<br>7: Channel 6<br>8: Channel 7 | - | 0: Channel 0 | Selects the measurement channel in the selected module. |
| S1...S16 Deg C/Dec F | 0: Deg C<br>1: Deg F | - | 0: Deg C | Selects the measurement temperature scale (Celsius or Fahrenheit). |
| S1...S16 Measurement | - | - | - | Displays the measurement value in the selected temperature scale. |
| S1...S16 Sensor | 0: Ok<br>1: Invalid | - | - | Displays the measured sensor's data validity. If the sensor reading has any problems, the sensor data is set to "Invalid" and the alarms are not activated. |
| S1...S16 Enable alarm 1 | 0: Disable<br>1: Enable | - | 0: Disable | Enables/disables the selection of Alarm 1 for the measurement channel x. |
| S1...S16 Alarm1 >/< | 0: ><br>1: < | - | 0: > | Selects whether the alarm activates when measurement is above or below the pick-up setting value. |
| S1...S16 Alarm1 | -101.0…2000.0deg | 0.1deg | 0.0deg | Sets the pick-up value for Alarm 1. The alarm is activated if the measurement goes above or below this setting mode (depends on the selected mode in "Sx Alarm1 >/<"). |
| S1...S16 sensor | 0: Ok<br>1: Invalid | - | - | Displays the measured sensor's data validity. If the sensor reading has any problems, the sensor data is set to "Invalid" and the alarms are not activated. |
| S1...S16 Enable alarm 2 | 0: Disable<br>1: Enable | - | 0: Disable | Enables/disables the selection of Alarm 2 for the measurement channel x. |
| S1...S16 Alarm2 >/< | 0: ><br>1: < | - | 0: > | Selects whether the measurement is above or below the setting value. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| S1...S16 Alarm2 | -101.0…2000.0deg | 0.1deg | 0.0deg | Sets the value for Alarm 2. The alarm is activated if the measurement goes above or below this setting mode (depends on the selected mode in "Sx Alarm2 >/<"). |

When the RTDs have been set, the values can be read to SCADA (or some other control system). The alarms can also be used for direct output control as well as in logics.

## Events

The resistance temperature detector function (abbreviated "RTD" in event block names) generates events and registers from the status changes in ALARM and MEAS INVALID. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The  function offers sixteen (16) 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. The function registers its operation into the last twelve (12) time-stamped registers.

Table. 5.4.11 - 96. Event messages.

| Event block name | Event names |
|---|---|
| RTD1 | S1 Alarm1 ON |
| RTD1 | S1 Alarm1 OFF |
| RTD1 | S1 Alarm2 ON |
| RTD1 | S1 Alarm2 OFF |
| RTD1 | S2 Alarm1 ON |
| RTD1 | S2 Alarm1 OFF |
| RTD1 | S2 Alarm2 ON |
| RTD1 | S2 Alarm2 OFF |
| RTD1 | S3 Alarm1 ON |
| RTD1 | S3 Alarm1 OFF |
| RTD1 | S3 Alarm2 ON |
| RTD1 | S3 Alarm2 OFF |
| RTD1 | S4 Alarm1 ON |
| RTD1 | S4 Alarm1 OFF |
| RTD1 | S4 Alarm2 ON |
| RTD1 | S4 Alarm2 OFF |
| RTD1 | S5 Alarm1 ON |
| RTD1 | S5 Alarm1 OFF |
| RTD1 | S5 Alarm2 ON |
| RTD1 | S5 Alarm2 OFF |
| RTD1 | S6 Alarm1 ON |
| RTD1 | S6 Alarm1 OFF |
| RTD1 | S6 Alarm2 ON |
| RTD1 | S6 Alarm2 OFF |

| Event block name | Event names |
|---|---|
| RTD1 | S7 Alarm1 ON |
| RTD1 | S7 Alarm1 OFF |
| RTD1 | S7 Alarm2 ON |
| RTD1 | S7 Alarm2 OFF |
| RTD1 | S8 Alarm1 ON |
| RTD1 | S8 Alarm1 OFF |
| RTD1 | S8 Alarm2 ON |
| RTD1 | S8 Alarm2 OFF |
| RTD1 | S9 Alarm1 ON |
| RTD1 | S9 Alarm1 OFF |
| RTD1 | S9 Alarm2 ON |
| RTD1 | S9 Alarm2 OFF |
| RTD1 | S10 Alarm1 ON |
| RTD1 | S10 Alarm1 OFF |
| RTD1 | S10 Alarm2 ON |
| RTD1 | S10 Alarm2 OFF |
| RTD1 | S11 Alarm1 ON |
| RTD1 | S11 Alarm1 OFF |
| RTD1 | S11 Alarm2 ON |
| RTD1 | S11 Alarm2 OFF |
| RTD1 | S12 Alarm1 ON |
| RTD1 | S12 Alarm1 OFF |
| RTD1 | S12 Alarm2 ON |
| RTD1 | S12 Alarm2 OFF |
| RTD1 | S13 Alarm1 ON |
| RTD1 | S13 Alarm1 OFF |
| RTD1 | S13 Alarm2 ON |
| RTD1 | S13 Alarm2 OFF |
| RTD1 | S14 Alarm1 ON |
| RTD1 | S14 Alarm1 OFF |
| RTD1 | S14 Alarm2 ON |
| RTD1 | S14 Alarm2 OFF |
| RTD1 | S15 Alarm1 ON |
| RTD1 | S15 Alarm1 OFF |
| RTD1 | S15 Alarm2 ON |
| RTD1 | S15 Alarm2 OFF |
| RTD1 | S16 Alarm1 ON |
| RTD1 | S16 Alarm1 OFF |


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| Event block name | Event names |
|---|---|
| RTD1 | S16 Alarm2 ON |
| RTD1 | S16 Alarm2 OFF |
| RTD2 | S1 Meas Ok |
| RTD2 | S1 Meas Invalid |
| RTD2 | S2 Meas Ok |
| RTD2 | S2 Meas Invalid |
| RTD2 | S3 Meas Ok |
| RTD2 | S3 Meas Invalid |
| RTD2 | S4 Meas Ok |
| RTD2 | S4 Meas Invalid |
| RTD2 | S5 Meas Ok |
| RTD2 | S5 Meas Invalid |
| RTD2 | S6 Meas Ok |
| RTD2 | S6 Meas Invalid |
| RTD2 | S7 Meas Ok |
| RTD2 | S7 Meas Invalid |
| RTD2 | S8 Meas Ok |
| RTD2 | S8 Meas Invalid |
| RTD2 | S9 Meas Ok |
| RTD2 | S9 Meas Invalid |
| RTD2 | S10 Meas Ok |
| RTD2 | S10 Meas Invalid |
| RTD2 | S11 Meas Ok |
| RTD2 | S11 Meas Invalid |
| RTD2 | S12 Meas Ok |
| RTD2 | S12 Meas Invalid |
| RTD2 | S13 Meas Ok |
| RTD2 | S13 Meas Invalid |
| RTD2 | S14 Meas Ok |
| RTD2 | S14 Meas Invalid |
| RTD2 | S15 Meas Ok |
| RTD2 | S15 Meas Invalid |
| RTD2 | S16 Meas Ok |
| RTD2 | S16 Meas Invalid |

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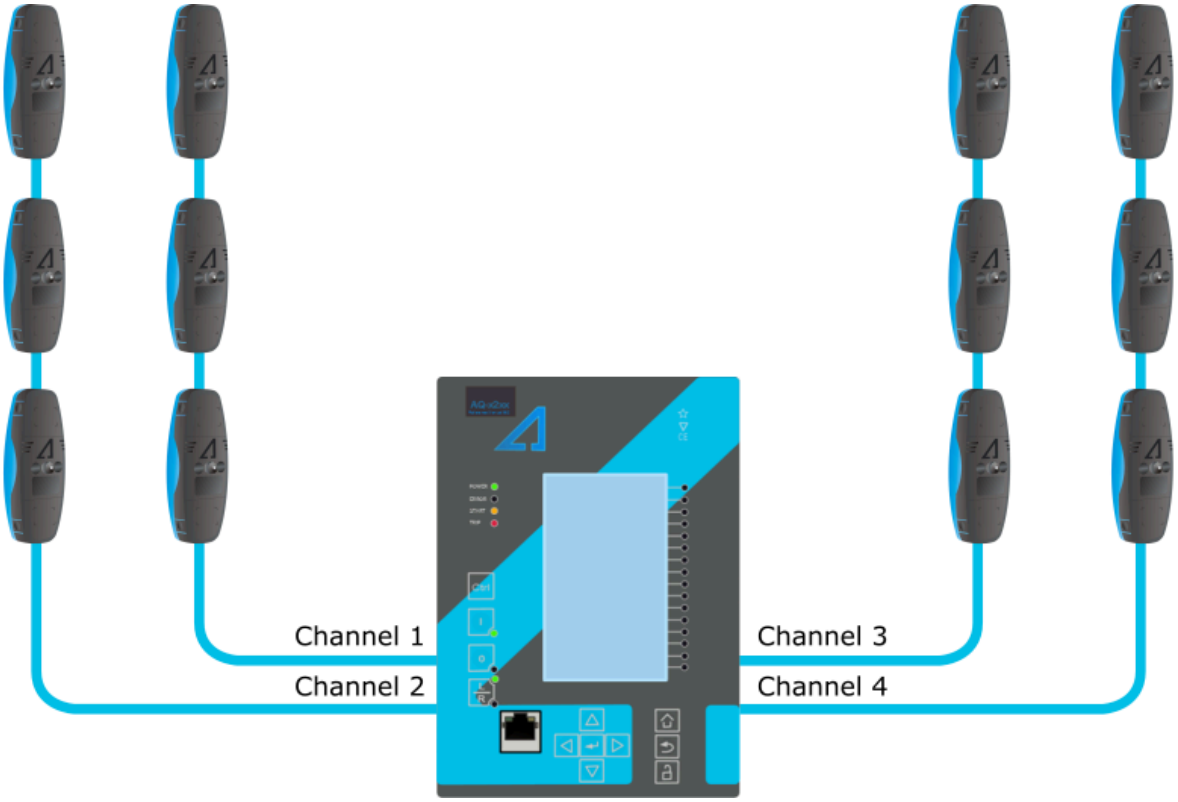
## 5.4.12 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc)

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.

Figure. 5.4.12 - 77. 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.


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Table. 5.4.12 - 97. 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. |
| 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.

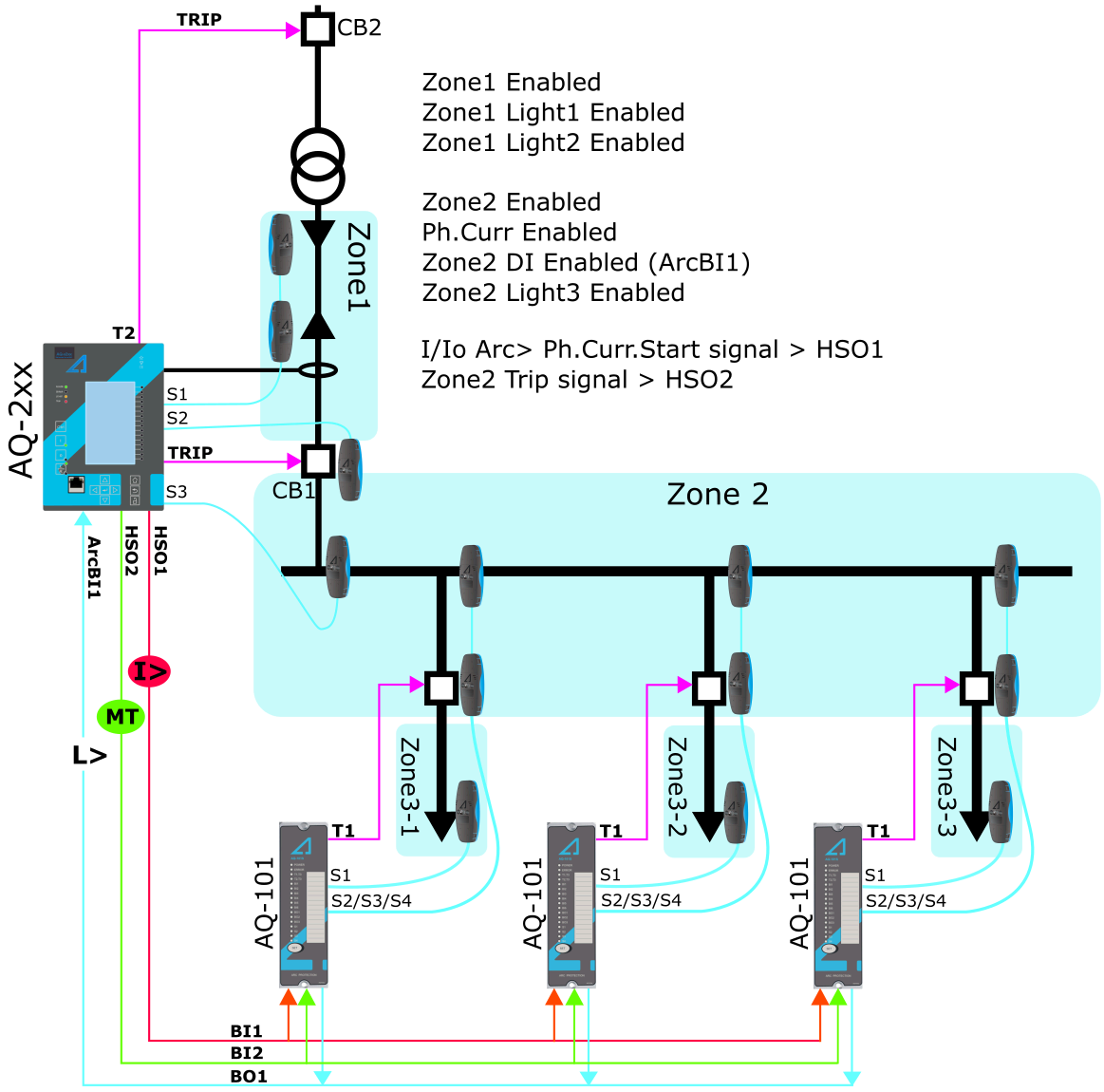
The function's outputs are TRIP, BLOCKED, light sensing etc. signals which can be used for direct I/O controlling and user logic programming. The function generates general time-stamped ON/OFF events to the common event buffer from each of the 26 output signals. The time stamp resolution is 1 ms. The 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.

Figure. 5.4.12 - 78. 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.



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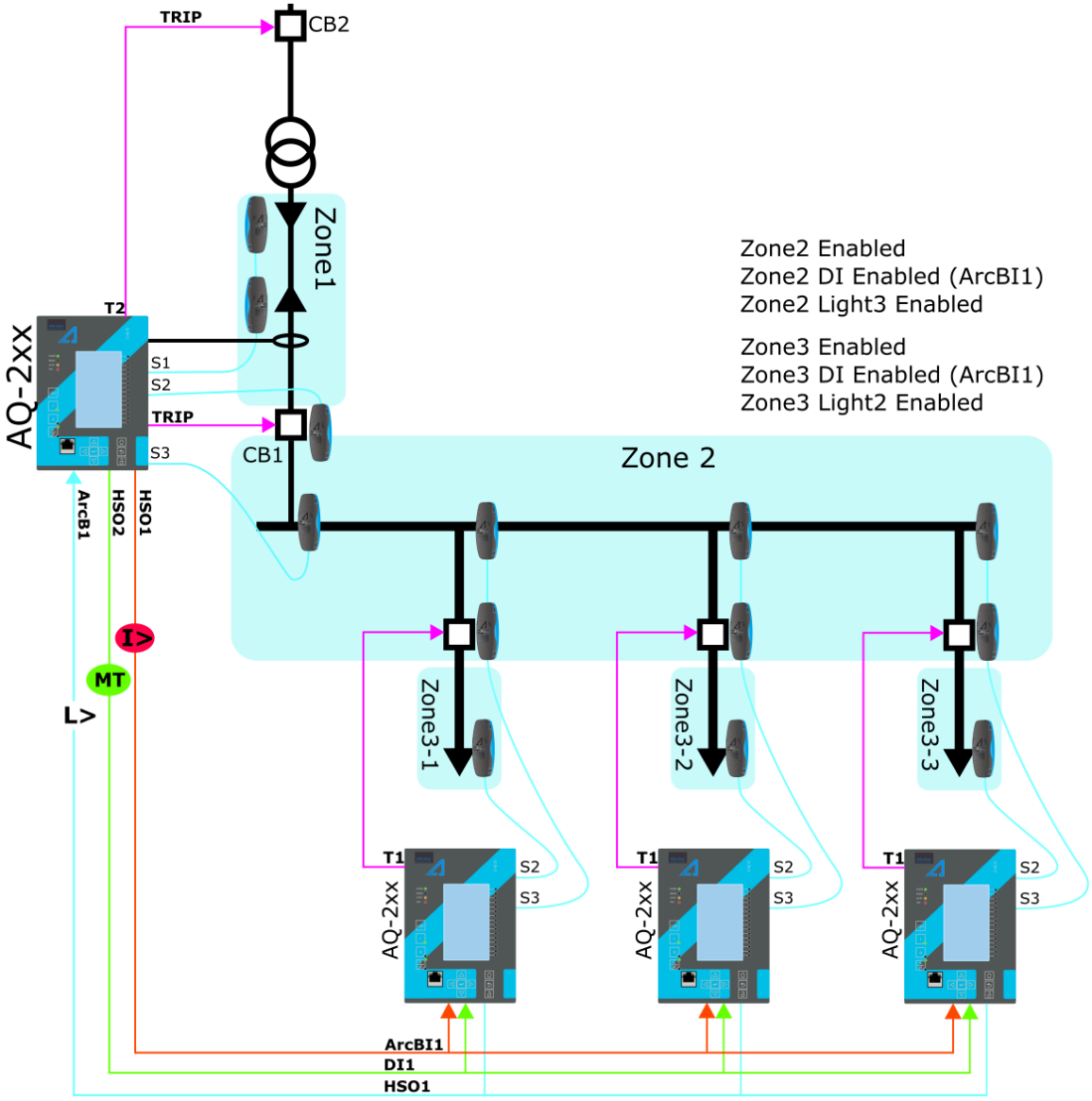
The next example is almost like the previous one: it is also a single-line diagram with AQ-2xx series relays. However, this time each outgoing feeder has an AQ-2xx protection relay instead of an AQ-101 arc protection relay.

Figure. 5.4.12 - 79. 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.

## 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 - 98. 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 | 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 2 sensors | | | |
| Channel 3 sensors | | | |
| Channel 4 sensors | | | |
| Channel 1 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. |
| Channel 2 sensor status | | | |



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| Name | Range | Default | Description |
|---|---|---|---|
| Channel 3 sensor status | | | |
| Channel 4 sensor status | | | |

## 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. 5.4.12 - 99. 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 |

| Name | Description | Range | Step | Default |
|---|---|---|---|---|
| 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.

## 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 - 100. 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. |



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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 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. 5.4.12 - 101. 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 |

| Event block name | Event names |
|---|---|
| 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 |
| 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. 5.4.12 - 102. 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 |



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# 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 - 103. 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 - 104. 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 - 105. 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 - 106. Event messages.

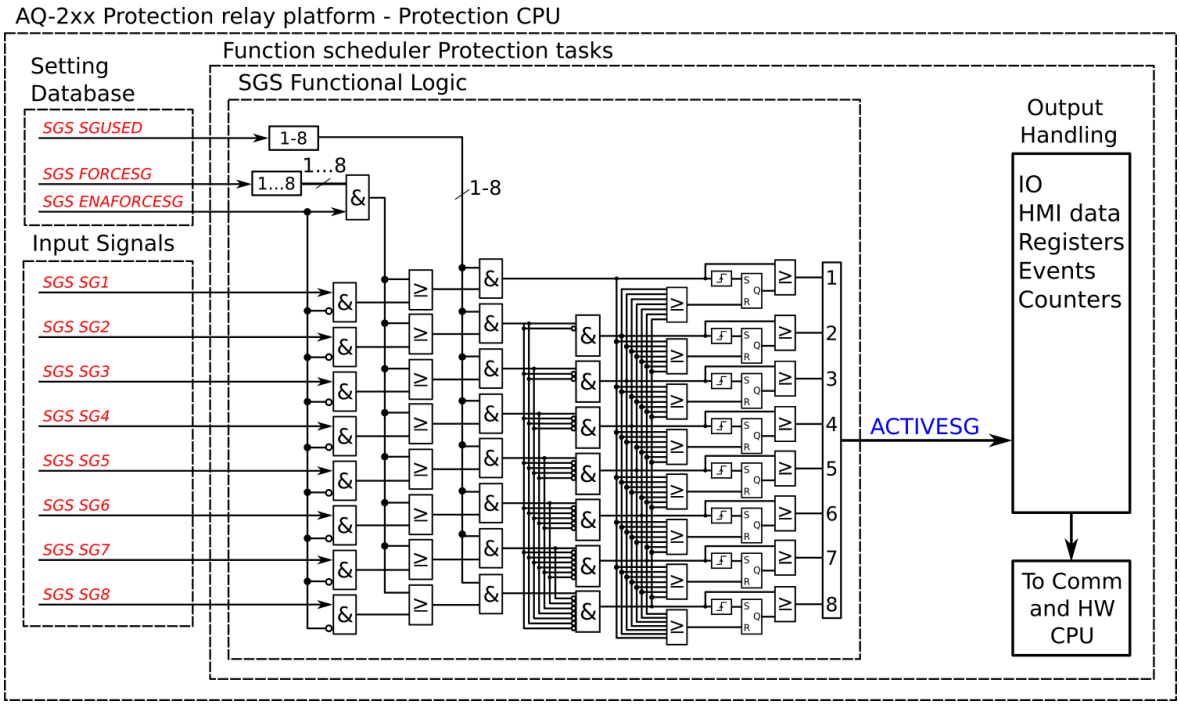
| Event block name | Event names |
|---|---|
| GNSIG | Common Start ON |
| GNSIG | Common Start OFF |
| GNSIG | Common Trip ON |
| GNSIG | Common Trip OFF |

## 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.

Figure. 5.5.2 - 80. Simplified function block diagram of the setting group selection function.



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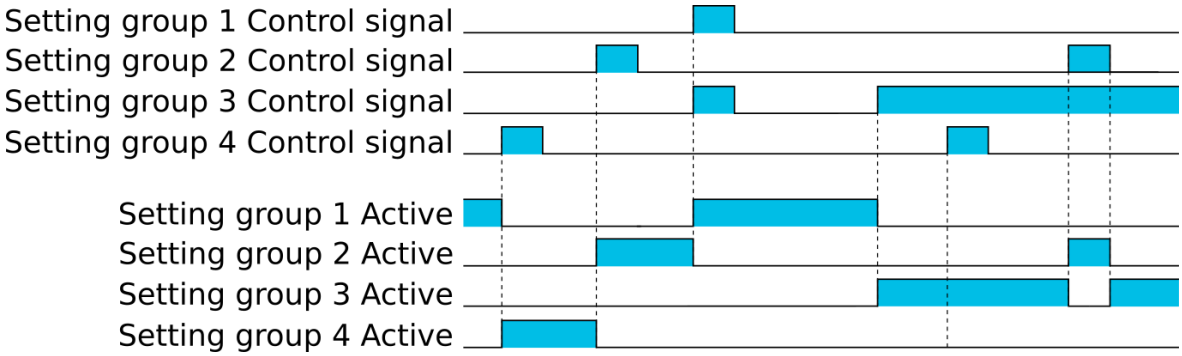
Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs and connected digital inputs. The user can also force any of the setting groups on when the "Force SG change" setting is enabled by giving the wanted quantity of setting 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 - 81. 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 - 107. 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. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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 - 108. 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. |
| Setting group 2 | 0: Not active<br>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<br>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<br>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<br>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<br>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<br>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<br>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. |



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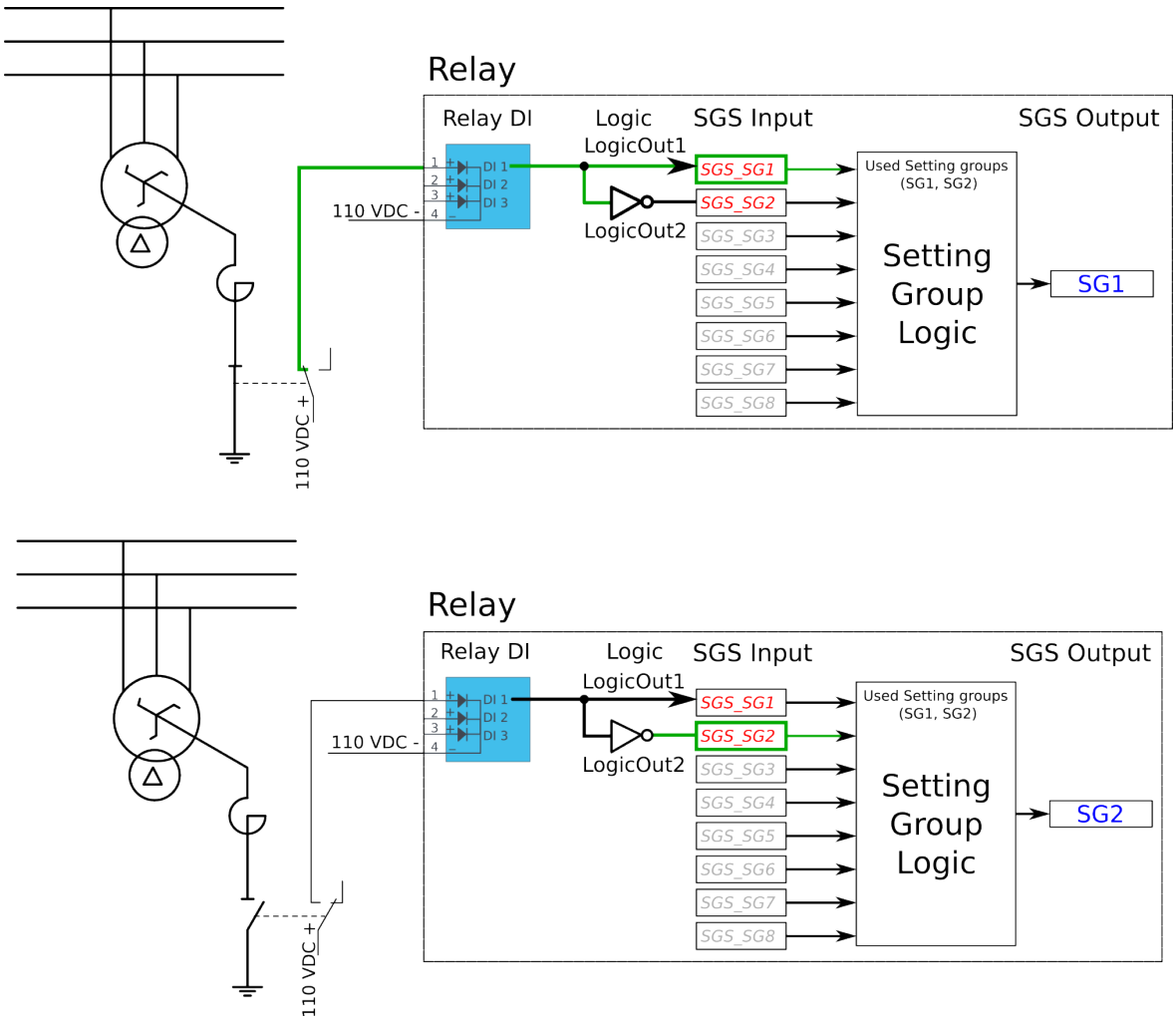
## Example applications for setting group control

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 - 82. 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.

Figure. 5.5.2 - 83. Setting group control – two-wire connection from Petersen coil status.

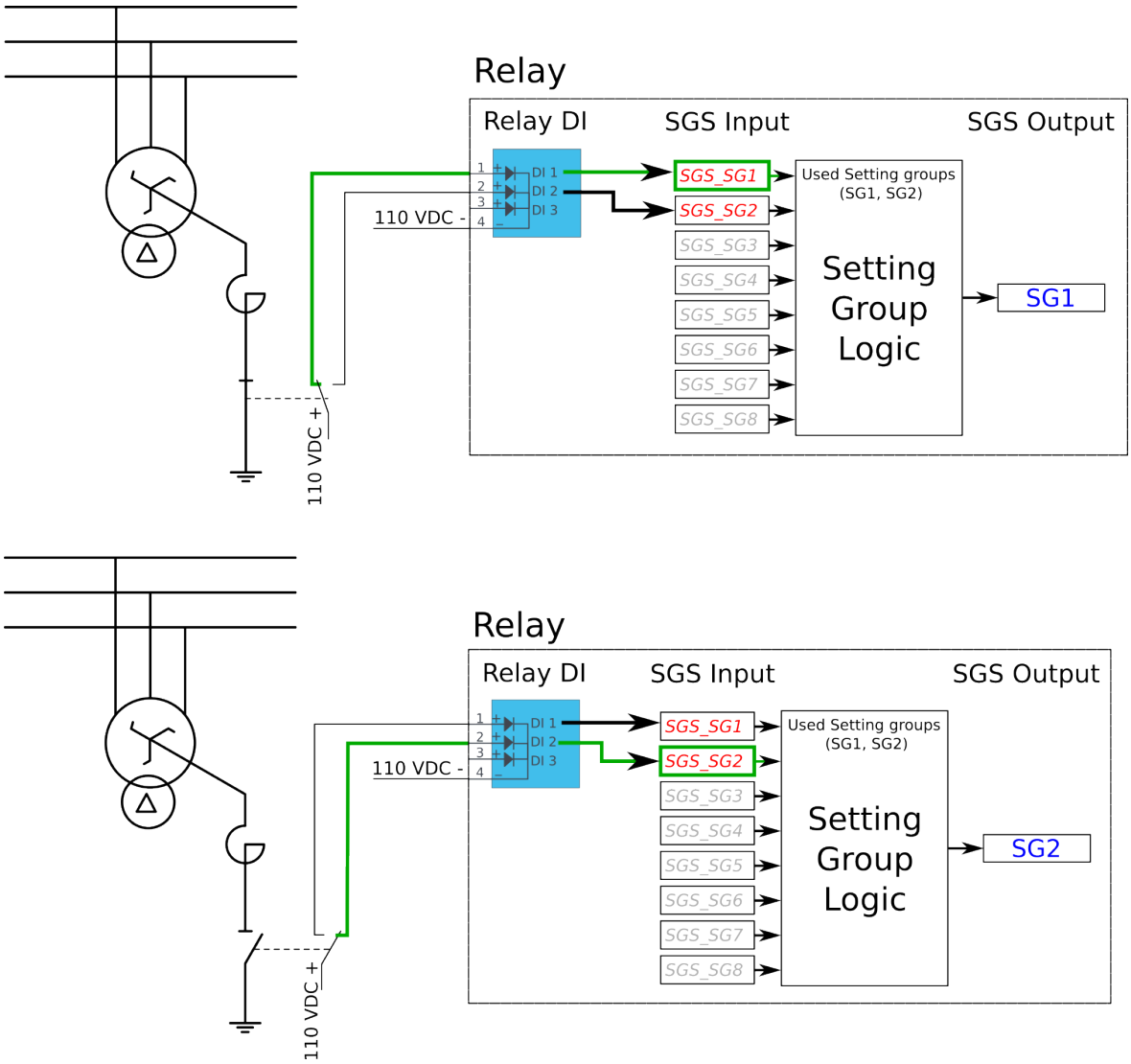





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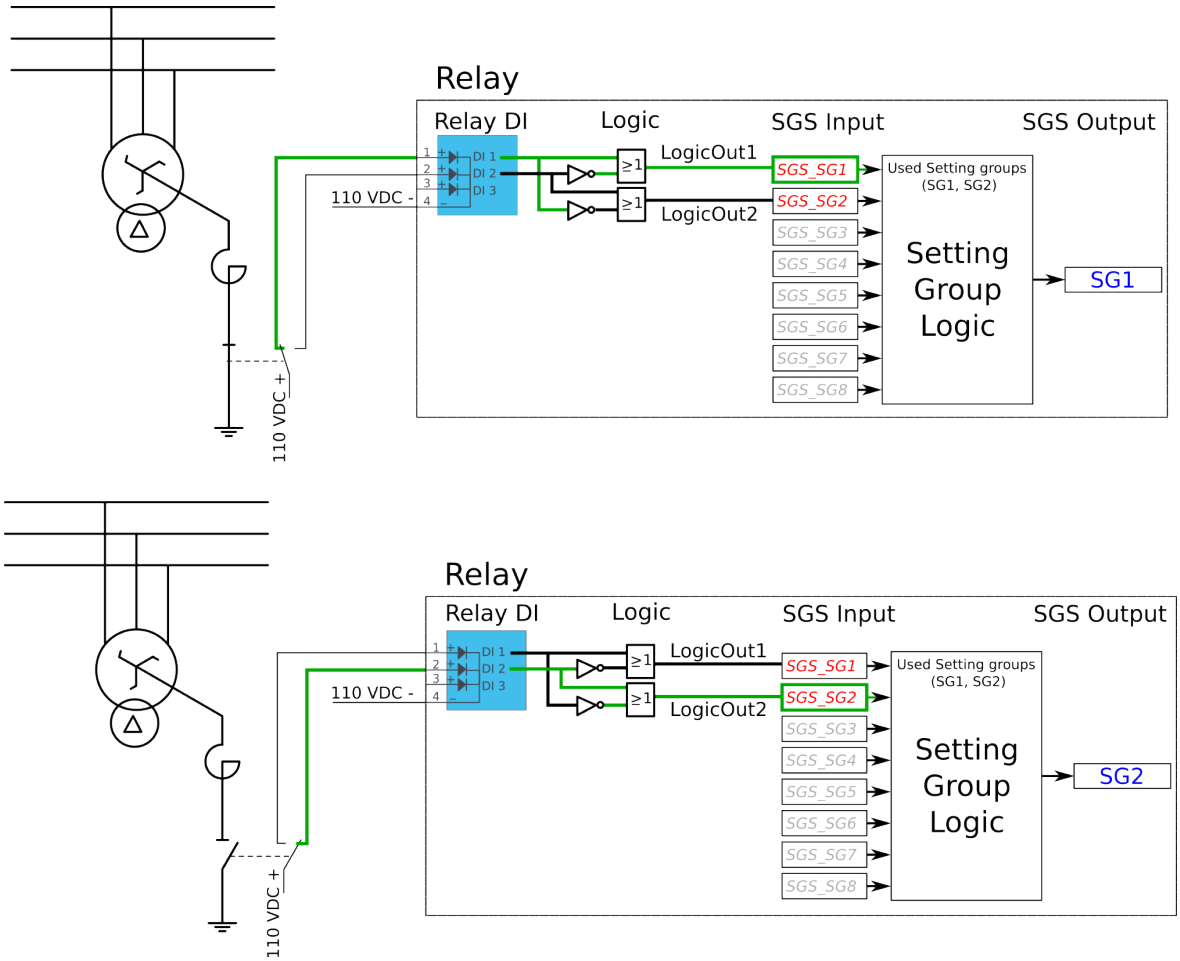
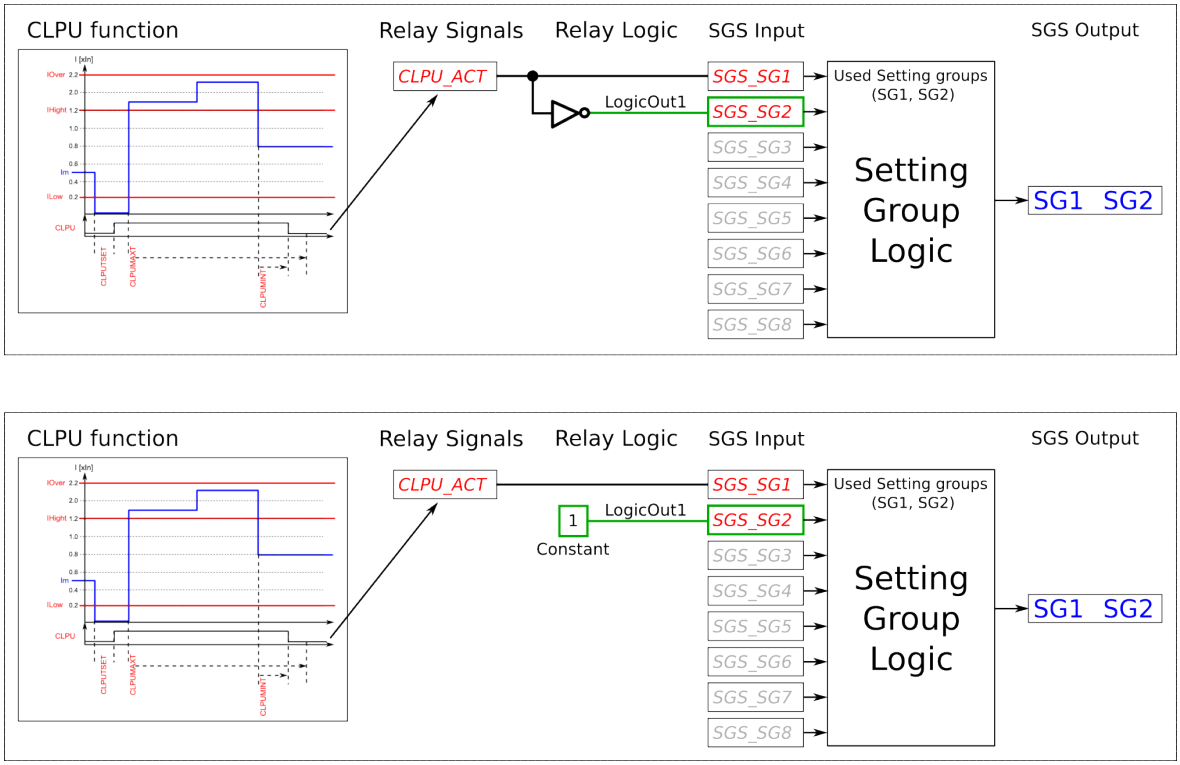
Figure. 5.5.2 - 84. Setting group control – two-wire connection from Petersen coil status with additional logic.




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).

Figure. 5.5.2 - 85. 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 - 109. 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 |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| 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).


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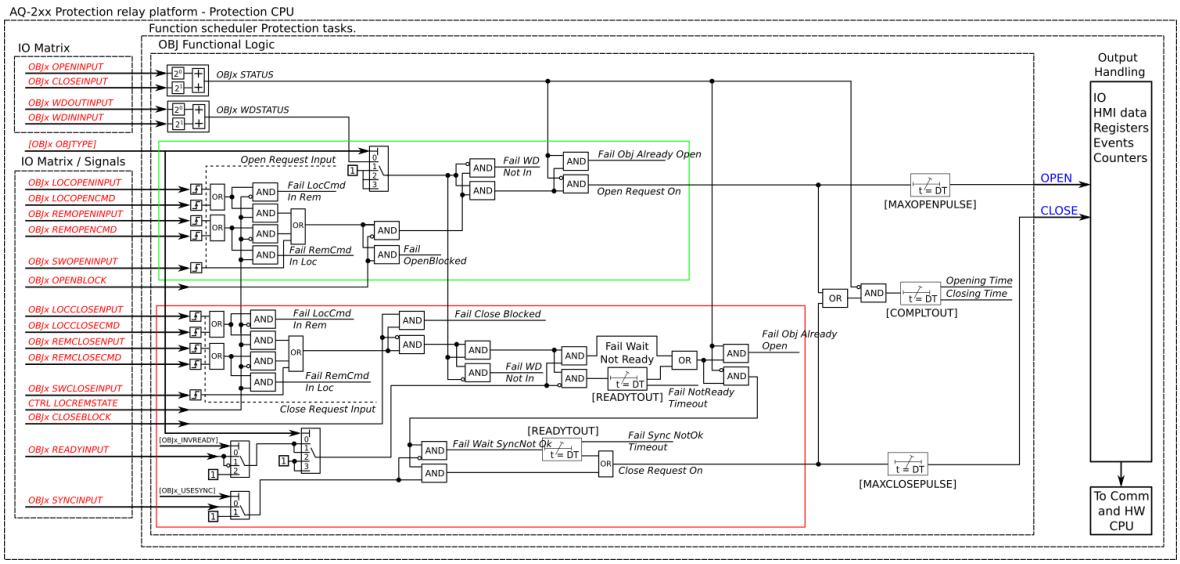
The function generates general time stamped ON/OFF events to the common event buffer from each of the two (2) output signals as well as several operational event signals. The time stamp resolution is 1 ms. The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAILED, and CLOSE FAILED events.

The following figure presents a simplified function block diagram of the object control and monitoring function.

Figure. 5.5.3 - 86. 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 - 110. 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. |

| 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. |



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| 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 - 111. 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 - 112. 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. |

| 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 - 113. 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 - 114. 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). |



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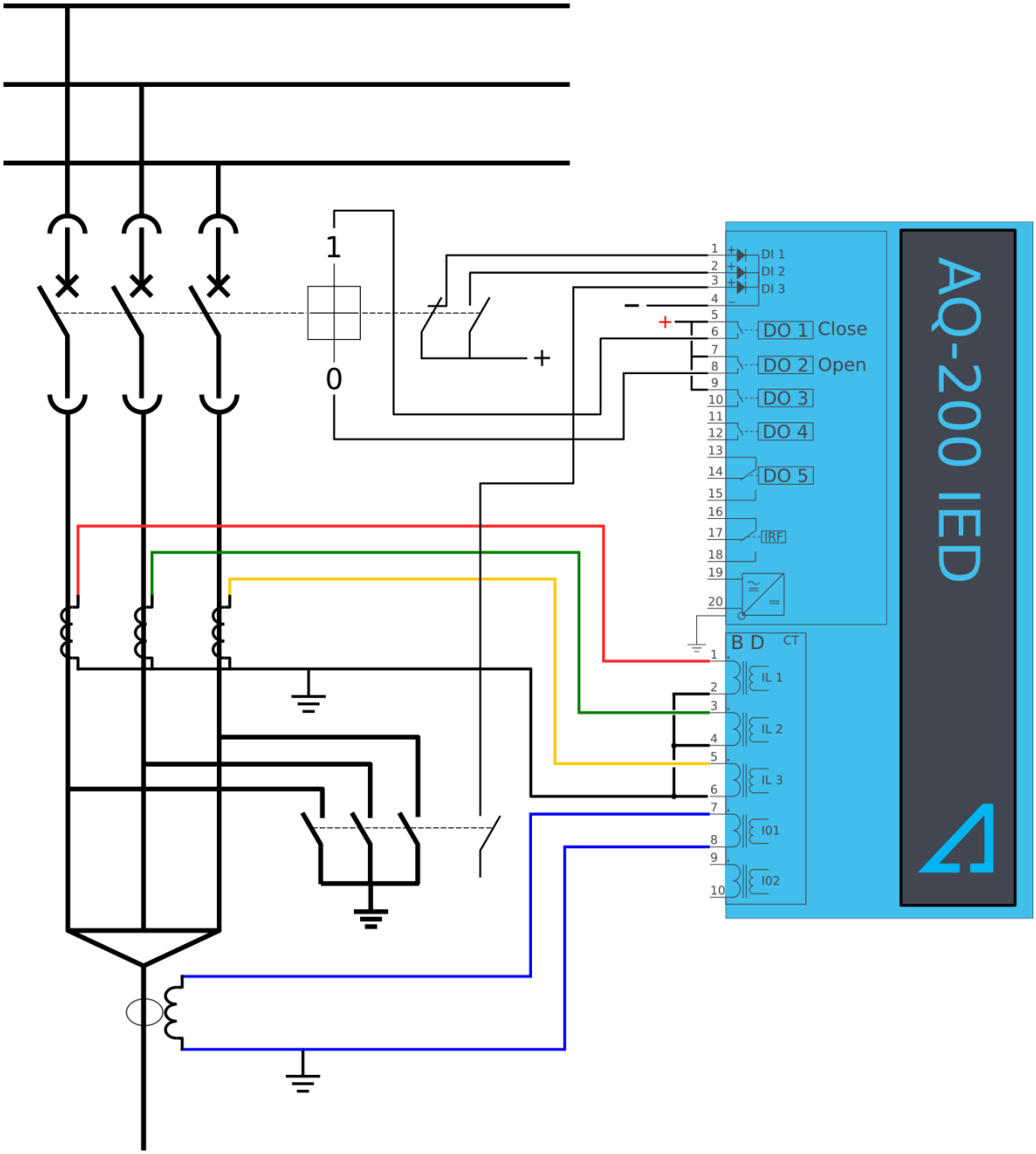
| Signal | Range | Description |
|---|---|---|
| Objectx REMOTE Close control input | | The remote Close command from a physical digital input (e.g. RTU). |
| Objectx REMOTE Open control input | | The remote Open command from a physical digital input (e.g. RTU). |
| Objectx Application Close | | The 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.

Figure. 5.5.3 - 87. 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.



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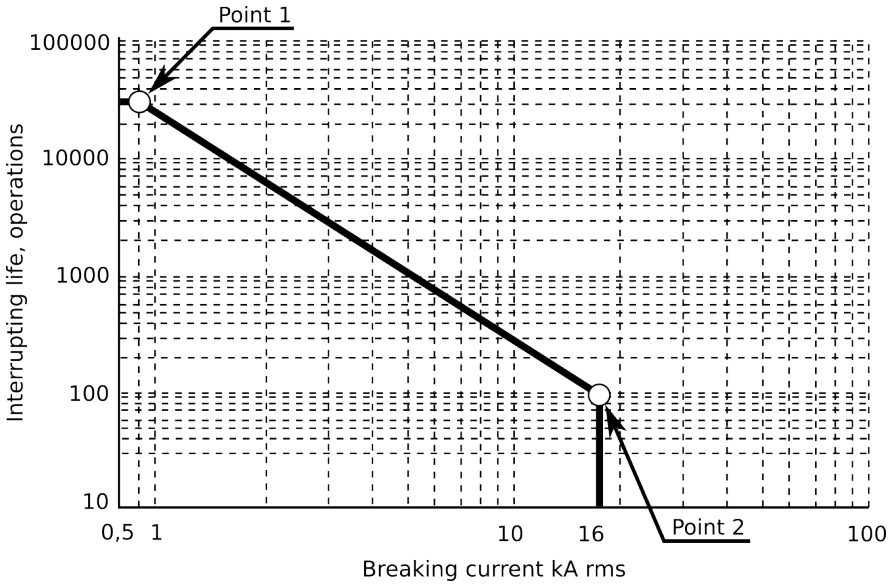
Figure. 5.5.3 - 88. Example of the circuit breaker interrupting life operations. Points 1 and 2 are user settable.




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 - 115. 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 - 116. 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. |
| Monitoring CT side | 1: CT1<br>2: CT2 | 1: CT1 | Defines which current measurement module is used by the 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. |

| Name | Range | Default | Description |
|---|---|---|---|
| Operation time open | 0...4 294 967 295 ms | - | Displays the latest breaker opening time. |
| 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 - 117. 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 |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| Event block name | Description |
|---|---|
| OBJ1...OBJ10 | WD in |
| 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 - 118. 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. |

| Name | Description |
|---|---|
| Object status | The status of the object. |
| 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 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.

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. 5.5.4 - 119. 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. 5.5.4 - 120. 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. |


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| Signal | Range | Description |
|---|---|---|
| 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. 5.5.4 - 121. 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 |
| 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 |

| Event block name | Event names |
|---|---|
| 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 |

### 5.5.5 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.

Table. 5.5.5 - 122. Main settings (output channels).

| Name | | Range | Default | Description |
|---|---|---|---|---|
| mA option card 1 | Enable mA output channels 1 and 2 | 0: Disabled 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 1: Enabled | 0: Disabled | Enables and disables the outputs of the mA output card 2. |
| | Enable mA output channels 7 and 8 | | | |



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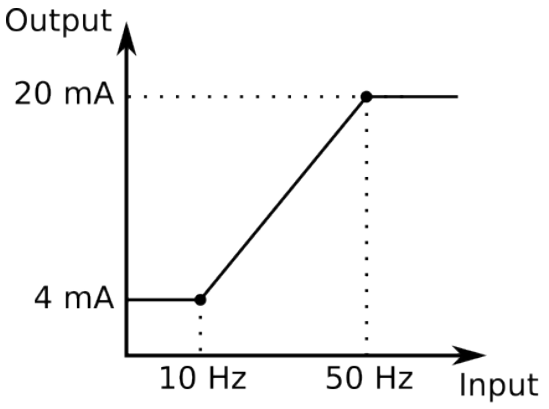
Table. 5.5.5 - 123. Settings for mA output channels.

| 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. 5.5.5 - 89. Example of the effects of mA output channel settings.



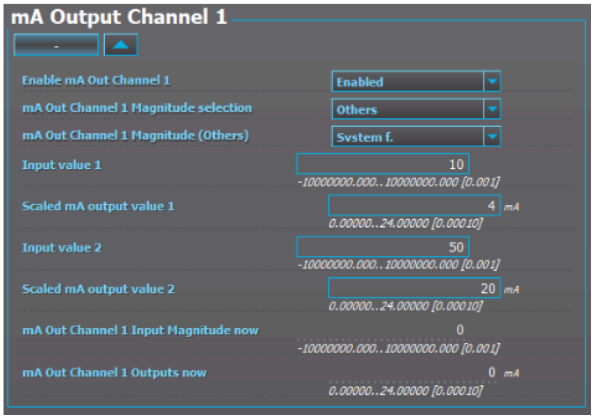



Table. 5.5.5 - 124. Hardware indications.

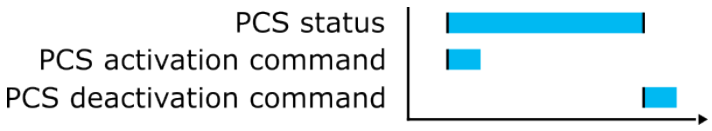
| Name | Range | Step | Description |
|---|---|---|---|
| Hardware in mA output channels 1...4 | 0: None<br>1: Slot A<br>2: Slot B<br>3: Slot C<br>4: Slot D<br>5: Slot E<br>6: Slot F<br>7: Slot G<br>8: Slot H<br>9: Slot I<br>10: Slot J<br>11: Slot K<br>12: Slot L<br>13: Slot M<br>14: Slot N<br>15: Too many cards installed | - | Indicates the option card slot where the mA output card is located. |
| Hardware in mA output channels 5...8 | | | |

Table. 5.5.5 - 125. 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 | $-10^7$...$10^7$ | 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. |

## 5.5.6 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. 5.5.6 - 126. 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. |



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| Name | Range | Default | Description |
|---|---|---|---|
| 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. 5.5.6 - 127. 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 |

## 5.5.7 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.

### 5.5.8 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
- mA inputs in "mA output & mA input" option cards
- Digital input voltages

Table. 5.5.8 - 128. 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. |


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| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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.

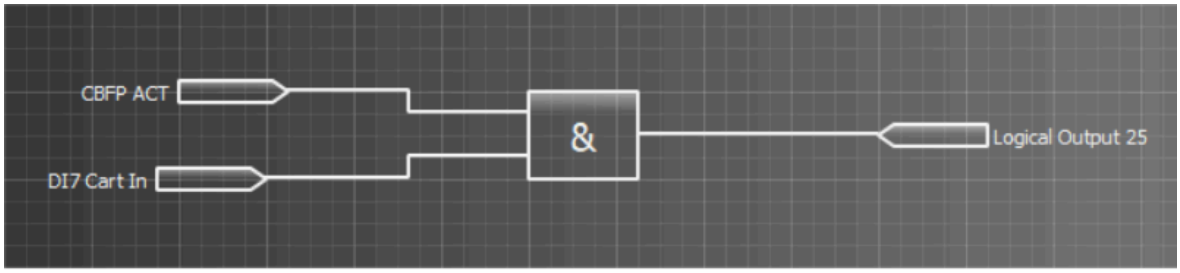
Table. 5.5.8 - 129. Output settings and indications.

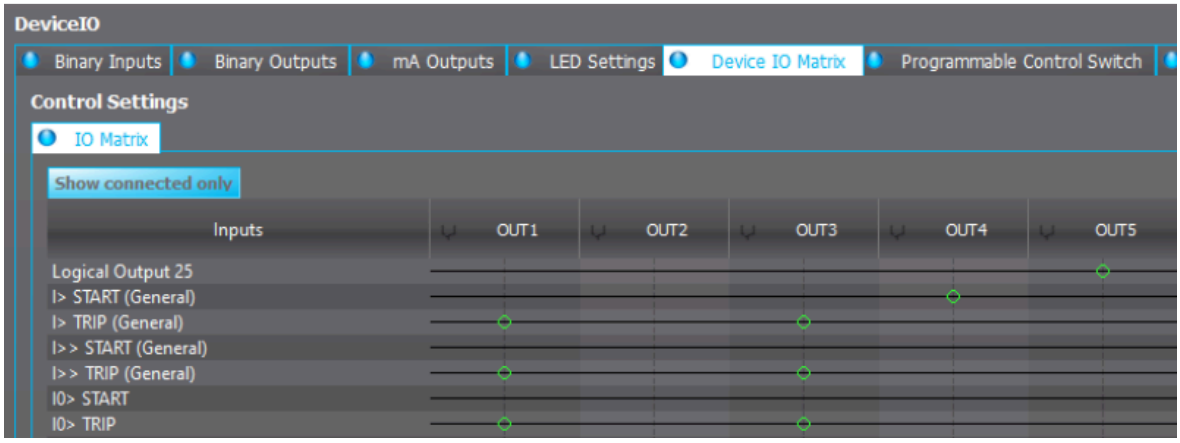
| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Curve 1...4 update cycle | 5...10 000ms | 5ms | 150ms | Defines the length of the input measurement update cycle. If the user wants a fast operation, this setting should be fairly low. |
| Scaled value handling | 0: Floating point<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. |

## 5.5.9 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".

Figure. 5.5.9 - 90. 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. 5.5.9 - 130. 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. |

## 5.5.10 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.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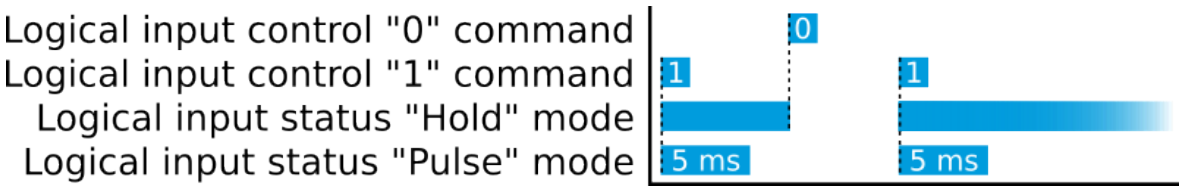
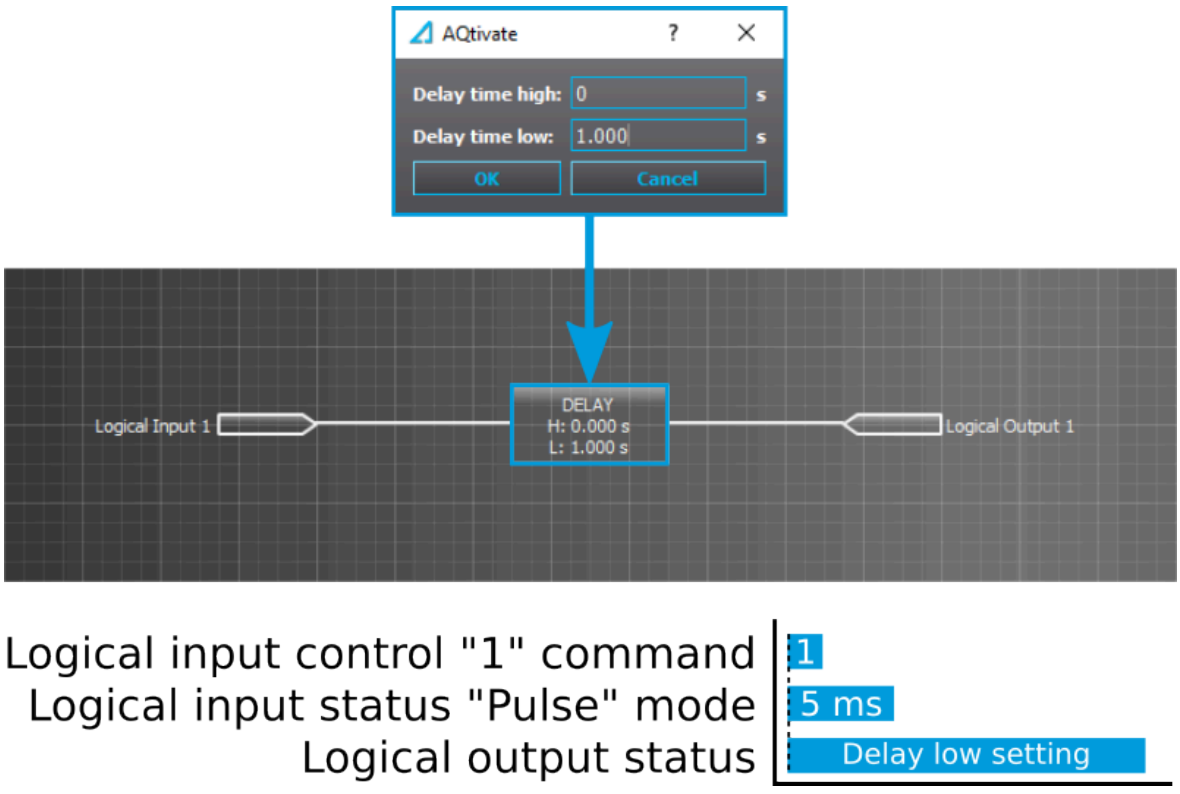
The figure below presents the operation of a logical input in Hold mode and in Pulse mode.

Figure. 5.5.10 - 91. 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. 5.5.10 - 92. 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. 5.5.10 - 131. Logical input user description.

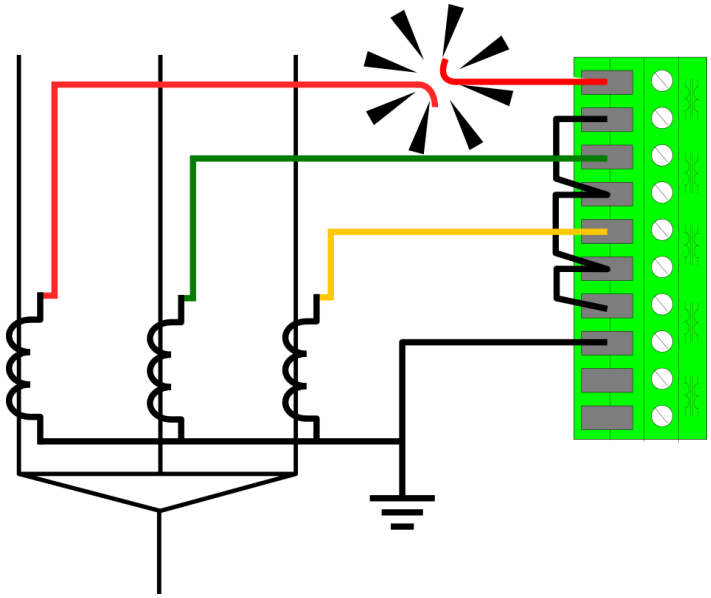
| Name | Range | Default | Description |
|---|---|---|---|
| User editable description LIx | 1...31 characters | Logical input x | Description of the logical input. This description is used in several menu types for easier identification. |

# 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 - 93. 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.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- 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.

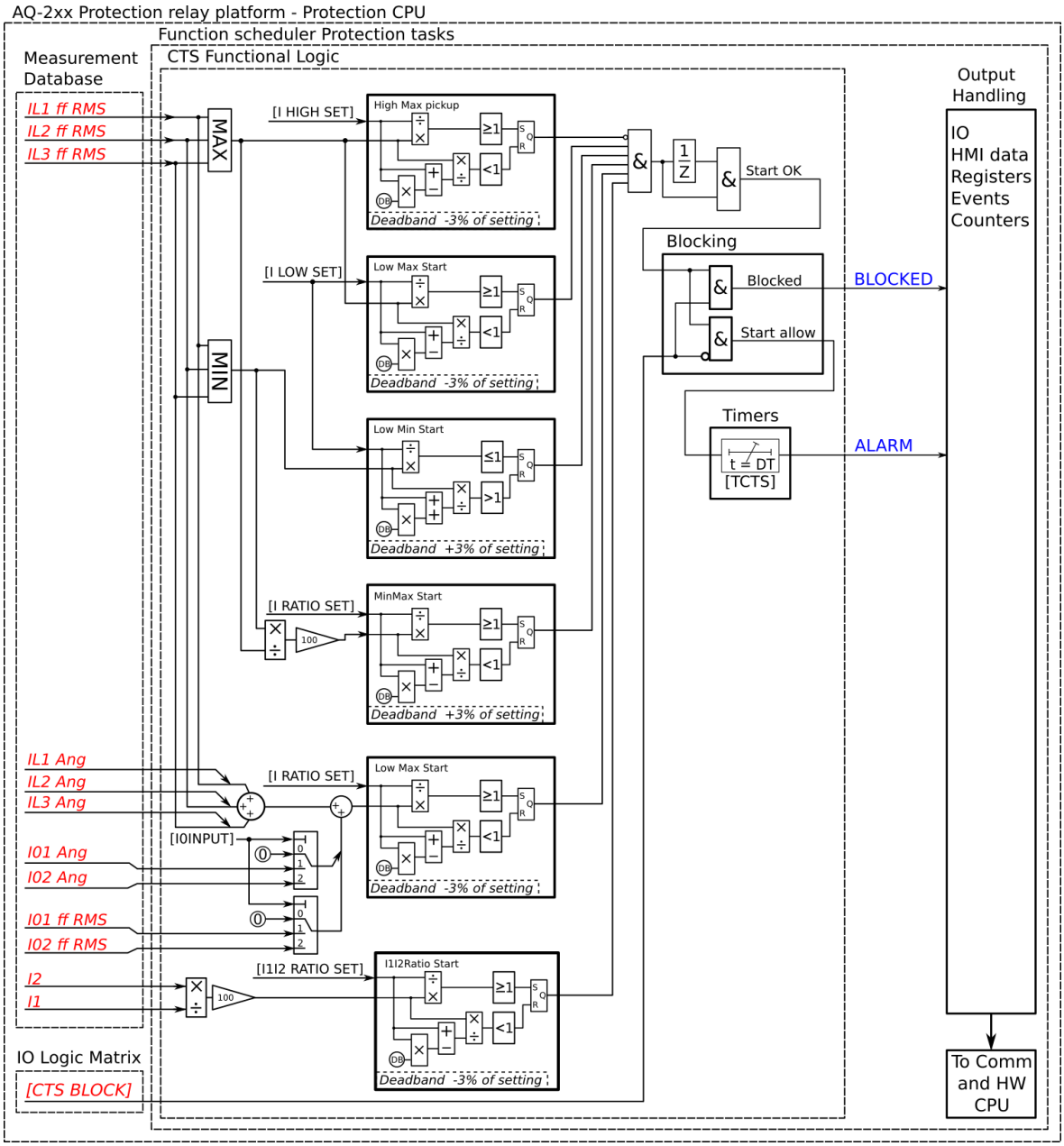
The inputs of the function are the following:

- 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.

Figure. 5.6.1 - 94. 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 - 132. 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 |



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| 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 - 133. 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.

Table. 5.6.1 - 134. 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 - 135. 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. |


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| 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.

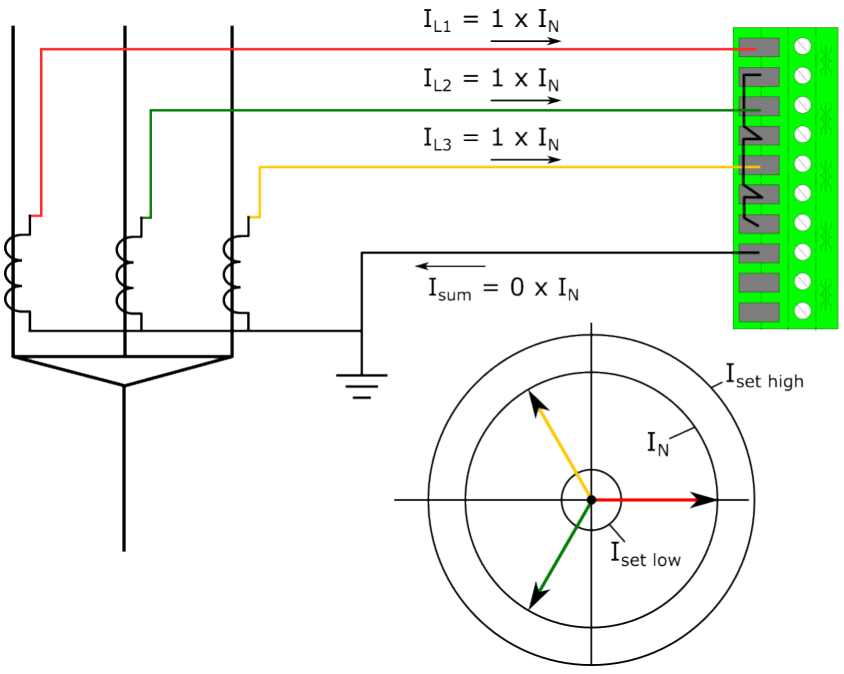
## Operating time characteristics

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 - 95. All works properly, no faults.

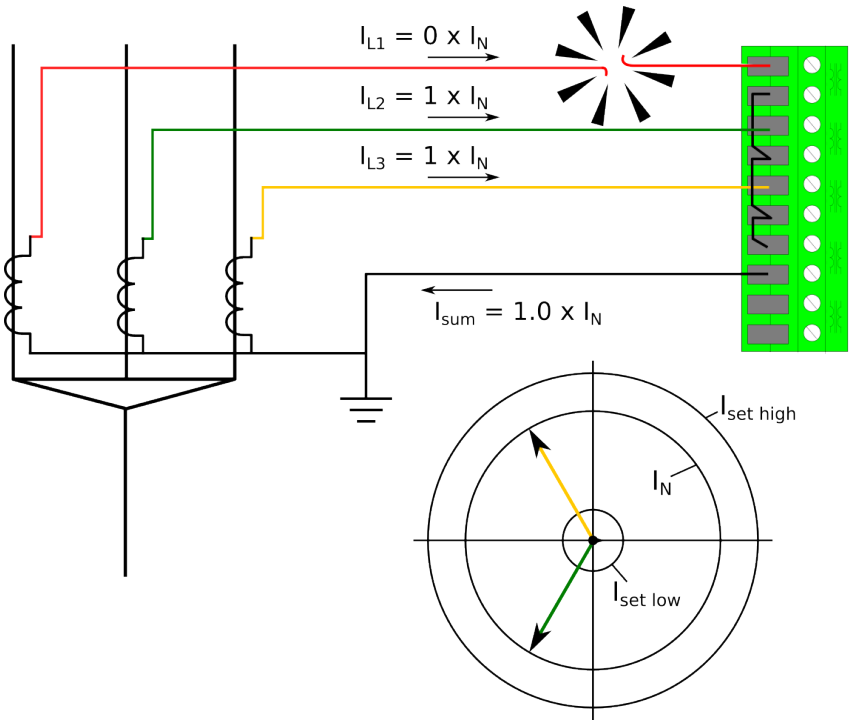



**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**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

Figure. 5.6.1 - 96. Secondary circuit fault in phase L1 wiring.



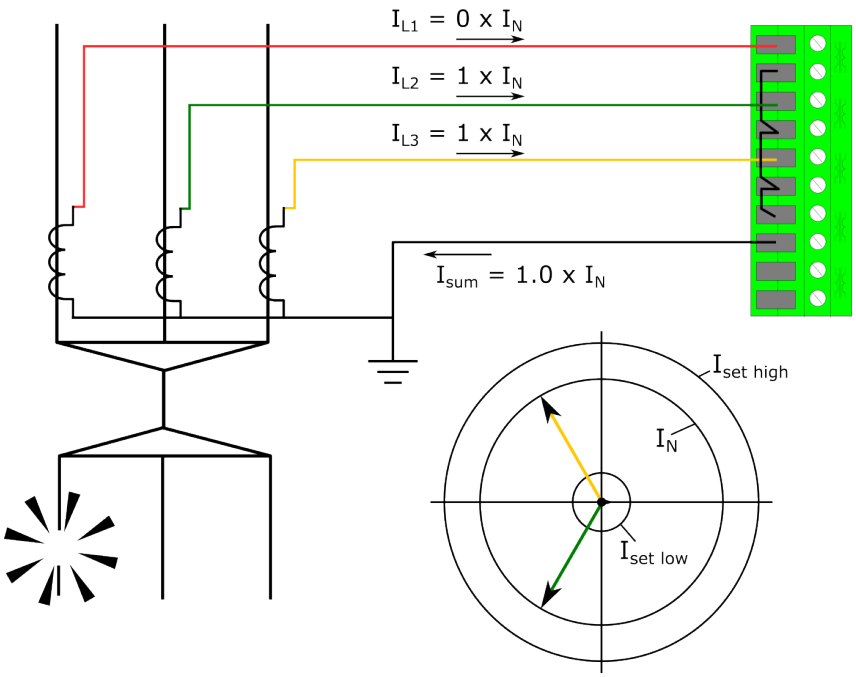

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**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 - 97. 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.



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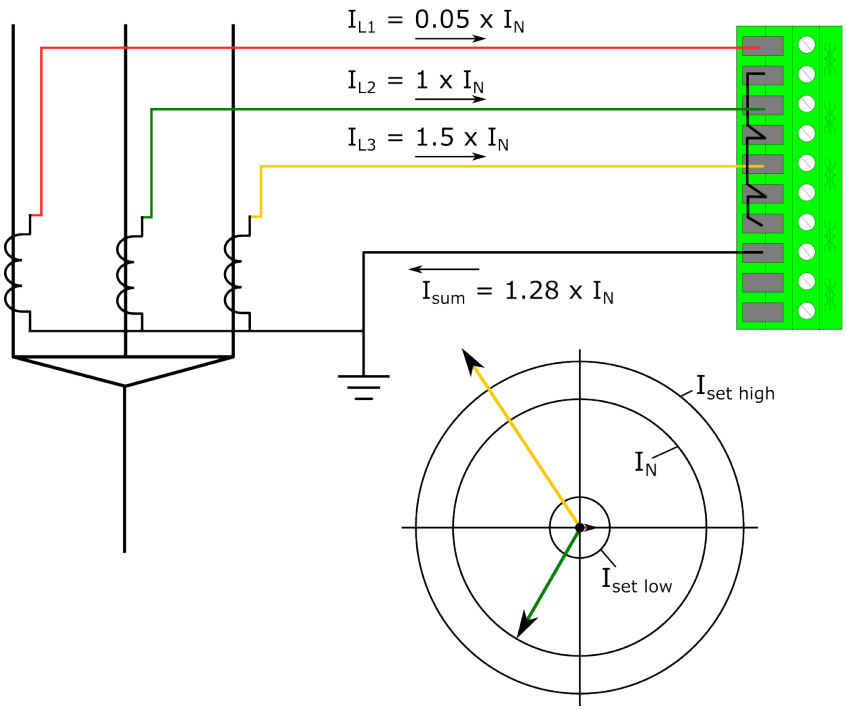
Figure. 5.6.1 - 98. No wiring fault but heavy unbalance.



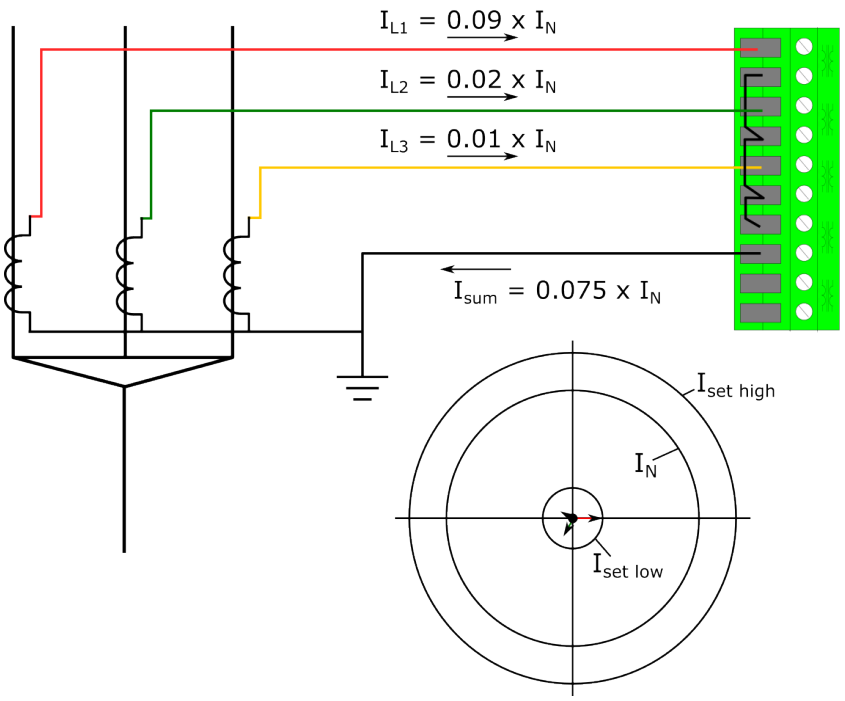

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = Not in use

**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 - 99. 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

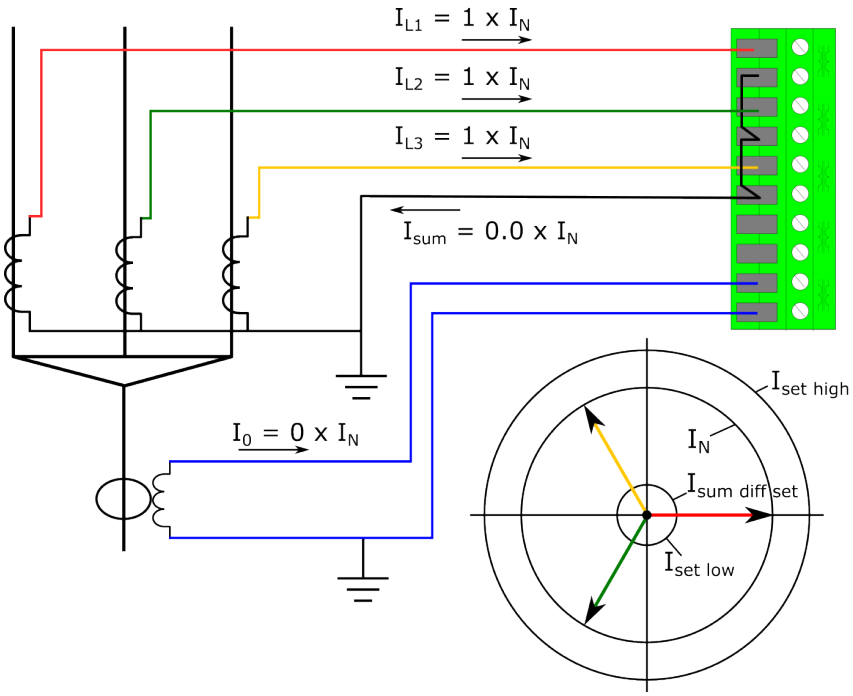
**Measurements:**
$I_{min}$ = 0.01 x $I_N$
$I_{max}$ = 0.09 x $I_N$
I1 = 0.04 x $I_N$
I2 = 0.03 x $I_N$
$I_{min}/I_{max}$ = 11.0 %
I2/I1 = 62.92 %

**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.

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 - 100. Normal situation, residual current also measured.



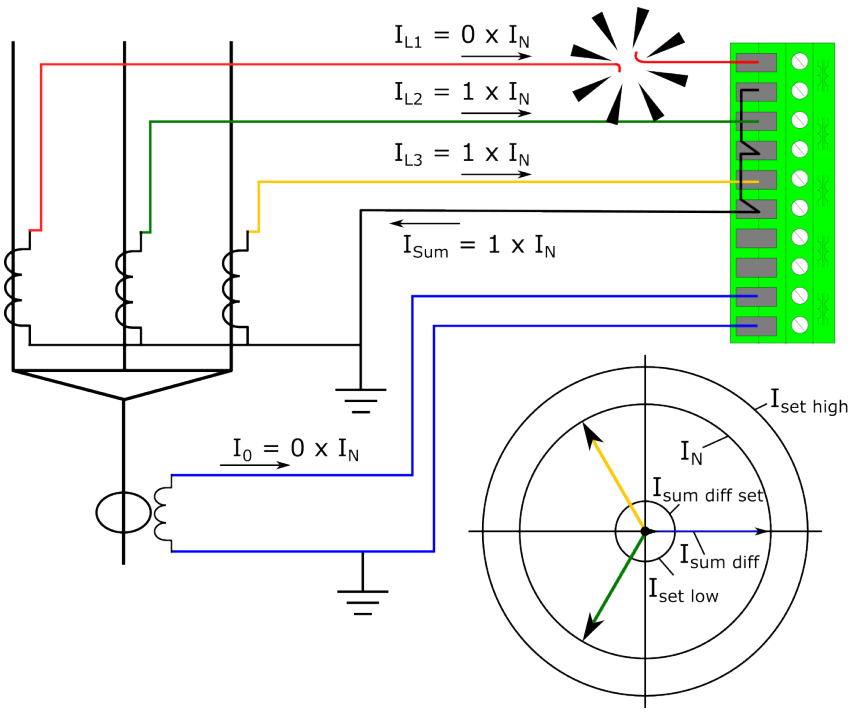

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**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 - 101. 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.


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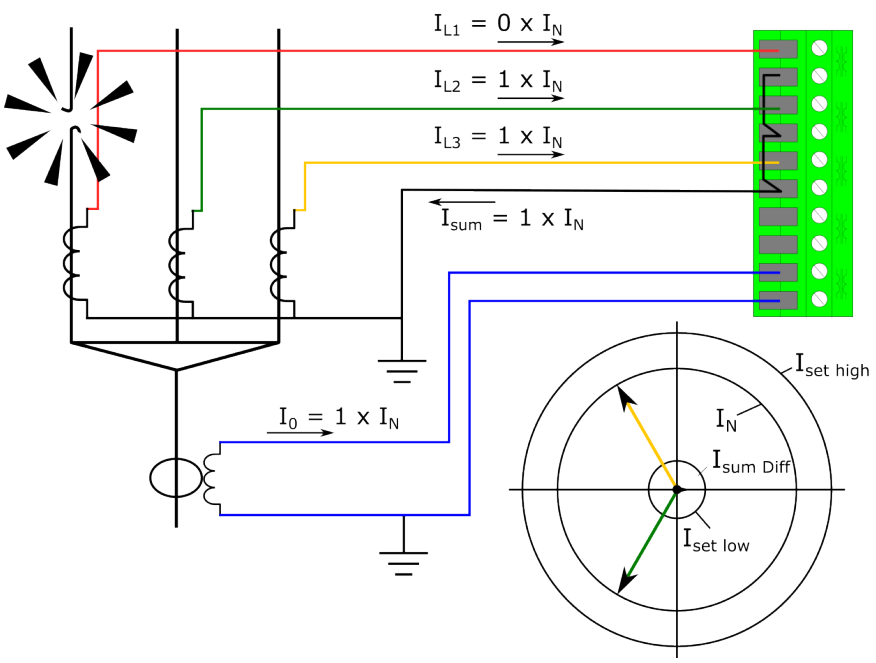
Figure. 5.6.1 - 102. Broken primary phase current wiring.



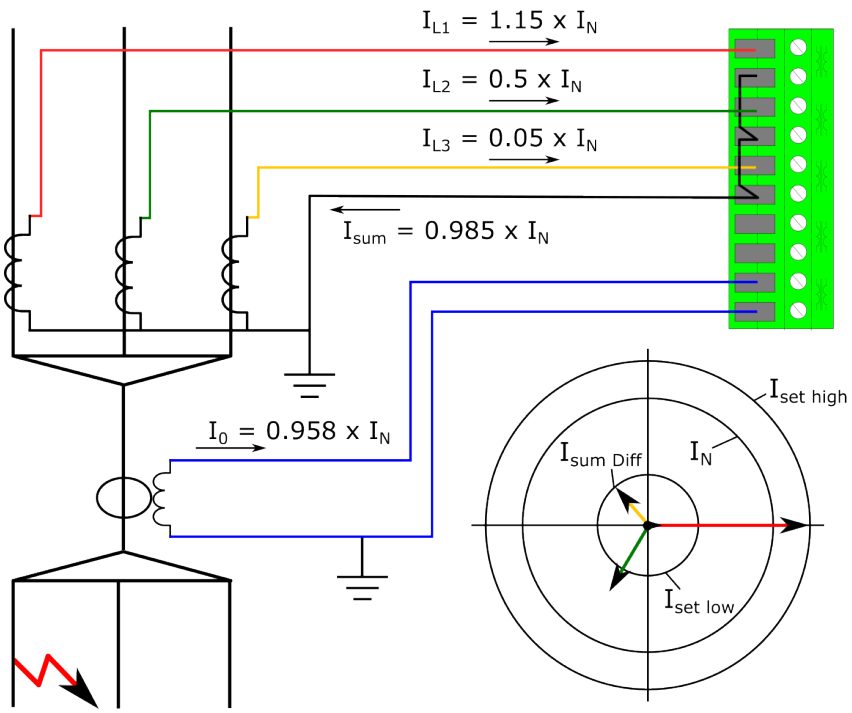

**Settings:**
$I_{set}$ High limit = 1.20 x $I_N$
$I_{set}$ Low limit = 0.10 x $I_N$
$I_{set}$ ratio = 10.00 %
I1/I2 ratio = 49.00 %
$I_0$ input = $I_{01}$
$I_{sum}$ Difference= 0.10 x $I_N$

**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 - 103. 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.

### 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 function offers two (2) independent stages.

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

Table. 5.6.1 - 136. Event messages.

| Event block name | Event names |
|---|---|
| CTS1 | Alarm ON |
| CTS1 | Alarm OFF |
| CTS1 | Block ON |
| CTS1 | Block OFF |
| CTS2 | Alarm ON |
| CTS2 | Alarm OFF |
| CTS2 | Block ON |
| CTS2 | 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 - 137. 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 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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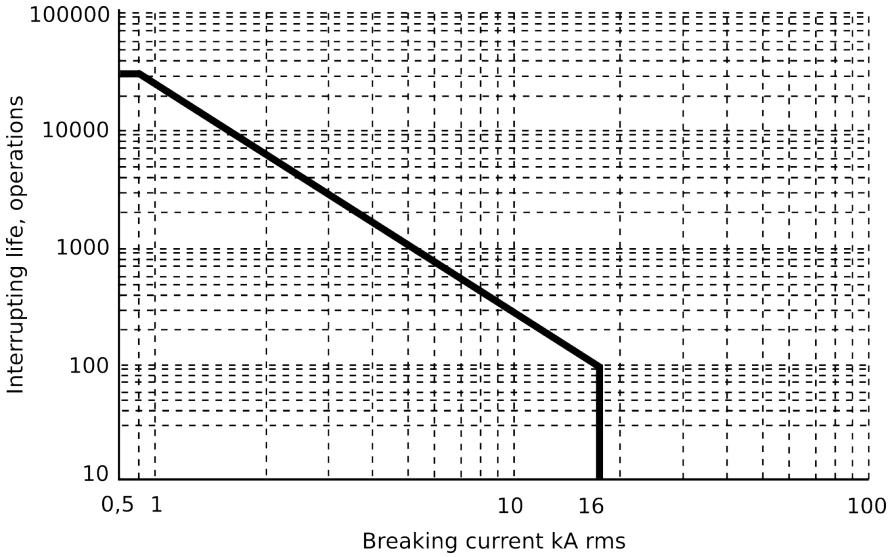
Figure. 5.6.2 - 104. Example of the circuit breaker interrupting life operations.




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.

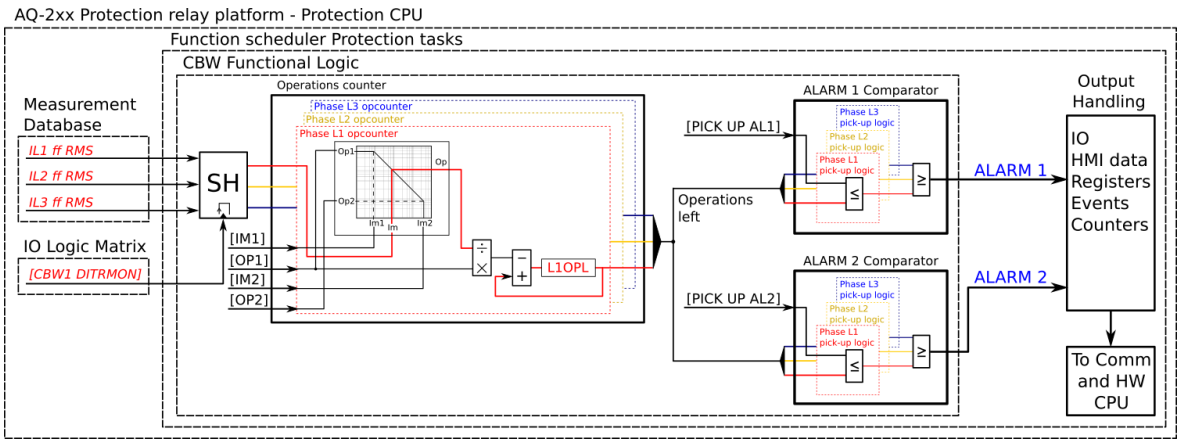
The inputs for the function are the following:

- 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. 5.6.2 - 105. 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. 5.6.2 - 138. 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. 5.6.2 - 139. 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. |
| CBW in side | 1:Side 1<br><br>2:Side 2 | 1:Side 1 | Defines which current measurement module is used by the function. |

## 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. 5.6.2 - 140. 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). |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## 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.

Table. 5.6.2 - 141. 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. 5.6.2 - 142. 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. 5.6.2 - 143. 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. 5.6.2 - 144. 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 |

## 5.6.3 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. 5.6.3 - 106. 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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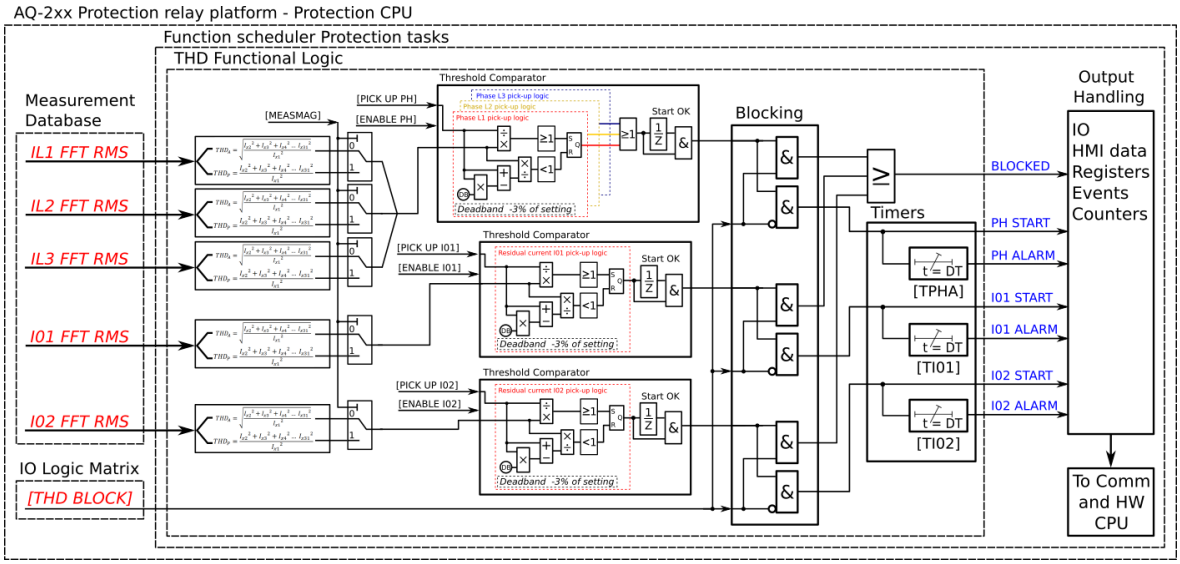
- setting parameters
- digital inputs and logic signals
- measured and pre-processed current magnitudes

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. 5.6.3 - 107. 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. 5.6.3 - 145. 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. 5.6.3 - 146. 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. |
| THD> in side | 0: CT1<br>1: CT2 | 0: CT1 | Defines which current measurement module the function uses. |
| 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. 5.6.3 - 147. 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. 5.6.3 - 148. 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. 5.6.3 - 149. 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.

Table. 5.6.3 - 150. 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. 5.6.3 - 151. 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. |

## 5.6.4 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.

Table. 5.6.4 - 152. Analog recording channels.

| Signal | Description |
|---|---|
| IL1 | Phase current $I_{L1}$ |


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| Signal | Description |
|---|---|
| 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) |
| 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. 5.6.4 - 153. 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. 5.6.4 - 154. 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) |
| 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) |



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| Signal | Description | Signal | Description |
|---|---|---|---|
| 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 |
| POW1 3PH Reactive power (Q) | Three-phase reactive power | Tr f CH x | Tracked frequency (channels A, B, C) |

| Signal | Description | Signal | Description |
|---|---|---|---|
| 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. 5.6.4 - 155. 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 |
| 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. |


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| Signal | Description | Signal | Description |
|---|---|---|---|
| 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. 5.6.4 - 156. 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. |
| 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. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| Recordings in memory | 0…100 | 1 | - | Displays how many recordings are stored in the memory. |

Table. 5.6.4 - 157. 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. 5.6.4 - 158. 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. 5.6.4 - 108. Disturbance recorder settings.

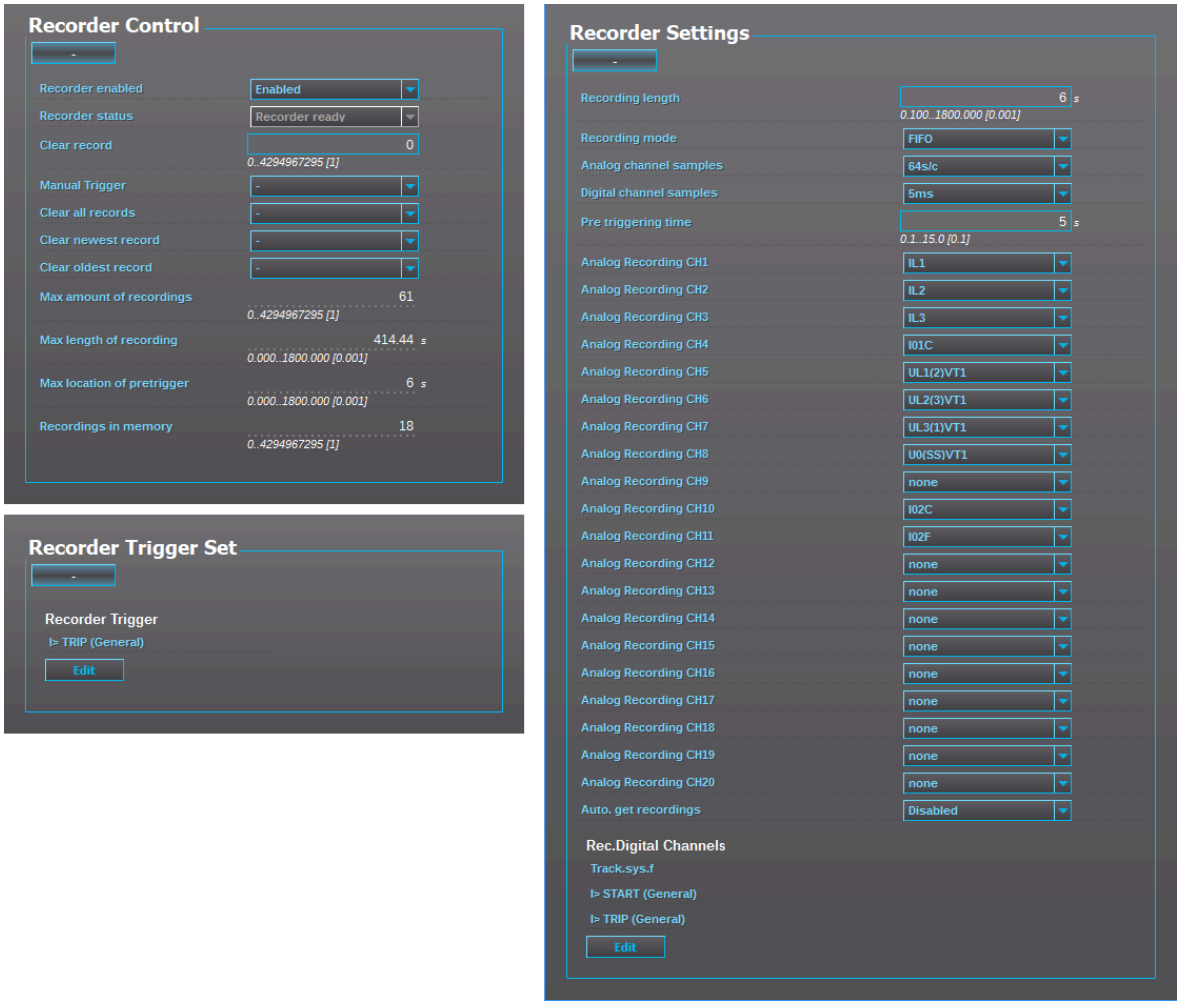
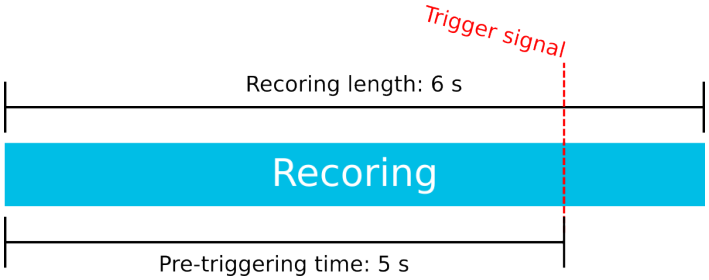
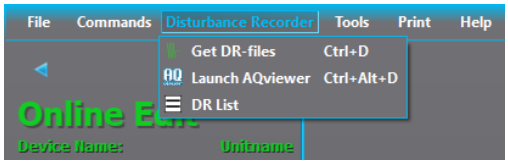



Figure. 5.6.4 - 109. Effects of recording length and pre-triggering time signals. This example is based on the settings shown above.




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.

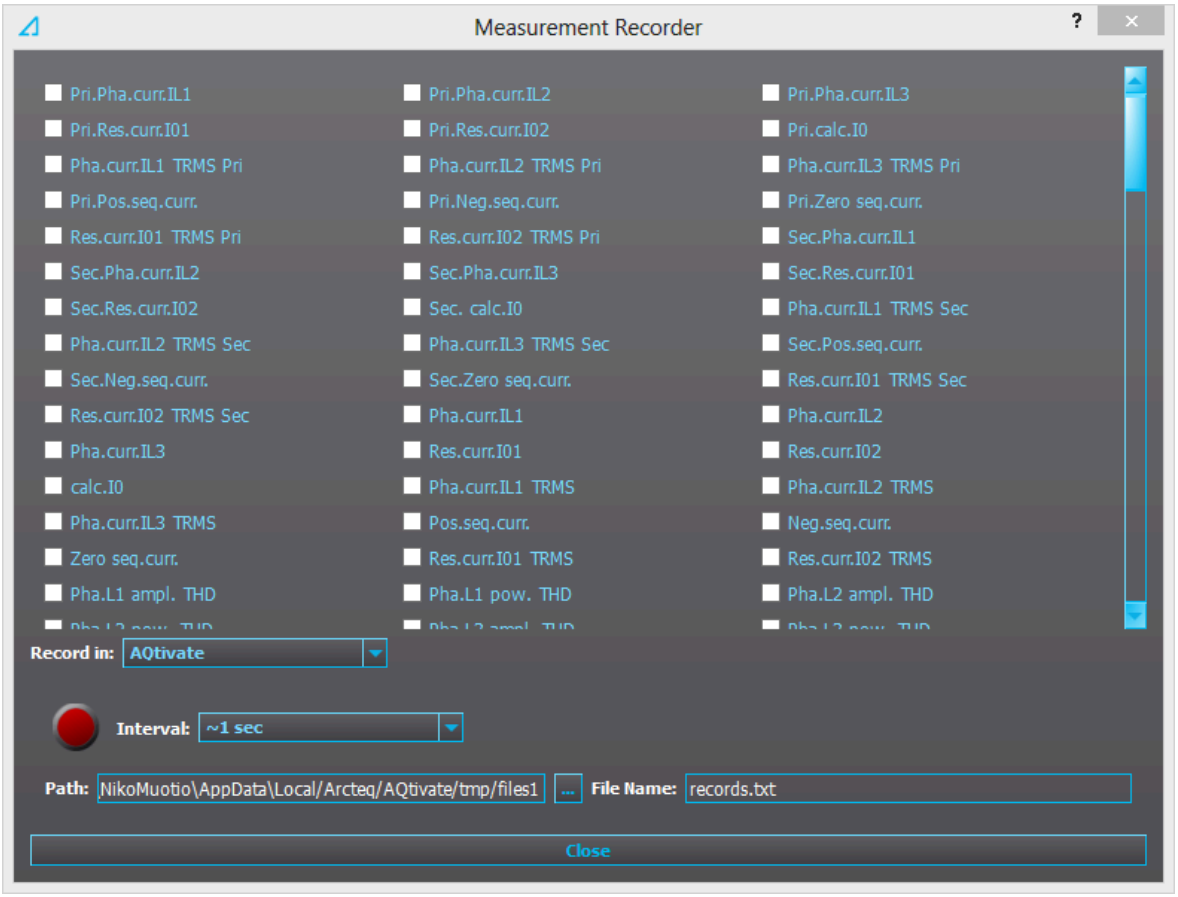
Table. 5.6.4 - 159. Event messages.

| 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 |

## 5.6.5 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.

### 5.6.6 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. 5.6.6 - 110. Measurement recorder values viewed with AQtivate PRO.

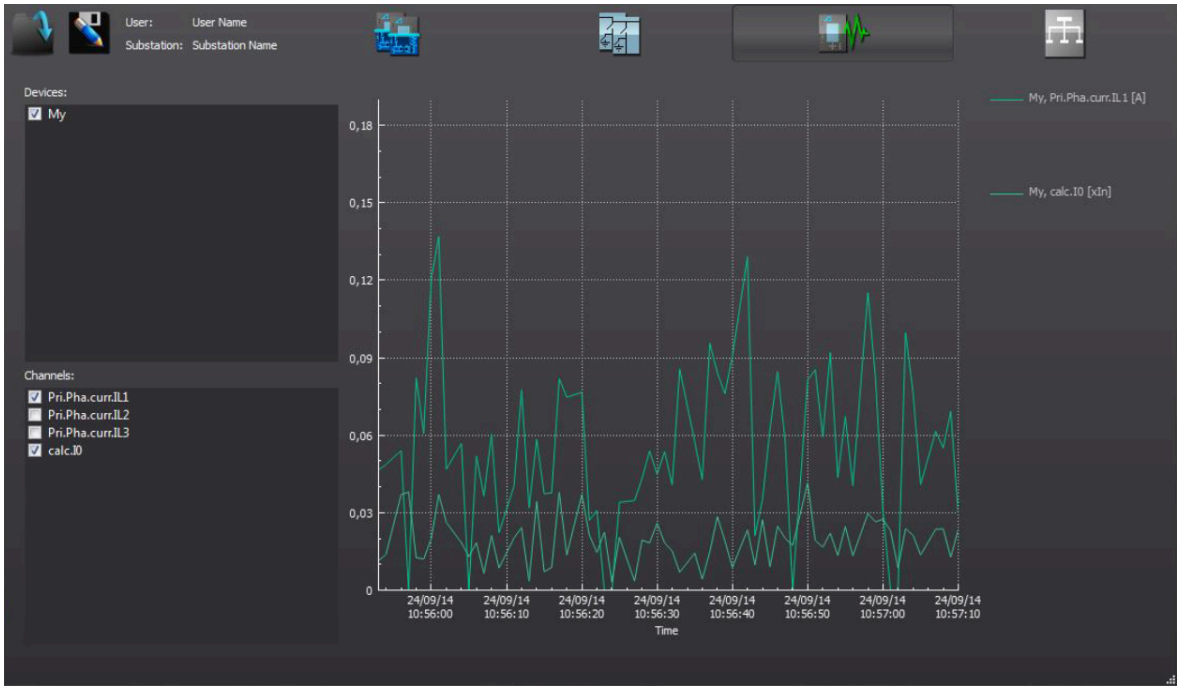


Table. 5.6.6 - 160. Available analog signals.

| | | |
|---|---|---|
| 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 | |

### 5.6.7 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. 5.6.7 - 161. 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. 5.6.7 - 162. 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 - 163. 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 - 164. 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 2nd h. | ILx 2nd harmonic value (in p.u.) |
| ILx 3rd h. | ILx 3nd harmonic value (in p.u.) |
| ILx 4th h. | ILx 4nd harmonic value (in p.u.) |
| ILx 5th h. | ILx 5nd harmonic value (in p.u.) |
| ILx 7th h. | ILx 7nd harmonic value (in p.u.) |
| ILx 9th h. | ILx 9nd harmonic value (in p.u.) |
| ILx 11th h. | ILx 11nd harmonic value (in p.u.) |
| ILx 13th h. | ILx 13nd harmonic value (in p.u.) |
| ILx 15th h. | ILx 15nd 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 - 165. 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 - 166. 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 - 167. 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 - 168. 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 - 169. 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 - 170. 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 - 171. 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 - 172. 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 - 173. 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 - 174. Pick-up settings.

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| PS# Pick-up term Mag# | 0: Over ><br>1: Over (abs) ><br>2: Under <<br>3: Under (abs) <<br>4: Delta set (%) +/- ><br>5: Delta abs (%) ><br>6: Delta +/- measval<br>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 - 175. 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 - 176. 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 - 177. 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 - 178. 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 - 179. 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 - 180. 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 - 181. 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 - 182. 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 - 183. 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 - 184. 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 - 185. 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 - 186. 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 - 187. 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 - 188. 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 - 189. 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 - 190. 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 - 191. 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 - 192. 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 - 193. 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 - 194. 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 - 195. 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 - 196. 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 - 197. 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 - 198. 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 - 199. 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 - 200. 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 - 201. 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 - 202. 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 - 203. 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 - 204. 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 - 205. 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 - 206. 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 - 207. 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 - 208. 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 - 209. 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 - 210. 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 - 211. 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 - 212. 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 - 213. 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 - 214. 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 - 215. 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 - 216. 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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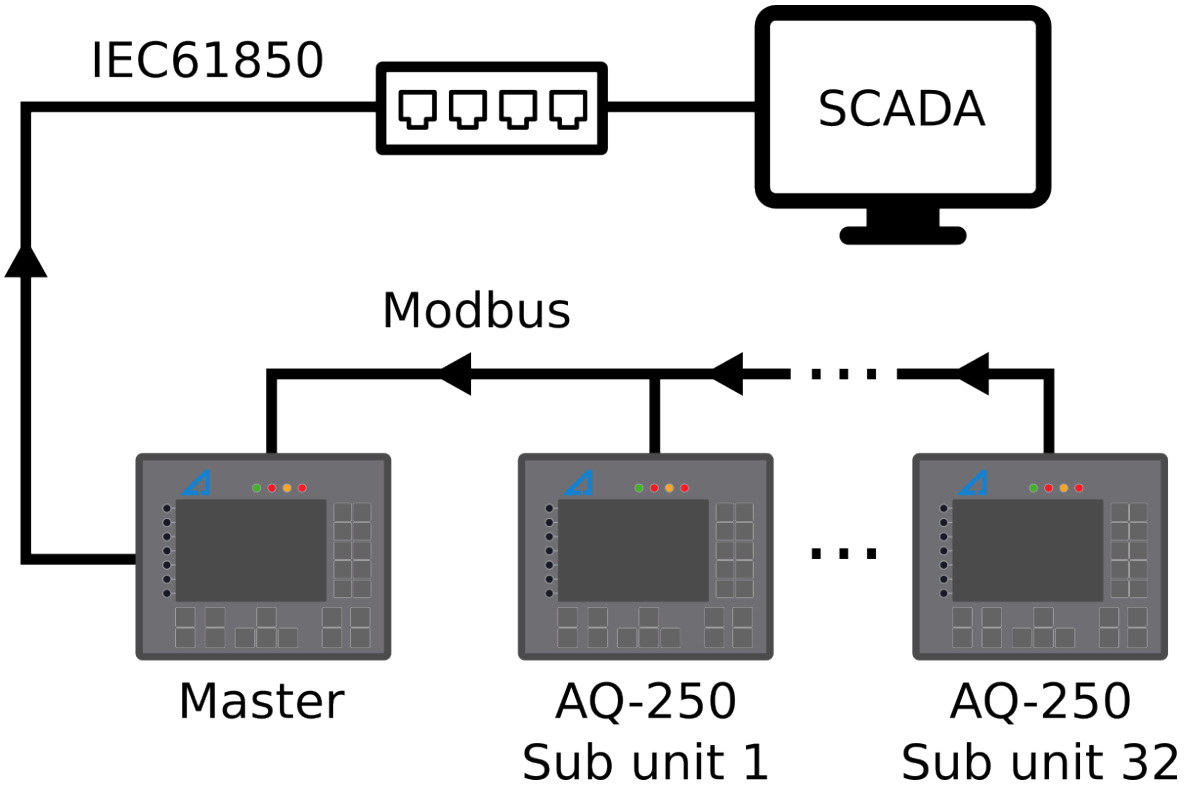
## 6.6 Modbus Gateway

Figure. 6.6 - 111. 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.

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 - 217. 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 - 218. 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 - 219. 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 - 220. 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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# 7 Connections and application examples

## 7.1 Connections of AQ-T256

Figure. 7.1 - 112. AQ-T256 variant without add-on modules.

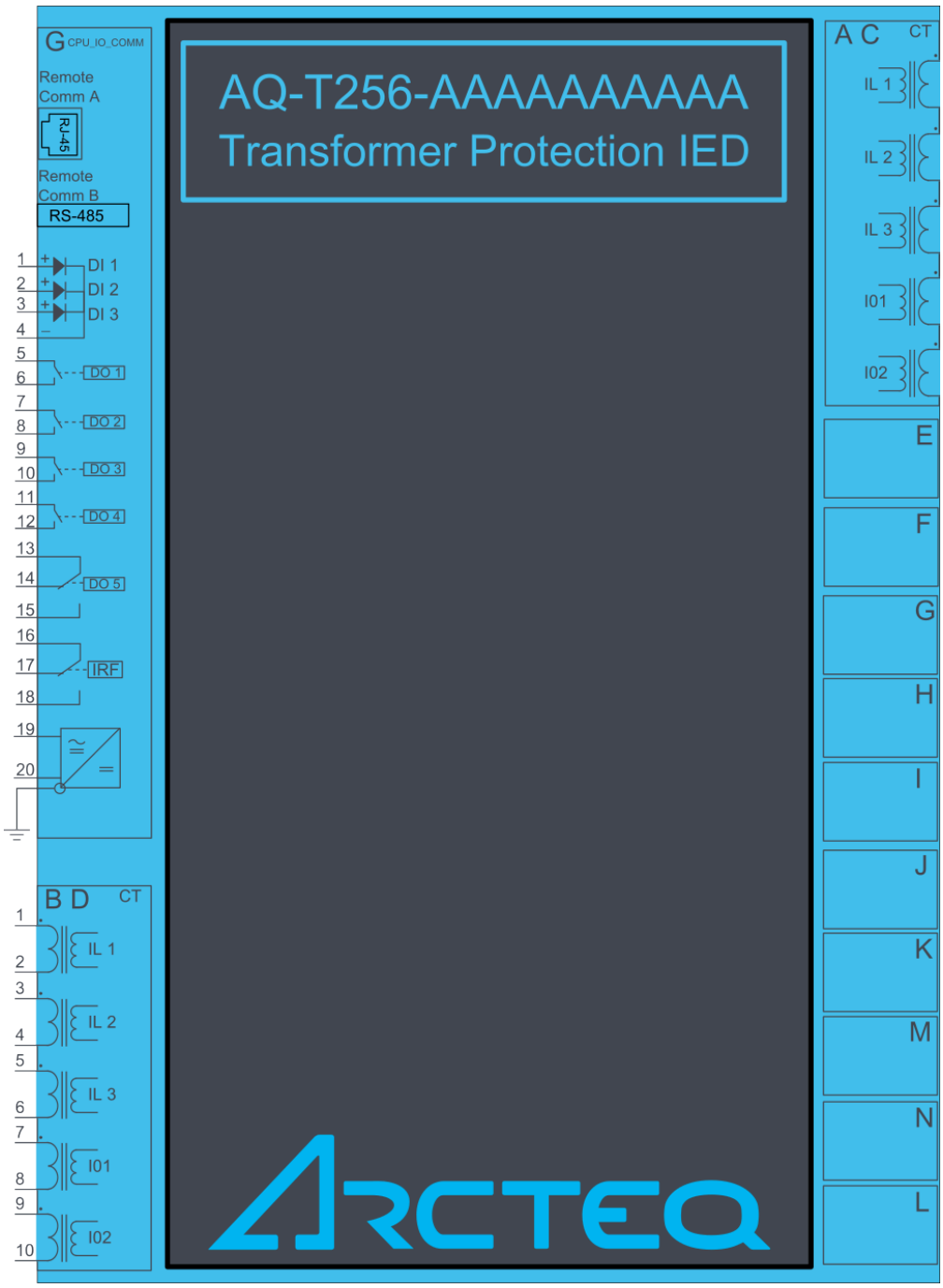

Figure. 7.1 - 113. AQ-T256 variant with digital input and output modules.

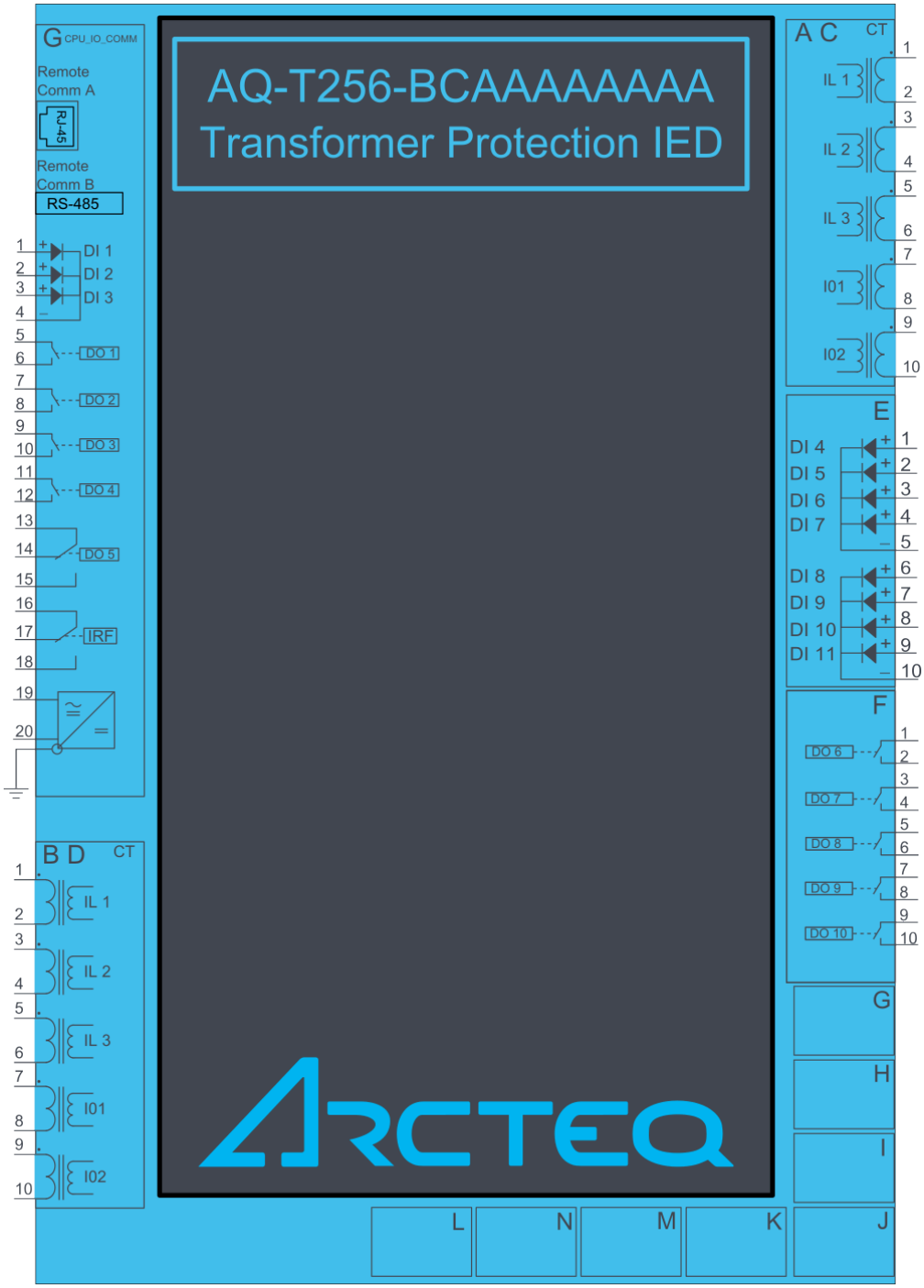




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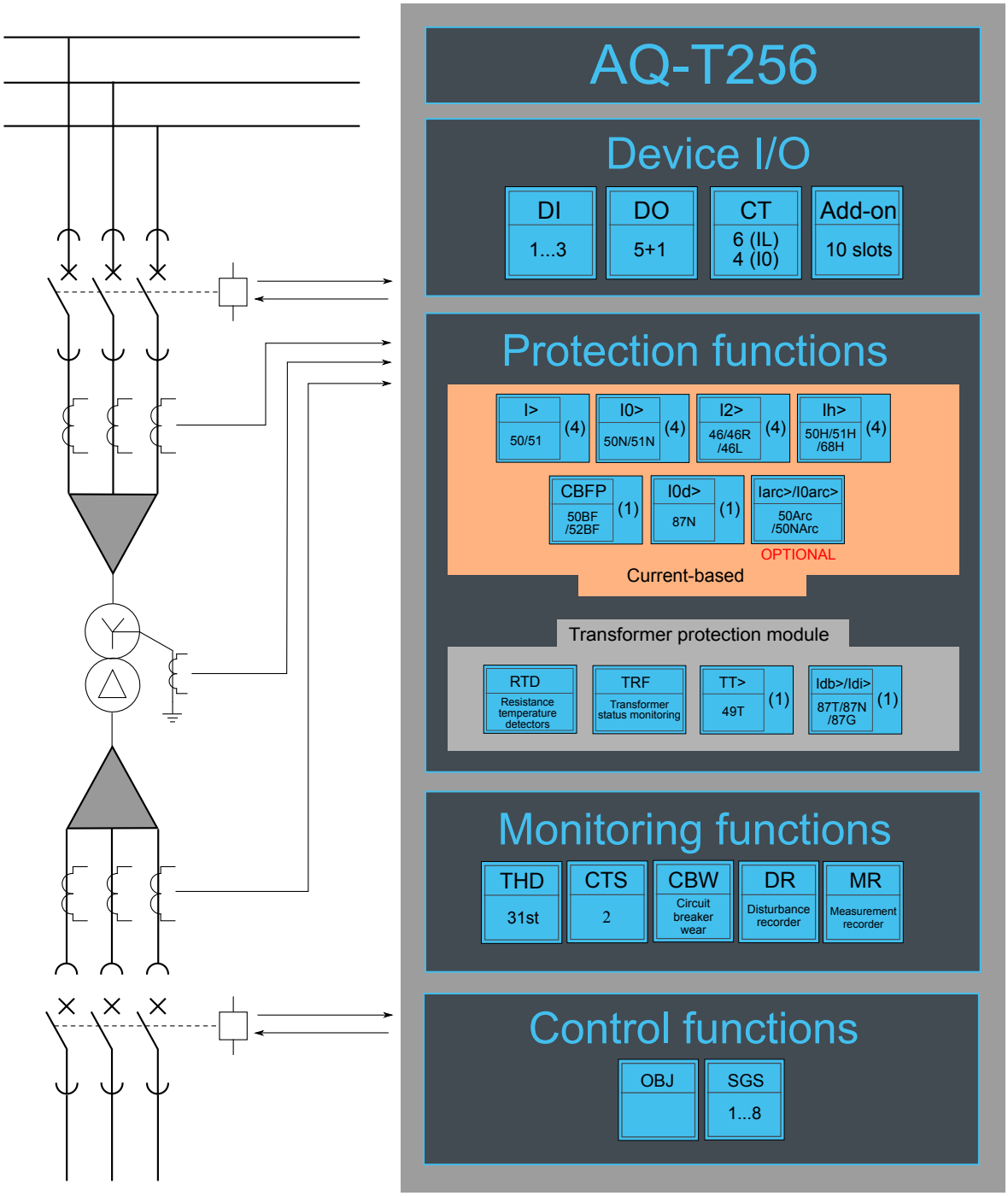
Figure. 7.1 - 114. AQ-T256 application example with function block diagram.

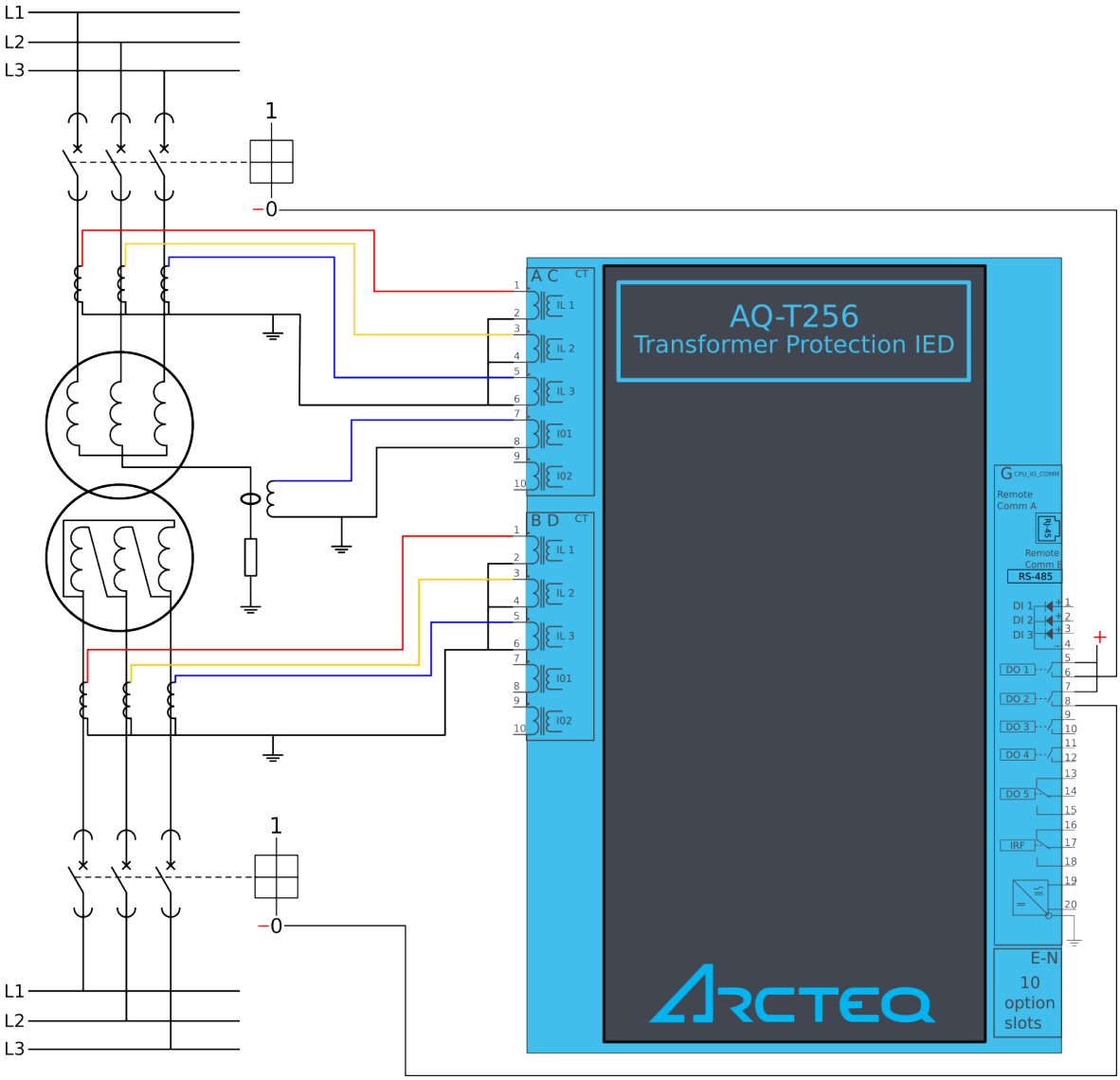



## 7.2 Application example and its connections

This chapter presents an application example for the two-winding transformer differential IED. The example is a regular differential scheme with restricted earth fault protection on the high-voltage side.

As can be seen in the image below, the example application has two current transformers. The first (upper) CT has the three phase current as well as the residual current (I01) connected. The second CT also has the three phase currents but no residual current connected.

Figure. 7.2 - 115. Application example and its connections.




## 7.3 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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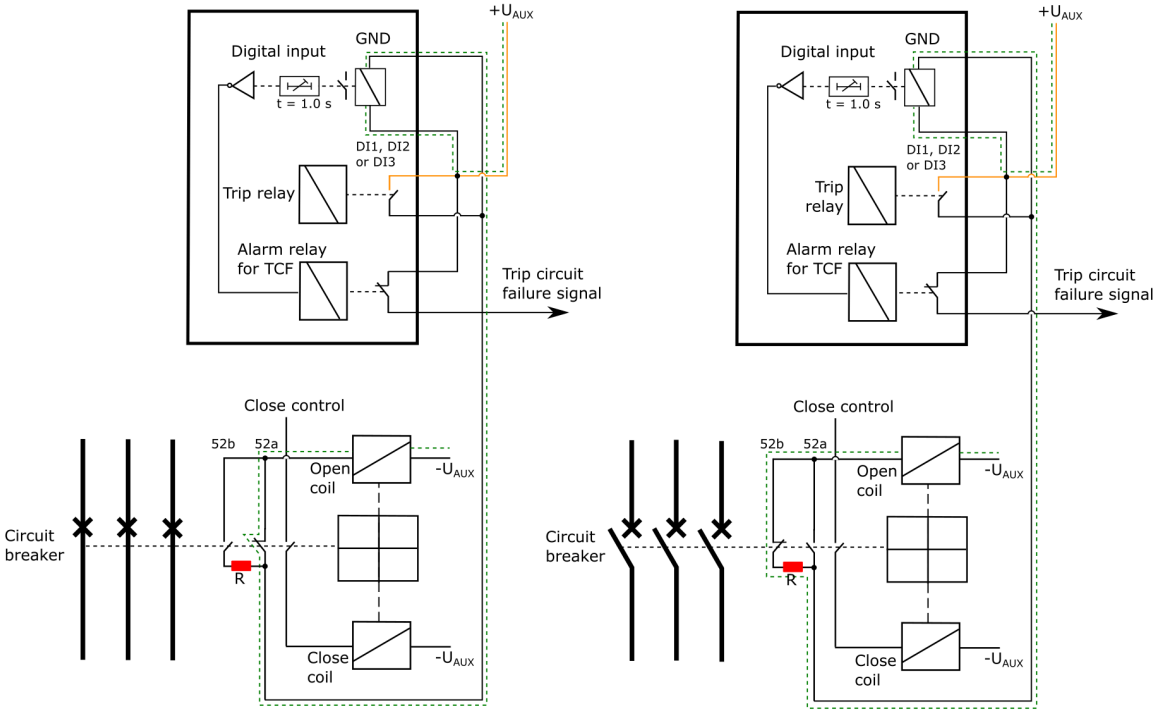
Figure. 7.3 - 116. Trip circuit supervision with one DI and one non-latched trip output.

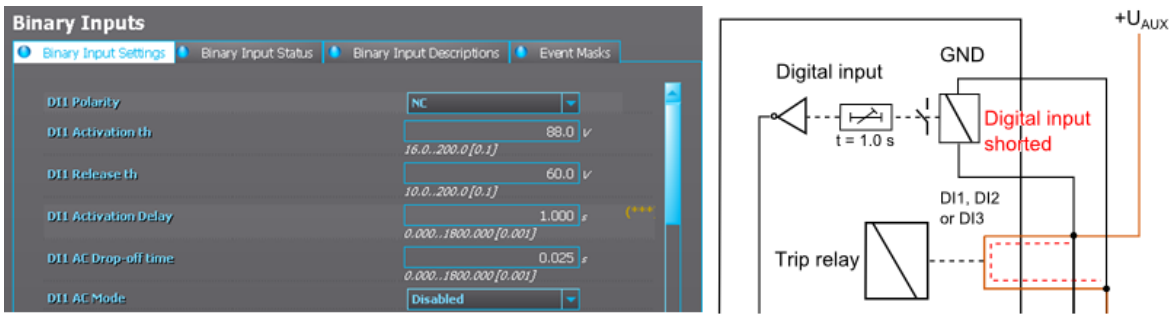



Note that the digital input that monitors the circuit is normally closed, and the same applies to the alarm relay if one is used. For monitoring and especially trip circuit supervision purposes it is recommended to use a normally closed contact to confirm the wiring's condition. An active digital input 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, $t_{DI} = t_{CB} + t_{IEDrelease} + t_{CBFP}$.

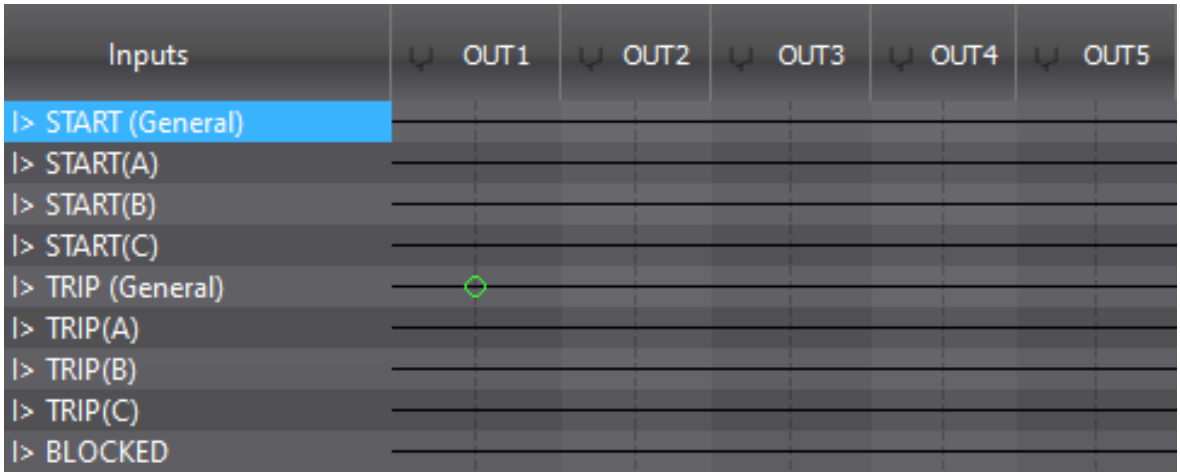
The image below presents the necessary settings when using a digital input for trip circuit supervision. The input's polarity must be NC (normally closed) and a one second delay is needed to avoid nuisance alarm while the circuit breaker is controlled open.

Figure. 7.3 - 117. 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. 7.3 - 118. 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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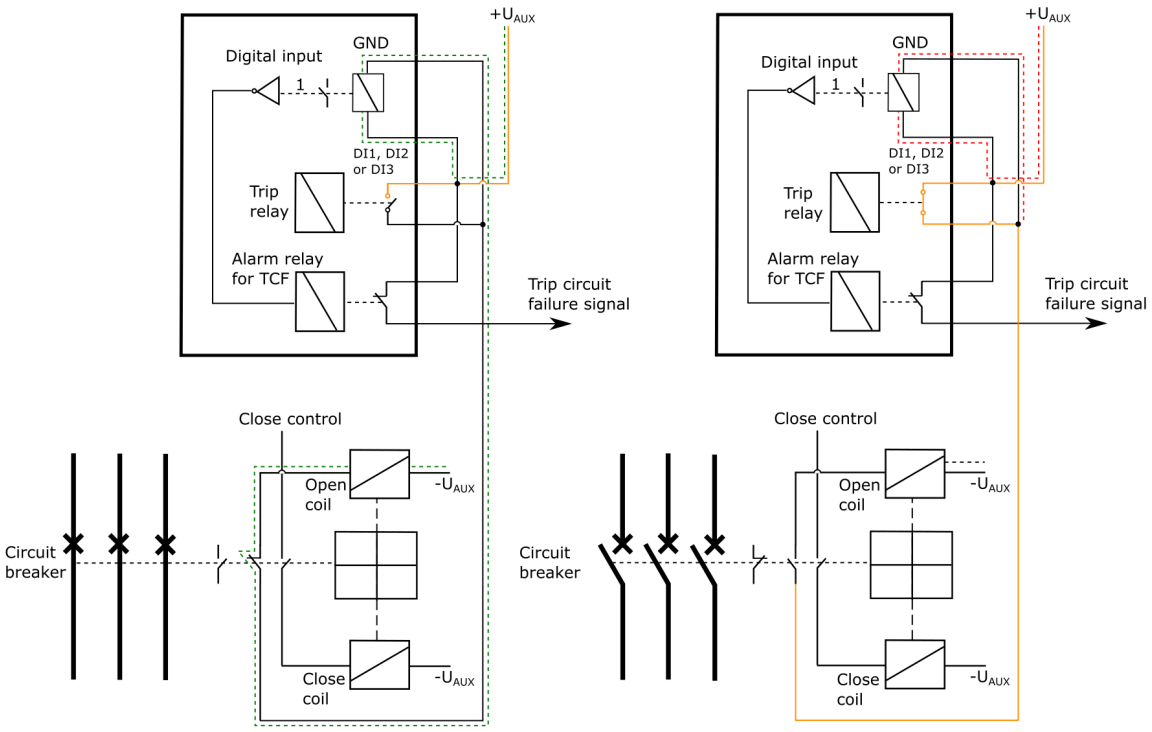
Figure. 7.3 - 119. Trip circuit supervision with one DI and one latched output contact.

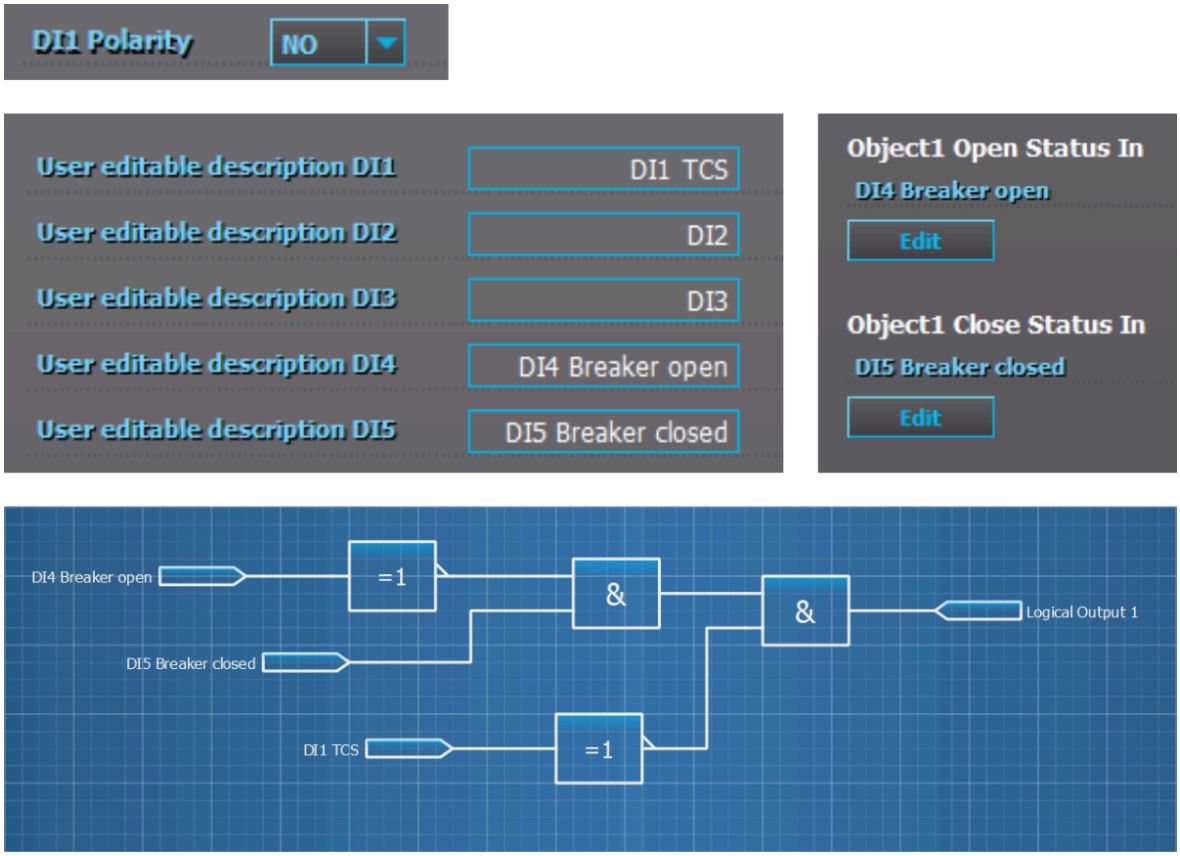



The trip circuit with a latched output contact can be monitored, but only when the circuit breaker's status is "Closed". Whenever the breaker is open, the supervision is blocked by an internal logic scheme. Its disadvantage is that the user does not know whether or not the trip circuit is intact when 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. 7.3 - 120. Example block scheme.



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# 8 Construction and installation

## 8.1 Construction

AQ-X256 is a member of the modular and scalable AQ-200 series, and it includes ten (10) 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 two separate current measurement modules.

The images below present the modules of both the non-optioned model (AQ-X256-XXXXXXX-AAAAAAAAAA) and the fully optioned model (AQ-X256-XXXXXXX-BBBBCCCCCJ).

Figure. 8.1 - 121. Modular construction of AQ-X256-XXXXXXX-AAAAAAAAAA

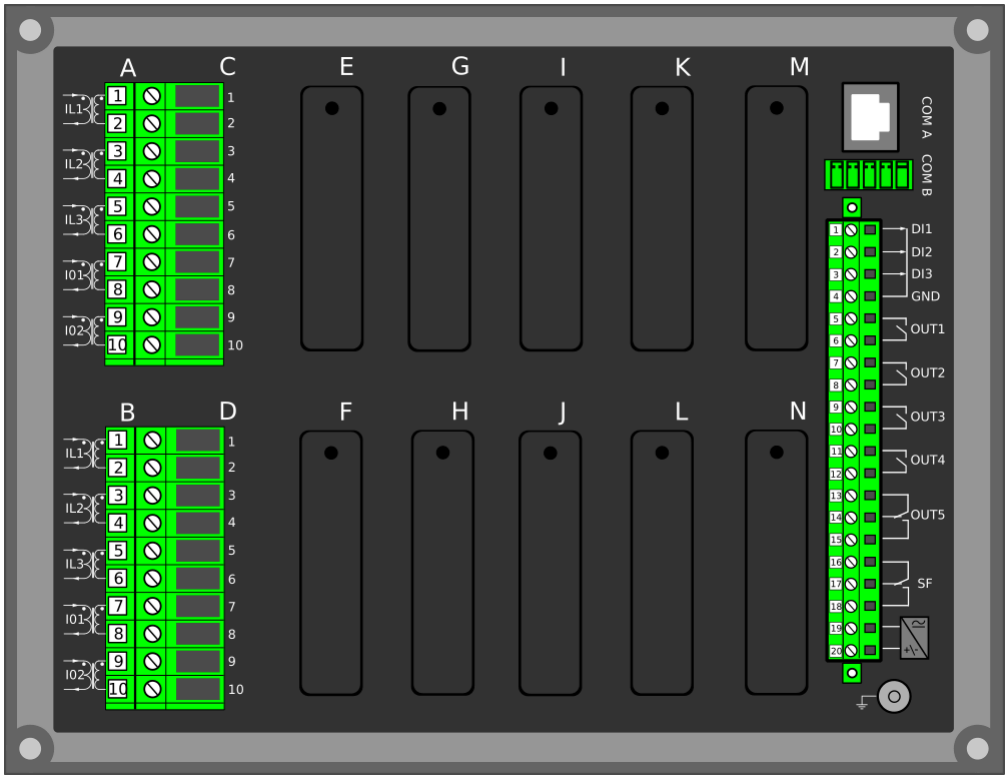
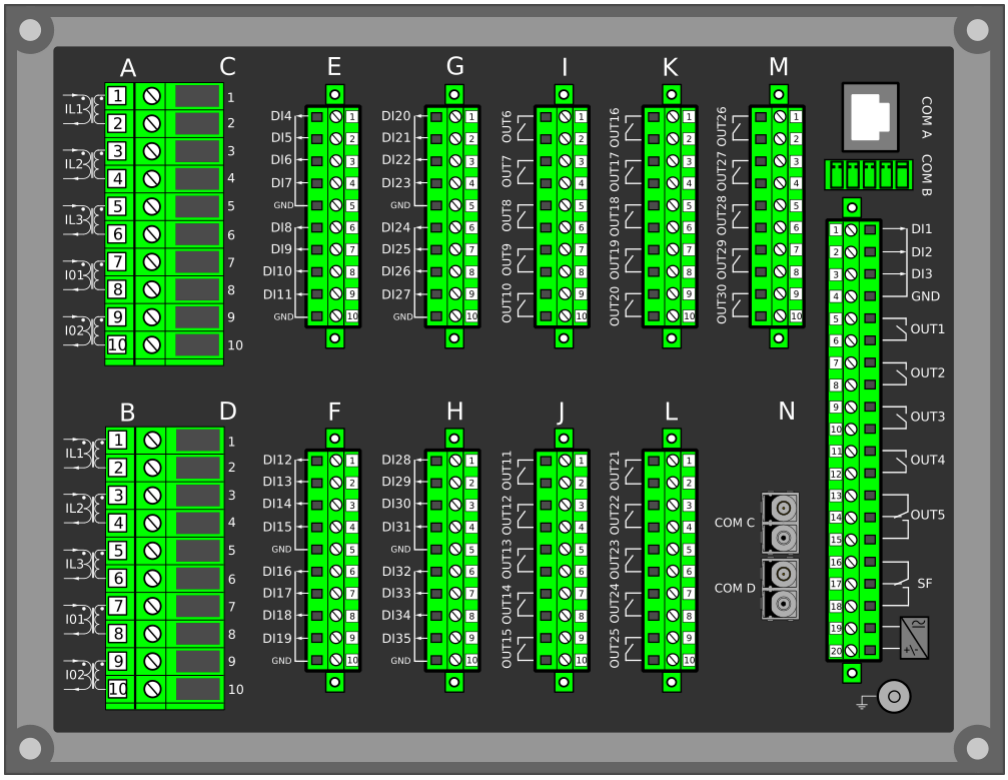


Figure. 8.1 - 122. Modular construction of AQ-X256-XXXXXXX-BBBBCCCCCJ




The modular structure of AQ-X256 allows for scalable solutions for different application requirements. In non-standard configurations Slots from E 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 E, Slot F, Slot G 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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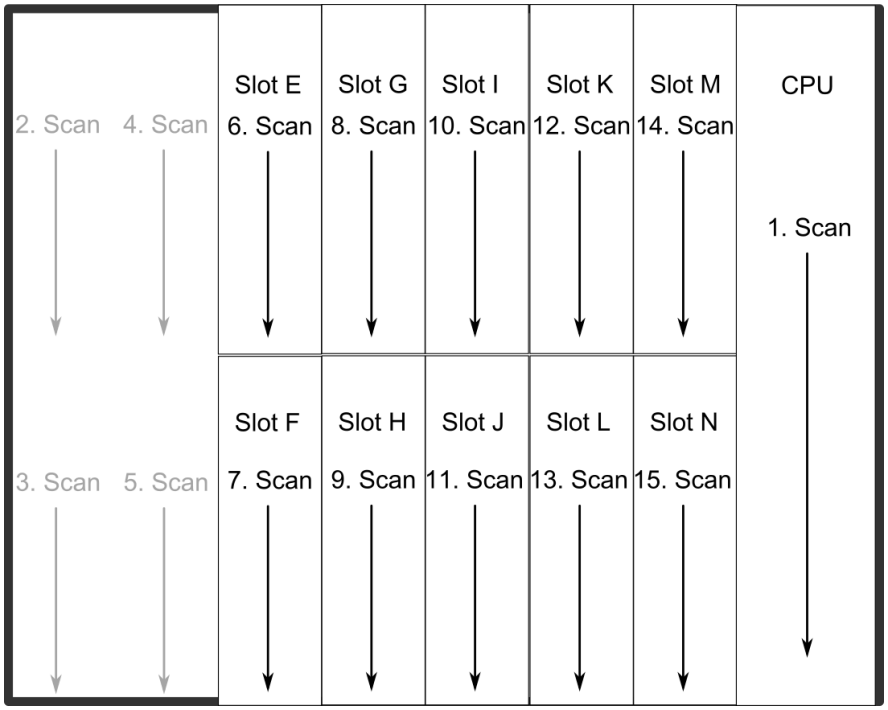
Figure. 8.1 - 123. AQ-X255 hardware scanning and I/O naming principles.




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, which should always remain empty in AQ-X256 devices. If it is not empty, the device issues an alarm.
3. Scan
   Scans Slot B, which should always remain empty in AQ-X256 devices, If it is not empty, the device issues an alarm.
4. Scan
   Scans Slot C and finds the five channels of the first CT module (fixed for AQ-X256). If the CTM is not found, the device issues an alarm.
5. Scan
   Scans Slot D and finds the five channels of the second CT module (fixed for AQ-X256). 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 (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.

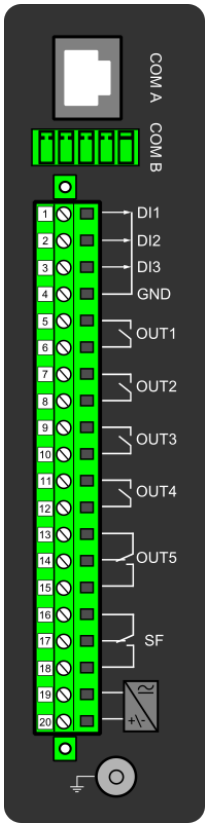
7. Scan
   Scans Slot F, and moves to the next slot if Slot F is empty. If the scan finds an 8DI module, it reserves the designations "DI4", "DI5", "DI6", "DI7", "DI8", "DI9", "DI10" and "DI11" to this slot. If Slot E also has an 8DI module (and therefore has already reserved these designations), the 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 E 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.
8. –15. Scan
   A similar operation to Scan 7 (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 fully optioned example case of AQ-X256-XXXXXXX-BBBBCCCCCJ (the first image pair, on the right) has a total of 35 digital input channels available: three (DI1…DI3) in the CPU module, and the rest in Slots E…H in groups of eight. It also has a total of 30 digital output channels available: five (DO1…DO5) in the CPU module, and the rest in Slots I…M in groups of five. 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-X256 IED family.

## 8.2 CPU module

Figure. 8.2 - 124. CPU module.





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| 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. |
| 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 - 221. 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. |

| Name | Range | Step | Default | Description |
|---|---|---|---|---|
| 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 - 222. 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!



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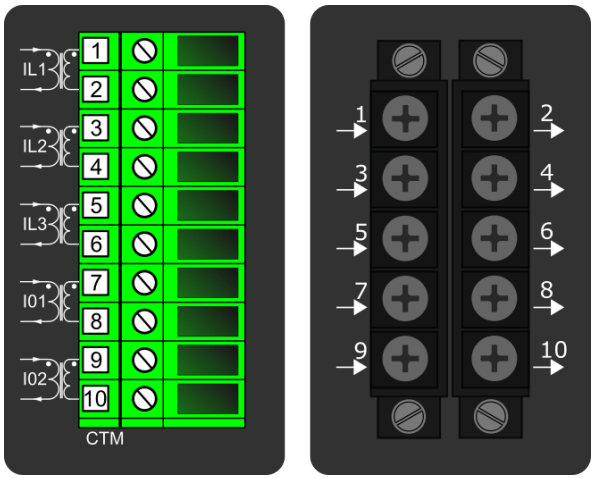
## 8.3 Current measurement module

Figure. 8.3 - 125. Module connections with standard and ring lug terminals.




| Connector | Description |
|---|---|
| CTM 1-2 | Phase current measurement for phase L1 (A). |
| 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)

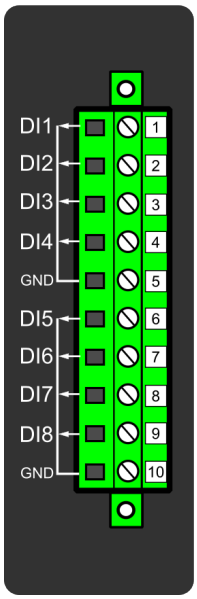
The characteristics of phase current inputs are as follows:

- 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 Digital input module (optional)

Figure. 8.4 - 126. 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 |
| 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.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## 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.

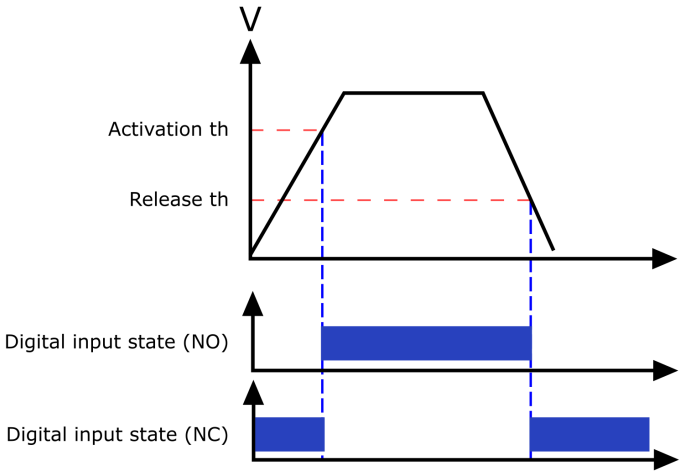
Table. 8.4 - 223. Digital input settings of DI8 module.

| 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. |
| 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. 8.4 - 127. 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. 8.4 - 224. 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*.

Table. 8.4 - 225. 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. |



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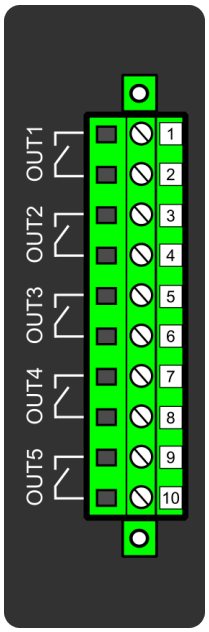
## 8.5 Digital output module (optional)

Figure. 8.5 - 128. 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. 8.5 - 226. 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. |

## 8.6 Point sensor arc protection module (optional)

Figure. 8.6 - 129. Arc protection module.

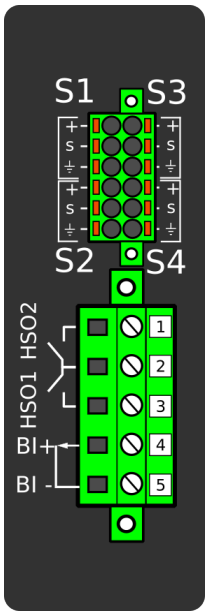



Table. 8.6 - 227. Module connections.

| 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) |

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.



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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.

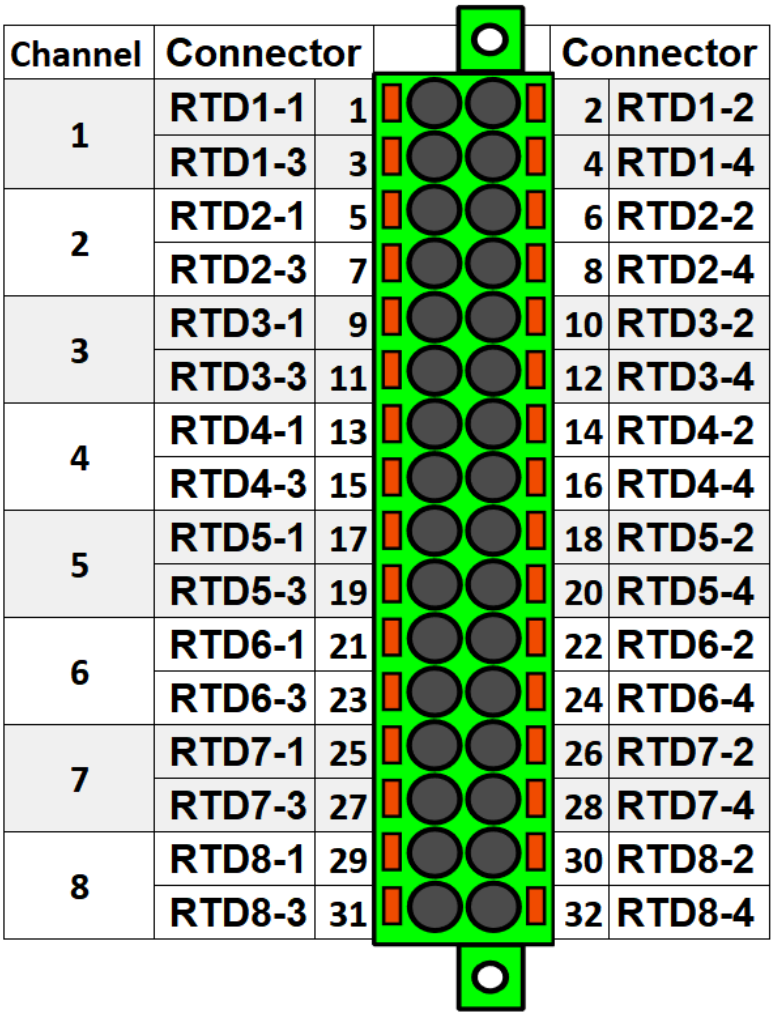
The rated voltage of the binary input is 24 VDC. The threshold picks up at ≥16 VDC. The binary input can be used for external light information or for similar applications. It can also be used as a part of various ARC schemes. Please note that the binary input's delay is 5…10ms.

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*).

## 8.7 RTD input module (optional)

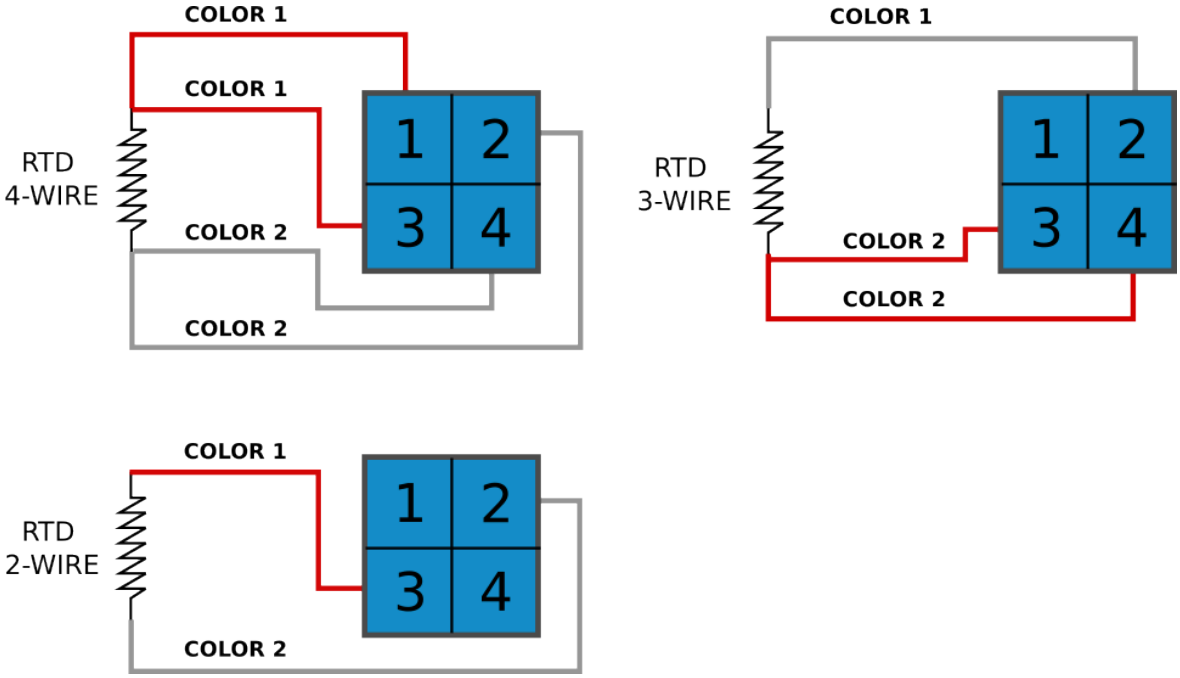
Figure. 8.7 - 130. RTD input module connectors.



| 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 |

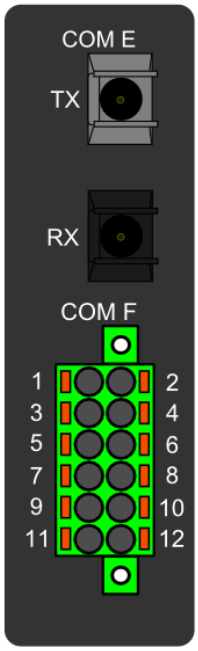
The RTD input module is an add-on module with eight (8) RTD input channels. Each input supports 2-wire, 3-wire and 4-wire RTD sensors. The sensor type can be selected with software for two groups, four channels each. The card supports Pt100 and Pt1000 sensors

Figure. 8.7 - 131. RTD sensor connection types.




## 8.8 Serial RS-232 communication module (optional)

Figure. 8.8 - 132. 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 |



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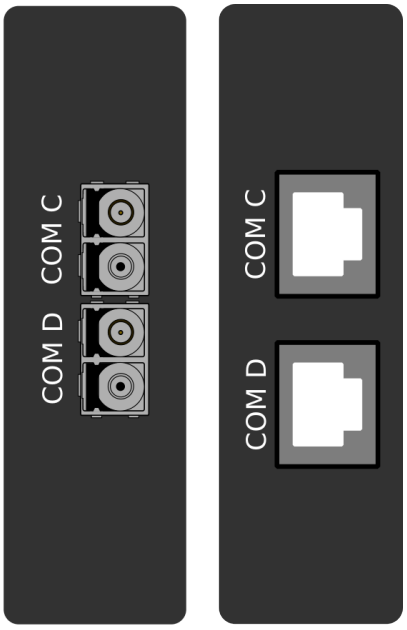
| Connector | Name | Description |
|---|---|---|
| COM F – Pin 1 | +24 V input | Optional external auxiliary voltage for serial fiber |
| COM F – Pin 2 | GND | Optional external auxiliary voltage for serial fiber |
| COM F – Pin 3 | - | - |
| COM F – Pin 4 | - | - |
| COM F – Pin 5 | RS-232 RTS | Serial 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.

## 8.9 LC or RJ45 100 Mbps Ethernet communication module (optional)

Figure. 8.9 - 133. LC and RJ45 100 Mbps Ethernet module connectors.

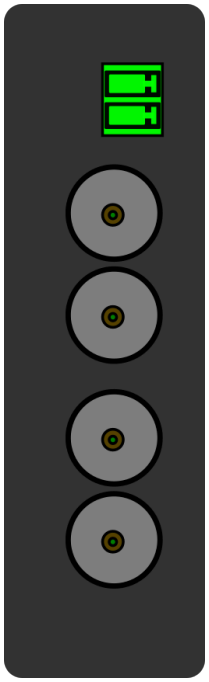


| Connector | Description (LC ports) | Description (RJ45) |
|---|---|---|
| COM C: | • Communication port C, 100 MbpsLC fiber connector.<br>• 62.5/125 µm or 50/125 µm multimode (glass).<br>• Wavelength 1300 nm. | • RJ-45 connectors<br>• 10BASE-T and 100BASE-TX |
| COM D: | • Communication port D, 100 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.

## 8.10 Double ST 100 Mbps Ethernet communication module (optional)

Figure. 8.10 - 134. 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 |



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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. 8.10 - 135. Example of a ring configuration.

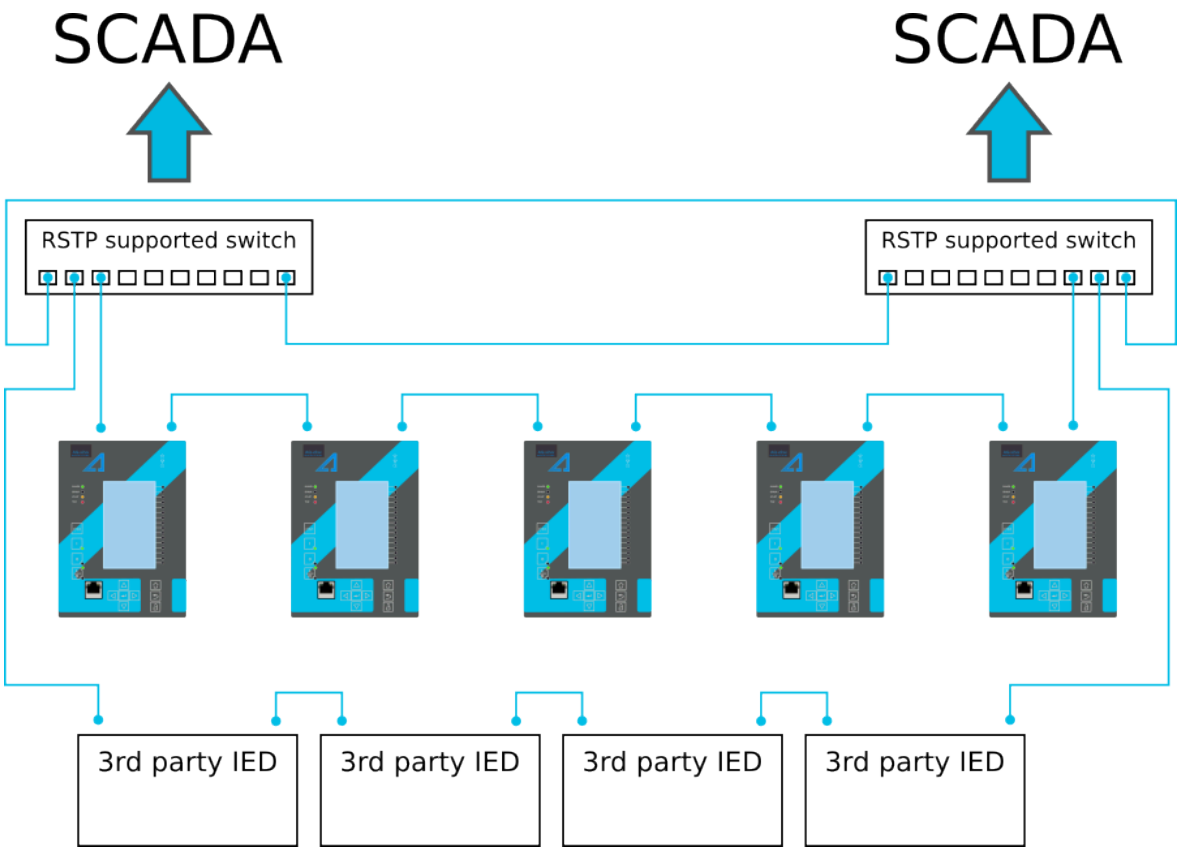
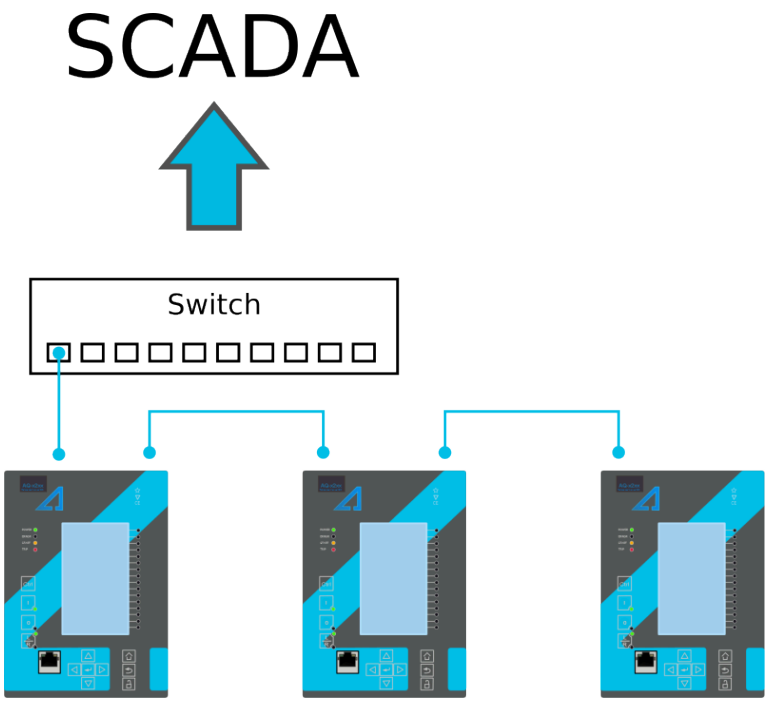
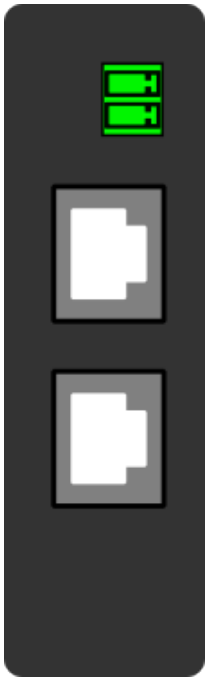


Figure. 8.10 - 136. Example of a multidrop configuration.




## 8.11 Double RJ45 10/100 Mbps Ethernet communication module (optional)

Figure. 8.11 - 137. Double RJ-45 10/100 Mbps Ethernet communication module.



| Connector | Description |
|---|---|
| Two-pin connector | • IRIG-B input |



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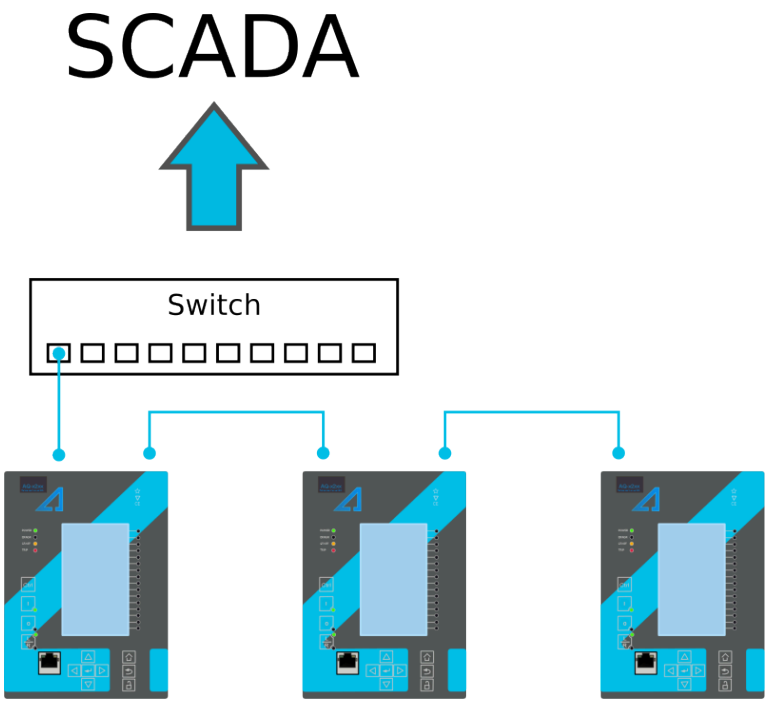
| Connector | Description |
|---|---|
| RJ-45 connectors | • Two Ethernet ports<br>• RJ-45 connectors<br>• 10BASE-T and 100BASE-TX |

This option card supports multidrop configurations.

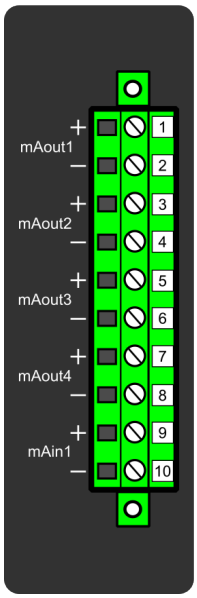
For other redundancy options, please refer to the option card "LC 100 Mbps Ethernet communication module".

Figure. 8.11 - 138. Example of a multidrop configuration.




## 8.12 Milliampere (mA) I/O module (optional)

Figure. 8.12 - 139. Milliampere (mA) I/O module connections.



| 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.

## 8.13 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. 8.13 - 140. Device dimensions.

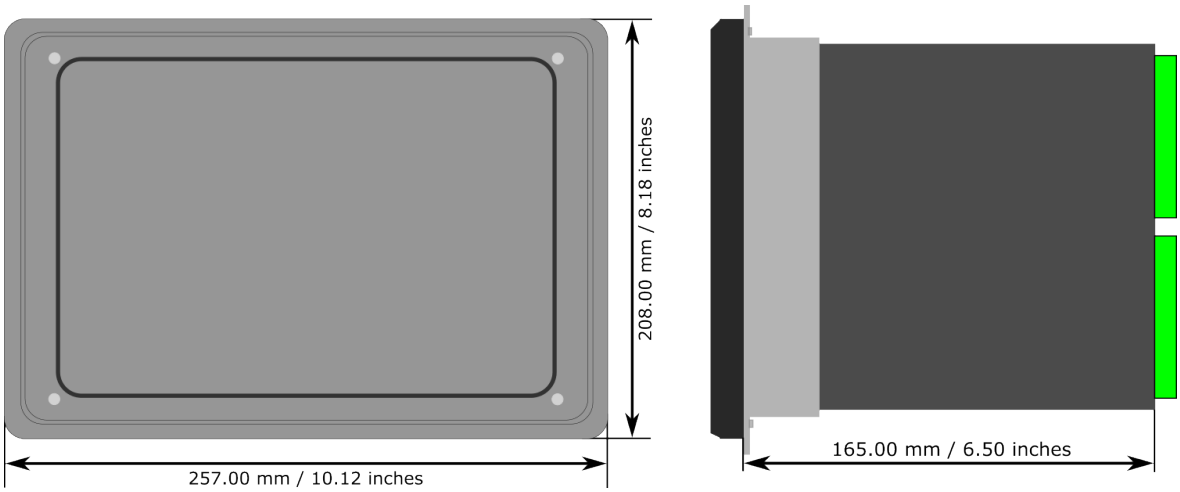




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Figure. 8.13 - 141. Device installation.

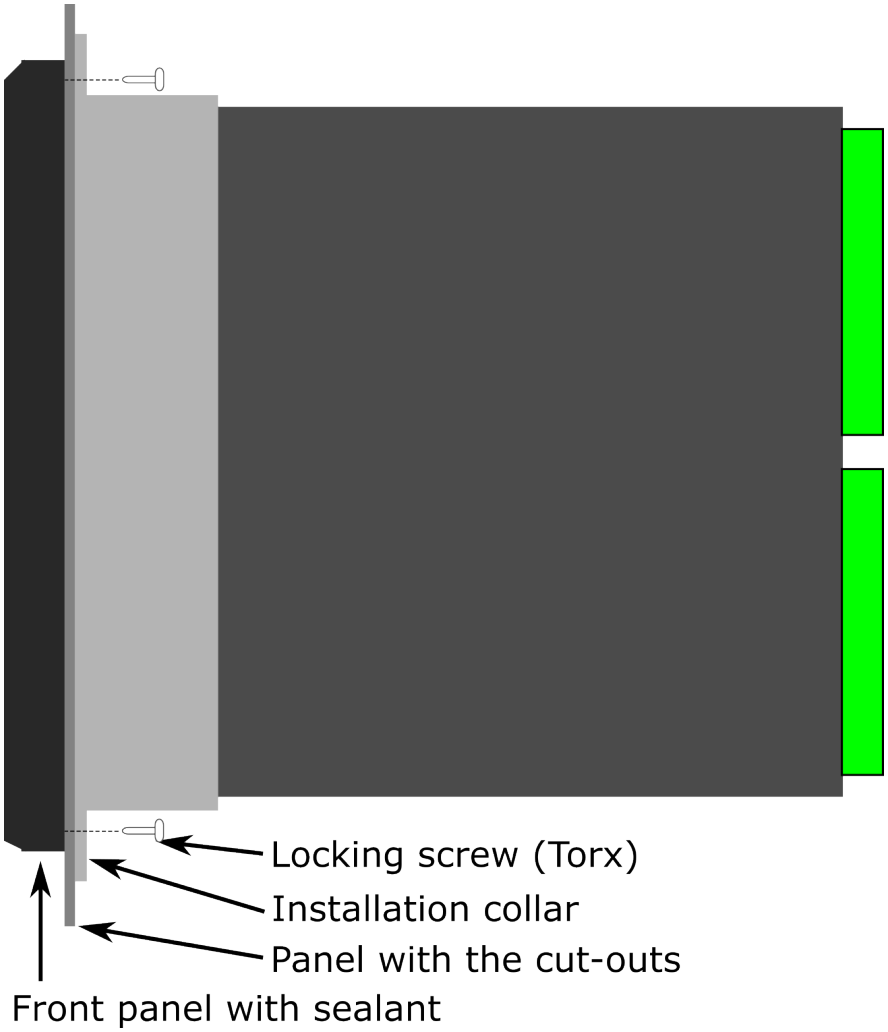
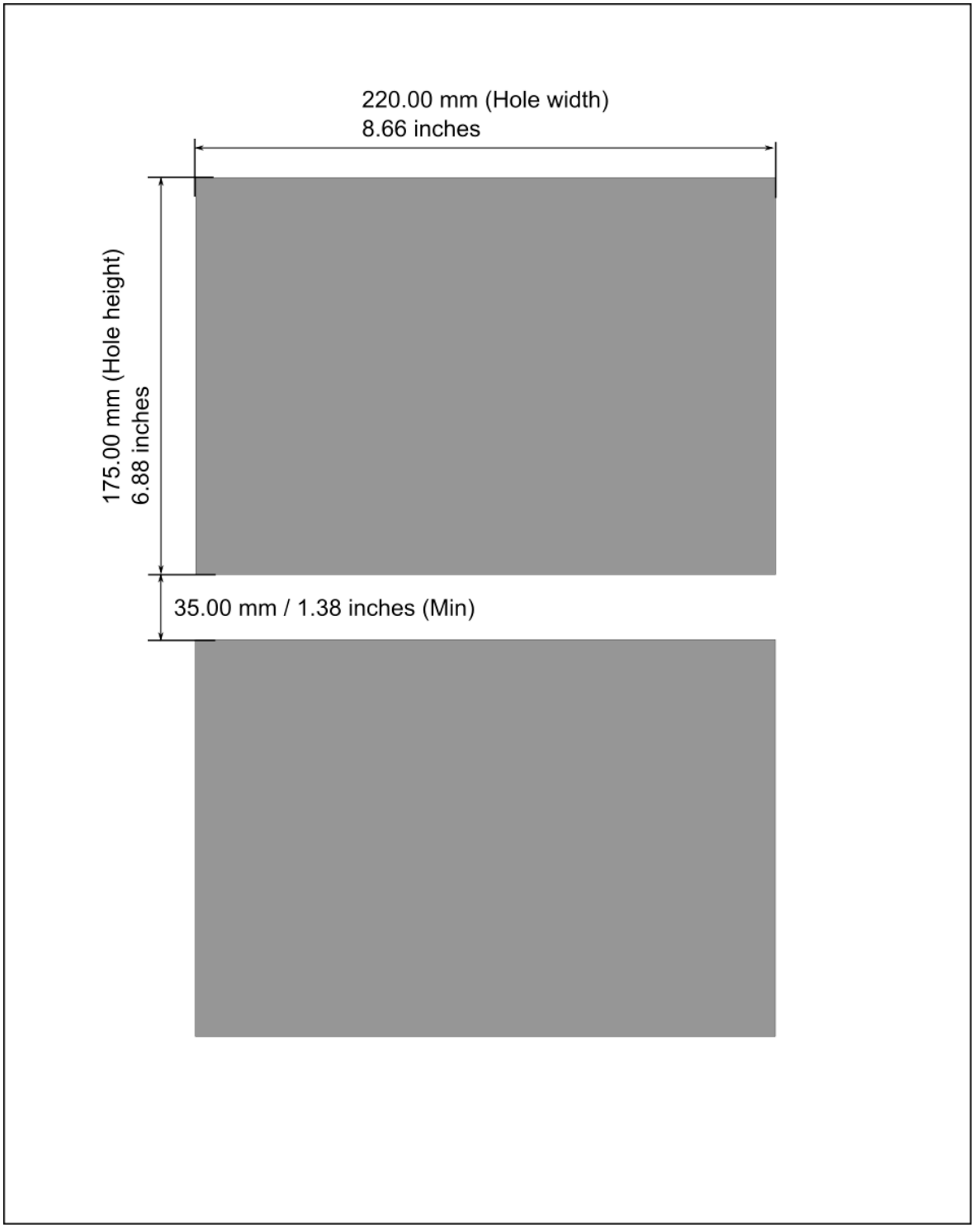


Figure. 8.13 - 142. Panel cut-out and spacing of the IED.



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# 9 Technical data

## 9.1 Hardware

### 9.1.1 Measurements

#### 9.1.1.1 Current measurement

Table. 9.1.1.1 - 228. Technical data for the current measurement module.

| 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) |
| 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 Frequency measurement

Table. 9.1.1.2 - 229. 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

### 9.1.2.1 Auxiliary voltage

Table. 9.1.2.1 - 230. Power supply model A

| Rated values |
|---|


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| | |
|---|---|
| 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 - 231. 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 - 232. 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 - 233. 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 - 234. 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 - 235. 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) |
| 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 |


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| | |
|---|---|
| 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 - 236. 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 - 237. 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 |
| **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 - 238. Technical data for the digital input module.

| 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><br>2.5 $mm^2$ |

### 9.1.3.2 Digital output module

Table. 9.1.3.2 - 239. Technical data for the digital output module.

| 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><br>Maximum wire diameter | <br><br>2.5 $mm^2$ |

### 9.1.3.3 Point sensor arc protection module

Table. 9.1.3.3 - 240. Technical data for the point sensor arc protection module.

| Connections |
|---|


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| | |
|---|---|
| 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 - 241. 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 - 242. Binary input channel

| | |
|---|---|
| Rated values | |
| Voltage withstand | 265 VDC |
| 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 - 243. Technical data for the milliampere module.

| |
|---|
| 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 - 244. Technical data for the RTD input module.

| 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 - 245. Technical data for the RS-232 & serial fiber communication module.

| 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 - 246. Technical data for the double LC 100 Mbps Ethernet communication module.

| Protocols | |
|---|---|
| Protocols | HSR and PRP |
| Ports | |
| Quantity of fiber ports | 2 |


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| | |
|---|---|
| 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 - 247. Technical data for the double ST 100 Mbps Ethernet communication module.

| General information | |
|---|---|
| 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 - 248. Technical data for the HMI TFT display.

| 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 - 249. 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 %$I_{fund}$ |
| 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 - 250. 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 × $I_n$ |


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

Table. 9.2.1.3 - 251. 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) | ±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 |

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

Table. 9.2.1.4 - 252. 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) | ±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 |


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| Instant operation time | |
|---|---|
| Start time and instant operation time (trip):<br>$I_M/I_{SET}$ ratio >1.05 | <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.

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

Table. 9.2.1.5 - 253. 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 | 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) | ±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 | ±1.0 % or ±55 ms<br>±15 ms |
| **Reset** | |
| Reset ratio | 97 % of the pick-up current setting |
| Reset time | <50 ms |

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

Table. 9.2.1.6 - 254. 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 |

### 9.2.1.7 Transformer thermal overload protection (TT>; 49T)

Table. 9.2.1.7 - 255. Technical data for the transformer 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) |
| **Setting specifications** | |
| Time constants τ | 1 heating, 1 cooling |
| 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 ºC and ºF |
| **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** | |



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| | |
|---|---|
| - Starting<br>- Operating time | ±0.5 % of the set pick-up value<br>±5 % or ± 500 ms |

### 9.2.1.8 Resistance temperature detectors

Table. 9.2.1.8 - 256. Technical data of the resistance temperature detectors.

| Inputs | |
|---|---|
| Resistance input magnitudes | Measured temperatures measured by RTD sensors |
| 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 |

### 9.2.1.9 Transformer status monitoring

Table. 9.2.1.9 - 257. Technical data for the transformer status monitoring function.

| Features | |
|---|---|
| Control scale | Common transformer data settings for all functions in the transformer module, the protection logic, the HMI and the I/O. |
| Settings | Transformer application nominal data |
| Other features | Status hours counters (normal load, overload, high overload)<br>Transformer status signals<br>Transformer data for functions |
| **Outputs** | |
| Light/no load | $I_M < 0.2 \times I_N$ |
| Inrush HV side detected | $I_M < 0.2 \times I_N \rightarrow I_M > 1.3 \times I_N$ |
| Inrush LV side detected | $I_M < 0.2 \times I_N \rightarrow I_M > 1.3 \times I_N$ |
| Load normal | $I_M > 0.2 \times I_N$… $I_M < 1.0 \times I_N$ |
| Overloading | $I_M > 1.0 \times I_N$… $I_M < 1.3 \times I_N$ |
| High overload | $I_M > 1.3 \times I_N$ |
| **Inaccuracy** | |
| Current detection | ±3 % of the set pick-up value > $0.5 \times I_N$ setting. 5 mA < $0.5 \times I_N$ setting |
| Detection time | ±0.5 % or ±10 ms |

### 9.2.1.10 Generator/transformer differential protection (Idb>/Idi>/I0dHV>/I0dLV>; 87T/87N/87G)

Table. 9.2.1.10 - 258. Technical data for the transformer differential protection function.

| Measurement inputs |
|---|

| | |
|---|---|
| Current inputs (CT1 and CT2 current measurement module) | 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)<br>Calculated residual current: $I_{L1}$ (A), $I_{L2}$ (B), $I_{L3}$ (C) |
| Current input magnitudes | The phase currents of the high-voltage and the low-voltage sides.<br>Residual current measurement for HV/LV REF protection.<br>Phase currents 2nd and 5th harmonic measurement. |
| Characteristics (differential and REF) | |
| Differential calculation mode<br>Bias calculation mode | Add or subtract (CT direction)<br>Average or maximum (sensitivity) |
| Idb> pick-up<br>Turnpoint 1<br>Slope 1<br>Turnpoint 2<br>Slope 2 | 0.01…100.00 %, step 0.01 %, default 10.00 %<br>0.01…50.00 × $I_N$, step 0.01× $I_N$, default 1.00 × $I_N$<br>0.01…250.00 %, step 0.01 %, default 10.00 %<br>0.01…50.00 × $I_N$, step 0.01 × $I_N$, default 3.00 × $I_N$<br>0.01…250.00 % by step 0.01 %, default 200.00 % |
| Idi> pick-up | 200.00...1500.00 %, step 0.01 %, default 600.00 % |
| Internal harmonic blocking selection | None, 2nd harmonic, 5th harmonic, both 2nd and 5th harmonic. |
| 2nd harmonic blocking pick-up | 0.01…50.00 %, step 0.01 %, default 15.00 % |
| 5th harmonic blocking pick-up | 0.01…50.00 %, step 0.01 %, default 35.00 % |
| Inaccuracy:<br>- Differential current<br>- 2nd harmonic | <br>±3.0 %ISET or ±75 mA (0.10…4.0 x ISET)<br>±1.5 %$I_{SIDE1}$ |
| Instant operation time | |
| Instant operation time >1.05 × $I_{SET}$ | <40 ms (Harmonic blocking active) |
| Instant operation time >3.00 × $I_{SET}$ | <30 ms (Harmonic blocking active) |
| Instant operation time >3.00 × $I_{SET}$ | ~15 ms (No harmonic blocking) |
| Reset | |
| Reset ratio: differential current | 97 % of the differential current setting (typically) |
| Reset time | <50 ms |

Note!

- The harmonic current is set and calculated according to the highest amplitude of side 1, 2 or 3 currents (Ih%/$I_{SIDE1/2/3}$). The harmonic current is calculated individually for each phase.

### 9.2.1.11 Arc fault protection (IArc>/I0Arc>; 50Arc/50NArc) (optional)

Table. 9.2.1.11 - 259. 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 |



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| | |
|---|---|
| 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.

## 9.2.2 Control functions

### 9.2.2.1 Setting group selection

Table. 9.2.2.1 - 260. 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 - 261. Technical data for the object control and monitoring function.

| | |
|---|---|
| **Signals** | |
| 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 | ±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. |

## 9.2.3 Monitoring functions

### 9.2.3.1 Current transformer supervision

Table. 9.2.3.1 - 262. 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) |



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### 9.2.3.2 Circuit breaker wear monitoring

Table. 9.2.3.2 - 263. 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 |

### 9.2.3.3 Total harmonic distortion

Table. 9.2.3.3 - 264. 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 | <br>±0.5 % or ±10 ms<br>Typically <20ms<br>Typically <25 ms |
| **Reset** | |
| Reset time | Typically <10 ms |
| Reset ratio | 97 % |

### 9.2.3.4 Disturbance recorder

Table. 9.2.3.4 - 265. Technical data for the disturbance recorder function.

| Recorded values | |
|---|---|
| Recorder<br>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 |
| 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 |

### 9.2.3.5 Event logger

Table. 9.2.3.5 - 266. 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 - 267. 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 - 268. Voltage tests.

| Dielectric voltage test |
|---|


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| | |
|---|---|
| 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 - 269. 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 - 270. 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 - 271. 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 - 272. 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 |
| Weight | 2.0 kg |



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# 10 Ordering information

AQ - T 2 5 6 A - P X 8 X A X A - X X X X X X X X X X

**Model**
T Transformer protection

**Device size**
5 1/2 of 19" rack

**Analog measurement**
6 10 Current measurement channels

**Functionality package**
A Standard

**Mounting**
P Panel mounted

**Auxiliary voltage**
H 80...265 VAC/DC
L 18...72 VDC

**Measurement accuracy**
8 N/A

**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 E, F, G, H, I, J, K, L, M, N (10 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. |
| 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. |



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# 11 Contact and reference information

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