ARCTEQ
PART OF ENSTO GROUP

AQ-F201

Overcurrent and earth fault relay

Instruction manual

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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.

Nothing contained in this document shall increase the liability or extend the warranty obligations of the manufacturer Arcteq Relays Ltd. The manufacturer expressly disclaims any and all liability for any damages and/or losses caused due to a failure to comply with the instructions contained herein or caused by persons who do not fulfil the aforementioned requirements. Furthermore, the manufacturer shall not be liable for possible errors in this document.

Please note that you must always comply with applicable local legislation and regulations. The manufacturer gives no warranties that the content of this document is in all respects in line with local laws and regulations and assumes no liability for such possible deviations.

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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. - Improved descriptions generally in many chapters. - Improved readability of a lot of drawings and images. - Updated protection functions included in every manual. - Every protection relay type now has connection drawing, application example drawing with function block diagram and application example with wiring. - Added General-menu description.
Revision	2.01
Date	6.11.2019
Changes	- Added description for LED test and button test. - Complete rewrite of every chapter. - Improvements to many drawings and formula images. - Order codes revised.
Revision	2.02
Date	7.7.2020
Changes	- A number of image descriptions improved.
Revision	2.03
Date	27.8.2020

Changes	- Terminology consistency improved (e.g. binary inputs are now always called digital inputs). - 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.). - Tech data updated: non-directional overcurrent - Tech data updated: non-directional earthfault - Tech data updated: current unbalance - Improvements to many drawings and formula images. - Improved and updated device user interface display images. - AQ-F201 Functions included list Added: Programmable control switches and measurement recorder. - Added 6th harmonic to harmonic overcurrent protection function. - Changed disturbance recorder maximum digital channel amount from 32 to 95. - Added residual current coarse and fine measurement data to disturbance recorder description. - Updated I01 and I02 rated current range. - Added inches to Dimensions and installation chapter. - Added raising frames, wall mounting bracket, combiflex frame to order code. - Added logical input and logical output function descriptions. - Additions to Abbreviations chapter. - Added button test description to Local panel structure chapter. - Added Fault register view to Basic configuration chapter. - Added parameter descriptions to General menu Device user interface chapter. - Protection device user interface chapter almost completely rewritten and restructured. - Added new parameter descriptions to Monitoring menu device user interface chapter. - Added note to Configuring user levels and passwords chapter that user level with a password automatically locks itself after 30 minutes of inactivity. - Added more "Tripped stage" indications and fault types to Measurement value recorder function. - Added sample rate to voltage and current measurement tech data.
Revision	2.04
Date	8.6.2021
Changes	- Increased the consistency in terminology - Various image upgrades - 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. - 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). - Added event history technical data
Revision	2.06
Date	21.6.2022

Changes	- Improved descriptions generally in many chapters. - Improved readability of a lot of drawings and images. - Order codes have been revised. - Added new trip detections and fault types to measurement value recorder. - Added user description parameter descriptions for digital inputs, digital outputs, logical inputs, logical outputs and GOOSE inputs. - Added spare part codes and compatibilities to option cards.
Revision	2.07
Date	7.7.2022
Changes	
Revision	2.08
Date	8.9.2022
Changes	- Added stage forcing parameter to function descriptions. - Fixes to "Real time signals to comm" description. - Added "Ethernet port" parameter description to IEC61850, IEC104 and Modbus TCP descriptions. - Removed "Measurement update interval" settings from Modbus description. No longer in use. - Renamed "System integration" chapter to "Communication" and restructured the chapters to be closer to how they are in the menus. - Added "Event logger" chapter.
Revision	2.09
Date	14.3.2023
Changes	- Updated the Arcteq logo on the cover page and refined the manual's visual look. - Added the "Safety information" chapter and changed the notes throughout the document accordingly. - Changed the "IED user interface" chapter's title to "Device user interface" and replaced all 'IED' terms with 'device' or 'unit'. - Updated the rated values for the change-over CPU digital outputs in "Technical data". - Added the maximum and minimum allowed tracking frequencies to the settings table of the "Frequency tracking and scaling" chapter (under "Measurements").
Revision	2.10
Date	19.6.2023
Changes	- Updated order codes.
Revision	2.11
Date	29.11.2023
Changes	- Added the 5 ms update time in the measurement chapters. - Added spring lock cage options for connectors. See the "Ordering information" chapter. - Updated the contact address for technical support in the "Contact and reference information" chapter.
Revision	2.12
Date	January 2024
Changes	- Added Chinese and Kazakh languages as language options in "General menu".

Revision	2.13
Date	September 2024
Changes	- Corrected the number of devices that fit a 19 in rack in the "Dimensions and installation" chapter.
Revision	2.14
Date	June 2025
Changes	- Updated the product and packaging weights. - Order code table updated.

1.2 Version 1 revision notes

Table. 1.2 - 2. Version 1 revision notes

Revision	1.00
Date	8.1.2013
Changes	• The first revision for AQ-F201.
Revision	1.01
Date	22.11.2013
Changes	• Order code updated, technical data updated. • The "Measurements" chapter added. • The IED user interface" chapter added.
Revision	1.02
Date	19.1.2015
Changes	• Updated technical data. • Added System integration texts: NTP, Modbus TCP/RTU, Modbus I/O, IEC 103 and SPA.
Revision	1.03
Date	12.6.2015
Changes	• Updated technical data. • Added more text to "System integration" (NTP, Modbus TCP/RTU, Modbus I/O, IEC 103 and SPA).
Revision	1.04
Date	12.1.2016
Changes	• Added the digital input operation description. • Improved formatting.
Revision	1.05
Date	30.5.2016

Changes	• Added the PCB and Terminal options to the order code.
Revision	1.06
Date	30.8.2016
Changes	• Added the password set-up guide (previously only in the AQtivate 200 user guide).
Revision	1.07
Date	16.1.2016
Changes	• Order code updated.
Revision	1.08
Date	12.12.2017
Changes	• Measurement value recorder description added. • ZCT connection added to the current measurement description. • Ring-lug CT card option description added. • Order code revised. • Non-standard inverse time delay curves added. • Internal harmonic blocking parameter added to the I> and I0> functions.
Revision	1.09
Date	13.4.2018
Changes	• I> and I0> pick-up ranges updated.
Revision	1.10
Date	9.8.2018
Changes	• THD monitoring description added. • Line thermal overload protection description added.
Revision	1.11
Date	18.1.2019
Changes	• HMI display technical data added.

1.3 Safety information

This document contains important instructions that should be saved for future use. Read the document carefully before installing, operating, servicing, or maintaining this equipment. Please read and follow all the instructions carefully to prevent accidents, injury and damage to property.

Additionally, this document may contain four (4) types of special messages to call the reader's attention to useful information as follows:

> NOTICE!
> "Notice" messages indicate relevant factors and conditions to the the concept discussed in the text, as well as to other relevant advice.

CAUTION!
"Caution" messages indicate a potentially hazardous situation which, if not avoided, **could** result in minor or moderate personal injury, in equipment/property damage, or software corruption.

WARNING!
"Warning" messages indicate a potentially hazardous situation which, if not avoided, **could** result in death or serious personal injury as well as serious damage to equipment/property.

DANGER!
"Danger" messages indicate an imminently hazardous situation which, if not avoided, **will** result in death or serious personal injury.

These symbols are added throughout the document to ensure all users' personal safety and to avoid unintentional damage to the equipment or connected devices.

Please note that although these warnings relate to direct damage to personnel and/or equipment, it should be understood that operating damaged equipment may also lead to further, indirect damage to personnel and/or equipment. Therefore, we expect any user to fully comply with these special messages.

1.4 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

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

2 General

AQ-F201 overcurrent and earth fault device is a member of the AQ 200 product line. However, while the hardware and the software are modular in the AQ 200 product line, AQ-F201 is provided as a fixed overcurrent and earth fault device with a factory set of I/O and functionality. This manual describes the specific application of the AQ-F201 overcurrent and earth fault device. For other AQ 200 and AQ 250 series products please consult their respective device manuals.

AQ-F201 offers a compact solution for any application that requires protection for non-directional overcurrent and earth faults. A selection of supportive functions for protection, measurement, monitoring, control and communication along with a large, programmable HMI guarantee the best price–performance ratio in its class of basic range relays.

3 Device user interface

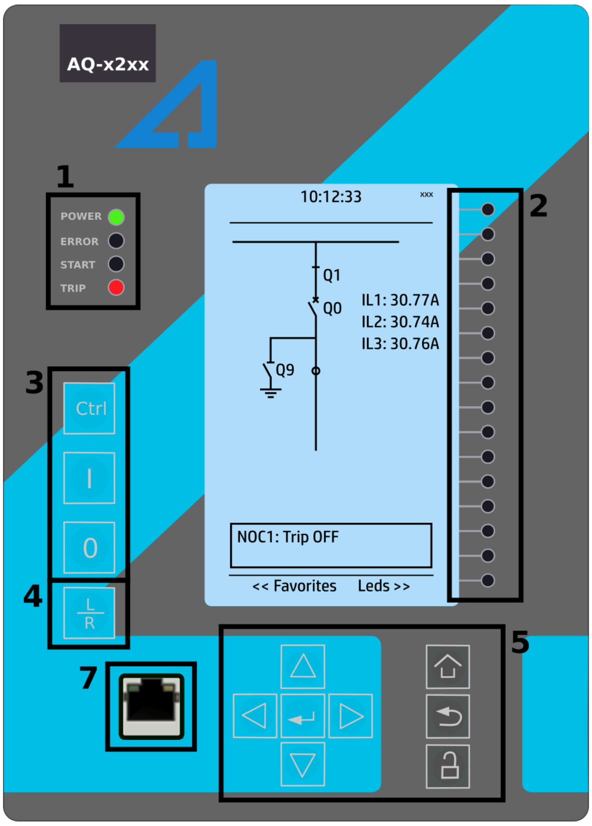
3.1 Panel structure

The user interface section of an AQ 200 or AQ 250 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 200 freeware software suite.

3.1.1 Local panel structure

The front panel of AQ 200 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.

Figure. 3.1.1 - 1. Local panel structure.



1. Four (4) default LEDs: "Power", "Error", "Start" (configurable) and "Trip" (configurable).
2. Sixteen (16) freely configurable LEDs 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 O buttons.
4. The L/R button switches between the local and the remote control modes.
5. Eight (8) buttons for device local programming: the four navigation arrows and the Enter button in the middle, as well as the Home, the Back and the password activation buttons.
6. One (1) RJ-45 Ethernet port for device 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 right side of the display. Their activation and color (green or yellow) are based on the settings the user has put in place in the software.

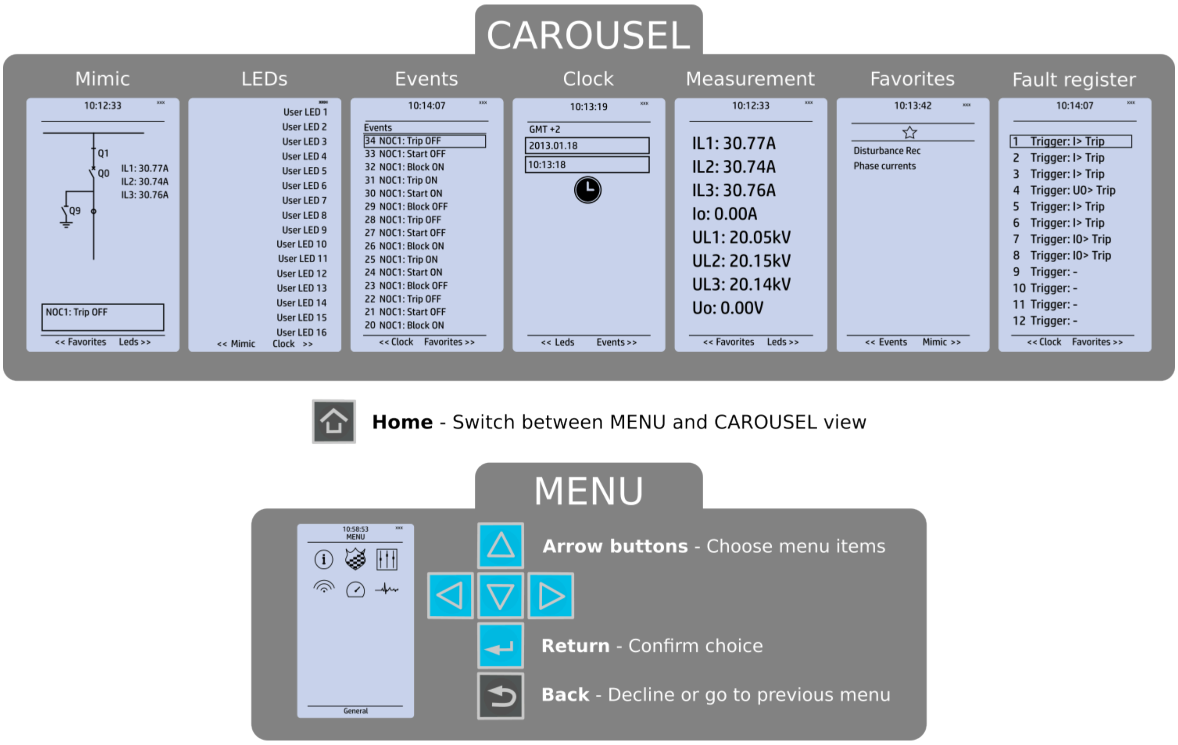
Holding the I (object control) button down for five seconds brings up the button test menu. It displays all the physical buttons on the front panel. Pressing any of the listed buttons marks them as tested. When all buttons are marked as having been tested, the device will return back to the default view.

3.2 Mimic and main menu

3.2.1 Basic configuration

The user interface is divided into seven (7) quick displays: "Mimic", "LEDs", "Events", "Clock", "Measurement", "Favorites" and "Fault register". The default quick display (as presented in the image below) is the mimic view; you can move through these menus by pressing the left and right arrow buttons. Please note that the available quick display carousel view might be different if you have changed the view with AQtivate's Carousel Designer tool.

Figure. 3.2.1 - 2. Basic navigation (general).



The Home button switches between the quick display carousel and the main display with the six (6) main configuration menus (*General*, *Protection*, *Control*, *Communication*, *Measurements* and *Monitoring*). Note that the available menus vary depending on the device type. You can select one of the menus by using the four navigation arrows and pressing Enter in the middle. The Back button takes you back one step. If you hold it down for three seconds, it takes you back to the main menu. You can also use it to reset the alarm LEDs you have set.

The password activation button (with the padlock icon) takes you to the password menu where you can enter the passwords for the various user levels (User, Operator, Configurator, and Super-user). See "Configuring user levels and their passwords" for more detail.

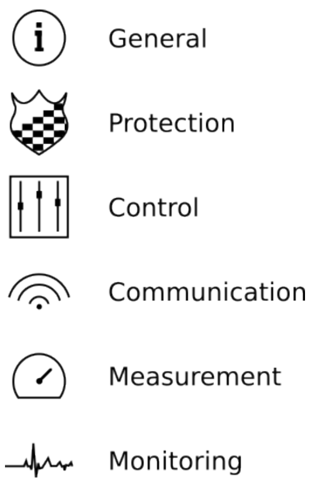
3.2.2 Navigation in the main configuration menus

All the settings in this device have been divided into the following six (6) main configuration menus:

- General
- Protection
- Control
- Communication
- Measurement
- Monitoring.

They are presented in the image below. The available menus vary according to the device type.

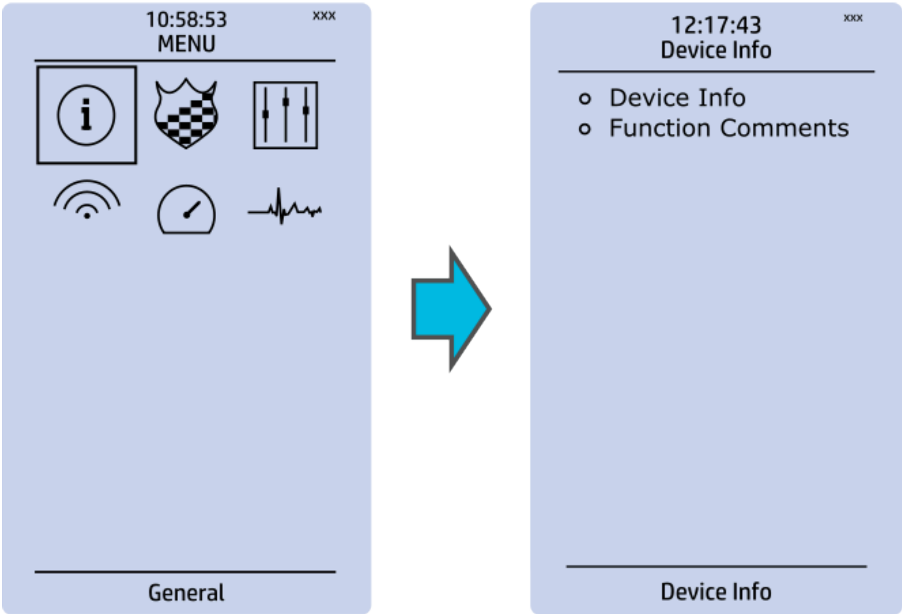
Figure. 3.2.2 - 3. Main configuration menus.



3.3 General menu

The *General* main menu is divided into two submenus: the *Device info* tab presents the information of the device, while the *Function comments* tab allows you to view all comments you have added to the functions.

Figure. 3.3 - 4. General menu structure.



Device info

Figure. 3.3 - 5. Device info.

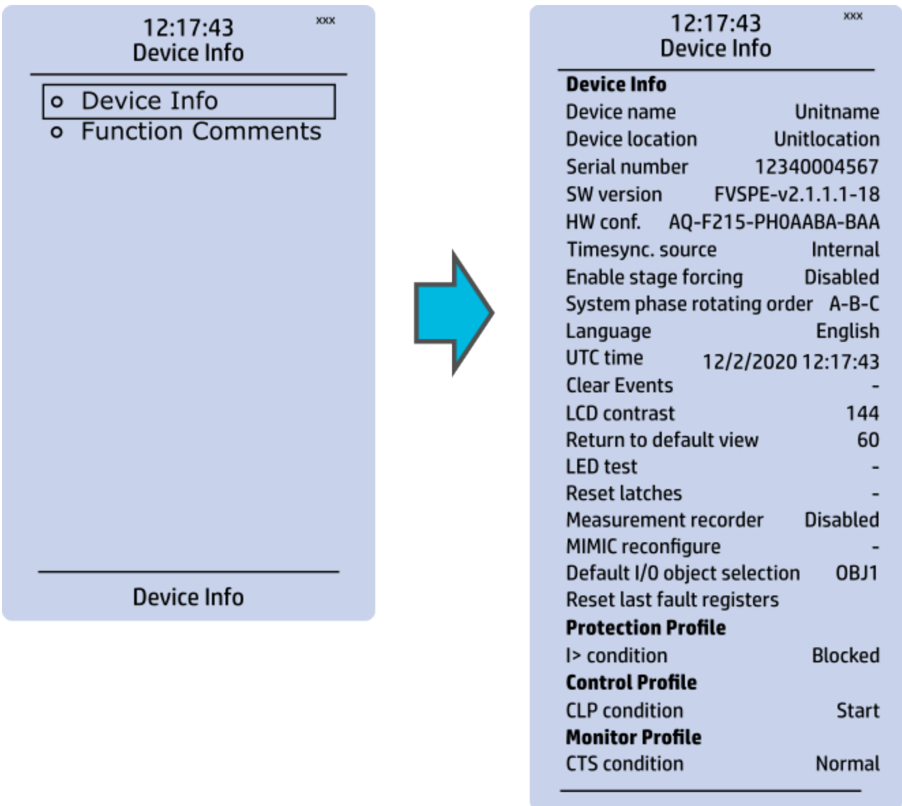


Table. 3.3 - 3. Parameters and indications in the *General* menu.

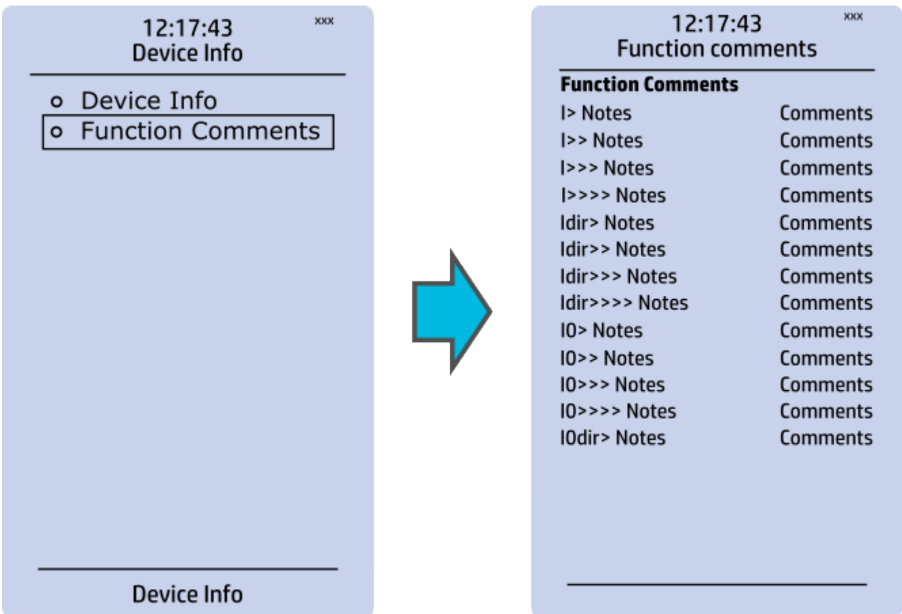
Name	Range	Step	Default	Description
Device name	-	-	Unitname	The file name uses these fields when loading the .aqs configuration file from the AQ-200 unit.
Device location	-	-	Unitlocation	
Serial number	-	-	-	Displays the unit's unique serial number. The serial number is also printed on the sticker located on the side of the unit.
Firmware version	-	-	-	Displays the software version (firmware) used by the unit. Upgradable by the user if a newer version is available.
Hardware configuration	-	-	-	Displays the hardware configuration of the unit. The hardware configuration is also printed on the sticker located on the side of the unit.
Time synchronization source	• Internal • External NTP • External Serial • IRIG-B	-	• Internal	If an external clock time synchronization source is available, the type is defined with this parameter. In the internal mode there is no external Timesync source. IRIG-B requires a serial fiber communication option card.
Enable stage forcing	• Disabled • Enabled	-	• 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.
System phase rotating order	• A-B-C • A-C-B	-	• A-B-C	Allows the user to switch the expected order in which the voltage and current phases are wired to the unit.
Language	• User defined • English • Finnish • Chinese • Spanish • French • German • Russian • Ukrainian • Kazakh	-	• 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 200 setting tool, AQtivate follows the value set into this parameter.
UTC time	-	-	-	Displays the UTC time used by the unit without time zone corrections.
Clear events	• - • Clear	-	• -	Clears the event history recorded in the device.
LCD Contrast	0…255	1	120	Changes the contrast of the LCD display.

Name	Range	Step	Default	Description
Return to default view	0…3600 s	10 s	0 s	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	• - • Activated	-	• -	When activated, all LEDs are lit up. LEDs with multiple possible colors blink each color.
Reset latches	• - • Reset	-	• -	Resets the latched signals in the logic and the matrix. When a reset command is given, the parameter automatically returns back to "-".
Measurement recorder	• Disabled • Enabled	-	• Disabled	Enables the measurement recorder tool, further configured in *Tools → Misc → Measurement recorder.*
Reconfigure mimic	• - • Reconfigure	-	• -	Reloads the mimic to the unit.
Reset last fault registers	-	-	-	Activation of input selected here resets the values in "Fault registers" view in carousel.
Protection/Control/ Monitor profile	-	-	-	Displays the status of all enabled functions.

Function comments

Function comments displays notes of each function that has been activated in the Protection, Control and Monitoring menu. Function notes can be edited by the user.

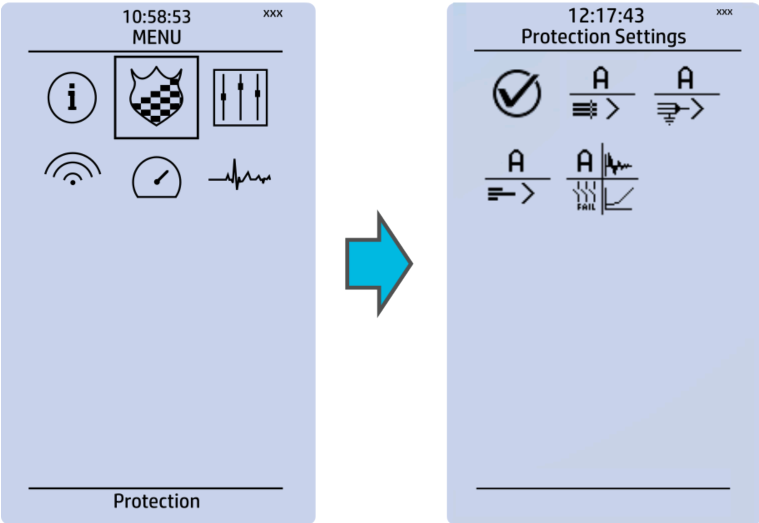
Figure. 3.3 - 6. Function comments.



3.4 Protection menu

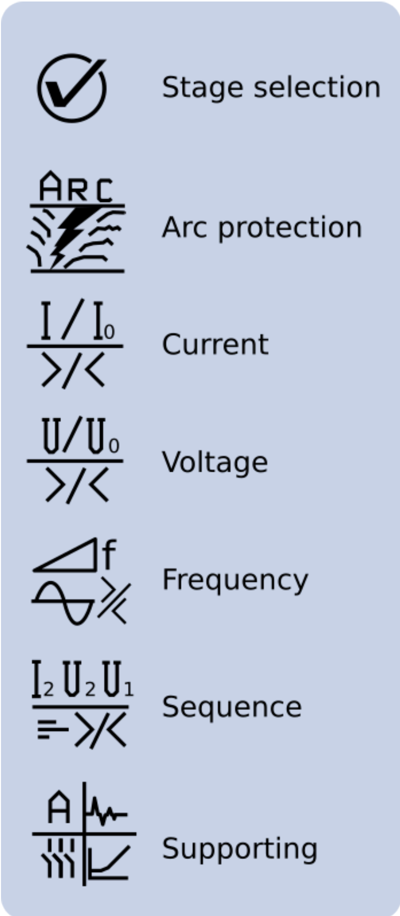
General

Figure. 3.4 - 7. Protection menu structure.



The *Protection* main menu includes the *Stage activation* submenu as well as the submenus for all the various protection functions, categorized under the following modules: "Arc protection", "Current", "Voltage", "Frequency", "Sequence" and "Supporting" (see the image below). The available functions depend on the device type in use.

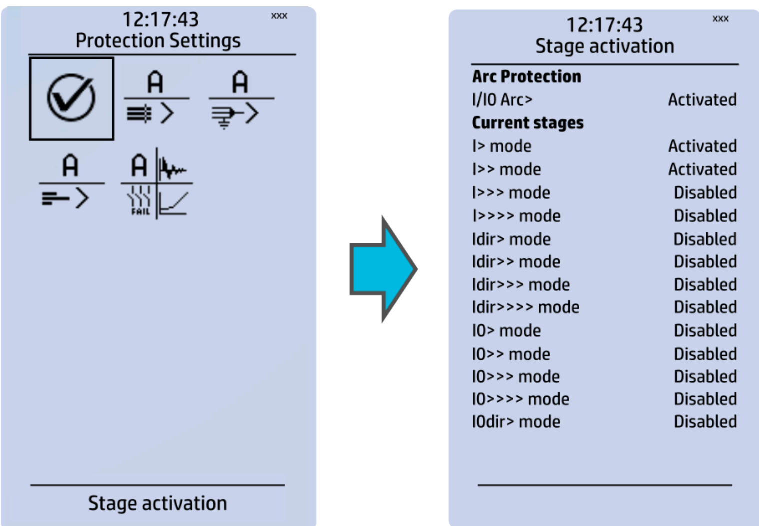
Figure. 3.4 - 8. Protection menu view.



Stage activation

You can activate the various protection stages in the *Stage activation* submenu (see the images below). Each protection stage and supporting function is disabled by default. When you activate one of the stages, its activated menu appears in the stage-specific submenu. For example, the I> (overcurrent) protection stage can be found in the "Current" module, whereas the U< (undervoltage) protection stage can be found in the "Voltage" module.

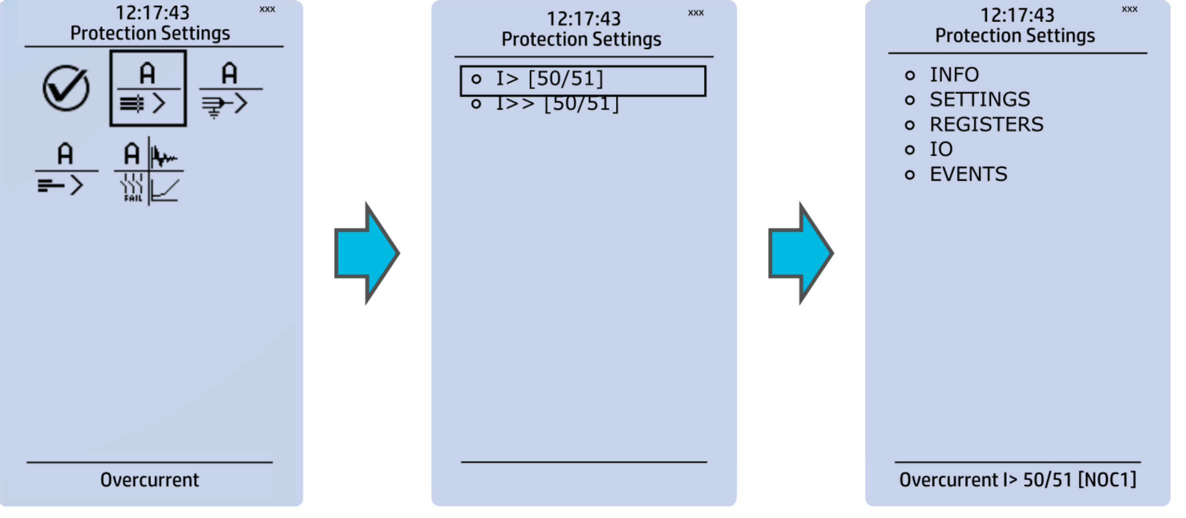
Figure. 3.4 - 9. Submenus for Stage activation.



Example of a protection stage and its use

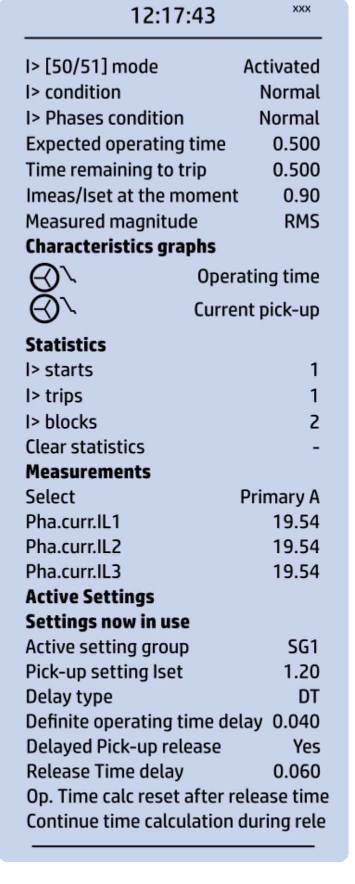
Once a protection stage has been activated in the *Stage activation* submenu, you can open its own submenu. In the image series below, the user has activated three current stages. The user accesses the list of activated current stages through the "Current" module, and selects the I> stage for further inspection.

Figure. 3.4 - 10. Accessing the submenu of an individual activated stage.



Each protection stage and supporting function has five sections in their stage submenus: "Info", "Settings", "Registers", "I/O" and "Events".

Figure. 3.4 - 11. Info.

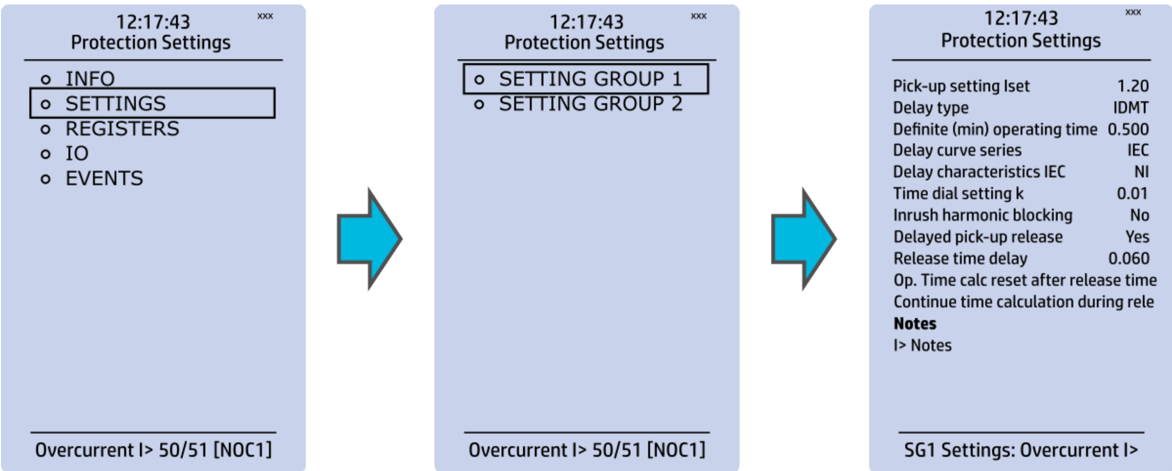


The "Info" section offers many details concerning the function and its status:

- Function condition: indicates the stage's condition which can be Normal, Start, Trip, or Blocked.
- Expected operating time: Expected time delay from detecting a fault to tripping the breaker. This value can vary during a fault if an inverse curve time delay (IDMT) is used.
- Time remaining to trip: When a fault is detected this value counts down towards zero. When zero is reached, the function will trip.
- Imeas/Iset at the moment: Displays the ratio between the measured value and the pick-up level.
- Measured magnitude: In some functions it is possible to choose the monitored magnitude between Peak-to-peak, TRMS, or RMS (the default is RMS; the available magnitudes depend on the function).
- Characteristics graphs: opens graphs related to the protection function.
- Statistics: indicates the number of function starts, trips and blocks (can be cleared through "Clear statistics" → "Clear").
- Measurements: displays the measurements carried out by the function.
- Active settings: displays the setting group that is currently in use and its settings (other setting groups can be set in the "Settings" section).

While the function is activated and disabled in the *Stage activation* submenu, you can disable the function through the "Info" section ("Function mode" at the top of the section).

Figure. 3.4 - 12. Settings.

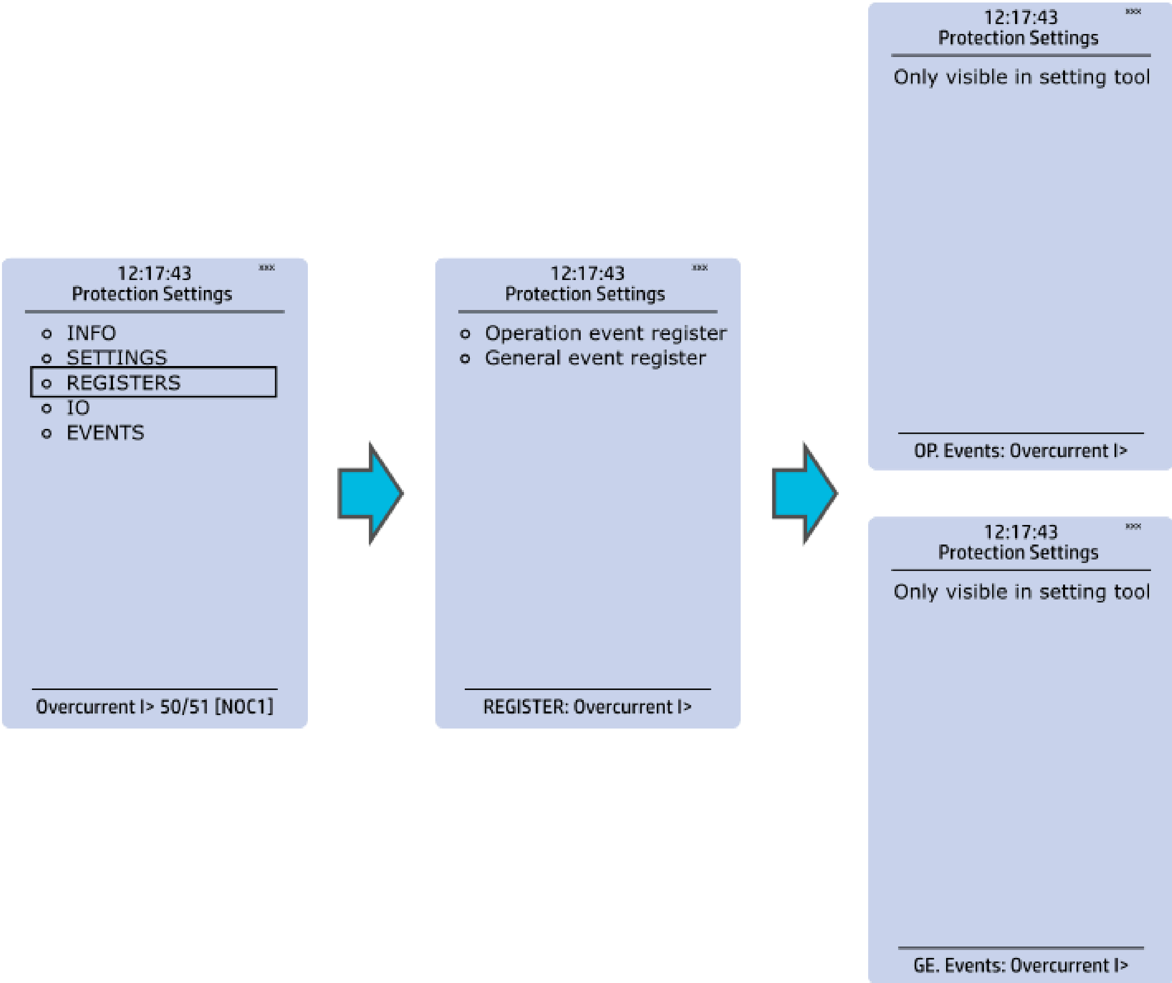


The stage settings vary depending on which protection function they are a part of. By default only one setting group of the eight available setting groups is activated. You can enable more groups in the *Control → Setting groups* menu, although they are set here in the "Settings" section.

Most protection functions follow the same structure:

- Pick-up setting: Defines the fault magnitude. Most functions pick-up value is in relation to the current transformer or voltage transformer nominal, but some functions use kW, ohm, Hz and other units. Voltage and current transformers nominal values can be set at *Measurement → Transformers*.
- Delay type and operating time delay settings are described in detail in General properties of a protection function chapter.

Figure. 3.4 - 13. Registers.

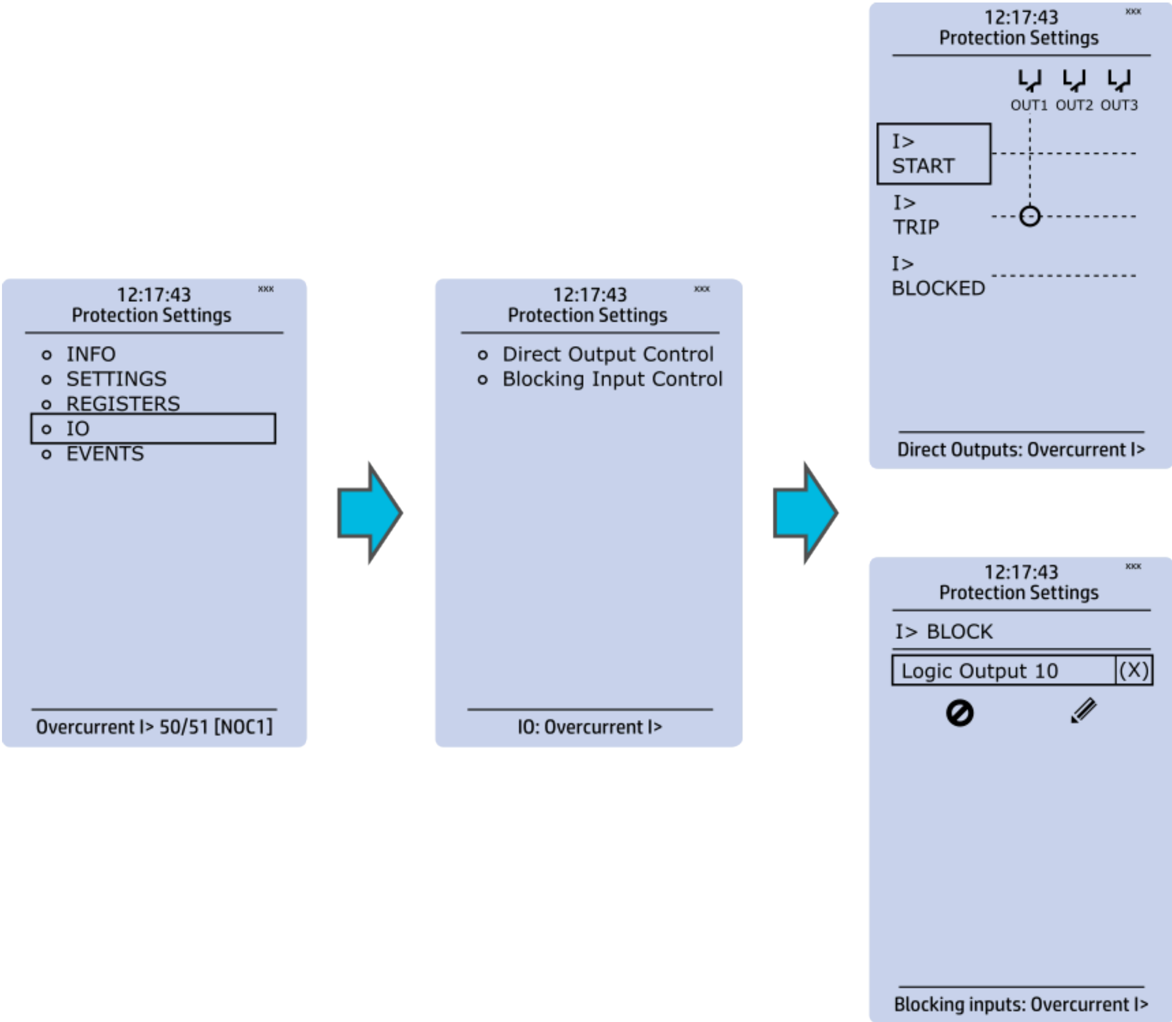


Register menu content is not available in the HMI. It can only be accessed with AQtivate setting tool. Stored in the "Registers" section you can find both "Operation event register" and "General event register".

"Operation event register" stores the function's specific fault data. There are twelve (12) registers, and each of them includes data like the pre-fault value, the fault value, the time stamp and the active group during the trigger. Data included in the register depend on the protection function. You can clear the the operation register by choosing "Clear registers" → "Clear".

"General event register" stores the event generated by the stage. These general event registers cannot be cleared.

Figure. 3.4 - 14. I/O.



The "I/O" section is divided into two subsections: "Direct output control" and "Blocking input control".

In "Direct output control" you can connect the stage's signals to physical outputs, either to an output relay or an LED (START or TRIP LEDs or one of the 16 user configurable LEDs). If the stage is blocked internally (DI or another signal), you can configure an output to indicate the stage that is blocked. A connection to an output can be either latched ("|x|") or non-latched ("x").

"Blocking input control" allows you to block stages. The blocking can be done by using any of the following:

- digital inputs
- logical inputs or outputs
- the START, TRIP or BLOCKED information of another protection stage
- object status information.

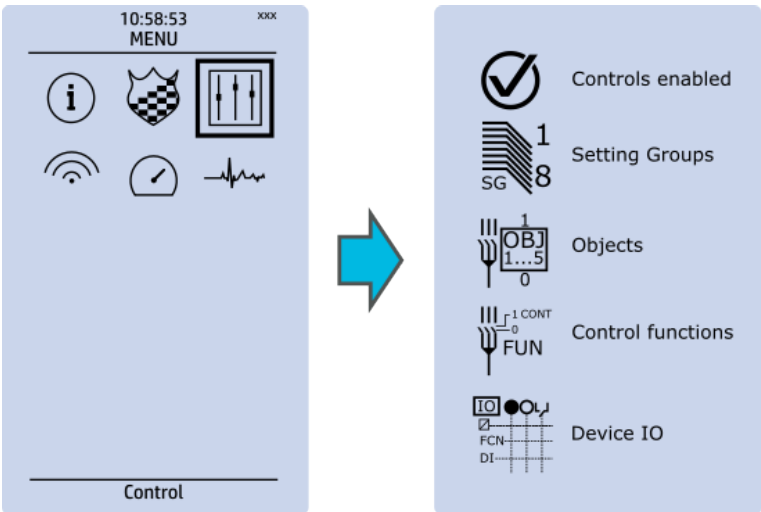
Figure. 3.4 - 15. Events.

You can mask on and mask off the protection stage related events in "Event mask". By default events are masked off. You can activate the desired events by masking them ("x"). Remember to save your maskings by confirming the changes with the check mark icon. If you want to cancel the changes, select the strike-through circle to do so. Only masked events are recorded to event history (which can be accessed in the "Events" view in the user view section).

3.5 Control menu

Main menu

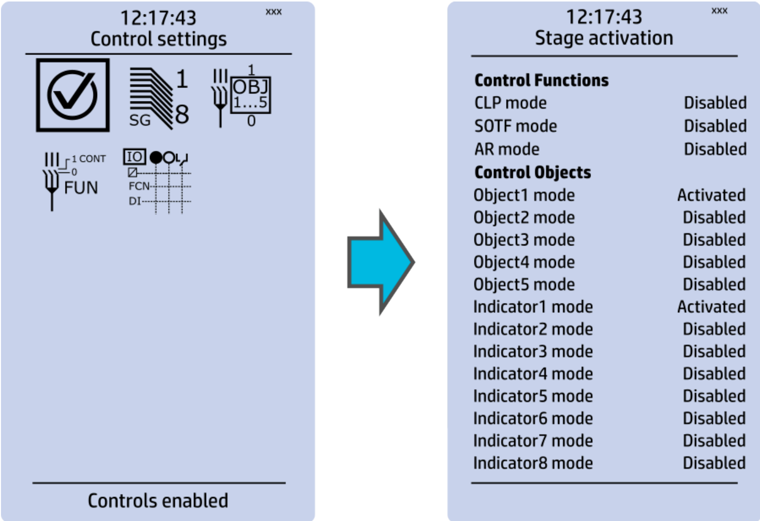
Figure. 3.5 - 16. Main menu structure.



The *Control* main menu includes submenus (see the image above) for enabling the various control functions and objects (*Controls enabled*), for enabling and controlling the setting groups (*Setting groups)*, for configuring the objects (*Objects*), for setting the various control functions (*Control functions)*, and for configuring the inputs and outputs (*Device I/O).* The available control functions depend on the model of the device in use.

Controls enabled

Figure. 3.5 - 17. Controls enabled submenu.

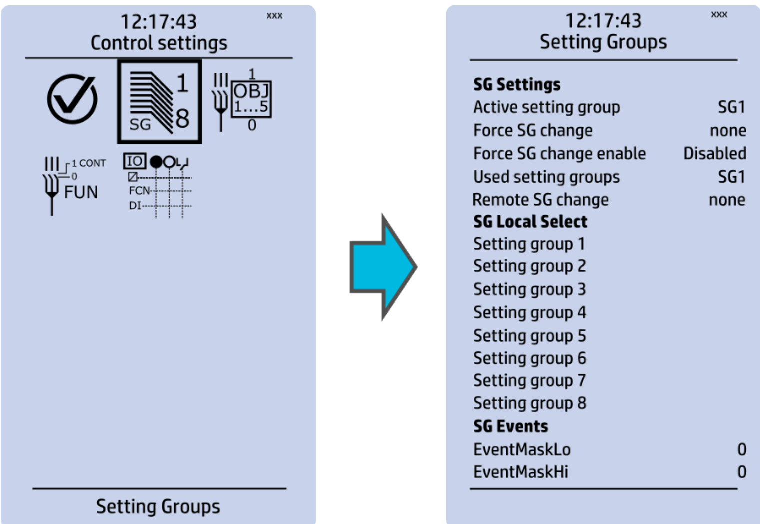


You can activate the selected control functions in the *Controls enabled* submenu. By default all the control functions are disabled. All activated functions can be viewed in the *Control functions* submenu (see the section "Control functions" below for more information).

In this submenu you can also activate and disable controllable objects. As with control functions, all objects are disabled by default. All activated objects can be viewed in the *Objects* submenu (see the section "Objects" below for more information).

Setting groups

Figure. 3.5 - 18. Setting groups submenu.



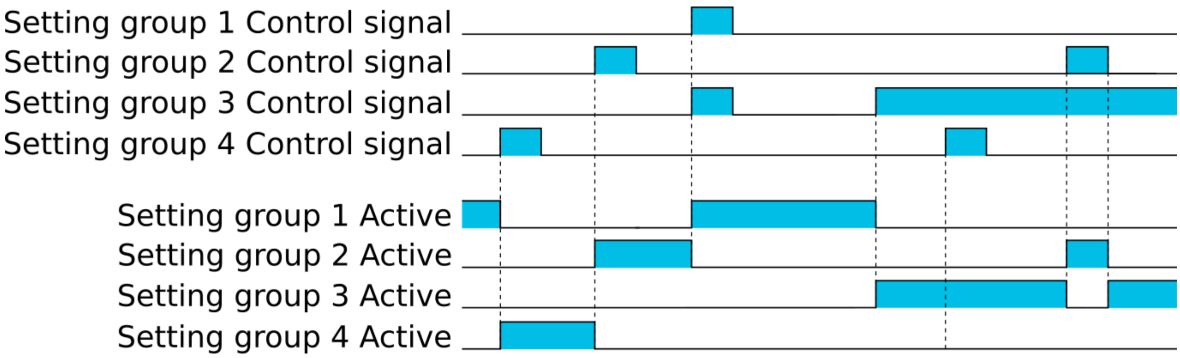
The *Setting groups* submenu displays all the information related to setting group changing, such as the following:

- Active setting group: displays the current active setting group (SG1…SG8).
- Force setting group change: this setting allows the activation of a setting group at will (please note that Force SG change enable must be "Enabled").

- Used setting groups: this setting allows the activation of setting groups SG1...SG8 (only one group is active by default).
- SG local select: selects the local control for the different setting groups (can use digital inputs, logical inputs or outputs, RTDs, object status information as well as stage starts, trips or blocks).
- Remote setting group change: When enabled it is possible to change the setting group manually through SCADA.
- SG events: event masking for setting groups (masks are OFF by default; please note that only masked events are recorded into the event history).

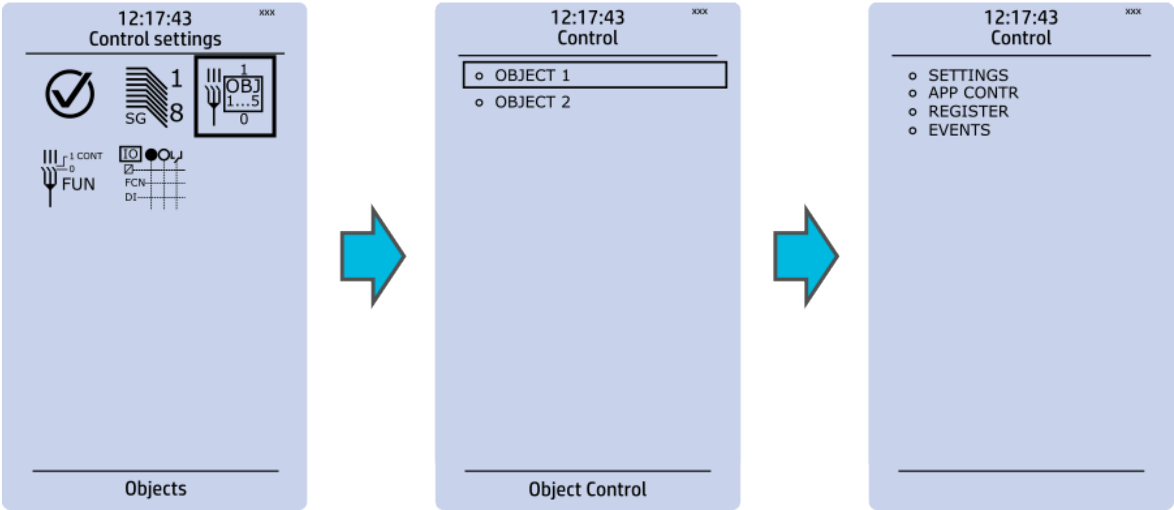
Setting group 1 (SG1) has the highest priority, while Setting group 8 (SG8) has the lowest priority. Setting groups can be controlled with pulses or with both pulses and static signals (see the image below).

Figure. 3.5 - 19. Example of setting group (SG) changing.



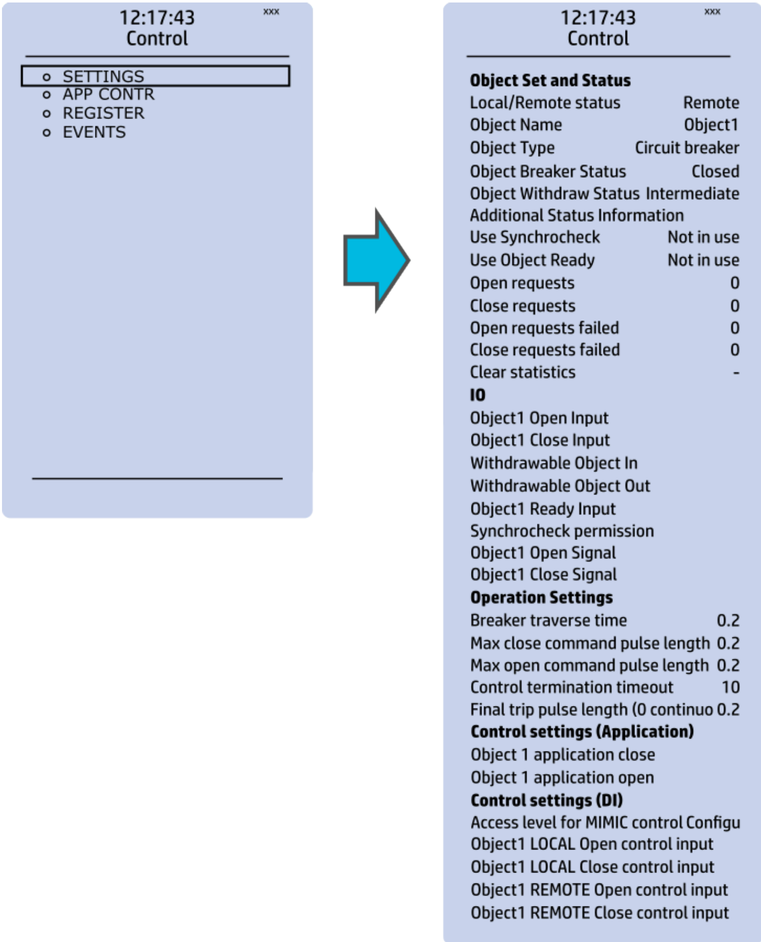
Objects

Figure. 3.5 - 20. Objects submenu.



Each activated object is visible in the *Objects* submenu. By default all objects are disabled unless specifically activated in the *Controls → Controls enabled* submenu. Each active object has four sections in their submenus: "Settings", "Application control" ("App contr"), "Registers" and "Events". These are described in further detail below.

Figure. 3.5 - 21. Settings section.



OBJECT SET AND STATUS

- Local/Remote status: control access may be set to Local or Remote (Local by default; please note that when local control is enabled, the object cannot be controlled through the bus and vice versa).
- Object name: the name of the object (objects are named "ObjectX" by default).
- Object type: selects the type of the object from Grounding disconnector, Motor-controlled disconnector, Circuit breaker and Withdrawable circuit breaker (Circuit breaker by default).
- Object x status: the status can be Bad, Closed, Open and Intermediate. The status "Intermediate" is the phase between "Open" and "Closed" where both status inputs are 0. The status "Bad" occurs when both status inputs of the object/cart are 1.
- Additional status information: gives feedback from the object on whether the opening and closing are allowed or blocked, whether the object is ready, and whether the synchronization status is ok.
- Use synchrocheck and Use Object ready: closing the object is forbidden when the sides are not synchronized or when the object is not ready to be closed.
- Open requests and Close requests: displays the statistics, i.e. the number of Open and Close requests.
- Open requests failed and Close requests failed: displays the statistics of Open and Close request failures. A request is considered to have failed when the object does not change its status as a result of that request.
- Clear statistics: statistics can be cleared by choosing "Clear statistics" and then "Clear".

I/O

- An object has both Open input and Close input signals which are used for indicating the status of the breaker on the HMI and in SCADA. Status can be indicated by any of the following: digital inputs, logical inputs or outputs.
- A withdrawable object has both In and Out inputs. The status can be indicated by any of the following: digital inputs, logical inputs or outputs.
- Both Object ready and Synchrocheck permission have status inputs. If either one is used, the input(s) must be active for the device to be able to give the "Object Close" command.
- Object open and Object close signals define which digital output is controlled.

OPERATION SETTINGS

- Breaker traverse time: determines how long a gap there can be between a status change from "Open" to "Closed" before an intermediate status is reported by the function.
- Max close/open command pulse length: defines the maximum length of "Open" and "Close" commands. If the status has changed before the maximum pulse length has elapsed, the pulse is cut short.
- Control termination timeout: If the status of the object does not change during the set time, an "Open/Close request failed" event is recorded.
- After the set delay, if the controlled object does not respond accordingly, the procedure is terminated and a fail message is issued.

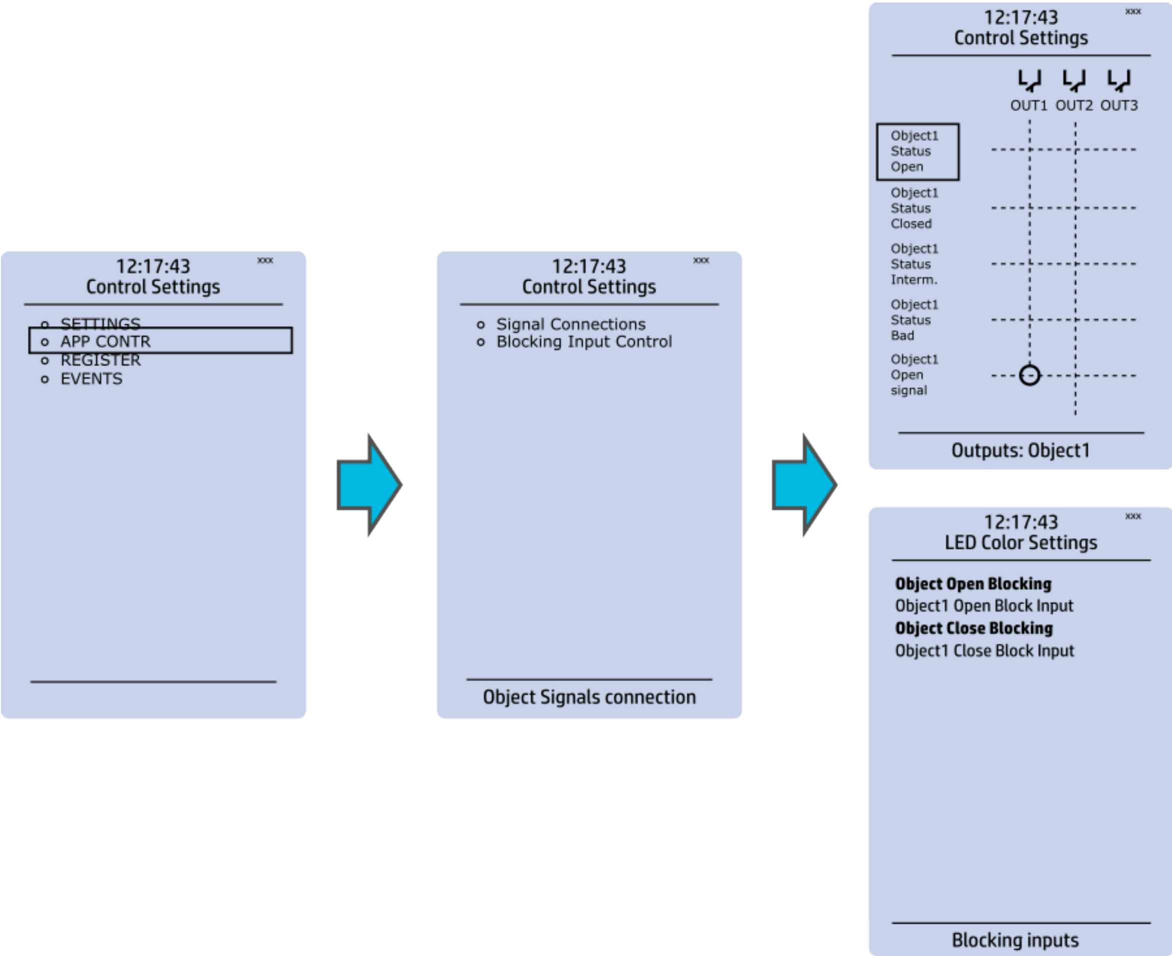
CONTROL SETTINGS (APPLICATION)

- Object application close and Object application open: a signal set to these points can be used to open and close the object. Controlling the object through this point does not follow the local/remote status of the device.

CONTROL SETTINGS (DI)

- Access level for MIMIC control: determines the access level required to control the MIMIC (each level has its own password). By default, the access level is set to "Configurator".
- You can use digital inputs to control the object locally or remotely. Remote controlling via the bus is configured on the protocol level.

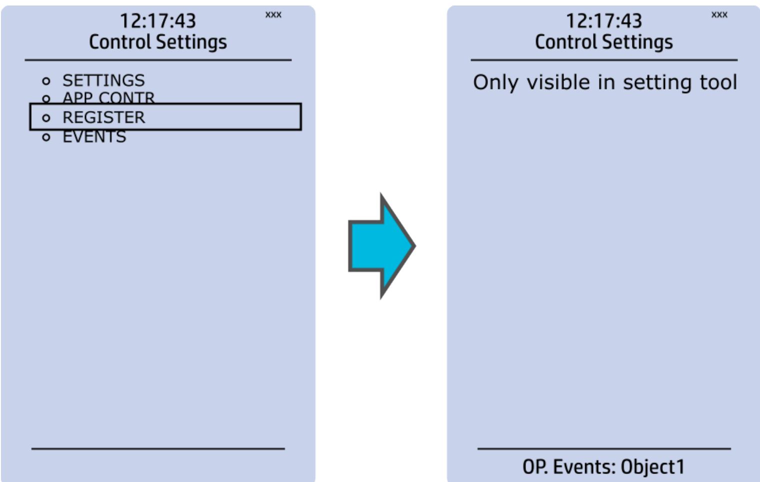
Figure. 3.5 - 22. Application control section.



You can connect object statuses directly to specific physical outputs in the "Signal connections" subsection (*Control → Application control*). A status can be connected to output relays, as well as to user-configurable LEDs. A connection to an output can be either latched ("|x|") or non-latched ("x").

Object blocking is done in the "Blocking input control" subsection. It can be done by any of the following: digital inputs, logical inputs or outputs, object status information as well as stage starts, trips or blocks.

Figure. 3.5 - 23. Registers section.



The "Registers"section stores the function's specific fault data. There are twelve (12) registers, and each of them includes data such as opening and closing times, command types and request failures. The data included in the register depend on the protection function. You can clear the the operation register by choosing "Clear registers" → "Clear".

Please note that the content of the *Registers* section is not available in the HMI. It can only be accessed via the AQtivate setting tool.

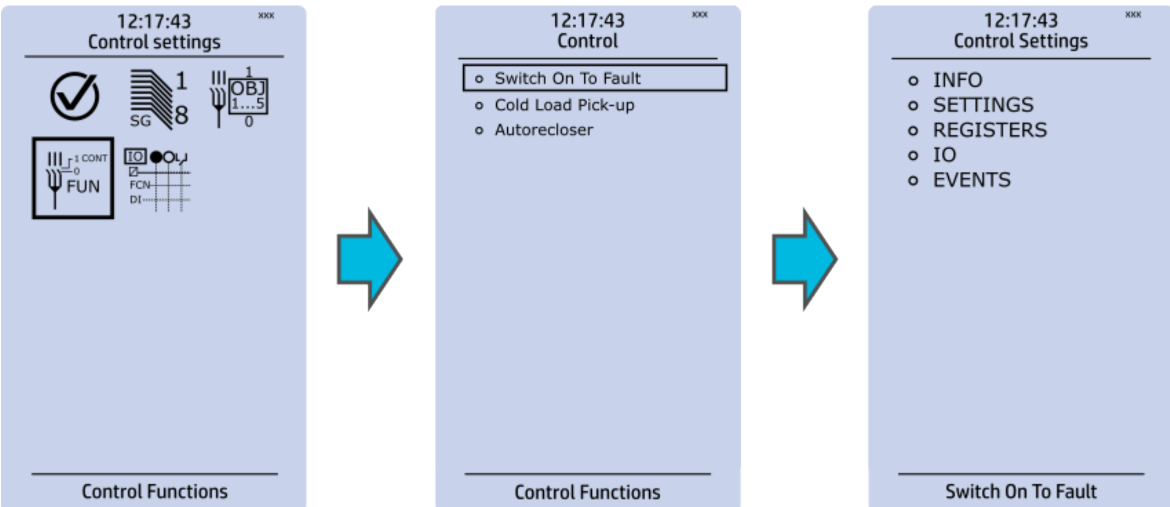
Figure. 3.5 - 24. Events section.

You can mask on and mask off events related to an object's stage in "Event mask". By default all events are masked off. You can activate the desired events by masking them ("x"). Please remember to save your maskings by confirming the changes with the check mark icon. If you want to cancel the changes, select the strike-through circle to do so. Only masked events are recorded to the event history (which can be accessed in the "Events" view in the user view section).

Control functions

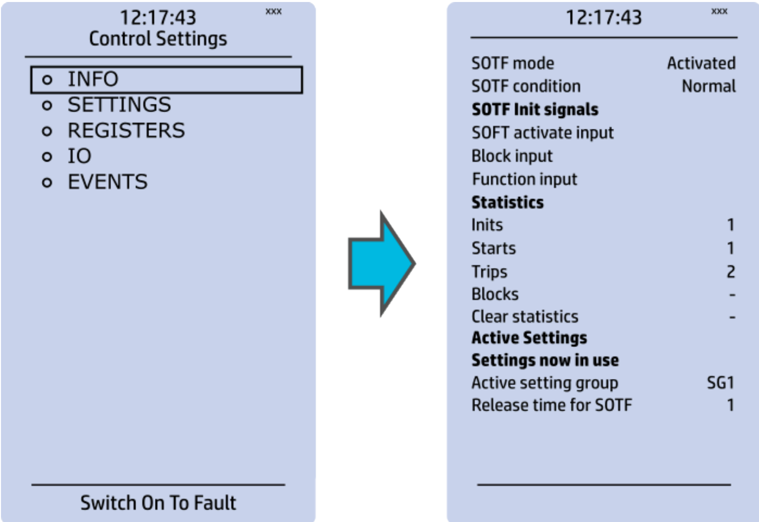
Once a control function has been activated in the *Controls* → *Controls enabled* submenu, its own submenu can be opened. In the image series below, the user has activated three control functions. The user accesses the list of activated control stages through the "Control functions" module, and selects the control function for further inspection.

Figure. 3.5 - 25. Control functions submenu.



Each control function that has been activated is listed in the *Control functions* submenu (see the middle image above). This submenu includes the following sections: "Info", "Settings", "Registers", "I/O" and "Events". The text below describes these in further detail.

Figure. 3.5 - 26. Info section.

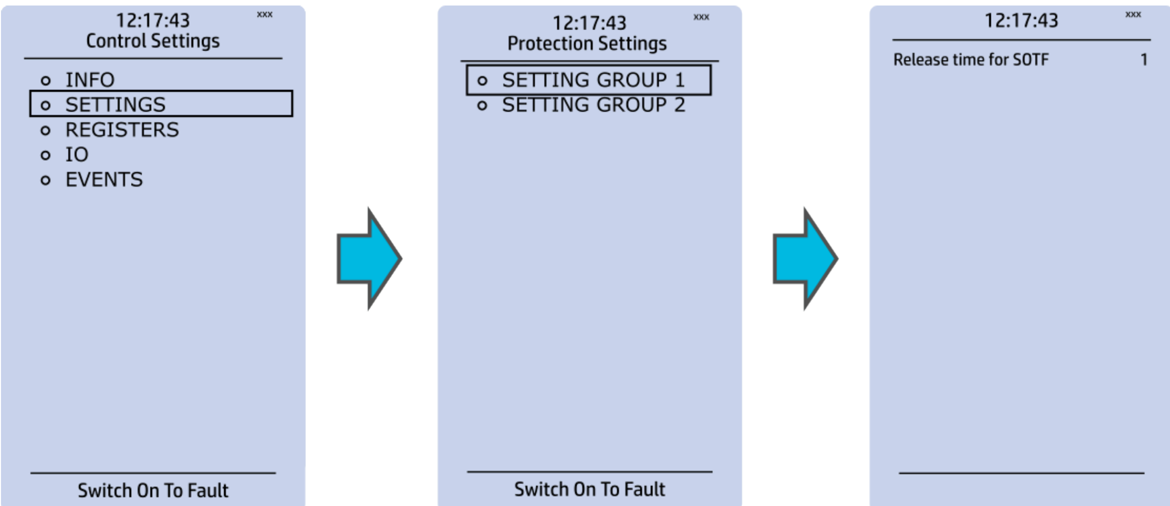


The "Info" section offers many details concerning the function and its status:

- Function condition: indicates the stage's condition which can be Normal, Start, Trip, or Blocked.
- Measured magnitude: In some functions it is possible to choose the monitored magnitude between Peak-to-peak, TRMS, or RMS (the default is RMS; the available magnitudes depend on the function).
- Statistics: indicates the number of function starts, trips and blocks (can be cleared through "Clear statistics" → "Clear").
- Measurements: displays the measurements carried out by the function.
- Active settings: displays the setting group that is currently in use and its settings (other setting groups can be set in the "Settings" section).

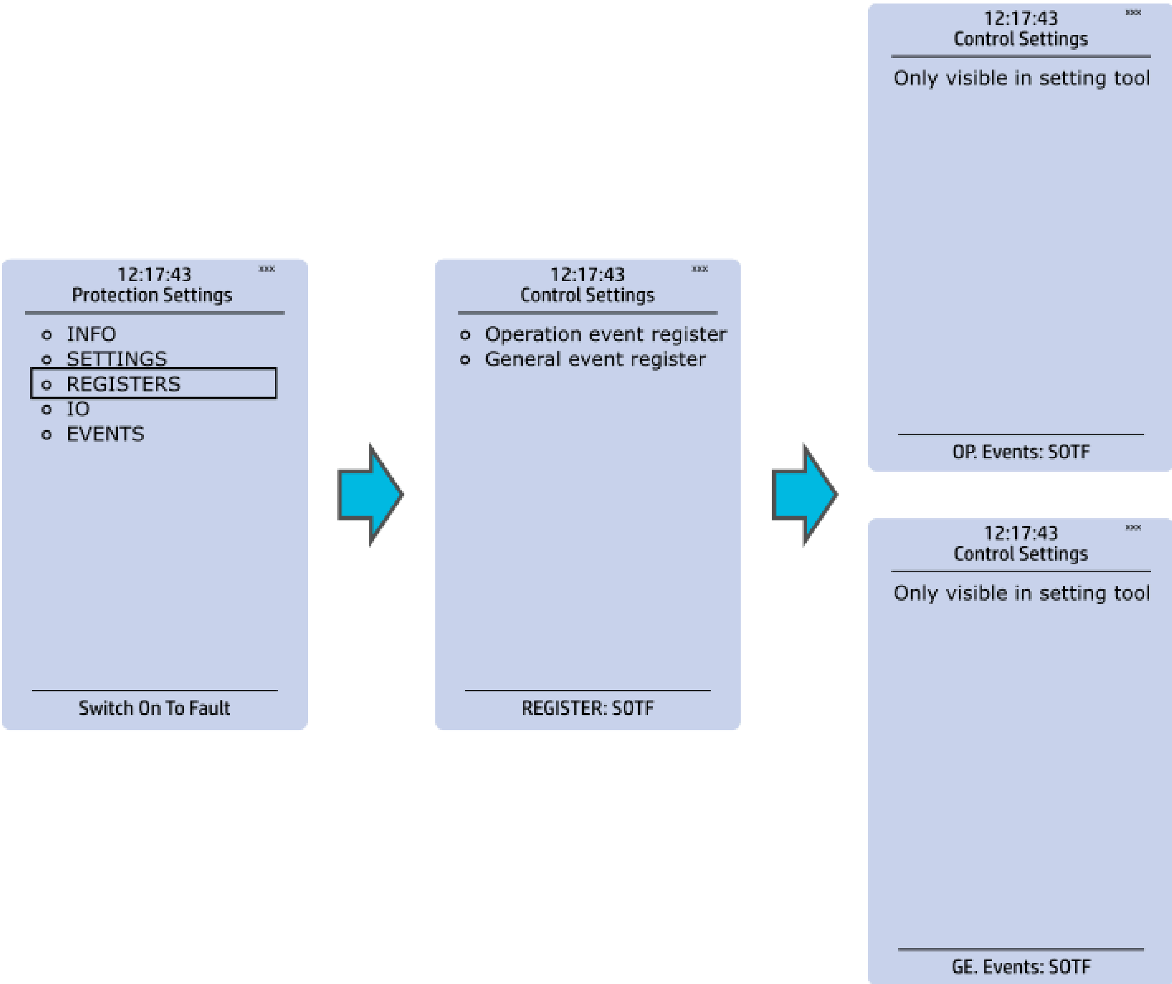
While the function is activated and disabled in the *Control → Controls enabled* submenu, you can disable the function through the "Info" section (the [function name] mode at the top of the section).

Figure. 3.5 - 27. Settings section.



The stage settings vary depending on which control function they are a part of. By default only one setting group of the eight available setting groups is activated. You can enable more groups in the *Control → Setting groups* menu, although they are set here in the "Settings" section.

Figure. 3.5 - 28. Registers section.

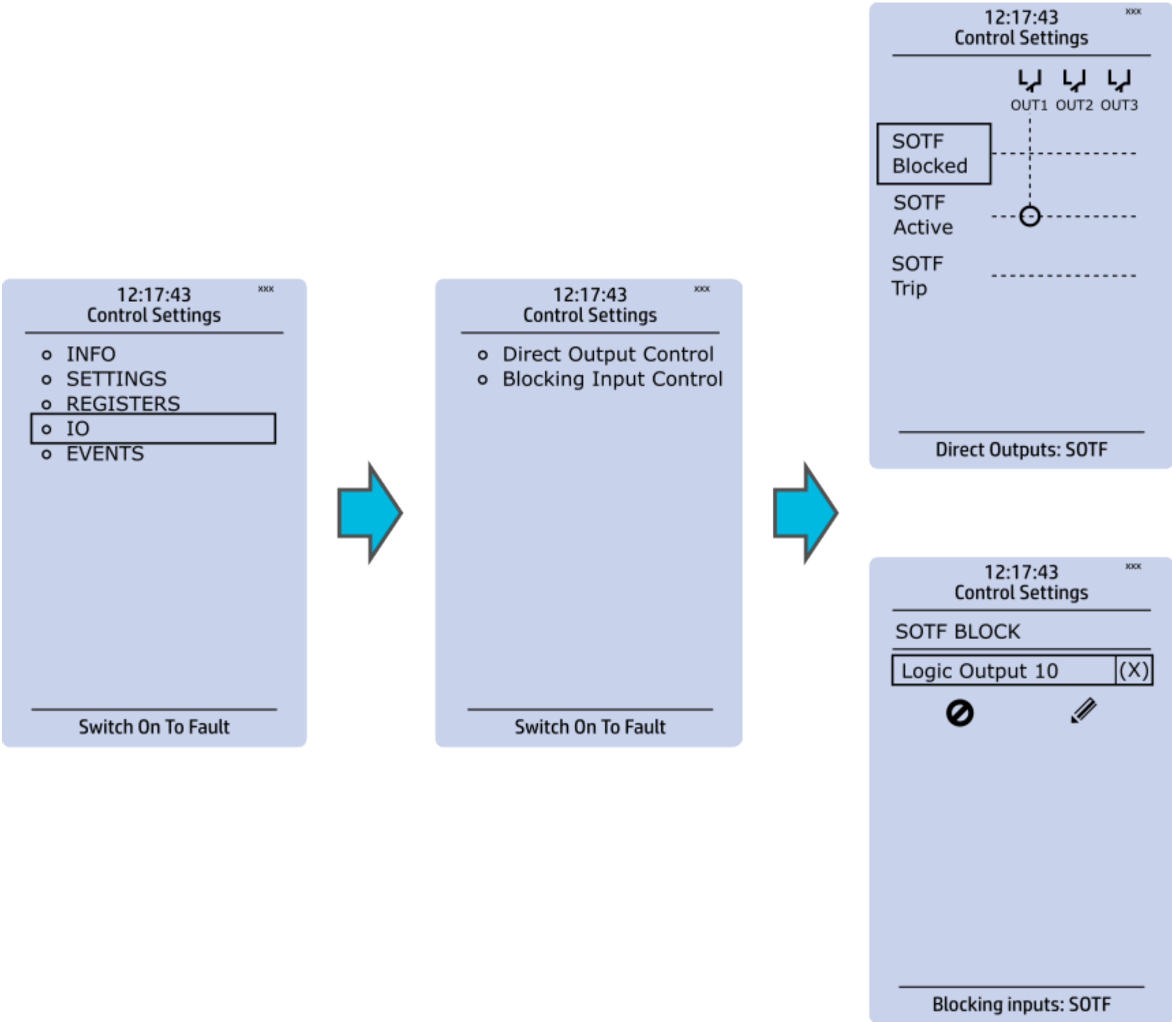


Please note that the content of the "Registers" section is not available in the HMI. It can only be accessed via the AQtivate setting tool. Stored in the "Registers" section you can find both "Operation event register" and "General event register".

"Operation event register" stores the function's specific operation data. There are twelve (12) registers, and each of them includes data like the pre-fault value, the fault value, the time stamp and the active group during the trigger. Data included in the register depend on the control function. You can clear the the operation register by choosing "Clear registers" → "Clear".

"General event register" stores the event generated by the stage. These general event registers cannot be cleared.

Figure. 3.5 - 29. I/O section.



The "I/O" section is divided into two subsections: "Direct output control" and "Blocking input control".

In "Direct output control" you can connect the stage's signals to physical outputs, either to an output relay or an LED (START or TRIP LEDs or one of the 16 user configurable LEDs). If the stage is blocked internally (by a digital input or another signal), you can configure an output to indicate the stage that is blocked. A connection to an output can be either latched ("|x|") or non-latched ("x").

"Blocking input control" allows you to block stages. The blocking can be done by using any of the following:

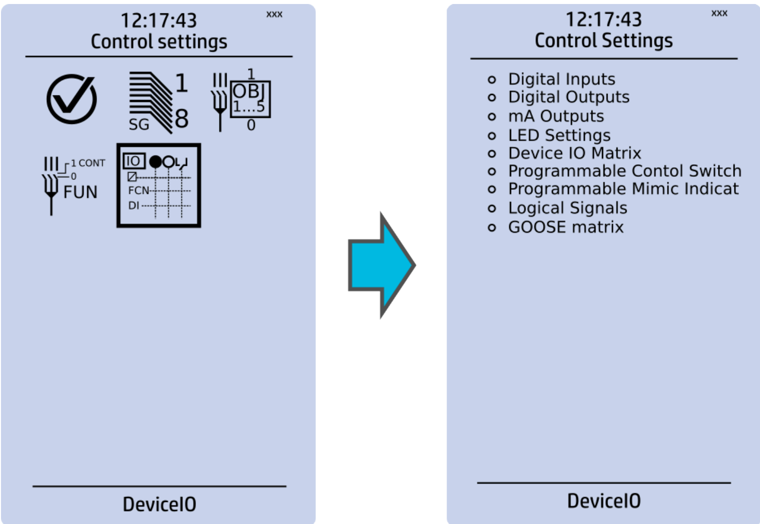
- digital inputs.
- logical inputs or outputs.
- the START, TRIP or BLOCKED information of another protection stage.
- object status information.

Figure. 3.5 - 30. Events section.

You can mask on and mask off events related to an object's stage in "Event mask". By default all events are masked off. You can activate the desired events by masking them ("x"). Please remember to save your maskings by confirming the changes with the check mark icon. If you want to cancel the changes, select the strike-through circle to do so. Only masked events are recorded to the event history (which can be accessed in the "Events" view in the user view section).

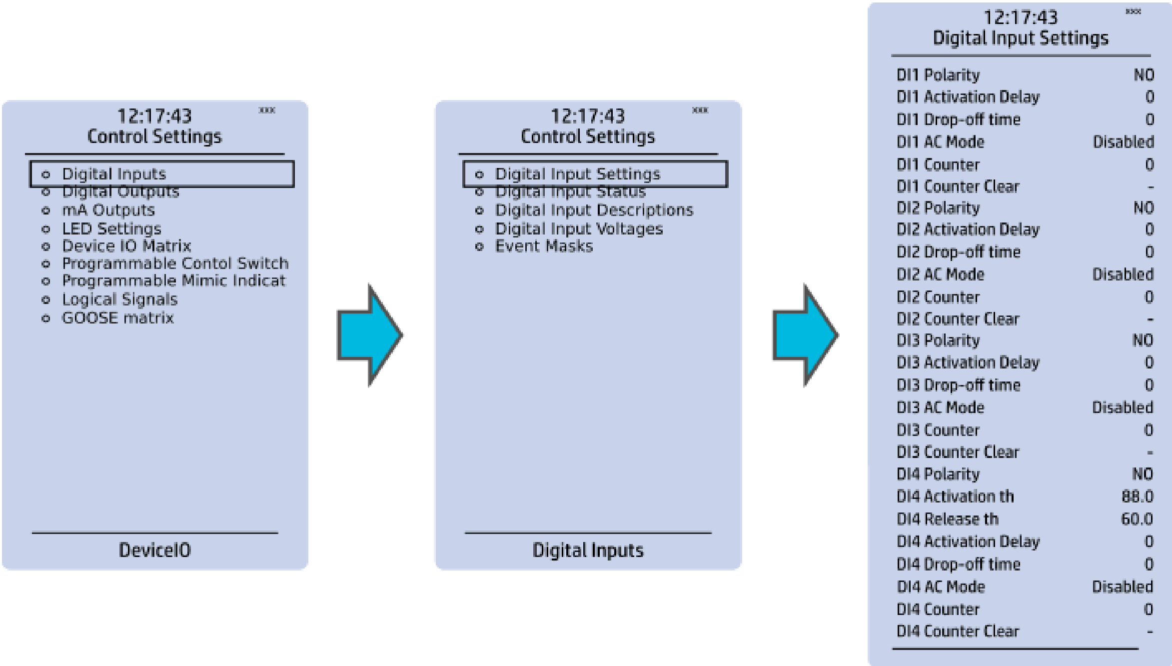
Device I/O

Figure. 3.5 - 31. Device I/O submenu.



The *Device I/O* submenu is divided into the following nine sections: "Digital inputs", "Digital outputs", "mA Outputs", "LED settings", "Device I/O matrix", "Programmable control switch", "Programmable Mimic Indicator", "Logic signals" and "GOOSE matrix". Please note that digital inputs, logic outputs, protection stage status signals (START, TRIP, BLOCKED, etc.) as well as object status signals can be connected to an output relay or to LEDs in the "Device I/O matrix" section.

Figure. 3.5 - 32. Digital input section.

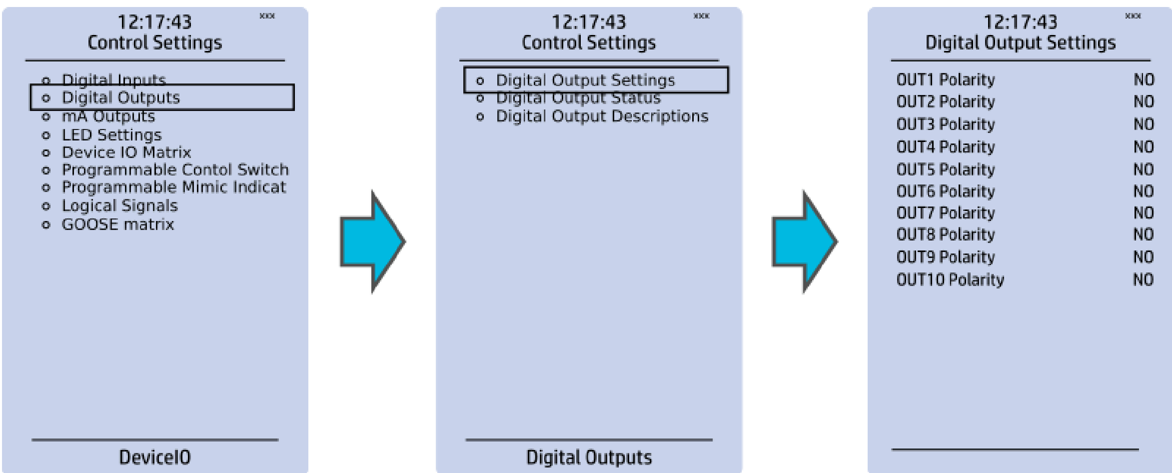


All settings related to digital inputs can be found in the "Digital inputs" section.

The "Digital inputs settings" subsection includes various settings for the inputs: the polarity selection determines whether the input is Normal Open (NO) or Normal Closed (NC) as well as the activation threshold voltage (16…200 V AC/DC, step 0.1 V) and release threshold voltage (10…200 V AC/DC, step 0.1 V) for each available input. There is also a setting to determine the wanted activation and release delay (0…1800 s, step 1 ms). Digital input activation and release threshold follow the measured peak value. The activation time of an input is 5…10 ms. The release time with DC is 5…10 ms, while with AC it is less than 25 ms. The first three digital inputs don't have activation and release threshold voltage settings as these have already been defined when the unit was ordered.

Digital input statuses can be checked from the corresponding subsection ("Digital input status"). The "Digital input descriptions" subsection displays the texts the user has written for each digital input. In the "Event masks" subsection you can determine which events are masked –and therefore recorded into the event history– and which are not.

Figure. 3.5 - 33. Digital outputs section.

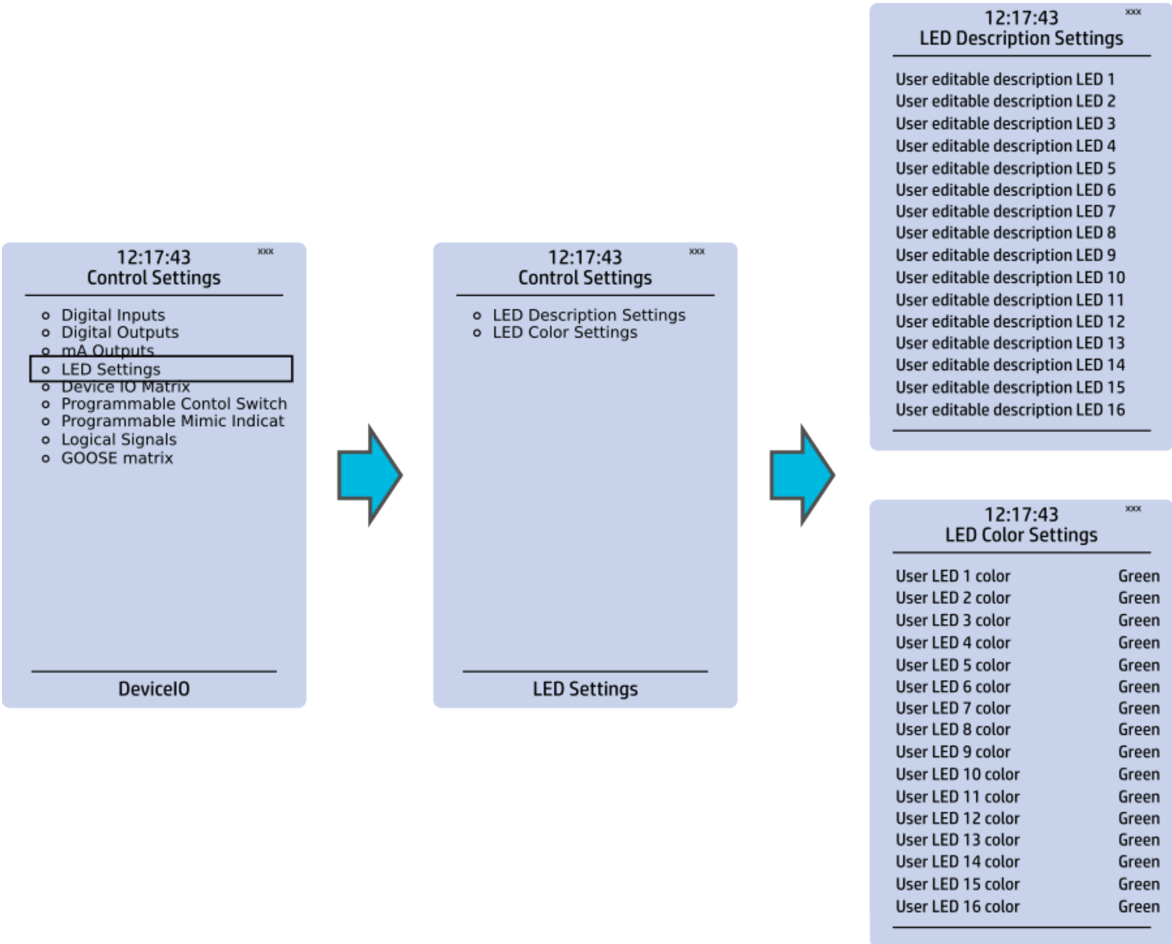


All settings related to digital outputs can be found in the "Digital outputs" section.

The "Digital outputs settings" subsection lets you select the polarity for each output; they can be either Normal Open (NO) or Normal Closed (NC). The default polarity is Normal Open. The operational delay of an output contact is approximately 5 ms. You can view the digital output statuses in the corresponding subsection ("Digital output status"). The "Digital output descriptions" subsection allows you to configure the description text for each output. All name changes affect the matrices as well as input–output selection lists.

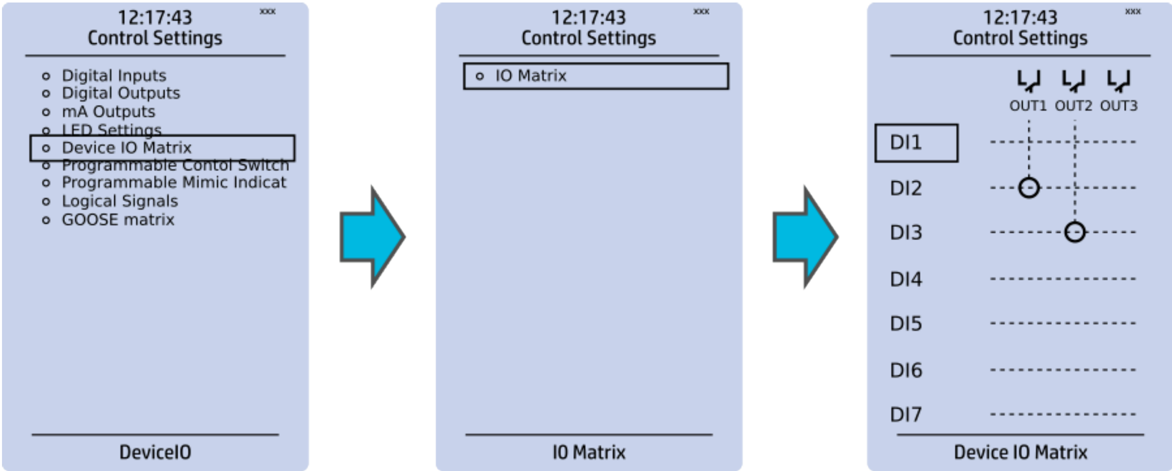
> NOTICE!
> An NC signal goes to the default position (NO) if the device loses the auxiliary voltage or if the system is fully reset. However, an NC signal does not open during voltage or during System full reset. An NC output signal does not open during a Communication or Protection reset.

Figure. 3.5 - 34. LED settings section.



The "LED settings" section allows you to modify the individual label text attached to an LED ("LED description settings"); that label is visible in the LED quick displays and the matrices. You can also modify the color of the LED ("LED color settings") between green and yellow; by default all LEDs are green.

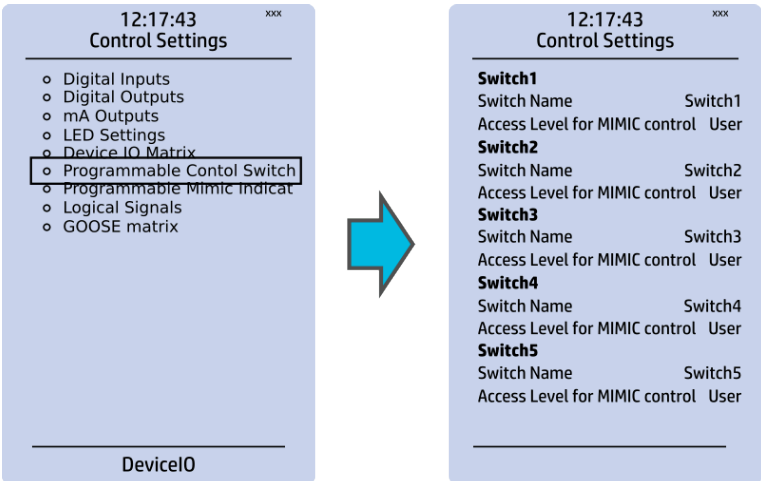
Figure. 3.5 - 35. Device I/O matrix section.



Through the "Device I/O matrix" section you can connect digital inputs, logical outputs, protection stage status signals (START, TRIP, BLOCKED, etc.), object status signals and many other binary signals to output relays, or to LEDs configured by the used. A connection can be latched ("|x|") or non-latched ("x"). Please note that a non-latched output is deactivated immediately when the triggering signal is disabled, while a latched signal stays active until the triggering signal deactivates and the latched function is manually cleared.

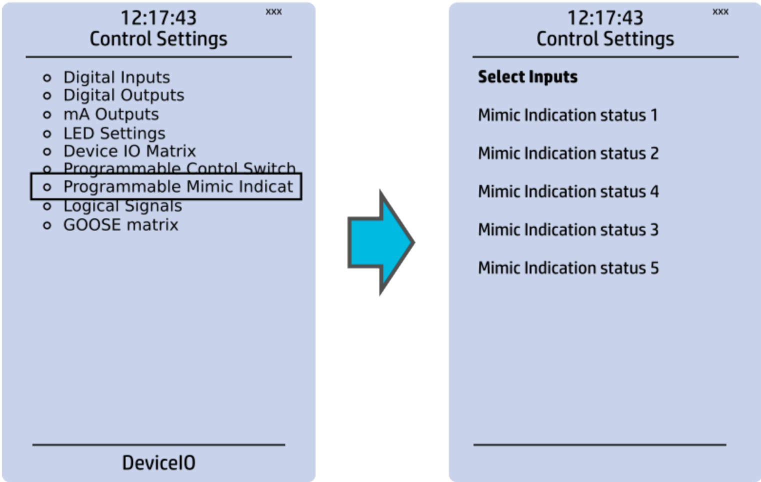
You can clear latched signals by entering the mimic display and the pressing the Back button on the panel.

Figure. 3.5 - 36. Programmable control switch section.



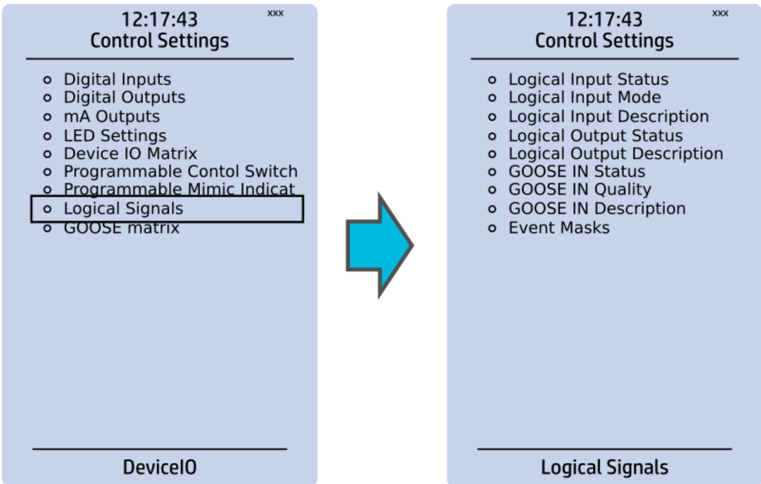
Programmable control switches (PCSs) are switches that can be used to control signals while in the mimic view. These signals can be used in a variety of situations, such as for controlling the logic program, for function blocking, etc. You can name each switch and set the access level to determine who can control the switch.

Figure. 3.5 - 37. Programmable mimic indicators section.



Programmable mimic indicators can be placed into the mimic to display a text based on the status of a given binary signal (digital input, logical signal, status of function start/tripped/blocked signals etc.). When configuring the mimic with the AQtivate 200 setting tool, it is possible to set a text to be shown when an input signal is ON and a separate text for when the signal is OFF.

Figure. 3.5 - 38. Logical signals section.



All AQ 200 series units have the following types of logical signals:

- 32 logical input signal status bits; the status of a bit is either 0 or 1.
- 32 logical output signal status bits; the status of a bit is either 0 or 1.
-
-

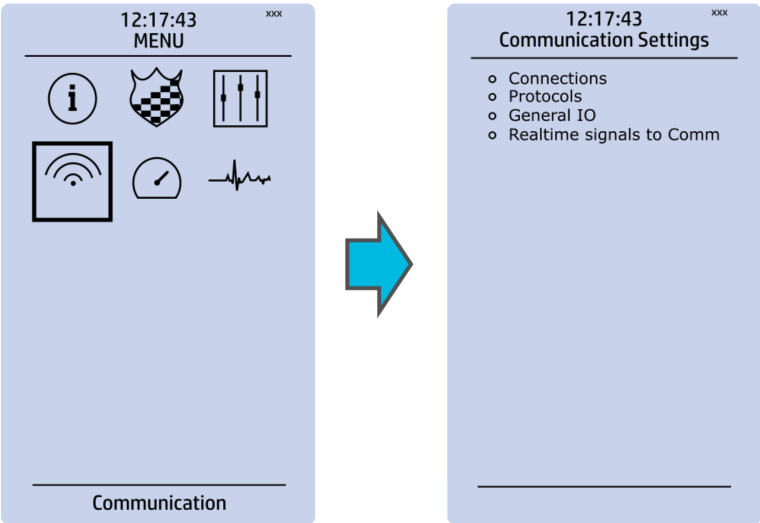
Logical input signals can be used when building a logic with the AQtivate 200 setting tool. The status of a logical input signal can be changed either from the mimic or through SCADA. By default logical inputs use "Hold" mode in which the status changes from 0 to 1 and from 1 to 0 only through user input. The mode of each input can be changed to "Pulse" in which a logical input's status changes from 0 to 1 through user input and then immediately back to 0.

Logical output signals can be used as the end result of a logic that has been built in the AQtivate 200 setting tool. The end result can then be connected to a digital output or a LED in the matrix, block functions and much more.

NOTICE!
Please refer to the "Communication" chapter for a more detailed description of the use of logical signals.

3.6 Communication menu

Figure. 3.6 - 39. Communication menu.

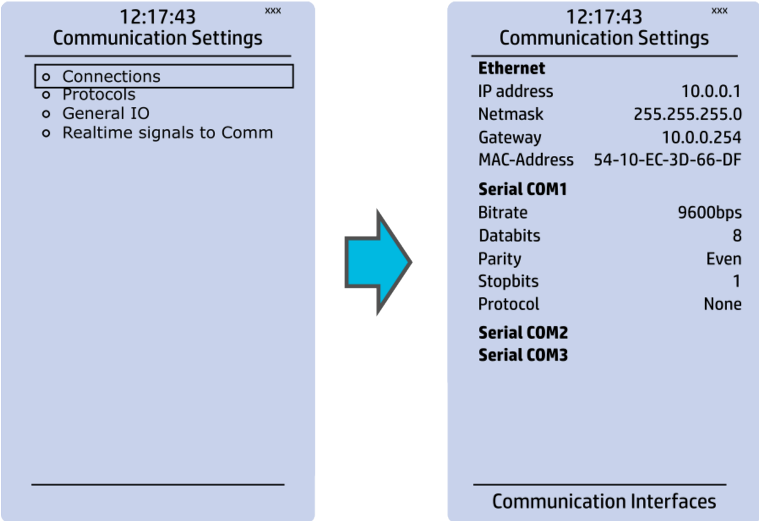


The *Communication* main menu includes four submenus (as seen in the figure above): *Connections*, *Protocols, General IO* and *Realtime signals to Comm*. All devices can be configured through the Ethernet connection in the back panel with the AQtivate 200 setting tool software. Connecting to AQtivate requires knowing the IP address of your device: this can be found in the *Communication* → *Connections* submenu. As a standard, the devices support the following communication protocols:

- NTP
- Modbus/TCP
- Modbus/RTU
- IEC-103
- IEC -101/104
- SPA
- DNP3
- ModbusIO.

Connections

Figure. 3.6 - 40. View of the Connections submenu.



The *Connections* submenu offers the following bits of information and settings:

ETHERNET

This section defines the IP settings for the Ethernet port in the back panel of the unit.

- IP address: the IP address of the device which can be set by the user (the default IP address depends on the device).
- Network: the network subnet mask is entered here.
- Gateway: the gateway is configured only when communicating with devices in a separate subnet.
- MAC-Address: The unique MAC address of the device, which is not configurable by the user.

SERIAL COM

This section defines the basic settings of the RS-485 port in the back panel of the unit.

- Bitrate: displays the bitrate of the RS-485 serial communication interface (9600 bps as standard, although it can be changed to 19,200 bps or to 38,400 bps if an external device supports the faster speed).
- Databits, Parity and Stopbits: these can be set according to the connected external devices.
- Protocol: by default the device does not have any serial protocol activated, although IEC 103, Modbus I/O and Modbus/RTU can be used for communication.

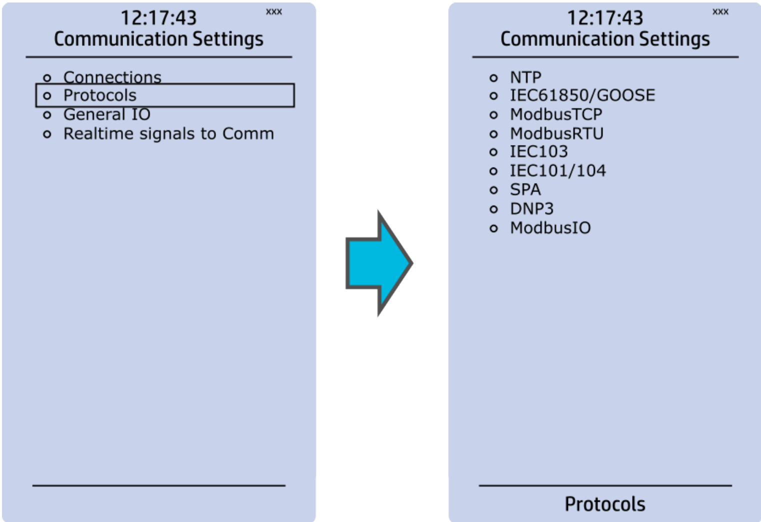
> **NOTICE!**
> When communicating with a device via the front Ethernet port connection, the IP address is always 192.168.66.9.

SERIAL COM1 & COM2

SERIAL COM1 and SERIAL COM2 are reserved for serial communication option cards. They have the same settings as the RS-485 port.

Protocols

Figure. 3.6 - 41. View of the Protocols submenu.



The *Protocols* submenu offers access to the various communication protocol configuration menus. Some of the communication protocols use serial communication and some use Ethernet communication. Serial communication protocols can be used with the RS-485 port. Ethernet communication protocols can be used with the RJ-45 port in the back of the unit.

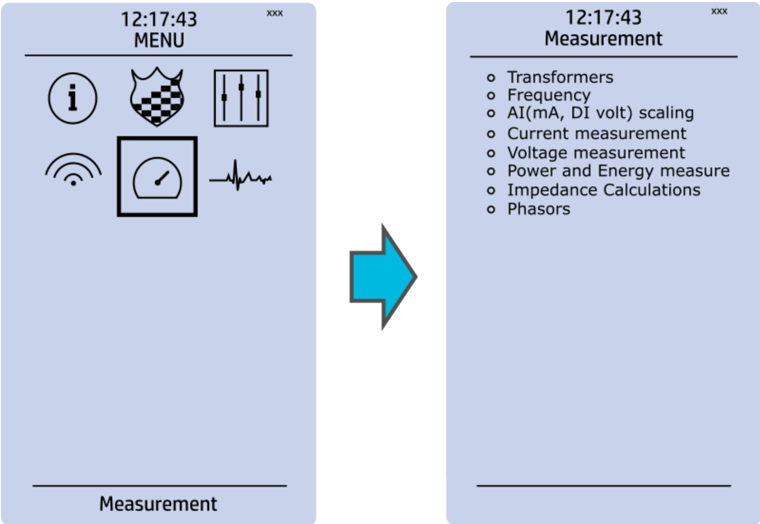
The communication protocols are:

- NTP: this protocol is used for time synchronization over Ethernet, and can be used simultaneously with Ethernet-based communication protocols.
-
- Modbus/TCP: an Ethernet-based communication protocol.
- Modbus/RTU: a serial communication protocol.
- IEC-103: a serial communication protocol.
- IEC-101/104: since the standards IEC 60870-5-101 and IEC 60870-5-104 are closely related, the IEC-101 protocol uses serial communication on the physical layer, whereas the IEC-104 protocol uses Ethernet communication.
- SPA: a serial communication protocol.
- DNP3: supports both serial and Ethernet communication.
- ModbusIO: used for connecting external devices like ADAM RTD measurement units.

NOTICE!
Please refer to the "Communication" chapter for a more detailed text on the various communication options.

3.7 Measurement menu

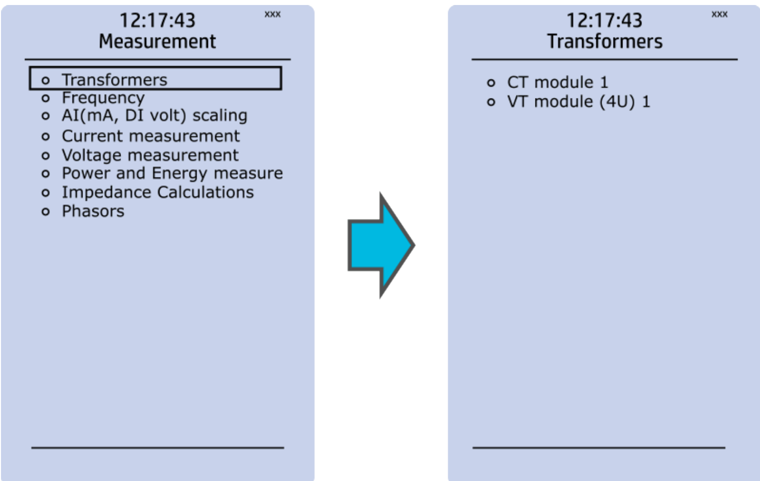
Figure. 3.7 - 42. Measurement section.



The *Measurement* menu includes the following submenus: *Transformers*, *Frequency*, *Current measurement*, *Voltage measurement*, *Power and energy measurement*, *Impedance calculations*, and *Phasors*. The available measurement submenus depends on the type of device in use. The ratio used by the current and voltage transformers is defined in the *Transformers* submenu, while the system nominal frequency is specified in the *Frequency* submenu. Other submenus are mainly for monitoring purposes.

Transformers

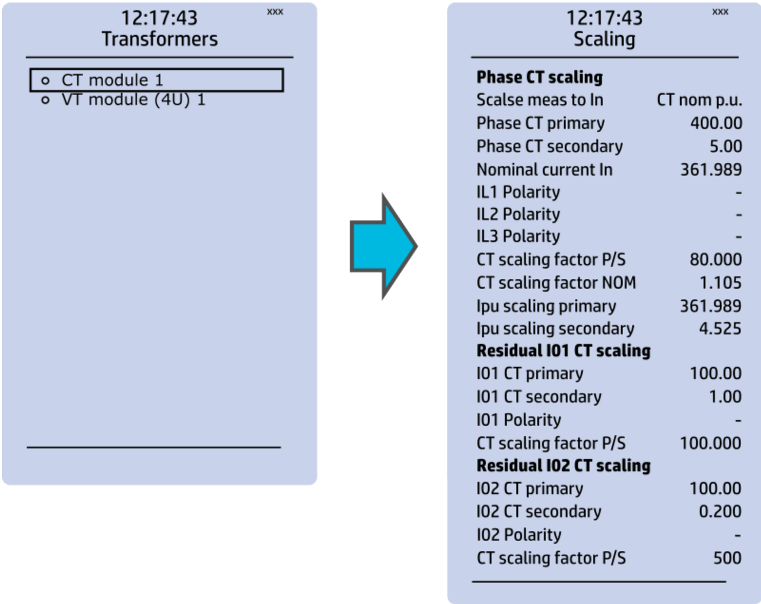
Figure. 3.7 - 43. Transformers section.



Transformers menu is used for setting up the measurement settings of available current transformer modules or voltage transformer modules. Some unit types have more than one CT or VT module. Some unit types like AQ-S214 do not have current or voltage transformers at all.

CT module

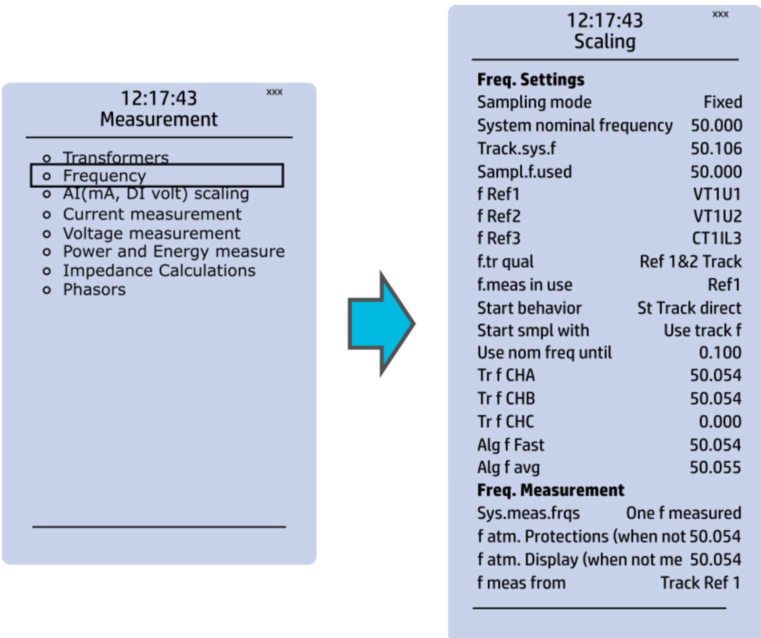
Figure. 3.7 - 44. CT module section.



The three main sections ("Phase CT scaling", "Residual I01 CT scaling" and "Residual I02 CT scaling") determine the ratio of the used transformers. Additionally, the nominal values are also determined in the *CT module* submenu. Sometimes a mistake in the wiring can cause the polarity to be changed; in such cases, you can invert the polarity of each phase current individually. The *CT module* submenu also displays additional information such as CT scaling factors and per-unit scaling factors.

Frequency

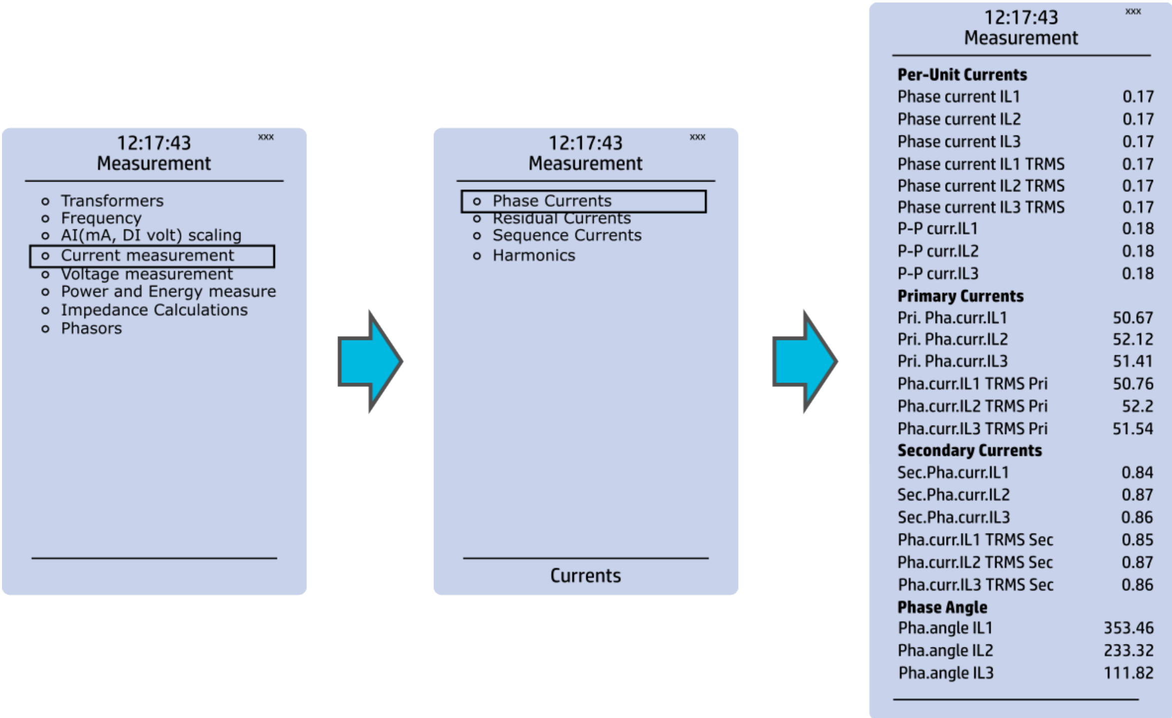
Figure. 3.7 - 45. Frequency submenu.



Frequency measurements use the fixed sampling mode as the default, and "System nominal frequency" should be set to the desired level. When "Sampling mode" is set to "Tracking", the device uses the measured frequency value as the system nominal frequency. There are three frequency reference channels: f Ref1, fRef2 and fRef3. With these parameters it is possible to set up three voltage or current channels to be used for frequency sampling. Parameter "f.meas in use" indicates which of the three channels are used for sampling if any.

Current measurement

Figure. 3.7 - 46. Current measurement submenu.



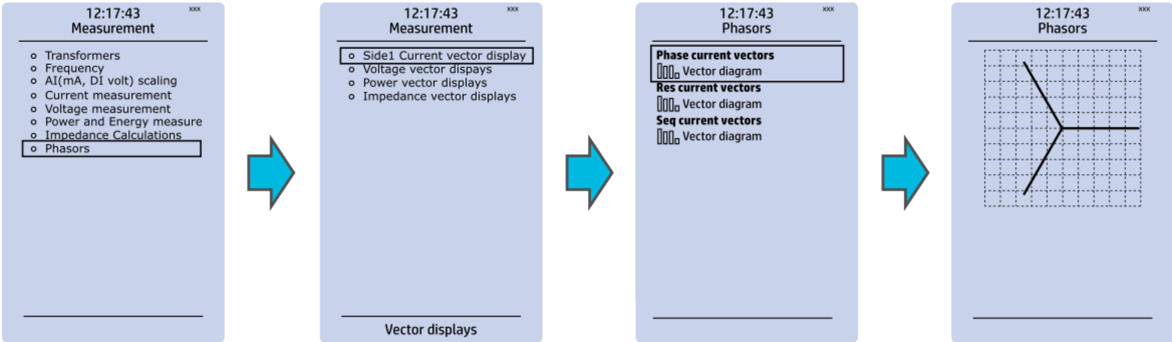
Current measurement submenu includes various individual measurements for each phase or phase-to-phase measurement.

The *Current measurement* submenu has been divided into four sections: "Phase currents", "Residual currents", "Sequence currents", and "Harmonics".

- "Phase currents" and "Residual currents" have been further divided into four subsections ("Per-unit currents", "Primary currents", "Secondary currents" and "Phase angle"), and they display the RMS, TRMS and peak-to-peak values, amplitude and power THD values as well as the angle of each measured component.
- "Sequence currents" has also been further divided into the four above-mentioned sections, and it calculates the positive, negative and zero sequence currents.
- "Harmonics" displays current harmonics up to the 31st harmonic for the three phase current (IL1, IL2, IL3) as well as the two residual currents (I01, I02); each component can be displayed as absolute or percentage values, and as primary or secondary amperages or in per-unit values.

Phasors

Figure. 3.7 - 47. Phasors submenu.

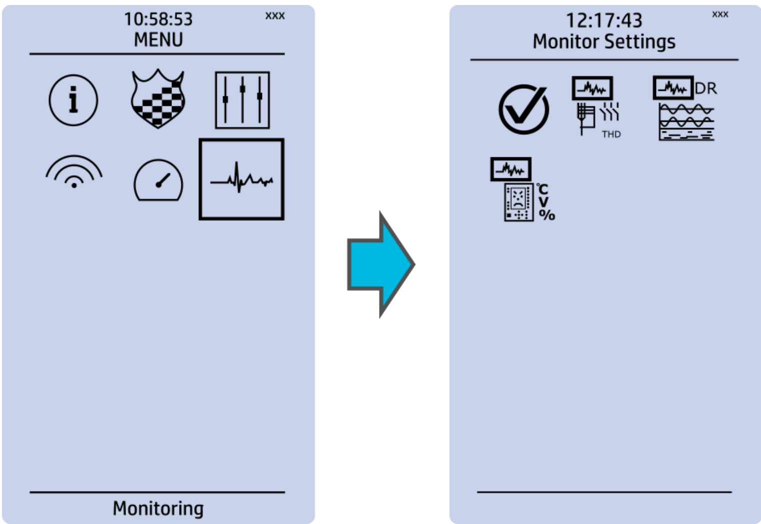


The *Phasors* submenu holds the vector displays for voltages and currents, as well as the various calculated components the device may have (e.g. power, impedance). Phasors are helpful when solving incorrect wiring issues.

3.8 Monitoring menu

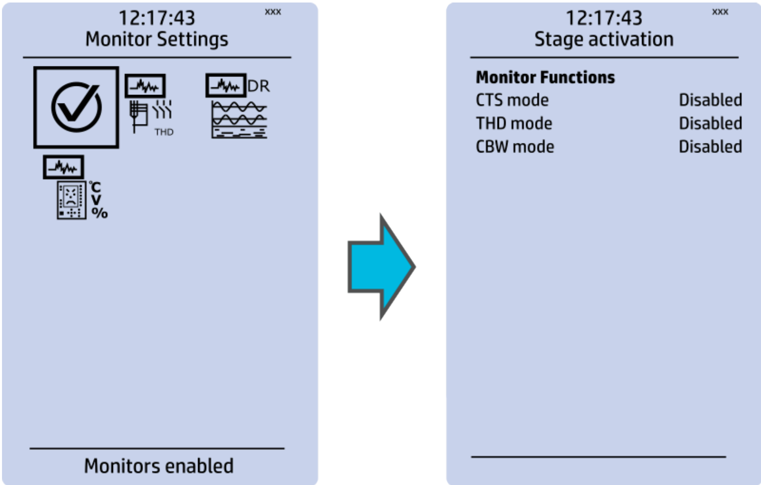
The *Monitoring* main menu includes submenus (see the image below) for enabling the various monitoring functions (*Monitors enabled*), setting the various monitoring functions (*Monitor functions*), controlling the disturbance recorder (*Disturbance REC*) and accessing the device diagnostics (*Device diagnostics*). The available monitoring functions depend on the type of the device in use.

Figure. 3.8 - 48. Monitoring menu view.



Monitors enabled

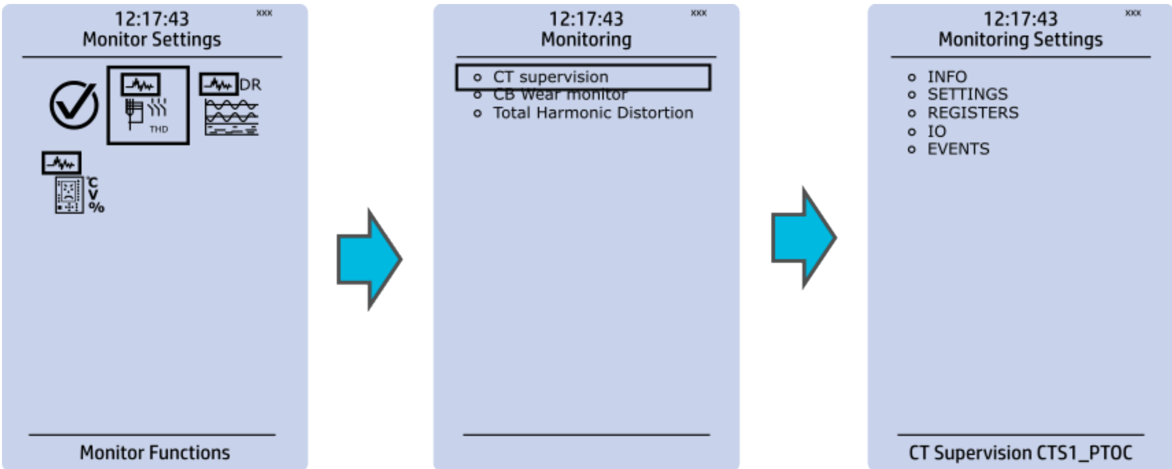
Figure. 3.8 - 49. Monitors enabled submenu.



You can activate the selected monitor functions in the *Monitors enabled* submenu. By default all the control functions are disabled. All activated functions can be viewed in the *Monitor functions* submenu (see the section "Monitor functions" below for more information).

Monitor functions

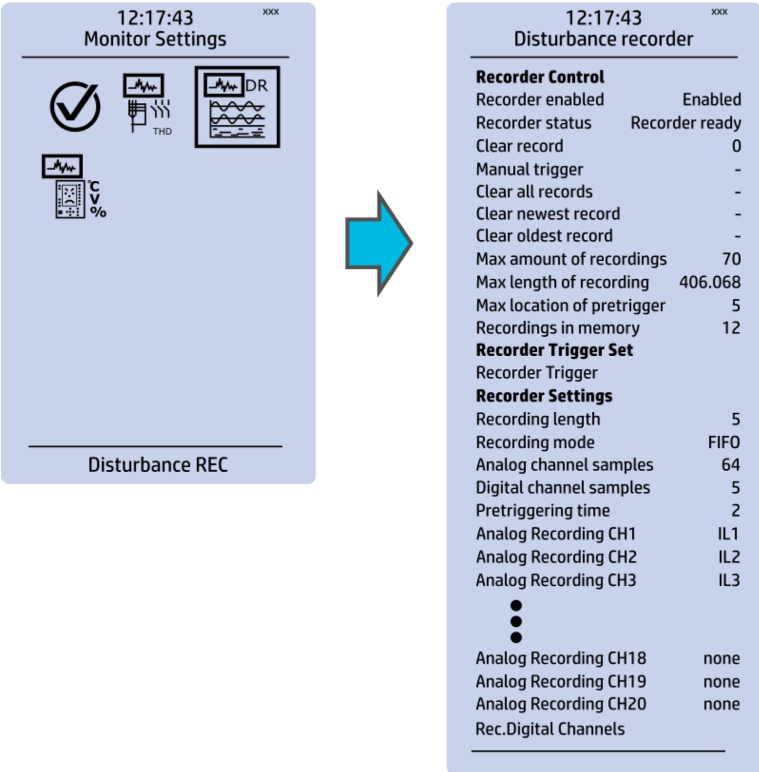
Figure. 3.8 - 50. Monitor function view.



Configuring monitor functions is very similar to configuring protection and control stages. They, too, have the five sections that display information ("Info"), set the parameters ("Settings"), show the inputs and outputs ("I/O") and present the events and registers ("Events" and "Registers").

Disturbance recorder

Figure. 3.8 - 51. Disturbance recorder settings.



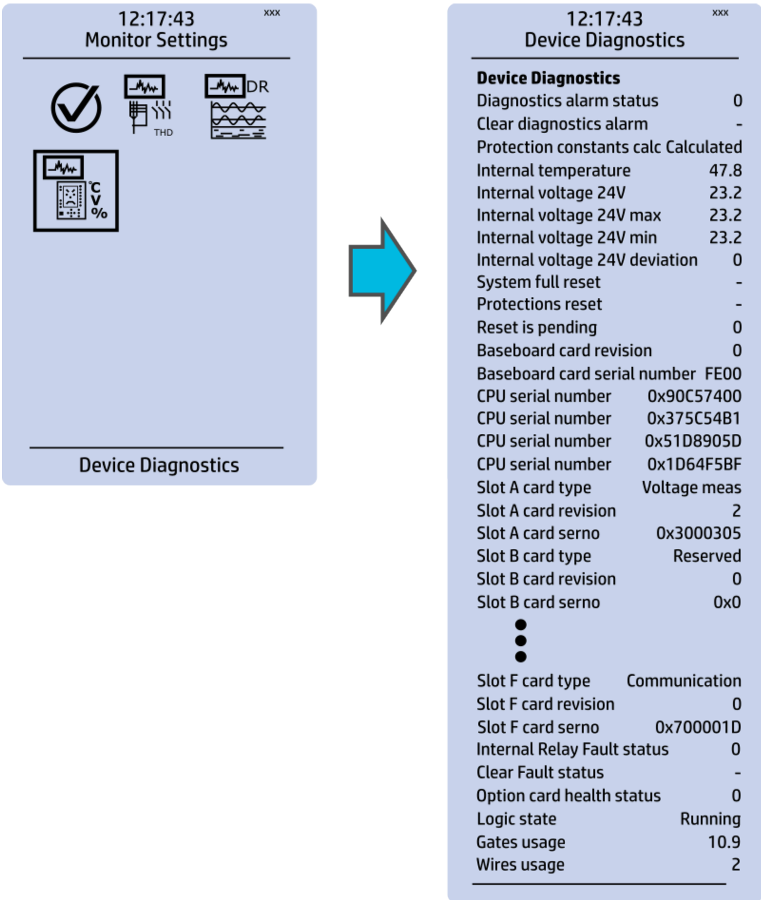
The *Disturbance recorder* submenu has the following settings:

- "Recorder enabled" enables or disables the recorder.
- "Recorder status" indicates the status of the recorder.
- "Clear record" records the chosen record in the memory.
- "Manual trigger" triggers the recorder when set to "Clear". Goes back to "-" when afterwards.
- "Clear all records", "Clear newest record" and "Clear oldest record" allows the clearing of all, the latest, or the oldest recording.
- "Max. amount of recordings" displays the maximum number of recordings; depends on the number of channels, the sample rate and the legnth of the file.
- "Max. length of recording" displays the maximum length of a single recording; depends on the number of chosen channels and the sample rate.
- "Recordings in memory" displays the number of recordings currently in the disturbance recorder's memory.
- "Recorder trigger" shows which signals or other states has been selected to trigger the recording (digital input, logical input or output, signals of a stage, object position, etc.); by default nothing triggers the recorder.
- "Recording length" displays the length of a single recording and can be set between 0.1…1,800.0 seconds.
- "Recording mode" can be selected to replace the oldest recording ("FIFO") or to keep the old recordings ("FILO").
- "Analog channel samples" determines the sample rate of analog channels, and it can be selected to be 8/16/32/62 samples per cycle.
- "Digital channel samples" displays the sample rate in a digital channel; this is a fixed 5 ms.
- "Pretriggering time" can be selected between 0.1…15.0 s.
- The device can record up to 20 (20) analog channels that can be selected from the twenty (20) available channels. Every measured current or voltage signal can be selected to be recorded.

- Enabling "Auto. get recordings" allows the device to automatically upload recordings to the designated FTP folder (which, in turn, allows any FTP client to read the recordings from the device's memory).
- "Rec. digital channels" is a long list of the possible digital channels that can be recorded (including primary and secondary amplitudes and currents, calculated signals, TRMS values, sequence components, inputs and outputs, etc.).

Device diagnostics

Figure. 3.8 - 52. Device diagnostics submenu.



The *Device Diagnostics* submenu gives a detailed feedback of the device's current condition. It also shows whether option cards have been installed correctly without problems. If you see something out of the ordinary in the *Device diagnostics* submenu and cannot reset it, please contact the closest representative of the manufacturer or the manufacturer of the device itself.

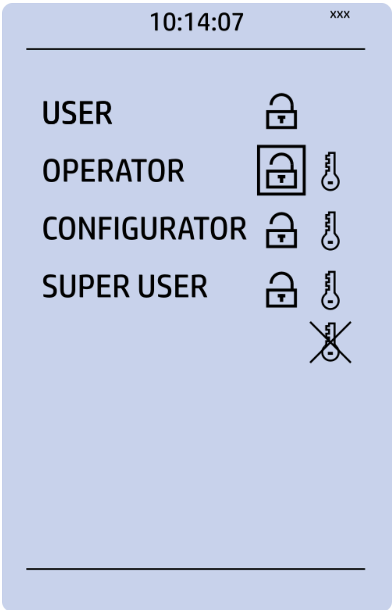
3.9 Configuring user levels and their passwords

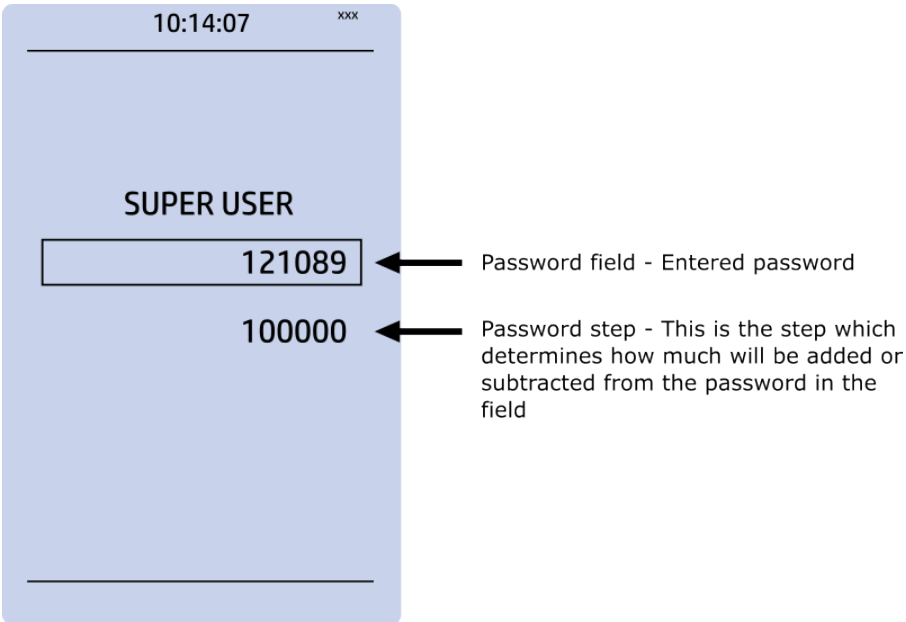
As a factory default, no user level is locked with a password in a device. In order to activate the different user levels, click the Lock button in the device's HMI and set the desired passwords for the different user levels.

> NOTICE!
> Passwords can only be set locally in an HMI.

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

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





You can set a new password for a user level by selecting the key icon next to the user level's name. After this you can lock the user level by pressing the Return key while the lock is selected. If you need to change the password, you can select the key icon again and give a new password. To remove the password, set the password to "0" (zero). 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.

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

4 Functions

4.1 Functions included in AQ-F201

The AQ-F201 overcurrent and earth fault device includes the following functions as well as the number of stages for those functions.

Table. 4.1 - 4. Protection functions of AQ-F201.

Name (number of stages)	IEC	ANSI	Description
NOC (3)	I> I>> I>>>	50/51	Non-directional overcurrent protection
NEF (3)	I0> I0>> I0>>>	50N/51N	Non-directional earth fault protection
CUB (1)	I2>	46/46R/46L	Negative sequence overcurrent/ phase current reversal/ current unbalance protection
HOC (1)	Ih>	50H/51H/68H	Harmonic overcurrent protection
CBFP (1)	CBFP	50BF/52BF	Circuit breaker failure protection
TOLF (1)	TF>	49F	Line thermal overload protection

Table. 4.1 - 5. Control functions of AQ-F201.

Name	IEC	ANSI	Description
SGS	-	-	Setting group selection (8 setting groups available)
OBJ	-	-	Object control and monitoring (1 object available)
CLPU	CLPU	-	Cold load pick-up
SOTF	SOTF	-	Switch-on-to-fault
PCS	-	-	Programmable control switch

Table. 4.1 - 6. Monitoring functions of AQ-F201.

Name	IEC	ANSI	Description
CTS	-	-	Current transformer supervision
DR	-	-	Disturbance recorder
CBW	-	-	Circuit breaker wear monitor

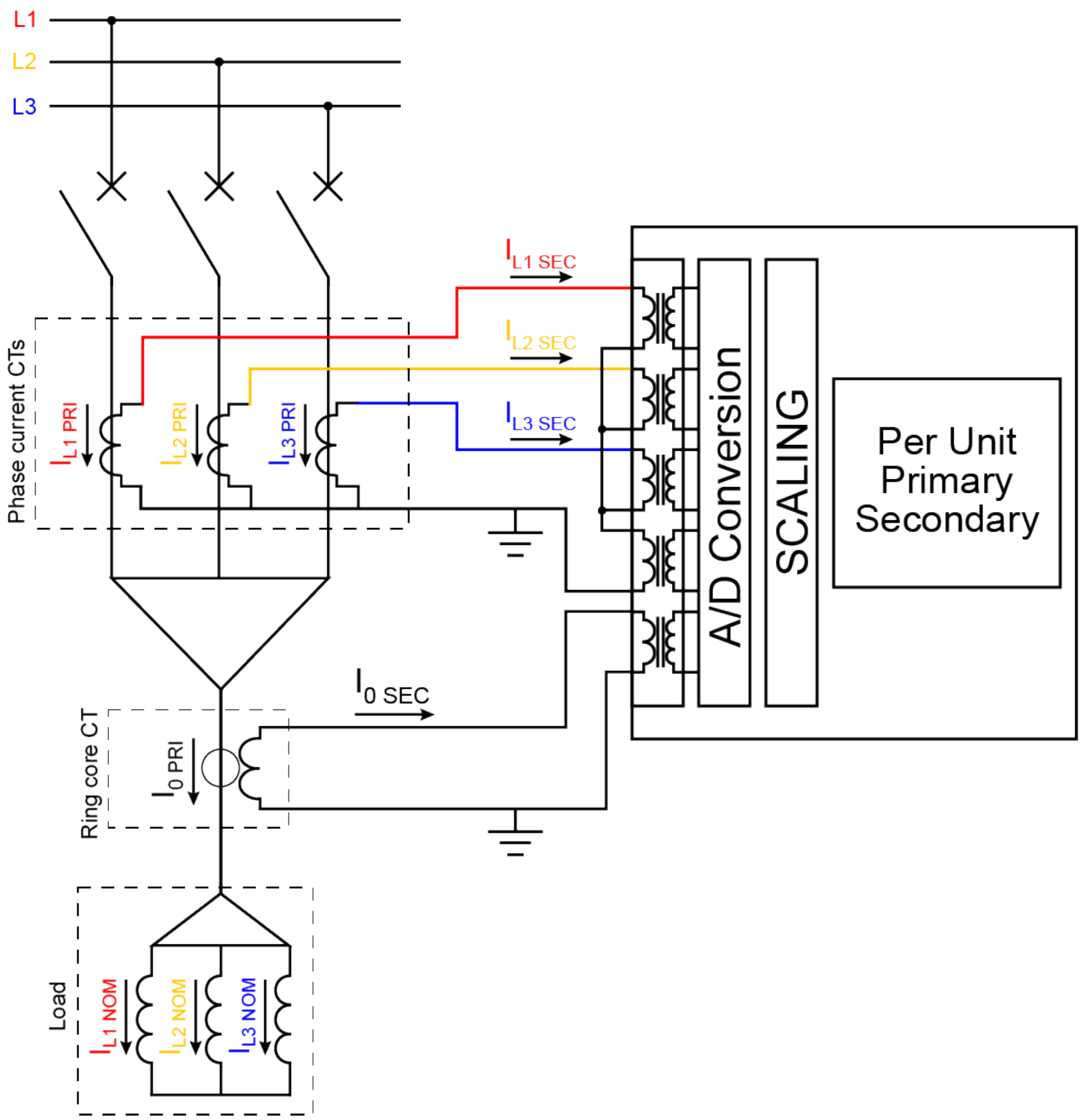
Name	IEC	ANSI	Description
THD	-	-	Current total harmonic distortion
MREC	-	-	Measurement recorder
VREC	-	-	Fault register

4.2 Measurements

4.2.1 Current measurement and scaling

The current measurement module (CT module, or CTM) is used for measuring the currents from current transformers. The current measurements are updated every 5 milliseconds. 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. 4.2.1 - 53. Current measurement terminology.



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

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

NOM: The nominal primary current of the protected object.

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

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

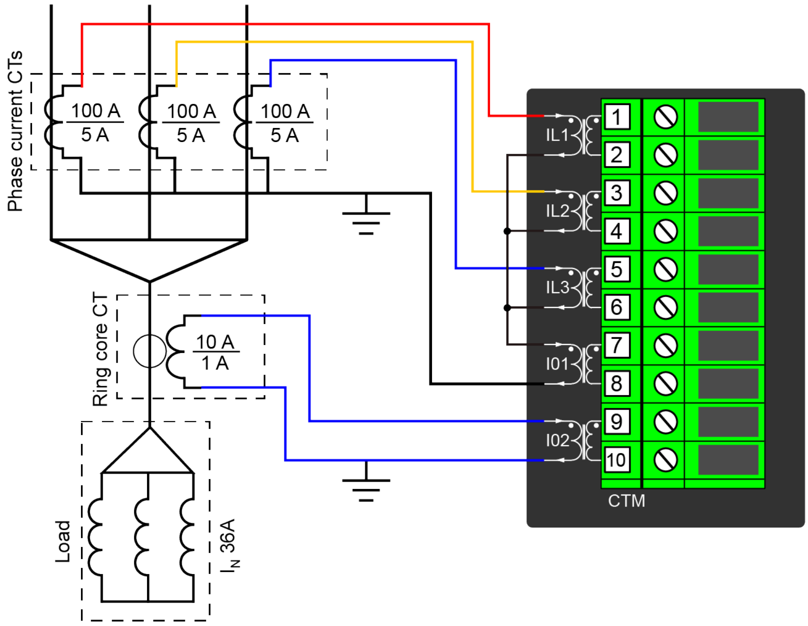
Normally, the primary current ratings for phase current transformers are 10 A, 12.5 A, 15 A, 20 A, 25 A, 30 A, 40 A, 50 A, 60 A and 75 A as well as their decimal multiples, while the secondary current ratings are 1 A and 5 A. Other, non-standard ratings can be directly connected as the scaling settings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

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

Example of CT scaling

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

Figure. 4.2.1 - 54. Connections.



The following table presents the initial data of the connection.

Table. 4.2.1 - 7. Initial data.

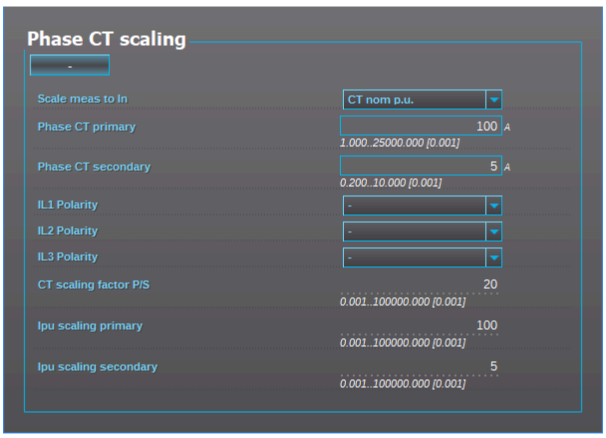
Phase current CT: • CT primary: 100 A • CT secondary: 5 A	Ring core CT in Input I02: • I0CT primary: 10 A • I0CT secondary: 1 A	Load (nominal): 36 A
• The phase currents are connected to the I01 residual via a Holmgren connection. • The starpoint of the phase current CT's secondary current is towards the line.		

Phase CT scaling

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

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

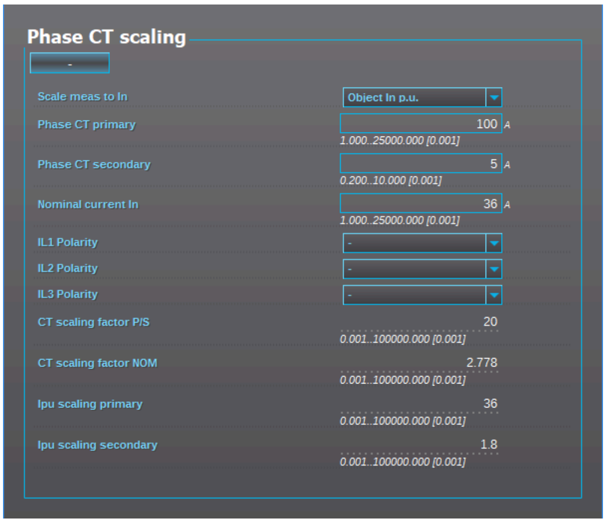
Figure. 4.2.1 - 55. Setting the phase current transformer scalings to CT nominal.



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

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

Figure. 4.2.1 - 56. Setting the phase current transformer scalings to the protected object's nominal current.



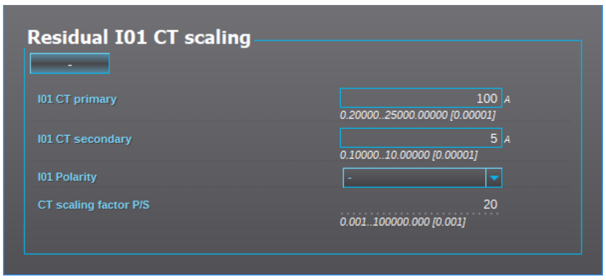
Once the measurement scaling is tied to the protected object's nominal current, the user must set the appropriate input for the "Nominal current In" setting. One can now see the differences between the two scaling options (CT nominal vs. object nominal). The "CT scaling factor P/S" is the direct ratio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

Residual I0 CT scaling

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

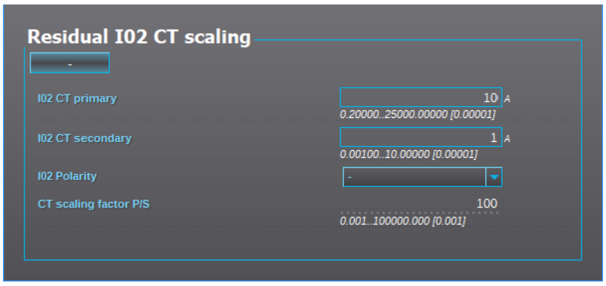
The phase current CTs are connected to the module via a Holmgren (summing) connection, which requires the use of coarse residual current measurement settings: the "I01 CT" settings are set according to the phase current CTs' ratings (100/5 A).

Figure. 4.2.1 - 57. Residual I01 CT scaling (coarse).



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

Figure. 4.2.1 - 58. Residual I02 CT scaling (sensitive).



Displaying the scaling

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

Figure. 4.2.1 - 59. Scalings display (based on the CT nominal).

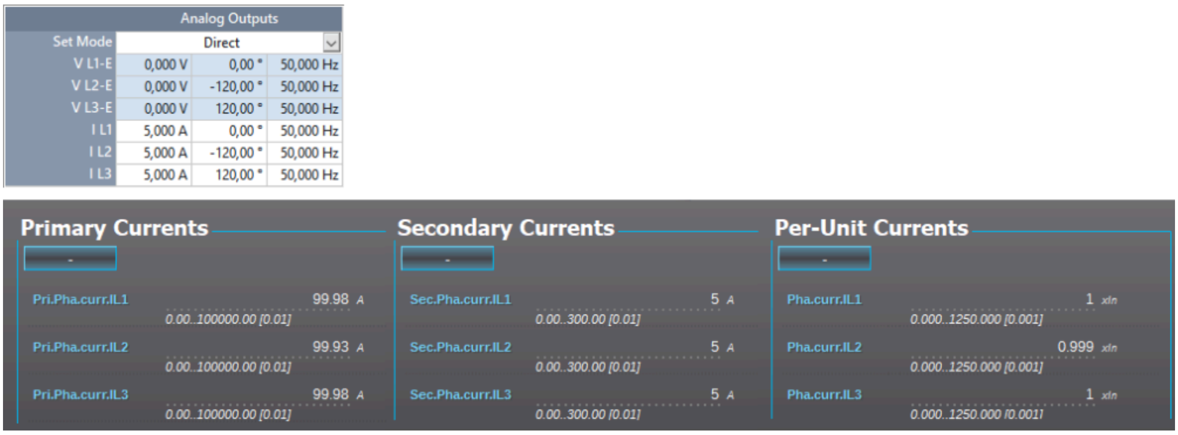
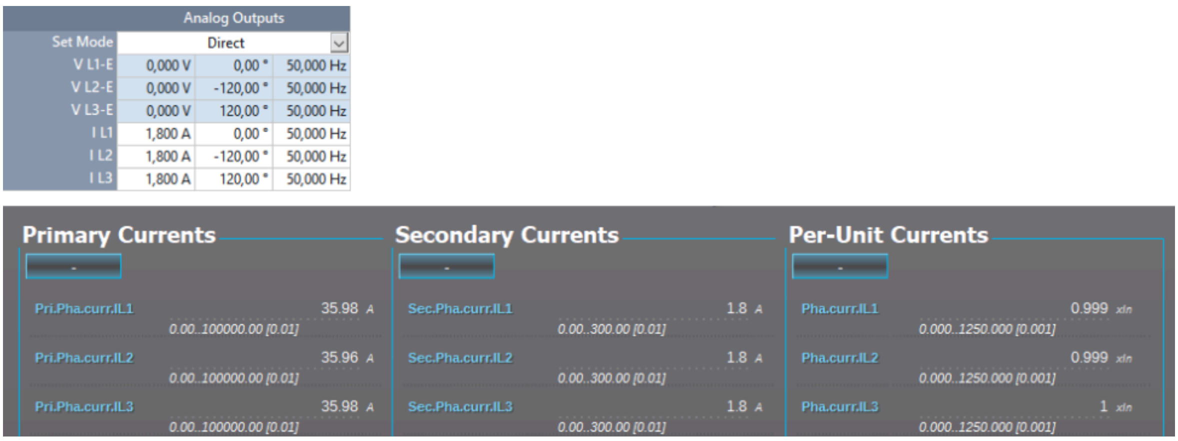


Figure. 4.2.1 - 60. Scalings display (based on the protected object's nominal current).

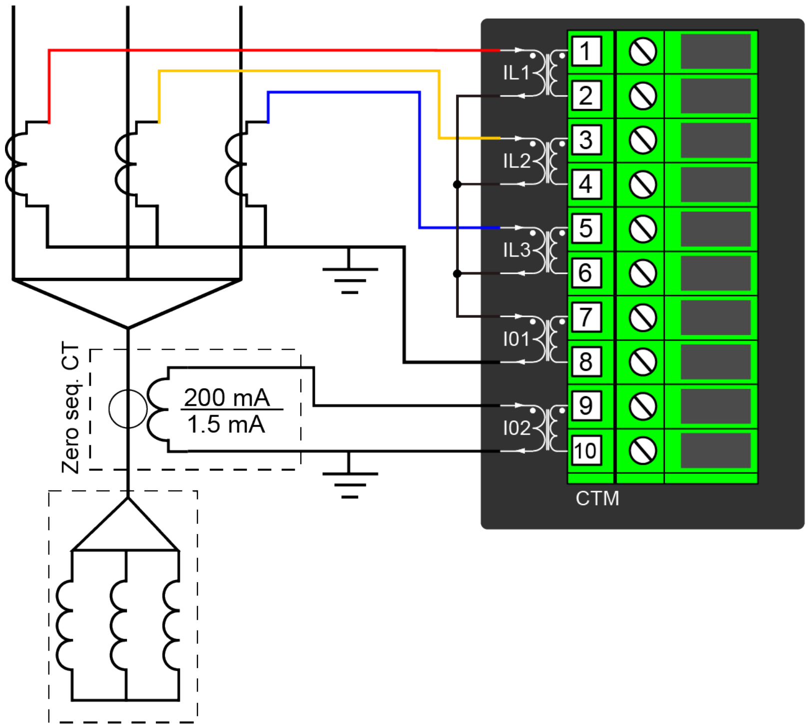


As the images above show, the scaling selection does not affect how primary and secondary currents are displayed (as actual values). The only effect is that the per-unit system in the device is scaled either to the CT nominal or to the object nominal, making the settings input straightforward.

Example of zero sequence CT scaling

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

Figure. 4.2.1 - 61. Connections of ZCT scaling.

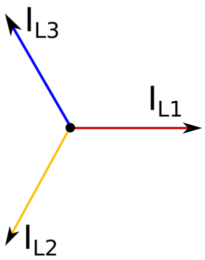


Troubleshooting

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

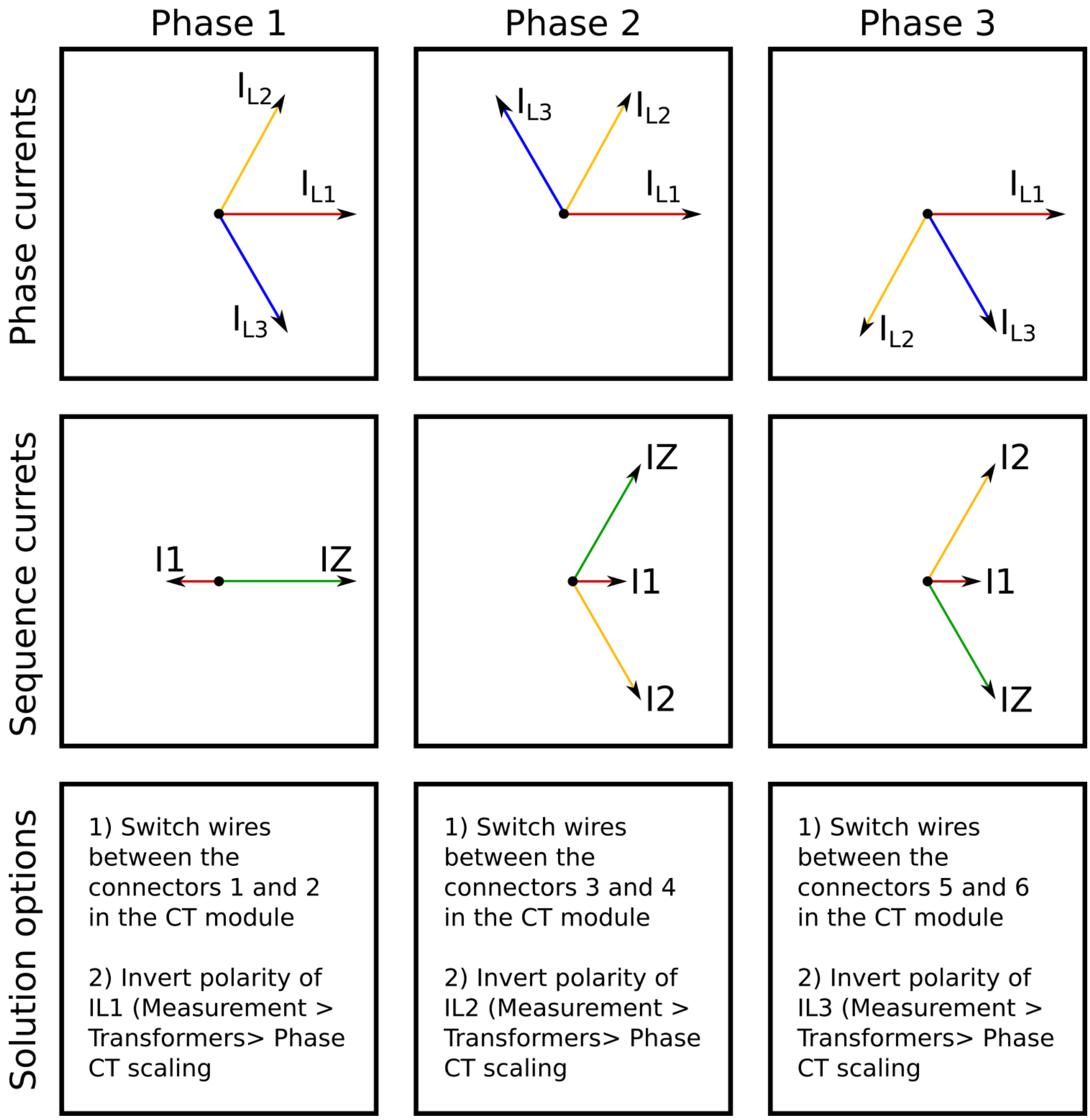
WARNING!
If you work with energized CTs, extreme caution needs to be taken when checking the connections! An opened CT secondary circuit may generate dangerously high voltages. A "buzzing" sound from the connector can indicate an open circuit.

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

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

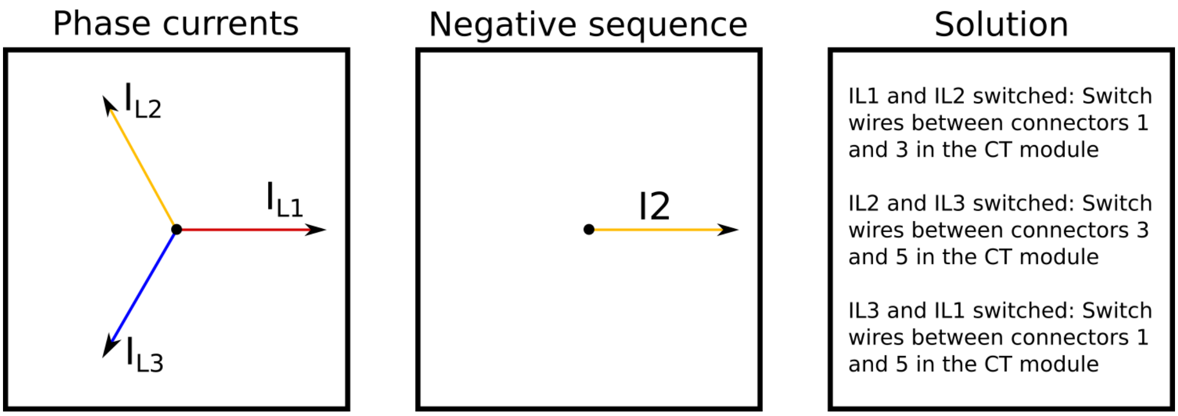
The following image presents the most common problems with phase polarity. Problems with phase polarity are easy to find because the vector diagram points towards the opposite polarity when a phase has been incorrectly connected.

Figure. 4.2.1 - 62. Common phase polarity problems.



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

Figure. 4.2.1 - 63. Common network rotation (mixed phases) problems.



Settings

Table. 4.2.1 - 8. Settings of the Phase CT scaling.

Name	Range	Step	Default	Description
Scale measurement to In	• CT nom p.u. • Object In p.u.	-	• CT nom p.u.	The selection of the reference used in the device's per-unit system scaling. Either the set phase current CT primary or the protected object's nominal current.
Phase CT primary	1.000…25 000.000A	0.001	100.000	The rated primary current of the current transformer.
Phase CT secondary	0.200…10.000A	0.001	5.000	The rated secondary current of the current transformer.
Nominal current In	1.000…25 000.000A	0.001	100.000	The nominal current of the protected object. This setting is only visible if the option "Object In p.u." has been selected in the "Scale measurement to In" setting.
IL1 Polarity	• - • Invert	-	-	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	• - • Invert	-	-	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	• - • Invert	-	-	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.

Name	Range	Step	Default	Description
CT scaling factor NOM	-	-	-	A feedback value; the calculated scaling factor that is the ratio between the set primary current and the set nominal current. This parameter is only visible if the option "Object In p.u." has been selected in the "Scale measurement to In" setting.
Ipu scaling primary	-	-	-	A feedback value; the scaling factor for the primary current's per-unit value.
Ipu scaling secondary	-	-	-	A feedback value; the scaling factor for the secondary current's per-unit value.

Table. 4.2.1 - 9. Settings of the Residual I01 CT scaling.

Name	Unit	Range	Step	Default	Description
I01 CT primary	A	0.200 00…25 000.000 00	0.000 01	100.000 00	The rated primary current of the current transformer.
I01 CT secondary	A	0.100 00…10.000 00	0.000 01	1.000 00	The rated secondary current of the current transformer.
I01 Polarity	-	• - • Invert	-	-	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. 4.2.1 - 10. Settings of the Residual I02 CT scaling.

Name	Unit	Range	Step	Default	Description
I02 CT primary	A	0.200 00…25 000.000 00	0.000 01	100.000 00	The rated primary current of the current transformer.
I02 CT secondary	A	0.001 00…10.000 00	0.000 01	0.200 00	The rated secondary current of the current transformer.
I02 Polarity	-	• - • Invert	-	-	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. 4.2.1 - 11. Per-unit phase current measurements.

Name	Unit	Range	Step	Description
Pha.curr.ILx	× In	0.000…1 250.000	0.001	The current fundamental frequency component (in p.u.) from each of the phase current channels.
Pha.curr.ILx TRMS	× In	0.00…1 250.00	0.01	The TRMS current (inc. harmonics up to 31st) measurement (in p.u.) from each of the phase current channels.
P-P curr.ILx	× In	0.00…500.00	0.01	The peak-to-peak current measurement (in p.u.) from each of the phase current channels.

Table. 4.2.1 - 12. Primary phase current measurements.

Name	Unit	Range	Step	Description
Pri.Pha.curr.ILx	A	0.00…1 000 000.00	0.01	The primary current measurement fundamental frequency component from each of the phase current channels.
Pha.curr.ILx TRMS Pri	A	0.00…1 000 000.00	0.01	The primary TRMS current (inc. harmonics up to 31st) measurement from each of the phase current channels.

Table. 4.2.1 - 13. Secondary phase current measurements.

Name	Unit	Range	Step	Description
Sec.Pha.curr.ILx	A	0.00…300.00	0.01	The primary current measurement fundamental frequency component from each of the phase current channels.
Pha.curr.ILx TRMS Sec	A	0.00…300.00	0.01	The primary TRMS current (inc. harmonics up to 31st) measurement from each of the phase current channels.

Table. 4.2.1 - 14. Phase angle measurements.

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

Table. 4.2.1 - 15. Per-unit residual current measurements.

Name	Unit	Range	Step	Description
Res.curr.I0x	× In	0.00…1 250.00	0.01	The current measurement fundamental frequency component (in p.u.) from the residual current channel I01 or I02.
Calculated I0	× In	0.00…1 250.00	0.01	The current measurement fundamental frequency component (in p.u.) from the calculated I0 current channel.
Res.curr.I0x TRMS	× In	0.00…1 250.00	0.01	The TRMS current (inc. harmonics up to 31st) measurement (in p.u.) from the residual current channel I01 or I02.
P-P curr.I0x	× In	0.00…500.00	0.01	The peak-to-peak current measurement (in p.u.) from the residual current channel I01 or I02.

Table. 4.2.1 - 16. Primary residual current measurements.

Name	Unit	Range	Step	Description
Pri.Res.curr.I0x	A	0.00…1 000 000.00	0.01	The primary current measurement fundamental frequency component from the residual current channel I01 or I02.
Pri.calc.I0	A	0.00…1 000 000.00	0.01	The primary current measurement fundamental frequency component from the calculated current channel I0.
Res.curr.I0x TRMS Pri	A	0.00…1 000 000.00	0.01	The TRMS current (inc. harmonics up to 31st) measurement from the primary residual current channel I01 or I02.

Table. 4.2.1 - 17. Secondary residual current measurements.

Name	Unit	Range	Step	Description
Sec.Res.curr.I0x	A	0.00…300.00	0.01	The secondary current measurement fundamental frequency component from the residual current channel I01 or I02.
Sec.calc.I0	A	0.00…300.00	0.01	The secondary current measurement fundamental frequency component from the calculated current channel I0.
Res.curr.I0x TRMS Sec	A	0.00…300.00	0.01	The secondary TRMS current (inc. harmonics up to 31st) measurement from the secondary residual current channel I01 or I02.

Table. 4.2.1 - 18. Residual phase angle measurements.

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

Table. 4.2.1 - 19. Per-unit sequence current measurements.

Name	Unit	Range	Step	Description
Positive sequence current	× In	0.00…1 250.00	0.01	The measurement (in p.u.) from the calculated positive sequence current.
Negative sequence current	× In	0.00…1 250.00	0.01	The measurement (in p.u.) from the calculated negative sequence current.
Zero sequence current	× In	0.00…1 250.00	0.01	The measurement (in p.u.) from the calculated zero sequence current.

Table. 4.2.1 - 20. Primary sequence current measurements.

Name	Unit	Range	Step	Description
Pri.Positive sequence curr.	A	0.00…1 000 000.00	0.01	The primary measurement from the calculated positive sequence current.
Pri.Negative sequence curr.	A	0.00…1 000 000.00	0.01	The primary measurement from the calculated negative sequence current.
Pri.Zero sequence curr.	A	0.00…1 000 000.00	0.01	The primary measurement from the calculated zero sequence current.

Table. 4.2.1 - 21. Secondary sequence current measurements.

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

Table. 4.2.1 - 22. Sequence phase angle measurements.

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

Table. 4.2.1 - 23. Harmonic current measurements.

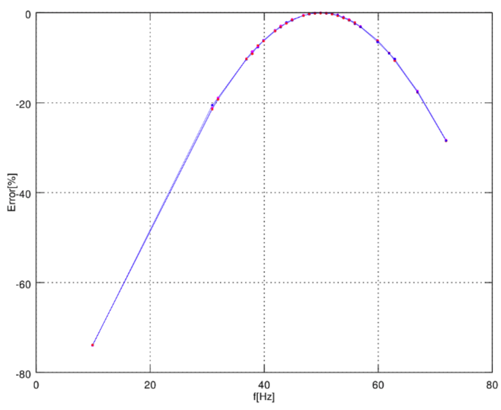
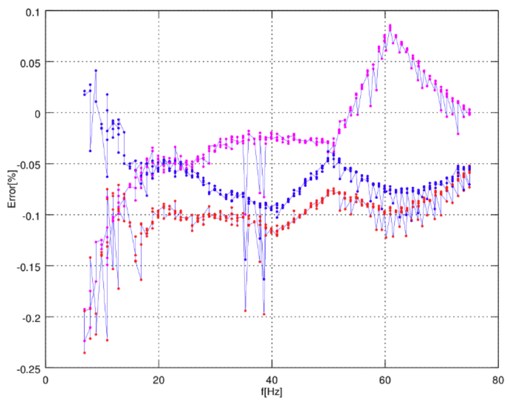
Name		Range	Step	Description
Harm Abs.or Perc.	-	• Percent • Absolute	-	Defines whether the harmonics are calculated as percentage or absolute values.
Harmonics display	-	• Per unit • Primary A • Secondary A	-	Defines how the harmonics are displayed: in p.u values, as primary current values, or as secondary current values.
Ixx maximum harmonic	A	0.00...100 000.00	0.01	Displays the maximum harmonics value of the selected current input ILx or I0x.
Ixx fundamental	A	0.00...100 000.00	0.01	Displays the current value of the fundamental frequency component (RMS) from the selected current input ILx or I0x.
Ixx harmonics (2^{nd}...31^{st} harmonic)	A	0.00…100 000.00	0.01	Displays the selected harmonic from the current input ILx or I0x.

Name		Range	Step	Description
Ixx Amplitude THD	%	0.000...100.000	0.001	Amplitude ratio THD voltage. Recognized by IEC.
Ixx Power THD	%	0.000...100.000	0.001	Power ratio THD voltage. Recognized by the IEEE.

4.2.2 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. 4.2.2 - 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.

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* → "Sampling 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. 4.2.2 - 25. Settings of the frequency tracking.

Name	Range	Step	Default	Description
Sampling mode	• Fixed • Tracking	-	Fixed	Defines which measurement sampling mode is in use: the fixed user-defined frequency, or the tracked system frequency.
Max. tracking frequency allowed (+Nom freq.)	0.001…75.000 Hz	0.001 Hz	0.001 Hz	Defines the upper limit for the deviation from the system nominal frequency to be tracked. If the frequency increases more than allowed from the nominal value, the tracking is discarded and the value of the nominal frequency will be used.
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".
Min. tracking frequency allowed (–Nom freq.)	0.001…75.000 Hz	0.001 Hz	0.001 Hz	Defines the lower limit for the deviation from the system nomnal frequency to be tracked. If the frequency decreases more than allowed from the nominal value, the tracking is discarded and the value of the nominal frequency will be used.
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	• None • CT1IL1 • CT2IL1 • VT1U1 • VT2U1	-	CT1IL1	The first reference source for frequency tracking.
Frequency reference 2	• None • CT1IL2 • CT2IL2 • VT1U2 • VT2U2	-	CT1IL2	The second reference source for frequency tracking.

Name	Range	Step	Default	Description
Frequency reference 3	• None • CT1IL3 • CT2IL3 • VT1U3 • VT2U3	-	CT1IL3	The third reference source for frequency tracking.
Frequency tracking quality	• No trackable channels • Reference 1 trackable • Reference 2 trackable • References 1 & 2 trackable • Reference 3 trackable • Reference 1 & 3 trackable • References 2 & 3 trackable • 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	• No track ch • Ref1 • Ref2 • Ref3	-	-	Indicates which reference is used at the moment for frequency tracking.
Start behavior	• Start tracking immediately • First nominal or tracked	-	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	• Use track frequency • Use nom frequency	-	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.
System measured frequency	• One f measured • Two f measured • Three f measured	-	-	Displays the amount of frequencies that are measured.

Name	Range	Step	Default	Description
f.atm. Protections	0.000…75.000Hz	0.001Hz	-	Frequency measurement value used by protection functions. When frequency is not measurable this value returns to value set to "System nominal frequency" parameter.
f.atm. Display	0.000…75.000Hz	0.001Hz	-	Frequency measurement value used in display. When frequency is not measurable this value is "0 Hz".
f measurement from	• Not measurable • Avg Ref 1 • Avg Ref 2 • Avg Ref 3 • Track Ref 1 • Track Ref 2 • Track Ref 3 • Fast Ref 1 • Fast Ref 2 • 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	• Not measurable • Fast Ref U3 • Fast Ref U4	-	-	Displays which voltage channel frequency reference is used by "system set" voltage channel.
SS2f meas.from	• Not measurable • Fast Ref U4	-	-	Displays if U4 channel frequency reference is measurable or not when the channel has been set to "system set" mode.

4.3 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. 4.3 - 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. 4.3 - 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	
Time synchronization source	• Internal • External NTP • External Serial • IRIG-B	Internal	If an external clock time synchronization source is available, the type is defined with this parameter. In the internal mode there is no external Timesync source. IRIG-B requires a serial fiber communication option card.
Enable stage forcing	• Disabled • Enabled	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.
System phase rotating order	• A-B-C • A-C-B	A-B-C	Allows the user to switch the expected order in which the phase measurements are wired to the unit.
Language	• User defined • English • Finnish • Chinese • Spanish • French • German • Russian • Ukrainian • Kazakh	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	• All • COM A • Double Ethernet card	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	• - • Clear	-	Clears the event history recorded in the AQ-200 device.
LCD Contrast	0…255	120	Changes the contrast of the LCD display.
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	• - • Activated	-	When activated, all LEDs are lit up. LEDs with multiple possible colors blink each color.
Reset latches	• - • Reset	-	Resets the latched signals in the logic and the matrix. When a reset command is given, the parameter automatically returns back to "-".
Measurement recorder	• Disabled • Enabled	Disabled	Enables the measurement recorder tool, further configured in *Tools → Misc → Measurement recorder.*

Name	Range	Default	Description
I/0 default object selection	• OBJ1 • OBJ2 • OBJ3 • OBJ4 • OBJ5 • OBJ6 • OBJ7 • OBJ8 • OBJ9 • OBJ10	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.
Reconfigure mimic	• - • Reconfigure	-	Reloads the mimic to the unit.

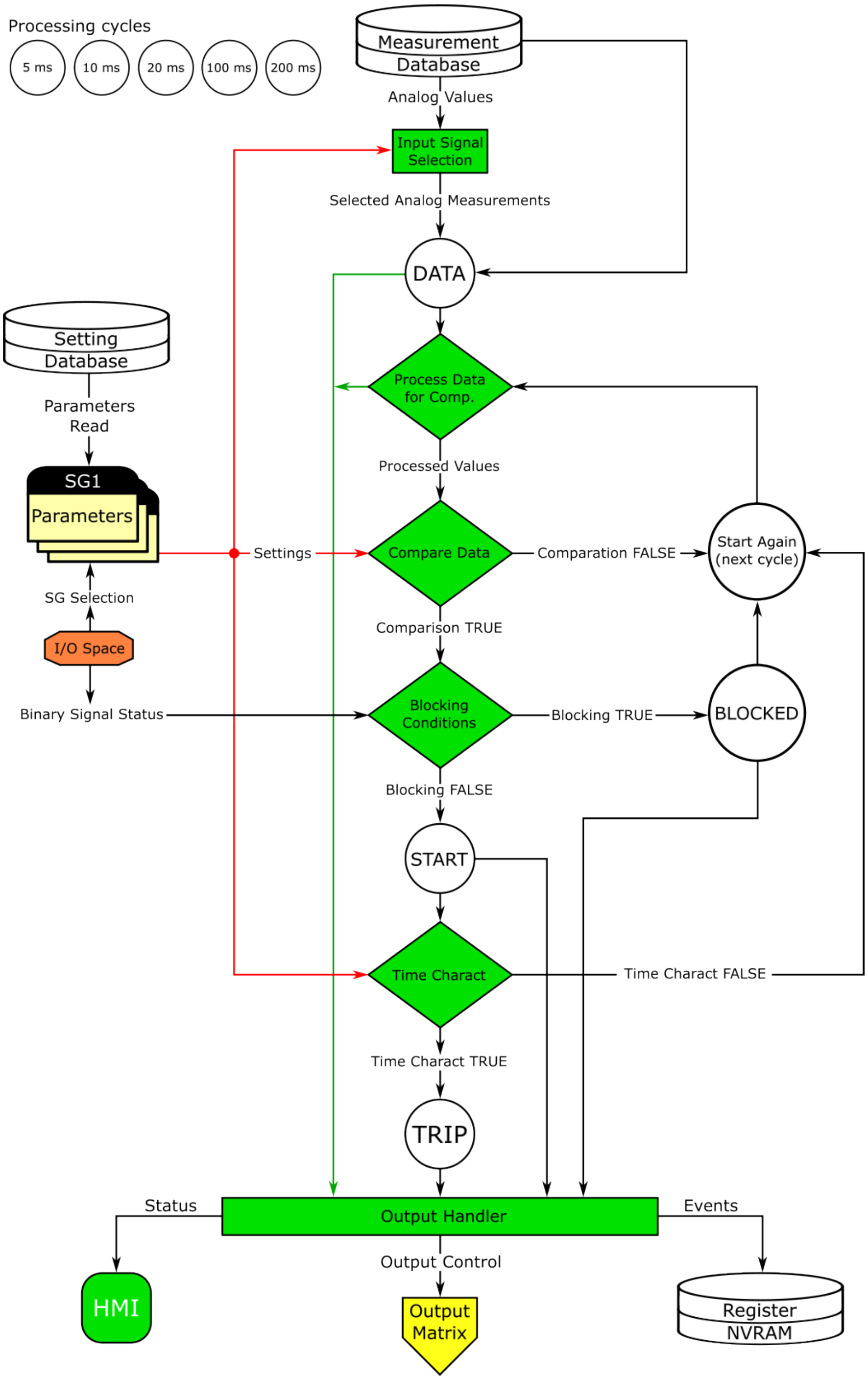
Table. 4.3 - 28. General menu logical inputs.

Name	Description
Reset last fault registers	Signal set to this point can be used for resetting latest recorded fault register.

4.4 Protection functions

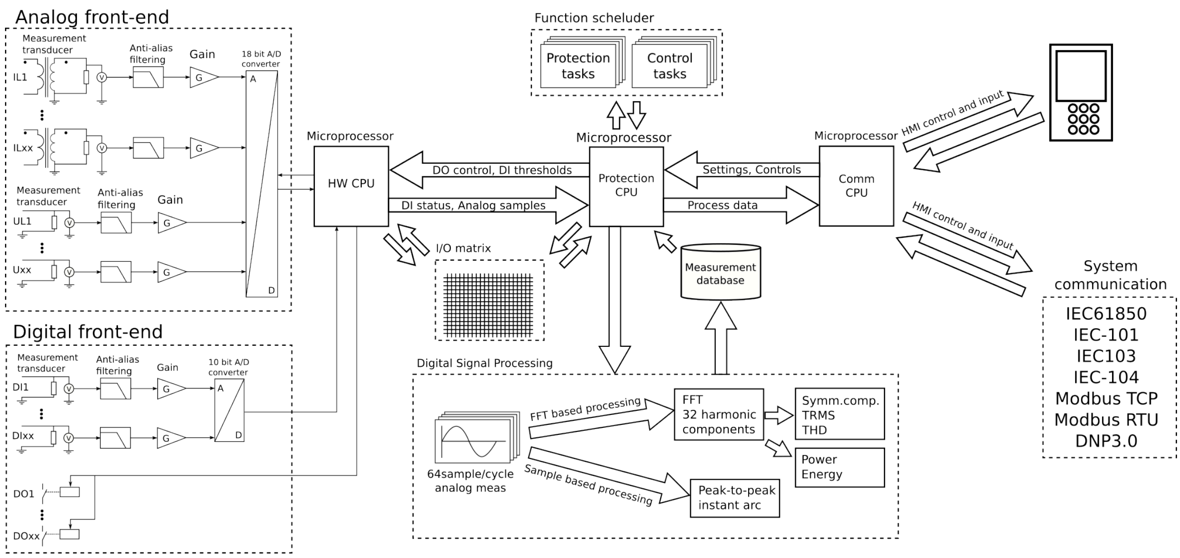
4.4.1 General properties of a protection function

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 delay 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.

Figure. 4.4.1 - 64. Principle diagram of the protection device 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. 4.4.1 - 65. Pick up and reset.

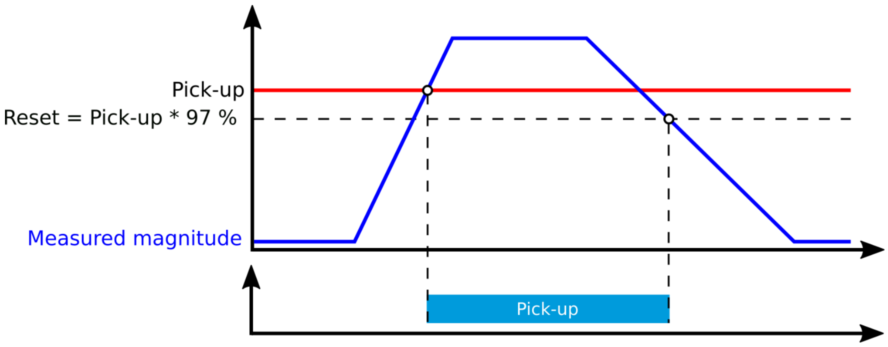
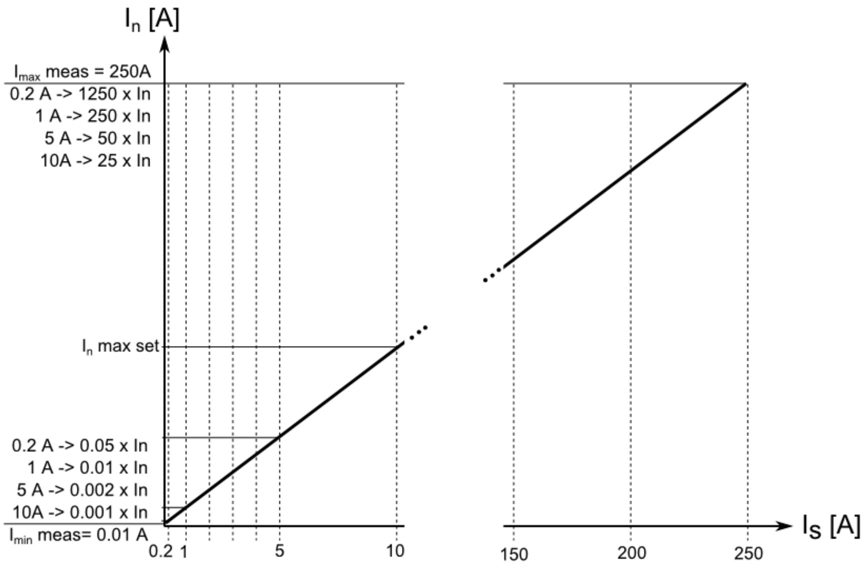


Figure. 4.4.1 - 66. Measurement range in relation to the nominal current.



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 device 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 active when the pick-up element is activated, a START signal is generated and the function proceeds to the time characteristics calculation.

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

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

The blocking inputs users can set are binary signals from the system. The blocking input 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

Three basic modes are available for delaying function operation:

- Instant operation: activates the trip signal simultaneously with the start signal with no additional time delay.
- Definite time operation (DT): activates the trip signal after a user-defined time delay regardless of themagnitude of the measured value(s) as long as the pick-up element is active.
- Inverse definite minimum time (IDMT): activates the trip signal after a time which is in relation to the set pick-up value and the measured value.

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 (minimum)operating time delay* 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. 4.4.1 - 67. Operating time delay: *Definite (minimum) operating time delay* and the minimum for tripping.

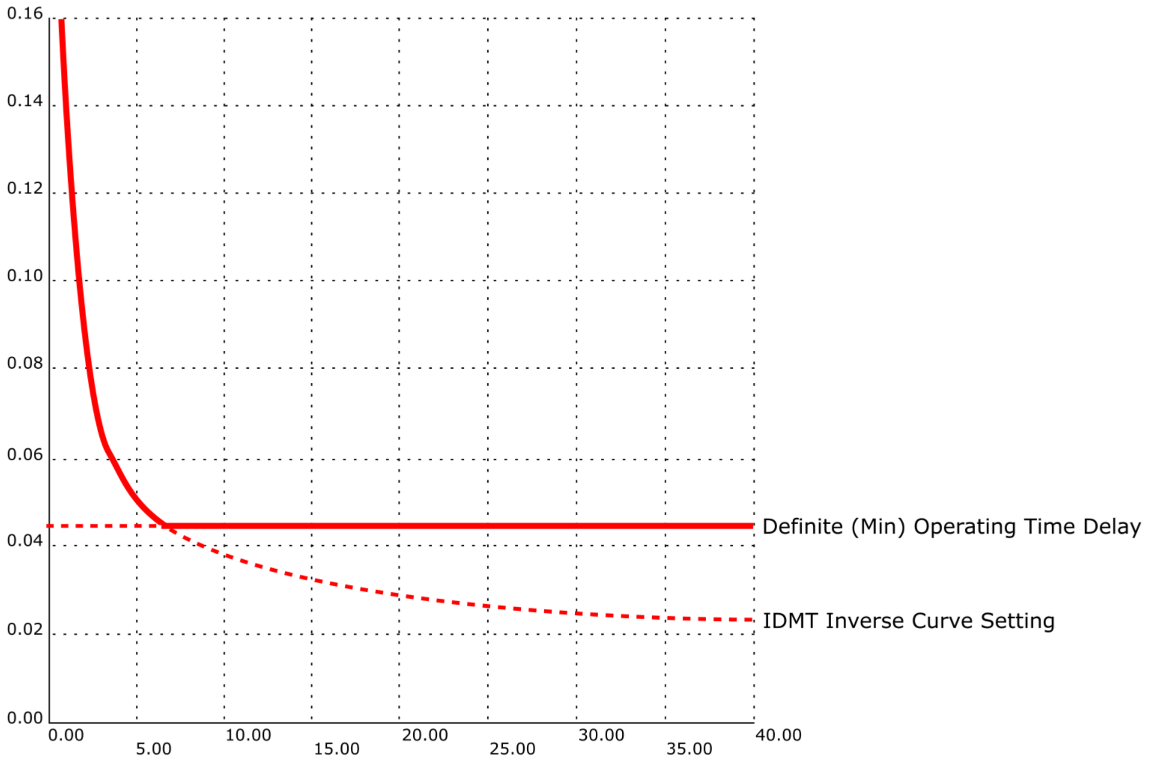


Table. 4.4.1 - 29. Operating time characteristics setting parameters (general).

Name	Range	Step	Default	Description
Delay type	• DT • IDMT	-	DT	Selects the delay type for the time counter. The selection is made between "Inverse definite minimum time" (IDMT) and "Definite time operation" (DT) characteristics.
Definite (minimum) 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. 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. 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	• IEC • IEEE	-	IEC	Selects whether the delay curve series for an IDMT operation follows either IEC or IEEE/ANSI standard defined characteristics. This setting is active and visible when the "Delay type" parameter is set to "IDMT".

Name	Range	Step	Default	Description
Delay characteristics IEC	• NI • EI • VI • LTI • Param	-	NI	Selects the IEC standard delay characteristics. 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. 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	• ANSI NI • ANSI VI • ANSI EI • ANSI LTI • IEEE MI • IEEE VI • IEEE EI • Param	-	ANSI NI	Selects the IEEE and ANSI standard delay characteristics. 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. 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. 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. 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…250.0000	0.0001	0.1850	Defines the Constant B for IEC/IEEE characteristics. 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. This setting is active and visible when the "Delay type" parameter is set to "IDMT" and the "Delay characteristic" parameter is set to "Param".

Figure. 4.4.1 - 68. Inverse definite minimum time formulas for IEC and IEEE standards.

IEC

$$t = \frac{kA}{\left(\frac{I_m}{I_{set}}\right)^B - 1}$$

t = Operating delay (s)
k = Time dial setting
I_m = Measured maximum current
I_{set} = Pick-up setting
A = Operating characteristics constant
B = Operating characteristics constant

Standard delays IEC constants

Type	A	B
Normally Inverse (*NI*)	0,14	0,02
Extremely Inverse (*EI*)	80	2
Very Inverse (*VI*)	13,5	1
Long Time Inverse (*LTI*)	120	1

IEEE/ANSI

$$t = k\left(\frac{A}{\left(\frac{I_m}{I_{set}}\right)^C - 1} + B\right)$$

t = Operating delay (s)
k = Time dial setting
I_m = Measured maximum current
I_{set} = Pick-up setting
A = Operating characteristics constant
B = Operating characteristics constant
C = Operating characteristics constant

Standard delays ANSI constants

Type	A	B	C
Normally Inverse (*NI*)	8,934	0,1797	2,094
Very Inverse (*VI*)	3,922	0,0982	2
Extremely Inverse (*EI*)	5,64	0,02434	2
Long Time Inverse (*LTI*)	5,614	2,186	1

Standard delays IEEE constants

Type	A	B	C
Moderately Inverse (*MI*)	0,0515	0,114	0,02
Very Inverse (*VI*)	19,61	0,491	2
Extremely Inverse (*EI*)	28,2	0,1217	2

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:

- non-directional overcurrent stages
- non-directional earth fault stages
- directional overcurrent stages
- directional earth fault stages.

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

Table. 4.4.1 - 30. Inverse definite minimum time formulas for nonstandard characteristics.

RI-type	RD-type
Used for getting the 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 = Operation delay (s) *k* = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting	*t* = Operation delay (s) *k* = Time dial setting I_m = Measured maximum current I_{set} = Pick-up setting

NOTICE!
When using RD-type and "k" has been set lower than 0.3 calculated operation time can be lower than 0 seconds with some measurement values. In these cases operation time will be instant.

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.

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

Table. 4.4.1 - 31. Setting parameters for reset time characteristics.

Name	Range	Step	Default	Description
Delayed pick-up release	• No • Yes	-	Yes	Resetting characteristics selection (either time-delayed or instant) after the pick-up element is released. If set to "Yes", 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. If the "Delayed pick-up release" setting is set to "Yes", the START signal is held on for the duration of the timer.
Op.Time calculation reset after release time	• No • Yes	-	Yes	Operating timer resetting characteristics selection. When set to "Yes", the operating time counter is reset after a set release time if the pick-up element is not activated during this time. When set to "No", the operating time counter is reset directly after the pick-up element is reset.
Continue time calculation during release time	• No • Yes	-	No	Time calculation characteristics selection. If set to "Yes", the operating time counter continues until a set release time even if the pick-up element is reset.

Figure. 4.4.1 - 69. No delayed pick-up release.

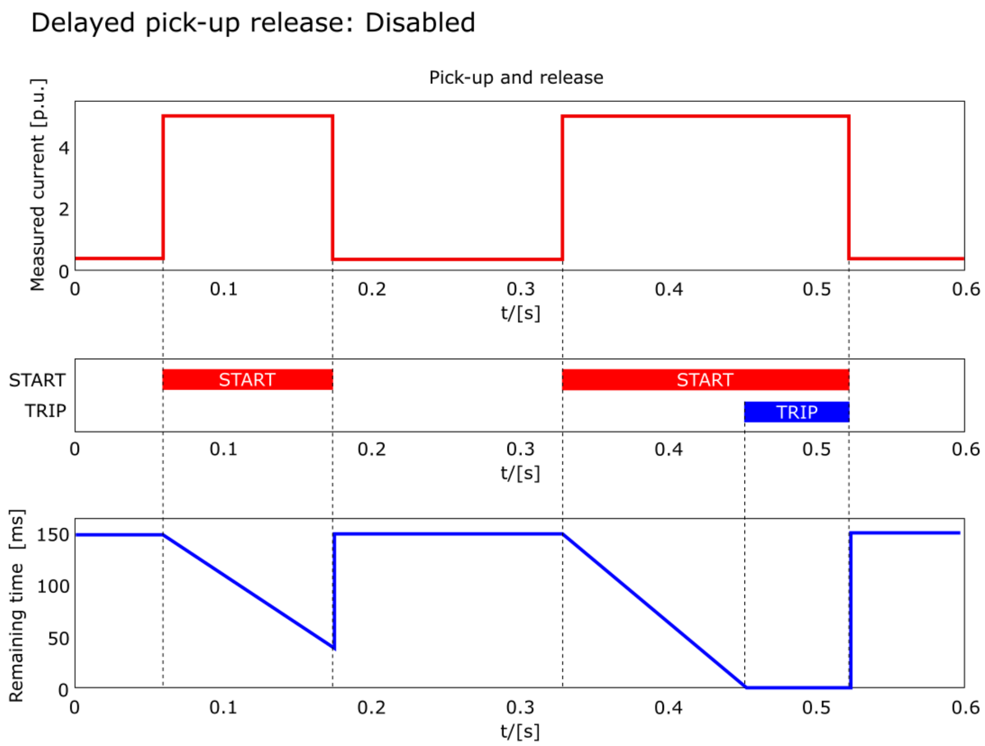


Figure. 4.4.1 - 70. Delayed pick-up release, delay counter is reset at signal drop-off.

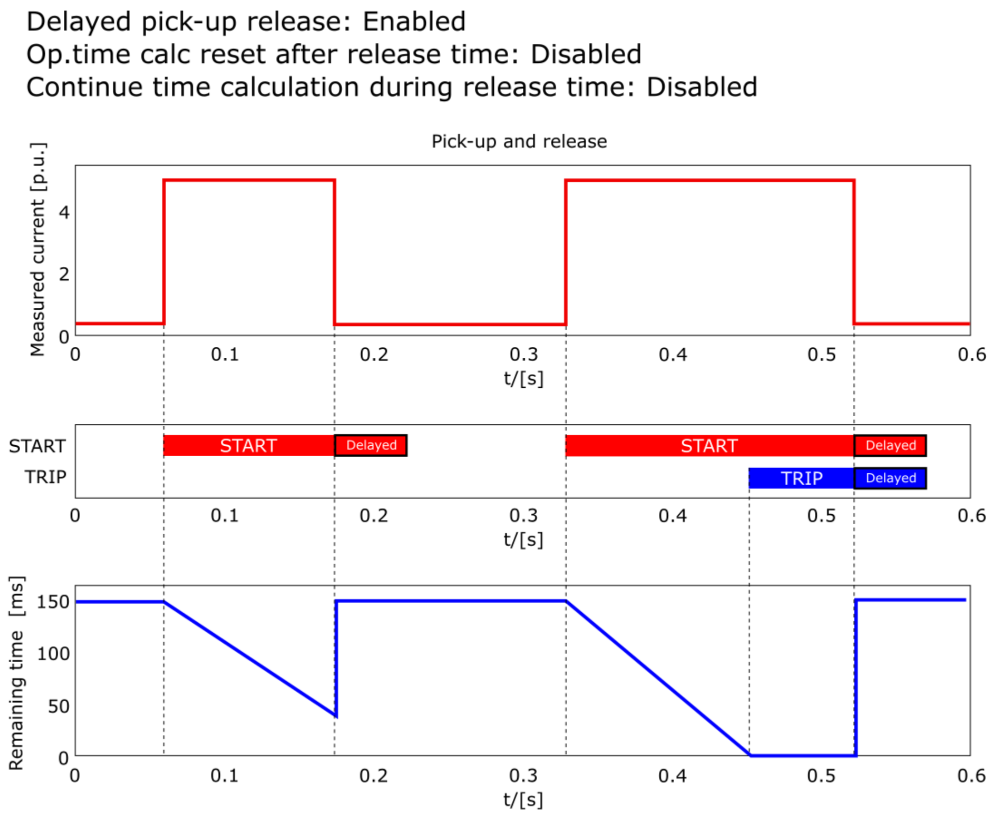


Figure. 4.4.1 - 71. Delayed pick-up release, delay counter value is held during the release time.

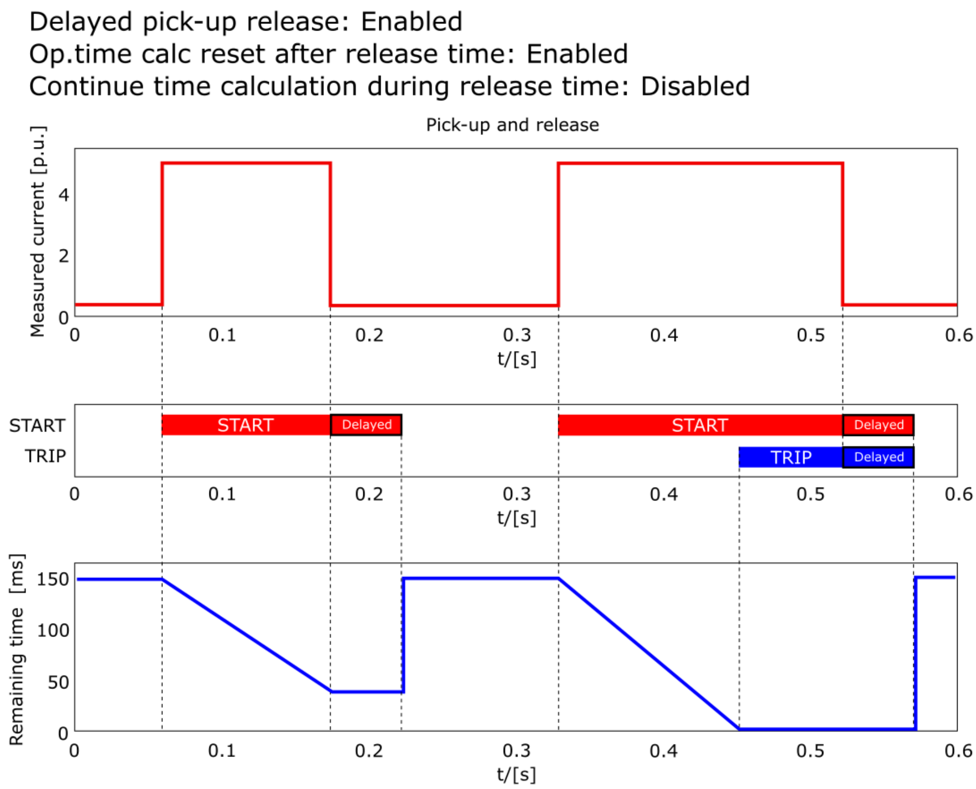
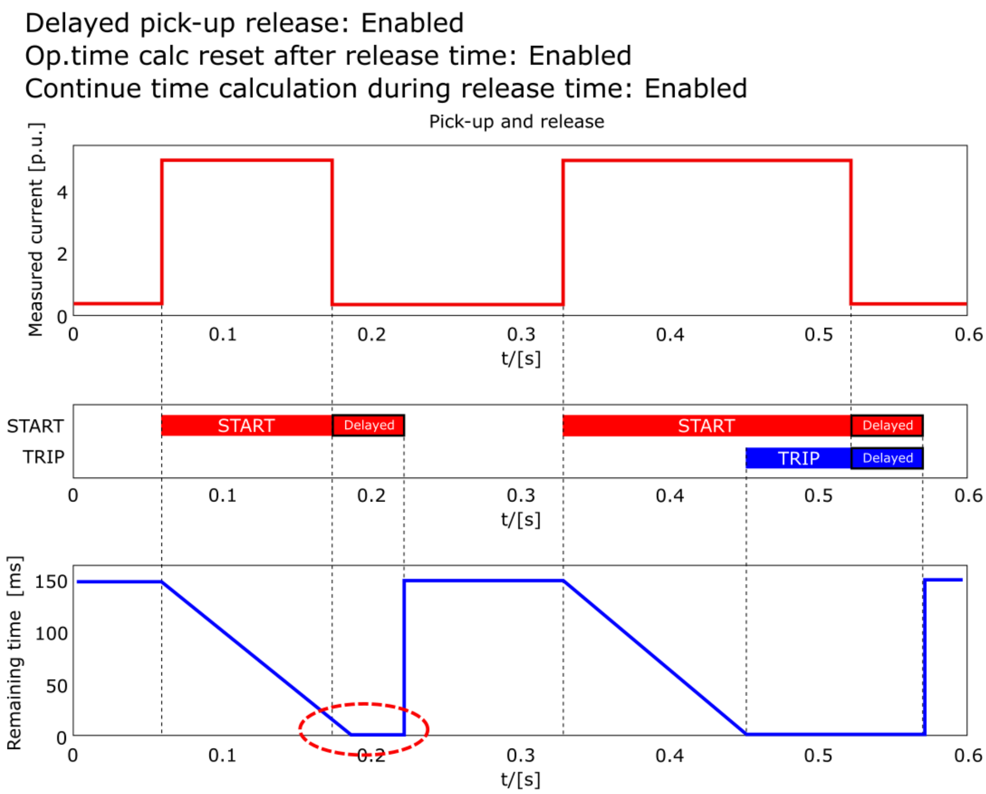


Figure. 4.4.1 - 72. Delayed pick-up release, delay counter value is decreasing during the release time.



Stage forcing

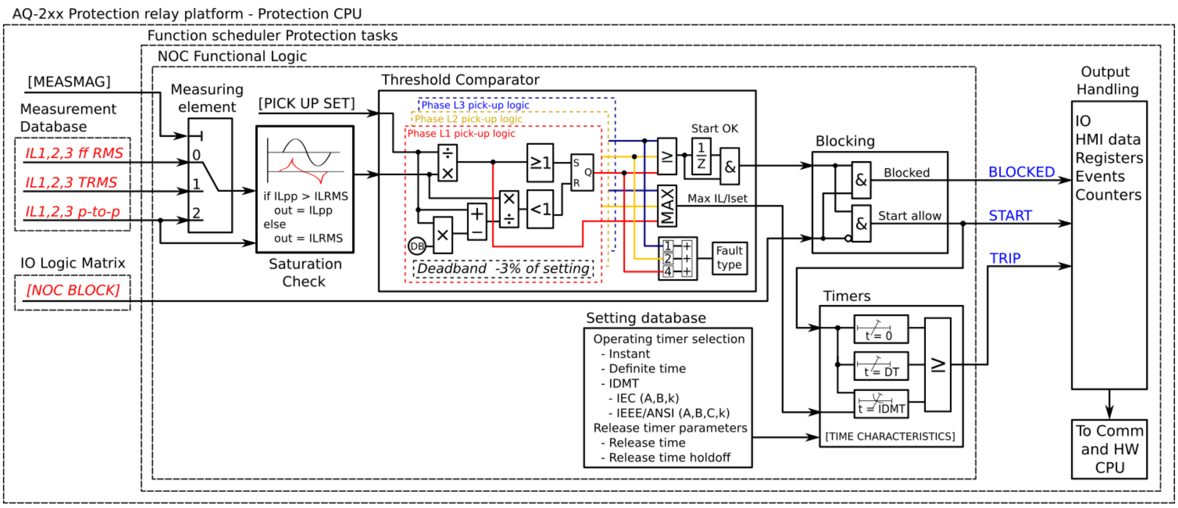
It is possible to test the logic, event processing and the operation of the device's logic by controlling the state of the protection functions manually without injecting any current into the device with stage forcing. To enable *Stage forcing* set the *Enable stage forcing* to ENABLED in the *General* 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.

> NOTICE!
> 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.

4.4.2 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 device model. The function offers three (3) independent stages. The operating characteristics are based on phase current magnitudes which the function constantly measures.

Figure. 4.4.2 - 73. Simplified function block diagram of the I> function.



Measured input

The function block uses phase current measurement values. The user can select the monitored magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

Table. 4.4.2 - 32. Measurement inputs of the I> function.

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement
I_{L1}TRMS	TRMS measurement of phase L1 (A) current

Signal	Description
I_{L2}TRMS	TRMS measurement of phase L2 (B) current
I_{L3}TRMS	TRMS measurement of phase L3 (C) current
I_{L1}PP	Peak-to-peak measurement of phase L1 (A) current
I_{L2}PP	Peak-to-peak measurement of phase L2 (B) current
I_{L3}PP	Peak-to-peak measurement of phase L3 (C) current

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. 4.4.2 - 33. General settings of the function.

Name	Range	Default	Description
Setting control from comm bus	• Disabled • Allowed	Disabled	Activating this parameter allows changing the pick-up level of the protection stage via SCADA.
I> force status to	• Normal • Start • Trip • Blocked • Start A • Start B • Start C • Trip A • Trip B • Trip C • Start AB • Start BC • Start CA • Start ABC • Trip AB • Trip BC • Trip CA • Trip ABC	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• RMS • TRMS • Peak-to-peak	RMS	Defines which available measured magnitude is used by the function.

Pick-up settings

The I_{set} setting parameter controls the 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. When the I_m exceeds the I_{set} value (in single, dual or all phases) it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.2 - 34. Pick-up settings.

Name	Range	Step	Default	Description
I_{set}	0.10…50.00×I_n	0.01×I_n	1.20×I_n	Defines the pick-up setting of the function.

Read-only parameters

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

Table. 4.4.2 - 35. Information displayed by the function.

Name	Range	Step	Description
I> condition	• Normal • Start • Trip • Blocked	-	Displays status of the protection function.
I> phases condition	• Normal • Start A • Start B • Start C • Trip A • Trip B • Trip C • Start AB • Start BC • Start CA • Start ABC • Trip AB • Trip BC • Trip CA • Trip ABC	-	Displays the status of phases individually.
Expected operating time	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured highest phase current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
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 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. 4.4.2 - 36. Internal inrush harmonic blocking settings.

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

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

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".

Events and registers

The non-directional overcurrent function (abbreviated "NOC" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and for user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

Table. 4.4.2 - 37. Event messages.

Event block name	Event names
NOC1...NOC3	Start ON
NOC1...NOC3	Start OFF
NOC1...NOC3	Trip ON
NOC1...NOC3	Trip OFF
NOC1...NOC3	Block ON

Event block name	Event names
NOC1...NOC3	Block OFF
NOC1...NOC3	Phase A Start ON
NOC1...NOC3	Phase A Start OFF
NOC1...NOC3	Phase B Start ON
NOC1...NOC3	Phase B Start OFF
NOC1...NOC3	Phase C Start ON
NOC1...NOC3	Phase C Start OFF
NOC1...NOC3	Phase A Trip ON
NOC1...NOC3	Phase A Trip OFF
NOC1...NOC3	Phase B Trip ON
NOC1...NOC3	Phase B Trip OFF
NOC1...NOC3	Phase C Trip ON
NOC1...NOC3	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.

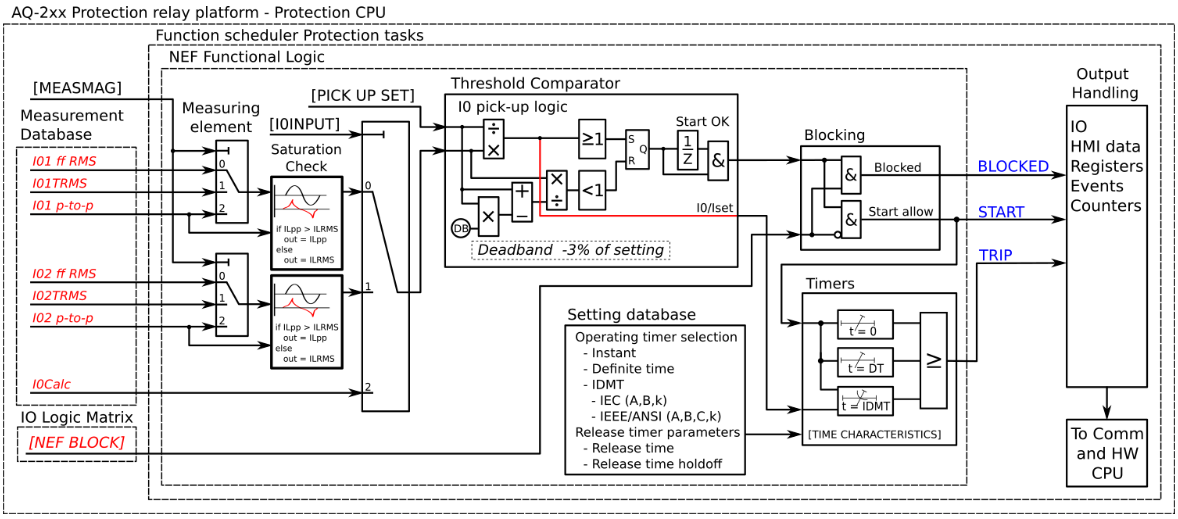
Table. 4.4.2 - 38. Register content.

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

4.4.3 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 decisions are based on the selected neutral current magnitude which the function constantly measures.

Figure. 4.4.3 - 74. Simplified function block diagram of the I0> function.



Measured input

The function block residual current measurement values. The available analog measurement channels are I_{01} and I_{02} (residual current measurement) and I_{0Calc} (residual current calculated from phase current). The user can select the monitored magnitude to be equal either to RMS values (fundamental frequency component), to TRMS values from the whole harmonic specter of 32 components, or to peak-to-peak values.

Table. 4.4.3 - 39. Measurement inputs of the I0> function.

Signal	Description
I_{01}RMS	Fundamental frequency component of coarse residual current measurement input I01
I_{01}TRMS	TRMS measurement of coarse residual current measurement input I01
I_{01}PP	Peak-to-peak measurement of coarse residual current measurement input I01
I_{02}RMS	Fundamental frequency component of sensitive residual current measurement input I02
I_{02}TRMS	TRMS measurement of coarse sensitive current measurement input I02
I_{02}PP	Peak-to-peak measurement of sensitive residual current measurement input I02
I_{0Calc}	Fundamental frequency component of the zero sequence current calculated from the three phase currents

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. 4.4.3 - 40. General settings of the function.

Name	Range	Default	Description
Setting control from comm bus	• Disabled • Allowed	Default	Activating this parameter permits changing the pick-up level of the protection stage via SCADA.
I0> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• RMS • TRMS • Peak-to-peak	RMS	Defines which available measured magnitude is used by the function. This parameter is available when "Input selection" has been set to "I01" or "I02".
Input selection	• I01 • I02 • I0Calc	I01	Defines which measured residual current is used by the function.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.3 - 41. Pick-up settings.

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

Read-only parameters

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

Table. 4.4.3 - 42. Information displayed by the function.

Name	Range	Step	Description
I0> condition	• Normal • Start • Trip • Blocked	-	Displays status of the protection function.

Name	Range	Step	Description
Detected I0 angle	-360.00...360.00deg	0.01deg	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	• - • A-G-R • B-G-F • C-G-R • A-G-F • B-G-R • 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	0.000...1800.000s	0.005s	Displays the expected operating time when a fault occurs. When IDMT mode is used, the expected operating time depends on the measured current value. If the measured current changes during a fault, the expected operating time changes accordingly.
Time remaining to trip	-1800.000...1800.000s	0.005s	When the function has detected a fault and counts down time towards a trip, this displays how much time is left before tripping occurs.
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, the 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. 4.4.3 - 43. Internal inrush harmonic blocking settings.

Name	Range	Step	Default	Description
Inrush harmonic blocking (internal-only trip)	• No • Yes	-	No	Enables and disables the 2nd harmonic blocking.
2nd harmonic block limit (Iharm/Ifund)	0.10…50.00%I_{fund}	0.01%I_{fund}	0.01%I_{fund}	The 2nd harmonic blocking limit.

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 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".

Events and registers

The non-directional earth fault function (abbreviated "NEF" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers three (3) independent stages; the events are segregated for each stage operation.

Table. 4.4.3 - 44. Event messages.

Event block name	Event names
NEF1...NEF3	Start ON
NEF1...NEF3	Start OFF
NEF1...NEF3	Trip ON
NEF1...NEF3	Trip OFF
NEF1...NEF3	Block ON
NEF1...NEF3	Block OFF

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

Table. 4.4.3 - 45. Register content.

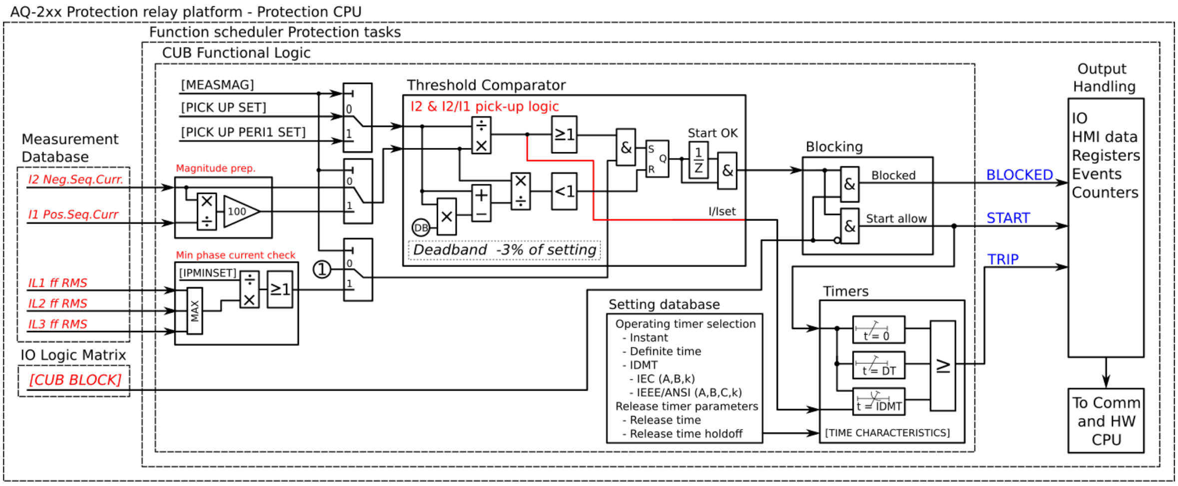
Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	A-G-R…C-G-F
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Trip time remaining	0 ms...1800s
Setting group in use	Setting group 1...8 active.

4.4.4 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 function 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.

Figure. 4.4.4 - 75. Simplified function block diagram of the CUB function.



Measured input

The function block uses positive and negative sequence currents calculated from the phase current measurement channels. In the broken conductor mode (I2/I1) the function also uses fundamental frequency component 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.

Table. 4.4.4 - 46. Measurement inputs of the I2> function.

Signal	Description
I1	Positive sequence current magnitude
I2	Negative sequence current magnitude
IZ	Zero sequence current magnitude
I1 ANG	Positive sequence current angle
I2 ANG	Negative sequence current angle
IZ ANG	Zero sequence current angle

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement

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.

Name	Range	Default	Description
I2> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Measured magnitude	• I2pu • I2/I1	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 settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.4 - 47. Pick-up settings.

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

Read-only parameters

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

Table. 4.4.4 - 48. Information displayed by the function.

Name	Range	Description
I2> condition	• Normal • Start • Trip • 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 variables the user can set are binary signals from the system. The blocking signal needs to reach the device minimum of 5 ms before the set operating delay has passed in order for the blocking to activate in time.

Operating time characteristics for trip and reset

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

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

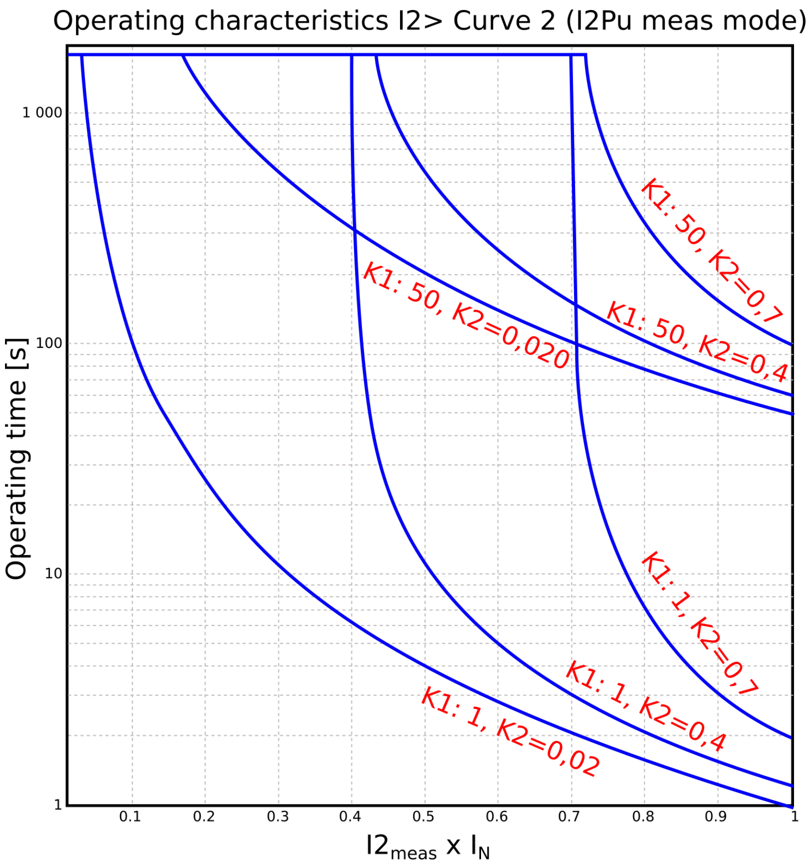
Both IEC and IEEE/ANSI standard characteristics as well as user settable parameters are available for the IDMT operation.

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

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

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

Figure. 4.4.4 - 76. 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" 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 the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers one (1) independent stage.

Table. 4.4.4 - 49. Event messages.

Event block name	Event names
CUB1	Start ON

Event block name	Event names
CUB1	Start OFF
CUB1	Trip ON
CUB1	Trip OFF
CUB1	Block ON
CUB1	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.

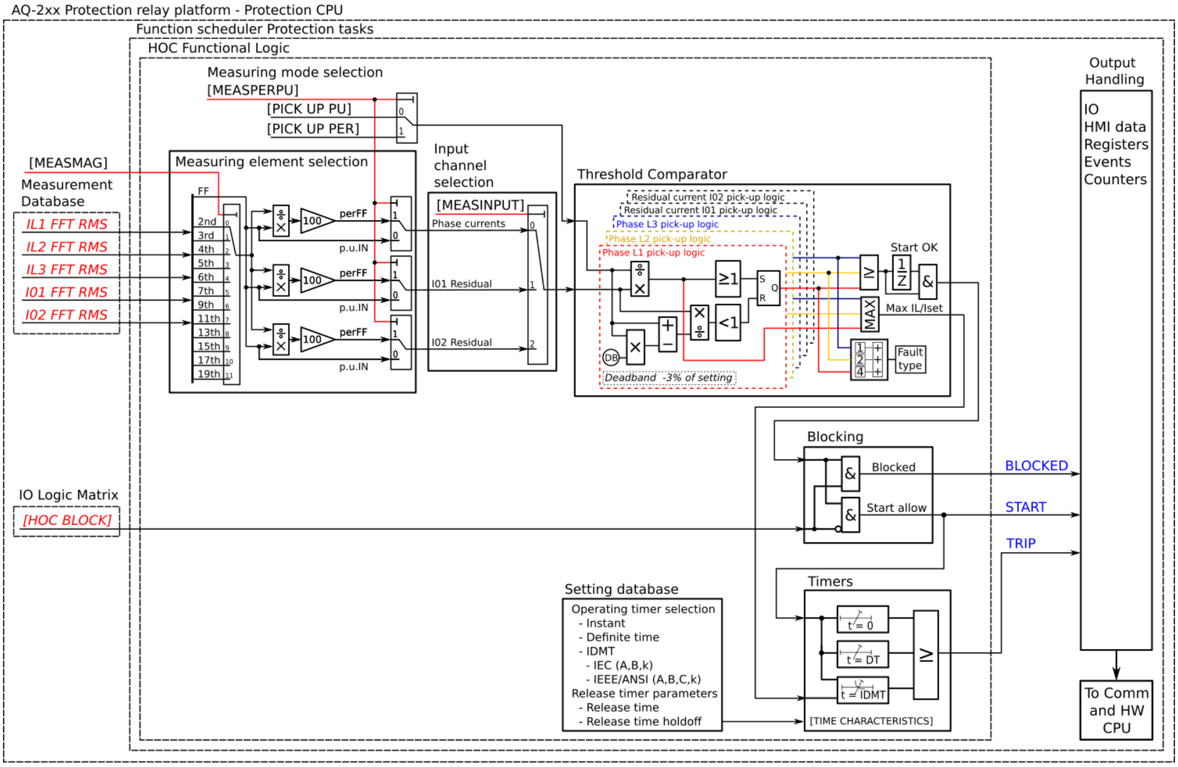
Table. 4.4.4 - 50. Register content.

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

4.4.5 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.

Figure. 4.4.5 - 77. 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 (fundamental frequency component) 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.

Table. 4.4.5 - 51. Measurement inputs of the Ih> function.

Signal	Description
I_{L1}FFT	The magnitudes (RMS) of phase L1 (A) current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.

Signal	Description
$I_{L2}FFT$	The magnitudes (RMS) of phase L2 (B) current components: - Fundamental - 2^{nd} harmonic - 3^{rd} harmonic - 4^{th} harmonic - 5^{th} harmonic - 6^{th} harmonic - 7^{th} harmonic - 9^{th} harmonic - 11^{th} harmonic - 13^{th} harmonic - 15^{th} harmonic - 17^{th} harmonic - 19^{th} harmonic.
$I_{L3}FFT$	The magnitudes (RMS) of phase L3 (C) current components: - Fundamental - 2^{nd} harmonic - 3^{rd} harmonic - 4^{th} harmonic - 5^{th} harmonic - 6^{th} harmonic - 7^{th} harmonic - 9^{th} harmonic - 11^{th} harmonic - 13^{th} harmonic - 15^{th} harmonic - 17^{th} harmonic - 19^{th} harmonic.
$I_{01}FFT$	The magnitudes (RMS) of residual $I0_1$ current components: - Fundamental - 2^{nd} harmonic - 3^{rd} harmonic - 4^{th} harmonic - 5^{th} harmonic - 6^{th} harmonic - 7^{th} harmonic - 9^{th} harmonic - 11^{th} harmonic - 13^{th} harmonic - 15^{th} harmonic - 17^{th} harmonic - 19^{th} harmonic.

Signal	Description
$I0_2$FFT	The magnitudes (RMS) of residual $I0_2$ current components: - Fundamental - 2nd harmonic - 3rd harmonic - 4th harmonic - 5th harmonic - 6th harmonic - 7th harmonic - 9th harmonic - 11th harmonic - 13th harmonic - 15th harmonic - 17th harmonic - 19th harmonic.

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. 4.4.5 - 52. Operating mode selection settings.

Name	Range	Default	Description
Ih> force status to	• Normal • Start • Trip • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Name	Range	Default	Description
Harmonic selection	• 2^{nd} harmonic • 3^{rd} harmonic • 4^{th} harmonic • 5^{th} harmonic • 6^{th} harmonic • 7^{th} harmonic • 9^{th} harmonic • 11^{th} harmonic • 13^{th} harmonic • 15^{th} harmonic • 17^{th} harmonic • 19^{th} harmonic	2^{nd} harmonic	Selects the monitored harmonic component.
Per unit or relative	• $\times I_n$ • Ih/IL	$\times I_n$	Selects the monitored harmonic mode. Either directly per unit $\times I_n$ or in relation to the fundamental frequency magnitude.
Measurement input	• IL1/IL2/IL3 • I01 • I02	IL1/IL2/IL3	Selects 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 settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.5 - 53. Pick-up settings.

Name	Range	Step	Default	Description
Ihset pu	0.05…2.00×I_n	0.01×I_n	0.20×I_n	Pick-up setting (per unit monitoring)
Ih/IL	5.00…200.00%	0.01%	20.00%	Pick-up setting (percentage monitoring)

Read-only parameters

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

Table. 4.4.5 - 54. Information displayed by the function.

Name	Range	Step	Description
Ih> condition	• Normal • Start • Trip • Blocked	-	Displays the status of the protection function.
Ih meas/ Ih set now	0.00...100000.00I_m/I_{set}	0.01I_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 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".

Events and registers

The harmonic overcurrent function (abbreviated "HOC" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. 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 function also provides a resettable cumulative counter for the START, TRIP and BLOCKED events.

The function offers one (1) independent stage.

Table. 4.4.5 - 55. 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

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. 4.4.5 - 56. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Fault type	L1-E…L1-L2-L3
Pre-trigger current	Start/Trip -20ms current
Fault current	Start/Trip current
Pre-fault current	Start -200ms current
Trip time remaining	0.000s ... 1800.000s

Register	Description
Setting group in use	Setting group 1...8 active

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

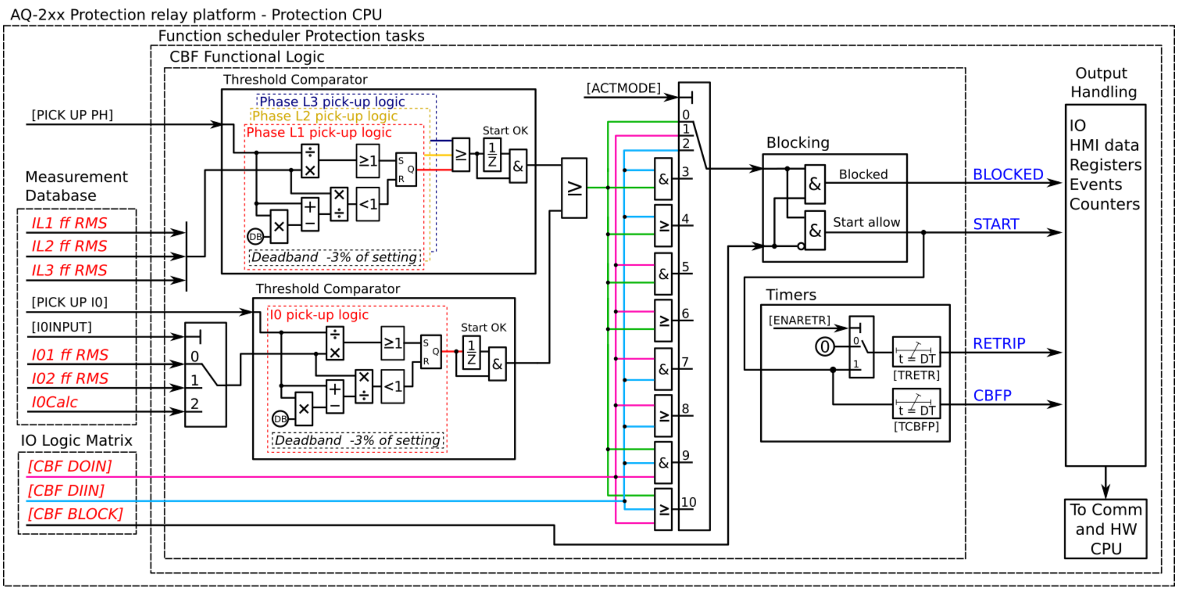
The circuit breaker failure protection function is used for monitoring the circuit breaker operation after it has received a TRIP signal. The function can also be used to retrip a failing breaker; if the retrip fails, an incoming feeder circuit breaker can be tripped by using the function's CBFP output. 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.

Figure. 4.4.6 - 78. Simplified function block diagram of the CBFP function.



Measured input

The function block uses fundamental frequency component of phase current and residual current measurement values. The user can select I01, I02 or the calculated I0 for the residual current measurement.

Table. 4.4.6 - 57. Measurement inputs of the CBFP function.

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current measurement

Signal	Description
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current measurement
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current measurement
I_{01}RMS	Fundamental frequency component of residual input I_{01} measurement
I_{02}RMS	Fundamental frequency component of residual input I_{02} measurement
I_{0Calc}	Calculated residual current from the phase current inputs

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. 4.4.6 - 58. 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. 4.4.6 - 59. General settings of the function.

Name	Range	Default	Description
CBFP force status to	• Normal • Start • ReTrip • CBFP • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.6 - 60. Operating mode and input signals selection.

Name	Range	Step	Default	Description
I0Input	• Not in use • I01 • I02 • I0Calc	-	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.
Actmode	• Current only • DO only • Signals only • Current and DO • Current or DO • Current and signals • Current or signals • Signals and DO • Signals or DO • Current or DO or signals • Current and DO and Signals	-	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. 4.4.6 - 61. 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.

Read-only parameters

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

Table. 4.4.6 - 62. Information displayed by the function.

Name	Range	Description
CBFP condition	• Normal • Start • ReTrip • CBFP On • 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 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.

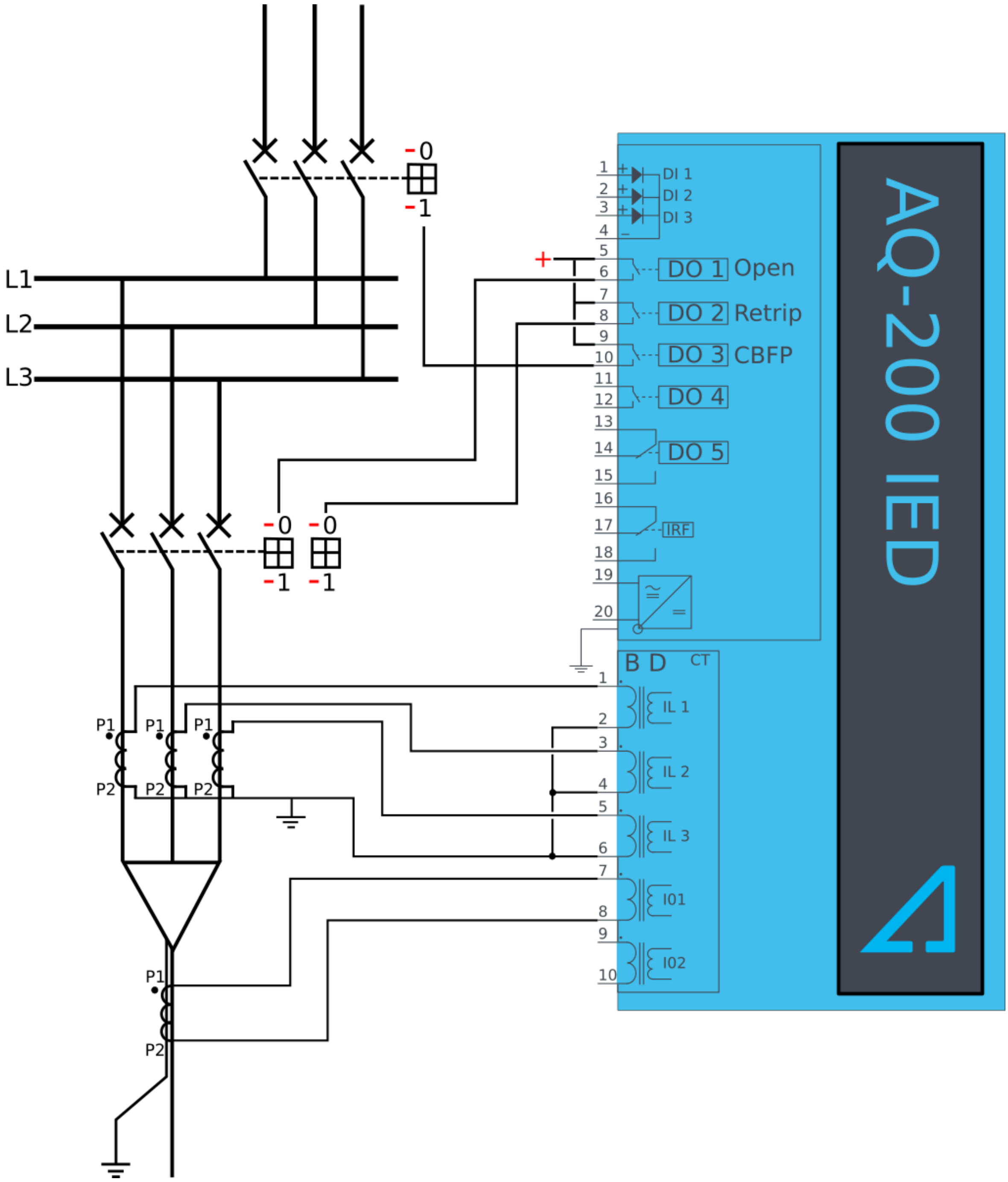
Table. 4.4.6 - 63. Setting parameters for operating time characteristics.

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

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

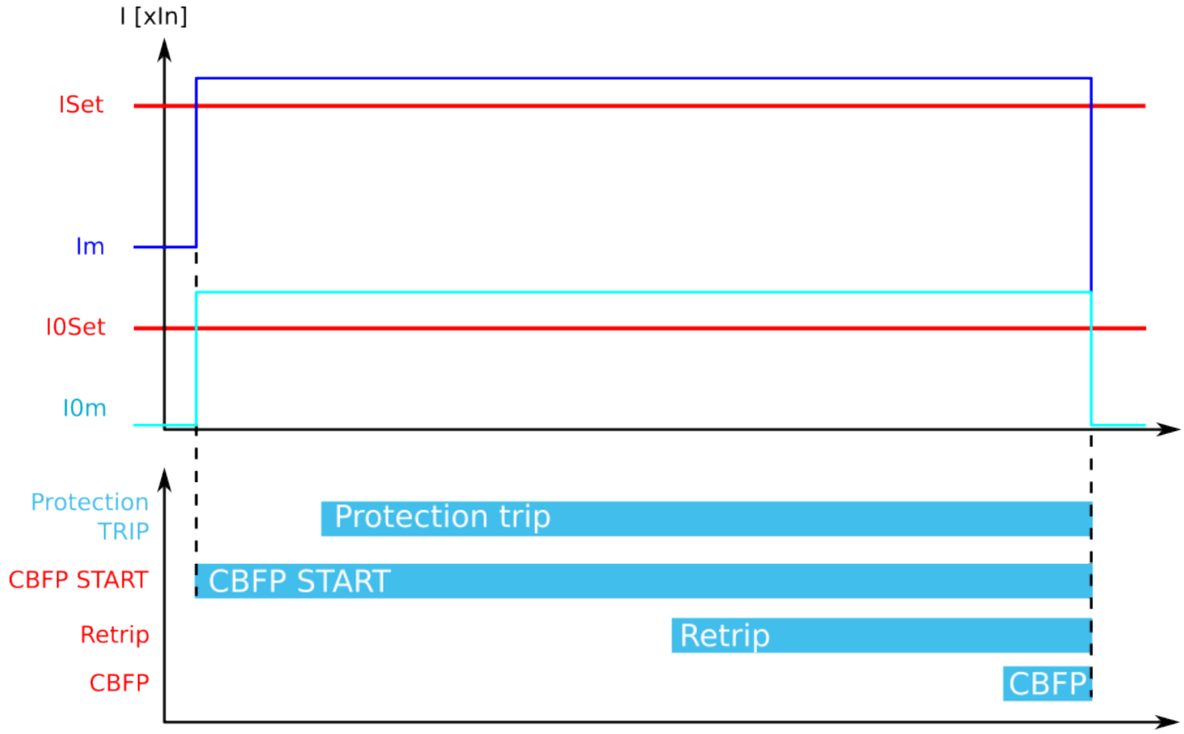
Trip, Retrip and CBFP in the device configuration

Figure. 4.4.6 - 79. Wiring diagram when Trip, Retrip and CBFP are configured to the device.



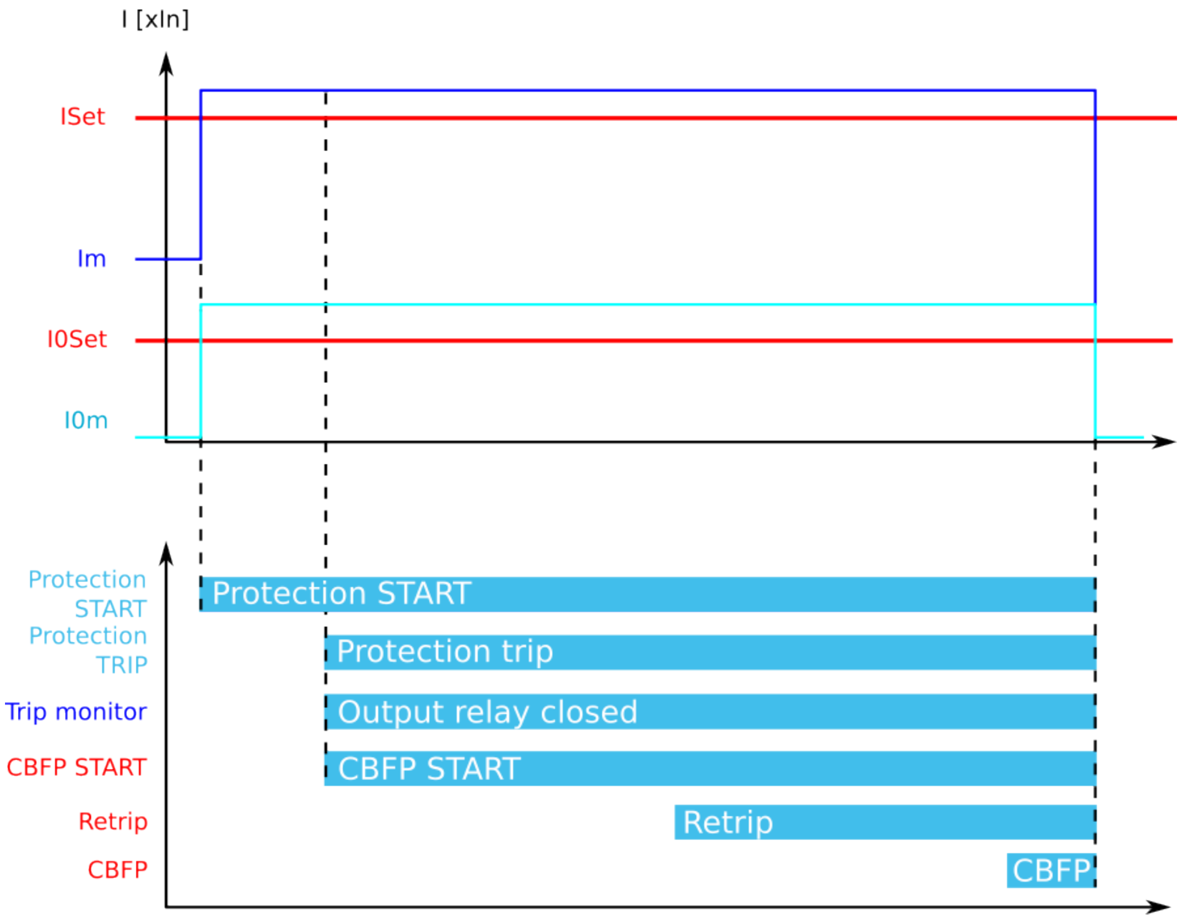
The retrip functionality can be used in applications whose circuit breaker has a retrip or a redundant trip coil available. The TRIP signal is normally wired to the breaker's trip coil from the device's trip output. The retrip is wired from its own device output contact in parallel with the circuit breaker's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

Figure. 4.4.6 - 80. Retrip and CBFP when "Current" is the selected criterion.



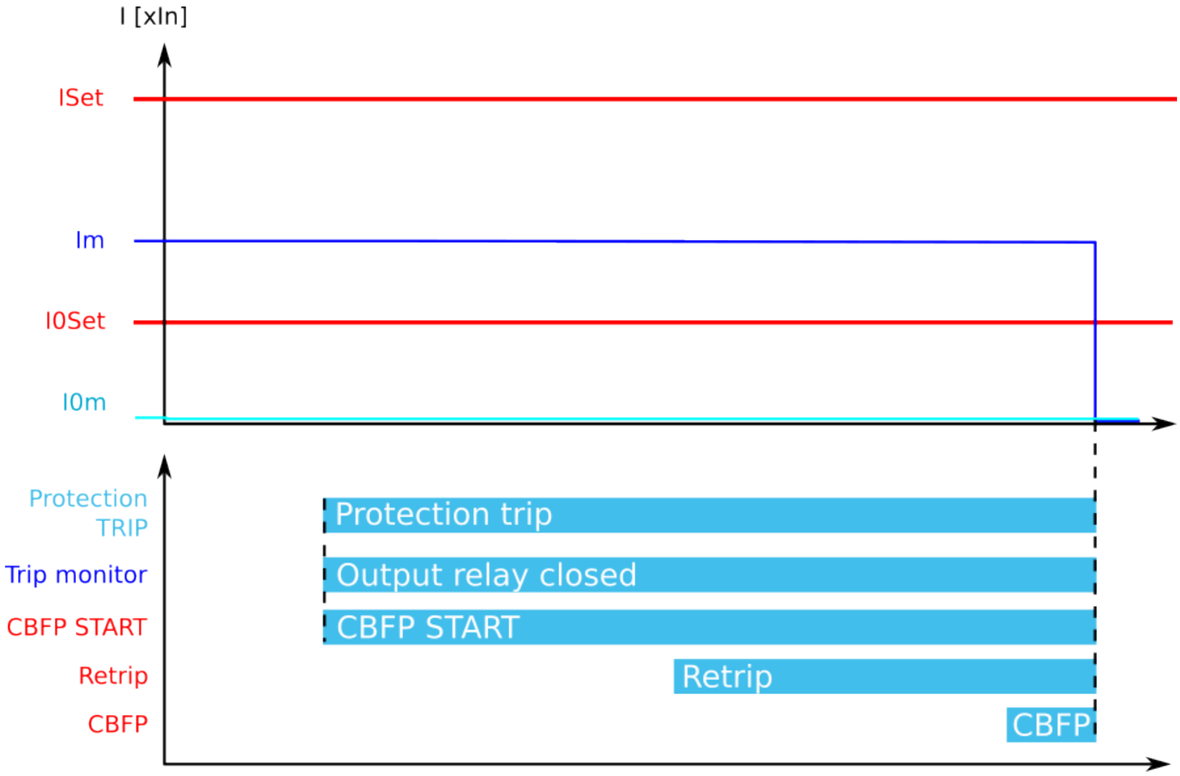
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counters for RETRIP and CBFP start calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the 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 incoming feeder breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings.

Figure. 4.4.6 - 81. 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 incoming feeder circuit 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.

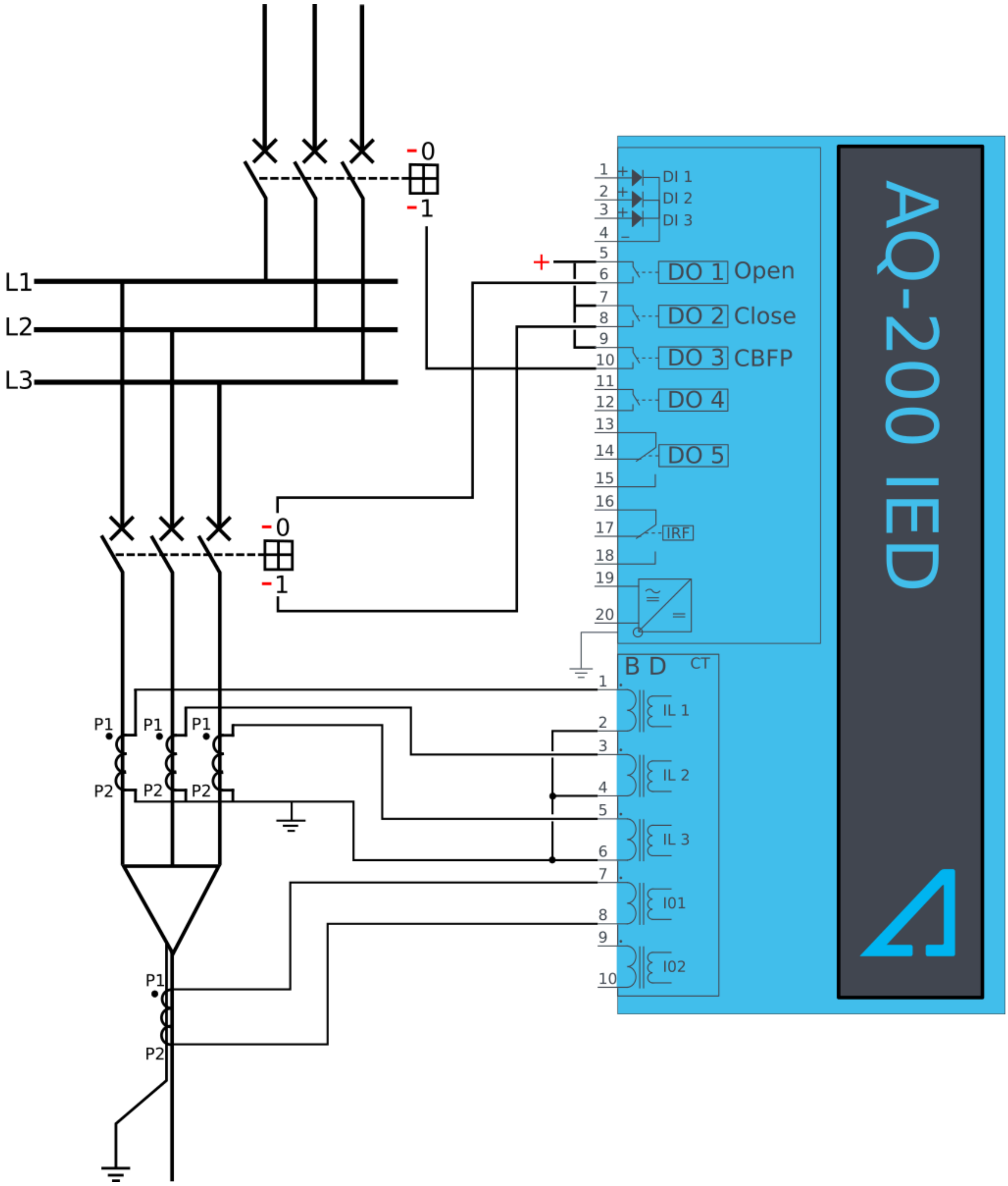
Figure. 4.4.6 - 82. Retrip and CBFP when "Current or DO" is the selected criterion.



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 incoming feeder circuit breaker. If the primary protection function clears the fault, both counters (RETRIP and CBFP) are reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled with current-based functions alone, with added security from current monitoring. Other function trips can also be included in the CBFP functionality.

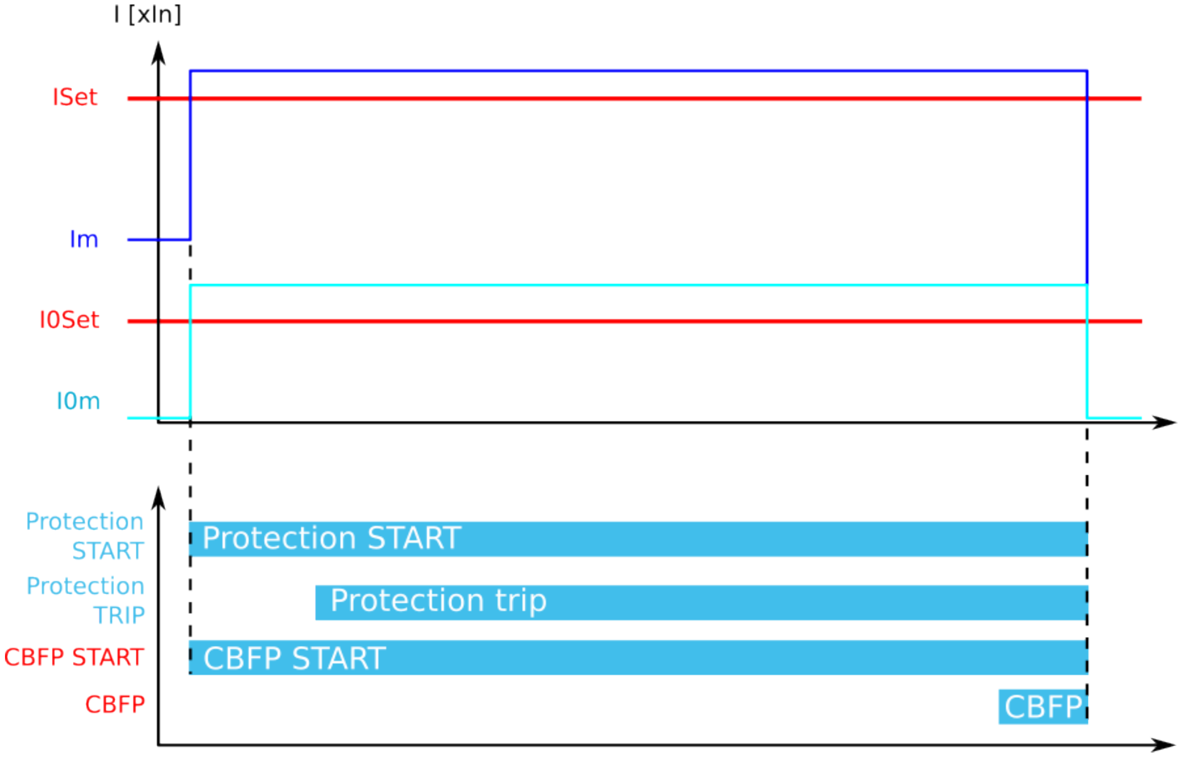
Trip and CBFP in the device configuration

Figure. 4.4.6 - 83. Wiring diagram when Trip and CBFP are configured to the device.



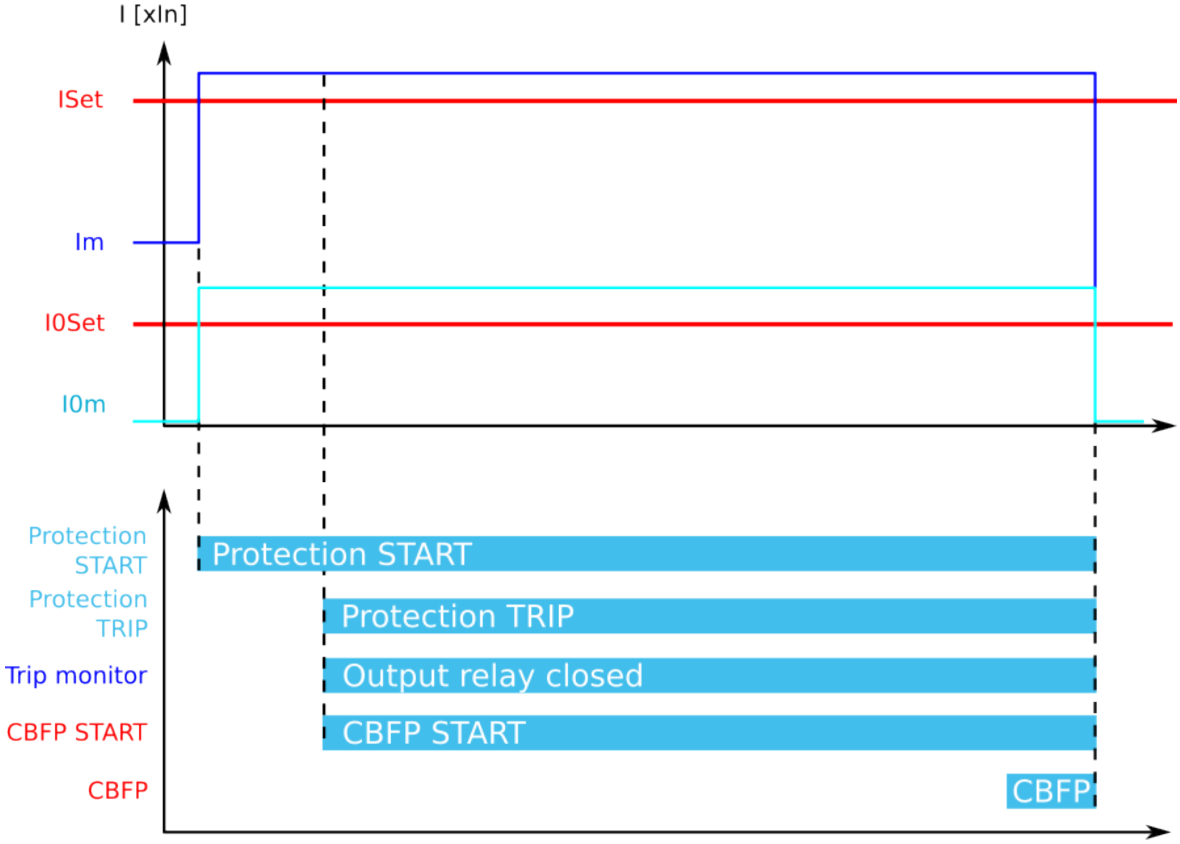
Probably the most common application is when the device's trip output controls the circuit breaker trip coil, while one dedicated CBFP contact controls the CBFP function. Below are a few operational cases regarding the various applications and settings of the CBFP function.

Figure. 4.4.6 - 84. CBFP when "Current" is the selected criterion.



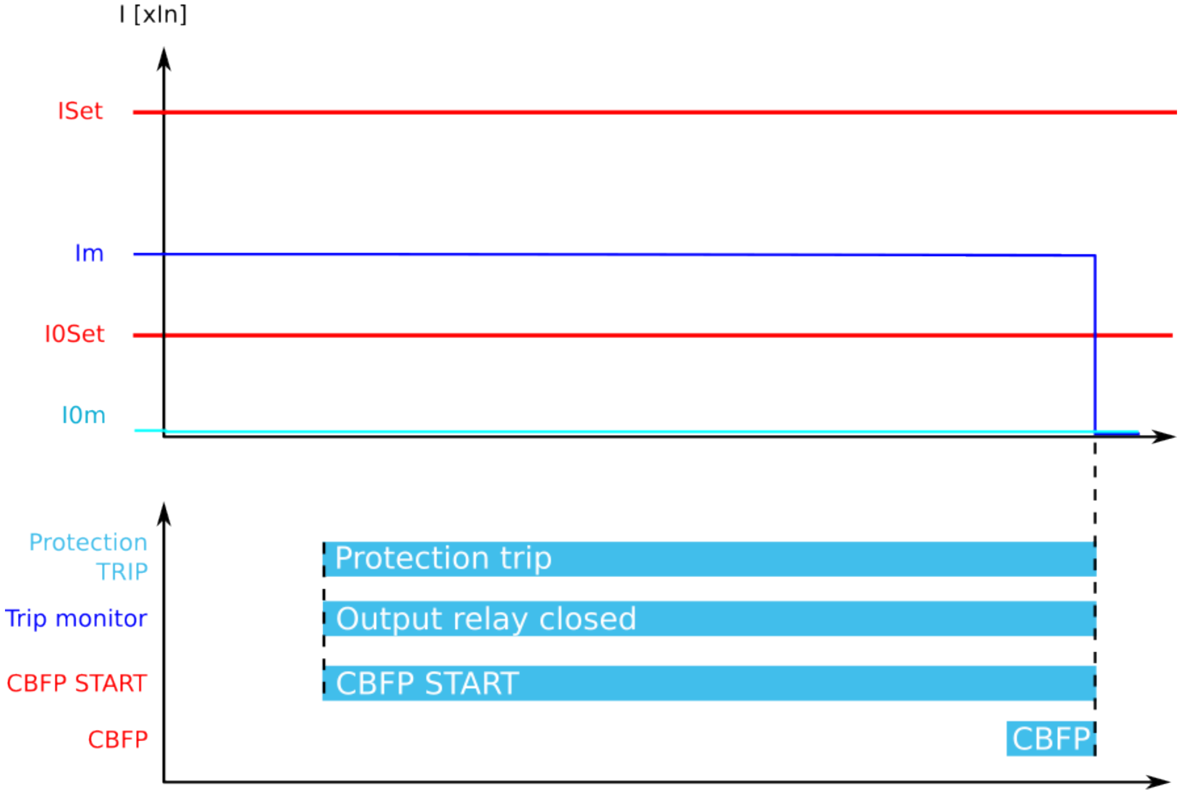
When the current threshold setting of I_{set} and/or $I0_{set}$ is exceeded, the current-based protection is activated and the counter for CBFP starts calculating the set operating time. The tripping of the primary protection stage is not monitored in this configuration. Therefore, if the current is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

Figure. 4.4.6 - 85. 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 incoming feeder circuit 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.

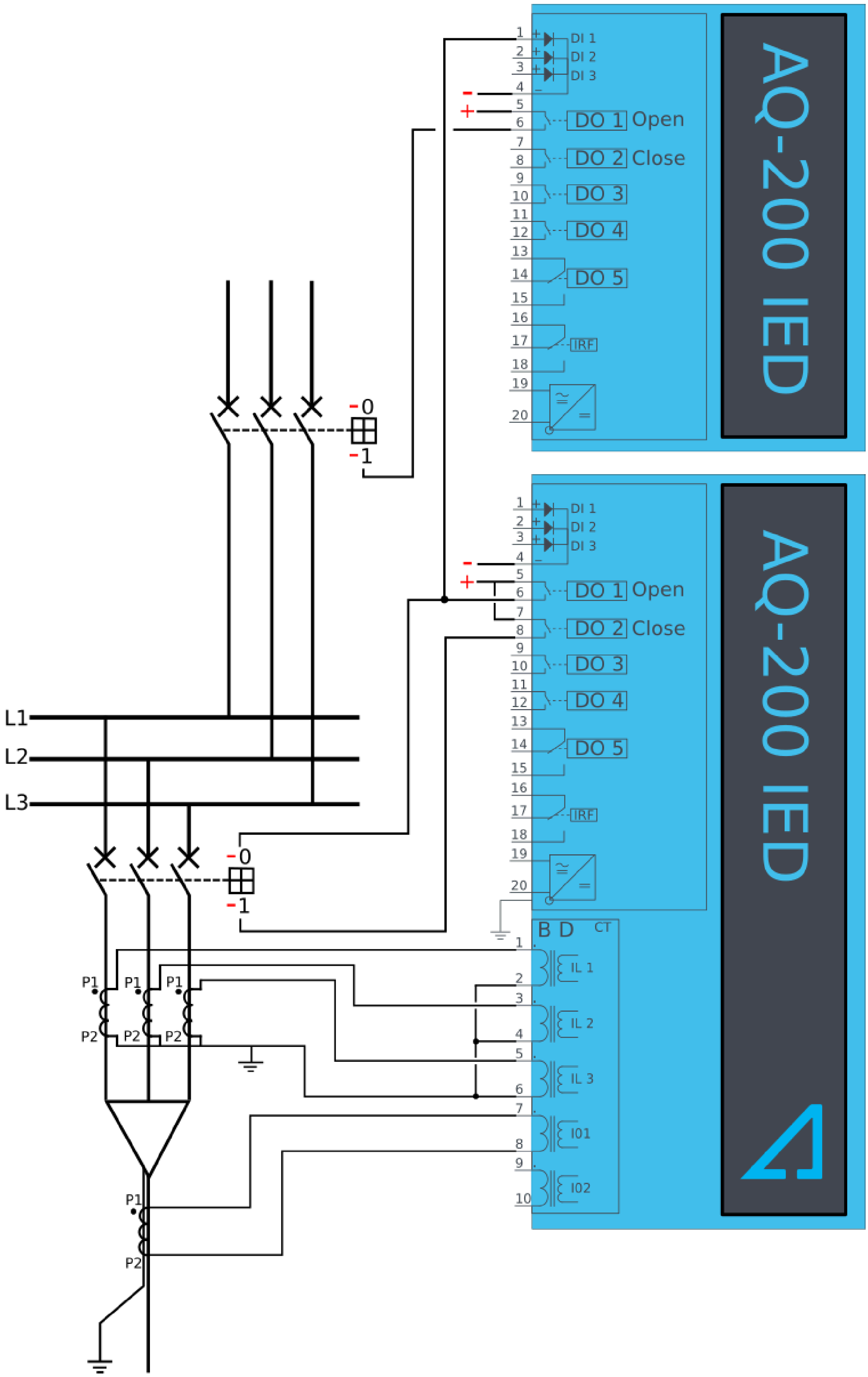
Figure. 4.4.6 - 86. CBFP when "Current or DO" is the selected criterion.



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 incoming feeder circuit breaker. The time delay counter for CBFP is reset as soon as the measured current is below the threshold settings and the tripping signal is reset. This configuration allows the CBFP to be controlled by current-based functions alone, with added security from current monitoring. Other function trips can also be included to the CBFP functionality.

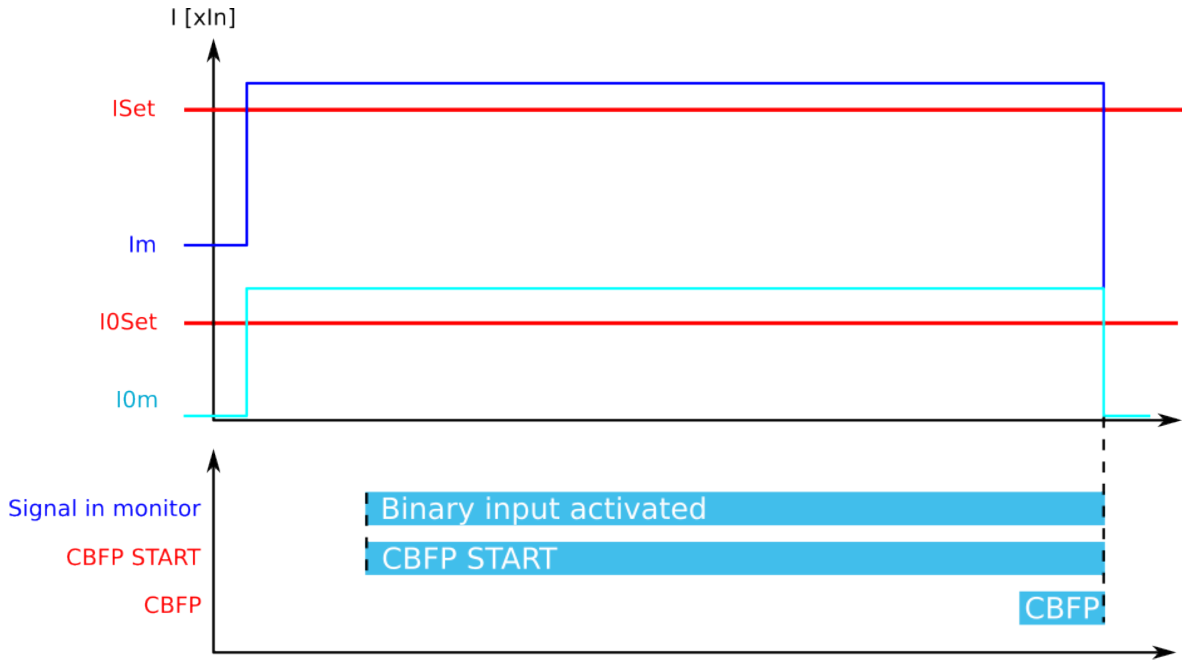
Device configuration as a dedicated CBFP unit

Figure. 4.4.6 - 87. 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 incoming feeder 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 incoming feeder. The following example does not use retripping and the CBFP signal is used as the incoming feeder trip from the outgoing breaker trip signal. The TRIP signal can also be transported between different devices by using GOOSE messages.

Figure. 4.4.6 - 88. 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 incoming feeder circuit 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 the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counters for RETRIP, CBFP, CBFP START and BLOCKED events.

Table. 4.4.6 - 64. Event messages.

Event block name	Event names
CBF1	Start ON
CBF1	Start OFF

Event block name	Event names
CBF1	Retrip ON
CBF1	Retrip OFF
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. 4.4.6 - 65. Register content.

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

4.4.7 Line thermal overload protection (TF>; 49F)

The line thermal overload function is used for the thermal capacity monitoring and protection of cables and overhead lines. This function can also be used for any single time constant application like inductor chokes, certain types of transformers and any other static units which do not have active cooling apart from the cables and overhead lines.

The function constantly monitors the instant values of phase TRMS currents (including harmonics up to 31st) and calculates the set thermal replica status in 5 ms cycles. The function includes a total memory function of the load current conditions according to IEC 60255-8.

The function is based on a thermal replica which represents the protected object's or cable's thermal loading in relation to the current going through the object. The thermal replica includes the calculated thermal capacity that the "memory" uses; it is an integral function which tells this function apart from a normal overcurrent function and its operating principle for overload protection applications.

The thermal image for the function is calculated according to the equation described below:

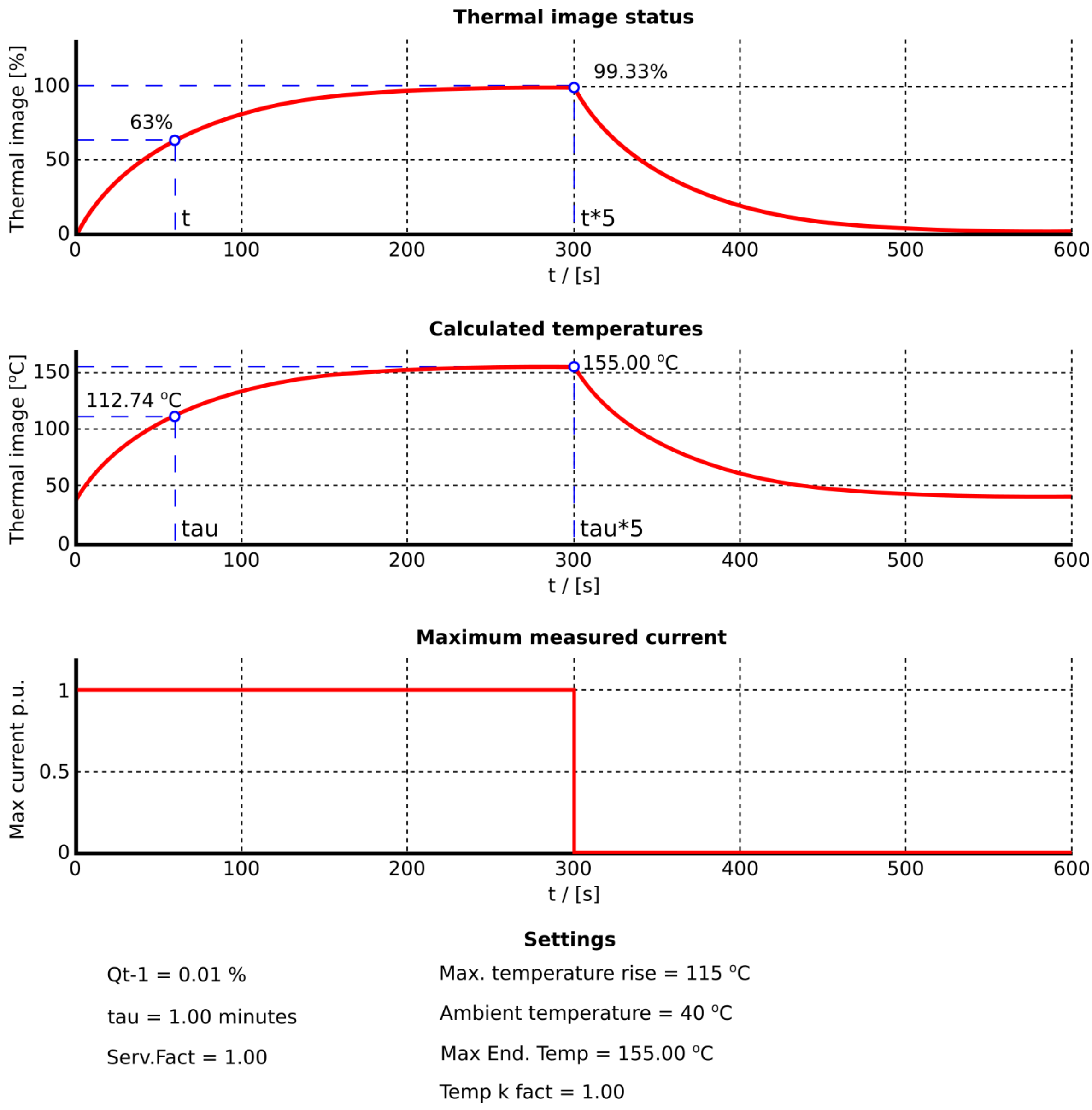
$$\theta_{t\%} = \left(\left(\theta_{t-1} - \left(\frac{I_{max}}{I_n \times k_{SF} \times k_{amb}}\right)^2 \times e^{-\frac{t}{\tau}}\right) + \left(\frac{I_{max}}{I_n \times k_{SF} \times k_{amb}}\right)^2\right) \times 100\%$$

Where:

- $\theta_{t\%}$ = Thermal image status in percentages of the maximum thermal capacity available
- θ_{t-1} = Thermal image status in a previous calculation cycle (the memory of the function)
- I_{max} = Measured maximum of the three TRMS phase currents
- I_n = Current for the 100 % thermal capacity to be used (the pick-up current in p.u., t_{max} achieved in τ x 5)
- k_{SF} = Loading factor (service factor), the maximum allowed load current in p.u., dependent on the protected object or the cable/line installation
- k_{amb} = Temperature correction factor, either from a linear approximation or from a settable ten-point thermal capacity curve
- e = Euler's number
- t = Calculation time step in seconds (0.005 s)
- τ = Thermal time constant of the protected object (in minutes)

The basic operating principle of the thermal replica is based on the nominal temperature rise, which is achieved when the protected object is loaded with a nominal load in a nominal ambient temperature. When the object is loaded with a nominal load for a time equal to its heating constant tau (τ), 63% of the nominal thermal capacity is used. When the loading continues until five times this given constant, the used thermal capacity approaches 100 % indefinitely but never exceeds it. With a single time constant model the cooling of the object follows this same behavior, the reverse of the heating when the current feeding is zero.

Figure. 4.4.7 - 89. Example of thermal image calculation with nominal conditions.



The described behavior is based on the assumption that the monitored object (whether a cable, a line or an electrical device) has a homogenous body which generates and dissipates heat with a rate proportional to the temperature rise caused by the current squared. This is usually the case with cables and other objects while the heat dissipation of overhead lines is dependent on the weather conditions. Weather conditions considering the prevailing conditions in the thermal replica are compensated with the ambient temperature coefficient which is constantly calculated and changing when using RTD sensor for the measurement. When the ambient temperature of the protected object is stable it can be set manually (e.g. underground cables).

The ambient temperature compensation takes into account the set minimum and maximum temperatures and the load capacity of the protected object as well as the measured or set ambient temperature. The calculated coefficient is a linear correction factor, as the following formula shows:

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

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

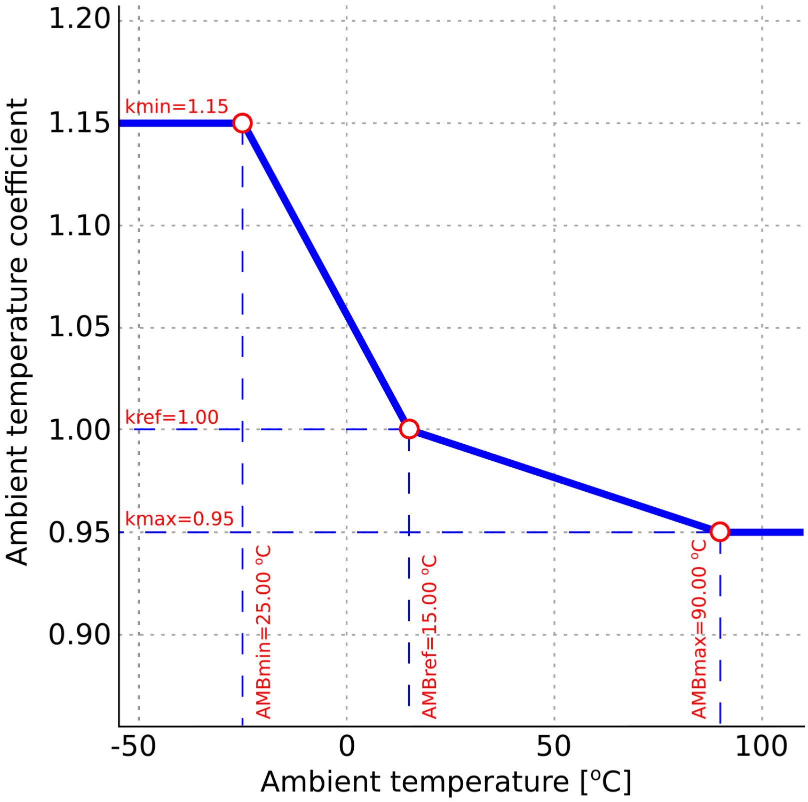
$$t_{amb} > t_{ref} = \left(\frac{k_{max} - 1}{t_{max} - t_{ref}} \times (t_{amb} - t_{ref})\right) + 1.0$$

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

Where:

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

Figure. 4.4.7 - 90. Ambient temperature coefficient calculation (a three-point linear approximation and a settable correction curve).



As can be seen in the diagram above, the ambient temperature coefficient is relative to the nominal temperature reference. By default the temperature reference is +15 °C (underground cables) which gives the correction factor value of 1.00 for the thermal replica.

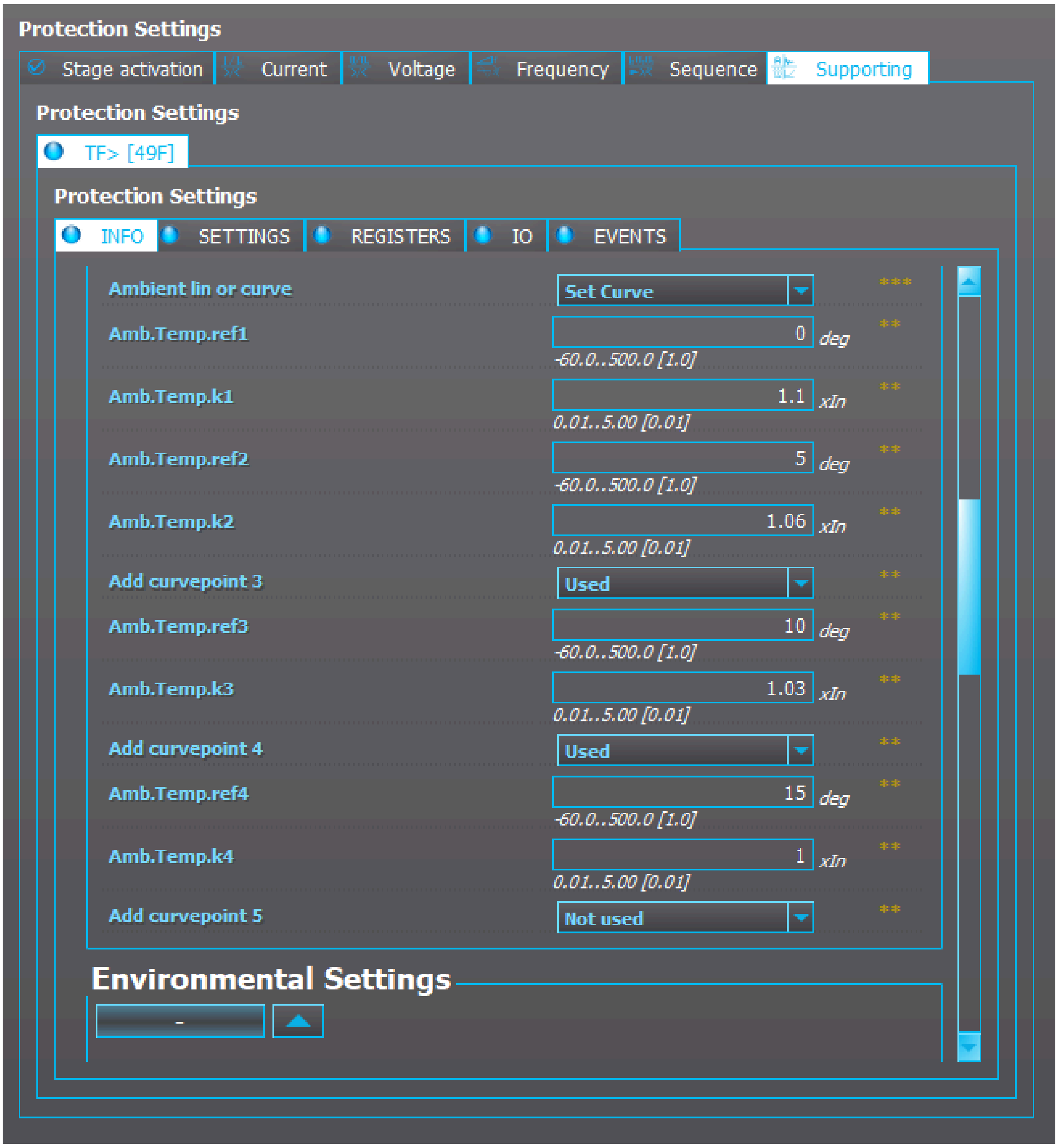
A settable thermal capacity curve uses the linear interpolation for ambient temperature correction with a maximum of ten (10) pairs of temperature–correction factor pairs.

Figure. 4.4.7 - 91. Example of the relationship between ground temperature and correction factor.

Conductor temperature	Ground temperature, C°										
C°	-5	0	5	10	15	20	25	30	35	40	45
90	1.13	1.10	1.06	1.03	1.00	0.96	0.93	0.89	0.86	0.82	0.77

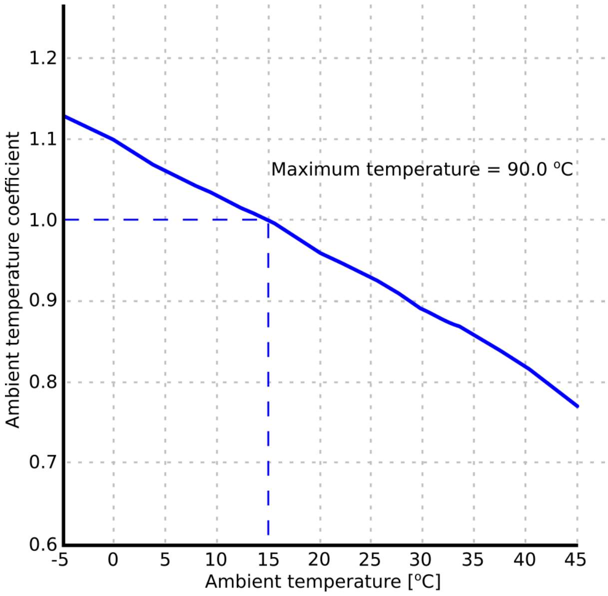
The temperature coefficient may be informed in a similar manner to the figure above in a datasheet provided by the manufacturer.

Figure. 4.4.7 - 92. Settings of the function's ambient temperature coefficient curve.



The temperature and correction factor pairs are set to the function's settable curve.

Figure. 4.4.7 - 93. Set correction curve for ambient temperature.



The correction curve for ambient temperature is shown in the figure above. The reference temperature for underground cables is usually +15 ˚C which gives a correction factor of 1.00 (in this case also the nominal temerature). The curve does not need to use as all the available points. The minimum setting is two pairs, resulting in a straight line.

For cables the ambient temperature correction is just one correction factor. The k_{SF} correction factor is used for non-changing corrections; its calculation is explained later in this manual. Calculating correction factors for a cable or overhead installation requires the consulting of the datasheet for the technical specifications of the used cable. This information is usually provided by the cable manufacturer. For example, cable data may be presented as in the figures below (an example from a Prysmian Group cable datasheet) which show the cable's temperature characteristics and voltage ratings (1st image) with different installations and copper or aluminum conductors (2nd and 3rd image).

Figure. 4.4.7 - 94. Example of a high-voltage cable datasheet.

Sample Constructions

72 kV Cables 36/66 kV Single core, XLPE-insulated high voltage power cables

Rated voltages
U_0/U = 38/66 kV
U_m = 72.5 kV
U_p = 325 kV
Rated temperatures
- Maximum permissible temp. of conductor in continuous use 90°C
- Maximum permissible temp. of conductor in short-circuit 250°C (for durations up to 5 sec.)

Standard IEC 60840

Nominal cross-sectional area of conductor	mm²	300	500	800	1200	1600

Continuous current-carrying capacities

Conductor	Cables laid	Conductor temperature	Laying formation	Screen circuit		300	500	800	1200	1600
Aluminium	In ground of 15°C	65°C	Flat	Open	A	435	575	750	910	1040
				Closed	A	415	525	640	710	750
			Trefoil	Open	A	415	545	700	830	930
				Closed	A	410	535	680	790	870
		90°C	Flat	Open	A	515	680	890	1080	1235
				Closed	A	490	625	770	860	920
			Trefoil	Open	A	490	645	830	990	1110
				Closed	A	485	635	805	945	1045
	In air of 25°C	90°C	Flat	Open	A	685	930	1265	1555	1815
				Closed	A	660	865	1105	1270	1390
			Trefoil	Open	A	605	820	1095	1335	1535
				Closed	A	600	810	1085	1320	1515
Copper	In ground of 15°C	65°C	Flat	Open	A	560	730	940	1200	1390
				Closed	A	520	635	740	820	855
			Trefoil	Open	A	535	685	860	1095	1240
				Closed	A	525	670	820	1005	1105
		90°C	Flat	Open	A	660	865	1115	1415	1645
				Closed	A	620	765	900	1005	1055
			Trefoil	Open	A	630	815	1025	1305	1485
				Closed	A	620	795	980	1205	1335
	In air of 25°C	90°C	Flat	Open	A	880	1185	1585	2040	2420
				Closed	A	830	1065	1305	1505	1620
			Trefoil	Open	A	775	1035	1355	1765	2065
				Closed	A	770	1025	1340	1685	1940

Maximum permissible short-circuit currents for short-circuit duration of one second

		300	500	800	1200	1600
Aluminium conductor	kA	28.3	47.2	75.6	113.4	151.2
Copper conductor	kA	42.8	71.4	114.2	171.4	228.5

The datasheet shows the currents which in a combination with a specific installation and a specific construction method achieve a specific conductor temperature in give standard conditions (e.g. a copper conductor reaches a temperature of 90 °C when, for example, it has a continuous current-carrying capacity of 815 A, an open screen circuit, and is laid in a trefoil formation in soil whose temperature is 15 °C).

The most important parameters for setting a working thermal image are the cable's current and the installation place. In addition to the above-mentioned current-carrying capacity table, the manufacturer should also provide data to allow for fine-tuning the thermal image. Equally important to the ampere–temperature values are the presumptive conditions under which the given continuous current-carrying capacity values can be expected to apply. The following figure is an example of these general presumption as presented in a Prysmian Group cable datasheet.

Figure. 4.4.7 - 95. General presumptions of high-voltage cables.

Continuous current-carrying capacity

A separate group of three single core cables can be continuously loaded according to the tables on pages 8 to 14 if the presumptions below are fulfilled. Correction factors for other installations are given in tables 1-7.
The current-carrying capacities are calculated in accordance with the IEC Publication 60287 and under the presumptions given below.

Presumptions

- One three-phase group of single core cables
- Maximum permissible temperature of inner conductor in continuous use:
- XLPE insulated cables 90°C
- Ambient air temperature 25°C
- Ground temperature 15°C
- Depth of laying of cables 1.0 m
- Distance between single core cables:
  - in case of flat formation = one cable diam.
  - in case of trefoil formation = cables touching each other
- Thermal resistivity of soil 1.0 K m/W
- Cable in air = heat dissipation conditions same as if cables in free air.
- Open screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other and earthed at one point only = screens bonded at a single point.
  In addition, screen circuit is considered open when cross-bonded at equal interval.
- Closed screen circuit in single core cable group = circuit of metal sheaths, concentric conductors or metallic screens connected to each other at both ends of the group and earthed at least at one end = screens bonded at both ends.

XLPE-insulated cables buried directly in ground

XLPE-insulated cables can continuously be loaded to a conductor temperature of 90°C.
In underground installations, if a cable in the ground is continuously operated at this highest rated conductor temperature, the thermal resistivity of the soil surrounding the cable may in the course of time increase from its original value as a result of the drying-out processes. As a consequence, the conductor temperature may greatly exceed the highest rated value.

Using single-point bonding or cross-bonding instead of both-end bonding results in considerable increase in current carrying capacity.

If the installation conditions vary from the presumed conditions manufacturers may give additional information on how to correct the the current-carrying capacity to match the changed conditions. Below is an example of the correction factors provided a manufacturer (Prysmian) for correcting the current-carrying capacity.

Figure. 4.4.7 - 96. Example of correction factors for the current-carrying capacity as given by a manufacturer.

Correction factors for the current-carrying capacity

The following tables of correction factors are to be applied to the current-carrying capacity when installation conditions vary from the presumptions above.

The rating for most conditions can be quickly estimated by multiplying the continuous current-carrying capacity value by the correction factors given in the appropriate tables 1-7.

Table 1. Correction factors for groups of cables buried directly in ground

Spacing between groups of cables, mm	Numbers of groups of single core cables beside each other: 2	3	4	5	6	8	10
0 (touching)	0.79	0.69	0.63	0.58	0.55	0.50	0.46
70	0.85	0.75	0.68	0.64	0.60	0.56	0.53
250	0.87	0.79	0.75	0.72	0.69	0.66	0.64

The values apply to groups of three single core cables (in trefoil or flat formation) without or with spacing between the cable groups horizontally placed.

Table 2. Correction factors for different thermal resistivities of soil

Thermal resistivity of soil Km/W	0.7	1.0	1.2	1.5	2.0	2.5	3.0
Correction factor	1.10	1.00	0.92	0.85	0.75	0.69	0.63

Examples of thermal resistivities of soil:

- dry sand (moisture content 0%) 3.0 K m/W
- dry gravel and clay 1.5 K m/W
- semi-dry gravel and sand (moisture content 10%) 1.2 K m/W
- semi-dry and moist gravel 1.0 K m/W
- moist clay and sand (moisture content 25%) 0.7 K m/W

Table 3. Correction factors for different installation depths in ground

Depth of laying, m	0.50-0.70	0.71-0.90	0.91-1.10	1.11-1.30	1.31-1.50
Rating factor	1.05	1.02	1.00	0.97	0.95

Table 4. Correction factors for different ground temperatures

Conductor temperature C°	Ground temperature, C°: -5	0	5	10	15	20	25	30	35	40	45
90	1.13	1.10	1.06	1.03	1.00	0.96	0.93	0.89	0.86	0.82	0.77
80	1.14	1.11	1.07	1.04	1.00	0.96	0.92	0.88	0.83	0.78	0.73
70	1.17	1.13	1.09	1.04	1.00	0.95	0.90	0.85	0.80	0.73	0.67
65	1.18	1.14	1.10	1.05	1.00	0.95	0.89	0.84	0.77	0.71	0.63

Table 5. Correction factors for different cables in unfilled plastic pipes

Spacing between the tubes, mm	Numbers of tubes beside each other: 1	2	3	4	5	6	8	10
0 (touching)	0.80	0.75	0.65	0.60	0.60	0.55	0.55	0.50
70		0.75	0.70	0.65	0.60	0.60	0.55	0.55
250		0.75	0.70	0.70	0.70	0.65	0.65	0.65

For parallel ducts with a group of three single core cables in each and with the cables equally loaded the current-carrying capacity indicated on pages 8 to 14 for cables buried directly in ground shall be reduced by correction factors given above.

The reduction in current carrying capacity can be avoided if the pipes after cable pulling are filled with material thermally equal to the ambient ground.

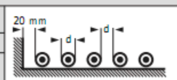
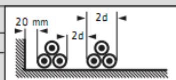
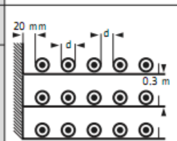
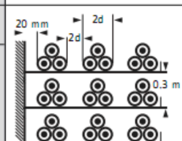
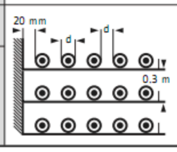
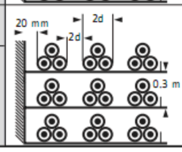
If factors in table 5 are used, factors in table 1 are not applicable.

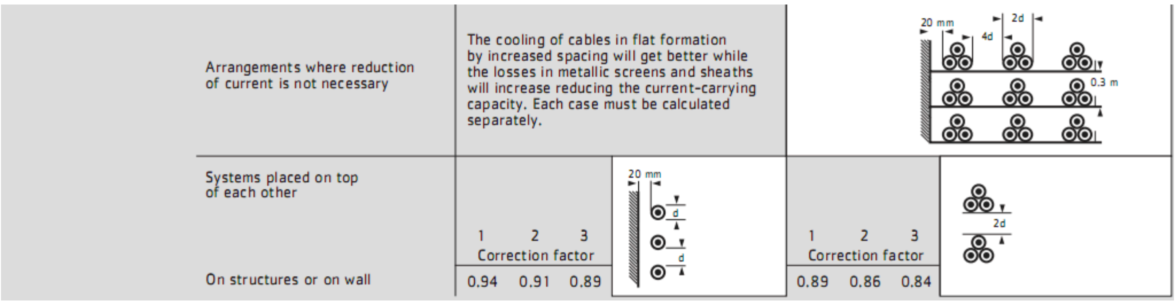
Table 6. Correction factors for different ambient air temperatures

Conductor temperature C°	Ambient air temperature, C°: 10	15	20	25	30	35	40	45	50	55
90	1.12	1.08	1.04	1.00	0.95	0.90	0.85	0.80	0.74	0.68
80	1.14	1.09	1.05	1.00	0.95	0.89	0.84	0.77	0.69	0.61
70	1.18	1.12	1.06	1.00	0.93	0.86	0.79	0.71	0.62	0.52
65	1.20	1.14	1.07	1.00	0.93	0.85	0.77	0.68	0.57	0.45

Table 7. Correction factors for different groups of three single core cables laid in the air

This applies only when the cable temperature does not affect the ambient air temperature.

Type of laying		Cables laid in flat formation. Spacing = One cable diameter (d). Distance from the wall not less than 20 mm.				Cables laid in trefoil formation. Spacing = Two cable diameters (2d). Distance from the wall not less than 20 mm.			
Number of groups		1	2	3		1	2	3	
On floor		Correction factor				Correction factor			
		0.92	0.89	0.88		0.95	0.90	0.88	
On metal trays (restricted air circulation)	Number of trays								
	1	0.92	0.89	0.88		0.95	0.90	0.88	
	2	0.87	0.84	0.83		0.90	0.85	0.83	
	3	0.84	0.82	0.81		0.88	0.83	0.81	
	6	0.82	0.80	0.79		0.86	0.81	0.79	
On metal ladders	Number of ladders								
	1	1.00	0.97	0.96		1.00	0.98	0.96	
	2	0.97	0.94	0.93		1.00	0.95	0.93	
	3	0.96	0.93	0.92		1.00	0.94	0.92	
	6	0.94	0.91	0.90		1.00	0.93	0.90	



Arrangements where reduction of current is not necessary	The cooling of cables in flat formation by increased spacing will get better while the losses in metallic screens and sheaths will increase reducing the current-carrying capacity. Each case must be calculated separately.			
Systems placed on top of each other On structures or on wall	Correction factor 1: 0.94, 2: 0.91, 3: 0.89		Correction factor 1: 0.89, 2: 0.86, 3: 0.84	

To demonstrate the importance of the k_{SF} (service factor, current-carrying capacity), let us calculate a cable installation with the correct k factor but without setting it to correct value.

First we read the initial data for the setup of the thermal image:

A 66 kV copper cable with a cross-section of 500 mm^2 is installed into ground. Its 1 s permissible short-circuit current is 71.4 kA and its insulation is XLPE. The cable's screen circuit is open and the laying formation is flat. Its current-carrying capacity is 575 A in 65 ˚C and 680 A in 90 ˚C. The reference temperature for ground installation is 15 ˚C.

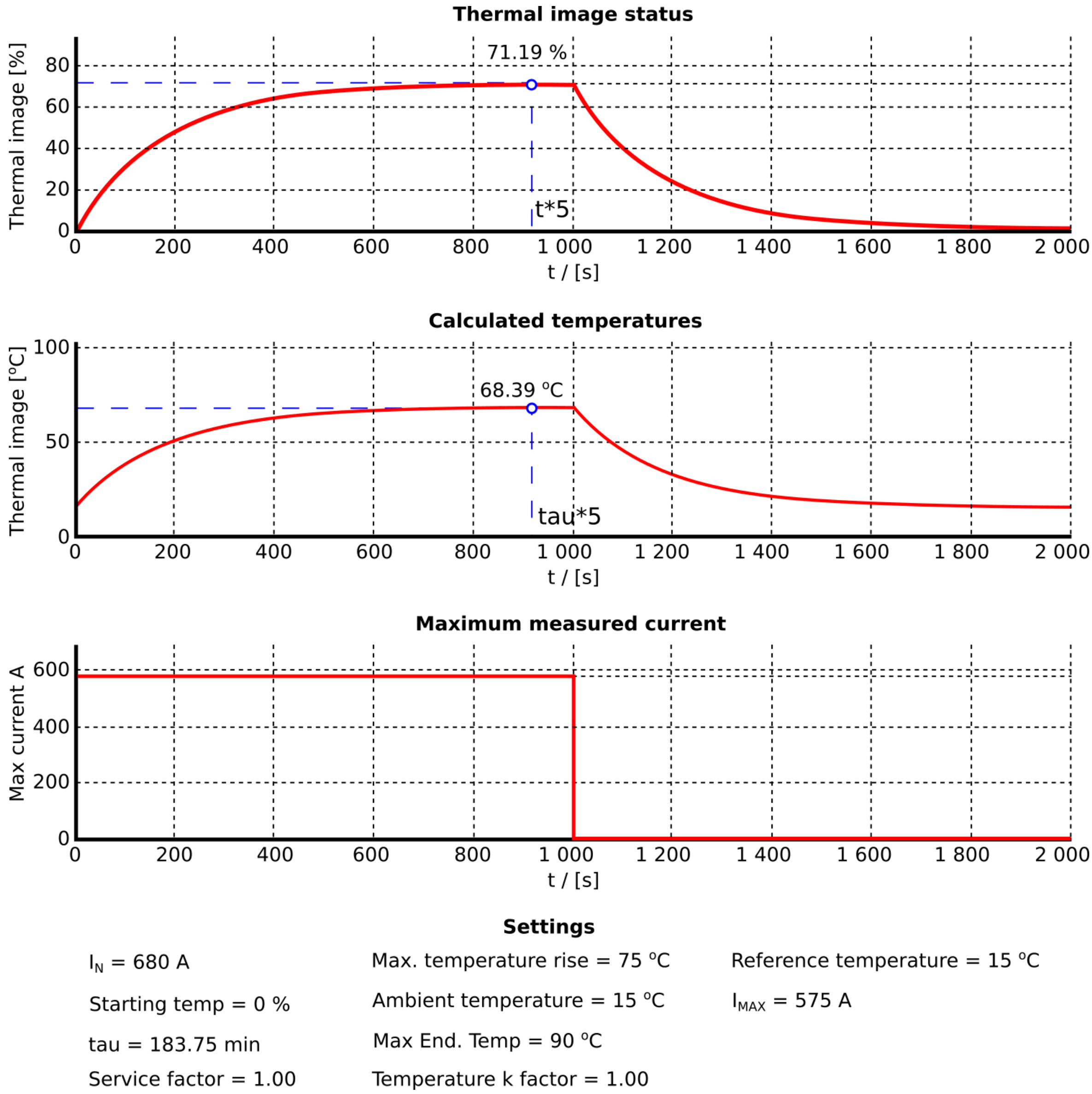
Let us calculate an estimation of the time constant τ based on the known one-second short-circuit current related to I_n. If the manufacturer has not provided the time constant, it can be estimated from the maximum permissable short-circuit current (usually a one second value). The function uses this same method to estimate the heating time constant.

$$\tau_{cable} = \frac{1\text{ s}}{60\text{ s}} \times \left(\frac{I_{1\,s}}{I_n}\right)^2 = \frac{1\text{ s}}{60\text{ s}} \times \left(\frac{71\,400\text{ A}}{680\text{ A}}\right)^2 = 183.75\text{ min}$$

The rest of the settings are in the initial data text above:

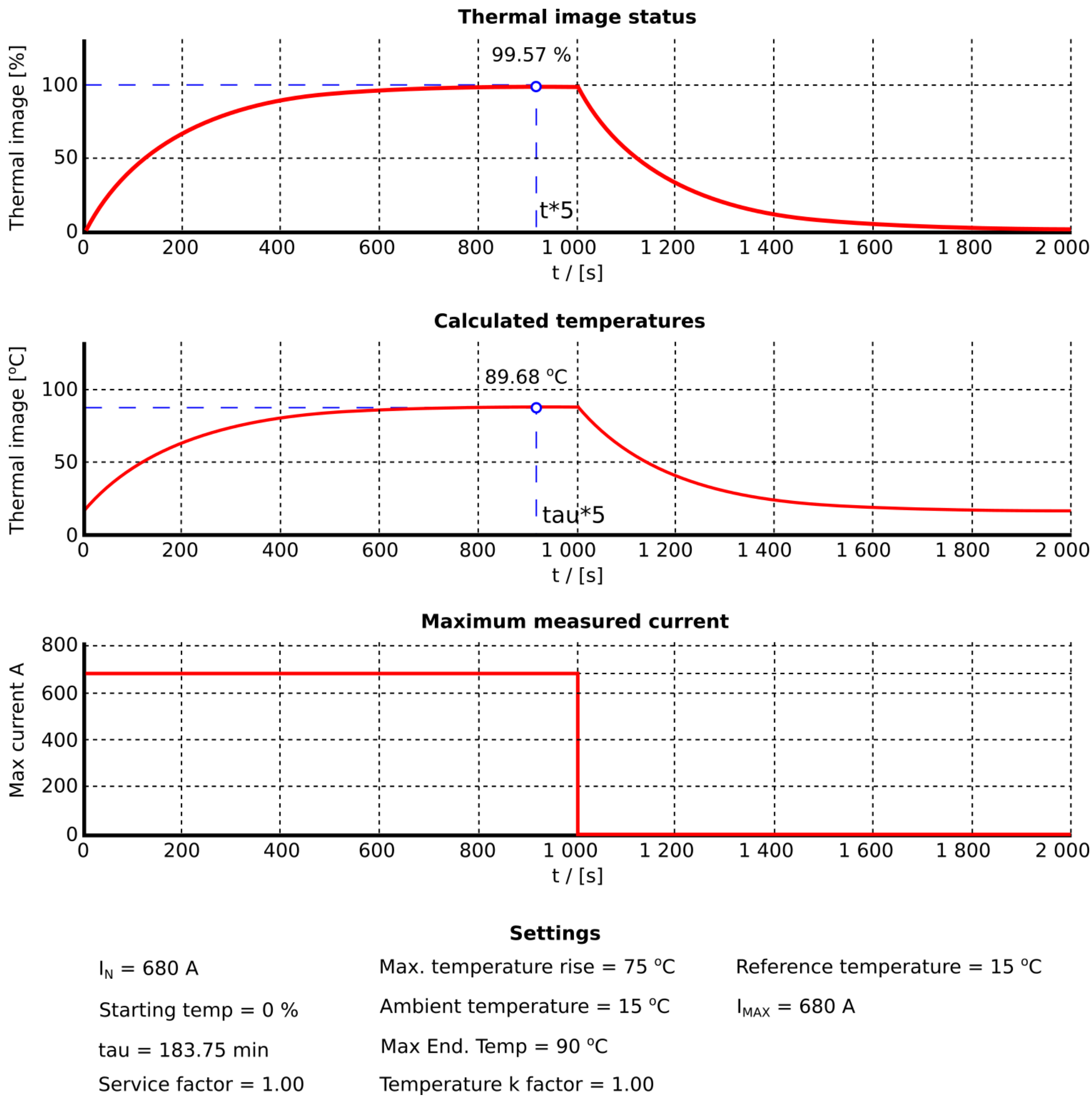
- I_n = 680 A
- T_{max} = 90 ˚C
- T_{amb} = 15 ˚C
- T_{ref} = 15 ˚C
- k_{SF} = 1.0.

Figure. 4.4.7 - 97. Thermal image response with nominal load (installation according to presumptions).



As the results show, the end temperature of 68.39 ˚C is reached when the cable is loaded with a stable current for time equalling five times the time constant τ. This uses approximately 71 % of the thermal capacity. According to the datasheet, this current should set the temperature around 65 ˚C; therefore, the model overprotects by three degrees.

Figure. 4.4.7 - 98. Thermal image response with maximum load (installation according presumptions).



The maximum allowed load results in the end temperature of 89.68 ˚C which means that 99.57 % of the thermal capacity is used. This result matches the expectations of the thermal image perfectly. The user can now securely set the cable's overheating alarm.

When comparing the result to the fully-tuned model in the application, let us include all of the installation correction factors to the image.

A 66 kV copper cable with a cross-section of 500 mm^2 is installed *with no adjacent cables (k=1)* into a *ground consisting of dry gravel and clay (k=0.85)* and *into the depth of 1.5 meters (k=0.95)*. The cable's 1 s permissible short-circuit current is 71.4 kA and its insulation is XLPE. The cable's screen circuit is open and the laying formation is flat. Its current-carrying capacity is 575 A in 65 ˚C and 680 A in 90 ˚C. The reference temperature for ground installation is 15 ˚C. The cable's thermal time constant is 183.8 min.

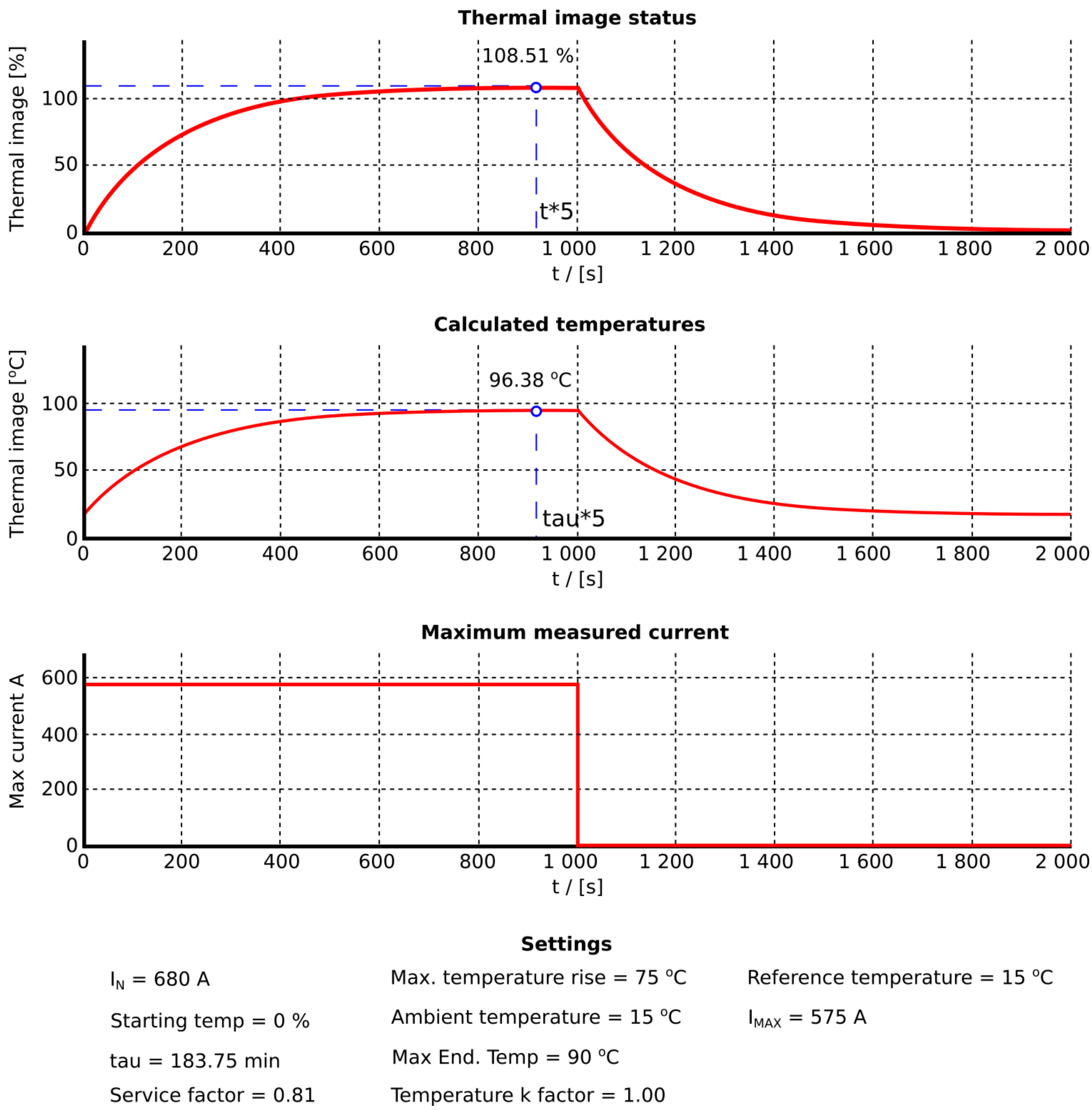
From this initial data one can calculate the k_{SF} correction factor according to the following formula (k factor related information in italics):

$$k_{SF} = 1 \times 0.85 \times 0.95 = 0.81$$

Therefore, the settings are as follows:

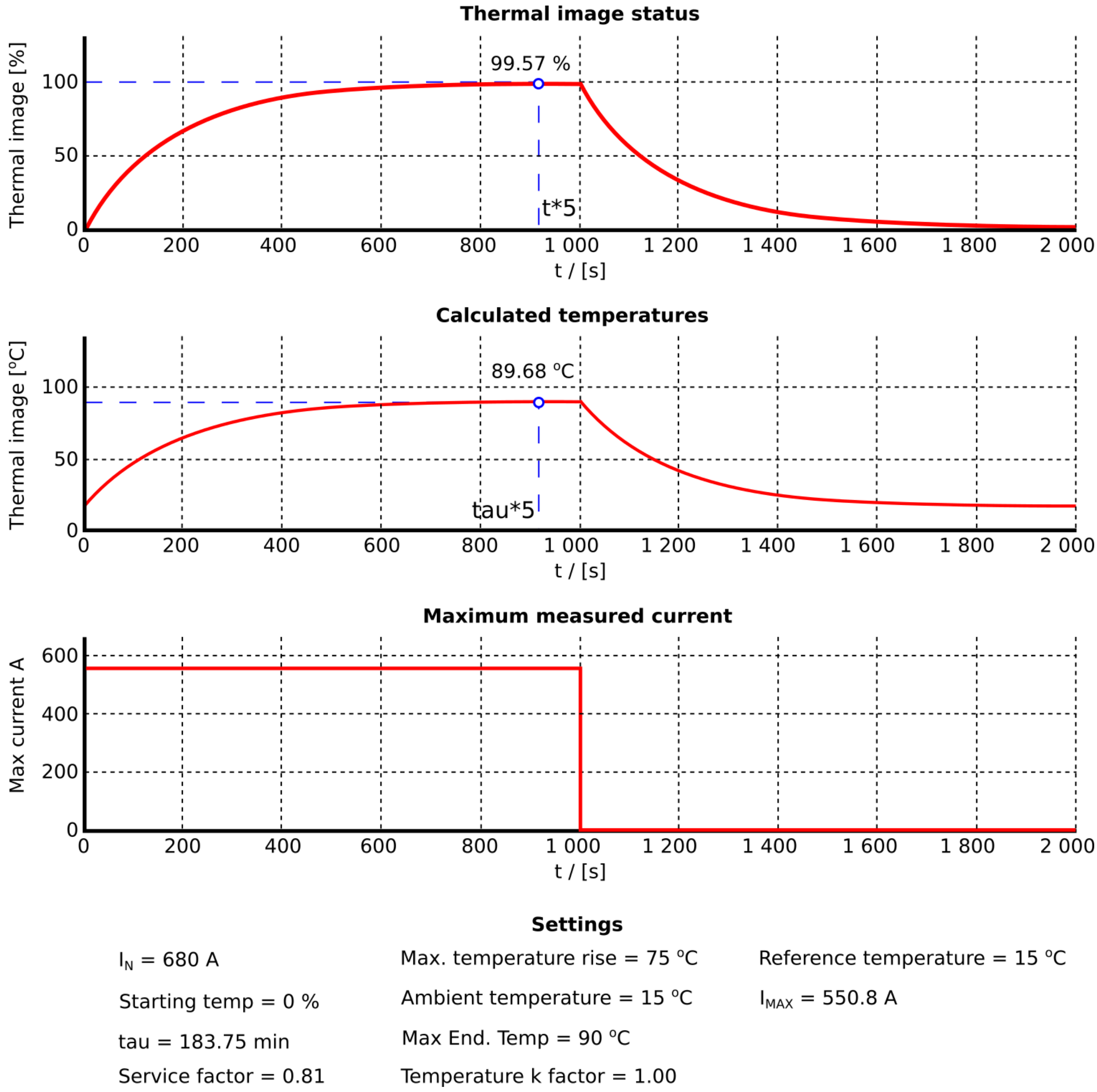
- I_n = 680 A
- T_{max} = 90 ˚C
- T_{amb} = 15 ˚C
- T_{ref} = 15 ˚C
- τ = 183.8 min
- k_{SF} = 0.81.

Figure. 4.4.7 - 99. Thermal image response with nominal currents and fine-tuned k_{SF} correction factor.



When trying to load the cable with the nominal current one can see the actual current-carrying capacity of the cable is much lower than in the presumptive conditions. A normal loading current can now warm up the cable too much and threaten its withstandability. If the k_{SF} had not been set, the thermal image would show a temperature of appr. 68 ˚C instead of the real temperature of 96 ˚C.

Figure. 4.4.7 - 100. Thermal response with k_{SF} factor correctly set.



When the installation conditions vary from the presumptive conditions, the cable's current-carrying capacity can be reduced so that the temperature of 90 ˚C is achieved with a 550 A current instead of the 680 A current given in the initial data.

Estimating trip time

Calculated effective nominal current:

$I_N = k_{SF} \times tamb_{fact} \times I_{Nom}$

Where:

- I_N = calculated effective nominal current
- k_{SF} = the service factor
- k_{amb} = the ambient temperature factor
- I_{Nom} = the nominal current of the protected device

Calculated end heating:

$\theta_{End} = (I_{meas}/I_N)^2$

Where:

- I_{meas} = the measured current
- I_N = the calculated effective nominal current

Calculated time constant:

$\tau = e^{(-0.005[s]\times(Tc[min]\times 60)[s])}$

Where:

- e = Euler's number
- τ_C = the time constant set by the user
- 0.005s is the program cycle time

Calculated active thermal status:

$\theta_{Calc} = ((\theta_{-1} - \theta_{End})\times\tau) + \theta_{End}$

Where:

- θ_{-1} = previous cycle calculation result (integrating function needs the memory to operate)
- θ_{End} = the calculated end heating (dependent on the measured current)
- τ = the calculated time constant

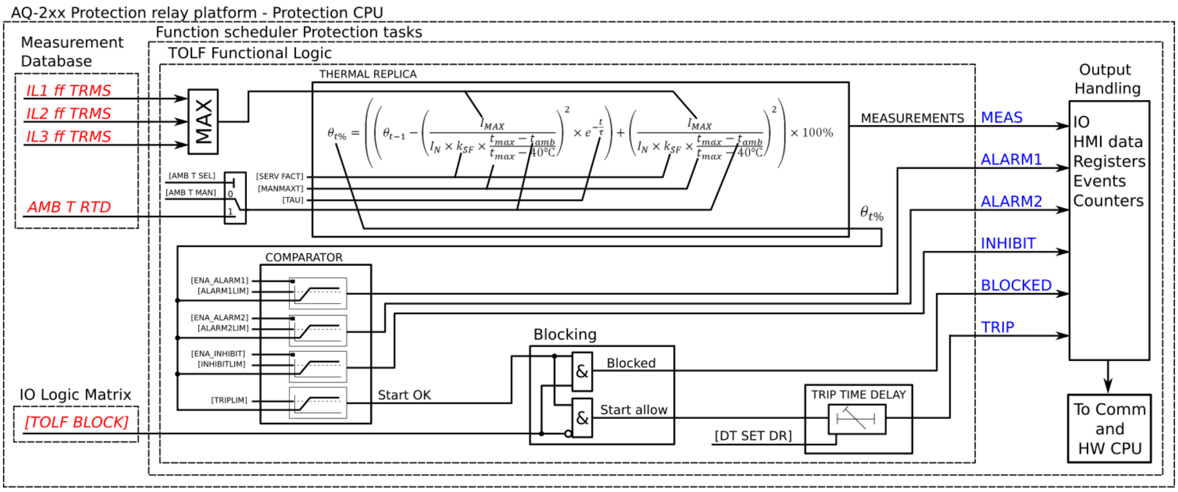
The tripping time can be calculated based on these previous calculations according to the following formula (the result in seconds). With this base information the tripping time can be calculated with the formula above (in seconds) when replacing the θ_{Calc} with the value of the thermal level which from the tripping time is wanted to be calculated (in per-unit value).

$$t_{est.\ trip} = l_n\left(\frac{I_{meas}{}^2 - (k_{fact}\times tamb_{fact}\times\sqrt{\theta_{Calc}}\times I_n)^2}{(I_{meas}{}^2 - I_n{}^2)}\right)\times\tau\times 60$$

Function inputs and outputs

The following figure presents a simplified function block diagram of the line thermal overload protection function.

Figure. 4.4.7 - 101. Simplified function block diagram of the TF> function.



Measured input

The function block uses phase current measurement values. The function block uses TRMS values from the whole harmonic specter of 32 components. RTD input can be used for measuring ambient temperature.

Table. 4.4.7 - 66. Measurement inputs of the TF> function.

Signal	Description
I_{L1} TRMS	TRMS measurement of phase L1 (A) current
I_{L2} TRMS	TRMS measurement of phase L2 (B) current
I_{L3} TRMS	TRMS measurement of phase L3 (C) current
RTD	Temperature measurement for the ambient correction

Table. 4.4.7 - 67. General settings (not selectable under setting groups)

Name	Range	Default	Description
TF> mode	• Disabled • Activated	Disabled	The selection of the function is activated or disabled in the configuration. By default it is not in use.
TF> force status to	• Normal • Blocked • Alarm1 On • Alarm2 On • Inhibit On • Trip On	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Temp C or F deg	• C • F	C	The selection of whether the temperature values of the thermal image and RTD compensation are shown in Celsius or in Fahrenheit.

Table. 4.4.7 - 68. Settings for thermal replica.

Name	Range	Step	Default	Description
IN thermal cap current	0.10…40.00xI$_n$	0.01xI$_n$	1.00xI$_n$	The current for the 100 % thermal capacity to be used (the pick-up current in p.u., with t_{max} achieved in time τ x 5).
Set or Estimate tau (t const)	• Set • Estimate	-	Set	The selection of the time constant setting. If "Set" is selected, the Tau (t const) setting is available and the time constant to be used can be set there. If "Estimate" is selected, the cable's initial data parameters are visible.
Tau (t const)	0.1…500.0min	0.1min	10.0min	The time constant setting. This time constant is used for heating and cooling of the protected object. This setting is visible if the "Set" is selected for the "Set or Estimate tau" setting.
Max. perm. OC. current (norm **ik**1s)	1…1 000 000A	1A	75 000A	The maximum-rated short-circuit current of the protected object (cable). Usually this value is presented as a one second value. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting.
Max. OC. time (norm 1 s)	0.1…5s	0.1s	1.0s	The time of the maximum-rated short-circuit current of the protected object (usually 1 s). This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting.
Nominal current	1…1 000 000A	1A	700A	The rated nominal current in the primary value of the protected object under nominal-rated conditions. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting.
Estimated tau	0…1800min	0.005min	191.3min (from defaults)	The estimated result which is used for the thermal replica's time constant. After the previous three required parameters are set the device will calculate this value. This setting is visible if "Estimate" is selected for the "Set or Estimate tau" setting.
k_{SF} (service factor)	0.01…5.00	0.01	1.00	The service factor which corrects the value of the maximum allowed current according to installation and other conditions varying from the presumptive conditions.
Cold reset default theta	0.0…150.0%	0.1%	60.0%	The thermal image status in the restart of the function/ 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. This parameter can be used when testing the function to manually set the current thermal cap to any value.

Table. 4.4.7 - 69. 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.

Name	Range	Step	Default	Description
Ambient temp. sel.	• Manual set • RTD	-	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	• Linear est. • Set curve	-	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 "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 ˚C and for cables in the air it is usually 25 ˚C. 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…5.00xI_n	0.01xI_n	1.00xI_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…5.00xI_n	0.01xI_n	1.00xI_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".

Name	Range	Step	Default	Description
Add curvepoint 3…10	• Not used • Used	-	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".

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.4.7 - 70. Pick-up settings.

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

Name	Range	Step	Default	Description
TF> Trip delay	0.000…3600.000s	0.005s	0.000s	The trip signal's additional delay. This delay delays the trip signal generation by a set time. The default setting is 0.000 s which does not give an added time delay for the trip signal.

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

Measurements and indications

The function outputs measured process data from the following magnitudes:

Table. 4.4.7 - 71. General status codes.

Name	Range	Description
TF> Condition	• Normal • Alarm 1 ON • Alarm 2 ON • Inhibit ON • Trip ON • 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	• Light / No load • High overload • Overloading • Load normal	The function's thermal image status. When the measured current is below 1 % of the nominal current, the status "Light/No load" is shown. When the measured current is below the trip limit, the status "Load normal" is shown. When the measured current is above the pick-up limit but below 2 x I_n , the status "Overloading" is shown. When the measured current is above 2 x I_n, the status "High overload" is shown.
TF> Setting alarm	• SF setting ok • 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.

Name	Range	Description
TF> Setting alarm	• Ambient setting ok • Ambient t set fault. Override to 1.0	Indicates if ambient temperature settings have been set wrong and actually used setting is 1.0. Visible only when there is a setting fault.
TF> Setting alarm	• Nominal current calc ok • Nominal current set fault. Override to 1.0	Indicates if nominal current calculation is set wrong and actually used setting is 1.0. Visible only when there is a setting fault.
TF> Setting alarm	• Ambient setting ok • Inconsistent setting of ambient k	Indicates if ambient k setting has been set wrong. Visible only when there is a setting fault.

Table. 4.4.7 - 72. Measurements.

Name	Range	Description/values
Currents	• Primary A • Secondary A • Per unit	The active phase current measurement from IL1 (A), IL2 (B) and IL3 (C) phases in given scalings.
Thermal image	Thermal image calc.	- TF> Trip expect mode: No trip expected/Trip expected - TF> Time to 100 % theta: Time to reach the 100 % thermal cap - TF> Rreference T curr.: reference/pick-up value (IEQ) - TF> Active meas. curr.: the measured maximum TRMS current at a given moment - TF> T est. with act. curr.: estimation of the used thermal capacity including the current at a given moment - TF> T at a given moment: the thermal capacity used at that moment
	Temp. estimates	- TF> Used k for amb. temp: the ambient correction factor at a givenmoment - TF> Max. temp. rise all.: the maximum allowed temperature rise - TF> Temp. rise atm: the calculated temperature rise at a given moment - TF> Hot spot estimate: the estimated hot spot temperature including the ambient temperature - TF> Hot spot max. all.: the maximum allowed temperature for the object
	Timing status	- TF> Trip delay remaining: the time to reach 100% theta - TF> Trip time to rel.: the time to reach theta while staying below the trip limit during cooling - TF> Alarm 1 time to rel.: the time to reach theta while staying below the Alarm 1 limit during cooling - TF> Alarm 2 time to rel.: the time to reach theta while staying below the Alarm 2 limit during cooling - TF> Inhibit time to rel.: the time to reach theta while staying below the Inhibit limit during cooling

Table. 4.4.7 - 73. Counters.

Name	Description / values
Alarm1 inits	The number of times the function has activated the Alarm 1 output
Alarm2 inits	The number of times the function has activated the Alarm 2 output
Restart inhibits	The number of times the function has activated the Restart inhibit output
Trips	The number of times the function has tripped
Trips Blocked	The number of times the function trips has been blocked

Events and registers

The line thermal overload protection function (abbreviated "TOLF" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the ALARM, INHIBIT, TRIP and BLOCKED events.

Table. 4.4.7 - 74. Event messages.

Event block name	Event names
TOLF1	Alarm1 ON
TOLF1	Alarm1 OFF
TOLF1	Alarm2 ON
TOLF1	Alarm2 OFF
TOLF1	Inhibit ON
TOLF1	Inhibit OFF
TOLF1	Trip ON
TOLF1	Trip OFF
TOLF1	Block ON
TOLF1	Block OFF

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

Table. 4.4.7 - 75. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss

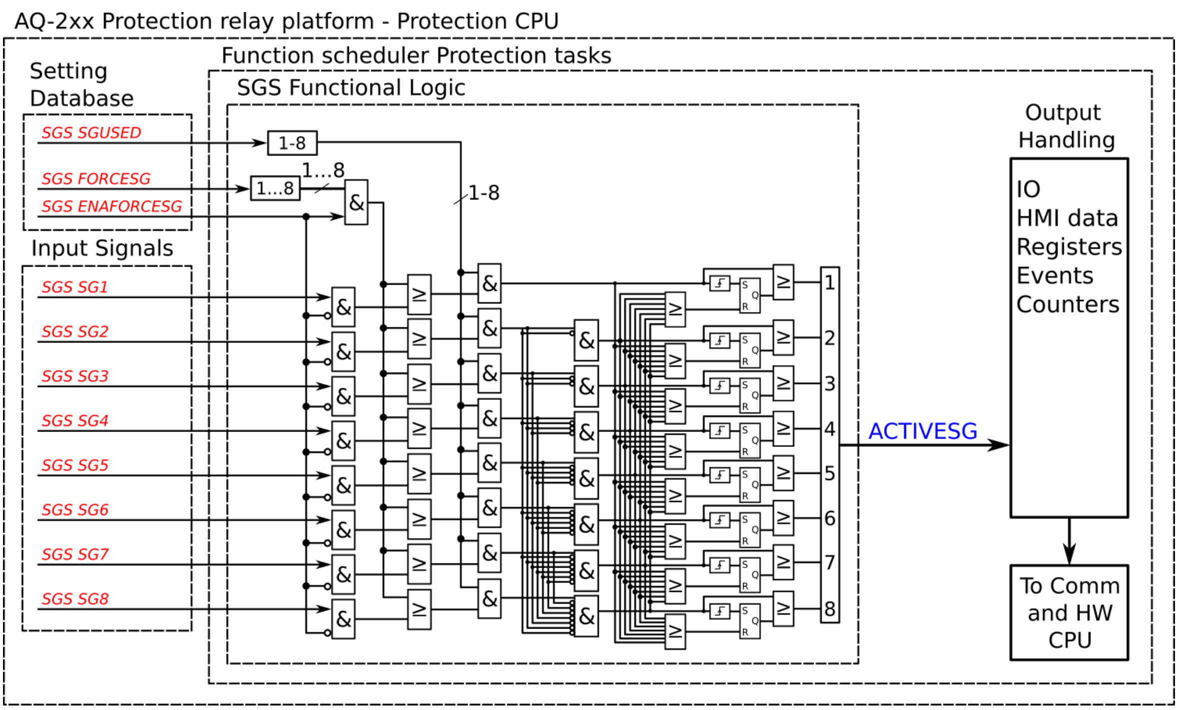
Name	Description
Event	Event name
Time to reach 100 % theta	seconds
Ref. T current	x I_n
Active meas. current	x I_n
T at a given moment	%
Max. temp. rise allowed	degrees
Temp. rise at a given moment	degrees
Hot spot estimate	degrees
Hot spot maximum allowed	degrees
Trip delay rem.	seconds
Setting group in use	Setting group 1...8 active

4.5 Control functions

4.5.1 Setting group selection

All device 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.

Figure. 4.5.1 - 102. Simplified function block diagram of the setting group selection function.

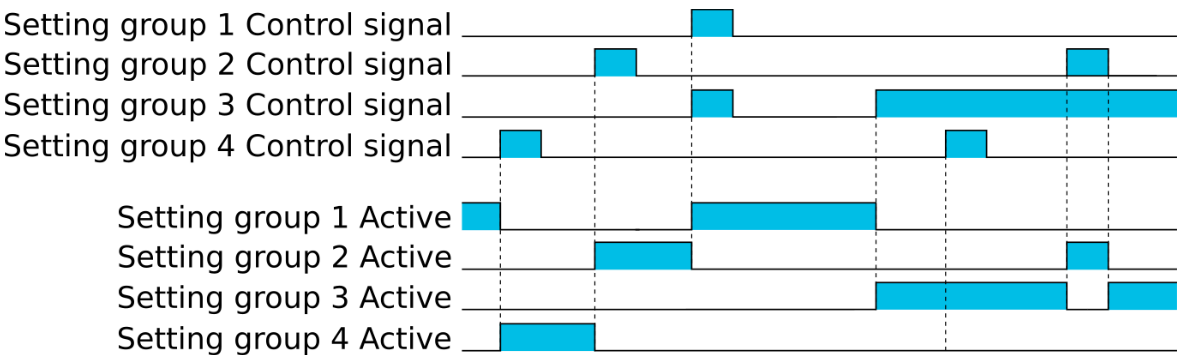


Setting group selection can be applied to each of the setting groups individually by activating one of the various internal logic inputs and connected digital inputs. The user can also force any of the setting groups on when the "Force SG change" setting is enabled by giving the wanted quantity of setting groups as a number in the communication bus or in the local HMI, or by selecting the wanted setting group from *Control → Setting groups*. When the forcing parameter is enabled, the automatic control of the local device is overridden and the full control of the setting groups is given to the user until the "Force SG change" is disabled again.

Setting groups can be controlled either by pulses or by signal levels. The setting group controller block gives setting groups priority values for situations when more than one setting group is controlled at the same time: the request from a higher-priority setting group is taken into use.

Setting groups follow a hierarchy in which setting group 1 has the highest priority, setting group 2 has second highest priority etc. If a static activation signal is given for two setting groups, the setting group with higher priority will be active. If setting groups are controlled by pulses, the setting group activated by pulse will stay active until another setting groups receives and activation signal.

Figure. 4.5.1 - 103. 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. 4.5.1 - 76. Settings of the setting group selection function.

Name	Range	Default	Description
Active setting group	• SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	SG1	Displays which setting group is active.

Name	Range	Default	Description
Force setting group	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	None	The selection of the overriding setting group. After "Force SG change" is enabled, any of the configured setting groups in the device 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	• Disabled • Enabled	Disabled	The selection of whether the setting group forcing is enabled or disabled. This setting has to be active before the setting group can be changed remotely or from a local HMI. This parameter overrides the local control of the setting groups and it remains on until the user disables it.
Used setting groups	• SG1 • SG1...2 • SG1...3 • SG1...4 • SG1...5 • SG1...6 • SG1...7 • SG1...8	SG1	The selection of the activated setting groups in the application. Newly-enabled setting groups use default parameter values.
Remote setting group change	• None • SG1 • SG2 • SG3 • SG4 • SG5 • SG6 • SG7 • SG8	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. 4.5.1 - 77. Signals of the setting group selection function.

Name	Description
Setting group 1	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	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	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	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	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.

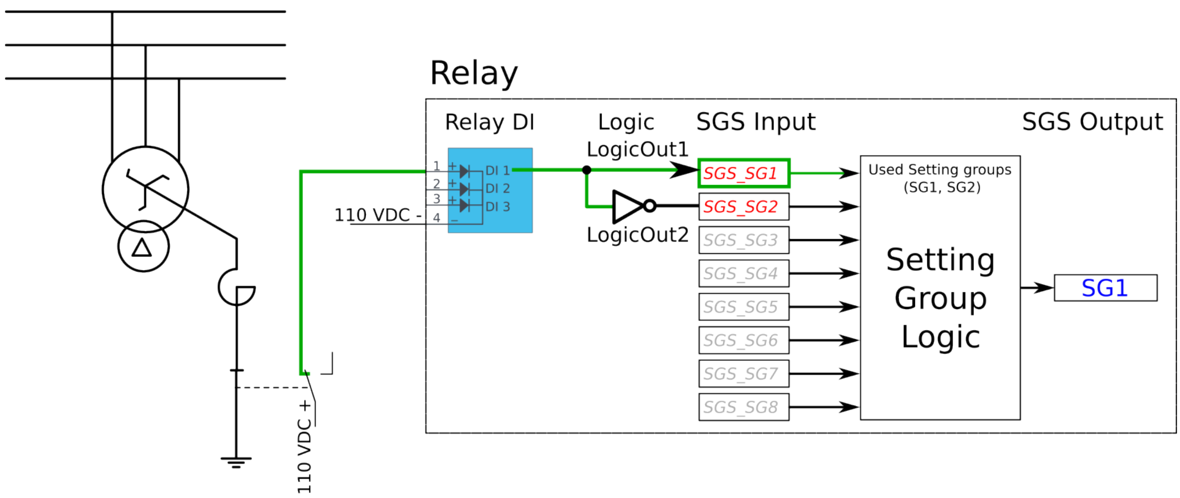
Name	Description
Setting group 6	The selection of Setting group 6 ("SG6"). Has the third lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, SG7 and SG8 requests will not be processed.
Setting group 7	The selection of Setting 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	The selection of Setting group 8 ("SG8"). Has the lowest priority input in setting group control. Can be controlled with pulses or static signals. If static signal control is applied, all other SG requests will be processed regardless of the signal status of this setting group.

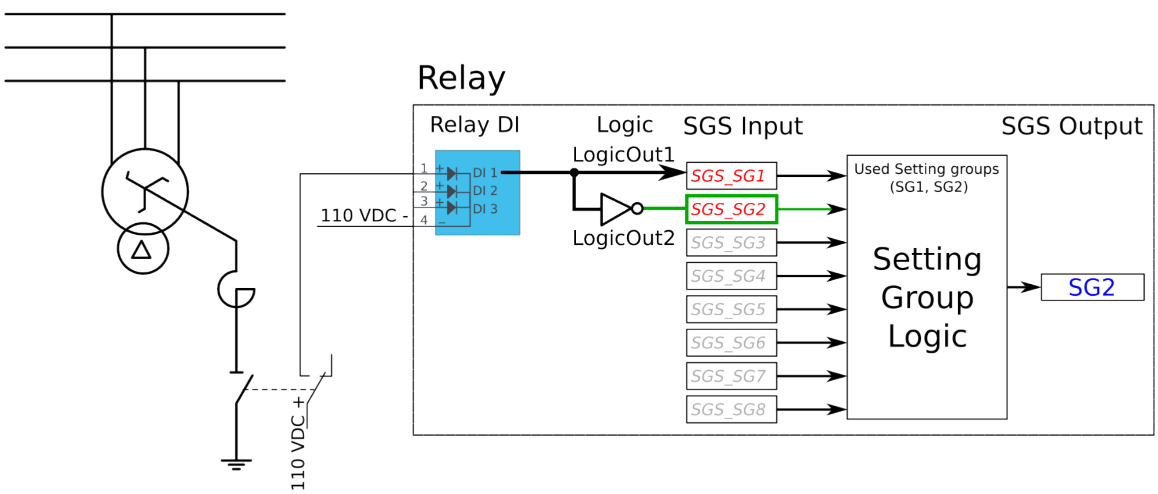
Example applications for setting group control

This chapter presents some of the most common applications for setting group changing requirements.

A Petersen coil compensated network usually uses directional sensitive earth fault protection. The user needs to control its characteristics between varmetric and wattmetric; the selection is based on whether the Petersen coil is connected when the network is compensated, or whether it is open when the network is unearthed.

Figure. 4.5.1 - 104. 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. 4.5.1 - 105. Setting group control – two-wire connection from Petersen coil status.

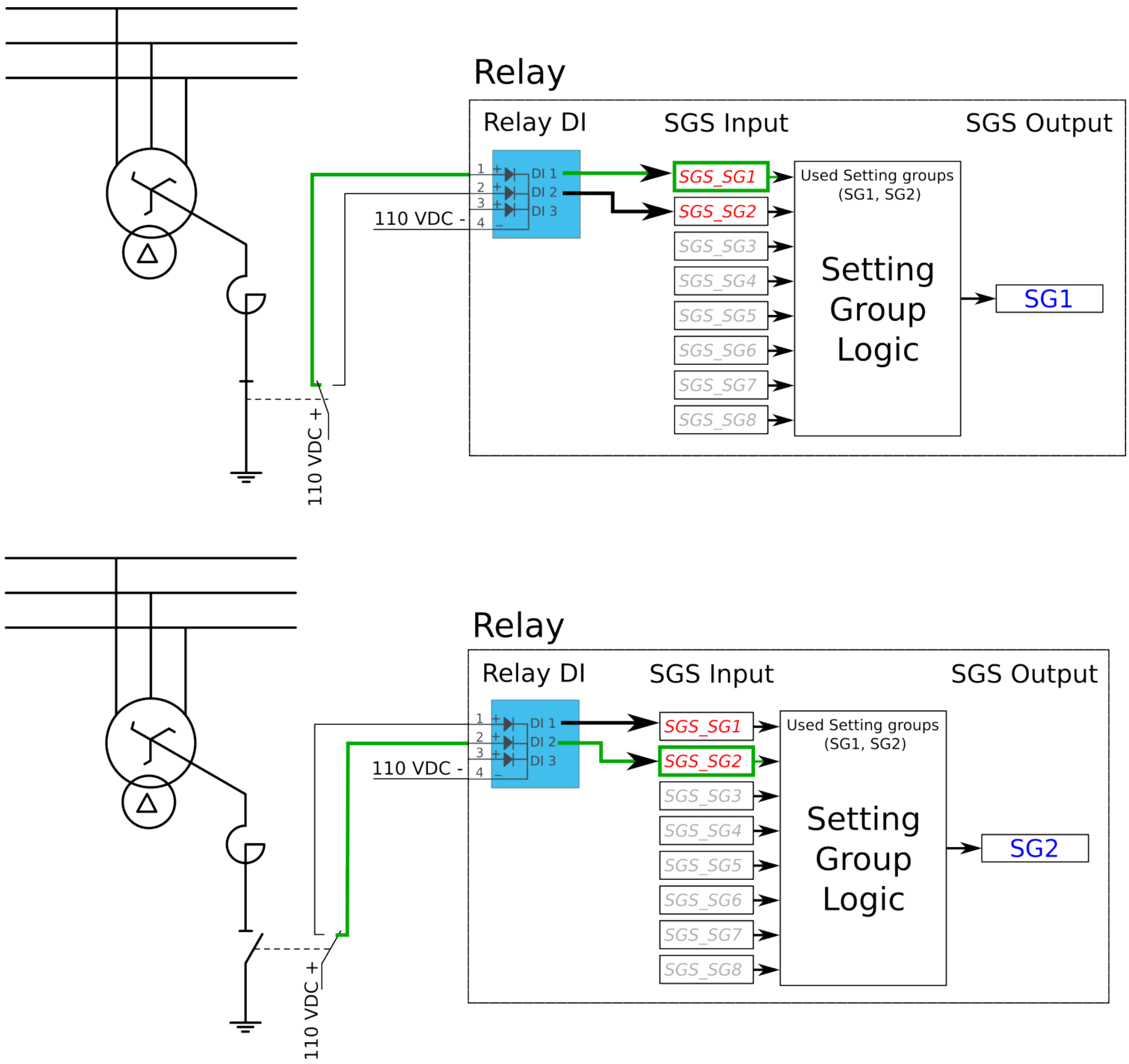
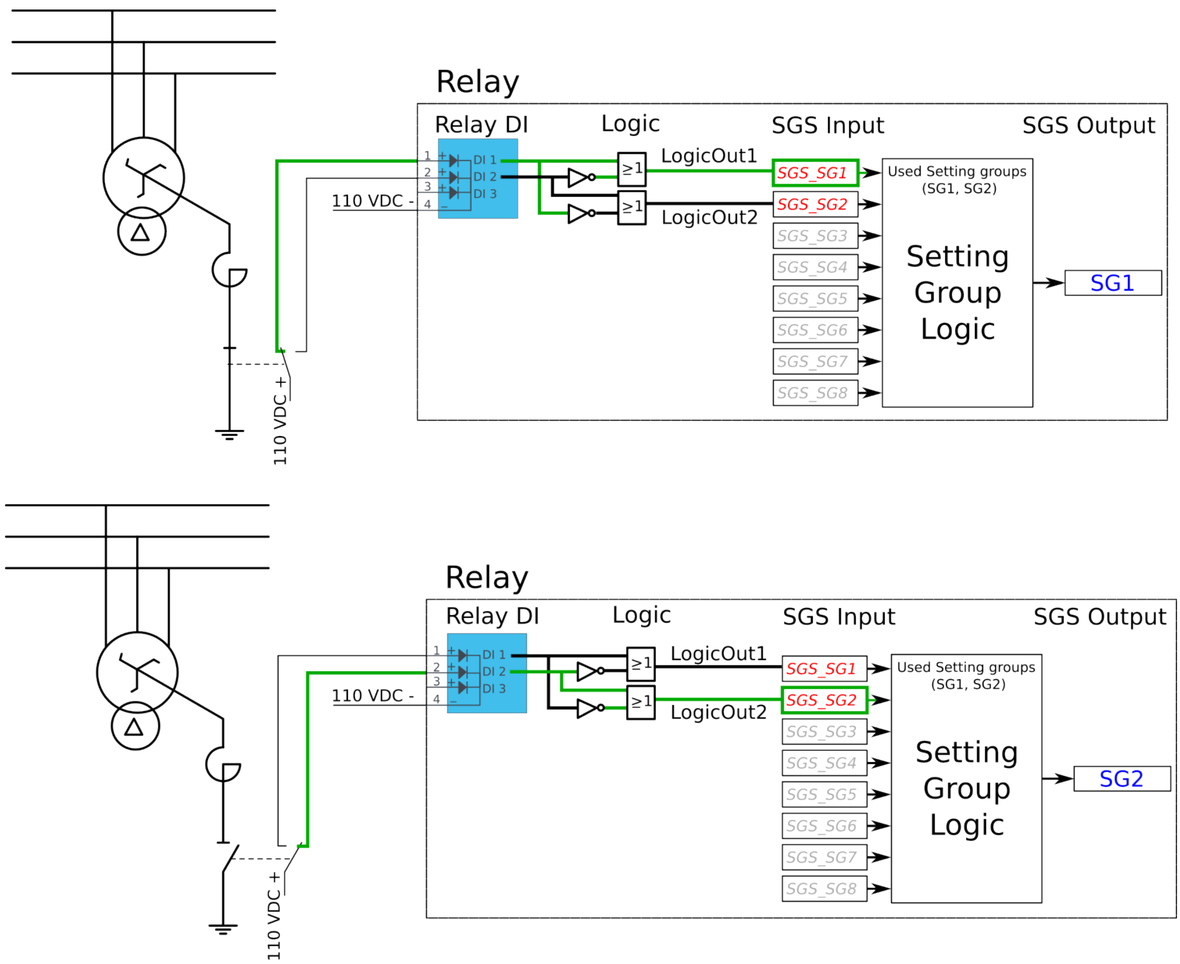


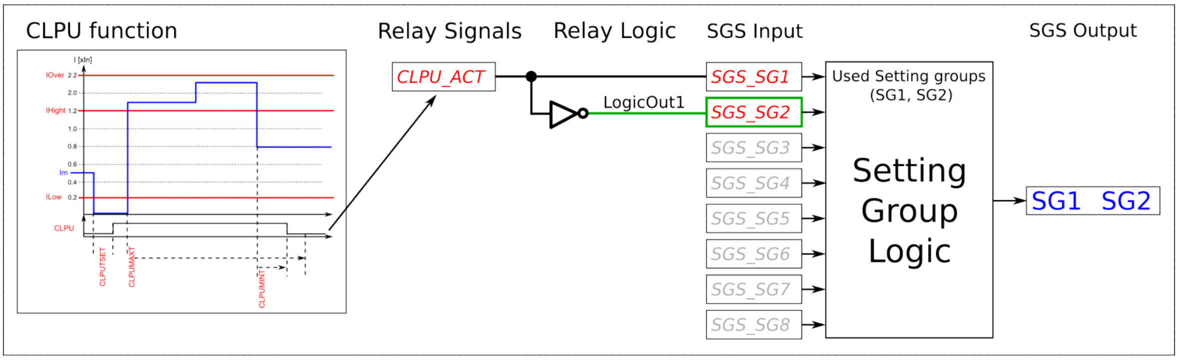
Figure. 4.5.1 - 106. Setting group control – two-wire connection from Petersen coil status with additional logic.

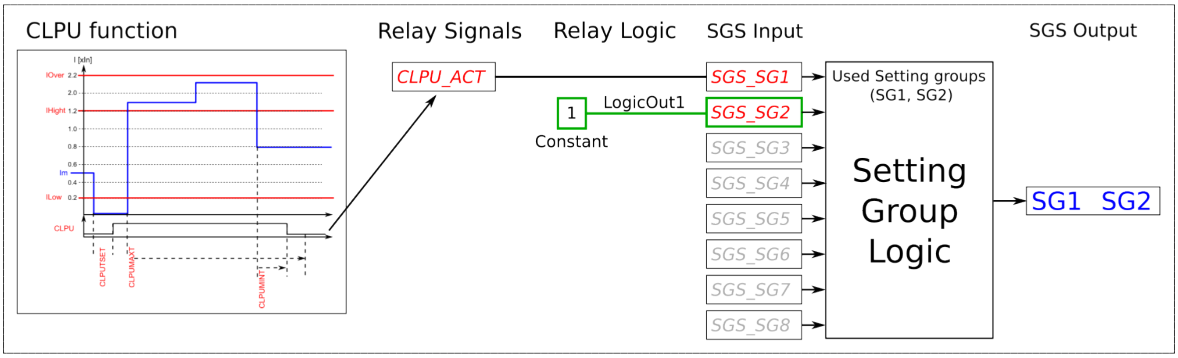


The images above depict a two-wire connection from the Petersen coil: the two images at the top show a direct connection, while the two images on the bottom include additional logic. With a two-wire connection the state of the Petersen coil can be monitored more securely. The additional logic ensures 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 device's internal logics. For example, the setting group change can be based on the cold load pick-up function (see the image below).

Figure. 4.5.1 - 107. 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 device'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 the status changes in the events listed below. 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.

Table. 4.5.1 - 78. Event messages.

Event block name	Event names
SGS	SG2...8 Enabled
SGS	SG2...8 Disabled
SGS	SG1...8 Request ON
SGS	SG1...8 Request OFF
SGS	Remote Change SG Request ON

Event block name	Event names
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...8 Active ON
SGS	SG1...8 Active OFF

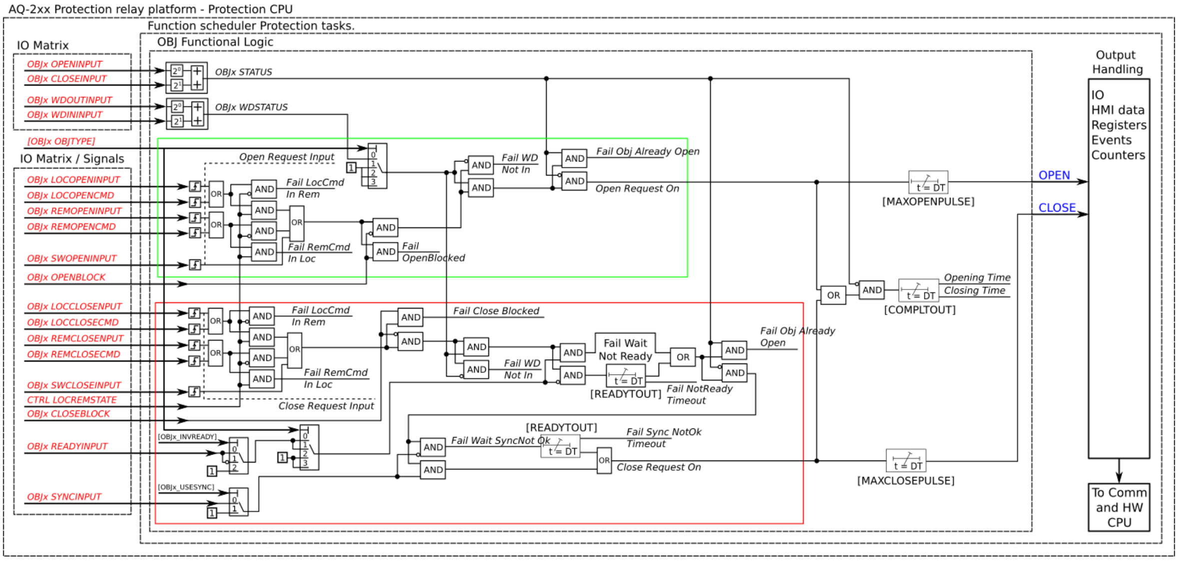
4.5.2 Object control and monitoring

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 device's configured digital inputs and outputs. The number of controllable and monitored objects in each device 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 devices front panel (HMI) or by external push buttons connected to devices 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).

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.

Figure. 4.5.2 - 108. 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. 4.5.2 - 79. Object settings and status parameters.

Name	Range	Default	Description
Local/Remote status	• Local • Remote	Remote	Displays the status of the device'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.
Object status force to	• Normal • Openreq On • Closereq On • Opensignal On • Closesignal On • WaitNoRdy On • WaitNoSnc On • NotrdyFail On • NosyncFail On • Opentout On • Clotout On • OpenreqUSR On • ClorеqUSR On	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
Object name	-	Objectx	The user-set name of the object, at maximum 32 characters long.

Name	Range	Default	Description
Object type	• Withdrawable circuit breaker • Circuit breaker • Disconnector (MC) • Disconnector (GND)	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	• Intermediate • Open • Closed • 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	• WDIntermediate • WDCartOut • WDCart In • WDBad • 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	• Open Blocked • Open Allowed • Close Blocked • Close Allowed • Object Ready • Object Not Ready • Sync Ok • Sync Not Ok	-	Displays additional information about the status of the object.
Use Synchrocheck	• Not in use • Synchrocheck in use	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. Synchrocheck status can be either an internal signal generated by synchrocheck function or digital input activation with an external synchrocheck device.
Use Object ready	• Ready High • Ready Low • Not in use	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	$0\ldots2^{32}-1$	-	Displays the number of successful "Open" requests.
Close requests	$0\ldots2^{32}-1$	-	Displays the number of successful "Close" requests.
Open requests failed	$0\ldots2^{32}-1$	-	Displays the number of failed "Open" requests.
Close requests failed	$0\ldots2^{32}-1$	-	Displays the number of failed "Close" requests.
Clear statistics	• - • Clear	-	Clears the request statistics, setting them back to zero (0). Automatically returns to "-" after the clearing is finished.

Table. 4.5.2 - 80. Object types.

Name	Functionalities	Description
Withdrawable circuit breaker	Breaker cart position Circuit breaker position Circuit breaker control Object ready check before closing breaker Synchrochecking before closing breaker Interlocks	The monitor and control configuration of the withdrawable circuit breaker.
Circuit breaker	Position indication Control Object ready check before closing breaker Synchrochecking before closing breaker Interlocks	The monitor and control configuration of the circuit breaker.
Disconnector (MC)	Position indication Control	The position monitoring and control of the disconnector.
Disconnector (GND)	Position indication	The position indication of the earth switch.

Table. 4.5.2 - 81. I/O.

Signal	Range	Description
Objectx Open Status In	Digital input or other logical signal selected by the user (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.
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.
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.
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.
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.
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.
Objectx Open Command	OUT1...OUTx	The physical "Open" command pulse to the device's output relay.
Objectx Close Command		The physical "Close" command pulse to the device's output relay.

Table. 4.5.2 - 82. 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.
Sync wait timeout	0.02…500.00 s	0.02 s	0.2 s	If synchrocheck is used, the object will wait for a "synchrocheck ok" signal before giving the closing command. This parameter will cancel the command if synchronization is not achieved on time.
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. 4.5.2 - 83. Control settings (DI and Application).

Signal	Range	Description
Access level for MIMIC control	• User • Operator • Configurator • 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).
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.

Signal	Range	Description
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.

In order for the blocking signal to be received on time, it has to reach the function 5 ms before the control command.

Events and registers

The object control and monitoring function (abbreviated "OBJ" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function also provides a resettable cumulative counter for OPEN, CLOSE, OPEN FAILED, and CLOSE FAILED events.

Table. 4.5.2 - 84. Event messages of the OBJ function.

Event block name	Description
OBJX	Object Intermediate
OBJX	Object Open
OBJX	Object Close
OBJX	Object Bad
OBJX	WD Intermediate
OBJX	WD Out
OBJX	WD in
OBJX	WD Bad
OBJX	Open Request ON/OFF
OBJX	Open Command ON/OFF
OBJX	Close Request ON/OFF
OBJX	Close Command ON/OFF
OBJX	Open Blocked ON/OFF
OBJX	Close Blocked ON/OFF
OBJX	Object Ready
OBJX	Object Not Ready

Event block name	Description
OBJX	Sync Ok
OBJX	Sync Not Ok
OBJX	Open Command Fail
OBJX	Close Command Fail
OBJX	Final trip ON/OFF
OBJX	Contact Abrasion Alarm ON/OFF
OBJX	Switch Operating Time Exceeded ON/OFF
OBJX	XCBR Loc ON/OFF
OBJX	XSWI Loc ON/OFF
OBJX	OBJX Cond monitoring alarm 1 ON/OFF
OBJX	OBJX Cond monitoring alarm 2 ON/OFF
OBJX	OBJX Trip Circuit Supervision ON/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.

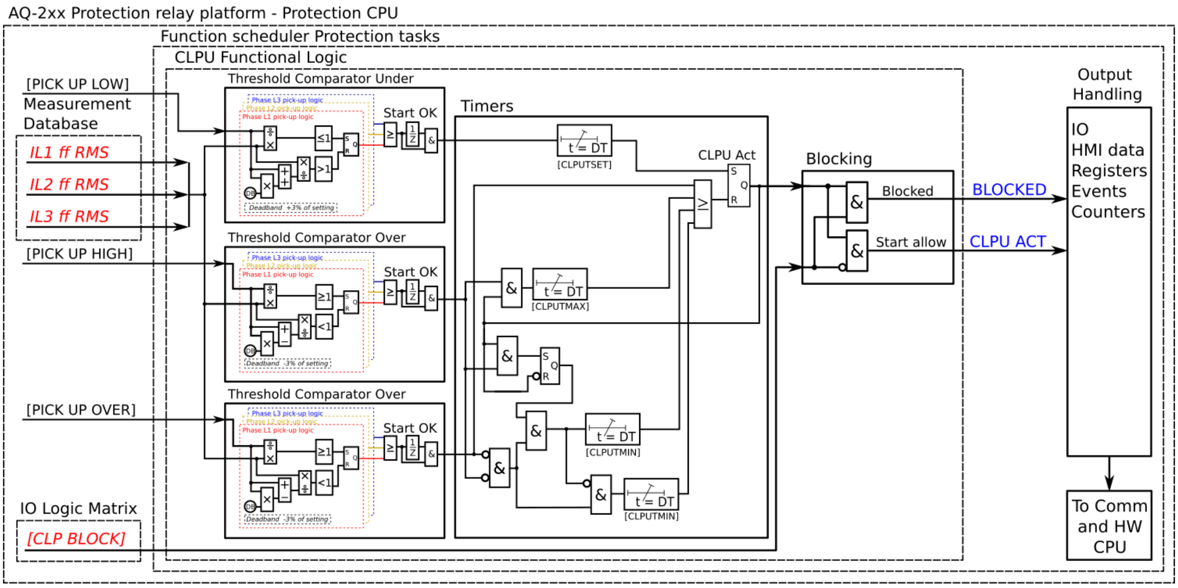
Table. 4.5.2 - 85. Register content.

Name	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Recorded Object opening time	Time difference between the object receiving an "Open" command and the object receiving the "Open" status.
Recorded Object closing time	Time difference between the object receiving a "Close" command and object receiving the "Closed" status.
Object status	The status of the object.
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.

4.5.3 Cold load pick-up (CLPU)

The cold load pick-up function is used for detecting so-called cold load situations, where a loss of load diversity has occured after distribution has been re-energized. The characteristics of cold load situations vary according to the types of loads individual feeders have. This means that this function needs to be set specifically according to the load type of the feeder it is monitoring. For example, in residential areas there are relatively many thermostat-controlled devices (such as heating and cooling machinery) which normally run in asynchronous cycles. When restoring power after a longer power outage, these devices demand the full start-up power which can cause the inrush current to be significantly higher than what the load current was before the outage. This is uncommon in industrial environments since the restoring of the production process takes several hours, or even days, and the power level goes back to the level it was before the outage. However, some areas of the industrial network may find the cold load pick-up function useful.

Figure. 4.5.3 - 109. Simplified function block diagram of the cold load pick-up function.



Measured input

The function block uses fundamental frequency component of phase current measurement values.

Table. 4.5.3 - 86. Measurement inputs of the cold load pick-up function.

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current

Pick-up settings

The I_{low}, I_{high} and I_{over} setting parameters control the the pick-up and activation of the cold load pick-up function. They define the maximum and minimum allowed measured current before action from the function. The function constantly calculates the ratio between the setting values and the measured magnitude (I_m) for each of the three phases. The reset ratio of 97 % is built into the function and is always relative to the setting value. The setting value is common for all measured phases. When the I_m exceeds the setting value (in single, dual or all phases) it triggers the pick-up operation of the function.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.5.3 - 87. Pick-up settings.

Name	Range	Step	Default	Description
I_{low}	0.01…40.00×In	0.01×In	0.20×In	The pick-up setting for low current detection. All measured currents must be below this setting in order for the cold load pick-up signal to be activated.
I_{high}	0.01…40.00×In	0.01×In	1.20×In	The pick-up setting for high current detection. All measured currents must exceed this setting in order for the cold load pick-up signal to be activated.
I_{over}	0.01…40.00×In	0.01×In	2.00×In	The pick-up setting for overcurrent detection. If this setting is exceeded by any of the measured currents, the cold load pick-up signal is released immediately.

Read-only parameters

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

Table. 4.5.3 - 88. Information displayed by the function.

Name	Range	Description
CLP condition	• Normal • Curr low • Overcurrent On • CLPU On • CLPU blocked	Displays status of the control function.

Function blocking

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

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

The 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 behavior of the function's operating timers can be set for activation as well as for the situation monitoring and release of the cold load pick-up.

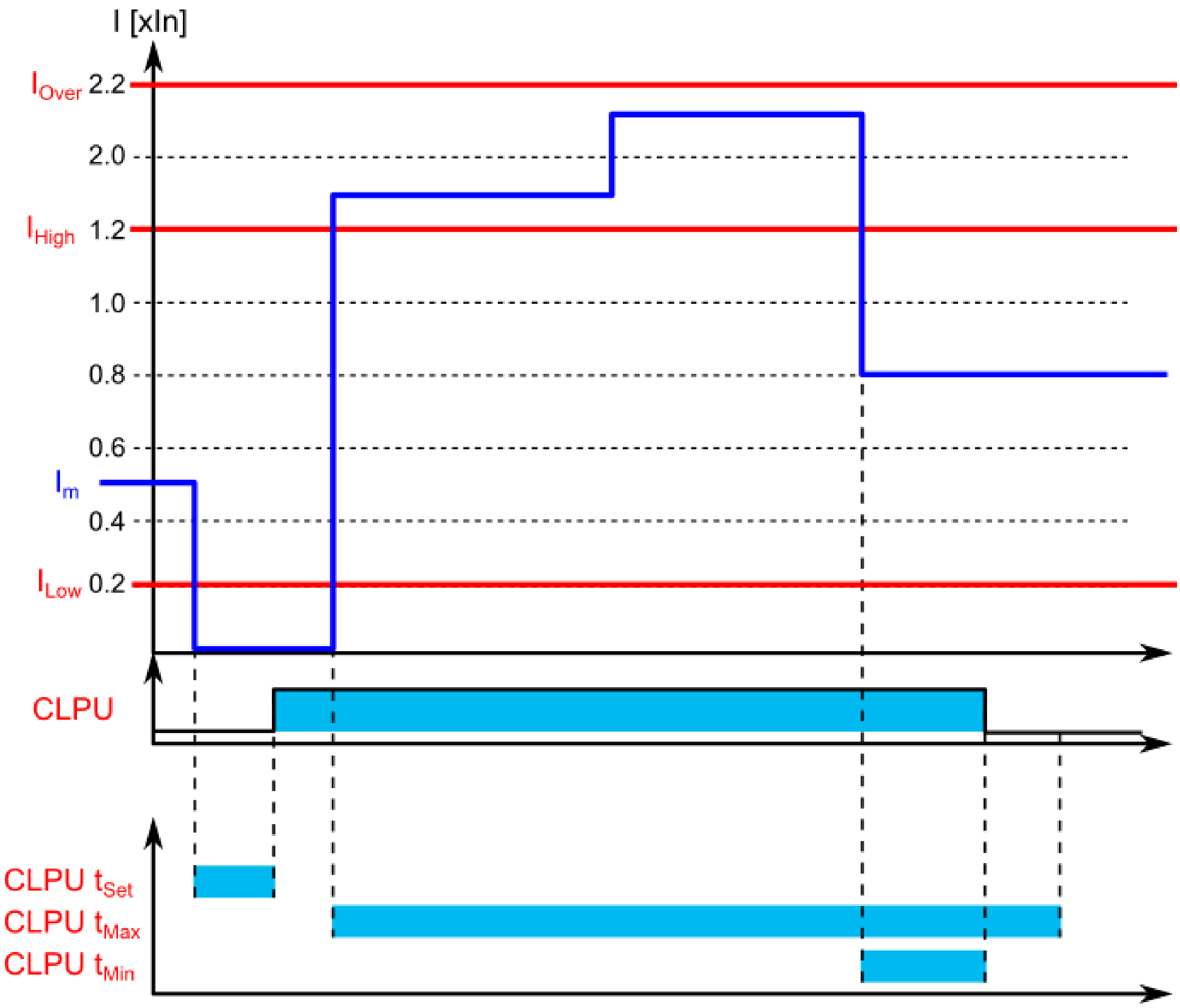
The table below presents the setting parameters for the function's time characteristics.

Table. 4.5.3 - 89. Setting parameters for operating time characteristics.

Name	Range	Step	Default	Description
T_{set}	0.000…1800.000s	0.005s	10.000s	The function's start timer which defines how long the I_{low} condition has to last before the cold load pick-up is activated.
T_{max}	0.000…1800.000s	0.005s	30.000s	The function's maximum timer which defines how long the starting condition can last and for how long the current is allowed to be over I_{high}.
T_{min}	0.000…1800.000s	0.005s	0.040s	The function's minimum timer which defines how long the starting condition has to last at the minimum. If the start-up sequence includes more than one inrush situation, this parameter may be used to prolong the cold load pick-up time over the first inrush. Additionally, this parameter operates as the "reclaim" time for the function in case the inrush current is not immediately initiated in the start-up sequence.

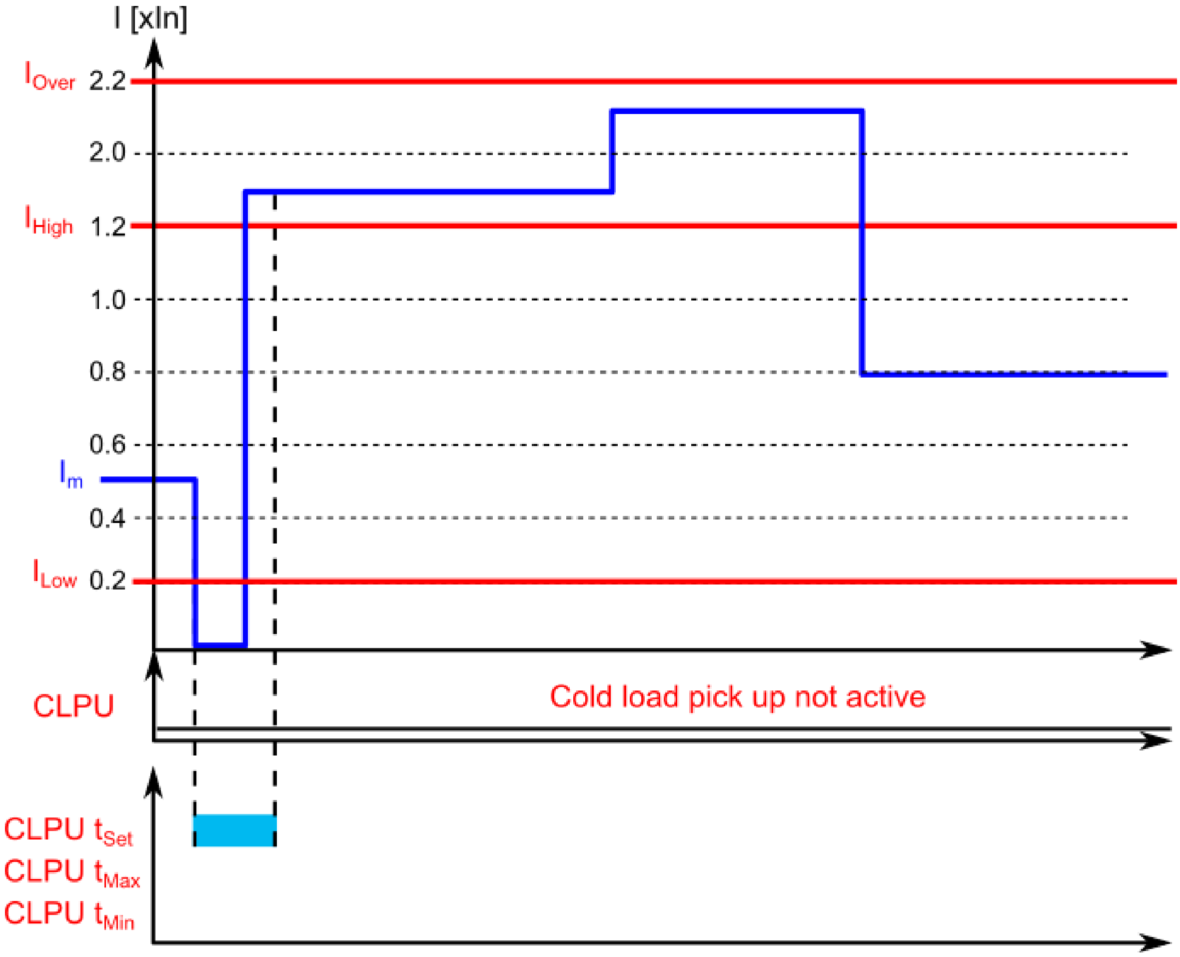
The six examples below showcase some typical cases with the cold load pick-up function.

Figure. 4.5.3 - 110. Example of timers and pick-up parameters (normal CLPU situation).



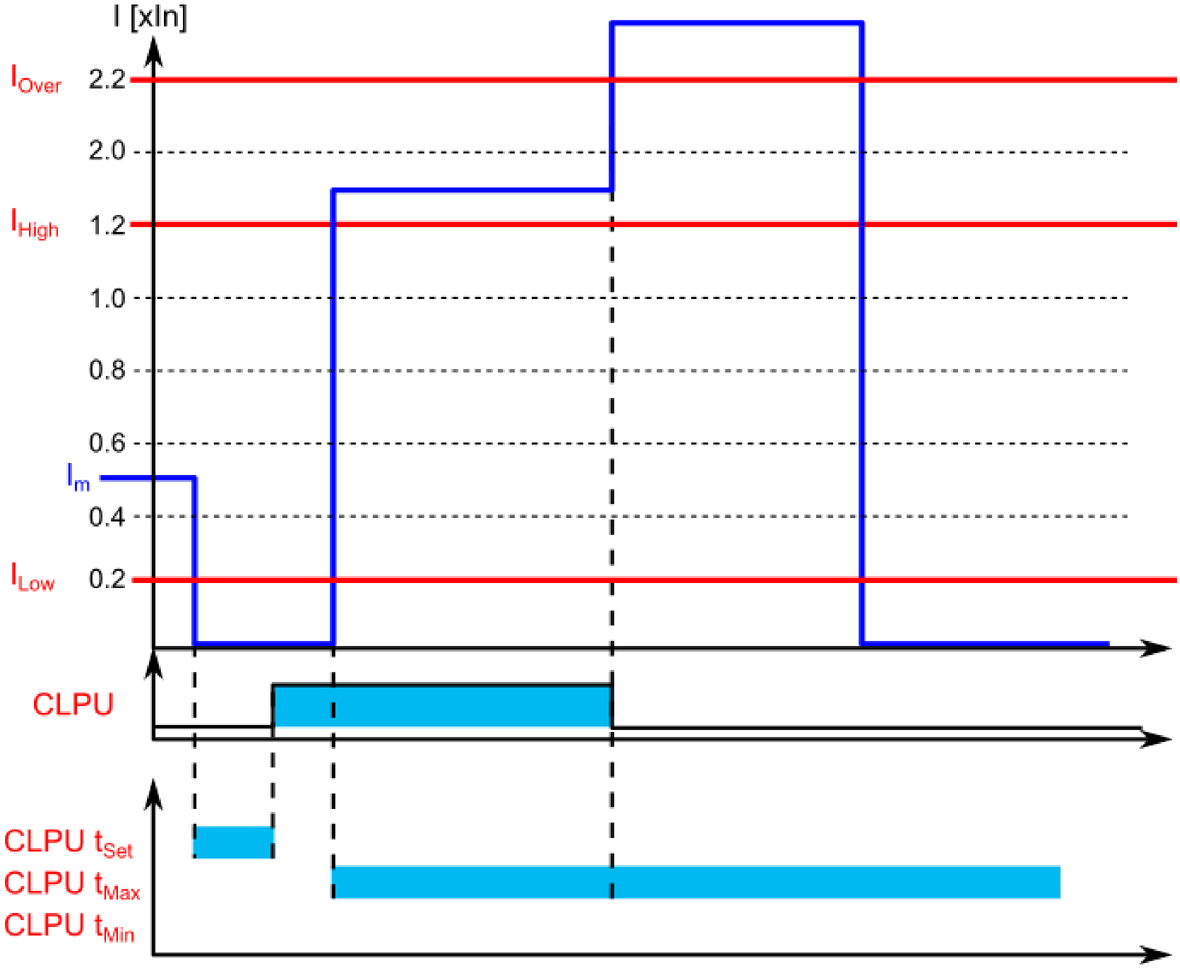
In the example above, the cold load pick-up function activates after the measured current dips below the I_{low} setting and has been there for T_{set} amount of time. When the current exceeds the I_{high} setting value, a timer starts counting towards the T_{max} time. The pick-up current is cleared before the the counter reaches the T_{max} time, when the measured current goes between of I_{low} and the I_{high}. This is when the start-up condition is considered to be over. The cold load pick-up signal can be prolonged beyond this time by setting the T_{min} to a value higher than 0.000 s.

Figure. 4.5.3 - 111. Example of timers and pick-up parameters (no cold load pick-up, I_{low} too short).



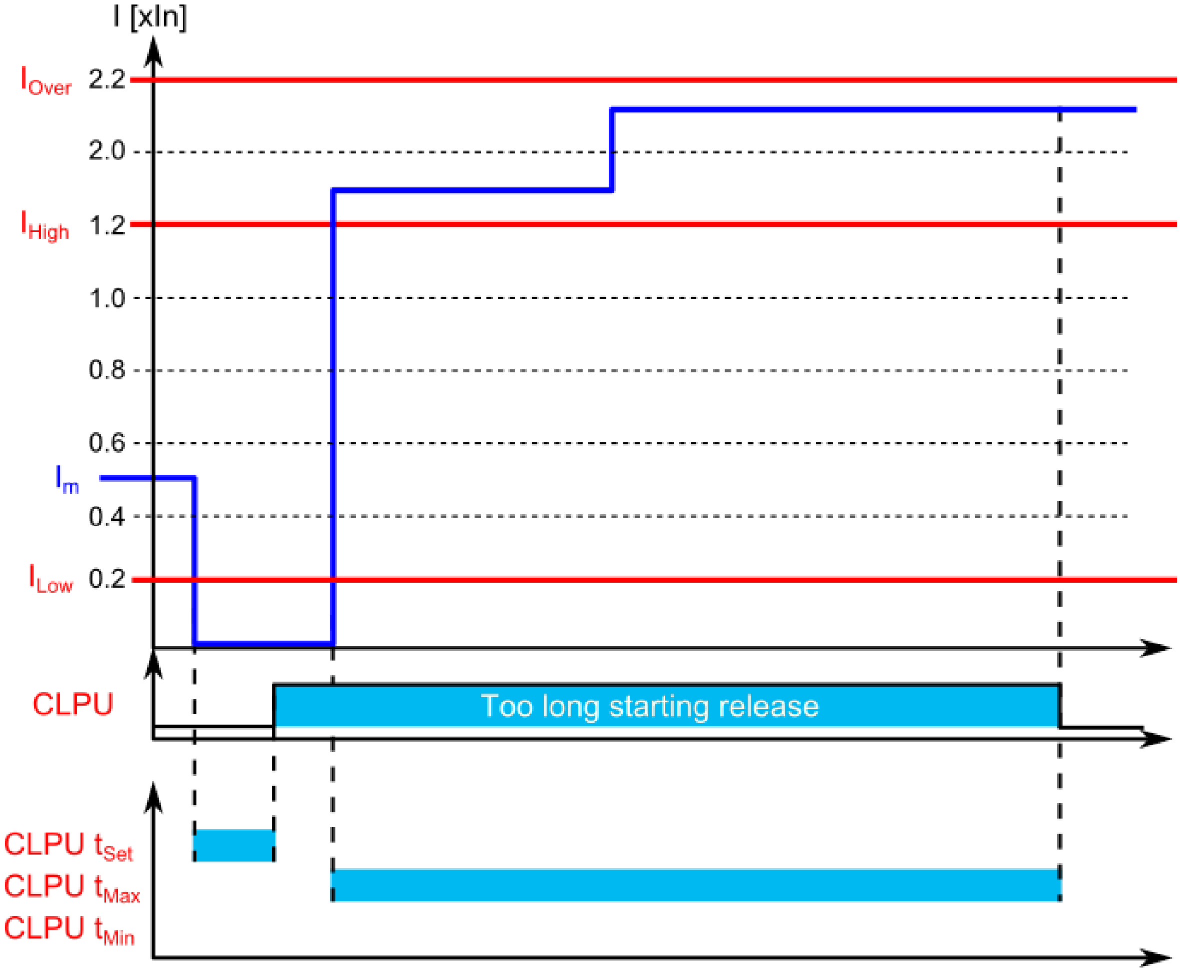
In the example above, the cold load pick-up function does not activate even when the measured current dips below the I_{low} setting, because the T_{set} is not exceeded and therefore no cold load pick-up signal is issued. If the user wants the function to activate within a shorter period of time, the T_{set} parameter can be se to a lower value. If the user wants no delay, the T_{set} can be zero seconds and the operation will be immediate.

Figure. 4.5.3 - 112. Example of timers and pick-up parameters (activated pick-up and instant release due to overcurrent).



In the example above, the cold load pick-up function activates after the measured current dips below the I_{low} setting and has been there for T_{set} amount of time. When the I_m exceeds the I_{high} setting, a counter starts counting towards the T_{max} time. The measured current exceeds the I_{over} setting during the start-up situation and causes the cold load pick-up signal to be released immediately.

Figure. 4.5.3 - 113. Example of timers and pick-up parameters (activated pick-up and instant release due to too long starting).



In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. When the current exceeds the I_{high} setting, a timer starts counting towards the T_{max} time. The measured current stays above the I_{high} setting until the T_{max} is reached, which causes the release of the cold load pick-up signal.

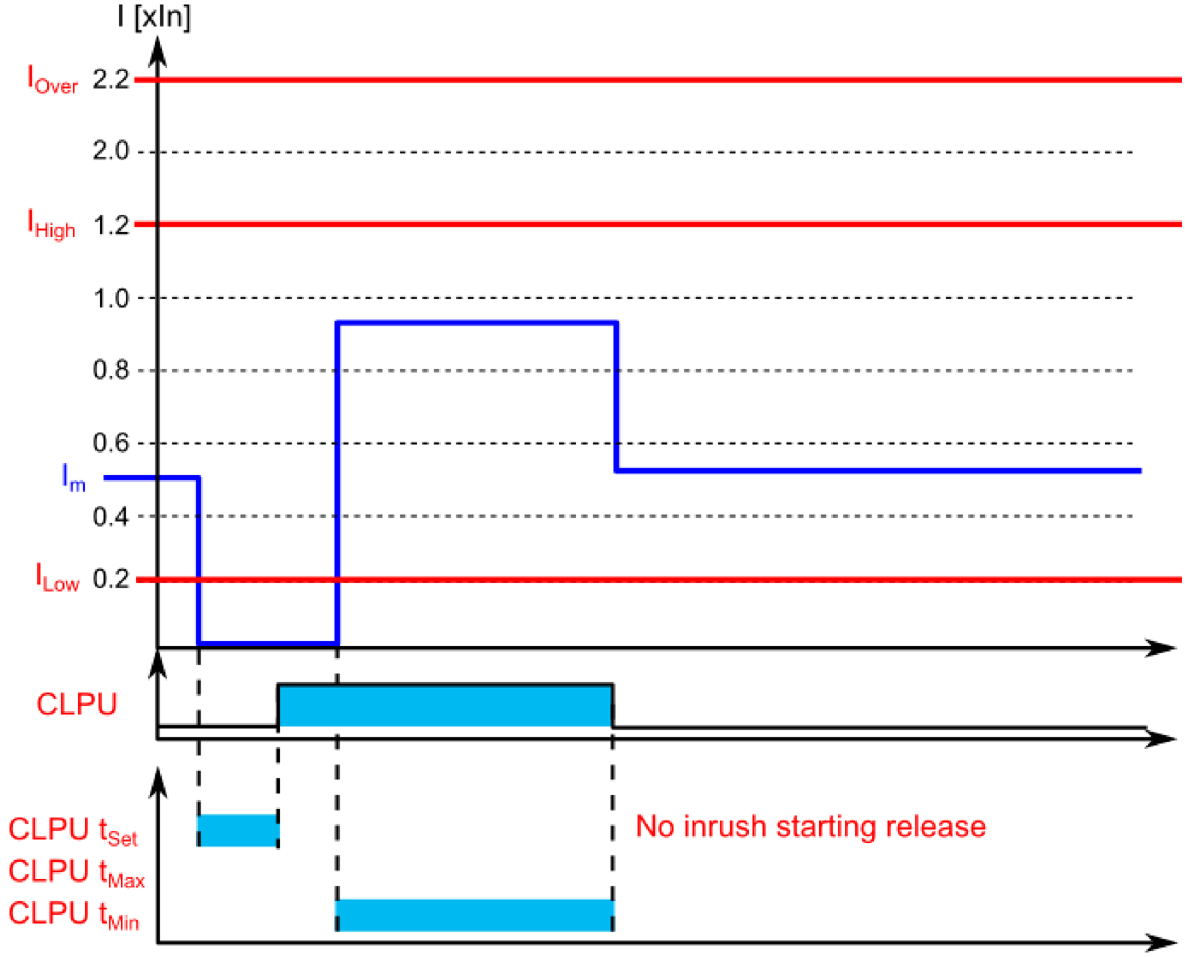
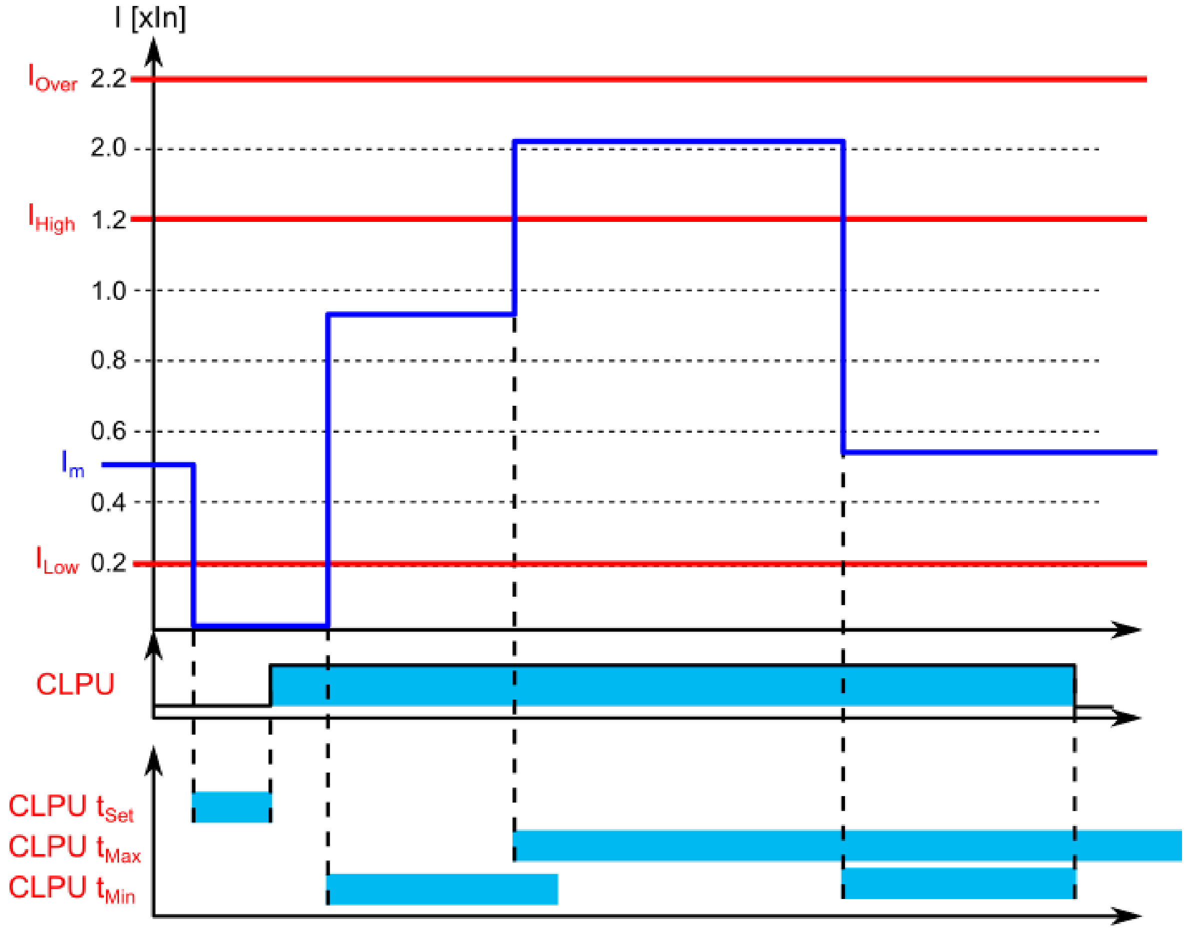


Figure. 4.5.3 - 114. Example of timers and pick-up parameters (no inrush current detected in the starting).

In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. The current stays between the I_{low} setting and the I_{high} setting, so the cold load pick-up signal is active for T_{min} time. As no inrush current is detected during that time, the signal is released.

Figure. 4.5.3 - 115. Example of timers and pick-up parameters (an inrush current detected during T_{min} time).



In the example above, the cold load pick-up function activates after the measured current has stayed below the I_{low} setting for a T_{set} amount of time. The current increases to between the I_{low} setting and the I_{high} setting, which causes a counter to start counting towards the T_{min} time. Before the counter reaches T_{min}, the current exceeds the I_{high} setting, which causes a counter to start counting towards the T_{max} time. The cold load pick-up signal remains active until the T_{max} has been reached, or until the start-up is over and the T_{min} time is over.

Events and registers

The cold load pick-up function (abbreviated "CLP" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the CLPU ACT and BLOCKED events.

Table. 4.5.3 - 90. Event messages.

Event block name	Event names
CLP1	LowStart ON
CLP1	LowStart OFF
CLP1	HighStart ON

Event block name	Event names
CLP1	HighStart OFF
CLP1	LoadNormal ON
CLP1	LoadNormal OFF
CLP1	Overcurrent ON
CLP1	Overcurrent OFF
CLP1	CLPUActivated ON
CLP1	CLPUActivated OFF
CLP1	Block ON
CLP1	Block OFF

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

Table. 4.5.3 - 91. Register content.

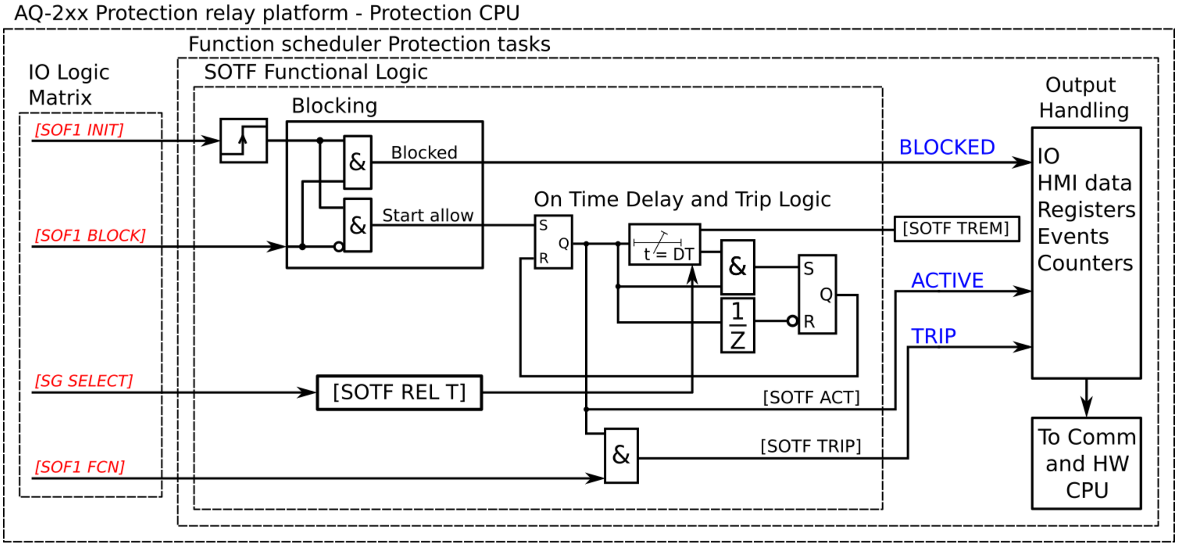
Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
L1/L2/L3 current	Phase currents on trigger time
Time to CLPUact	Time remaining before the function is active
CLPU active time	The time the function has been active before starting
Start-up time	Recorded starting time
Releasing time of CLPU	Reclaim time counter
Setting group in use	Setting group 1...8 active

4.5.4 Switch-on-to-fault (SOTF)

The switch-on-to-fault (SOTF) function is used for speeding up the tripping when the breaker is closed towards a fault or forgotten earthing to reduce the damage in the fault location. The function can be used to control protection functions, or it can be used to directly trip a breaker if any of the connected protection functions starts during the set SOTF time. The operation of the function is instant after the conditions are met and any one signal connected to the "*Function input*" input activates.

The function can be initiated by a digital input, or by a circuit breaker "Close" command connected to the "*SOTF activate input*" input. The duration of the SOTF-armed condition can be set by the "Release time for SOTF" setting parameter; it can be changed if the application so requires through setting group selection.

Figure. 4.5.4 - 116. Simplified function block diagram of the switch-on-to-fault function.



Input signals

The function block does not use analog measurement inputs. Instead, its operation is based entirely on binary signal statuses.

Table. 4.5.4 - 92. Input signals.

Input	Description
Activate input	The digital input or logic signal for the function to arm and start calculating the SOTF time. Any binary signal can be used to activate the function and start the calculation. The rising edge of the signal is considered as the start of the function.
Block input	The input for blocking the function. Any binary signal can be used to block the function from starting.
Function input	The function input activates the function's instant trip if applied when the function is calculating the SOTF time.

Settings

The switch-on-to-fault function has one setting and it determines how long the function remains active after it has been triggered. If the inputs receive any of the set signals during this time, the function's trip is activated.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.5.4 - 93. Settings of the function.

Name	Range	Default	Description
SOTF force status to	• Normal • Blocked • Active • Trip	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Name	Range	Default	Description
Release time for SOTF	0.000…1800.000s	1.000s	The time the function is active after triggering.

Read-only parameters

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

Table. 4.5.4 - 94. Information displayed by the function.

Name	Range	Description
SOTF condition	• Normal • Init • Active • Trip • Blocked	Displays status of the control function.

Function blocking

The function can be blocked by activating the BLOCK input. This prevents the function's active time from starting.

Events and registers

The switch-on-to-fault function (abbreviated "SOF" in event block names) generates events and registers from the status changes in the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the INIT, BLOCKED, ACTIVE and TRIP events.

Table. 4.5.4 - 95. Event messages.

Event block name	Event names
SOF1	SOTF Init ON
SOF1	SOTF Init OFF
SOF1	SOTF Block ON
SOF1	SOTF Block OFF
SOF1	SOTF Active ON
SOF1	SOTF Active OFF
SOF1	SOTF Trip ON
SOF1	SOTF Trip OFF

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

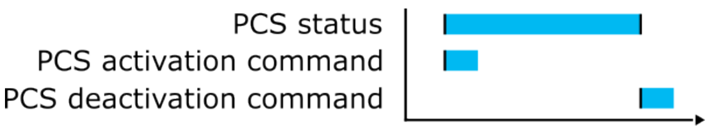
Table. 4.5.4 - 96. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Used SG	Setting group 1...8 active
SOTF remaining time	The time remaining of the set release time.
SOTF been active time	The time the function has been active.

4.5.5 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 device's 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).

Figure. 4.5.5 - 117. When a PCS has been controlled "ON" or "OFF", the PCS will keep its state.



Settings.

These settings can be accessed at *Control → Device I/O → Programmable control switch*.

Table. 4.5.5 - 97. Settings.

Name	Range	Default	Description
Switch name	-	Switchx	The user-settable name of the selected switch. The name can be up to 32 characters long.
Access level for Mimic control	• User • Operator • Configurator • Super user	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 the status changes in the events listed below. 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. The function offers five (5) independent switches. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.5 - 98. 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

4.5.6 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 "4x mA output & 1x mA input" option cards
- mA input in "4x mA input & 1x mA output" option cards
- Digital input voltages

Table. 4.5.6 - 99. Main settings (input channel).

Name	Range	Step	Default	Description
Analog input scaling	• Disabled • Activated	-	Disabled	Enables and disables the input.

Name	Range	Step	Default	Description
Scaling curve 1...10	• Disabled • Activated	-	Disabled	Enables and disables the scaling curve and the input measurement.
Curve 1...10 input signal select	• S7 mA Input • S8 mA Input • S15 mA Input • S16 mA Input • DI1...DI20 Voltage • RTD S1...S16 Resistance • mA In 1 (I card 1) • mA In 2 (I card 2) • mA In 1 (T card 1) • mA In 2 (T card 1) • mA In 3 (T card 1) • mA In 4 (T card 1) • mA In 1 (T card 2) • mA In 2 (T card 2) • mA In 3 (T card 2) • mA In 4 (T card 2)	-	S7 mA Input	Defines the measurement used by scaling curve.
Curve 1...10 input signal filtering	• No • Yes	-	No	Enables calculation of the average of received signal.
Curve 1...10 input signal filter time constant	0.005...3800.000 s	0.005 s	1 s	Time constant for input signal filtering. This parameter is visible when "Curve 1...4 input signal filtering" has been set to "Yes".
Curve 1...10 input signal out of range set	• No • Yes	-	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...10 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...10 input	-1 000 000.00...1 000 000.00	0.00001	-	Displays the input measurement received by the curve.
Curve1...10 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.

Name	Range	Step	Default	Description
Curve1...10 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...10 input out of range" signal, which can be used inside logic or with other functions of the device. 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. 4.5.6 - 100. Output settings and indications.

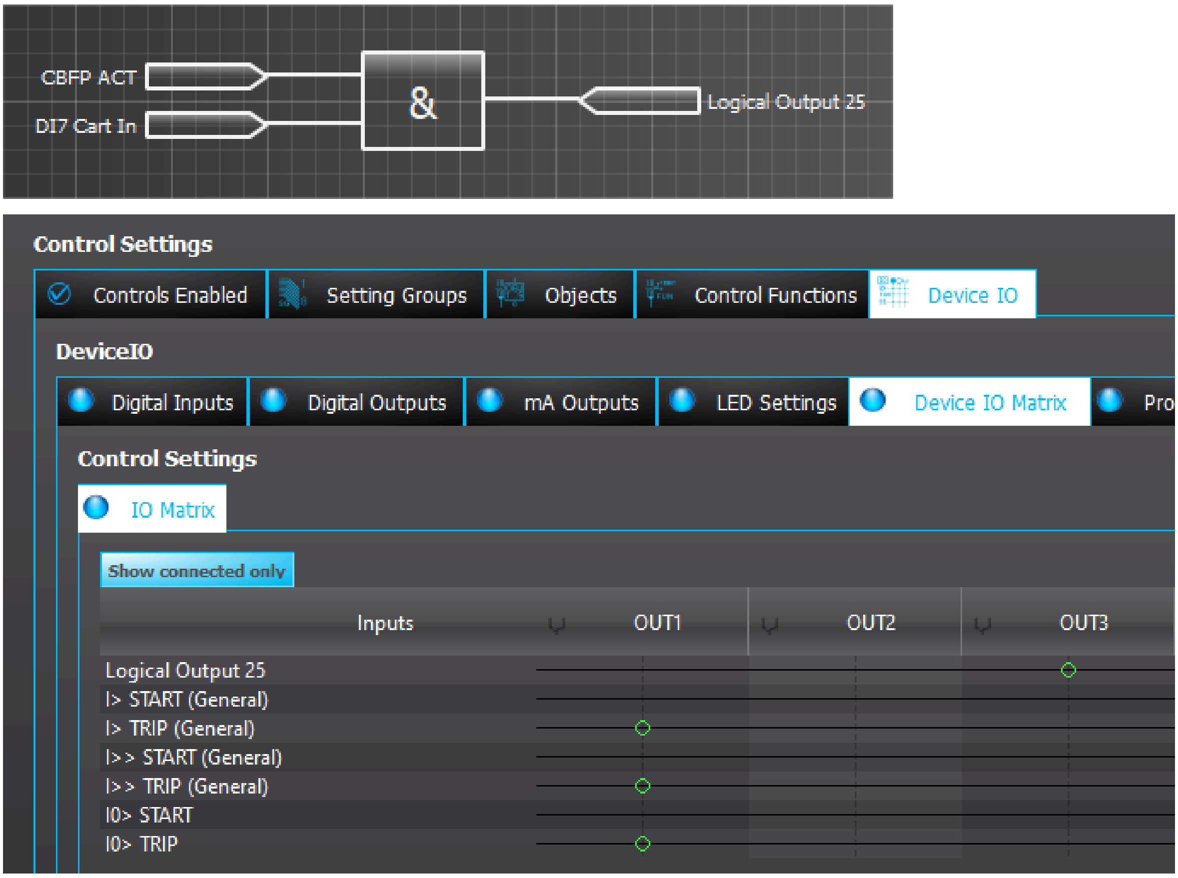
Name	Range	Step	Default	Description
Curve 1...10 update cycle	5...10 000ms	5ms	150ms	Defines the length of the input measurement update cycle. If the user wants a fast operation, this setting should be fairly low.
Scaled value handling	• Floating point • Integer out (Floor) • Integer (Ceiling) • Integer (Nearest)	-	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.

Name	Range	Step	Default	Description
Add curvepoint 3...20	• Not used • Used	-	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.

4.5.7 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. 32 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 3 ("OUT3") when the circuit breaker's cart status is "In".

Figure. 4.5.7 - 118. 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
-
-
- etc.

Table. 4.5.7 - 101. Logical output user description.

Name	Range	Default	Description
User editable description LO1...32	1...31 characters	Logical output 1...32	Description of the logical output. This description is used in several menu types for easier identification.

Events

The logical outputs (abbreviated "LOGIC" in event block names) generates events from the status changes in the events listed below. 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. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.7 - 102. Event messages.

Event block name	Event names
LOGIC1	Logical out 1...32 ON
LOGIC1	Logical out 1...32 OFF

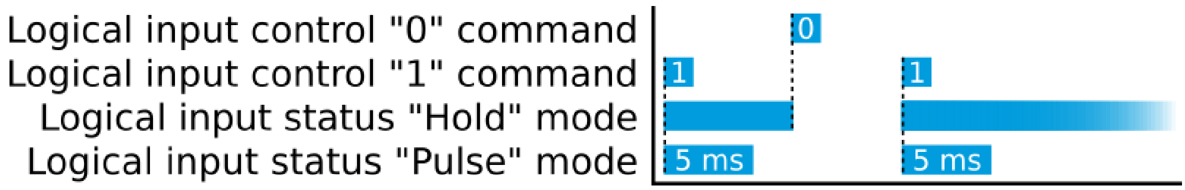
4.5.8 Logical inputs

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. Logical inputs are volatile signals: their status will always return to "0" when the AQ-200 device is rebooted. 32 logical inputs are available.

Logical inputs have two modes available: Hold and Pulse. When a logical input which has been set to "Hold" mode is controlled to "1", the input will switch to status "1" and it stays in that status until it is given a control command to go to status "0" or until the device is rebooted. When a logical input which has been set to "Pulse" mode is controlled to "1", the input will switch to status "1" and return back to "0" after 5 ms.

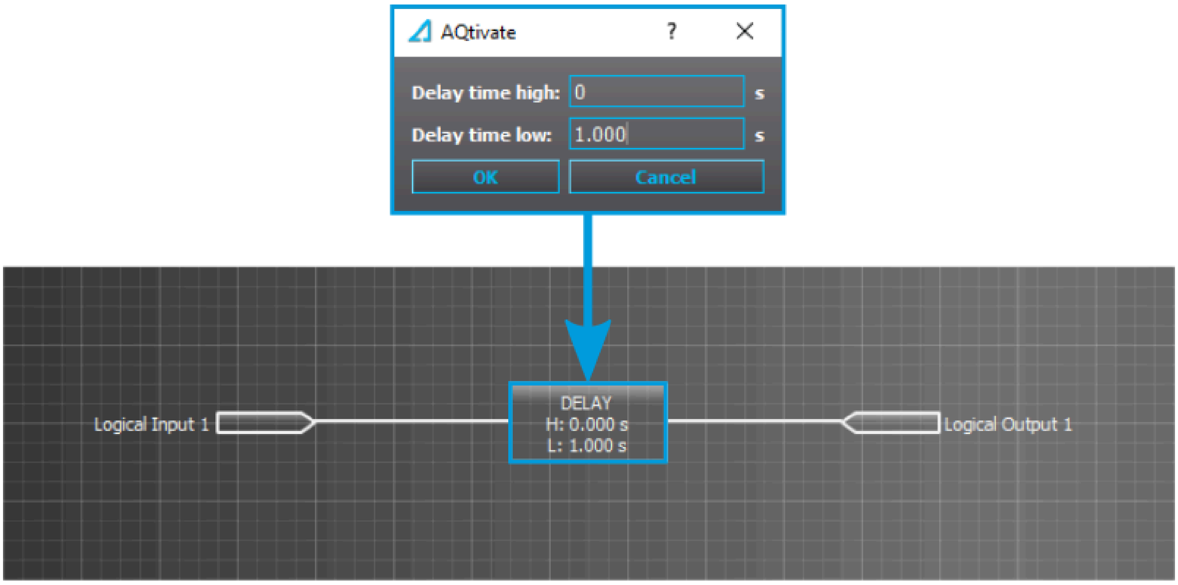
The figure below presents the operation of a logical input in Hold mode and in Pulse mode.

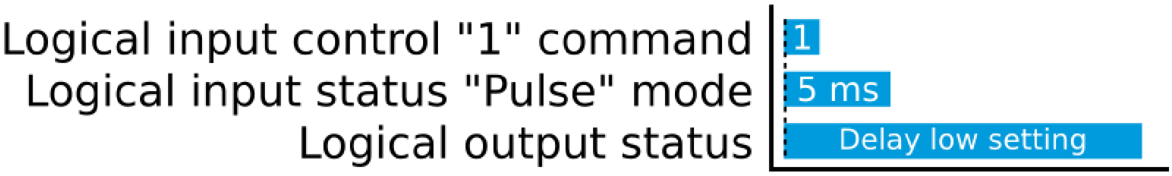
Figure. 4.5.8 - 119. Operation of logical input in "Hold" and "Pulse" modes.



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. 4.5.8 - 120. 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
-
-
- etc.

Table. 4.5.8 - 103. Logical input user description.

Name	Range	Default	Description
User editable description LI1...32	1...31 characters	Logical input 1...32	Description of the logical input. This description is used in several menu types for easier identification.

Events

The logical outputs (abbreviated "LOGIC" in event block names) generates events from the status changes in the events listed below. 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. The function's output signals can be used for direct I/O controlling and user logic programming.

Table. 4.5.8 - 104. Event messages.

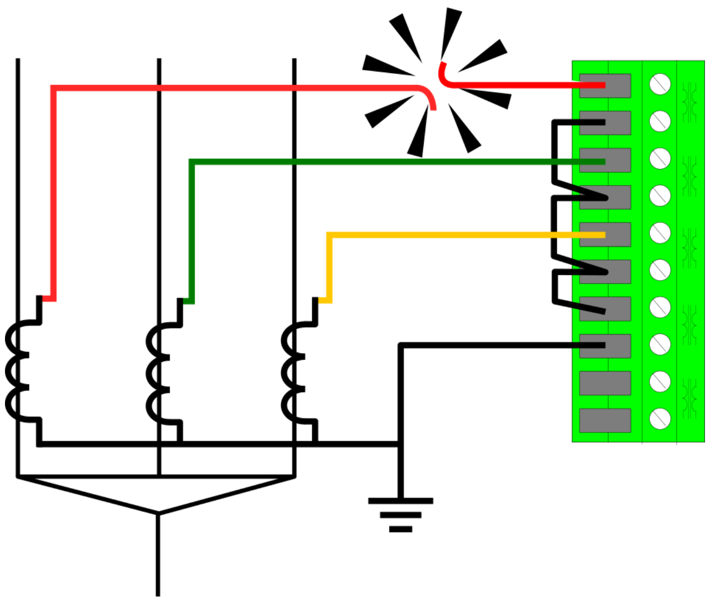
Event block name	Event names
LOGIC2	Logical in 1...32 ON
LOGIC2	Logical in 1...32 OFF

4.6 Monitoring functions

4.6.1 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. 4.6.1 - 121. Secondary circuit fault in phase L1 wiring.

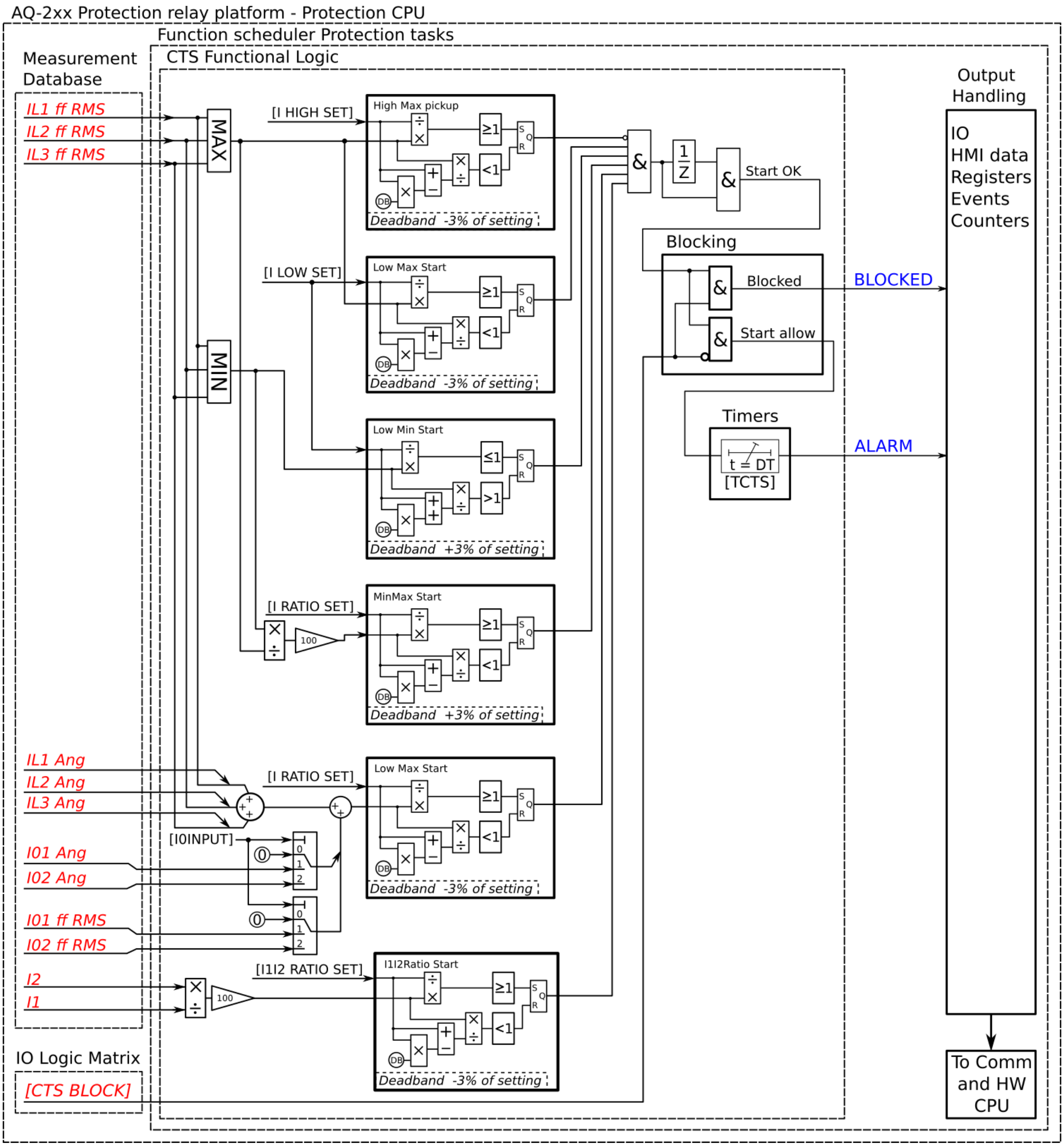


The function constantly monitors the instant values and the key calculated magnitudes of the phase currents. Additionally, the residual current circuit can be monitored if the residual current is measured from a dedicated residual current CT. The user can enable and disable the residual circuit monitoring at will.

The following conditions have to be 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 minimum and maximum of the three-phase currents is below the I_{set} *ratio* setting.
- The ratio between the negative sequence and the positive sequence exceeds the *I2/I1 ratio* setting.
- The calculated difference (IL1+IL2+IL3+I0) exceeds the I_{sum} *difference* setting (optional).
- The above-mentioned condition is met until the set time delay for alarm.

Figure. 4.6.1 - 122. Simplified function block diagram of the CTS function.



Measured input

The function block uses fundamental frequency component of phase current measurement values and residual current measurement values. The function supervises the angle of each current measurement channel. Positive sequence current and negative sequence currents are calculated from the phase currents. The user can select what is used for the residual current measurement: nothing, the I01 channel, or the I02 channel.

Table. 4.6.1 - 105. Measured inputs of the CTS function.

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current

Signal	Description
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current
I_{01}RMS	Fundamental frequency component of residual input I01
I_{02}RMS	Fundamental frequency component of residual input I02

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. 4.6.1 - 106. General settings of the function.

Name	Range	Default	Description
CTS force status to	• Normal • Alarm • Blocked	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.
I0 input selection	• Not in use • I01 • I02	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	• Add • Subtract	Add	Defines the polarity of residual current channel connection.
Compensate natural unbalance	• - • Comp	-	When activated while the line is energized, the currently present calculated residual current is compensated to 0.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.1 - 107. 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. If this condition is met, it is considered as fault and the function is not activated.

Name	Range	Step	Default	Description
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. 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. 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. This condition has to be met for the function to activate. 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.

Read-only parameters

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

Table. 4.6.1 - 108. Information displayed by the function.

Name	Range	Step	Description
Uncompensated residual unbalance Pri	• Normal • Start • Trip • 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.
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 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".

Typical cases of current transformer supervision

The following nine examples present some typical cases of the current transformer supervision and their setting effects.

Figure. 4.6.1 - 123. All works properly, no faults.

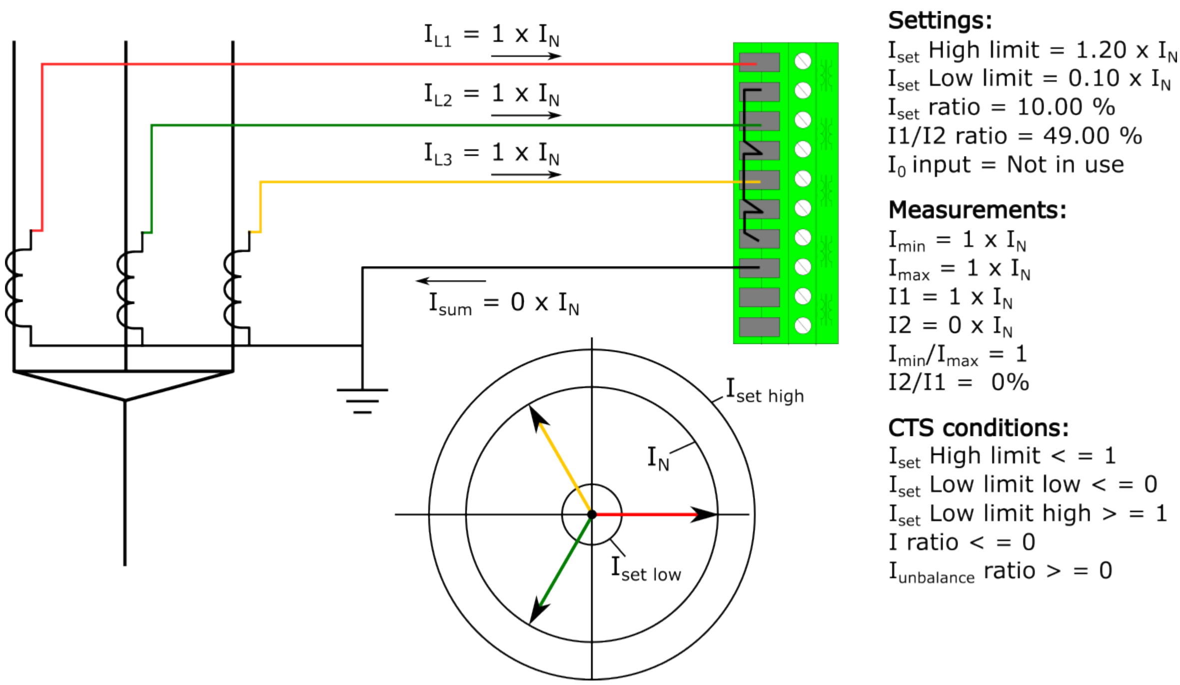
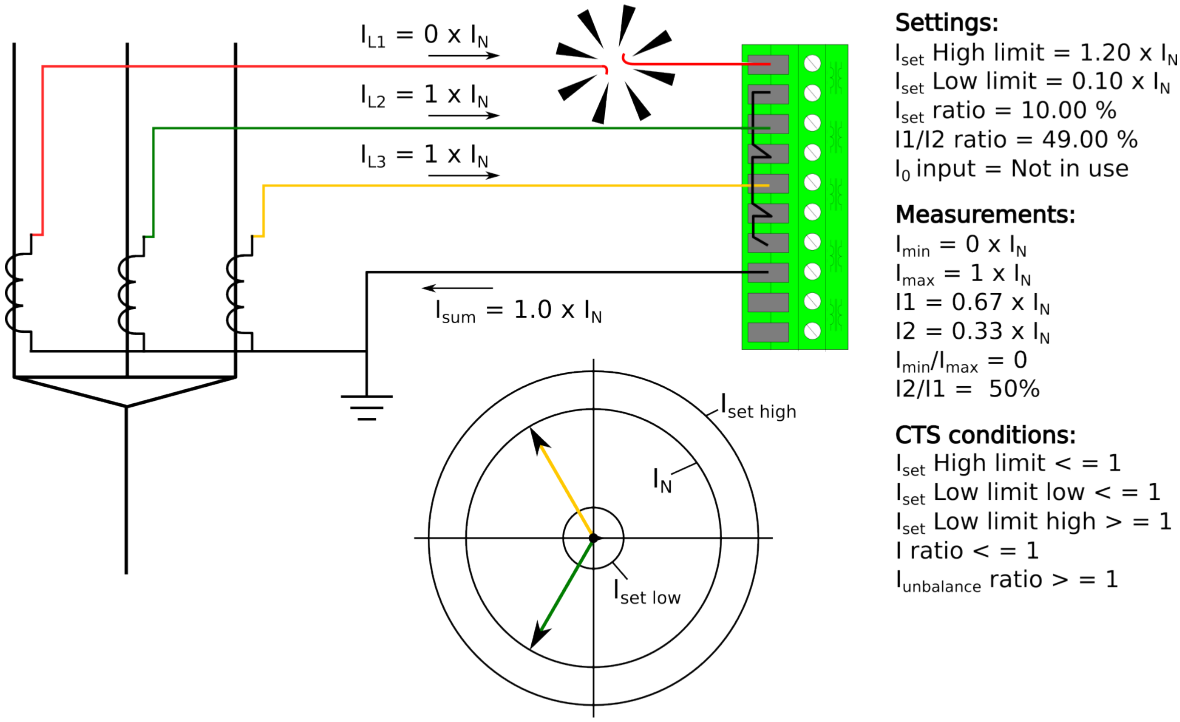
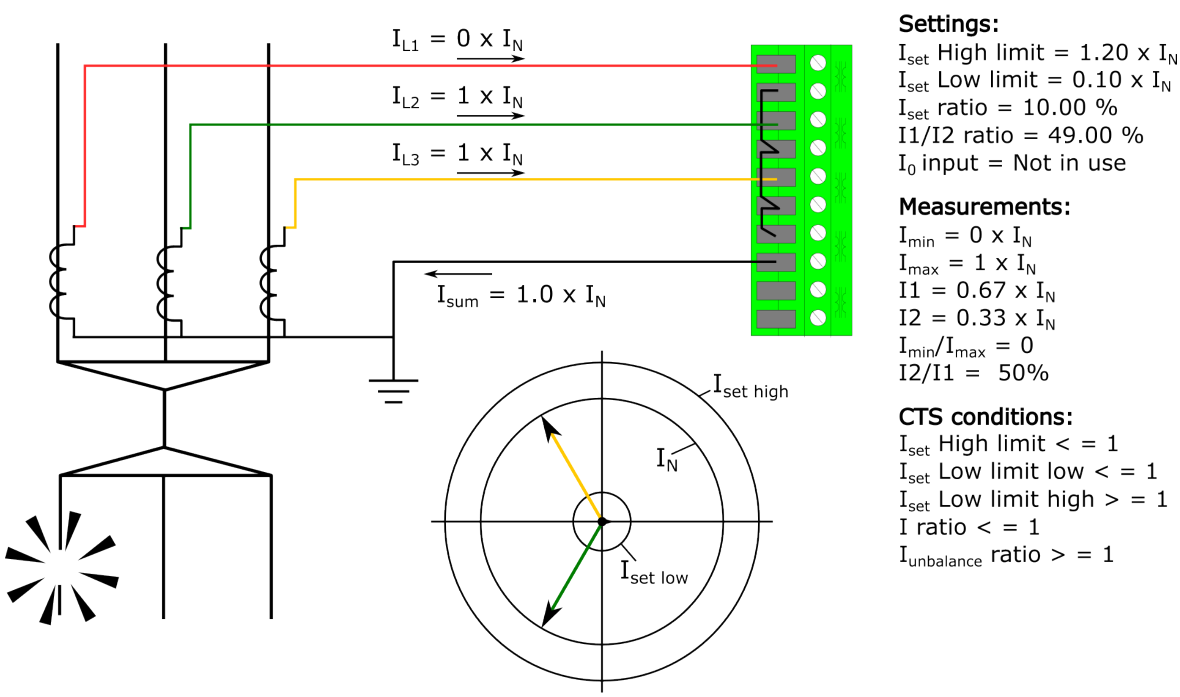


Figure. 4.6.1 - 124. Secondary circuit fault in phase L1 wiring.



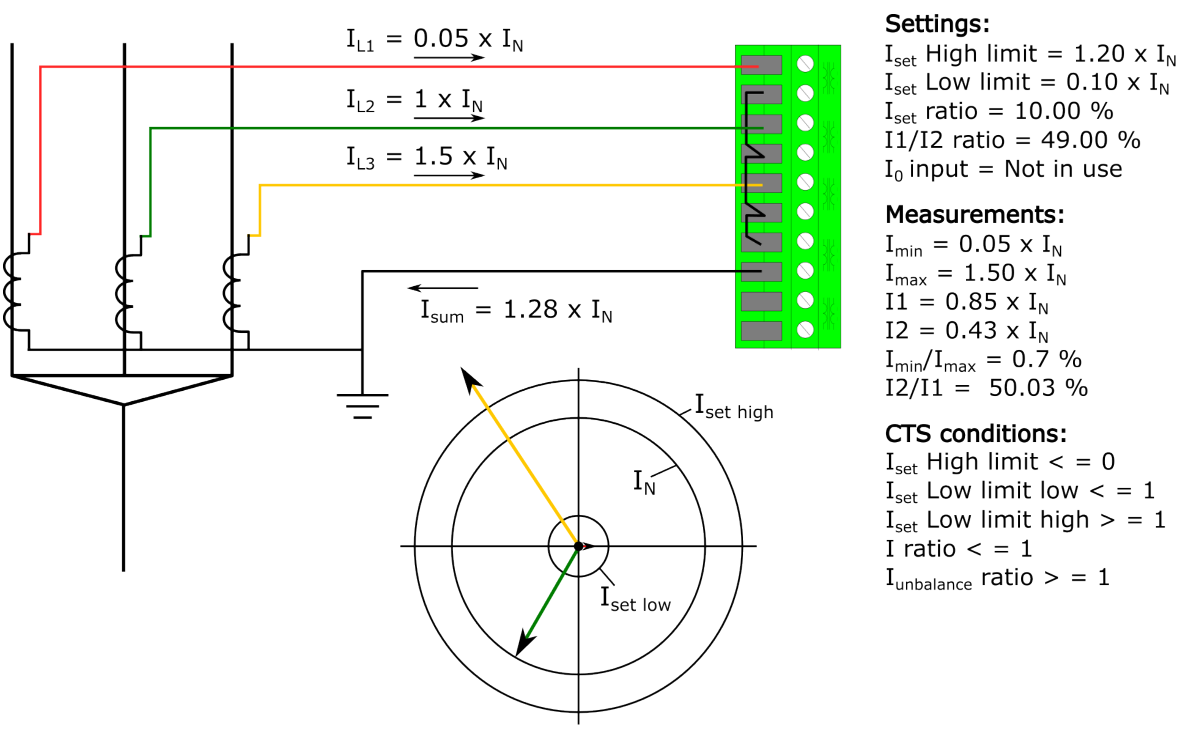
When a fault is detected and all conditions are met, the CTS timer starts counting. If the situation continues until the set time has passed, the function issues an alarm.

Figure. 4.6.1 - 125. Primary circuit fault in phase L1 wiring.



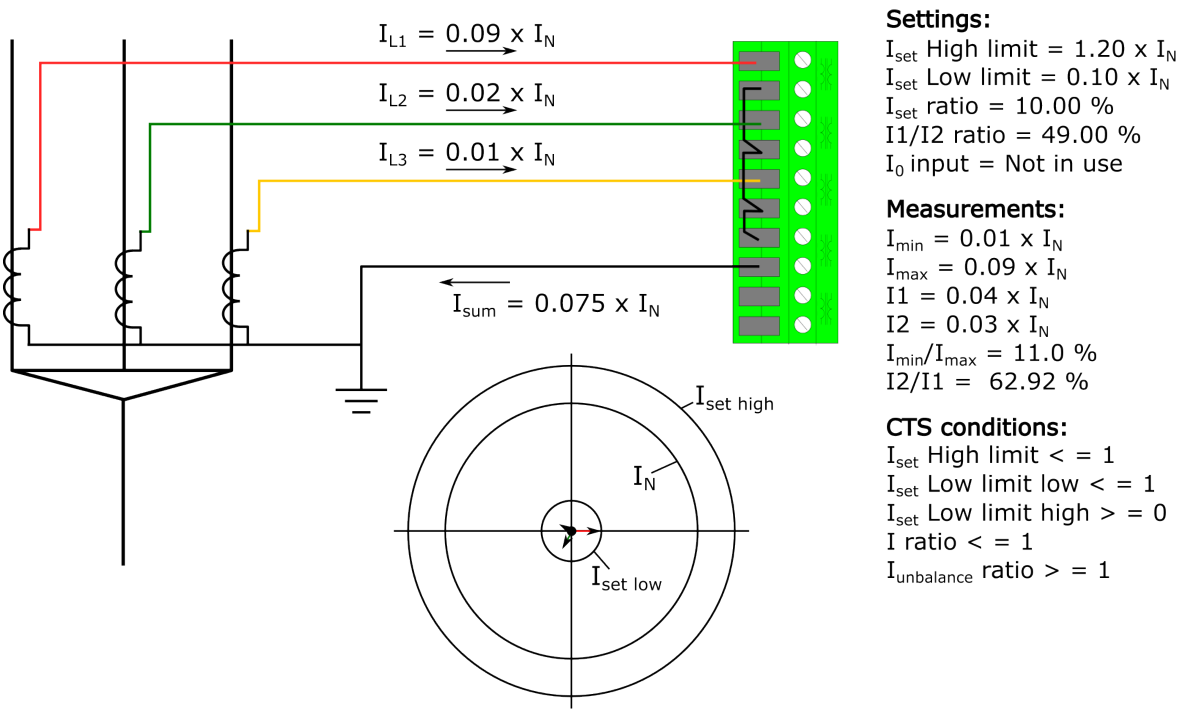
In this example, distinguishing between a primary fault and a secondary fault is impossible. However, the situation meets the function's activation conditions, and if this state (secondary circuit fault) continues until the set time has passed, the function issues an alarm. This means that the function supervises both the primary and the secondary circuit.

Figure. 4.6.1 - 126. No wiring fault but heavy unbalance.



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.

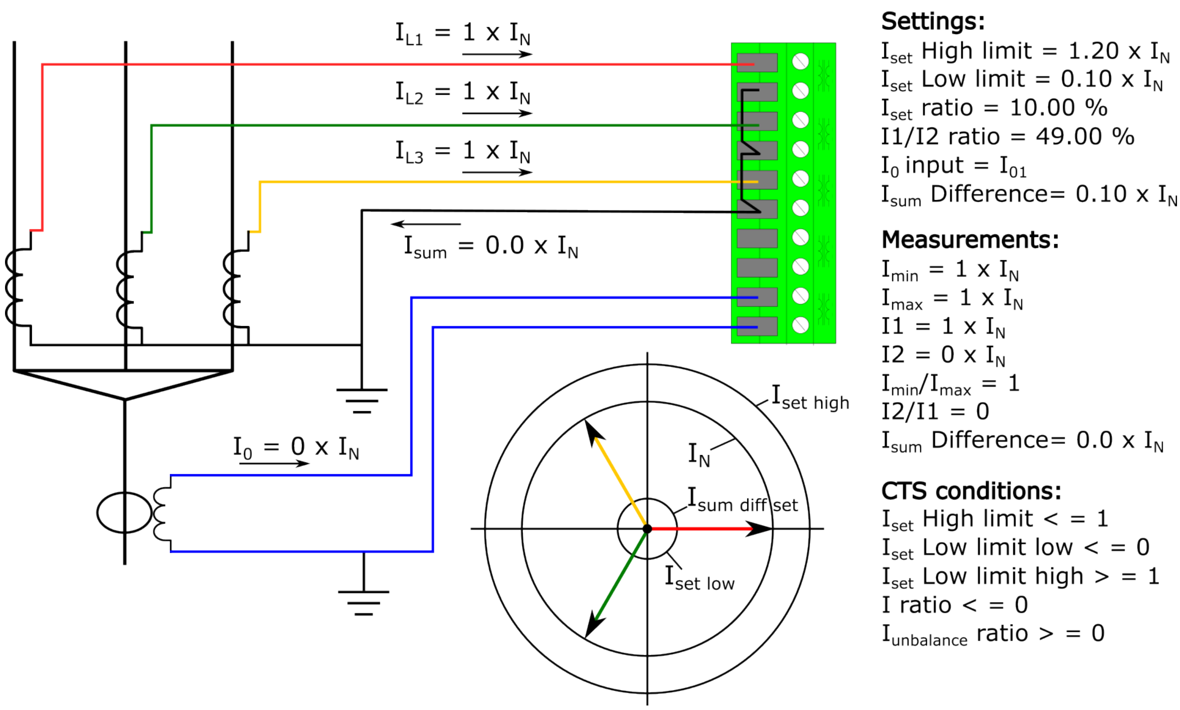
Figure. 4.6.1 - 127. Low current and heavy unbalance.



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.

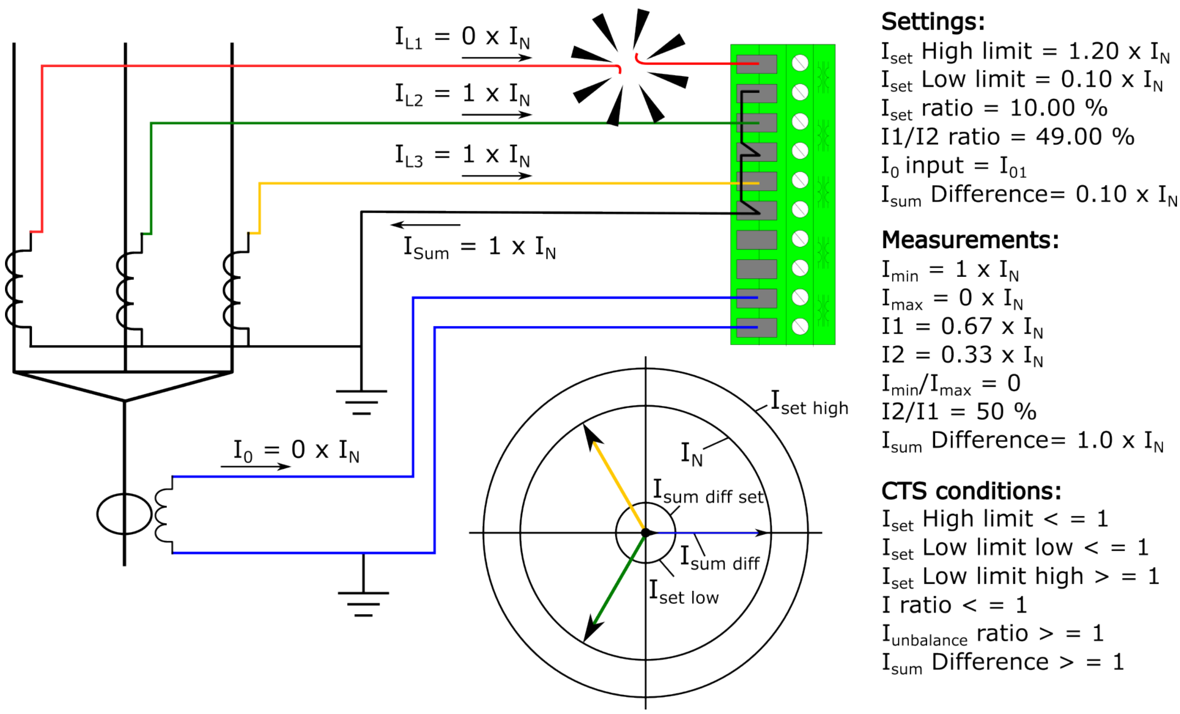
If the I_{set} *high limit* and I_{set} *low limit* setting parameters are adjusted according to the application's normal behavior, the operation of the function can be set to be very sensitive for broken circuit and conductor faults.

Figure. 4.6.1 - 128. Normal situation, residual current also measured.



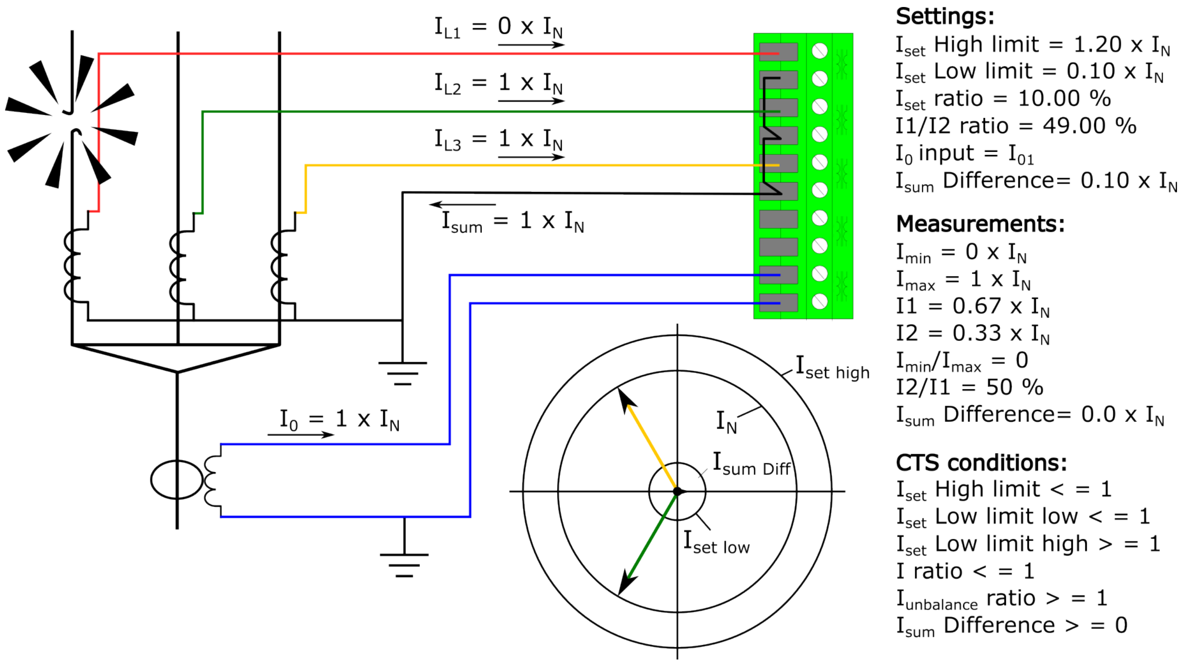
When the residual condition is added with the "I0 input selection", the sum of the current and the residual current are compared against each other to verify the wiring condition.

Figure. 4.6.1 - 129. Broken secondary phase current wiring.



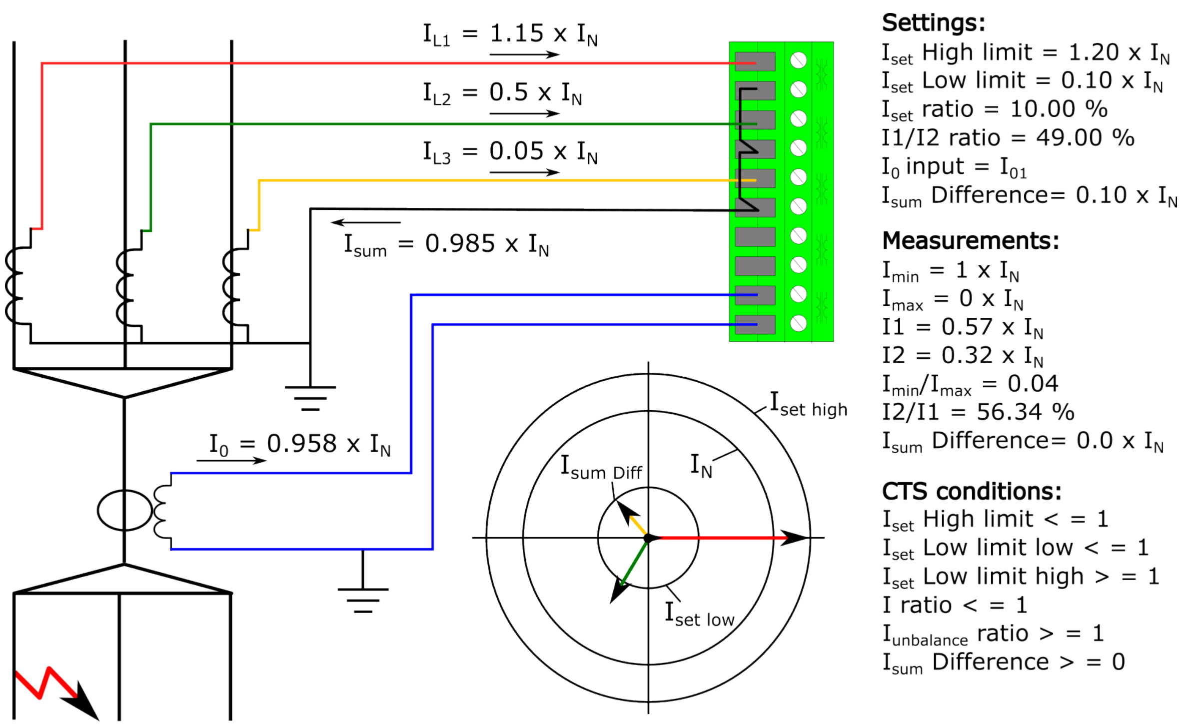
When phase current wire is broken all of the conditions are met in the CTS and alarm shall be issued in case if the situation continues until the set alarming time is met.

Figure. 4.6.1 - 130. Broken primary phase current wiring.



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. 4.6.1 - 131. Primary side high-impedance earth fault.



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 the events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the CTS ALARM and BLOCKED events.

Table. 4.6.1 - 109. Event messages.

Event block name	Event names
CTS1	Alarm ON
CTS1	Alarm OFF
CTS1	Block ON
CTS1	Block OFF

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

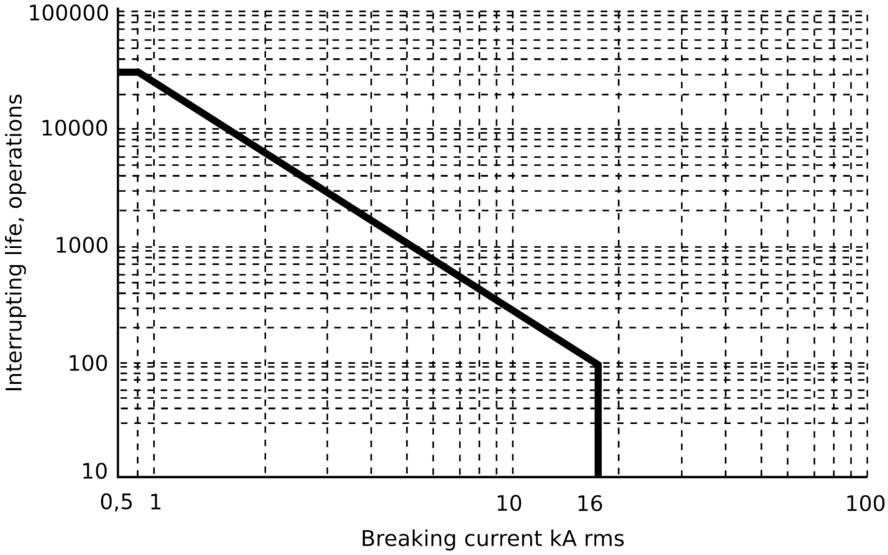
Table. 4.6.1 - 110. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Trigger currents	The phase currents (L1, L2 & L3), the residual currents (I01 & I02), and the sequence currents (I1 & I2) on trigger time.
Time to CTSact	Time remaining before alarm activation.
Fault type	The status code of the monitored current.
Setting group in use	Setting group 1...8 active

4.6.2 Circuit breaker wear monitoring

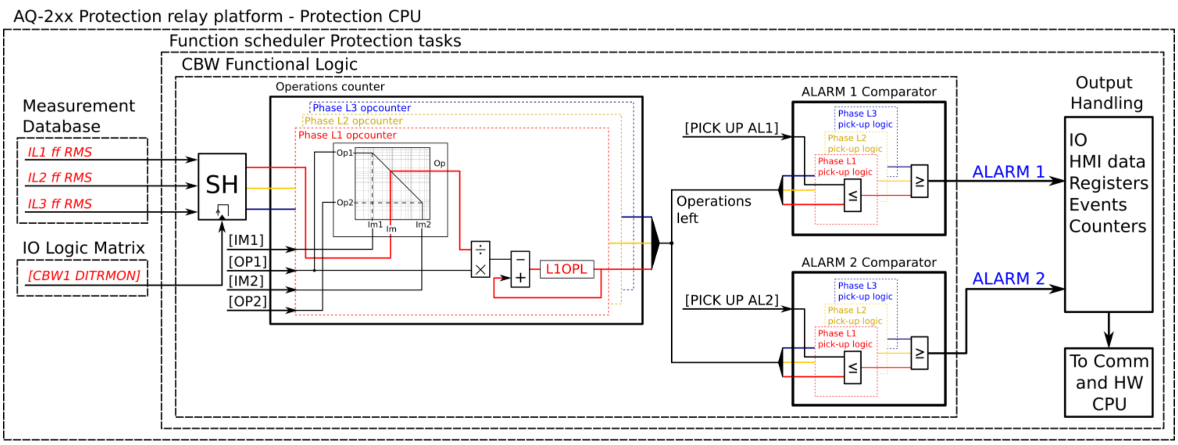
The circuit breaker wear function is used for monitoring the circuit breaker's lifetime and its maintenance needs caused by interrupting currents and mechanical wear. The function uses the circuit breaker's manufacturer-supplied data for the breaker operating cycles in relation to the interrupted current magnitudes.

Figure. 4.6.2 - 132. 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.

Figure. 4.6.2 - 133. Simplified function block diagram of the circuit breaker wear function.



Measured input

The function block uses fundamental frequency component of phase current measurement values.

Table. 4.6.2 - 111. Measurement inputs of the circuit breaker wear function.

Signal	Description
I_{L1}RMS	Fundamental frequency component of phase L1 (A) current
I_{L2}RMS	Fundamental frequency component of phase L2 (B) current
I_{L3}RMS	Fundamental frequency component of phase L3 (C) current

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. 4.6.2 - 112. General settings.

Name	Range	Default	Description
CBW force status to	• Normal • Alarm1 On • Alarm2 On	Normal	Force the status of the function. Visible only when *Enable stage forcing* parameter is enabled in *General* menu.

Circuit breaker characteristics settings

The circuit breaker characteristics are set by two operating points, defined by the nominal breaking current, the maximum allowed breaking current and their respective operation settings. This data is provided by the circuit breaker's manufacturer.

Table. 4.6.2 - 113. Settings for circuit breaker characteristics.

Name	Range	Step	Default	Description
Operations 1	0…200 000	1	50 000	The number of interrupting life operations at the nominal current (Close - Open).
Operations 2	0…200 000	1	100	The number of interrupting life operations at the rated breaking current (Open).
Current 1 (I_{nom})	0…100.00kA	0.01kA	1kA	The rated normal current (RMS).
Current 2 (I_{max})	0…100.00kA	0.01kA	20kA	The rated short-circuit breaking current (RMS).

Pick-up settings

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. 4.6.2 - 114. Pick-up settings.

Name	Range	Default	Description
Alarm 1	• Disabled • Enabled	Disabled	Enable and disable the Alarm 1 stage.
Alarm 1 Set	0…200 000	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	• Disabled • Enabled	Disabled	Enable and disable the Alarm 2 stage.

Name	Range	Default	Description
Alarm 2 Set	0…200 000	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

Parameter	Setting
Current 2	16.00 kA
Operations 2	100 operations
Enable Alarm 1	Enabled
Alarm 1 Set	1000 operations
Enable Alarm 2	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.

Read-only parameters

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

Table. 4.6.2 - 115. Information displayed by the function.

Name	Range	Description
CBW condition	• Normal • Alarm1 On • 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 the events listed below. The user can select which event messages are stored in the main event buffer: ON, OFF, or both. The function's outputs can be used for direct I/O controlling and user logic programming. The events triggered by the function are recorded with a time stamp.

The function also provides a resettable cumulative counter for the "Open" operations as well as the ALARM 1 and ALARM 2 events.

Table. 4.6.2 - 116. 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. 4.6.2 - 117. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
Trigger current	Phase currents on trigger time
Deducted Op	L1/L2/L3 Deducted operations from the cumulative sum
Operations left	L1/L2/L3 Operations left

4.6.3 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. 4.6.3 - 134. THD calculation formulas.

$$THD_P = \frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}$$

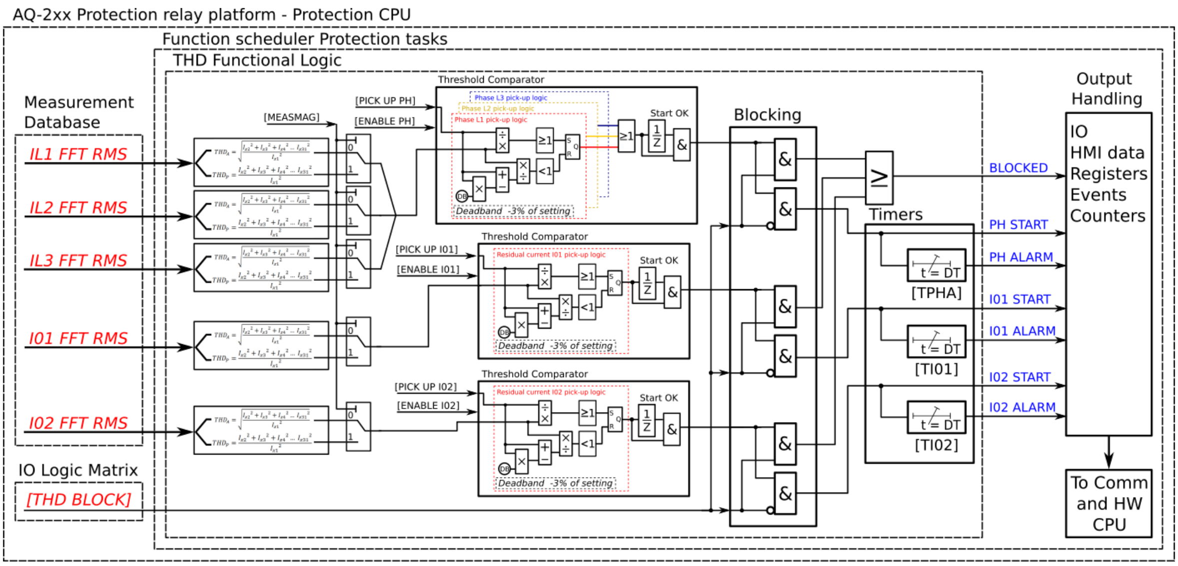
, where
I = measured current,
x= measurement input,
n = harmonic number

$$THD_A = \sqrt{\frac{{I_{x2}}^2 + {I_{x3}}^2 + {I_{x4}}^2 \ldots {I_{x31}}^2}{{I_{x1}}^2}}$$

, 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.

Figure. 4.6.3 - 135. Simplified function block diagram of the total harmonic distortion monitor function.



Measured input

The function block uses phase and residual current measurement channels. 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.

Table. 4.6.3 - 118. Measurement inputs of the total harmonic distortion monitor function.

Signal	Description
I_{L1}FFT	FFT measurement of phase L1 (A) current
I_{L2}FFT	FFT measurement of phase L2 (B) current
I_{L3}FFT	FFT measurement of phase L3 (C) current
I_{01}FFT	FFT measurement of residual I01 current
I_{02}FFT	FFT measurement of residual I02 current

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. 4.6.3 - 119. General settings.

Name	Range	Default	Description
Measurement magnitude	• Amplitude • Power	Amplitude	Defines which available measured magnitude the function uses.

Pick-up settings

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.

Setting group selection controls the operating characteristics of the function, i.e. the user or user-defined logic can change function parameters while the function is running.

Table. 4.6.3 - 120. Pick-up settings.

Name	Range	Step	Default	Description
Enable phase THD alarm	• Enabled • Disabled	-	Enabled	Enables and disables the THD alarm function from phase currents.
Enable I01 THD alarm	• Enabled • Disabled	-	Enabled	Enables and disables the THD alarm function from residual current input I01.
Enable I02 THD alarm	• Enabled • Disabled	-	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.

Name	Range	Step	Default	Description
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.

Read-only parameters

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

Table. 4.6.3 - 121. Information displayed by the function.

Name	Range	Description
THD condition	• Normal • Start • Alarm • 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 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. 4.6.3 - 122. 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 events listed below. 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.

The function's outputs can be used for direct I/O controlling and user logic programming. The function also provides a resettable cumulative counter for the START, ALARM and BLOCKED events.

Table. 4.6.3 - 123. Event messages.

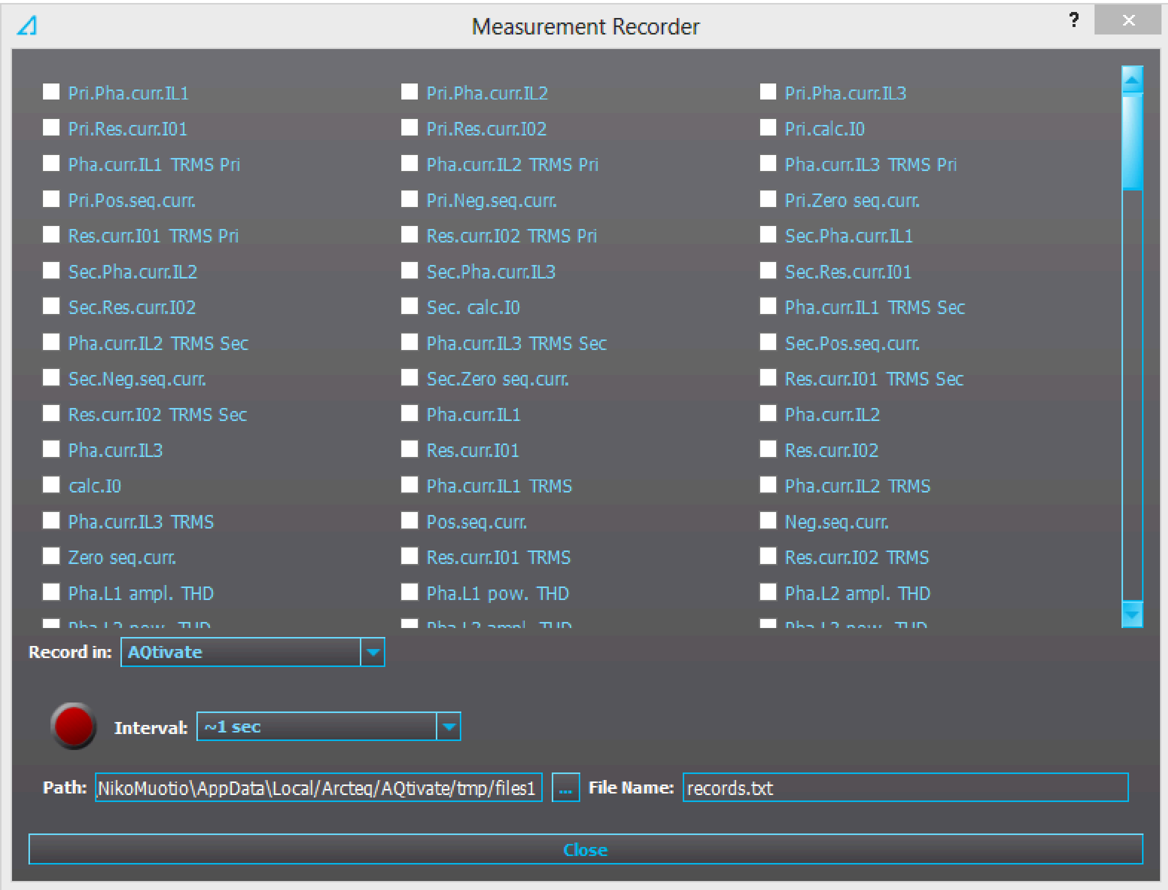
Event block name	Event names
THD1	THD Start Phase ON
THD1	THD Start Phase OFF
THD1	THD Start I01 ON
THD1	THD Start I01 OFF
THD1	THD Start I02 ON
THD1	THD Start I02 OFF
THD1	THD Alarm Phase ON
THD1	THD Alarm Phase OFF
THD1	THD Alarm I01 ON
THD1	THD Alarm I01 OFF
THD1	THD Alarm I02 ON
THD1	THD Alarm I02 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. 4.6.3 - 124. Register content.

Register	Description
Date and time	dd.mm.yyyy hh:mm:ss.mss
Event	Event name
L1h, L2h, L3h Fault THD	Start/Alarm THD of each phase.
Setting group in use	Setting group 1...8 active.

4.6.4 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 device 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 device.

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 device, 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).

Figure. 4.6.4 - 136. Measurement recorder values viewed with AQtivate PRO.

Table. 4.6.4 - 125. 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
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
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	

4.6.5 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.

4.6.6 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 96 digital channels simultaneously with the twenty (20) measured analog channels. Maximum capacity of recordings is 100.

The recorder provides an effective 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 recording 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 96 digital channels are supported.

Table. 4.6.6 - 126. Analog recording channels.

Signal	Description
IL1	Phase current I_{L1}
IL2	Phase current I_{L2}
IL3	Phase current I_{L3}

Signal	Description
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_{L12} (VT card 1)
U2(3)VT1	Line-to-neutral U_{L2} or line-to-line voltage U_{L23} (VT card 1)
U3(1)VT1	Line-to-neutral U_{L3} or line-to-line voltage U_{L31} (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 1)
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_{L12} (VT card 2)

Signal	Description
UL2(3)VT2	Line-to-neutral U_{L2} or line-to-line voltage U_{L23} (VT card 2)
UL3(1)VT2	Line-to-neutral U_{L3} or line-to-line voltage U_{L31} (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. 4.6.6 - 127. 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. 4.6.6 - 128. 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)

Signal	Description	Signal	Description
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)
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)

Signal	Description	Signal	Description
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 device.
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. 4.6.6 - 129. 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

Signal	Description	Signal	Description
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.
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.

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 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". The recording size affects how many recordings can be stored at a time, but the number can't exceed 100 recordings.

Table. 4.6.6 - 130. Recorder control settings.

Name	Range	Description
Recorder enabled	• Enabled • Disabled	Enables and disables the disturbance recorder function.
Recorder status	• Recorder ready • Recording triggered • Recording and storing • Storing recording • Recorder full • Wrong config	Indicates the status of recorder. "Wrong config" is activated if: • "Pre-triggering time" is longer than "Max length of recording" setting • "Max amount of recordings" is "1" and "Recording mode" is "FIFO". • "1ms" digital channel sample rate is selected when analog channel sample rate is 8 or 16 s/c.
Clear record+	0…2^{32}-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	• - • Trig	Triggers disturbance recording manually. This parameter will return back to "-" automatically.
Clear all records	• - • Clear	Clears all disturbance recordings.

Name	Range	Description
Clear newest record	• - • Clear	Clears the newest stored disturbance recording.
Clear oldest record	• - • Clear	Clears the oldest stored disturbance recording.
Max. number of recordings	0…100	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	Displays the maximum length of a single recording.
Max. location of the pre-trigger	0.000...1800.000s	Displays the highest pre-triggering time that can be set with the settings currently in use.
Recordings in memory	0…100	Displays how many recordings are stored in the memory.

Table. 4.6.6 - 131. 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. 4.6.6 - 132. Recorder settings.

Name	Range	Default	Description
Recording length	0.100...1800.000s	1s	Sets the length of a recording.
Recording mode	• FIFO • Keep olds	FIFO	Selects what happens when the memory is full. "FIFO" (= first in, first out) replaces the oldest stored recording with the latest one. "Keep olds" does not accept new recordings.
Analog channel samples	• 64s/c • 32s/c • 16s/c • 8s/c	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	• 5 ms	5 ms	The fixed sample rate of the recorded digital channels. Recorded digital channels can be chosen with "Recorder digital channels" below.
Pretriggering time	0.2…15.0s	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".

Name	Range	Default	Description
Automatically get recordings	• Disabled • Enabled	Disabled	Enables and disables the automatic transfer of recordings. The recordings are taken from the device's protection CPU and transferred to the device's FTP directory in the communication CPU; the FTP client then automatically loads the recordings from the device and transfers them further to the SCADA system. Please note that when this setting is enabled, all new disturbance recordings will be pushed to the FTP server of the device. 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. When a recording has been sent to the FTP server of the device, it is no longer accessible through setting tools *Disturbance recorder → Get DR files* command.
Recorder digital channels	0…96 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".

NOTICE!
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.

NOTICE!
When writing new disturbance recorder settings to the device, any existing recordings in the device memory will be deleted.

Estimating the maximum length of total recording time

Once the disturbance recorder's settings have been made and loaded to the device, 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 device 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. 4.6.6 - 137. Disturbance recorder settings.

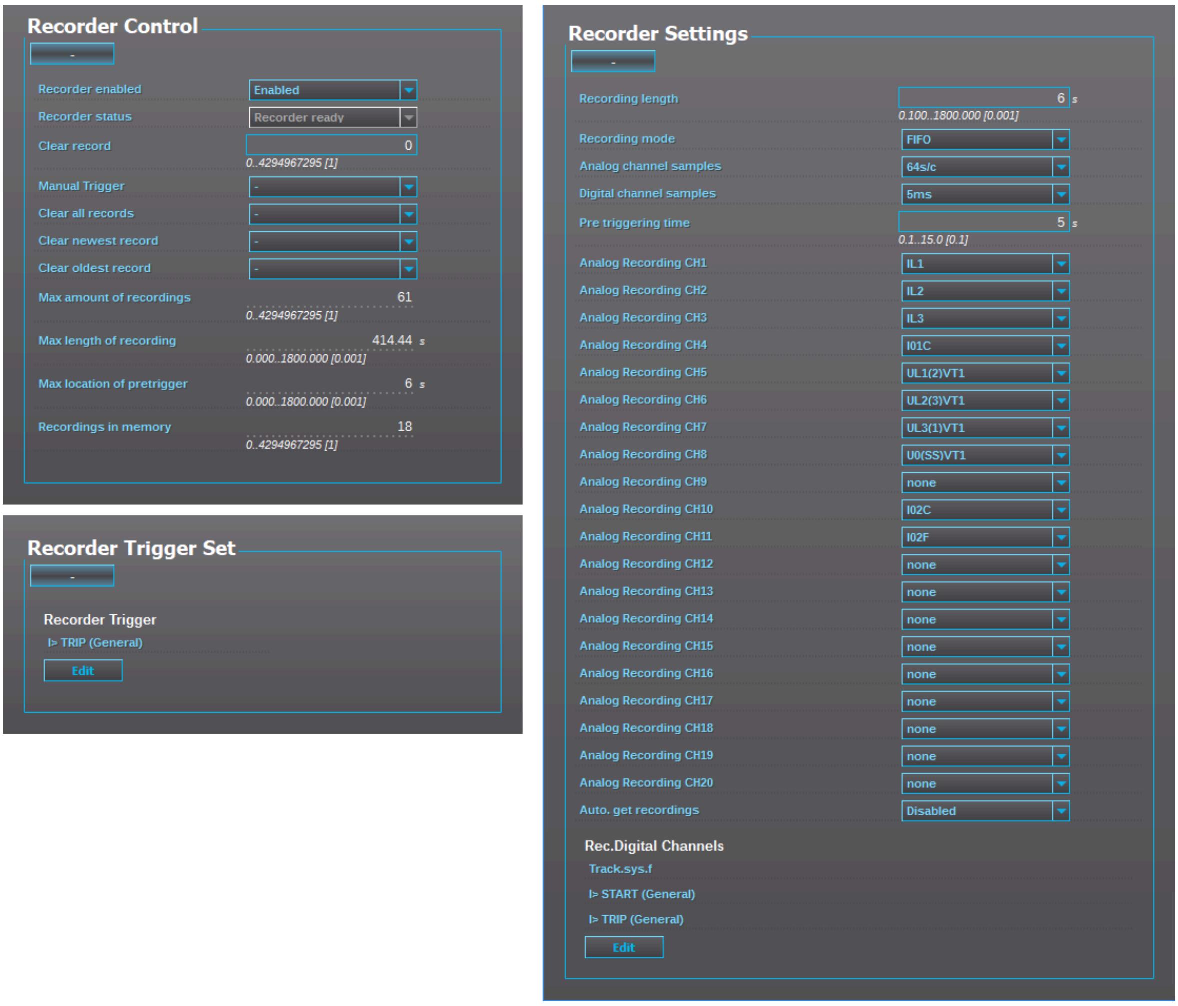
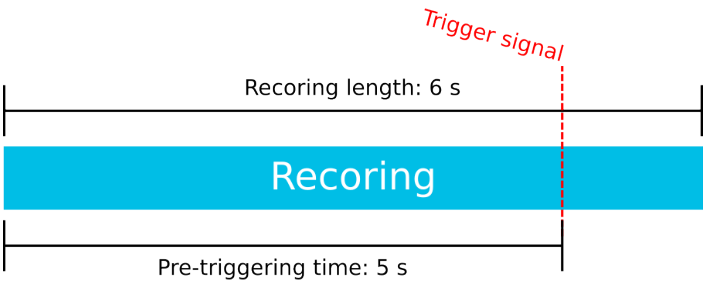
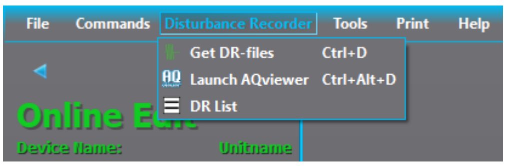


Figure. 4.6.6 - 138. Effects of recording length and pre-triggering time signals. This example is based on the settings shown above.



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*.



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 in the events listed below. Events cannot be masked off. The events triggered by the function are recorded with a time stamp.

Table. 4.6.6 - 133. 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 Communication

5.1 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. 5.1 - 134. 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.
Storm Protection	• Disable • Enable	When enabled, the Storm protection functionality of the internal switch in the device is enabled. This functionality aims to protect the device from excess ethernet traffic caused by storm situation. When enabled, the packet rate allowed to pass through on the ingress port towards the device, is limited to 150 packets per second. Multicast packets are also included in the packet limit.
Double Ethernet card mode	• Switch • HSR • PRP	If the device has a double ethernet option card it is possible to choose its mode.
COM A and Ethernet option card connection	• Block all • Allow both directions • Allow COM A to option card • 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	• Disable • Enable	Disables or enables "Double Ethernet Link A down" and "Double Ethernet Link B down" logic signals and events.
Double Ethernet PRP ports	• AB • BA	LanA and LanB port assigment for communication cards that support PRP.

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. 5.1 - 135. 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. 5.1 - 136. Serial COM1 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by RS-485 port.
Databits	7...8	Databits used by RS-485 port.
Parity	• None • Even • Odd	Paritybits used by RS-485 port.
Stopbits	1...2	Stopbits used by RS-485 port.
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • 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. 5.1 - 137. Serial COM2 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by serial fiber channels.
Databits	7...8	Databits used by serial fiber channels.
Parity	• None • Even • Odd	Paritybits used by serial fiber channels.
Stopbits	1...2	Stopbits used by serial fiber channels.

Name	Range	Description
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • IEC101	Communication protocol used by serial fiber channels.
Echo	• Off • On	Enable or disable echo.
Idle Light	• Off • On	Idle light behaviour.

Table. 5.1 - 138. Serial COM3 settings.

Name	Range	Description
Bitrate	• 9600bps • 19200bps • 38400bps	Bitrate used by RS-232 port.
Databits	7...8	Databits used by RS-232 port.
Parity	• None • Even • Odd	Paritybits used by RS-232 port.
Stopbits	1...2	Stopbits used by RS-232 port.
Protocol	• None • ModbutRTU • ModbusIO • IEC103 • SPA • DNP3 • IEC101	Communication protocol used by RS-232 port.

5.2 Time synchronization

Time synchronization source can be selected with "Time synchronization" parameter in the "General" menu.

Table. 5.2 - 139. General time synchronization source settings.

Name	Range	Description
Time synchronization source	• Internal • External NTP • External serial • IRIG-B •	Selection of time synchronization source.

5.2.1 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.

5.2.2 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. 5.2.2 - 140. 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. 5.2.2 - 141. Client settings.

Name	Range	Description
IP address	0.0.0.0...255.255.255.255	Defines the address of the NTP client. NOTE: This address must be different than the general IP address of the device.
Netmask	0.0.0.0...255.255.255.255	Defines the client's netmask.
Gateway	0.0.0.0...255.255.255.255	Defines the client's gateway.
MAC address	00-00-00-00-00-00...FF-FF-FF-FF-FF-FF	Displays the MAC address of the client.
Network status	• Running • IP error • NM error • GW error	Displays the status or possible errors of the NTP (client) settings.

Table. 5.2.2 - 142. Status.

Name	Range	Description
NTP quality for events	• No sync • Synchronized	Displays the status of the NTP time synchronization at the moment. NOTE: This indication is not valid if another time synchronization method is used (external serial).

Name	Range	Description
NTP-processed message count	0...4294967295	Displays the number of messages processed by the NTP protocol.

NOTICE!
A unique IP address must be reserved for the NTP client. The device's IP address cannot be used.

Additionally, the time zone of the device can be set by connecting to the device and the selecting the time zone at *Commands → Set time zone* in AQtivate setting tool.

5.3 Communication protocols

The following chapters will describe all available communication protocols. The device includes an RJ-45 ethernet port and an RS-485 serial port, which are able to use communication protocols. See other options for communication ports under "Construction and installation".

NOTICE!
Only one communication protocol can be used at a time by an AQ-210 device!

5.3.1 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 user can enable the Modbus TCP protocol at *Communication → Protocols → Modbus TCP*. The user can enable the Modbus RTU protocol at *Communication → Connections*.

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 device 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 device and the master. Modbus map can be edited with Modbus Configurator (*Tools → Communication → Modbus Configurator*).

Table. 5.3.1 - 143. Modbus TCP settings.

Parameter	Range	Description
Enable Modbus TCP	• Disabled • 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.
Event read mode	• Get oldest available • Continue previous connection • New events only	Get oldest event possible (Default) Continue with the event idx from previous connection Get only new events from connection time and forward.

Table. 5.3.1 - 144. 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

5.3.2 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.

The user can enable the IEC 103 protocol at *Communication → Connections*.

NOTE: Once the configuration file has been loaded, the IEC 103 map of the device can be found in the AQtivate software (*Tools → IEC 103 map*).

Table. 5.3.2 - 145. IEC 103 settings.

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.

The following table presents the setting parameters for the IEC 103 protocol.

5.3.3 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").

The user can enable the IEC104 protocol at *Communication → Protocols → IEC101/104*. The user can enable the IEC101 protocol at *Communication → Connections*.

IEC 101 settings

Table. 5.3.3 - 146. 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. 5.3.3 - 147. IEC 104 settings.

Name	Range	Step	Default	Description
IEC 104 enable	• Disabled • Enabled	-	Disabled	Enables and disables the IEC 104 communication protocol.
IP port	0…65 535	1	2404	Defines the IP port used by the protocol.
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.

Name	Range	Step	Default	Description
APDU timeout (t1)	0...3600 s	1 s	0 s	The maximum amount of time the slave waits for a transmitted Application Protocol Data Unit (APDU) to be confirmed as received by the master.
Idle timeout (t3)	0...3600 s	1 s	0 s	The slave outstation can use a test fram to determine if the channel is still available after a prolonged period of communications inactivity. Test frame is sent at an interval specified here.

Measurement scaling coefficients

The measurement scaling coefficients are available for the following measurements, in addition to the general measurement scaling coefficient:

Table. 5.3.3 - 148. Measurements with scaling coefficient settings.

<table>
<tr><th>Name</th><th>Range</th></tr>
<tr><td>Active energy</td><td rowspan="12">• No scaling
• 1/10
• 1/100
• 1/1000
• 1/10 000
• 1/100 000
• 1/1 000 000
• 10
• 100
• 1000
• 10 000
• 100 000
• 1 000 000</td></tr>
<tr><td>Reactive energy</td></tr>
<tr><td>Active power</td></tr>
<tr><td>Reactive power</td></tr>
<tr><td>Apparent power</td></tr>
<tr><td>Power factor</td></tr>
<tr><td>Frequency</td></tr>
<tr><td>Current</td></tr>
<tr><td>Residual current</td></tr>
<tr><td>Voltage</td></tr>
<tr><td>Residual voltage</td></tr>
<tr><td>Angle</td></tr>
</table>

Deadband settings.

Table. 5.3.3 - 149. Analog change deadband settings.

<table>
<tr><th>Name</th><th>Range</th><th>Step</th><th>Default</th><th>Description</th></tr>
<tr><td>General deadband</td><td>0.1…10.0%</td><td>0.1%</td><td>2%</td><td>Determines the general data reporting deadband settings.</td></tr>
<tr><td>Active energy deadband</td><td>0.1…1000.0kWh</td><td>0.1kWh</td><td>2kWh</td><td rowspan="2">Determines the data reporting deadband settings for this measurement.</td></tr>
<tr><td>Reactive energy deadband</td><td>0.1…1000.0kVar</td><td>0.1kVar</td><td>2kVar</td></tr>
</table>

Name	Range	Step	Default	Description
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	-	Determines the integration time of the protocol. If this parameter is set to "0 ms", no integration time is in use.

5.3.4 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*.

The user can enable the SPA protocol at *Communication → Connections*.

Table. 5.3.4 - 150. SPA setting parameters.

Name	Range	Description
SPA address	1...899	SPA slave address.
UTC time sync	• Disabled • 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*.

NOTICE!
To access SPA map and event list, an .aqs configuration file should be downloaded from the device.

5.3.5 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).

The user can enable the DNP3 TCP protocol at *Communication → Protocols → DNP3*. The user can enable the DNP3 serial protocol at *Communication → Connections*.

Settings

The following table describes the DNP3 setting parameters.

Table. 5.3.5 - 151. Settings.

Name	Range	Step	Default	Description
Enable DNP3 TCP	• Disabled • Enabled	-	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.
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.

Name	Range	Step	Default	Description
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. 5.3.5 - 152. Default variations.

Name	Range	Default	Description
Group 1 variation (BI)	• Var 1 • Var 2	Var 1	Selects the variation of the binary signal.
Group 2 variation (BI change)	• Var 1 • Var 2	Var 2	Selects the variation of the binary signal change.
Group 3 variation (DBI)	• Var 1 • Var 2	Var 1	Selects the variation of the double point signal.
Group 4 variation (DBI change)	• Var 1 • Var 2	Var 2	Selects the variation of the double point signal.
Group 20 variation (CNTR)	• Var 1 • Var 2 • Var 5 • Var 6	Var 1	Selects the variation of the control signal.
Group 22 variation (CNTR change)	• Var 1 • Var 2 • Var 5 • Var 6	Var 5	Selects the variation of the control signal change.
Group 30 variation (AI)	• Var 1 • Var 2 • Var 3 • Var 4 • Var 5	Var 5	Selects the variation of the analog signal.
Group 32 variation (AI change)	• Var 1 • Var 2 • Var 3 • Var 4 • Var 5 • Var 7	Var 5	Selects the variation of the analog signal change.

Setting the analog change deadbands

Table. 5.3.5 - 153. 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.

5.3.6 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. 5.3.6 - 154. 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	• ADAM-4018+ • 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. 5.3.6 - 155. Channel settings.

Name	Range	Step	Default	Description
Thermocouple type	• +/- 20mA • 4…20mA • Type J • Type K • Type T • Type E • Type R • Type S	-	4…20mA	Selects the thermocouple or the mA input connected to the I/O module. 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	• Invalid • OK	-	-	Displays the input status of the selected channel.

5.4 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. 5.4 - 156. Fault register settings.

Name	Range	Step	Default	Description
Select record source	Not in use I>, I>>, I>>>, I>>>> (IL1, IL2, IL3) Id>, Id>>, Id>>>, Id>>>> (IL1, IL2, IL3) I0>, I0>>, I0>>>, I0>>>> (I0) I0d>, I0d>>, I0d>>>, I0d>>>> (I0) FLX (Fault locator)	-	Not in use	Selects the protection function and its stage to be used as the source for the fault register recording. 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 • START signal • START and TRIP signals	-	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.

5.5 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 ten (10) 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 device uses these values as the basis when it calculates the primary and secondary values of currents, voltages, powers, impedances and other values.

Table. 5.5 - 157. 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.

Signals	Description
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, I01Ang, I02Ang, I0CalcAng I1Ang, I2Ang	Angles of each measured current.
Voltages	
UL1Mag, UL2Mag, UL3Mag, UL12Mag, UL23Mag, UL31Mag, 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, UL12Ang, UL23Ang, UL31Ang, 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 P3PH Q3PH	Three-phase apparent, active and reactive power.
SL1, SL2, SL3, PL1, PL2, PL3, QL1, QL2, QL3	Phase apparent, active and reactive powers.
tanfi3PH tanfiL1 tanfiL2 tanfiL3	Tan (φ) of three-phase powers and phase powers.
cosfi3PH cosfiL1 cosfiL2 cosfiL3	Cos (φ) of three-phase powers and phase powers.
Impedances and admittances	
RL12, RL23, RL31 XL12, XL23, XL31 RL1, RL2, RL3 XL1, XL2, XL3 Z12, Z23, Z31 ZL1, ZL2, ZL3	Phase-to-phase and phase-to-neutral resistances, reactances and impedances.
Z12Ang, Z23Ang, Z31Ang, ZL1Ang, ZL2Ang, ZL3Ang	Phase-to-phase and phase-to-neutral impedance angles.

Signals	Description
Rseq, Xseq, Zseq RseqAng, XseqAng, ZseqAng	Positive sequence resistance, reactance and impedance values and angles.
GL1, GL2, GL3, G0 BL1, BL2, BL3, B0 YL1, YL2, YL3, Y0	Conductances, susceptances and admittances.
YL1angle, YL2angle, YL3angle, 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

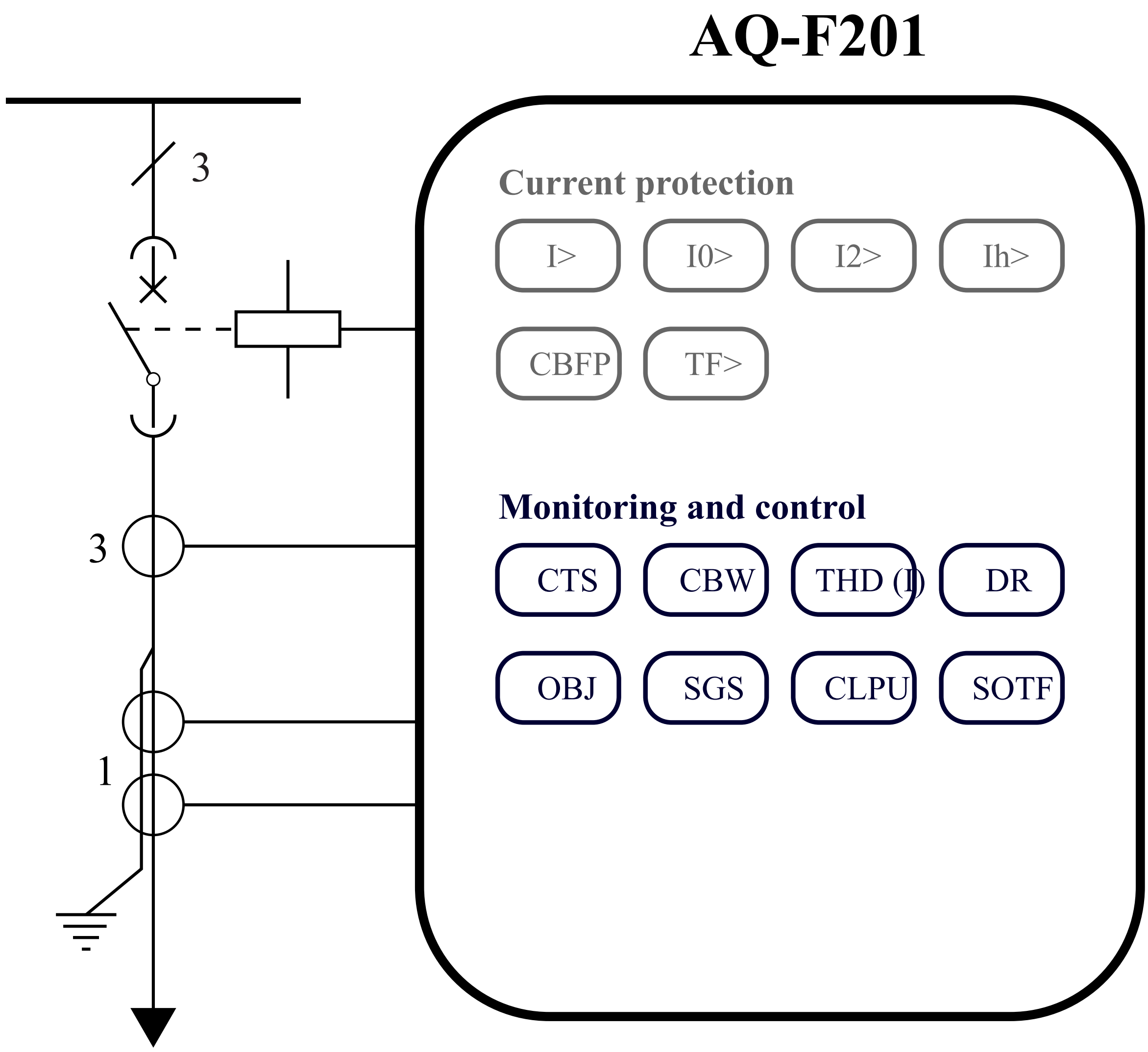
Table. 5.5 - 158. Settings.

Name	Range	Step	Default	Description
Measurement value recorder mode	• Disabled • Activated	-	Disabled	Activates and disables the real-time signals to communication.
Scale current values to primary	• No • Yes	-	No	Selects whether or not values are scaled to primary.
Slot X magnitude selection	• Currents • Voltages • Powers • Impedance (ZRX) and admittance (YGB) • Others	-	Currents	Selects the measured magnitude catecory of the chosen slot.
Slot X magnitude	Described in table above ("Available measured values")	-	-	Selects the magnitude 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. The unit depends on the selected magnitude (either amperes, volts, or per-unit values).

6 Connections and application examples

6.1 Connections of AQ-F201

Figure. 6.1 - 139. AQ-F201 application example with function block diagram.

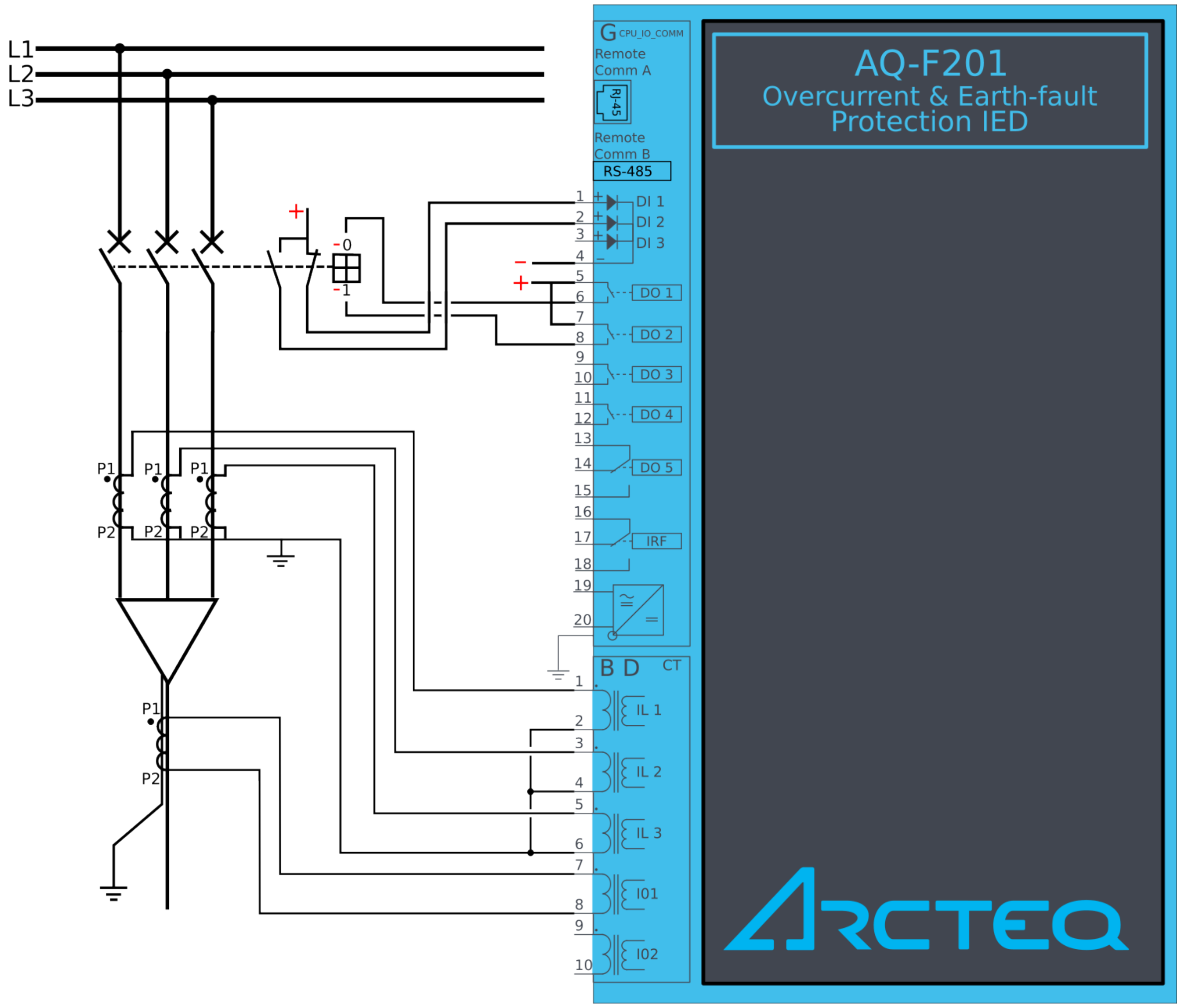


6.2 Application example and its connections

This chapter presents an application example for the feeder protection relay.

As can be seen in the image below, the example application has connected the three phase currents and the residual current (I01). Additionally, the digital inputs are connected to indicate the breaker status, while the digital outputs are used for breaker control.

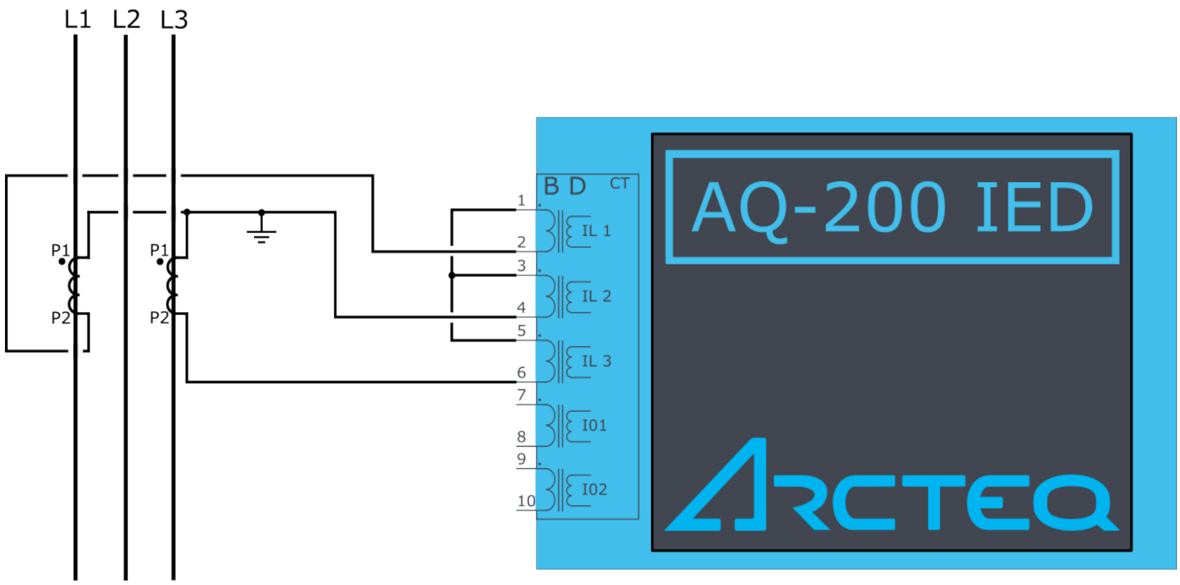
Figure. 6.2 - 140. Application example and its connections.



6.3 Two-phase, three-wire ARON input connection

This chapter presents the two-phase, three-wire ARON input connection for any AQ-200 series device with a current transformer. The example is for applications with protection CTs for just two phases. The connection is suitable for both motor and feeder applications.

Figure. 6.3 - 141. ARON connection.



The ARON input connection can measure the load symmetrically despite the fact that one of the CTs is missing from the installation. Normally, Phase 2 does not have a current transformer installed as an external fault is much more likely to appear on Lines 1 or 3.

A fault between Line 2 and the earth cannot be detected when the ARON input connection is used. In order to detect an earth fault in Phase 2, a cable core CT must be used.

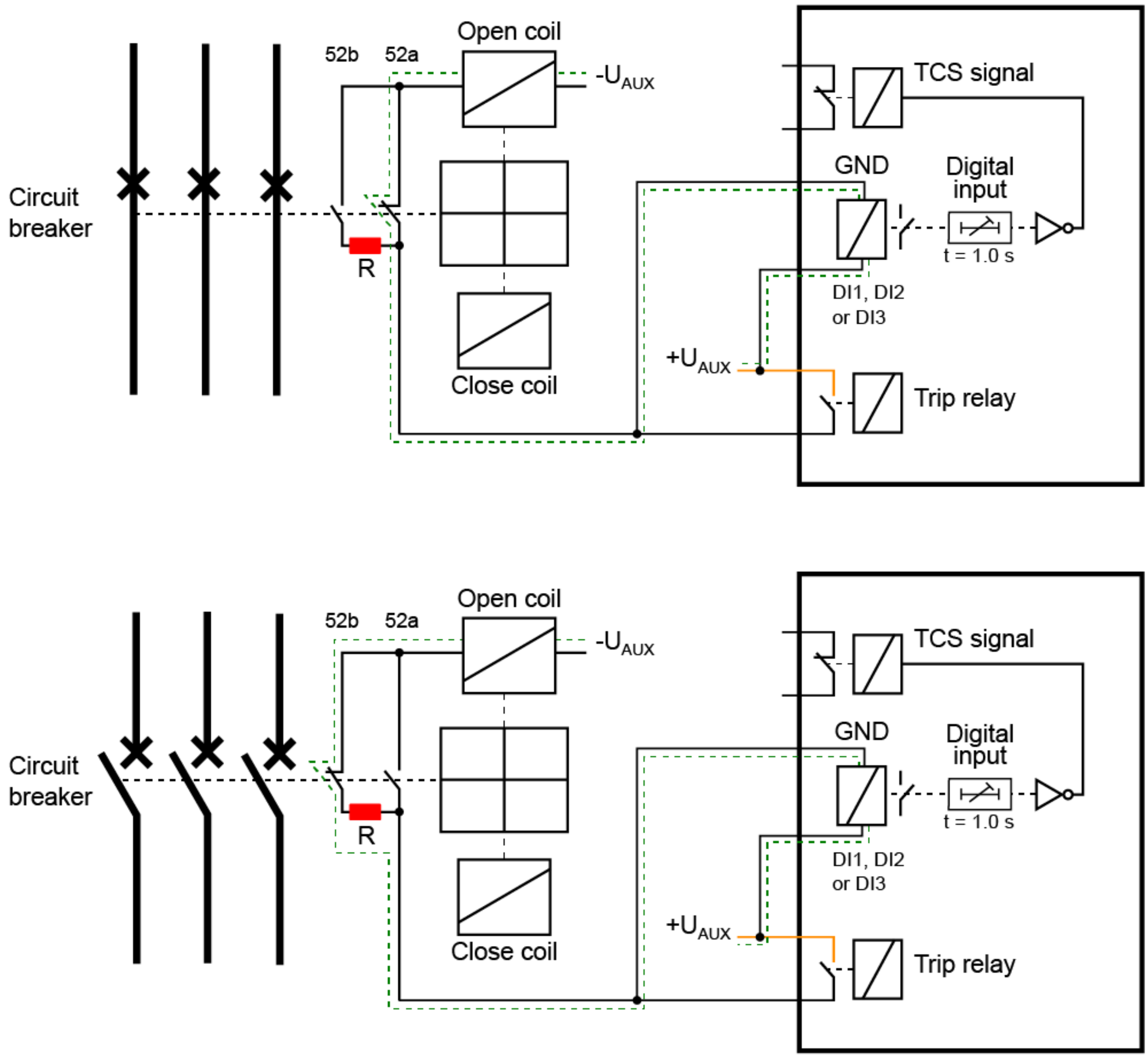
6.4 Trip circuit supervision (95)

Trip circuit supervision is used to monitor the wiring from auxiliary power supply, through the device'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 when 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.

Figure. 6.4 - 142. Trip circuit supervision with one DI and one non-latched trip output.

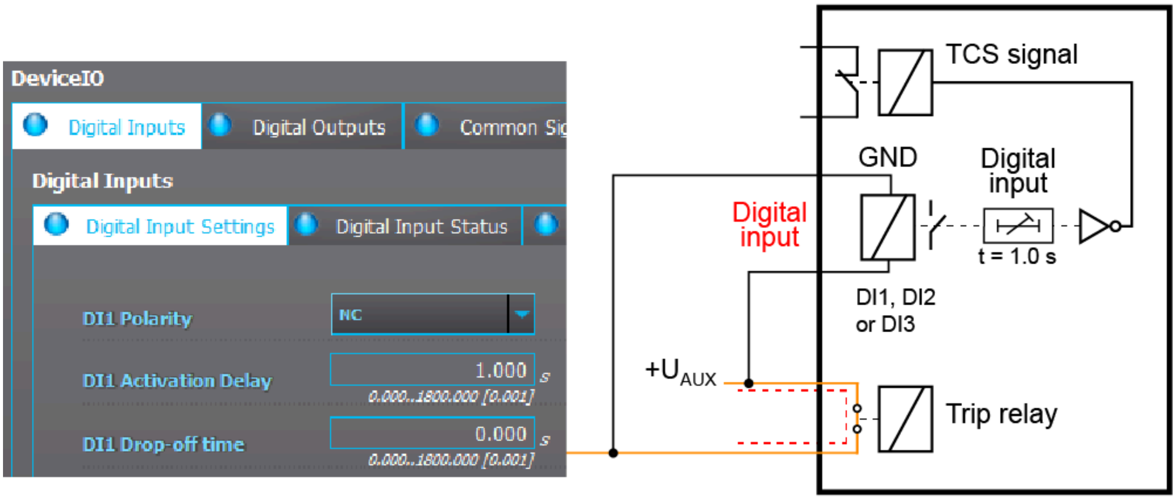


Note that the digital input that monitors the circuit is normally closed, and the same applies to the alarm relay if one is used. For monitoring and especially trip circuit supervision purposes it is recommended to use a normally closed contact to confirm the wiring's condition. An active digital input 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 is opening. 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. 6.4 - 143. Settings for a digital input used for trip circuit supervision.

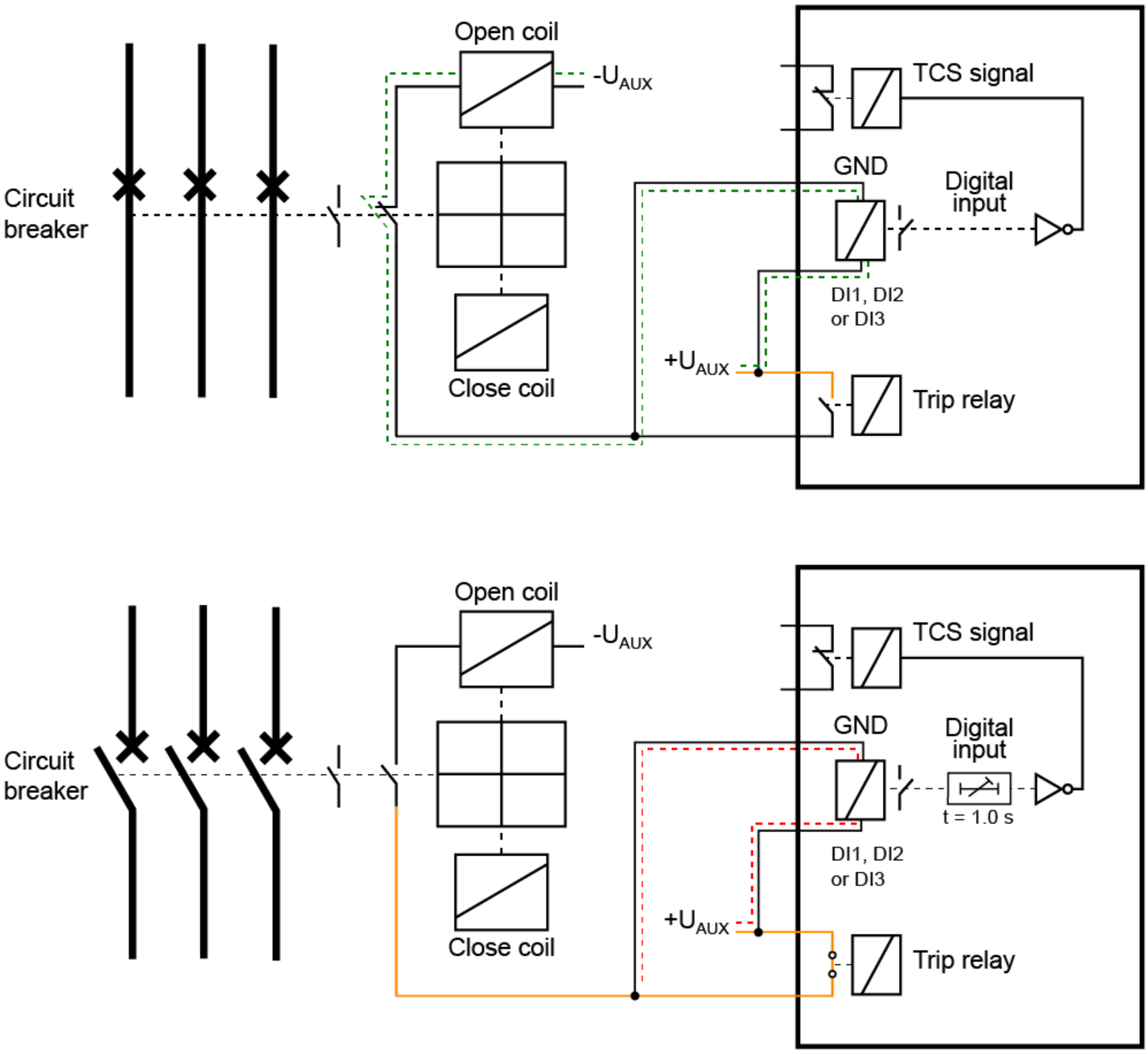


The open coil remains energized only as long as the circuit breaker is opened and the trip relay is open. This takes approximately 100 ms depending on the size and type of the breaker. When the breaker opens, the auxiliary contacts of the circuit breaker open the inductive circuit; however, the trip contact does not open at the same time. The device'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 device's trip output.

Figure. 6.4 - 144. Trip circuit supervision with one DI and one latched output contact.

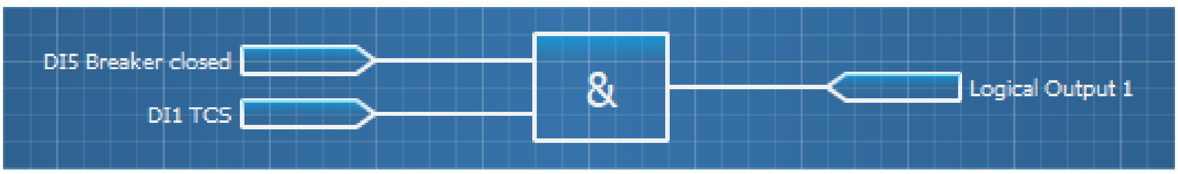


The trip circuit with a latched output contact can be monitored, but only when the circuit breaker's status is "Closed". Whenever the breaker is open, the supervision is blocked by an internal logic scheme. Its disadvantage is that the user does not know whether or not the trip circuit is intact before 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. 6.4 - 145. Example block scheme.

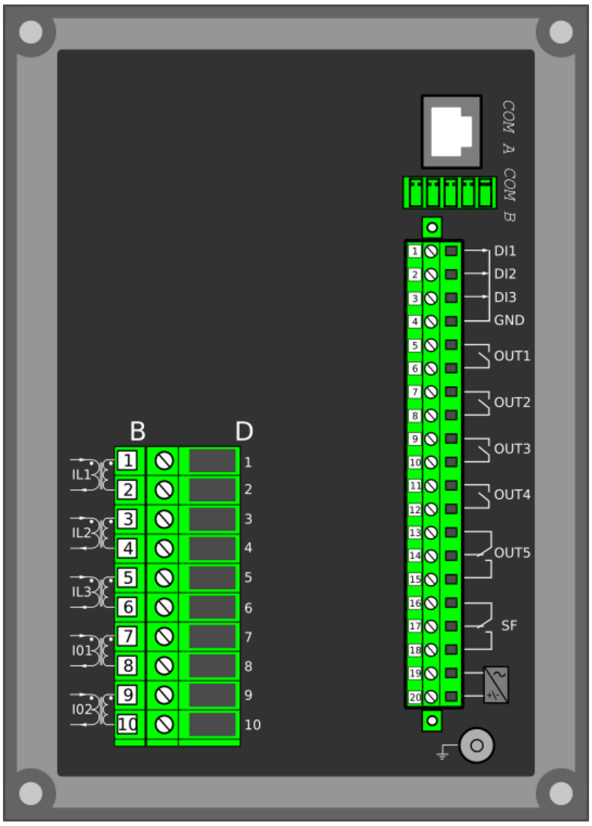


7 Construction and installation

7.1 Construction

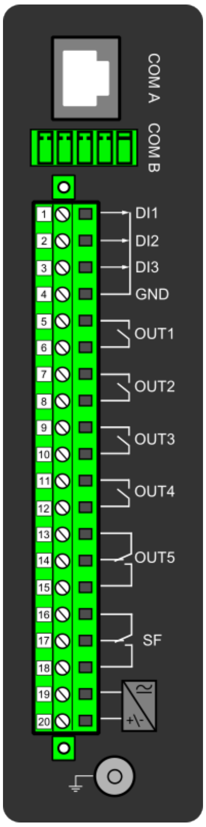
Even though AQ-F201 is a member of the modular and scalable AQ-200 series, it does not have optional modules. This means that the construction and content of the device's hardware are fixed. The device includes the CPU module (which consists of the CPU, a number of inputs and outputs, and the power supply) as well as one current measurement module.

Figure. 7.1 - 146. Connections and modules in AQ-F201.



7.2 CPU module

Figure. 7.2 - 147. CPU module.



Connector	Description
COM A	Communication port A, or the RJ-45 port. Used for the setting tool connection and for SCADA communication.
COM B	Communication port B, or the RS-485 port. Used for SCADA communication. 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.

Connector	Description
X1-13:14:15	Signaling relay 5, with a changeover contact. Not to be used in trip coil control.
X1-16:17:18	System fault's signaling 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 80…265 VAC/DC (model A; order code "H") or 18…75 DC (model B; order code "L"). Positive side (+) to Pin 20.
GND	The device'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 device's basic digital I/O.

The digital output controls are also set by the user with software. 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 (80…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 inputs

The current consumption of the digital inputs is 2 mA when activated. The range of the operating voltage is 24 V/110 V/220 V depending on the ordered hardware. All digital inputs are scanned in 5 ms program cycles. Pick-up and release delays as well as the NO/NC selection can be set with software.

The settings described in the table below can be found at *Control → Device I/O → Digital input settings* in the device settings.

Table. 7.2 - 159. Digital input settings.

Name	Range	Step	Default	Description
DIx Polarity	• NO (Normally open) • NC (Normally closed)	-	NO	Selects whether the status of the digital input is 1 or 0 when the input is energized.
DIx Activation delay	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay for the status change from 0 to 1.
DIx Drop-off time	0.000…1800.000 s	0.001 s	0.000 s	Defines the delay for the status change from 1 to 0.
DIx AC mode	• Disabled • Enabled	-	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
-
-
- etc.

Table. 7.2 - 160. 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.

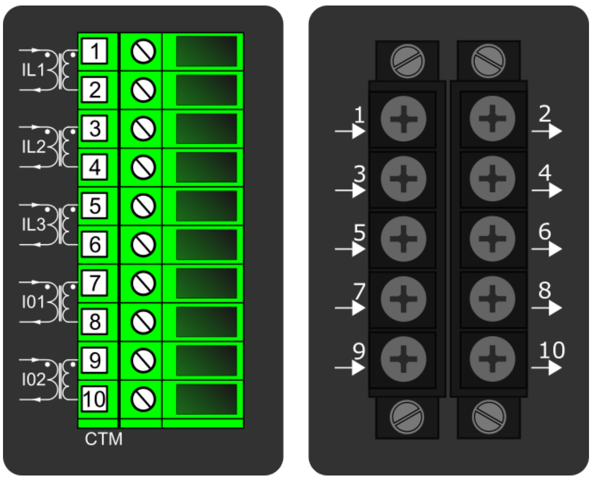
Scanning cycle

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.

NOTICE!
The mechanical delay of the relay is not included in these approximations!

7.3 Current measurement module

Figure. 7.3 - 148. 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.

7.4 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 quarter (¼) of the rack's width, meaning that a total of three 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. 7.4 - 149. Device dimensions.

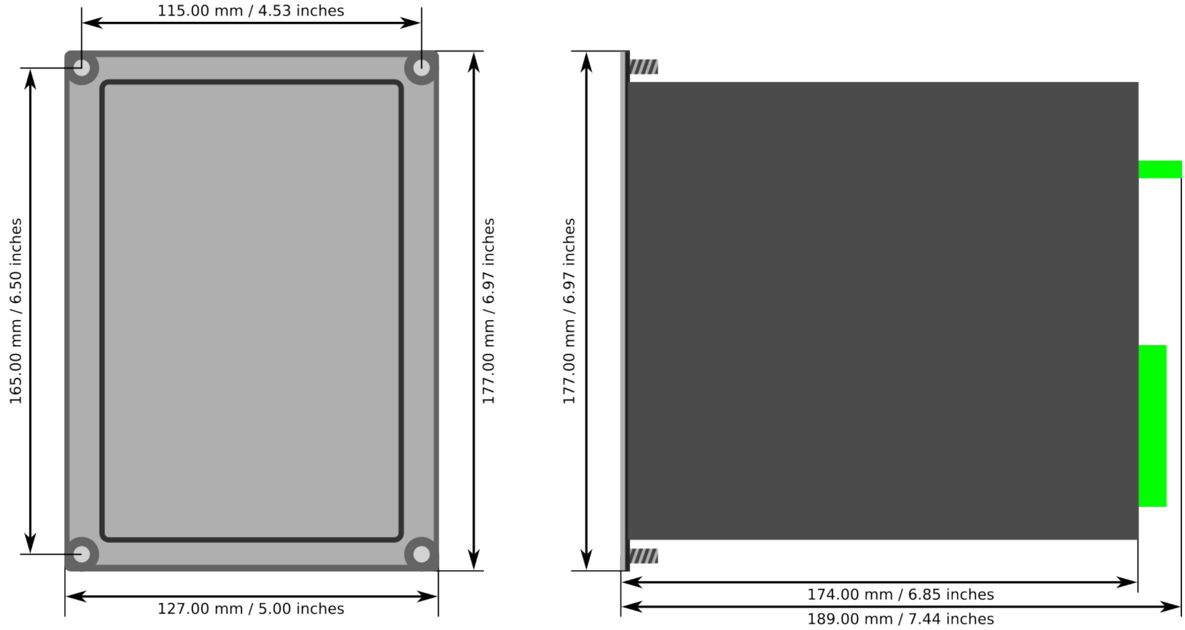


Figure. 7.4 - 150. Device installation.

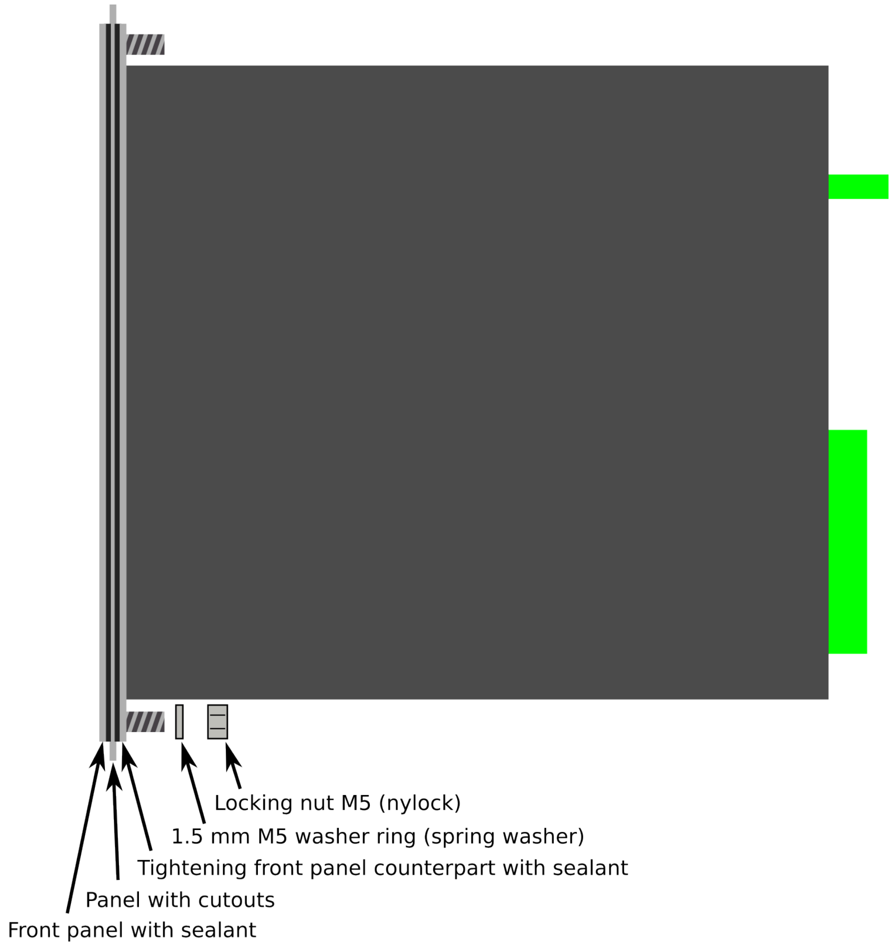
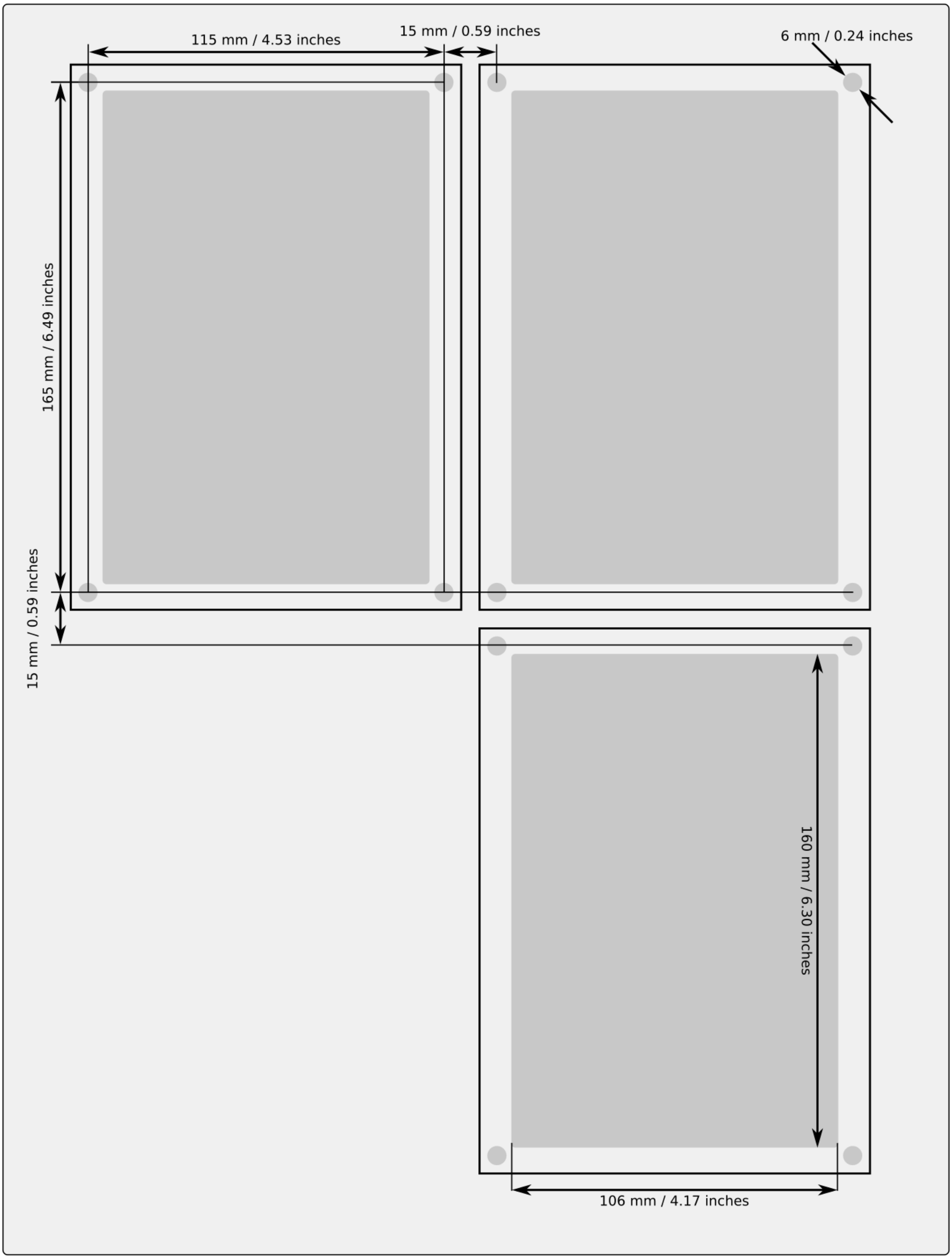


Figure. 7.4 - 151. Panel cutout dimensions and device spacing.



8 Technical data

8.1 Hardware

8.1.1 Measurements

8.1.1.1 Current measurement

Table. 8.1.1.1 - 161. Technical data for the current measurement module.

Connections	
Measurement channels/CT inputs	Three phase current inputs: IL1 (A), IL2 (B), IL3 (C) 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…20 A)
Thermal withstand	20 A (continuous) 100 A (for 10 s) 500 A (for 1 s) 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 4…20 × I_N < ±0.5 % 20…50 × I_N < ±1.0 %
Angle measurement inaccuracy	< ±0.2° (I> 0.1 A) < ±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) 100 A (for 10 s) 500 A (for 1 s) 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 10…150 × I_N < ±0.5 %
Angle measurement inaccuracy	< ±0.2° (I> 0.05 A) < ±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) 100 A (for 10 s) 500 A (for 1 s) 1250 A (for 0.01 s)
Frequency measurement range	From 6…75 Hz fundamental, up to the 31st 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 25…375 × I_N < ±1.0 %
Angle measurement inaccuracy	< ±0.2° (I> 0.01 A) < ±1.0° (I≤ 0.01 A)
Burden (50/60Hz)	<0.1 VA
Transient overreach	<5 %
Screw connection terminal block (standard)	
Terminal block	Phoenix Contact FRONT 4-H-6,35
Nominal cross section (solid or stranded wire)	4 mm^2
Ring lug terminal block connection (option)	
Ring terminal dimensions	Max 8mm diameter, with minimum 3,5mm screw hole

NOTICE!
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.

8.1.1.2 Frequency measurement

Table. 8.1.1.2 - 162. Frequency measurement accuracy.

Frequency measurement performance	
Frequency measuring range	6…75 Hz fundamental, up to the 31st harmonic current or voltage

Inaccuracy	<1 mHz

8.1.2 CPU & Power supply

8.1.2.1 Auxiliary voltage

Table. 8.1.2.1 - 163. Power supply model A

Rated values	
Rated auxiliary voltage	80…265 V (AC/DC)
Power consumption	< 7 W (no option cards) < 15 W (maximum number of option cards)
Maximum permitted interrupt time	< 60 ms with 110 VDC
DC ripple	< 15 %
Other	
Minimum recommended fuse rating	MCB C2

Table. 8.1.2.1 - 164. Power supply model B

Rated values	
Rated auxiliary voltage	18…72 VDC
Power consumption	< 7 W (no option cards) < 15 W (maximum number of option cards)
Maximum permitted interrupt time	< 90 ms with 24 VDC
DC ripple	< 15 %
Other	
Minimum recommended fuse rating	MCB C2

8.1.2.2 CPU communication ports

Table. 8.1.2.2 - 165. Front panel local communication port.

Port	
Port media	Copper Ethernet RJ-45
Number of ports	1
Port protocols	PC-protocols FTP
Features	

Data transfer rate	100 MB/s
System integration	Can't be used for system protocols, only for local programming

Table. 8.1.2.2 - 166. Rear panel system communication port A.

Port	
Port media	Copper Ethernet RJ-45
Number of ports	1
Features	
Port protocols	IEC 104 Modbus/TCP DNP3 FTP
Data transfer rate	100 MB/s
System integration	Can be used for system protocols and for local programming

Table. 8.1.2.2 - 167. Rear panel system communication port B.

Port	
Port media	Copper RS-485
Number of ports	1
Features	
Port protocols	Modbus/RTU IEC 103 IEC 101 DNP3 SPA
Data transfer rate	65 580 kB/s
System integration	Can be used for system protocols

8.1.2.3 CPU digital inputs

Table. 8.1.2.3 - 168. 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 Release threshold	Order code defined: 19, 90,170 V 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

8.1.2.4 CPU digital outputs

Table. 8.1.2.4 - 169. Digital outputs (Normally Open)

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	5 A
Make and carry 0.5 s Make and carry 3 s	30 A 15 A
Breaking capacity, DC (L/R = 40 ms) at 48 VDC at 110 VDC at 220 VDC	 1 A 0.4 A 0.2 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally Open / Normally Closed

Table. 8.1.2.4 - 170. Digital outputs (Change-Over)

Rated values	
Rated auxiliary voltage	265 V (AC/DC)
Continuous carry	2.5 A
Make and carry 0.5 s Make and carry 3 s	30 A 15 A
Breaking capacity, DC (L/R = 40 ms) at 48 VDC at 110 VDC at 220 VDC	 1 A 0.3 A 0.15 A
Control rate	5 ms
Settings	
Polarity	Software settable: Normally Open / Normally Closed

CAUTION!
Please note, that signaling relay 5 and system fault's signaling relay are designed only for signaling purposes, and are not to be used in trip coil control.

8.1.3 Display

Table. 8.1.3 - 171. Technical data for the HMI LCD display.

Dimensions and resolution	
Number of dots/resolution	320 x 160
Size	84.78 × 49.90 mm (3.34 × 1.96 in)
Display	
Type of display	LCD
Color	Monochrome

8.2 Functions

8.2.1 Protection functions

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

Table. 8.2.1.1 - 172. 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 TRMS phase currents 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: - Current - 2^{nd} harmonic blocking	±0.5 %I_{set} or ±15 mA (0.10…4.0 × I_{set}) ±1.0 %-unit of the 2^{nd} harmonic setting
Operation time	
Definite time function operating time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time: I_m/I_{set} ratio > 3 - Definite time: I_m/I_{set} ratio = 1.05…3	±1.0 % or ±20 ms ±1.0 % or ±30 ms

IDMT setting parameters: - k Time dial setting for IDMT - A IDMT constant - B IDMT constant - C IDMT constant	 0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…250.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	 ±1.5 % or ±20 ms ±20 ms
Retardation time (overshoot)	<30 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3 - I_m/I_{set} ratio = 1.05…3	 <35 ms (typically 25 ms) <50 ms
Reset	
Reset ratio	97 % of the pick-up current setting
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

NOTICE!
The release delay does not apply to phase-specific tripping!

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

Table. 8.2.1.2 - 173. Technical data for the non-directional earth fault function.

Measurement inputs	
Current input (selectable)	Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine) 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) TRMS residual current (I_{01} or I_{02}) Peak-to-peak residual current (I_{01} or I_{02})
Pick-up	
Used magnitude	Measured residual current I01 (1 A) Measured residual current I02 (0.2 A) Calculated residual current I0Calc (5 A)
Pick-up current setting	0.0001…40.00 × I_n, setting step 0.0001 × I_n
Inaccuracy: - Starting I01 (1 A) - Starting I02 (0.2 A) - Starting I0Calc (5 A)	 ±0.5 %$I0_{set}$ or ±3 mA (0.005…10.0 × I_{set}) ±1.5 %$I0_{set}$ or ±1.0 mA (0.005…25.0 × I_{set}) ±1.0 %$I0_{set}$ or ±15 mA (0.005…4.0 × I_{set})
Operating time	

Definite time function operating time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time: I_m/I_{set} ratio > 3 - Definite time: I_m/I_{set} ratio = 1.05…3	 ±1.0 % or ±20 ms ±1.0 % or ±30 ms
IDMT setting parameters: - k Time dial setting for IDMT - A, B, C IDMT constants	 0.01…25.00, step 0.01 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	 ±1.5 % or ±20 ms ±20 ms
Retardation time (overshoot)	<30 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 3.5 - I_m/I_{set} ratio = 1.05…3.5	 <50 ms (typically 35 ms) <55 ms
Reset	
Reset ratio	97 % of the pick-up current setting
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.0 % or ±50 ms
Instant reset time and start-up reset	<50 ms

NOTICE!
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.

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

Table. 8.2.1.3 - 174. 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) Negative sequence current (I2)
Pick-up	
Used magnitude	Negative sequence component I2pu Relative unbalance I2/I1
Pick-up setting	0.01…40.00 × I_n, setting step 0.01 × I_n (I2pu) 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: - Starting I2pu - Starting I2/I1	±1.0 %-unit or ±100 mA (0.10…4.0 × I_n) ±1.0 %-unit or ±100 mA (0.10…4.0 × I_n)
Operating time	
Definite time function operating time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time (I_m/I_{set} ratio > 1.05)	±1.5 % or ±60 ms
IDMT setting parameters: - k Time dial setting for IDMT - A IDMT Constant - B IDMT Constant - C IDMT Constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…250.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±2.0 % or ±30 ms ±20 ms
Retardation time (overshoot)	<5 ms
Instant operation time	
Start time and instant operation time (trip): - I_m/I_{set} ratio > 1.05	<70 ms
Reset	
Reset ratio	97 % of the pick-up setting
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.5 % or ±60 ms
Instant reset time and start-up reset	<55 ms

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

Table. 8.2.1.4 - 175. Technical data for the harmonic overcurrent function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) 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) Harmonic relative (Ih/IL)
Pick-up setting	0.05…2.00 × I_N, setting step 0.01 × I_N (× I_N) 5.00…200.00 %, setting step 0.01 % (Ih/IL)

Inaccuracy: - Starting × I_N - Starting × Ih/IL	<0.03 × I_N (2^{nd}, 3^{rd}, 5^{th}) <0.03 × I_N tolerance to Ih (2^{nd}, 3^{rd}, 5^{th})
Operation time	
Definite time function operating time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio >1.05)	±1.0 % or ±35 ms
IDMT setting parameters: k Time dial setting for IDMT A IDMT constant B IDMT constant C IDMT constant	0.01…25.00, step 0.01 0…250.0000, step 0.0001 0…250.0000, step 0.0001 0…250.0000, step 0.0001
Inaccuracy: - IDMT operating time - IDMT minimum operating time	±1.5 % or ±20 ms ±20 ms
Instant operation time	
Start time and instant operation time (trip): I_M/I_{SET} ratio >1.05	<50 ms
Reset	
Reset ratio	95 % of the pick-up setting
Reset time setting Inaccuracy: Reset time	0.000…150.000 s, step 0.005 s ±1.0 % or ±35 ms
Instant reset time and start-up reset	<50 ms

NOTICE!
Harmonics generally: The amplitude of the harmonic content must 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.

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

Table. 8.2.1.5 - 176. 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) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)

Current input magnitudes	RMS phase currents 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: - IL1…IL3 - I01, I02, I0Calc	0.10…40.00 × I_N, setting step 0.01 × I_N 0.005…40.00 × I_N, setting step 0.005 × I_N
Inaccuracy: - Starting phase current (5A) - Starting I01 (1 A) - Starting I02 (0.2 A) - Starting I0Calc (5 A)	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET}) ±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × I_{SET}) ±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × I_{SET}) ±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: - Current criteria (I_M/I_{SET} ratio 1.05→) - DO or DI only	±1.0 % or ±55 ms ±15 ms
Reset	
Reset ratio	97 % of the pick-up current setting
Reset time	<50 ms

8.2.1.6 Line thermal overload protection (TF>; 49F)

Table. 8.2.1.6 - 177. Technical data for the line thermal overload protection function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	TRMS phase currents (up to the 31st harmonic)
Settings	
Time constants τ	1
Time constant value	0.0…500.00 min, step 0.1 min
Service factor (maximum overloading)	0.01…5.00 × I_N, step 0.01 × I_N
Thermal model biasing	- Ambient temperature (Set –60.0…500.0 deg, step 0.1 deg and RTD) - Negative sequence current
Thermal replica temperature estimates	Selectable between °C and °F
Outputs	

- Alarm 1 - Alarm 2 - Thermal trip - Trip delay - Restart inhibit	0…150 %, step 1 % 0…150 %, step 1 % 0…150 %, step 1 % 0.000…3600.000 s, step 0.005 s 0…150 %, step 1 %
Inaccuracy	
- Starting - Operating time	±0.5 % of the set pick-up value ±5 % or ± 500 ms

8.2.2 Control functions

8.2.2.1 Setting group selection

Table. 8.2.2.1 - 178. 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 binary 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

8.2.2.2 Object control and monitoring

Table. 8.2.2.2 - 179. Technical data for the object control and monitoring function.

General	
Number of objects	1
Supported object types	Circuit breaker Circuit breaker with withdrawable cart Disconnector (MC) Disconnector (GND)
Signals	
Input signals	Digital inputs Software signals
Output signals	Close command output 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: - 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.

8.2.2.3 Cold load pick-up (CLPU)

Table. 8.2.2.3 - 180. Technical data for the cold load pick-up function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C)
Current input magnitudes	RMS phase currents
Pick-up	
Pick-up current setting - $I_{LOW}/I_{HIGH}/I_{OVER}$	0.01…40.00 × I_N, setting step 0.01 × I_N
Reset ratio	97 % of the pick-up current setting
Inaccuracy: - Current	±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET})
Operation time	
Definite time function operating time settings: - t_{SET} - t_{MAX} - t_{MIN}	0.000…1800.000 s, setting step 0.005 s 0.000…1800.000 s, setting step 0.005 s 0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time (I_M/I_{SET} ratio = 1.05/0.95)	±1.0 % or ±45 ms
Instant operation time	
CLPU activation and release	<45 ms (measured from the trip contact)

NOTICE!
A single-phase current (IL1, IL2 or IL3) is enough to prolong or release the blocking during an overcurrent condition.

8.2.2.4 Switch-on-to-fault (SOTF)

Table. 8.2.2.4 - 181. Technical data for the switch-on-to-fault function.

Initialization signals	
SOTF activate input	Any blocking input signal (Object closed signal, etc.)
Pick-up	
SOTF function input	Any blocking input signal (I> or similar)
SOTF activation time	
Activation time	<40 ms (measured from the trip contact)
SOTF release time	
Release time setting	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time	 ±1.0 % or ±30 ms
SOTF instant release time	<40 ms (measured from the trip contact)

8.2.3 Monitoring functions

8.2.3.1 Current transformer supervision

Table. 8.2.3.1 - 182. Technical data for the current transformer supervision function.

Measurement inputs	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) (optional) Residual current channel I_{02} (Fine) (optional)
Current input magnitudes	RMS phase currents RMS residual current (I_{01}, I_{02}) (optional)
Pick-up	
Pick-up current settings: - I_{SET} high limit - I_{SET} low limit - I_{SUM} difference - I_{SET} ratio - I2/I1 ratio	 0.10…40.00 × I_N, setting step 0.01 × I_N 0.10…40.00 × I_N, setting step 0.01 × I_N 0.10…40.00 × I_N, setting step 0.01 × I_N 0.01…100.00 %, setting step 0.01 % 0.01…100.00 %, setting step 0.01 %
Inaccuracy: - Starting IL1, IL2, IL3 - Starting I2/I1 - Starting I01 (1 A) - Starting I02 (0.2 A)	 ±0.5 %I_{SET} or ±15 mA (0.10…4.0 × I_{SET}) ±1.0 %$I2_{SET}$ / $I1_{SET}$ or ±100 mA (0.10…4.0 × I_N) ±0.5 %$I0_{SET}$ or ±3 mA (0.005…10.0 × I_{SET}) ±1.5 %$I0_{SET}$ or ±1.0 mA (0.005…25.0 × I_{SET})
Time delay for alarm	
Definite time function operating time setting	0.000…1800.000 s, setting step 0.005 s

Inaccuracy_ - Definite time (I_M/I_{SET} ratio > 1.05)	±2.0 % or ±80 ms
Instant operation time (alarm): - I_M/I_{SET} ratio > 1.05	<80 ms
Reset	
Reset ratio	97/103 % of the pick-up current setting
Instant reset time and start-up reset	<80 ms

8.2.3.2 Circuit breaker wear monitoring

Table. 8.2.3.2 - 183. Technical data for the circuit breaker wear monitoring function.

Pick-up	
Breaker characteristics settings: - Nominal breaking current - Maximum breaking current - Operations with nominal current - Operations with maximum breaking current	 0.00…100.00 kA, setting step 0.001 kA 0.00…100.00 kA, setting step 0.001 kA 0…200 000 operations, setting step 1 operation 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: - Current measurement element - Operation counter	 0.1× I_N > I < 2 × I_N ±0.2 % of the measured current, rest 0.5 % ±0.5 % of operations deducted

8.2.3.3 Current total harmonic distortion

Table. 8.2.3.3 - 184. Technical data for the total harmonic distortion function.

Input signals	
Current inputs	Phase current inputs: I_{L1} (A), I_{L2} (B), I_{L3} (C) Residual current channel I_{01} (Coarse) Residual current channel I_{02} (Fine)
Current input magnitudes	Current measurement channels (FFT result) up to the 31st harmonic component.
Pick-up	
Operating modes	Power THD 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	0.000…1800.000 s, setting step 0.005 s
Inaccuracy: - Definite time operating time - Instant operating time, when I_M/I_{SET} ratio > 3 - Instant operating time, when I_M/I_{SET} ratio $1.05 < I_M/I_{SET} < 3$	±0.5 % or ±10 ms Typically <20ms Typically <25 ms
Reset	
Reset time	Typically <10 ms
Reset ratio	97 %

8.2.3.4 Event logger

Table. 8.2.3.4 - 185. Technical data for the event logger function.

General information	
Event history capacity	15 000 events
Event timestamp resolution	1 ms

8.2.3.5 Disturbance recorder

Table. 8.2.3.5 - 186. Technical data for the disturbance recorder function.

Recorded values	
Recorder analog channels	0…20 channels Freely selectable
Recorder digital channels	0…96 channels Freely selectable analog and binary signals 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 The maximum length is determined by the chosen signals.
Number of recordings	0…100, 60 MB of shared flash memory reserved The maximum number of recordings according to the chosen signals and operation time setting combined

8.3 Tests and environmental

Electrical environment compatibility

Table. 8.3 - 187. Disturbance tests.

All tests	CE-approved and tested according to EN 60255-26
Emissions	
Conducted emissions: EN 60255-26 Ch. 5.2, CISPR 22	150 kHz…30 MHz
Radiated emissions: EN 60255-26 Ch. 5.1, CISPR 11	30…1 000 MHz
Immunity	
Electrostatic discharge (ESD): EN 60255-26, IEC 61000-4-2	Air discharge 15 kV Contact discharge 8 kV
Electrical fast transients (EFT): EN 60255-26, IEC 61000-4-4	Power supply input 4 kV, 5/50 ns, 5 kHz Other inputs and outputs 4 kV, 5/50 ns, 5 kHz
Surge: EN 60255-26, IEC 61000-4-5	Between wires 2 kV, 1.2/50 µs Between wire and earth 4 kV, 1.2/50 µs
Radiated RF electromagnetic field: EN 60255-26, IEC 61000-4-3	f = 80….1 000 MHz, 10 V/m
Conducted RF field: EN 60255-26, IEC 61000-4-6	f = 150 kHz….80 MHz, 10 V (RMS)

Table. 8.3 - 188. Voltage tests.

Dielectric voltage test	
EN 60255-27, IEC 60255-5, EN 60255-1	2 kV (AC), 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. 8.3 - 189. Mechanical tests.

Vibration test	
EN 60255-1, EN 60255-27, IEC 60255-21-1 Class 1	2…13.2 Hz, ± 3.5 mm 13.2…100 Hz, ± 1.0 g
Shock and bump test	
EN 60255-1,EN 60255-27, IEC 60255-21-2 Class 1	20 g, 1 000 bumps/direction.

Table. 8.3 - 190. 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 Operational: +55 °C, 16 h
Cold test	
EN 60255-1, IEC 60068-2-1	Storage: –40 °C, 16 h Operational: –20 °C, 16 h

Table. 8.3 - 191. Environmental conditions.

IP classes	
Casing protection class	IP54 (front) 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. 8.3 - 192. Dimensions and weight.

Without packaging (net)	
Dimensions	Height: 117 mm (4U) Width: 127 mm (¼ rack) Depth: 174 mm (no cards & connectors)
Weight	Appr. 1.75 kg
With packaging (gross)	
Dimensions	Height: 170 mm Width: 242 mm Depth: 219 mm
Weight	Appr. 2.25 kg

9 Ordering information

AQ - F 2 0 1 - P X 8 X A X A

Model
- **F** Feeder protection

Mounting
- **P** Panel mounting

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

Measurement accuracy class
- **8** N/A

Terminals
- **A** Standard
- **B** Ring-lug current terminals
- **C** Standard current terminals, spring cage I/O terminals
- **D** Ring-lug current terminals, spring cage I/O 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

Accessories

Order code	Description	Note
AX007	External 6-channel 2 or 3 wires RTD Input module, pre-configured	Requires an external 24 VDC supply.
AX008	External 8-ch Thermocouple mA Input module, pre-configured	Requires an external 24 VDC supply.
AQX009	Raising frame 87 mm	-
AX010	Raising frame 40 mm	-
AQX011	AQ-210 series combiflex frame	-
AQX012	AQ-210 series wall mounting bracket	-
AQ-01A	Light point sensor unit (8,000 lux threshold)	Max. cable length 200 m

10 Contact and reference information

Manufacturer

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