NEO 3000
SYSTEM

FPC 680

User manual

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Iskra®

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Document history

1.0	First release
1.1	Updated chapters of communication IEC61850
1.2	Updated chapters of communication, general part
1.3	Updated pictures
1.4	Updated chapters Modbus, LDU pannel, protection functions
1.5	Release July 2013
1.6	Updated chapters: RS485 connector, technical data, ordering
1.7	Updated chapters: diagnostics, callibration, safety instructions, operating conditions, technical data, wiring diagram, PSM, ACQ, LDU panel
1.8	Added FLOC
1.9	Updated cover, technical data, ordering, separation of electrical schemes

Table of contents

1 Safety instructions

1.1 Device function

The device is intended for operation in power substation on bay level, where specific overvoltages can occur. The device meets all safety regulations as specified for protection, control and measuring equipment for use in power substations. It is manufactured and tested according to IEC 60255-26 (Electrical relays: Electromagnetic compatibility requirements for measuring relays and protection equipment) and IEC 60255-27 (Measuring relays and protection equipment Part 27: Product safety requirements) product standards.

1.2 Explanation of safety symbols

Depending on the device layout, the following labels and symbols can be used on device itself or in the corresponding technical documentation:

	WARNING! Risk of electrical shock!
	CAUTION! Refer to product technical documentation!
	Protective and functional ground terminal.
	Waste Electrical and Electronic Equipment (WEEE) Directive 2002/96/EC; the affixed product label indicates that you must not discard this electrical / electronic product in domestic household waste.

1.3 Safety warnings

Safety instructions and warnings should be considered before commencing any works on the device. They are provided for device proper installation, handling and maintenance and to provide guidelines for safe operation conditions. It is the user's responsibility that equipment is installed, operated and used in accordance with its intended function and in the manner specified in user manual. Failure to comply with these manual's instructions may impair the operational safety function of the device.

WARNING!

Hazardous voltages possible of causing death can be present on the exposed electrical elements. Failure to observe the safety regulations during installation, commissioning, operation and maintenance can result in severe personal injury and/or equipment damage.

WARNING!

The device housing must be correctly earthed before it is connected to power supply. Earthing is executed with a flat braid which is screwed on the device with a designated screw and a washer. Non-earthed operating devices are hazardous to persons.

WARNING!

Never open the secondary circuits of current transformer (CT) secondary circuit when the current transformer is energized. Before disconnecting the current circuits, always short circuit the CT secondary circuit. Omitting that instruction can result in lethal hazard and equipment insulation deterioration due to high voltage inductions!

WARNING!

Opening of the device and changing its parts or electronic components during device operation is strictly prohibited. There is a possibility of high voltage stroke into a person or equipment damage.

WARNING!

Only qualified personnel familiar with the warnings and safety information stated in this document and other safety regulations are permitted to handle this device.

WARNING!

When handling devices with optic communication the user should not look directly into the optical heads. There is a possibility of eye injuries.

1.4 Liability statement

The contents of this manual has been checked by the manufacturer to ensure the descriptions of both hardware and software are as accurate as possible. However, deviations may occur so no liability can be accepted for any errors or omissions contained in the given information.

The contents of this manual will be checked in periodical intervals, and corrections will be made in the following editions. We reserve the right to make technical improvements without prior notice.

1.5 Contact

If you have any questions or comments related to this product please contact us at:

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1.6 Copyright

2 Introduction

2.1 General device information

The NEO3000 FPC and CAU devices are components of the NEO3000 system that is intended for protection, control and communication in distribution and industrial electrical networks.

The NEO3000 devices are entirely configured and controlled with the *NEO3000 Power System Manager* (*PSM*) user interface on the PC computer. It is accessed via a computer network or directly via a dedicated network adapter on the front or the back side of the device.

The device communicate through various communication standards, such as IEC 61850 MMS and GOOSE, IEC 60870-5-101...104, DNP3 or Modbus protocols. These protocols are usually used in electrical systems. Depending on the protocol into the master system the connection can be executed as a network or serial connection through an optic ST adapter, RJ45 or a DB9 serial adapter.

Device can record events with a time resolution of 1 ms. It enables clock synchronization via a local as well as via universal time (UTC), through standard communication SNTP or NTP protocols. The self-test functions are integrated as standard and they offer a high level of device availability.

The needs of individual projects determine various versions of the device considering mounting type, inputs and outputs number, number of communications, etc.

The FPC680 device is intended for protection on medium voltage lines, but can also be used as a backup protection for transformers or high voltage lines. It includes the complete range of protection functions and functions of control and local automation.

The FPC680 device basic are the protection functions with added control functions and local automation functions. Because different types of protection functions are used on different types of electrical networks, the device is designed to suit the majority of such cases.

FPC680 can be used in:

- directly earthed networks
- resistor earthed networks
- Petersen coil earthed networks
- isolated networks.

Figure 2.1: FPC680 device

The FPC680 device is intended for:

- overhead lines protection in radial networks that are resistor earthed and where there is a possibility of high impedance earth fault
- protection of lines in radial networks that are directly earthed, especially as a backup protection
- cable lines protection in larger radial networks that are resistor earthed and where the capacitive currents are comparable with the earth fault current
- protection of lines in radial isolated networks or networks that are earthed via the Petersen coil, and where the capacitive current in the protected line is significantly smaller than the capacitive current of the complete system
- protection of lines in radial isolated networks or networks that are earthed via the Petersen coil, and where the capacitive current in the protected line is comparable with the capacitive current of the complete system
- protection of two-way supplied lines in networks that are directly or resistor earthed
- protection of two-way supplied lines in isolated networks or in networks that are earthed via the Petersen coil

2.2 Hardware and software description

Because of the EMC compatibility requirements, CE directive and environmental standards the device is designed as a unified compact device with modular structure.

2.2.1 Hardware

The device hardware includes a housing and various cards that are connected together to a bus and screwed down on the front panel. The panel with cards is inserted into the housing frame and also screwed down to this housing.

2.2.1.1 Mechanical system

The device housing with an integrated LDU panel is intended for flush mount into a cabinet (e.g. into cabinet with rotating frame). The version with a separate LDU panel or without it is intended for surface mount (e.g. on the back side of a cabinet). Connectors and device signalization (LEDs) are located on the terminals panel of the device and the LDU panel. The entire housing is made of stainless steel and is resistant to corrosion. Dimensions and weights can be found in the Technical data chapter.

2.2.1.2 Hardware modules

Device includes various cards that are combined into 4 functional modules:

- Core module
  - Motherboard with up to 12 galvanically isolated analog inputs and up to one DC input (AI-CPU)
  - Communication card (COM)
- DI module
  - Base card with 22 digital inputs (DI)
  - Plug-in card with 22 LEDs (LED-DI)
- DC-DO module
  - Base card with 8 digital outputs and a DC or AC power supply (DC-DO)
  - Plug-in card with 8 LEDs (LED-DO)
- TRA module
  - Transformer card with max. 5 current inputs and 4 voltage inputs (TRA)

One device can house all together up to 8 DI and DO modules. This modules can be replaced very easily, no reprogramming or reconfiguration of parameters are needed.

2.2.1.3 LEDs

The LEDs on the device housing give you the first information about the status and operation of the device. A green one, first in the upper left part of the device front panel (Ready LED), indicates normal device operation when all vital processes and functions are in operation. In case of an alarm in the system the red ALARM LED illuminates.

Some devices can have additional LEDs integrated in the digital inputs and outputs card. An illuminated LED next to an input indicates a present signal on this input, and an illuminated LED next to an output indicates that a particular relay is closed.

2.2.2 Software

The NEO3000 devices simultaneously use multifunctional and multi-user operation system with real time task execution support. The device executes the tasks (applications) and by this the operation for which it is intended. The applications can be of standard and Real Time (RT) type. The latter includes time critical operations execution and where a time determining is necessary, e.g. at protection and control of electrical systems and industrial processes. Standard type applications provide support for communication protocols and device management.

The software design is modular so that various client needs can be satisfied by adding or removing different functional modules.

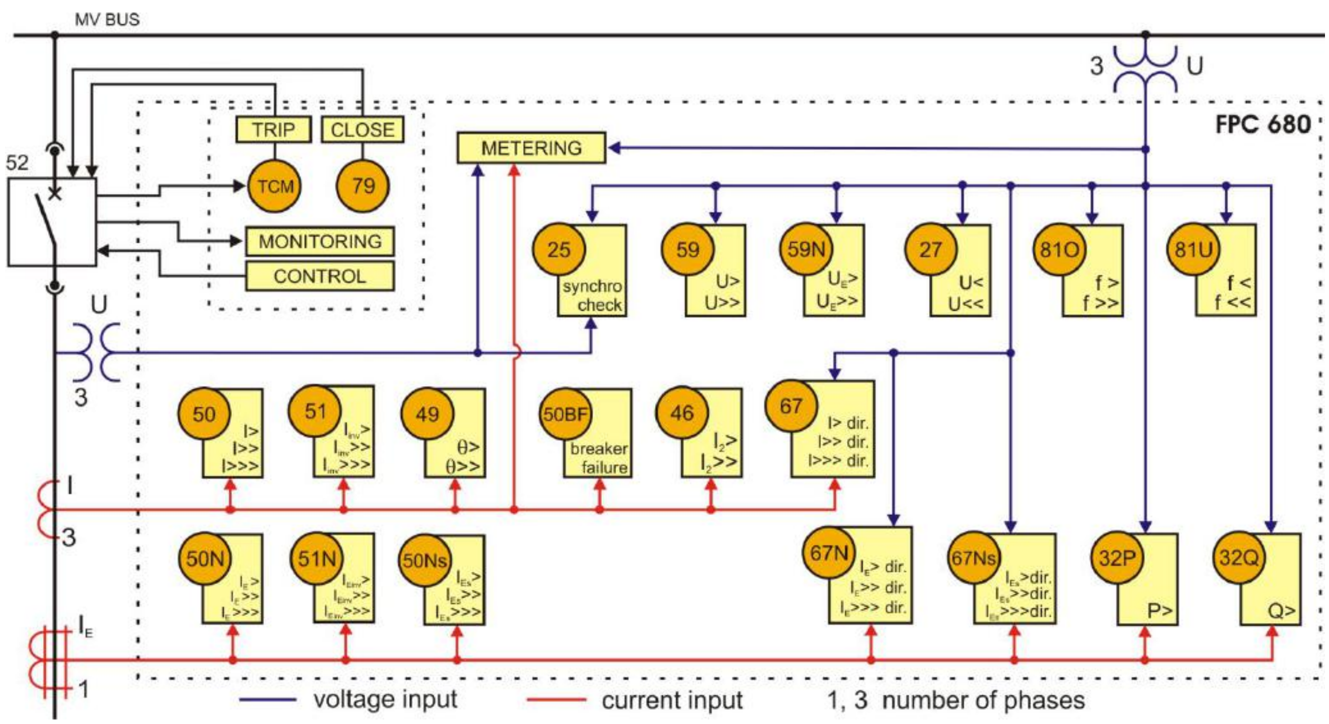

Figure 2.2: Modular design of software

2.2.3 Self-diagnostics

The device has a built-in self-diagnostics, which is responsible for supervising the proper functioning of the entire system. Status information on the operation of the device itself can be sent via the communication protocol. A set of monitoring functions runs inside of the device for various device components such as CPU, critical tasks, hardware components, such as DI cards, DO cards, AI cards and internal power supply voltages. In the case of critical errors in device the relay is disabled and the device automatically reboots.

The device can indicate internal error through a special relay output (*Ready relay, DO8*) and through communication protocol. In addition, device records relevant logs, such as events of device restarts, temperature and components operation.

3 General functions

3.1 Local Display Unit - LDU

Local Display Unit (LDU) is intended for communication between human and device or electrical system. It only operates as dependent unit in connection with another device or system via serial or network communication. It displays the device data and offers the following displays or functions:

- display of several main pages
- display of measurements and counters
- commands issuing, local/remote control switch
- display of events and alarms list (on the screen or with LEDs)
- acknowledgement of displayed alarms
- function keys for short cuts
- device setting (parametrizing)
- device status display: digital inputs, basic settings

On the front side, the LDU panel has an LCD display, two system LEDs and 16 adjustable function LEDs, control mode signalization, 16 keys and a local network connector. From the back side it is connected to the NEO3000 device. In case of fault or communication failure between the LDU and the device, all LEDs go off and a NEO3000 logo is displayed. When the communication is re-established, the display and LEDs are refreshed.

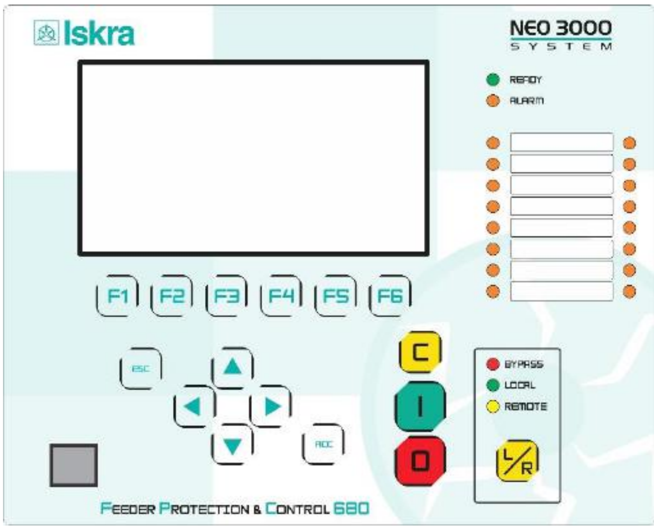

Figure 3.1: LDU layout

3.1.1 Display

Display is a backlit monochrome LCD, it measures 11 x 6 cm and enables display of 240 x 128 pixels or 30 x 16 characters.

The display is multilingual and has user customized readouts. All views on the display are shown as pages. One view can consist of several pages. The row on the bottom shows active navigation keys.

3.1.2 Keys

On the front panel there are 16 keys that have different functions on different pages. The role of individual keys is described at individual functions.

Table 3.1: Explanation of keys on the device

◄	Move left, one level back.	ESC	Exit from the current view, cancellation of operation.
►	Move right, one level forward.	ACC	Selection confirmation, alarms acknowledging.
▲	Move up.	C	Command execution mode, command selection.
▼	Move down, main menu.	I	Close command.
L/R	Local/Remote control mode switch	O	Open command.
F1..6	Function keys, shortcuts		

3.1.2.1 Local/Remote switch control

The L/R key and 3 LEDs: LOCAL, REMOTE and BYPASS are intended for switching Local/Remote control mode. There are 4 control modes (Table 3.2). The indication of LEDs changes according to the mode. If the LDU has no information about the control, then none of the control mode LEDs is illuminated.

Table 3.2: Control modes and indications

Control mode	LED	Description
Local mode	LOCAL	Only local execution of commands is possible, with interlocking check.
Local mode without interlocking	LOCAL + BYPASS	Only local execution of commands is possible (from the LDU), without interlocking check.
Remote mode	REMOTE	Only remote execution of commands is possible, with interlocking check.
Remote mode without interlocking	REMOTE + BYPASS	Only remote execution of commands is possible, without interlocking check.

3.1.2.2 Manual control mode switch

With a short press on the L/R key you can switch between local and remote control mode with interlocking check.

A 3 second pressing of the L/R key in the command menu activates the local mode without interlocking check. On command menu exit, the control mode switches back to active interlocking check mode.

3.1.2.3 Function keys

The function keys on the front panel serve as short cuts for quick access to frequently used pages. With function keys you can access menus and parameters or execute a command.

3.1.3 LEDs

The device has several LEDs of different colours for signalling of different statuses. Individual LEDs are described below.

3.1.3.1 READY LED

READY LED is a green colour system LED. It illuminates when the device is connected to rated voltage and operates faultlessly. The device operates faultlessly, if the rated voltage is ok, there is no fault or error on the hardware or software, and if all important functions operate faultlessly.

3.1.3.2 ALARM LED

ALARM is a red colour system LED. It indicates a group alarm of the device and operates as shown in Table 3.3.

Table 3.3: ALARM LED operation

	Acknowledgement	Action
without present alarms	acknowledged	is off
	unacknowledged	blinks
at least one alarm present	acknowledged	illuminates
	unacknowledged	blinks

3.1.3.3 Function LEDs

Function LEDs are programmable red LEDs. The programmable LEDs indicate an individual alarm status according to their indication type (Non-latched, Latched steady, Latched blinking), as shown in Table 3.4.

Table 3.4: Operation of a programmable LED

	Acknowledgement	Non-latched	Latched steady	Latched blinking
alarm not present	acknowledged	is off	is off	is off
	unacknowledged	is off	illuminates	blinks
alarm present	acknowledged	illuminates	illuminates	illuminates
	unacknowledged	illuminates	illuminates	blinks

If the same LED can indicate several alarms, it indicates the one with the highest priority. Priorities from lowest to highest: Non-latched, Latched steady, Latched blinking.

3.1.4 Local service connector

The local communication connector is of Ethernet (ETH) type and is intended for local accessing of the device with the connected LDU. A PC with an installed PSM user interface software that is used for device initialization and installation of the device parametrization is connected to this connector.

3.1.5 Connection to power supply

After the connection of LDU to power supply, the screen displays the manufacturer's logo (Figure 3.2) and all LEDs illuminate for 3 seconds. The 3 second illumination of LEDs is intended for their operation diagnostics. In case of a malfunction or communication failure between the LDU and the device, the following system readout is displayed: *System error: Device not ready*.

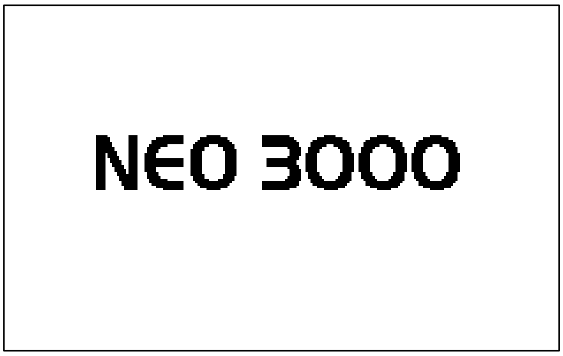

Figure 3.2: Display at LDU panel start.

3.1.6 Main page

The main page is displayed as a first page after a successful communication with the device to which the LDU is connected to (Figure 3.3). There can be several main pages. Use directional keys ◄ and ► to switch between them. The following elements can be displayed on the main page:

- feeder single line diagram, background picture,
- picture or feeder name,

- animated elements, e.g. circuit breaker, disconnecting switch, etc.,
- basic measurements,
- date and time.

The layout of the display is determined in the device settings. Animated elements are similar to icons, but animated. They change according to the monitored value. Besides this, the animated elements can also execute commands, as described in chapter 3.1.6.2 Commands. The basic measurements normally show the most important values in a bay or electrical system.

If no key is pressed for a certain time, the LDU displays the main page again. In this case, all non-issued commands and unsaved changes of settings are cleared.

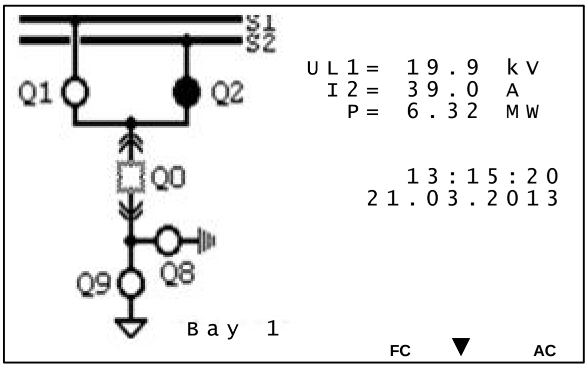

Figure 3.3: Example of main page

Table 3.5: Functions of keys on the main page

◄	Display of previous page	ESC	Display of first page
►	Display of next page	ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲		C	Command page
▼	Main menu	I	
L/R	Control mode switch	O	

3.1.6.1 Animated elements

The animated elements in the main page serve for graphical representation of the monitored element state. Maximum 4 different states are possible. Usually, the picture shows the state of switches (circuit breakers and disconnectors).

The maximum number of different animations (types) is 6.

The maximum number of all animations is 15.

3.1.6.2 Commands

Commands for the animated elements can be issued via the C, I and O command keys. All commands are disabled if the LDU does not have the correct information on the local/remote control mode. In case of a remote control mode the *Remote* text is displayed, and in case of an undefined state the *Undefined* text is displayed.

The command menu can be accessed with a short press on the **C** key. The background, feeder name, animated elements and text of command execution are displayed. If in command menu no key is pressed for five minutes, the basic picture is displayed.

Upon entering the command mode the first command element starts to blink. This means a command for that element can be issued. The display of basic measurements hides. A text for selected element appears in the command window, ex. *Select Q0*. Use the **C** key to move between the command elements. Use the **ESC** key to return to the main page.

Press the **I** key to choose close or **O** key to choose open command. In the command window you can see which command will be executed and for which element, e.g. *Close Q0*.

An execution of selected command is confirmed with the **ACC** key or cancelled with the **ESC** key. The command is executed only if the interlocking check has been successful.

After the command execution feed-back information start to display. The feed-back information is displayed until the end of command execution or if user presses the **ESC** or **C** key. If the command time-out runs out the *Command timeout* is displayed.

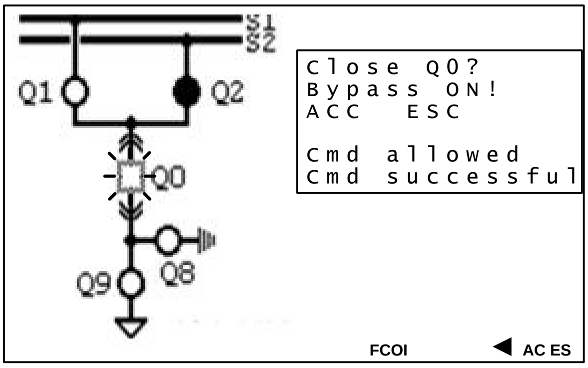

Figure 3.4: Command confirmation display

Table 3.6: Key functions in command mode

◄		ESC	main page / execution cancellation
►		ACC	command execution confirmation
▲		C	selecting command elements
▼		I	close command selection
L/R	control mode switch	O	open command selection

3.1.7 Main menu

The main menu can be accessed by pressing the ▼ key on the main page. Submenus of all in settings enabled functions appear in the main menu.

List of possible submenus:

- list of alarms, see chapter 3.1.8.1 Display of alarms in a list
- list of events, see chapter 3.1.9 List of events
- measurements, see chapter 0
- Analog measurements
- digital inputs, see chapter 3.1.11 Digital inputs
- settings, see chapter 3.1.12 Device parametrizing
- device status, see chapter 3.1.13 Device status
- LEDs test

The last option, the **LED test**, is intended for LEDs operation testing. If this option is selected, all LEDs illuminate for 3 seconds.

By displaying the main menu, the display of basic measurements is hidden.

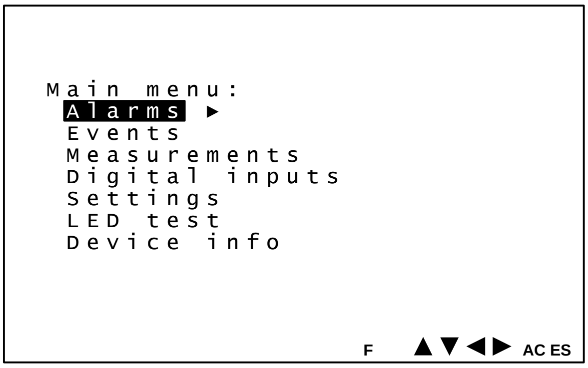

Figure 3.5: Example of the main menu

Table 3.7: Functions of keys in the main menu

◄	previous menu	ESC	main page
►	access into the selected menu	ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲	move one row up	C	
▼	move one row down	I	
L/R	control mode switch	O	

3.1.8 Alarms page

Some states in the electrical system or in the device represent alarm states (alarms), and their changes represent events. At device start-up all present alarms are unacknowledged, e.g. the LEDs start to blink. An alarm can be independently displayed in three different ways:

- on LEDs,
- in List of alarms or
- in List of events.

3.1.8.1 Display of alarms in a list

Maximum number of pages for alarms display is 14, and on each page a maximum of 14 alarms can be displayed. First row shows the name of the current page: *Alarms,* the number of the current page and the number of all pages.

Each alarm is displayed in its own row. Next to the alarm description, its status is displayed: acknowledged, unacknowledged, present, not present as blinking, full or empty square. The alarms status display is shown in Table 3.8.

Table 3.8: Alarm status display in the list of alarms

	Acknowledgement	**Non-latched mode**	**Latched steady mode**	**Latched blinking mode**
alarm not present	acknowledged	empty	empty	empty
	unacknowledged	empty	crossed	blinks
alarm present	acknowledged	crossed	crossed	crossed
	unacknowledged	crossed	crossed	blinks

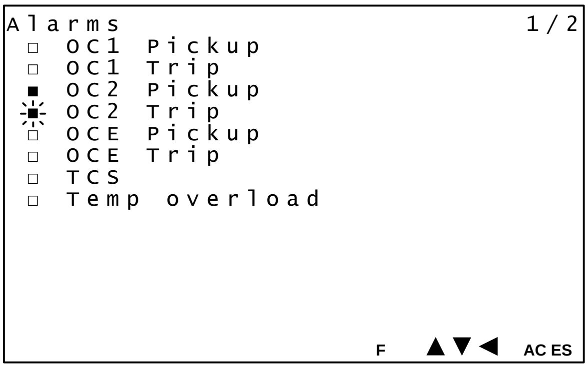

Figure 3.6: Display of alarms

Table 3.9: Functions of keys at alarm display

◄	previous menu	ESC	main page
►		ACC	acknowledgement of alarms on the displayed page
▲	move one page up	C	
▼	move one page down	I	
L/R	control mode switch	O	

3.1.8.2 Acknowledging of alarm display

Alarm display can be "acknowledged" or "unacknowledged". The unacknowledged alarm display occurs in case of a new alarm, and the acknowledged alarm display occurs when this alarm is confirmed by the operator. The acknowledgment of alarm display is independent for all LEDs and list of alarms. It is executed with the ACC key.

Acknowledge can be done in several ways:

- Acknowledge of LEDs only: short press on the ACC key on all pictures, except on the list of alarms and in command mode.
- Acknowledge of current alarm page only: short press on the ACC key on the *Alarm list* page.
- Acknowledge of all alarms: longer pressing of the ACC key on all pages, where the ACC key has a function of acknowledging of all alarms. The acknowledging is executed after 3 seconds, regardless if the key is still pressed.
- remote acknowledge of all alarms

Note: The term "all alarms" applies to all LED alarms and all alarms on all alarm pages.

3.1.9 List of events page

An event occurs when the status of an alarm changes. Event is displayed in the events list and its format depends on the device settings. After a device restart the recorded events are restored from device permanent memory. The foreseen space for events display can show the last 98 events in chronological order (14 pages x 7 events). Only one page at a time can be displayed.

First row shows the name of the current page: *Events,* the number of the current page and the number of all pages. Each event displayed occupies two rows. In the first row the event name and in the second line the time of occurrence in *yyyy-mm-dd hh:nn:ss.iii* (year, month, day, hour, minute, second and millisecond) format.

When the events page is opened for the first time, initially the first events page is displayed with the last events in chronological order. The events are arranged chronologically from the most recent on top to the oldest on the bottom. If during the reviewing of events a new event occurs, the currently opened page remains open for at least 30 seconds, and then the first page with the most recent event displays.

```
Events                                  1/1
OC2  Trip
     2013-03-23  11:15:06.885
OC2  Pickup
     2013-03-23  11:15:06.180
OC1  Pickup
     2013-03-12  05:54:12.710
OC1  Pickup
     2013-03-10  23:12:34.284
OC1  Pickup
     2013-02-11  22:30:32.912


                       F    ▲▼◀   AC ES
```

Figure 3.7: Display of events

Table 3.10: Functions of keys at events display

◀	previous menu	ESC	main page
▶		ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲	move one page up	C	
▼	move one page down	I	
L/R	control mode switch	O	

3.1.10 Analog measurements page

The measurements that are measured by the device are displayed on the **Analog measurements** page. Maximum number of measurements displayed on one page is 14 and they are displayed in a column. Three pages are available for the display of analog measurements, which is all together 3 x 14 = 42 measurements. Use directional keys ▲ and ▼ to switch between pages.

Usually, the basic measurements are displayed: U_{L1}, U_{L2}, U_{L3}, U_{L12}, I_{L1}, I_{L2}, I_{L3}, I_e, *P, Q, PF. Additionally, at the SinhroCheck function also both frequencies and the line-to-line voltage of another system are displayed.*

The measurements are displayed in rows, one measurement per row, in a format like: *IL1 = 20.6 A*. Display shows: First row shows the current page: *Measurements,* the number of the current page and the number of all pages.

```
Measurements                            1/3

 UL1  =  19.91  kV
 UL2  =  19.84  kV
 UL3  =  20.01  kV
 IL1  =   37.1  A
 IL2  =   39.0  A
 IL3  =   40.2  A


                       F    ▲▼◀   AC ES
```

Figure 3.8: Display of analog measurements

Table 3.11: Functions of keys at measurements display

◀	previous menu	ESC	main page
▶		ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲	move one page up	C	
▼	move one page down	I	

L/R	control mode switch	O	

3.1.11 Digital inputs pages

The **Digital inputs** page displays the state on physical digital inputs of the device. The digital input value is displayed in a square next to the input number. If the input is not active the square is empty, and if the input is active the square is full. First row shows the name of the current page: *Digital inputs*.

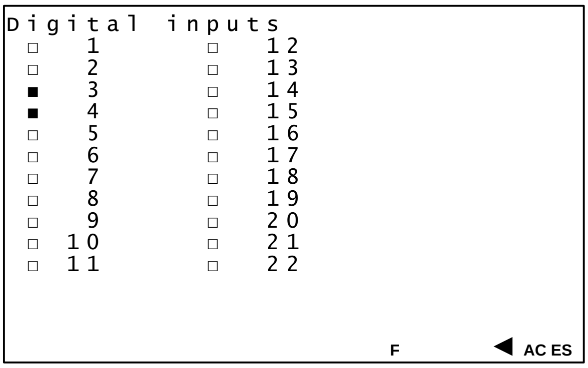

Figure 3.9: Display of digital inputs statuses

Table 3.12: Functions of keys at digital inputs statuses display

◄	previous menu	ESC	main page
►		ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲		C	
▼		I	
L/R	control mode switch	O	

3.1.12 Device parametrizing pages

The LDU interface enables the setting of parameters for control and protection functions and other functions of the device. Use the main menu and select *Settings*. The name and the number of the current page and the number of all pages are displayed on top of the page. In the bottom two rows the commands for saving all settings and cancelling all changes are displayed. The device parameters are organized in tree structure.

A parameter containing the name of the setting, its value and unit is displayed in a separate row. The parameter values can be decimal numbers, with limited number of decimal spaces.

Upon entering the parametrizing mode the first level of settings is displayed. Use directional keys ◄, ►, ▲, ▼ to move through the settings and sub-trees and select the setting. Use the **Esc** key to move to the first level.

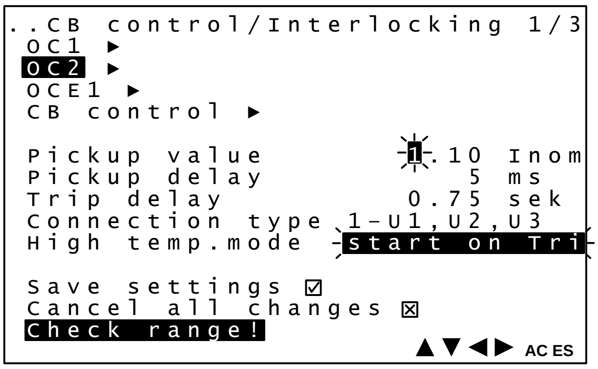

Figure 3.10: Symbolic picture of the page with device parameters

Table 3.13: Functions of keys at device parametrizing

◄	Move left, one level back.	ESC	Escape from the current view, cancellation of changes.
►	Move right, one level forward.	ACC	Value confirmation, confirmation of changes.
▲	Move up.	C	
▼	Move down.	I	
L/R	Control mode switch.	O	

3.1.12.1 Setting parameters

A setting is changed by selecting the setting and pressing **Acc**. For numeric parameters, the last digit of a value starts to blink. Use directional keys ◄, ► to move through digits. Use directional keys ▲, ▼ to change the selected digit.

Press **Acc** to confirm the entered value, and press **Esc** to cancel the setting procedure. Upon confirmation, the setting value is checked for range restrictions. If the value is outside of the valid range the *Check range!* is displayed and the user remains at editing of a setting. Otherwise the new setting is confirmed and the user can continue with next selection.

3.1.12.2 Setting the date and time

Time and date setting is located on the first level. Time is entered in the format hh:mm. The clock is set at the moment when **Acc** is pressed but it is applied to the device when new settings are saved. Date is entered in the format dd.mm.yyyy.

3.1.12.3 Saving new settings

All changes can be saved on the first page by selecting an option for saving all settings *Save settings* and pressing **Acc**. Use the **Esc** key to cancel changes. Next a question to save all settings *Save changes?* is displayed. Use the **Acc** key to confirm saving or use the **Esc** key to reject new settings. For cancelling all changes there is also an option *Cancel all changes*.

If a password check is enabled, the password question *Enter password* is displayed before saving the changes. Four zeros which are the initial entering value for the password appear. Enter valid password and confirm by pressing the **Acc** key. The password must be entered only once and then remains active until it expires by inactivity time-out (**Inactivity time**).

Before the saving procedure the LDU checks if another user may have remotely changed the device settings during the editing time. If this is the case, the LDU displays *Settings altered! Save anyway?* By pressing the **Esc** key you are returned back to the previous page, and by pressing the **Acc** key the changes are confirmed.

The confirmed settings are saved in the device permanent memory and applied immediately. *Saving and applying…* is displayed and then the LDU returns to the main page.

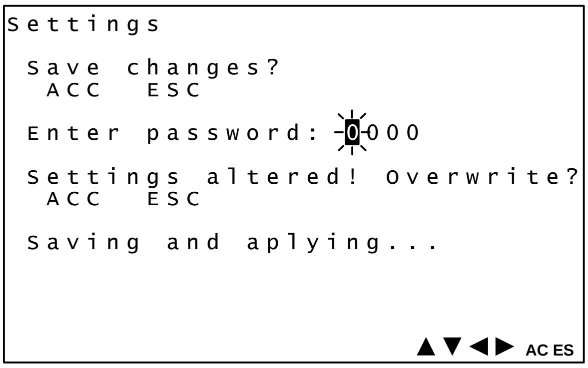

Figure 3.11: Example of saving the settings to the device

3.1.13 Device status page

This page contains all important information about the device. Network settings, major statuses and the NTP status of the device are displayed. First row shows the current page: *Device info* and the number of the current page. If the information is too long for one row, it is displayed in two or more rows. The information displayed are:

- Network:
  - Hostname: device name
  - MAC: physical MAC address of network adapter
  - Topology: set topology of network: *Star*, *Ring*, *Double Star*
  - ETHx IP: IP address on the ETHx interface, more than one are possible
  - Stat1|2: connection status on both ETH interfaces in format: *<status1> | <status2>*
  - RSTP stat: RSTP protocol status, e.g. *Fwd/R, Fwd/D*
- Time synchronization:
  - NTP Stat: NTP protocol status and the last offset from the exact time, *Synch* – synchronized and *Not synch* - unsynchronized, *Down* - not operational
- Software info:
  - Release: device software indication
  - Date: release date of the device software indication
- Hardware info:
  - Type: hardware indication
  - Ordering: hardware ordering code
  - Serial No: device serial number
  - Date: device production date

```
Device info                    1/2

Network:
 MAC      :  00:17:08:2F:EA:B3
 Topolog:  star
 ETH1 IP:  192.168.0.10
 ETH1 IP:  192.168.1.10
 Stat1|2:  UP/DOWN
 RSTP st:  Fwd/R

NTP:
 Stat     :  OK

                  F   ▲▼◀   AC ES
```

```
Device info                    2/2

Software info:
 Release  :  FPC680-1.1
 Date     :  December 2011

Hardware info:
 Type     :  FPC680
 Ordering:  1A/1A/1A/1A/1A/1A/
  1A/1A/1A/1A/1A/1A/1A/1A/1A
 Serial n:  123A
 Date     :  January 2012

                  F   ▲▼◀   AC ES
```

Figure 3.12: Display example of device data

Table 3.14: Functions of keys at device readout

◄	Move to next page.	ESC	Escape from the current view, cancellation of changes.
►	Move to previous page.	ACC	LED alarms acknowledgement, acknowledgement of all alarms
▲		C	
▼		I	
L/R	Control mode switch.	O	

3.2 Power system settings

The module enables setting of electrical system properties at one place which apply for all the other modules in the device. There are settings for nominal values of electrical system, current and voltage transformers and device settings. The module enables parametrizing of the device in user-friendly engineering units (e.g.

150 A, 20 kV) and a uniform entering of common parameters. These settings affect the operation of the majority of protection and control functions, in which the settings are usually set in relative units.

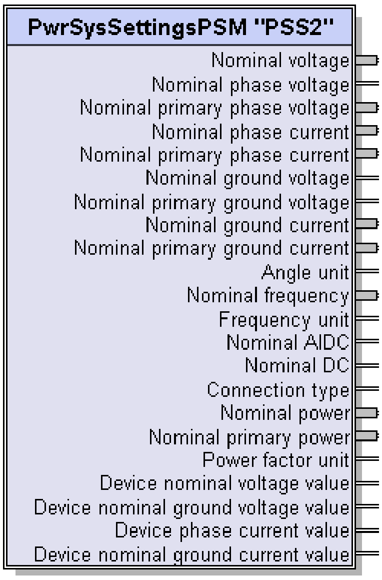

Figure 3.13: Power system settings function block

3.2.1 Operation

Based on the entered data the module calculates output values. They are calculated only at device start-up before all other modules start and are not changed later on. For new changes to take effect, the device must be restarted.

3.2.1.1 Methods of connecting currents and voltages to terminals

The device can be connected to primary current and voltage transformers by different methods depending on the bay equipment. The connection method is selected with the **Connection type** parameter. This parameter does not affect protection modules.

Table 3.15: Different types of currents and voltages connection to device terminals.

Method	Voltage connections	Current connections*	Note
1	U1 U2 U3 UE	I1 I2 I3	three-phase wiring
2	U12 U23 UE	I1 I2 I3	Aaron wiring, I0 = 0
3	U23 U31 UE	I1 I2 I3	...
4	U12 U31 UE	I1 I2 I3	...
5	U12	I3	simplified wiring
6	U23	I1	...
7	U31	I2	...
8	U1	I1	single-phase wiring
9	U2	I2	...
10	U3	I3	...

** Physical connection of these currents and voltages is optional, depending on which modules are using these values. Example: At method 2 the* Power and Energy *module does not use the current I2, therefore the connection is not necessary. But the* Over Current protection - *OC module (at protection relay) uses all three currents, therefore all must be connected.*

3.2.2 Parameters, inputs and outputs

/ Power system settings	
Settings name text (max. 31 characters)	Settings set name.
Connection type 1 – U1, U2, U3 & I1, I2, I3 2 – U12, U23, I1, I3 3 – U23, U31, I1, I2 4 – U12, U31, I2, I3 5 – U12, I3 6 – U23, I1 7 – U31, I2 8 – U1, I1 9 – U2, I2 10 – U3, I3	Type of currents and voltages connection to device terminals
Primary system voltage 0,1...**20,0**...1.000 kV	Primary nominal line-to-line voltage of electrical system
Primary system current 1...**300**...60.000 A	Primary nominal current of electrical system
Primary system ground current 0,1...**150,0**...60.000 A	Primary nominal ground current of electrical system
VT primary 0,1...**20,0**...1.000 kV	Primary voltage of voltage transformer for line-to-line voltages
VT secondary 1...**100**...1.000 V	Secondary voltage of voltage transformer for line-to-line voltages
Ground VT primary 0,001...**11,540**...1000 kV	Primary voltage of voltage transformer for ground fault voltages
Ground VT secondary 1...**100**...1.000 V	Secondary voltage of voltage transformer for ground fault voltages
Phase CT primary 1...**300**...60.000 A	Primary current of current transformer for phase currents
Phase CT secondary 0,1 ...**1,0**...1.000 A	Secondary current of current transformer for phase currents
Ground CT primary 0,1...**150,0**...60.000 A	Primary current of current transformer for ground currents
Ground CT secondary 0,1...**1,0**...1.000 A	Secondary current of current transformer for ground currents
Nominal system frequency **50** Hz	Nominal frequency of electrical system

Nominal voltage output (analog)	Raw value at nominal line-to-line voltage of bay
Nominal phase voltage output (analog)	Raw value at nominal phase voltage of bay
Nominal ground voltage output (analog)	Raw value at nominal ground fault voltage of bay
Nominal phase current output (analog)	Raw value at nominal phase current of bay
Nominal ground current output (analog)	Raw value at nominal ground fault current of bay
Primary nominal voltage output (analog)	Raw value for primary nominal line-to-line voltage of bay
Primary nominal ground voltage output (analog)	Raw value for primary nominal ground fault voltage of bay
Primary nominal phase current output (analog)	Raw value for primary nominal phase current of bay
Primary nominal ground current output (analog)	Raw value for primary nominal ground fault current of bay

Primary nominal power output (analog)	Raw value for primary nominal power of bay
Nominal frequency output (analog)	Raw value at nominal frequency of electrical system
Nominal power output (analog)	Raw value at nominal power of bay
Nominal AIDC output (analog)	Raw value at nominal AIDC channel current/voltage
Nominal DC output (analog)	Raw value at nominal DC board current/voltage
Frequency unit output (analog)	Raw value of frequency unit 1 Hz
Angle unit output (analog)	Raw value of angle unit 1°
Power factor unit output (analog)	Raw value of power factor maximum value (1).
Connection type output (analog)	Connection method according to **Connection type**. Values range is from 1 to 10
Device voltage value output (analog)	Raw value of nominal line-to-line device voltage
Device ground voltage value output (analog)	Raw value of nominal device ground fault voltage
Device phase current value output (analog)	Raw value of nominal device phase current
Device ground current value output (analog)	Raw value of nominal device ground fault current

3.3 Line state detection

The *Line State Detection* (*LSD*) module is intended for voltage and current line states detection with emphasis on determining whether the line is closed or open. For the *LSD* function execution it is necessary to collect voltages behind the circuit breaker on the line side. It is used especially as an input data for all modules requiring the information about the line state. For line state detection the line-to-line voltages and phase currents are used. Phase or line-to-line voltages used as a criterion of state detection can be acquired in the device.

During operation the following voltage and current conditions can appear on the line:

- open line state, zero voltage and current, stable state
- healthy state of operation: healthy line voltage, stable state
- fault state: disturbance, short circuit, overvoltage, undervoltage

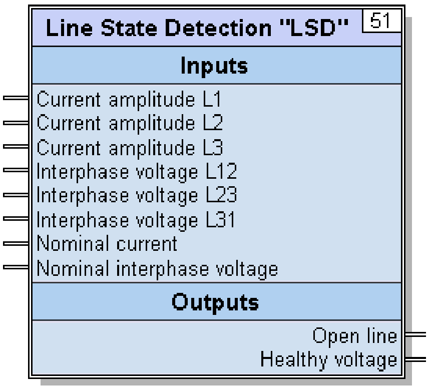

Figure 3.14: Line state detection function block

3.3.1 Operation logic

The *Line State Detection* module constantly calculates two line states (**Open line** and **Healthy voltage**) in its outputs. The **Open line** output determines the open line state.

Open line is set when:

- all currents are below the **Open line current** parameter value with **Enable Open line current** parameter enabled and
- all voltages are under the **Open line voltage** parameter value with **Enable Open line voltage** parameter enabled.

The **Healthy voltage** output determines the healthy line voltage. **Healthy voltage** is set when all voltages are between **Min healthy voltage** and **Max healthy voltage**.

Table 3.16: States according to output signals

Open line	Healthy voltage	Description
0	0	fault state
0	1	healthy state of operation
1	0	open line state
1	1	module or device fault

The **Max healthy voltage** parameter value should be set lower than the **Min healthy voltage** value as the two ranges overlap. In case of fault state, the both output values will be 0.

For a more stable operation the voltages and currents have a 1% hysteresis above the setting according to nominal value. Figure 3.15 shows individual ranges and switching between ranges with regard to hysteresis.

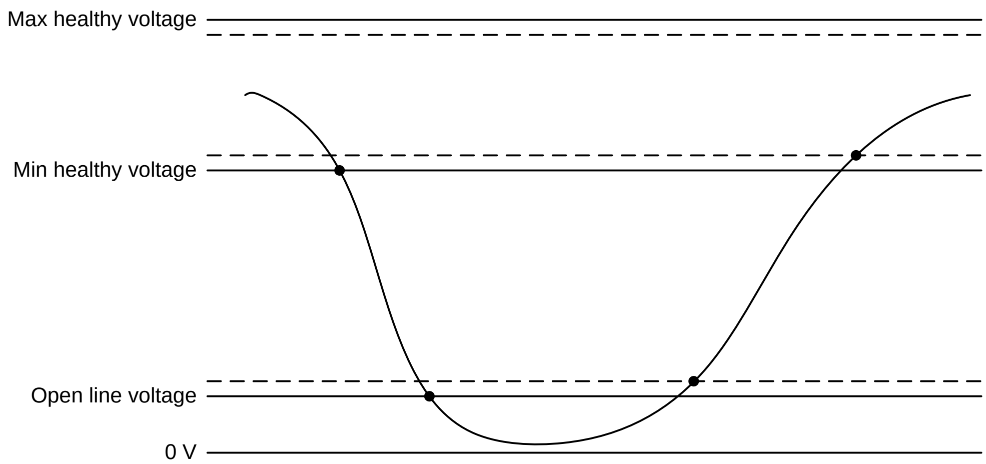

Figure 3.15: Switching between ranges with regard to hysteresis

3.3.2 Parameters table

\ Control settings \	
Open line current 0.00...**0.04**...0.30 In	Current amplitude under which an open line is assumed.
Open line voltage 0.00...**0.10**...0.70 Un	Voltage amplitude under which an open line is assumed.
Min healthy voltage 0.80...**0.90**...1.10 Un	Minimum amplitude for healthy voltage detection.
Max healthy voltage 1.00...**1.10**...1.30 Un	Maximum amplitude for healthy voltage detection.

Enable Open line current **true**, false	Enabling of current criterion for open line detection.
Enable Open line voltage **true**, false	Enabling of voltage criterion for open line detection.

\ Inputs \

Current amplitude L1...L3 input (analog)	Amplitudes of currents.
Interphase voltage L12...L31 input (analog)	Amplitudes of line-to-line voltages.
Nominal current constant input (analog)	Nominal phase current - In.
Nominal voltage constant input (analog)	Nominal line-to-line voltage - Un.

\ Outputs \

Open line output (digital)	Zero voltage state detection.
Healthy voltage output (digital)	Healthy state detection.

3.4 Retentive registers

The **Retentive registers** module is intended for saving the inputs/outputs values into the permanent registers in case of a temporary device switch-off or loss of the power supply. Values that are usually permanently stored in the device are:

- statistical counters of protection and circuit breakers operation
- energy counters
- current states (e.g. ARC states, control mode position).

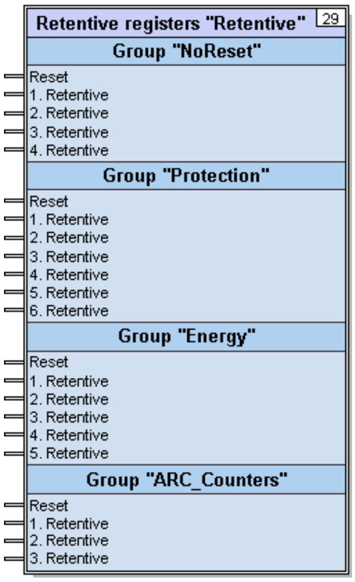

Figure 3.16: Retentive registers module

3.4.1 Operation description

During device operation the current values of signals are stored into the registers on permanent device memory. In the device start-up process the saved signal values are restored to the database before start-up of other modules.

In case of power supply failure the database will contain values recorded at the last recording cycle. When resetting the stored values, the new state is immediately written in the permanent device memory.

The time of values retention in a state without the power supply depends on hardware implementation. You can find the information about the guaranteed time of data retention in the device technical data. After the guaranteed time runs out, the data is compromised and are gradually lost until the memory is completely emptied.

The **Retentive…** inputs are organized in groups - **Group…**. The groups can be added or deleted in the user interface. Each group is assigned with a connection for deleting registers values inside this group. The deleting process is triggered by writing value 1 into the **Reset** input. By this action a value 0 is written in the registers inside the group. A period for value saving is set with **Save period** parameter and the location of file on device file system with **File** parameter.

With the user interface, a manual input of values can also be set.

3.4.2 Parameters, inputs and outputs

/	
Save period 5...**30**...90000 s	Saving cycle of signals to permanent device memory.
File text	Complete path and the file name on device file system.

/ Group 1...20	
Name text	Group name.
Reset input (digital)	Resetting of registers in this group to value 0.
Retentive 1...100 input (random)	Signals to be saved. Can be digital or analog signal.

4 Acquisition and calculation functions

4.1 Acquisition

The ACQ (acquisition) module is intended for acquisition of electrical values that are brought to physical external inputs/outputs of the device. In this module the settings of input and output cards must be set correctly. Input-output cards give sampled values that the ACQ module periodically acquires from physical digital and analog inputs of the device. Besides this, it controls the close/open of digital relays and acquires time from the internal clock of the device. The acquired values are written in the RT database where they are available to all other functions or modules. The acquisition is divided into the acquisition of data for protection functions (*Protection*) and the acquisition of operational measurements (*Measurement*). The acquisition period for protection measurement is 5 ms, while it is 80 ms for operational measurements.

The device includes main input card (it comprises the processor part and the FPGA circuit) and input and output cards. The ACQ module depends on physical characteristics of the card. With regard to the set of available cards and their characteristics, certain limitations and default values apply, e.g. a number of channels in the card. The ACQ module supports cards of different capacities.

In the device there can be different types and number of input and output cards. Each card has its own physical address which is set with the **Address** parameter in a form of number 0, 1, 2, …. The physical inputs on a card are marked as data channels. In case of false settings of the physical address or if two cards have the same address set, the acquisition will not operate correctly.

In the device there can be different types and number of input and output cards:

- DI – card for input of digital signals
- DO – card for control of digital outputs, relays
- AI – card for input of AC currents and voltages
- DCI – card for input of DC currents and voltages

Analog values, which the ACQ function writes into the registers, are in raw value. Raw value of 1 and raw value at nominal value are defined by hardware configuration of the device. They are stated in *Technical data* of the device. The state of external digital physical inputs is recorded in the module outputs with value 0 or 1.

External digital relays are controlled with digital signals through inputs of the *DO card* module. If value 1 arrives to a module input, the relay will close, and if value 0 arrives, the relay will open.

4.1.1 Set of measurements, modules

The settings are separated for each card and each set individually. For each set of measurements it has its own part or a block. A list of all blocks is shown in Table 4.1.

Table 4.1: A table of all sets of measurements, ACQ module blocks

Block name	Description
ACQ Common	Common settings and signals
AC-P Fundamental	Amplitudes and angles of currents and voltages of fundamental harmonic, frequency of selected voltage for protection measurements.
AC-P Harmonics H...	Amplitudes of current and voltage harmonics.
AC-M Fundamental	Amplitude and angles of currents and voltages of the fundamental harmonic.
AC-M Harmonics Ch...	Amplitudes of current and voltage harmonics for operational measurements.
AC-M RMS	RMS amplitudes of fundamental harmonic of currents and voltages.
AC-M THD	Distortion of fundamental harmonic of currents and voltages.
AC-M Frequency	Frequencies of fundamental harmonic of currents and voltages.

AC Phase-to-phase	Calculation of phase-to-phase voltages
AI-DC input	Amplitude of DC current and voltage.
DI card...	Values of digital inputs for each DI card individually
DO card...	Commands for digital outputs for each DO card individually
DCI card...	Values of DC inputs for each DCI card individually
LEDs	LEDs control

The number of inputs/outputs must not exceed the actual physical number of inputs/outputs on a card. Inputs/outputs on a card are ordered in a sequence which cannot be changed. A detailed description of inputs/outputs names and settings is given with every card individually.

4.1.1.1 Number of individual cards

Maximal number of DI and DO cards in a device is 8, but there can only be one AI card. Maximal number of DO cards is 3. Cards are marked as described below:

- DI cards are marked from address 0 forward: 0, 1, 2, ...
- DO cards are marked from address 7 backward: 7, 6, 5, ...

For correct device operation, the cards set in settings must match the physically integrated cards in a device.

In case more cards than set are integrated into a device, the unset cards will not be active. A record about the inactive cards will be made in the system log.

In case less cards than set are integrated into a device, the data from non existing cards will not be valid. The data for fault cards will not be valid as well.

WARNING! If less cards than set are integrated into a device, the ACQ will stop at device startup.

4.1.2 ACQ common

ACQ common settings are set in the *ACQ common* module.

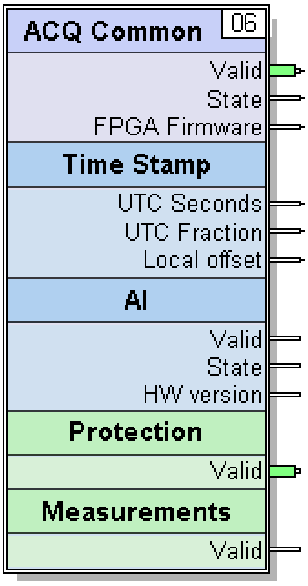

Figure 4.1: Function block of ACQ common

4.1.2.1 Acquisition of time

The ACQ acquires time from the device internal clock and writes it on outputs in the **Time Stamp** section. All other modules use this time for their operation (e.g. at tagging the events with time). According to the standard, the number of seconds since 1.1.1970 at 0:00 is written on the **Seconds** output. Other modules using this data also apply to this standard. Microseconds are written on the **Fraction** output.

4.1.2.2 Enabling and disabling of acquisition

Enabling and disabling of acquisition is executed on all levels. In this way, acquisition of the whole card or of an individual input/output can be enabled. This is executed with the **Enable** parameter.

4.1.2.3 State of operation

The ACQ module monitors and writes its state of operation and states of individual cards through **State** and **Valid** outputs. The **State** output gives information about the state of a card and The **Valid** output gives information whether the data are valid. If the card operates correctly, both outputs should have value 1. On the **HW version** output you can find the number of the card version.

Data validation depends on the input cards. Possible reasons for invalid data are:

- In the device there is no input card with the set **Address**
- Bus fault
- Input card fault
- Input card is disabled with the **Enable** parameter.

WARNING! ACQ is the most important function of the device. In case the ACQ module does not function correctly, the analog and digital inputs are not collected, and the issuing of commands onto digital inputs does not function as well.

All information about the ACQ module errors is written in the system log.

The **State** module gives information about the module state (see Table 4.2).

Table 4.2: Description of module states, the **State** output

State	Meaning
0	Undefined status; indicates non-initialized state.
1	Operation without errors.
2	Warning; minor irregularities exist, but they are not critical on the module operation.
3	Error; the module operates with errors which influence in the module and data. State outputs on lower levels have errors.
4	Critical error; the module does not operate due to a critical error at initialization or failure of hardware during operation.

4.1.2.4 Parameters table

ACQ Common

Valid output (digital)	Acquisition data validation. 1 – Regular operation. 0 – Acquisition does not operate or it operates with errors; a service inspection is needed.
State output (analog+)	Module state. 1 – Operation without errors. 0, 2, 3... – Acquisition operates with errors (Table 4.2), a service inspection is needed.
FPGA Firmware output (analog)	At initialization the driver reports the actual FPGA firmware version.

ACQ Common / Time Stamp

UTC Seconds output (analog)	Time in seconds since 1.1.1970 according to UNIX standard.

UTC Fraction output (analog)	Remainder of second in microseconds.
Local offset output (analog)	Local time zone difference to UTC in seconds.

ACQ Common / AI

Enable **true**, false	Enabling of card/module operation.
AC reference Input 1…**5**…12	Selection of a reference physical channel for voltage; a channel with UL1 voltage is usually chosen.
Zero dead band 0...**4**...1000	Minimal possible value of the measurement in a raw value. All measurements below a dead band are measured as 0.
Valid output (digital)	Card data validation: 1 – Regular card operation 0 – Acquisition from this card is not possible
State output (analog)	Input/output card state. 1 – Operation without errors. 0, 2, 3... – Acquisition operates with errors, a service inspection is needed.
HW version output (analog)	Hardware version.

ACQ Common / AI / Protection

Enable **true**, false	Data acquisition for protection enabling.
Frequency channel 1...**5**...8	Selection of a physical channel reference for frequency acquisition; a channel with UL1 voltage is usually chosen.
Valid output (digital)	Card data validation (data for protection): 1 – Regular operation 0 – Data are not valid

ACQ Common / AI / Measurement

Enable **true**, false	Data acquisition for measurements enabling.
Valid output (digital)	Card data validation: 1 – Regular operation 0 – Data are not valid

ACQ Common / AI / Calibration

Enable **true**, false	Enabling of calibration operation.
File File path	Calibrations file path and name.

4.1.3 Digital inputs acquisition (DI card)

The digital signals are acquired by the *DI card*. Each DI card has its own DI settings section. One *DI card* includes several digital inputs. Each digital input can be disabled with the **Enable** parameter.

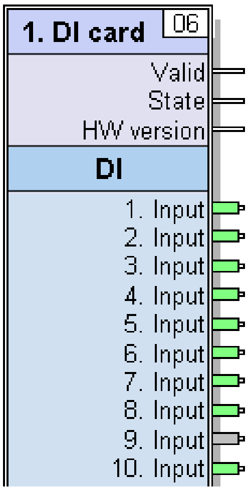

Figure 4.2: Function block of DI card

At the digital signal acquisition the amplitude of an input signal can oscillate. It is therefore necessary to define a filter against the signal oscillation (**Debounce**) for each digital input separately. It determines how long digital 1 must be present on an input before it is registered as valid and written on the output. The debounce filter operates at positive as well as negative passing of a physical signal. By raising the filter value, the dead time of digital input acquisition is also prolonged.

The digital signal value depends on the voltage level on the physical input. The voltage level is digitalized and on the output digital 0 or 1 appears. Normally, the output value is 1 if the input voltage is higher than 80% of the nominal value. If it is lower, the value is 0.

The card gives additional information about its operation and operation of individual channels through the **State** output. If the **State** output value is 1, the card operates correctly.

Note: If the card does not operate correctly, the State output value is more than 1. Individual bits of 8 - 30 output indicate validation of individual channel.

4.1.3.1 Parameters table

DI card / DI…	
Enable **true**, false	Enabling of digital input operation.
Debounce 0…**8**…255 ms	Debounce filter setting – dead-time delay 0 – filter disabled
Input output (digital)	Measured value on physical input.

DI card...	
Address **1**…8	Physical card address.
Valid output (digital)	Card data validation: 1 – Regular card operation 0 – Acquisition from this card does not function
State output (analog)	Card state: 1 – Operation without errors. 0, 2, 3... – Acquisition functions with errors; a service inspection is needed.
HW version output (analog)	Hardware version.

4.1.4 Digital outputs control (DO card)

Physical digital outputs or relays are controlled by the DO card. Each DO card is represented with its own *DO card* module. One DO card includes several digital outputs. Each digital output can be enabled with the **Enable** parameter and controlled through the **Value** input. A command is transmitted from the processor over a bus to the DO card and finally to the physical relay which closes or opens.

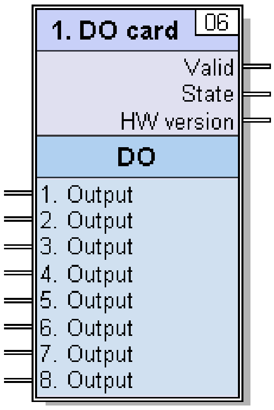

Figure 4.3: Function block of DO card

The DO card gives additional information about its operation and operation of individual digital outputs through the **State** output. If the **State** output value is 1, the card operates flawlessly.

Note: If the card does not operate flawlessly, the State output value is more than 1. Individual bits from 8 to 30 indicate validation of individual digital outputs.

4.1.4.1 Ready relay

One of relays is usually used as a *Ready relay*. By default, the last digital output on first DO card is configured as *Ready relay*. In device there are several important internal signals which indicate the valid state of operation of device individual components. In device configuration all important internal signals are connected to *Ready relay* digital output so that in normal condition *Ready relay* digital output is closed. If any of important internal signals indicate device error or power supply outage the ready relay opens after a certain time (**Reset delay** parameter). A digital output that serves as a *Ready relay* must have the **Reset** parameter enabled.

4.1.4.2 Device reboot

At device reboot, outputs can stay in their last position or they are reset in their original position. To set this function, each digital output on the DO card has the option **Reset**. The reset delay time is set for an individual DO card with the **Reset delay** parameter.

Note: At power supply failure the digital outputs always return into their original position.

4.1.4.3 Parameters table

DO card...	
Address 1…8	Physical card address.
Reset Delay 0,01 – 30,00 sec	Time in which, in case of an error, the set output automatically switches off (Ready relay function)
Valid output (digital)	Card data validation: 1 – Regular card operation 0 – Acquisition from this card is not working
State output (analog)	Card state. 1 – Operation without errors. 0, 2, 3... – Acquisition functions with errors; a service inspection is needed.
HW version output (analog)	Hardware version.

DO card / DO…	
Enable **true**, false	Enabling of operation of output relay.
Output input (digital)	Value on a digital output: 1 – Closed 0 – Opened
Reset **true**	Activation of automatic relay switch off function at non-operating driver. For compatibility only parameter, value must always be *True*.

4.1.5 Acquisition of analog AC inputs (AI card)

The analog AI card acquires analog AC voltages and currents, and is a mandatory card in the device. It includes up to 12 galvanically isolated analog AC inputs and one DC input as well as up to 8 adjustable fast LEDs. It is equipped with a DSP processor which processes sample signals and performs mathematical operations of the Fourier Transform.

The following values are acquired:

- Amplitudes, angles and frequencies of phase currents and voltages of fundamental harmonic
- Amplitudes of phase angles and voltages of harmonics

The reference physical input is selected with the **Reference Input** parameter. The selected reference input angle will be 0 and all other angles will be relative to the reference one.

4.1.5.1 Calibration

For accurate voltage and current measurements the device must be calibrated. Calibration is executed with a separate procedure described in the *Device calibration* chapter. If the device is not calibrated, certain measurement inaccuracy occurs. When the device is calibrated, factors for the correction of the measured values are written in a special calibration file so that measurement error is compensated and expected values within permitted tolerances are obtained on the output.

The calibration file is defined in a module (*ACQ Common*) with the parameter **Calibration / File**. The file is created automatically at device calibration procedure. If there is no file in the device or it is corrupted, the calibration parameters are not considered, measurements have certain inaccuracy, and *WARNING* notice appears for the calibration file in the device system log.

4.1.5.2 Output values

Analog values that the modules write on their outputs are in raw value. Raw value depends on the type and version of an analog card, and is given in Technical data specification of the device. Nominal values are included in RT database and are set with *Power system setting* module.

Example: A DSP card acquires AC currents linearly in range from 0 to 32,676 raw value. An input range is from 0 to 20-times nominal value. When there is nominal current on the card input, there is raw value of 2400 on the output register, and at 20-times nominal current the raw value is 48000.

4.1.5.3 Channels

AI board has a number of measuring channels, through which the measurements are captured. The order of measuring channels depends on the type of AI board. AI board type can be deduced from the ordering code of the device:

```
FPC 680 - SW / H / AI / C1 / C2 / C3 / C4 / PS / S1 …
                    |
               AI board type
```

In the device configuration AI board channels need to be connected to the appropriate sinks and named according to the type of channel. For example, the current channel is connected to the sink of the phase currents and named IL1.

The following table describes all types of AI cards and the order of channels.

Table 4.3: AI board types

	Channels											
AI board type	1	2	3	4	5	6	7	8	9	10	11	12
A - 4 CT + 4 VT	I1	I2	I3	I4	U1	U2	U3	U4				
B - 5 CT + 4 VT	I1	I2	I3	I4	U1	U2	U3	U4	I5			
C - 4 CT + 5 VT	I1	I2	I3	I4	U1	U2	U3	U4	U5			
D - 3 CT + 1 CTs + 4 VT	I1	I2	I3	Is	U1	U2	U3	U4				
E - 3 CT + 2 CTs + 4 VT	I1	I2	I3	Is1	U1	U2	U3	U4	Is2			
F - 4 CT + 1 CTs + 4 VT	I1	I2	I3	Is	U1	U2	U3	U4	I4			
G - 3 CT + 1 CTs + 5 VT	I1	I2	I3	Is	U1	U2	U3	U4	U5			
H - 3 CT + 1 CTs + 4 VT + 3 CT + 1 CTs	I1	I2	I3	Is1	U1	U2	U3	U4	I4	I5	I6	Is2
I - 4 CT + 4 VT + 4 CT	I1	I2	I3	I4	U1	U2	U3	U4	I5	I6	I7	I8
J - 4 CT + 3 VT + 5 CT	I1	I2	I3	U1	U2	U3	I4	I5	I6	I7	I8	I9
K - 3 CT + 1 CTs	I1	I2	I3	Is								
L - 4 VT	U1	U2	U3	U4								
M - 4 CT + 1 CTs + 7 VT	I1	I2	I3	Is	U1	U2	U3	U4	I4	U5	U6	U7

4.1.5.4 Data measurement groups

Data acquisition is divided into two parts:

- Acquisition of measurements for protection (*Protection)*
- Acquisition of operational measurements (*Measurement)*

Measurements for protection are used for the operation of fast protection algorithms and functions. They must respond rapidly as in case of faults. At such measurements the acquisition speed is essential.

Operation measurements are acquired slowly but they are more accurate from the measurements for protection. They are intended for monitoring of operation and statistics. Operation measurements are usually communicated into control centres.

Individual modules are described below. Each of them covers a certain group of measurements:

4.1.5.5 Measurements for protection – fundamental harmonic (AC fundamental)

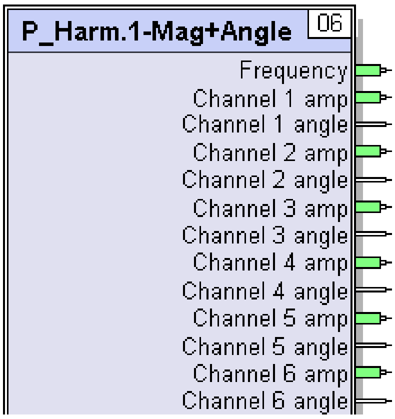

Figure 4.4: Function block of measurement for protection – fundamental harmonic

AC-P Fundamental	
Enable **true**, false	Enabling of acquisition of a group of fundamental harmonic for protection measurement.
Frequency output (analog)	Frequency of fundamental harmonic of a selected channel.
Channel 1 amp output (analog)	Amplitude of channel 1 of fundamental harmonic.
Channel 1 angle output (analog)	Angle of channel 1 of fundamental harmonic.
Channel 2 amp output (analog)	Amplitude of channel 2 of fundamental harmonic.
Channel 2 angle output (analog)	Angle of channel 2 of fundamental harmonic.
...	...

4.1.5.6 Measurements for protection – higher harmonics (AC harmonics H, etc.)

AC-P Harmonics Hn	
Enable **true**, false	Enabling of acquisition of a group of n-harmonic.
Channel 1 amp output (analog)	Amplitude of channel 1 of n-harmonic.
Channel 2 amp output (analog)	Amplitude of channel 2 of n-harmonic.

4.1.5.7 Operational measurements – fundamental harmonic (AC Fundamental Measurement)

AC-M Fundamental	
Enable **true**, false	Enabling of acquisition of a group of fundamental harmonic for operational measurement.
Channel 1 amp output (analog)	Amplitude of channel 1 of fundamental harmonic.
Channel 1 angle output (analog)	Angle of channel 1 of fundamental harmonic.
Channel 2 amp output (analog)	Amplitude of channel 2 of fundamental harmonic.
Channel 2 angle output (analog)	Angle of channel 2 of fundamental harmonic.

...	...

4.1.5.8 Operational measurements – RMS values (AC RMS Measurement)

AC-M RMS	
Enable **true**, false	Enabling of acquisition of a RMS measurements.
Channel 1 RMS output (analog)	RMS amplitude of channel 1 of fundamental harmonic.
Channel 2 RMS output (analog)	RMS amplitude of channel 2 of fundamental harmonic.
...	...

4.1.5.9 Operational measurements – distortion (AC THD Measurement)

AC-M THD	
Enable **true**, false	Enabling of acquisition of a THD measurements.
Channel 1 THD output (analog)	Distortion of channel 1 of fundamental harmonic.
Channel 2 THD output (analog)	Distortion of channel 2 of fundamental harmonic.
...	...

4.1.5.10 Operation measurements - frequency (AC Frequency Measurement)

AC-M Frequency	
Enable **true**, false	Enabling of acquisition of a frequency measurement.
Channel 1 freq output (analog)	Frequency of channel 1 of fundamental harmonic.
Channel 2 freq output (analog)	Frequency of channel 2 of fundamental harmonic.
...	...

4.1.5.11 Operation measurements – high harmonics (AC Harmonics Measurement Ch..)

AC-M Harmonics Ch1...n	
Enable **true**, false	Enabling of acquisition of a group of n-harmonic.
Amplitude h2 output (analog)	Amplitude of harmonic 2 of n-channel.
Amplitude h3 output (analog)	Amplitude of harmonic 3 of n-channel.
...	...

4.1.6 Calculation of phase-to-phase voltages (AC Phase-to-phase voltages)

The *ACQ AI-P2P* module calculates phase-to-phase voltages from the measured phase voltages. Phase-to-phase voltages are UL12, UL23 and UL31. Phase voltages are connected through **Phase amp...** and **Phase angle...** inputs. Module calculates up to 3 independent phase-to-phase values.

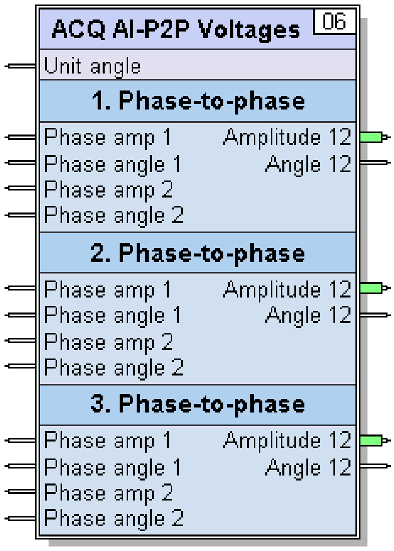

Figure 4.5: Function block of phase-to-phase voltages

Phase and phase-to-phase voltages can be connected to the device. Connection is set in the **Connection type** parameter. In case of phase-to-phase connection, there is no measurement of phase voltages in the device. Description of the **Connection Type** parameter operation:

- *Phase*: from two phases the phase-to-phase is calculated according to equation:
  U12 = U1 – U2
- *Phase-to-Phase*: the result is the value from the first connection:
  U12 = U1

*Example: For the calculation of UL23 phase-to-phase voltage the first and second phase voltages are UL2 and UL3 . There are two outputs: phase-to-phase voltage amplitude (**Amplitude 12**) and its angle (**Phi 12**). The calculation is as fast as the acquisition of phase voltages (in the ACQ AI-Prot module).*

4.1.6.1 Parameters table

AC Phase-to-phase	
Connection Type **Phase**, Phase-to-phase	Type of device connection to voltage inputs: - *Phase* – phase connection, - *Phase-to-phase* – phase-to-phase connection.
Unit angle constant input (analog)	Unit angle 1°.

AC Phase-to-phase / Phase-to-phase...	
Phase amp 1 input (analog)	Phase voltage 1, amplitude.
Phase angle 1 input (analog)	Phase voltage 1, angle.
Phase amp 2 input (analog)	Phase voltage 2, amplitude.
Phase angle 2 input (analog)	Phase voltage 2, angle.
Amplitude 12 output (analog)	Calculated amplitude of phase-to-phase voltage.
Phi 12 output (analog)	Calculated angle of phase-to-phase voltage.

4.1.7 Acquisition of DC voltage or current (AI-DC input)

One channel on the AI card is intended for acquisition of DC voltage or current. Values are acquired through the *AI-DC input* module. The type and range of DC input is set physically on the AI card (see *Service manual).*

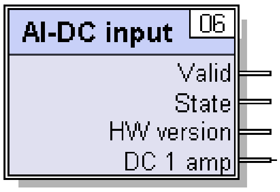

Figure 4.6: Function block of DC voltage and current

4.1.7.1 Parameters table

AI-DC input	
Enable **true**, false	Enabling of acquisition of an AI-DC input.
Zero dead band 0…**10**…10000	Minimal possible amplitude value.
Valid output (digital)	Card data validation: 1 – Regular card operation 0 – Acquisition from this card is not working
State output (digital)	Card state. 1 – Operation without errors. 0, 2, 3... – Acquisition functions with errors; a service inspection is needed.
HW version output (digital)	Hardware version.
DC 1 amp output (analog)	DC amplitude.

4.1.8 LEDs control

The device can have up to 8 programmable LEDs. They are controlled through **Value** inputs. A LED can illuminate or blink fast or slowly according to the **Priority**.

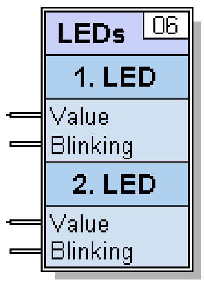

Figure 4.7: LEDs function block

Detailed operation is shown in the table below (Table 4.4).

Table 4.4: LED states table

Value	*Blinking*	*Priority*	LED state
0	*0*	*x*	Does not illuminate
1	*0*	*x*	Illuminates

x	*1*	*Slow*	Blinks slowly
x	*1*	*Fast*	Blinks fast

4.1.8.1 Parameters table

LEDs / LED…	
Enable **true**, false	Enabling of LED operation.
Value input (digital)	Command, LED must: 1 – illuminate 0 – not illuminate
Blinking input (digital)	Blinking, LED must: 1 – blink 0 – not blink
Priority **Slow**, Fast	Blinking mode: *Slow* – slow blinking *Fast* – fast blinking

4.1.9 Acquisition of analog DC inputs (DCI card)

The DCI card acquires analog DC voltages and currents. The values are acquired through the *DCI card* module. A type and range of DC inputs are set physically on the DCI card (see *Service manual).*

4.1.9.1 Parameters table

DCI card...	
Address 1…8	Physical card address.
Valid output (digital)	Card data validation: 1 – Regular card operation 0 – Acquisition from this card is not working
State output (digital)	Card state. 1 – Operation without errors. 0, 2, 3... – Acquisition functions with errors; a service inspection is needed.
HW version output (digital)	Hardware version.

DCI card / DC …	
Enable **true**, false	Operation enabling. ☑ – Input acquisition enabled, ☐ – Input acquisition disabled.
Amplitude input (digital)	DC input amplitude value.

4.1.10 DPRAM Data of FPGA (only for diagnostics)

The signal samples are primarily processed in the FPGA circuit and entered into the DPRAM memory registers of the FPGA circuit. The driver accesses the DPRAM through a 16-bit bus. Valid data are written on the module outputs.

For testing and diagnostics purposes, rough values can be monitored directly from the FPGA chip. Setting of the FPGA registers range that will be monitored is set in the **Common / DPRAM Data** section. The initial register (**Data Block**) and a number of registers (**Data count**) to be monitored are set. Maximal number of registers is 128. Data are acquired on outputs starting with the **Data Start** register to the last register.

ACQ Common / DPRAM Data	
Enable **true**, false	Enabling of operation of acquiring rough data from DPRAM.
Data Block 0000…FFFF	Address of the first desired memory location in the DPRAM (hex)
Data Count **1**…10...128	Required number of locations.
Data Start output (analog)	RT base output where the readout values are entered.

4.2 Power and energy

The module takes collected voltages and currents in different wirings and calculates the power of individual phases, total three-phase power and energy. The module distinguishes between inductive and capacitive load, peak and off-peak tariff and received or transmitted energy. The calculated values are accessible on module outputs from where they can be transmitted over communication to the control system.

The module calculates:

- Active power of individual phase fundamental frequency (3 x P_x)
- Reactive power of individual phase fundamental frequency (3 x Q_x)
- Active power of three-phase fundamental frequency (P)
- Reactive power of three-phase fundamental frequency (Q)
- Apparent power of three-phase fundamental frequency (S)
- Apparent power RMS
- Power factor of fundamental frequency three-phase system ($cos\varphi$, DPF)
- RMS factor of three-phase power (PF)
- Load reactive power type (capacitive or inductive)
- Fundamental frequency active energy (W_P)
- Fundamental frequency reactive energy (W_Q)

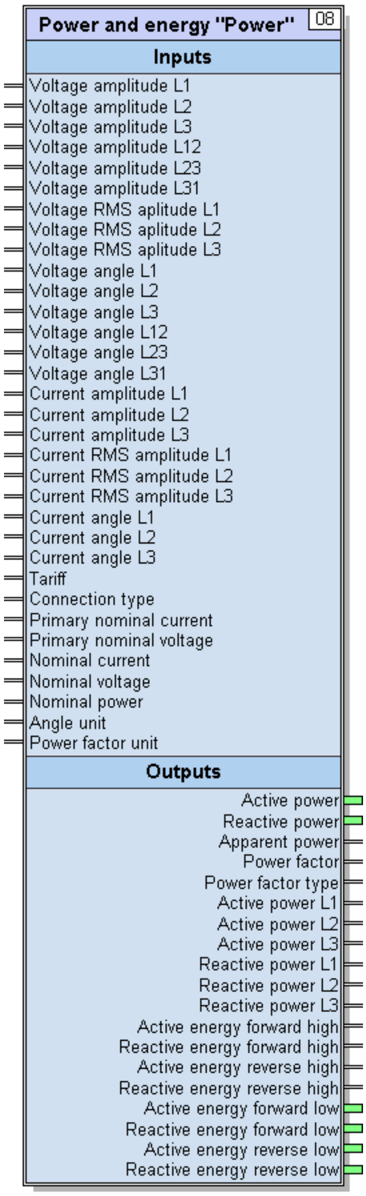

Figure 4.8: Power and energy function block

The module calculates power and energy from the fundamental frequency amplitudes of the network, and the apparent power from the RMS values of currents and voltages. Calculation is executed in the range *0.05…20* times nominal current. Outputs are in raw value.

4.2.1 Power calculation

Three-phase nominal power is defined with raw value parameter **Nominal power**. It is chosen according to requirements of communication with the master system and desired measuring range. The nominal phase power is 1/3 of nominal total power. Figure 4.9 shows a vector diagram of active, reactive and apparent power.

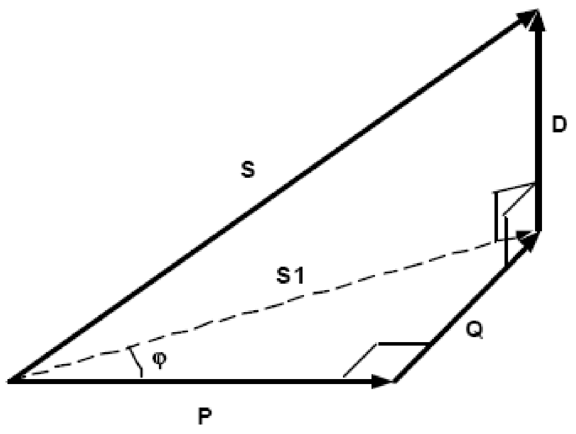

Figure 4.9: Relation of P, Q, D, S and S1 power

Powers of an individual phase are calculated with the following equations:

$$\vec{S} = \vec{U} \cdot \vec{I}^* = P + jQ$$

$$P_{L1} = U_{L1} \cdot I_{L1} \cdot \cos\varphi_{L1} \quad Q_{L1} = -U_{L1} \cdot I_{L1} \cdot \sin\varphi_{L1}$$

The total power of a three-phase system is a sum of individual phase powers:

$$P = \sum_{1}^{3}(P_{Li}) \quad Q = \sum_{1}^{3}(Q_{Li})$$

$$S_1 = \sqrt{P^2 + Q^2} = \sum_{1}^{3}(U_{Li} \cdot I_{Li}) = \frac{P}{\cos\varphi} = \frac{Q}{\sin\varphi}$$

$$S = \sqrt{P^2 + Q^2 + D^2} = \sum_{1}^{3}(U_{RMS\,Li} \cdot I_{RMS\,Li})$$

Meaning of signs used:

P................active power of three-phase system fundamental harmonic
Q................reactive power of three-phase system fundamental harmonic
φ................angle between P and S_1
D................power of three-phase system higher harmonics
P_{L1}..............active power of fundamental harmonic in phase L1
Q_{L1}.............reactive power of fundamental harmonic in phase L1
S_1................apparent power of three-phase fundamental harmonic
S................apparent power of three-phase system, all harmonics
φ_{L1}..............angle between current and phase L1 voltage
U_{1L1}............fundamental harmonic of phase L1 voltage
U_{nL1}............n harmonic of phase L1 voltage
U_{L1}.............fundamental harmonic of phase L1 voltage
I_{L1}...............fundamental harmonic of phase L1 current
$U_{RMS\,L1}$........effective value of phase L1 voltage
$I_{RMS\,L1}$.........effective value of phase L1 current

4.2.2 Power factor

The three-phase power factor is a relation between reactive and apparent power in a system. According to direction of the total power of a three-phase system it can be positive or negative. The given value is normalized according to the **Power factor unit** parameter. Depending on how the higher harmonics are regarded, is possible to distinguish between different factors.

$$DPF = \cos\varphi = \frac{P_1}{S_1}$$

$$PF = \frac{P_1}{S}$$

$$TPF = \frac{P}{S}$$

P_1 ....fundamental harmonic active power
P.................active power, all harmonics
S.................apparent power, all harmonics
S_1................fundamental harmonic apparent power
$cos\varphi$............fundamental harmonic power factor
DPF ....displacement power factor, same as $cos\varphi$
PF ....power factor, higher harmonics are ignored
TPF ....true power factor, all harmonics are considered

Load reactive power type output **Power factor type** is calculated according to load power diagram of the three-phase system. Table 4.5 shows its value according to the load character.

Table 4.5: Power factor type according to load character

Load character	Power factor type
Load uses reactive power, inductive character	0
Load generates reactive power, capacitive character	1

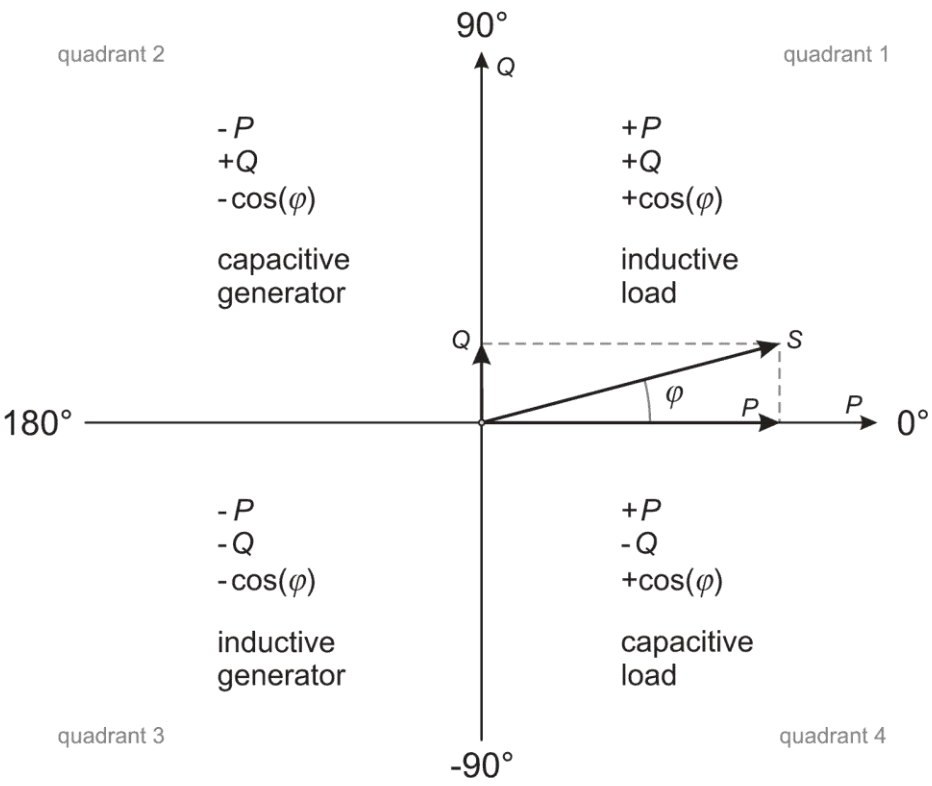

Figure 4.10: Load power diagram

4.2.3 Energy calculation

The energy is calculated by integrating power in time and the results are written to corresponding **...energy...** outputs. Raw value representing 1 kWh of energy is determined with the **Energy factor** parameter. When the energy outputs reaches the maximum value 2^32, it starts with 0 again.

For calculations the following equations are used:

$$W_P = P \cdot t$$

$$W_Q = Q \cdot t$$

Meaning of signs used:

W_P.............active energy of three-phase system

W_Q.............reactive energy of three-phase system

t..................time period

P.................active power of three-phase system fundamental harmonic

Q................reactive power of three-phase system fundamental harmonic

4.2.3.1 Energy direction

The module integrates the energy separately for received and transmitted energy according to signs of total active and total reactive power. Positive power denotes transmitted energy, direction is called **"forward"**. Negative power denotes received energy, direction is called **"reverse"**.

4.2.3.2 Energy measuring tariff

The energy measuring tariff is determined by the value at the **Tariff** input. At value 1 the tariff is peak and is integrated into **…high** outputs, and at value 0 it is integrated into **…low** outputs. By default the input is usually linked to permanent registers in the *Retentive registers* module, so the device remembers the last value after reboot.

4.2.4 Analog inputs connection

The measuring mode is set according to physical connection type with one of the methods listed below. The corresponding currents and phase or line-to-line voltages are used in the calculation. In case of non-symmetrical loads an accurate measuring of three-phase total power is only possible in case of known phase voltages and currents of individual phases. The powers of individual phases without the input data are not calculated.

Table 4.6: Types of power measuring according to connection

Method	Voltage connections	Current connections	Note
1	UL1, UL2, UL3	IL1, IL2, IL3	full three-phase wiring
2	U12, U23, x	IL1, x, IL3	Aaron wiring, $I_o = 0$
3	x, U23, U31	IL1, IL2, x	...
4	U12, x, U31	x, IL2, IL3	...
5	U12, x, x	x, x, IL3	simplified wiring
6	x, U23, x	IL1, x, x	...
7	x, x, U31	x, IL2, x	...
8	UL1, x, x	IL1, x, x	single phase wiring
9	x, UL2, x	x, IL2, x	...
10	x, x, UL3	x, x, IL3	...

Powers by phases **Active power L1 / ...2 / ...3**, **Reactive power L1 / ...2 / ...3** are calculated only at the 1st method. At methods 1, 8, 9 and 10 the apparent power and power factor are calculated only from the RMS value of currents and voltages if they are available, i.e. connected. Otherwise they are calculated from the fundamental harmonic values.

The wiring type is determined by the **Connection type** input, which is linked from the *Power system settings* module. If the input is not linked, the 1st method is used by default. In case the **Connection type** has an invalid value, the module is not active and it does not perform calculations.

4.2.5 Table of inputs, outputs and parameters

Settings

Energy factor 0.01…**1.00**…1000.00 kWh/pulse	Energy counter constant for 1 kWh.

Inputs

Tariff input (digital)	Tariff choice: 0 – off-peak or low tariff 1 – peak or high tariff
Voltage amplitude L1...L3 input (analog)	Voltage amplitude of phase Ln fundamental harmonic.
Voltage amplitude L12...L31 input (analog)	Line-to-line voltage amplitude of phase Lnn fundamental harmonic.
Voltage RMS amplitude L1...L3 input (analog)	Voltage RMS amplitude of phase Ln.
Voltage angle L1...L3 input (analog)	Voltage angle of phase Ln fundamental harmonic.
Voltage angle L12...L31 input (analog)	Line-to-line voltage angle of phase Lnn fundamental harmonic.

Current amplitude L1...L3 input (analog)	Current amplitude of phase Ln fundamental harmonic.
Current RMS amplitude L1...L3 input (analog)	Current RMS amplitude of phase Ln.
Current angle L1...L3 input (analog)	Current angle of phase Ln fundamental harmonic.
Connection type constant input (analog)	Type of currents and voltages connection on device terminals.
Primary nominal current constant input (analog)	Primary nominal current. 1 A = 10 in raw value.
Primary nominal voltage constant input (analog)	Primary nominal voltage. 1 kV = 10 in raw value.
Nominal current constant input (analog)	Nominal current in raw value.
Nominal voltage constant input (analog)	Nominal interphase voltage in raw value.
Nominal power constant input (analog)	Nominal power in raw value.
Angle unit constant input (analog)	Angle unit value of 1° in raw value.
Power factor unit constant input (analog)	Value of power factor of 1 in raw value.

Outputs

Active power output (analog)	Active power of three-phase system (fundamental harmonic).
Reactive power output (analog)	Reactive power of three-phase system (fundamental harmonic).
Apparent power output (analog)	Three-phase system apparent power.
Power factor output (analog)	Three-phase power factor.
Power factor type output (digital)	Load type: 0 – inductive 1 – capacitive
Active power L1...L3 output (analog)	Active power in phase Ln (fundamental harmonic).
Reactive power L1...L3 output (analog)	Reactive power in phase Ln (fundamental harmonic).
Active energy forward high counter (analogue)	Energy calculation: active, forwarded, peak tariff
Reactive energy forward high counter (analogue)	Energy calculation: reactive, forwarded, peak tariff
Active energy reverse high counter (analogue)	Energy calculation: active, reversed, peak tariff
Reactive energy reverse high counter (analogue)	Energy calculation: reactive, reversed, peak tariff
Active energy forward low counter (analogue)	Energy calculation: active, forwarded, off- peak tariff
Reactive energy forward low counter (analogue)	Energy calculation: reactive, forwarded, off- peak tariff
Active energy reverse low counter (analogue)	Energy calculation: active, reversed, off- peak tariff
Reactive energy reverse low counter (analogue)	Energy calculation: reactive, reversed, off- peak tariff

4.3 Symmetrical components

With a symmetrical components method, every rotating three-phase electrical system can be divided into three symmetrical systems: positive sequence system, negative sequence system and zero sequence system. This applies to both currents and voltages.

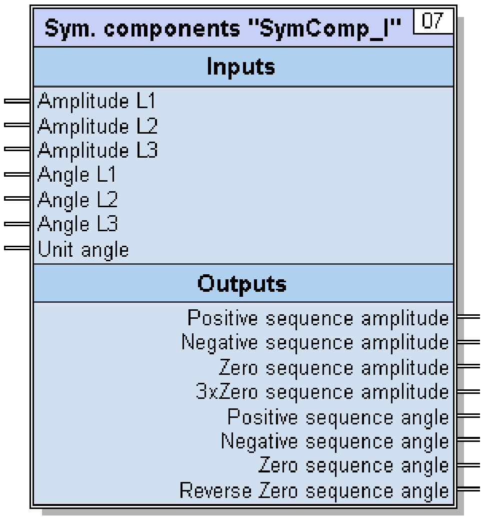

Figure 4.11: Symmetrical components module

4.3.1 Symmetrical components calculation

The three-phase symmetrical components system is calculated with the following equation:

$$\begin{bmatrix} \vec{I}_0 \\ \vec{I}_1 \\ \vec{I}_2 \end{bmatrix} = \frac{1}{3} \cdot \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \cdot \begin{bmatrix} \vec{I}_{L1} \\ \vec{I}_{L2} \\ \vec{I}_{L3} \end{bmatrix}$$

Variables:

a .... +120° rotation operator

I_0............... zero sequence component

I_1............... positive sequence component

I_2............... negative sequence component

I_{L1} .... 1st phase component

I_{L2} .... 2nd phase component

I_{L3} .... 3rd phase component

The given equations can apply for both currents and voltages. For calculation of all symmetrical components two modules are used. One for currents and one for voltages.

An algorithm calculates amplitudes and angles of symmetrical components in every real-time cycle. For zero sequence next to the **Zero sequence angle** component, the **Zero sequence angle** rotated for 180° is calculated and presented as the **Reverse Zero sequence angle**.

Besides the symmetrical components the module also calculates the **3xZero sequence amplitude**. This is used for calculation of residual three-phase component I_E with **3xZero sequence amplitude** and **Reverse Zero sequence angle,** and U_E with **3xZero sequence amplitude** and **Zero sequence angle**. With definitions the following equations are used:

$$\vec{I}_{L1} + \vec{I}_{L2} + \vec{I}_{L3} + \vec{I}_E = 0$$

$$\vec{I}_E = -\left(\vec{I}_{L1} + \vec{I}_{L2} + \vec{I}_{L3}\right)$$

$$\vec{I}_E = -3\vec{I}_0$$

$$\vec{U}_E = \left(\vec{U}_{L1} + \vec{U}_{L2} + \vec{U}_{L3}\right)$$

$$\vec{U}_E = 3\vec{U}_0$$

where the:

I_E …………is the residual current component
U_E............. is the residual voltage component

4.3.2 Module parameters

\ Inputs \	
Amplitude L1 input (analog +)	Phase L1 amplitude
Amplitude L2 input (analog +)	Phase L2 amplitude
Amplitude L3 input (analog +)	Phase L3 amplitude
Angle L1 input (analog ±)	Phase L1 angle
Angle L2 input (analog ±)	Phase L2 angle
Angle L3 input (analog ±)	Phase L3 angle
Unit angle constant input (analog +)	1° unit angle in raw value

\ Outputs \	
Positive sequence amplitude output (analog +)	Positive sequence amplitude
Negative sequence amplitude output (analog +)	Negative sequence amplitude
Zero sequence amplitude output (analog +)	Zero sequence amplitude
3x Zero sequence amplitude output (analog +)	Triple zero sequence amplitude
Positive sequence angle output (analog ±)	Positive sequence angle
Negative sequence angle output (analog ±)	Negative sequence angle
Zero sequence angle output (analog ±)	Zero sequence angle
Reverse Zero sequence angle output (analog ±)	Zero sequence angle + 180°

4.4 Disturbance recorder

Oscillography is a method of time recording of an event - usually of disturbances, short circuits, etc. All analog and digital inputs of a device, internal signals and digital outputs that are constantly being written in the memory can be recorded. The chosen trigger starts the recording process, then the record is first stored in the device buffer and then in the internal data system of device flash memory. From this moment on the data is available to the upper level system, which can read them and then writes them to a local hard drive for later analysis. The device can automatically send the disturbance records to the predefined FTP server. Disturbance records format is COMTRADE.

All analog inputs of the device and analog outputs of modules can be recorded - all together 64 analog channels. The maksimal number of digital information that can be recorded is 64.

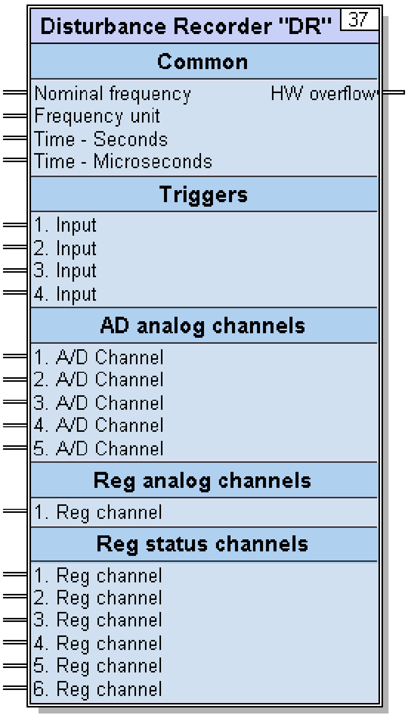

Figure 4.12: Disturbance recorder module

4.4.1 Operation description

4.4.1.1 Triggers

The record trigger starts the recording and can be any digital signal. There can be multiple **Triggers…** set and all are of equal importance. If several triggers are set at the same time, the first according to settings is taken into account. The name of the trigger that starts the recording process is written in the record name.

4.4.1.2 Limitations and exceeding of space

A device has its physical limitations regarding the amount of memory and available space in the file system. If during the samples recording on one or several channels the space runs short, device will record data within its capabilities.

If during the recording process the space runs short, the **Overflow case** rule is applied:

- *Delete last* - the last (latest) records are deleted
- *Delete first* - the first (oldest) records are deleted

4.4.1.3 Acquisition of values, channels

The values that can be acquired during the recording process are analog channels of an analog input card and signals from functional modules. It is possible to choose between the analog channels from the analog input cards (**A/D analog...**) and analog and digital modules signals (**Reg...**), by specifying channels (**...channel**) which will be recorded.

The sampling frequency is set with the **Sample rate** parameter and is rounded up or down to the nearest possible frequency, supported by the hardware or the CPU processor. In case the hardware cannot record the required records because of parameters exceed the hardware capabilities, the "*Warning*" message appears in system log. In such cases device will record data within its capabilities.

4.4.2 Writing of records into Comtrade files

After triggering the records are written into the file system in a Comtrade, 1999 format file. Date, time and contents info are added to the filename (set by **File name** parameter). Until the record is complete the file is has the .part file extension. There are two files written for every record: a configuration (.cfg) file and a data (.dat) file.

The filename consists of multiple parts, separated by dots:

`root.yyyy-mm-dd.hh-mm-ss.mss.trigger`

Table 4.7: Components of the records filename:

Filename component	Description
`root`	The initial part, file name root, specified in the settings (**File name**)
`yyyy-mm-dd`	The date of records triggering.
`hh-mm-ss`	The time of records triggering.
`mss`	The millisecond of records triggering in 000 format.
`trigger`	the name of the trigger that started the recording. (**Trigger/Identifier**)

4.4.3 Automatic FTP transfer

When a Comtrade record is written into the file system, it can be automatically transferred from device to a FTP server. The automatic transfer is enabled by the **Enable FTP upload** parameter. For correct operation the address, server port, username and the password must also be specified with **FTP server**, **FTP port, FTP username** and **FTP password** parameters. After the file transfer the device verifies if each file has been sent successfully. If not, the device retries again every 5 minutes.

4.4.4 Parameters, inputs and outputs table

\	
Enabled **true**, false	Module operation enabling.
Station name text 0…64 characters	Station name according to Comtrade standard.
Device ID text 0…64 characters	Device name or label according to Comtrade standard.
Data file format **ASCII**	Data file format according to Comtrade standard.
Overflow case **Delete_first**, Delete_last	Scenario at space running short: *Delete_first* – the first, oldest samples/records are deleted *Delete_last* – the last, newest samples/records are deleted
File name max. 31 characters	The root of the name of the file into which the records are written.
Pre rate 0...**400**...4000 ms	Time share of the record before the trigger event. The setting must be smaller than **Duration** time.
Duration 100...**2000**...9000 ms	Length of the record.
Enable FTP upload true, **false**	Enabling transfer of records to the FTP server.
FTP server text	IP address of FTP server, where the Comtrade records are transferred.
FTP username text	FTP server username.
FTP password text	FTP server password.

FTP port 1...**21**...65535	FTP server port.
HW overflow output (digital)	Exceeding of space on the hardware memory (e.g. FPGA) occurred, 5s pulse signal.
Nominal frequency constant (analog)	Nominal frequency.
Frequency unit constant (analog)	Frequency unit value.
Sample rate 8...**32**...256 spp	Sampling frequency when recording A/D analog channel, number of samples per period, *spp*)
Status channel buffer size 100...**1000**	The circular buffer size for digital signals records. The value means the maximal number of signal changes that can be recorded with one action.
Time – Seconds input (analog)	System time, seconds part.
Time – Microseconds input (analog)	System time, microseconds part.

\ Triggers \ Trigger 1..32

Input input (digital)	Recording trigger. The triggering is started on rising edge.
Identifier text 1...64 characters	Trigger name

\ A/D analog channel 0...64

A/D Channel input	Connection to the channel amplitude of the *AI* module analog input card.
Channel identifier text 0…64 characters	Channel name... *ch_id*
Unit text 1…32 characters	Measuring value unit, *uu*
Multiplier decimal number	Amplitude multiplier, *a*
Offset decimal number	Amplitude offset, *b*
Skew decimal number	Time skew, *skew*
Primary decimal number	Primary nominal value, *primary*
Secondary decimal number	Secondary nominal value, *secondary*
PS **P**, S	Data scaling type, *PS*: *P* – primary *S* – secondary

\ Reg analog channel 0…64

Reg channel input (analog)	Connection to the analog signal, which is recorded.
Channel identifier text 0…64 characters	Channel name, *ch_id*
Unit text 1…32 characters	Measuring value unit, *uu*
Multiplier decimal number	Amplitude multiplier, *a*
Offset decimal number	Amplitude offset, *b*

Skew decimal number	Time skew, *skew*
Primary decimal number	Primary nominal value, *primary*
Secondary decimal number	Secondary nominal value, *secondary*
PS **P**, S	Data scaling type, *PS*: *P* – primary *S* – secondary

\ Reg status channel 0…64	
Reg channel input (digital)	Connection to the status digital signal, which is recorded.
Channel identifier text 0…64 characters	Channel name, *ch_id*
Normal state **0**, 1	Normal state of digital signal according to Comtrade standard.

4.5 Dataset event

The **Dataset event** module is intended for recording of analog and digital values at the time of any event, e.g protection tripping. It is possible to monitor several different values and they can be added by parametrization to module inputs. The module only records the last event. Every new event overwrites the old event values.

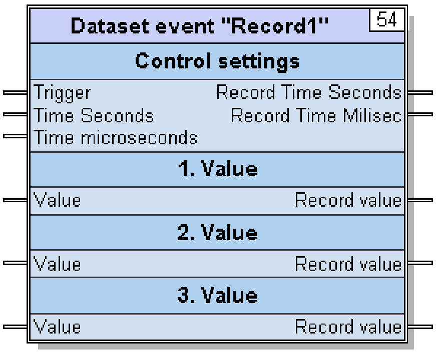

Figure 4.13: Dataset event function block

4.5.1 Operation description

The signal for the triggering of a recording is the **Trigger** input. At triggering moment, the values of **Value** inputs are recorded into the **Recorded Value** outputs, for each monitored value separately. In the same way the triggering time to the **Record Time – Seconds** and **Record Time – Milisec** outputs are recorded. These values can be then sent via communication as an analog events by connecting them to one of the communication protocols.

4.5.2 Parameters, inputs and outputs

\ Control settings	
Trigger input (digital)	Triggering of the recording
Time – Seconds input (analog)	System time in seconds.
Time – Microseconds input (analog)	System time, microseconds.

Record Time – Seconds output (analog)	The time of the last triggering, seconds.
Record Time – Milisec. output (analog)	The time of the last triggering, milliseconds.

\ Value 1 … 100

Value input (random)	Current monitored value.
Record value output (random)	Last recorded monitored value.

4.6 Fault locator

Main goal of the protection and measuring devices on power lines is selective and reliable operation in case of faults on protected part of the line. In addition to basic functions, the device also includes fault locator function. Main advantage of a device with a build-in fault locator is independence from control center and communication lines (when calculating fault location) - since the calculation is carried out in the device itself.

Thus, an even higher level of operational reliability of the electric power system is achieved.

Fault locator allows to:

- record time of failure
- calculate fault type
- calculate fault distance
- calculate fault resistance
- calculate amplitudes of fault currents
- assess the quality of calculations

Fault locator function is separated from protection functions and is executed after protection functions. It has an independent storage for measured values of current and voltage as well as its own filtering algorithms. The only information that it receives from protection functions is the starting signal (**Pickup** and **Trip**).

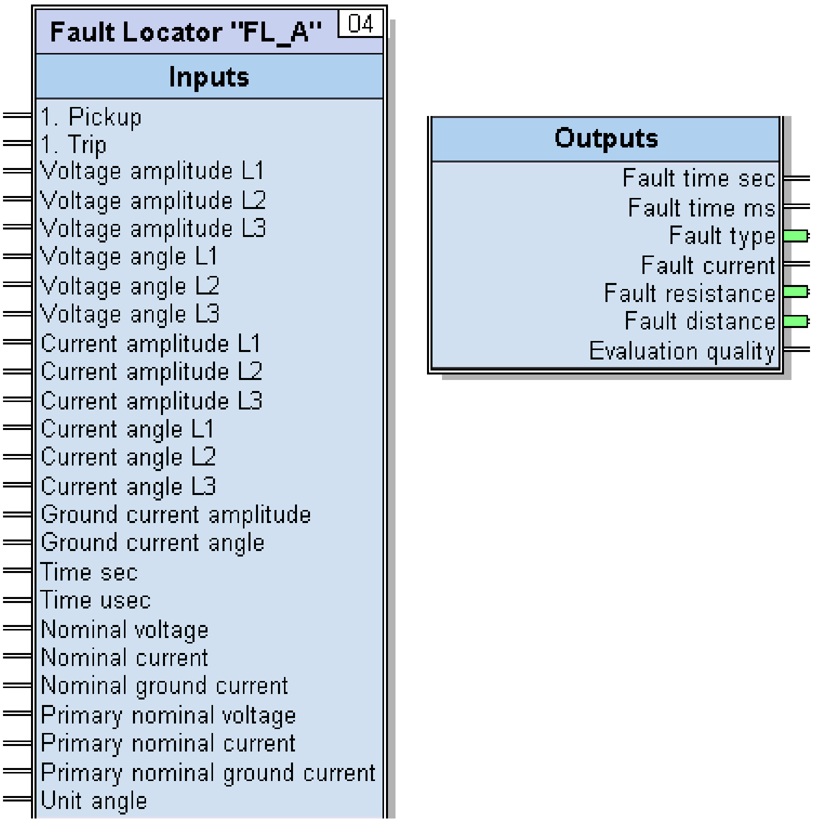

Figure 4.14: Fault locator function block

4.6.1 Operation description

When a fault occurs, module analyses the values of currents and voltages before and during the fault. Based on the parameters of the power line, special algorithm is used to calculate fault distance in km units.

Calculation of fault location is triggered only if a fault is detected on power line, which causes the relay to trip. Trigger condition for fault location calculation is therefore only when both **Pickup** in **Trip** inputs signals are active. If there is only fault detection - without tripping, location calculation will not be executed (by default). However, we can still choose to have the location calculated on fault detection only if **Pickup** signal from protection is connected to both **Pickup** and **Trip** inputs of the *Fault locator* module.

Algorithm calculates fault location in case of fault on an operational power-line and also, if we try to switch-on a faulty power-line. In the latter case, the calculation will be less accurate since there is no pre-fault data available. Algorithm accuracy depends on the accuracy of the entered power-line parameters, particularly in case of earth faults. Those are most frequent and currents that flow in these type of faults are small. For a successful fault calculation, fault condition must be present for at least one period (20ms). Calculation quality can be accessed via output **Evaluation quality**.

If the calculation of fault location is not possible due to low quality of fault input data, values of quality of calculation, fault distance and resistance are all set to 0. Other output values are calculated normally.

4.6.2 Fault type detection

Fault locator determines the type of fault and the phases in fault, according to analysis of currents and voltages. Depending on fault type detected, corresponding value will be set at output **Fault type**:

Table 4.8: Different fault types "**Fault type**"

Fault type	Fault type output	Description
L1-E	11	Single-pole ground fault in phase L1.
L2-E	12	Single-pole ground fault in phase L2.

L3-E	13	Single-pole ground fault in phase L3.
L1-L2	21	Double-pole circuit between phases L1 and L2.
L2-L3	22	Double-pole circuit between phases L2 and L3.
L3-L1	23	Double-pole circuit between phases L3 and L1.
L1-L2-E	31	Double-pole circuit with earth between phases L1 and L2.
L2-L3-E	32	Double-pole circuit with earth between phases L2 and L3.
L3-L1-E	33	Double-pole circuit with earth between phases L3 and L1.
L1-L2-L3	41	Three-pole circuit.

4.6.3 Table of parameters, inputs and outputs

Control settings	
Line resistance R1 0,00…0,10…10,00 ohm/km	Primary resistance of the positive line component, ohm/km.
Line inductance X1 0,00…0,40…10,00 ohm/km	Primary inductance of the positive line component, ohm/km.
Ground resistance RE 0,00…0,10…10,00 ohm/km	Primary resistance of the line zero component, ohm/km.
Ground inductance XE 0,00…0,40…10,00 ohm/km	Primary inductance of the line zero component, ohm/km.

Inputs	
Pickup 1..10 input (digital)	Start of failure condition.
Trip 1..10 input (digital)	Confirmation of the switch-off failure.
Voltage amplitude L1 input (analog)	Voltage amplitude of the basic harmonic phase L1.
Voltage amplitude L2 input (analog)	Voltage amplitude of the basic harmonic phase L2.
Voltage amplitude L3 input (analog)	Voltage amplitude of the basic harmonic phase L3.
Voltage angle L1 input (analog)	Voltage angle of the basic harmonic phase L1.
Voltage angle L2 input (analog)	Voltage angle of the basic harmonic phase L2.
Voltage angle L3 input (analog)	Voltage angle of the basic harmonic phase L3.
Current amplitude L1 input (analog)	Current amplitude of the basic harmonic phase L1.
Current amplitude L2 input (analog)	Current amplitude of the basic harmonic phase L2.
Current amplitude L3 input (analog)	Current amplitude of the basic harmonic phase L3.
Current angle L1 input (analog)	Current angle of basic harmonic phase L1.
Current angle L2 input (analog)	Current angle of basic harmonic phase L2.

Current angle L3 input (analog)	Current angle of basic harmonic phase L3.
Ground current amplitude input (analog)	Earth current basic harmonic amplitude.
Ground current angle input (analog)	Earth current basic harmonic angle.
Time sec input (analog)	Device time in seconds, Unix format.
Time usec input (analog)	Decimal part of time of the device in microseconds.
Nominal voltage constant (analog)	Number of parts at nominal interphase voltage of feeder.
Nominal current constant (analog)	Number of parts at nominal phase current of feeder.
Nominal ground current constant (analog)	Number of parts at nominal earth fault current of feeder.
Primary nominal voltage constant (analog)	Nominal primary interphase voltage. 1 kV = 10 raw value.
Primary nominal current constant (analog)	Nominal primary phase current 1 A = 10 raw value.
Primary nominal ground current constant (analog)	Nominal primary ground current, 1 A = 10 raw value.
Unit angle constant (analog)	Number of parts of unit angle for 1°.

Outputs

Fault time, sec output (analog)	Fault time, Unix format.
Fault time, us output (analog)	Fault time, microseconds.
Fault type output (analog)	Fault type: check table in chapter “Fault type detection” (first detected fault).
Fault current output (analog)	Maximum fault current.
Fault resistance output (analog)	Fault resistance, 1 Ohm = 10 raw value, (first detected fault).
Fault distance output (analog)	Fault distance, 1 km = 10 raw value.
Evaluation quality output (analog)	Evaluation quality, 0 - bad, 10 – excellent.

5 Protection functions

The basic purpose of protection functions is to protect the electrical system in case of disturbances such as short circuits or high impedance faults, voltage drop, frequency drop, etc. In such cases, the protection must quickly and selectively separate the faulty network part from operation.

According to analog inputs, measurements the individual protection functions operate independently of one another.

Protection functions can be set locally via a PC with a *PSM (Power System Manager)* software or via a local LDU panel. Setting via a PSM enables a remote parameterizing even from higher control levels. Every protection function or protection module is defined with its own input and output digital and analog signals that can be arbitrary linked to other functional modules with the *PSM* tool.

The following chapters include a presentation of the operation and setting of individual protection modules in the device. For this purpose the descriptions of listed functions include a configuration and parameterizing structure of individual functions that can be used via the *PSM tool*.

5.1 Overcurrent protection (I>)

Overcurrent protection is one of the basic functions of the protection relay protecting the feeder or other elements of the electrical system from overcurrents in event of faults. A fault is an abnormally high current amplitude in any phase. Several overcurrent protection modules with different settings can run independently in device at the same time. Usually the overcurrent protection function uses three protection levels.

Separated protection levels are used for any type of fault possible on the line or on other elements of electrical system, such as single phase, two phase, and three phase short circuit. Directional criteria and time characteristic can be used for each level of the overcurrent protection.

The overcurrent protection module monitors I_{L1}, I_{L2} and I_{L3} phase current, provided by the *ACQ* module, which takes care of acquisition of currents, voltages and digital inputs. The currents are acquired through separate protection current transformers in different variations (for example: 1 A or 5 A). In case of a directional operation, the protection module needs U_{L1}, U_{L2} and U_{L3} phase voltages in order to be able to calculate the angles between phase currents and voltages. The voltages are also acquired by the *ACQ* module but through separate measuring voltage transformers (for example: 100/3, 110/3).

Overcurrent protection can be affected by various blockings of internal or external statuses. The overcurrent protection has 10 digital inputs allocated for this purpose. Any of external digital inputs can be used for overcurrent protection blocking. The block signal can be delivered through logical function and through arithmetic's. The external or internal signal can be used for example as a result of interlocking, checking of voltage presence, synchronism check, spring charge check, etc. In case of blocked operation, the **Pickup blocked** signal is set. Overcurrent protection also be used only for signalling by setting **Alarm Only** parameter.

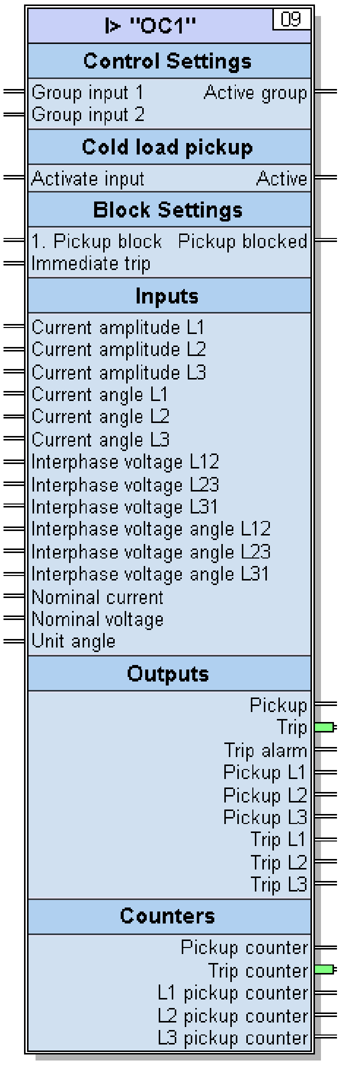

Figure 5.1: Three phase overcurrent protection module

5.1.1 Three phase ovecurrent protection

Three phase overcurrent protection is intended for detecting line-to-line faults on the medium voltage line or other elements of electrical system. Since this type of line can be interconnected the selectivity of tripping should be provided. The selectivity is achieved by coordinating trip delays. For this purpose the current dependant inverse time characteristics (IDMT) or current independent time delay (*Definite time*, *Instantaneous*) options can be selected. All settings apply to all three phases.

5.1.2 Non directional overcurrent protection

Non directional overcurrent protection is generally used in radial networks. Analog measurement and numerical calculation of protection functions are executed for each phase independently. Non directional mode is set with the **Directional mode** parameter set to *Off*.

The **Drop-out delay** protection reset time is used if very long time characteristics are used. It prevents the overcurrent protection resets in case the fault current falls below the pick-up value for a short period of time.

If you want the protection to operate in a time independent manner, the **Operate mode** should be set to *Definite time*. The operation time delay is set in the **Trip delay** parameter.

The protection operation time delay can be permanently disabled by choosing the **Operate mode** = *Instantaneous* setting. This way, the **Trip** is set immediately when a fault is detected. The time delay can also be disabled dynamically with the use of the **Immediate trip** input.

*Example: Dynamic function of **Immediate trip** is very useful in connection with the* ARC *function for clearing the temporary faults such as air discharge. Under this conditions, the protection operation is not selective.*

5.1.3 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

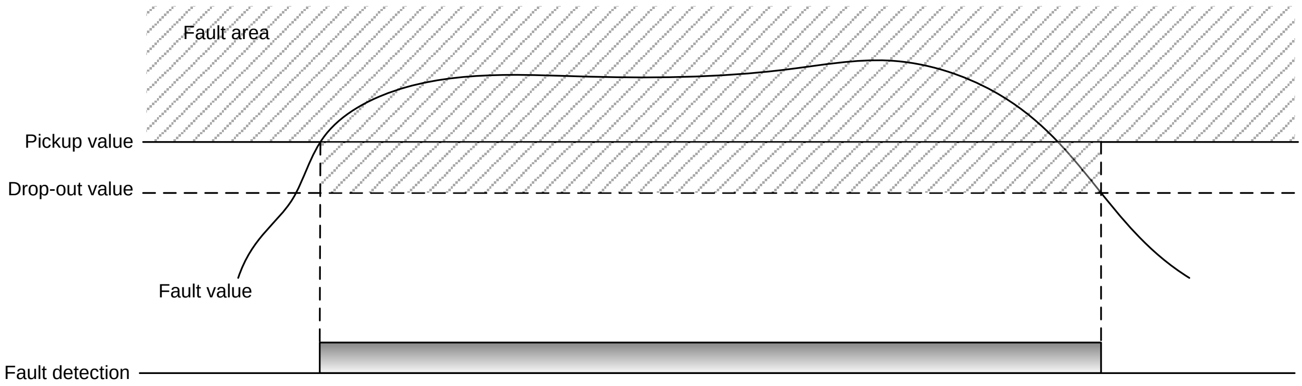

Figure 5.2: Protection operating range - fault area

5.1.3.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

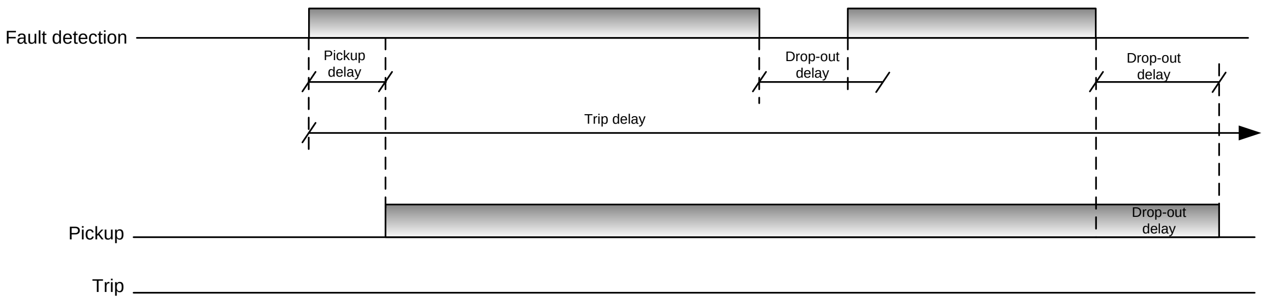

Figure 5.3: **Pickup** signal

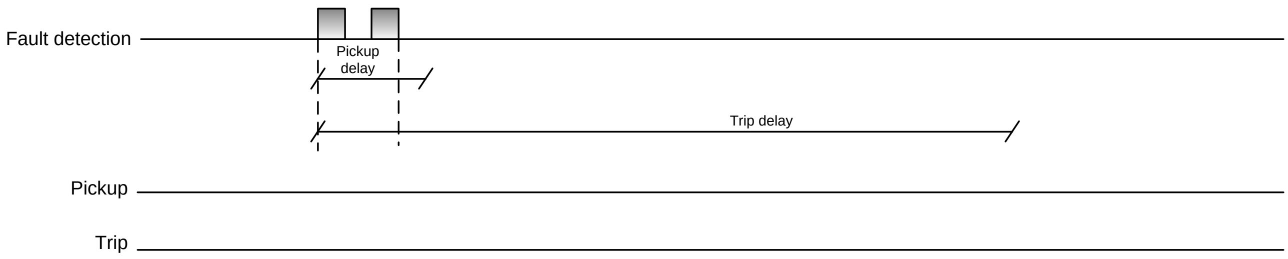

Figure 5.4: Fault confirmation time (**Pickup delay**)

5.1.3.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** = *0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

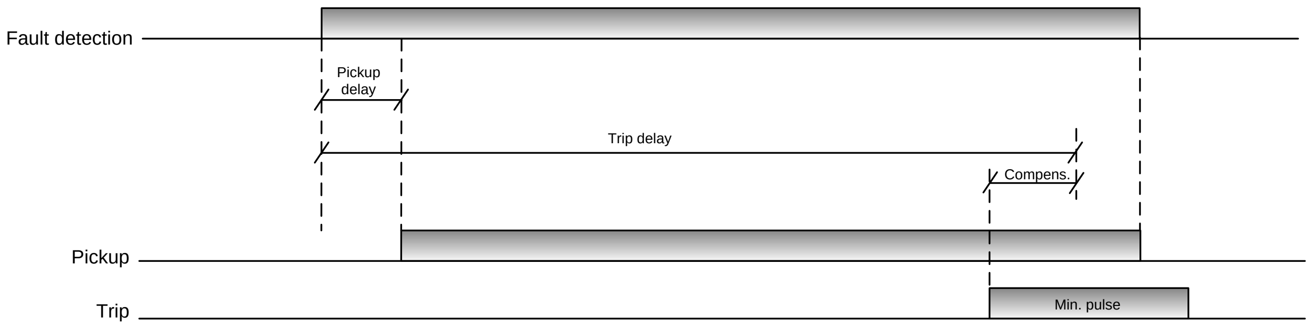

Figure 5.5: Protection operation

5.1.3.3 Three-phase operation

A protection algorithm is executed separately and independently for each individual phase. If a fault detection occurs at least on one phase and there is no blocking a joint **Pickup** signal is set. In case a fault is detected on one or more phases and at the same time a blocking is present a **Pickup blocked** signal is set.

5.1.3.4 Time characteristics

Inverse time characteristics (*IDMT – Inverse Definite Minimum Time*) are selected according to IEC 60255-4: 1974 and British Standard B.S.142:1966 standards regulations. The main purpose of characteristics is to enable shorter time of protection trip when the fault amplitude is greater. At a set fault value the protection must trip in time that can be read out from a characteristic.

The available area of inverse time characteristic is defined in a range between 1.1 and 20 x I_p, where I_p stands for **Pickup value** limit. Amplitudes above 20 x I_p have an equal trip delay as the amplitude at 20 x I_p . Amplitudes from 1.1x I_p and lower have an equal trip delay as the amplitude at 1,1 x I_p.

The type of time characteristic can be chosen with the **Operate mode** parameter. It is necessary to set the **Pickup value** and **IDMT coefficient** parameters. Values are used with all types of time characteristics. The **IDMT coefficient** factor defines the time delay level. Lower values indicate faster operation at equal fault values. With inverse characteristics the **Open compensation** parameter is not used.

The fault amplitude is not always constant and can change during fault duration. For this reason the algorithm dynamically integrates parts of time during the fault according to particular characteristic and when the sum reaches the switch off limit the protection trips.

$$T = \frac{k \cdot \beta}{\left(\frac{I}{I_P}\right)^{\alpha} - 1}$$

Table 5.1: Coefficients of IEC characteristics

Name of characteristic	α	β
Normal inverse	0.02	0.14
Very inverse	1	13.5
Extremely inverse	2	80
Long time inverse	1	120

T .... protection trip time
k .... **IDMT coefficient** factor
α, β .... table factors according to IEC standard
I .... fault amplitude
I_P .... set limit of fault range, **Pickup value**

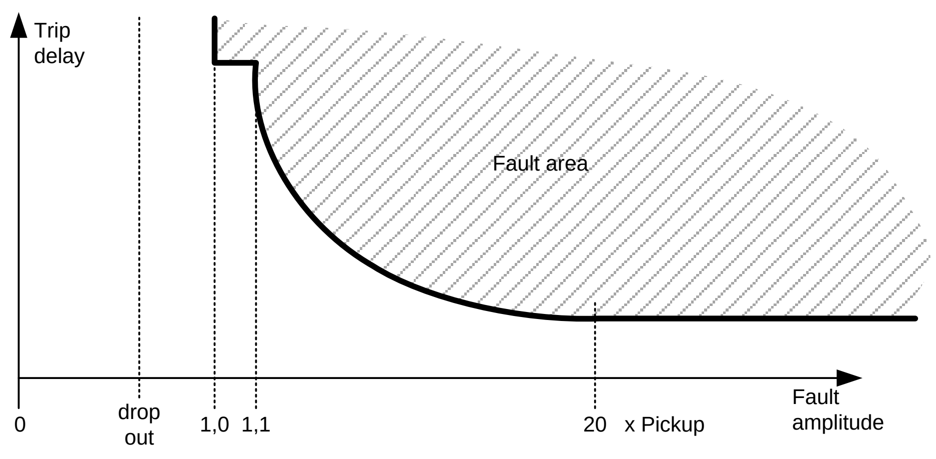

Figure 5.6: Time inverse characteristic

5.1.4 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.2: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.1.5 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

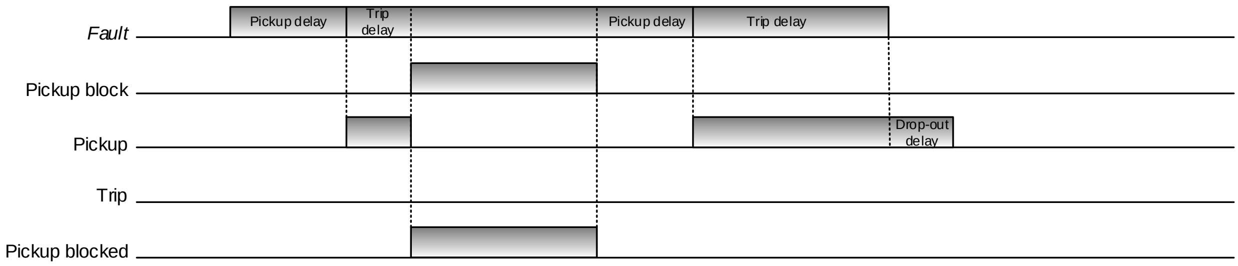

Figure 5.7: Protection blocking

5.1.5.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

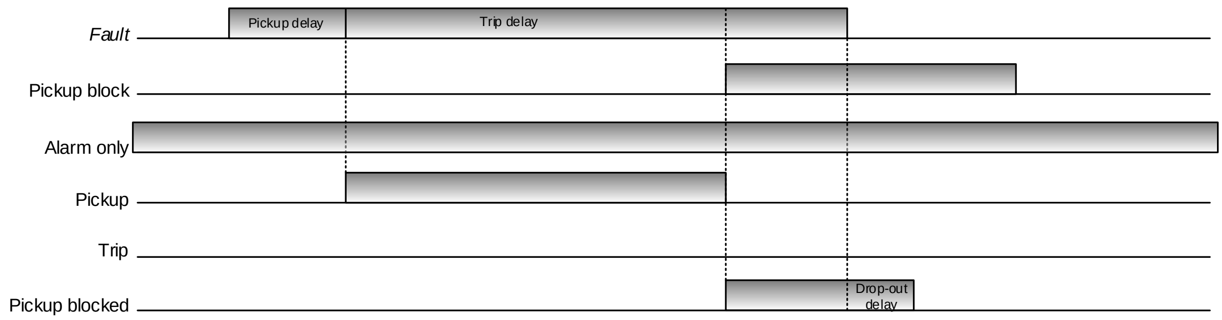

Figure 5.8: Alarm only

5.1.6 Direction detection

Directional protection is used for selective protection of lines in meshed networks and protection of parallel lines. For achievement of selectivity the protection must determine the direction of fault according to a reference direction.

An additional condition for fault detection is the correct direction of the fault, which must be within a range of directional characteristic. The protection can therefore operate only, if the fault value and direction is within the range of operation. Otherwise the protection is blocked. Fault direction is determined only on phases with faults. On other, healthy phases the direction is ignored.

Fault direction is determined with an angle between fault direction and reference direction. The range of operation is defined by **RCA Direction angle** and **RCA Correction angle** parameters.

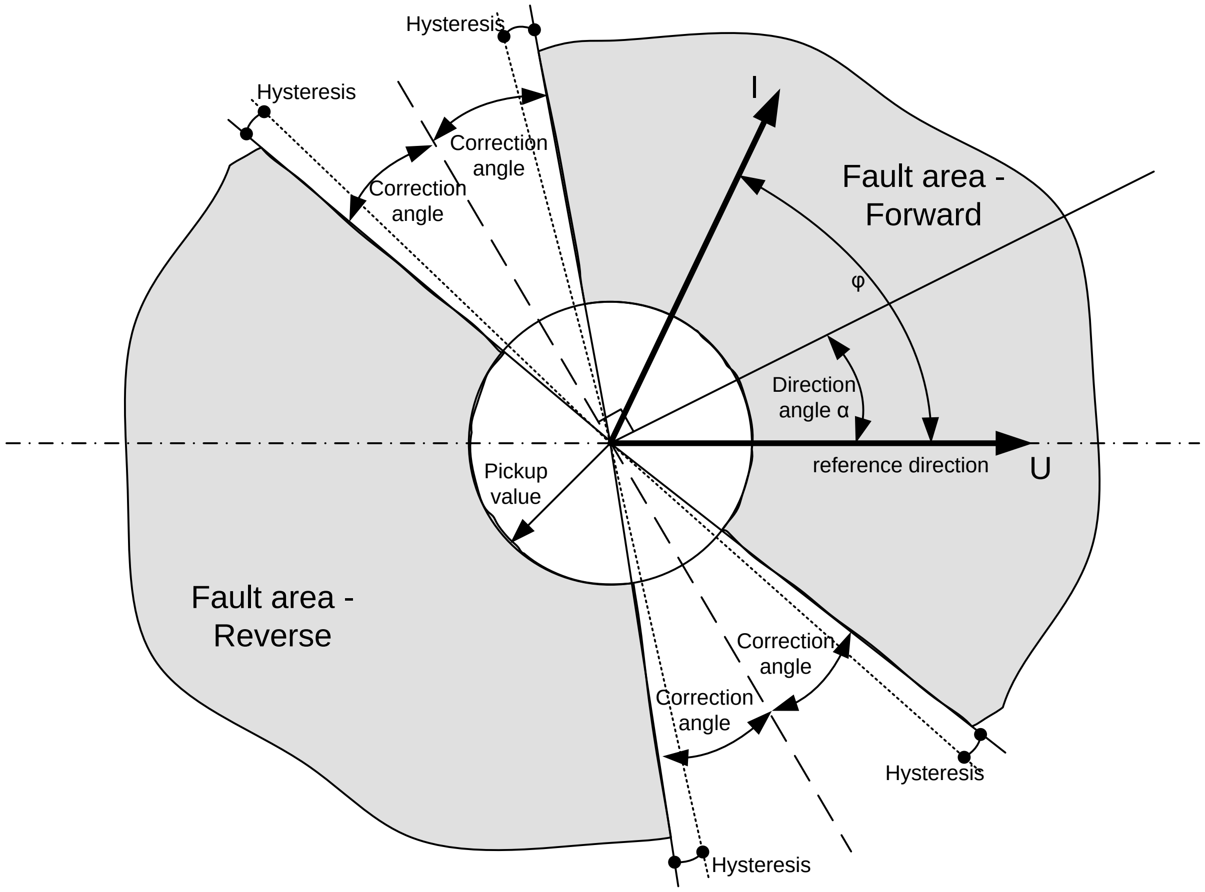

Figure 5.9: RCA direction, directional blocking

5.1.6.1 Reference direction

The direction of currents is determined by independent measuring elements for each phase. To determine the direction of phase current, the opposite healthy line-to-line voltages are used (for example: UL2-UL3 vlotage is used for IL1 curent). This ensures a solid determination of direction even in cases when the phase voltage in the faulty phase drops considerably. Reference voltages used for the selected phase and earth fault measuring element according to fault type are shown in the table below (Table 4.3).

Table 5.3: Reference phases used for direction at different fault types

Fault type	L1	L2	L3
L1	X		
L2		X	
L3			X
E			
L1,E	X		
L2,E		X	
L3,E			X
L1,L2	X	X	
L2,L3		X	X
L1,L3	X		X
L1,L2,E	X	X	
L2,L3,E		X	X
L1,L3,E	X		X
L1,L2,L3	X	X	X
L1,L2,L3, E	X	X	X

Table 5.4: Faults and reference directions for phase faults

Phase	Fault	Direction
L1	I_{L1}>	UL2-UL3 + 90°
L2	I_{L2}>	UL3-UL1 + 90°
L3	I_{L3}>	UL1-UL2 + 90°

The line-to-line voltage used is rotated for 90° in direction of the faulty phase to represent the reference direction, as if the matching phase voltage would be used (UL1 for IL1).

In case of line-to-line faults the **RCA Direction angle** and limits of the directional characteristic will slightly change (to positive or negative direction), but the change doesn't influence the selective direction determination since the current is always located in second or fourth quadrant of the directional characteristics.

The following parameters of directional element have to be set:

- reference angle of current direction according to reference voltage - **RCA Direction angle**.
- setting the directional characteristic operating range - **RCA Correction angle**
- **RCA Minimal voltage** reference voltage setting above which direction determination is still valid.
- **Directional mode** selection for forward or reverse.

In case the reference voltage at directional overcurrent protection falls below the set **RCA Minimal voltage** value, protection operates in a non-directional mode.

The recommended **RCA Minimal voltage** value is 0.01 of the nominal line-to-line voltage and the recommended value of the **RCA Direction angle** is *-45°*.

Note: Usually, the line-to-line voltages are calculated from adequate phase voltages, therefore the voltage measuring have to be connected in Line to Neutral connection according to the wiring diagram from the user manual.

5.1.7 Cold load pickup

When energizing the long zero voltage period loads, a temporary increased starting current, which can be up to several times higher than the nominal current appears. That starting current would cause unwanted protection operation, therefore the pickup limit must be raised temporarily. The start of this function is usually triggered by manual close of the circuit breaker. The module offers the **Activate input** digital input to which a command or status of load closing are connected. Increase pickup factor and duration time value are set with **Cold load pickup / Level** and **Duration** parameters.

With inverse characteristics, the *Cold load pickup* influences only the fault detection limit, whereas the time calculation of the inverse characteristic is not affected. Characteristic is linked to a regular (non-increased) **Pickup level** value.

5.1.8 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.1.9 Module parameters, inputs and outputs

Group settings …	
Operate mode Off Instantaneous Definite time Normal inverse Very inverse Extremely inverse Long-time inverse	Protection operation mode: *Off* – protection disabled *Instantaneous* – immediate operation *Definite time* – constant time of operation *... inverse* – selected IDMT characteristic
IDMT coefficient 0.05…1.00	Coefficient of selected IDMT characteristic
Pickup value 0.05...1.00…40.00 x In	Monitored value, above which the protection starts.
Trip delay 0.00...0.50…300.00 sec	Fixed delay of **Trip** signal.
Directional mode Off, Forward, Reverse	Operation mode setting. Forward: Directional element forward operation mode. Reverse: Directional element reverse operation mode.
RCA Direction angle -90...45…90 °	Reference angle for the current direction according to the reference voltage.

Control settings	
Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.

Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.

Drop-out ratio 0.90...**0.95**...0.99	Drop-out value below which the protection drops.
RCA Correction angle **0**...90°	Angle correction for directional criteria.
RCA Minimal voltage 0.00...**0.65**…1.00 Un	The lowest reference voltage amplitude at which the directional element still operates. If the reference voltage is below this value, the protection operates in non-directional mode.

Cold load pickup

Enabled true, **false**	Enabling of *Cold load pickup* function.
Activate input input (digital)	Signal for activation the increased values.
Level 1.01...**1.50**…10.00 x Ip	**Pickup value** and **Dropout value** increase factor.
Duration 0…**60**…3.600 sec	**Pickup value** increase duration time.
Active output (digital)	Function state: 1: function is active 0: function is not active

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Inputs

Current amplitude L1 input (analog)	Current L1 amplitude.
Current amplitude L2 input (analog)	Current L2 amplitude.
Current amplitude L3 input (analog)	Current L3 amplitude.
Current angle L1 input (analog)	Current L1 angle.
Current angle L2 input (analog)	Current L2 angle.
Current angle L3 input (analog)	Current L3 angle.
Phase-to-phase voltage L12 input (analog)	U12 phase-to-phase voltage amplitude.

Phase-to-phase voltage L23 input (analog)	U23 phase-to-phase voltage amplitude.
Phase-to-phase voltage L31 input (analog)	U31 phase-to-phase voltage amplitude.
Phase-to-phase volt angle L12 input (analog)	L12 phase-to-phase voltage angle.
Phase-to-phase volt angle L23 input (analog)	L23 phase-to-phase voltage angle.
Phase-to-phase volt angle L31 input (analog)	L31 phase-to-phase voltage angle.
Nominal current constant input (analog)	Nominal current.
Nominal voltage constant input (analog)	Nominal phase-to-phase voltage.
Unit angle constant input (analog)	1° angle unit value.

Outputs

Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**...1000 ms	Minimal time of **Trip** output signal.

Pickup L1 output (digital)	Phase L1 pickup.
Pickup L2 output (digital)	Phase L2 pickup.
Pickup L3 output (digital)	Phase L3 pickup.
Trip alarm L1 output (digital)	Trip indication in phase L1.
Trip alarm L2 output (digital)	Trip indication in phase L2.
Trip alarm L3 output (digital)	Trip indication in phase L3.

Counters

Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

L1 pickup counter counter	Phase L1 pickup counter.
L2 pickup counter counter	Phase L2 pickup counter.
L3 pickup counter counter	Phase L3 pickup counter.

5.2 Earth fault overcurrent protection (IE>)

Earth fault overcurrent protection is intended for detection of earth faults in resistor earthed, coil earthed or isolated electrical networks. In this way, earth fault current is smaller than phase fault currents. Therefore, earth fault protection pickup value setting is normally lower than phase overcurrent protection pickup value setting.

Earth fault current is main monitored value on which protection operates. Several earth fault overcurrent protections with different settings can run at the same time independently of one another with its own settings. Usually three earth fault overcurrent protection levels are set: IE>, IE>> and IE>>>. If device has a sensitive current inputs, earth fault overcurrent operation operates in a range up to 0.005 % of the nominal current. For time delay, current independent or current dependent time delay can be set.

Use of a *GFD – Ground Fault Detection* functionality enables selective operation of earth fault overcurrent protection at 200% of primary currents without the use of direction criteria. In this way, the conditional signal to the sensitive earth fault overcurrent protection can be set, allowing it to operate down to 0.5 % of the nominal current. This signal is usually acquired through a device external digital input and is generated by external sensitive overcurrent protection of transformer neutral current.

If protection is set to directional mode, protection will trip only in defined direction (RCA mode). Direction can be correctly measured if the fault current (IE) and residual voltage (UE) values are high enough. The protection can also be set to operate in Wattmetric and Varmetric modes.

Earth fault overcurrent protection can be set to operate in different modes:

- earth fault overcurrent
- earth fault overcurrent with the RCA direction criteria,
- earth fault overcurrent with Wattmetric (IE·cosφ> criteria) or
- earth fault overcurrent with Warmetric (IE·sinφ > criteria).
- earth fault overcurrent with GFD criteria.

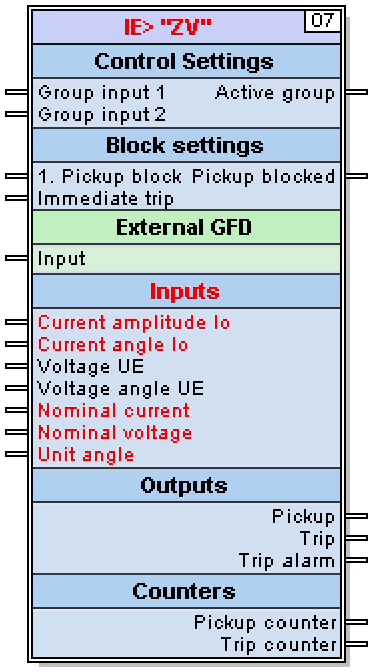

Figure 5.10: Earth fault overcurrent protection function block.

5.2.1 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

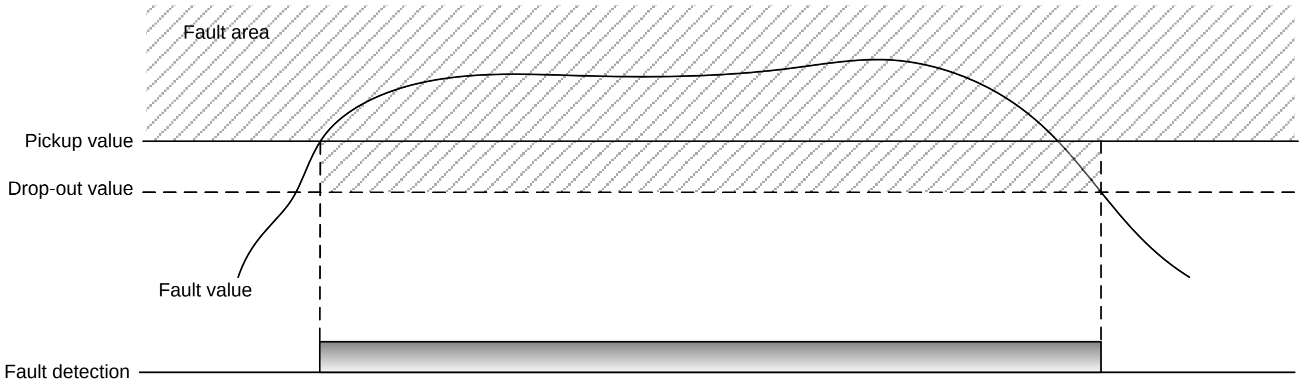

Figure 5.11: Protection operating range - fault area

5.2.1.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

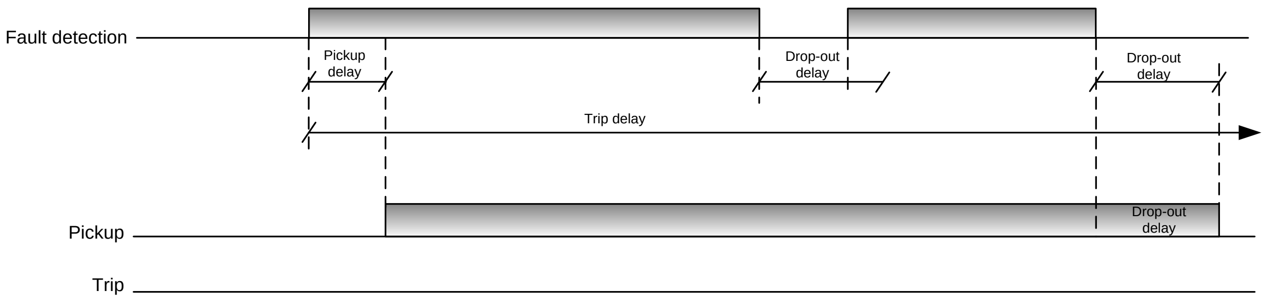

Figure 5.12: **Pickup** signal

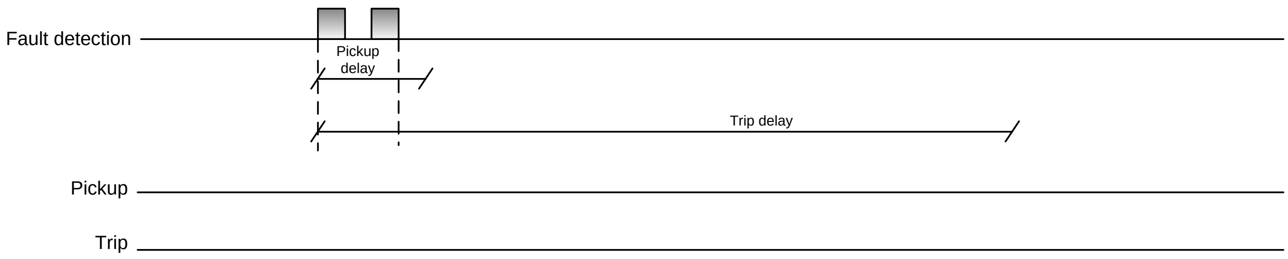

Figure 5.13: Fault confirmation time (**Pickup delay**)

5.2.1.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

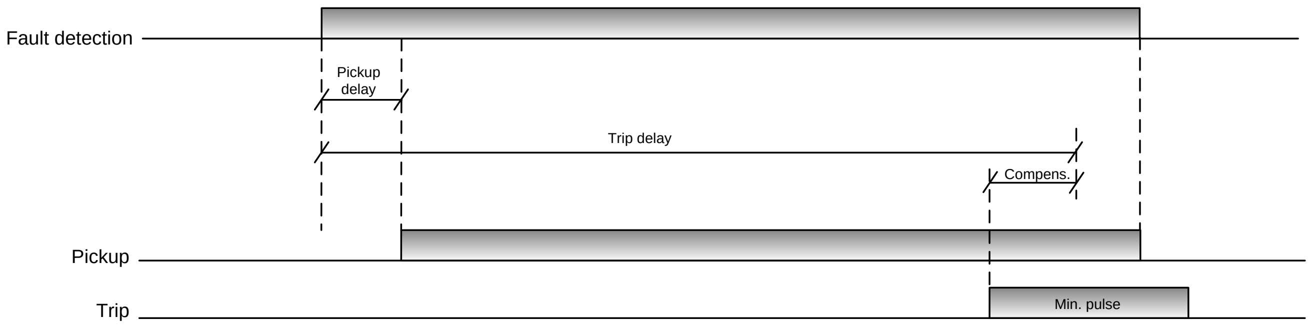

Figure 5.14: Protection operation

Time characteristics

Inverse time characteristics (*IDMT – Inverse Definite Minimum Time*) are selected according to IEC 60255-4: 1974 and British Standard B.S.142:1966 standards regulations. The main purpose of characteristics is to enable shorter time of protection trip when the fault amplitude is greater. At a set fault value the protection must trip in time that can be read out from a characteristic.

The available area of inverse time characteristic is defined in a range between 1.1 and 20 x I_p, where I_p stands for **Pickup value** limit. Amplitudes above 20 x I_p have an equal trip delay as the amplitude at 20 x I_p . Amplitudes from 1.1x I_p and lower have an equal trip delay as the amplitude at 1,1 x I_p.

The type of time characteristic can be chosen with the **Operate mode** parameter. It is necessary to set the **Pickup value** and **IDMT coefficient** parameters. Values are used with all types of time characteristics. The **IDMT coefficient** factor defines the time delay level. Lower values indicate faster operation at equal fault values. With inverse characteristics the **Open compensation** parameter is not used.

The fault amplitude is not always constant and can change during fault duration. For this reason the algorithm dynamically integrates parts of time during the fault according to particular characteristic and when the sum reaches the switch off limit the protection trips.

$$T = \frac{k \cdot \beta}{\left(\frac{I}{I_P}\right)^{\alpha} - 1}$$

Table 5.5: Coefficients of IEC characteristics

Name of characteristic	α	β
Normal inverse	0.02	0.14
Very inverse	1	13.5
Extremely inverse	2	80
Long time inverse	1	120

T .... protection trip time
k .... **IDMT coefficient** factor
α, β .... table factors according to IEC standard
I .... fault amplitude
I_P .... set limit of fault range, **Pickup value**

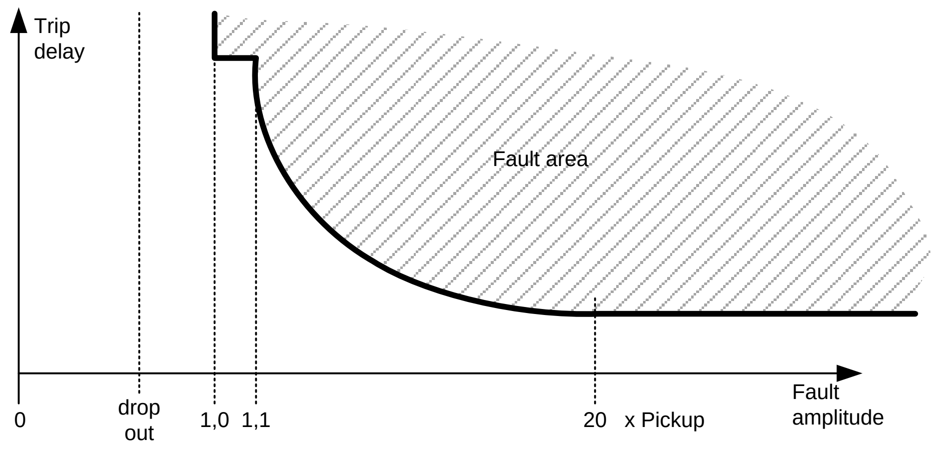

Figure 5.15: Time inverse characteristic

5.2.2 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.6: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.2.3 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

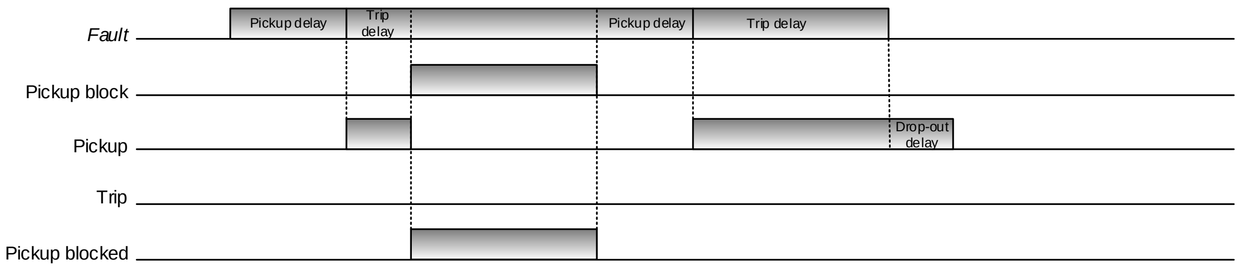

Figure 5.16: Protection blocking

5.2.3.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

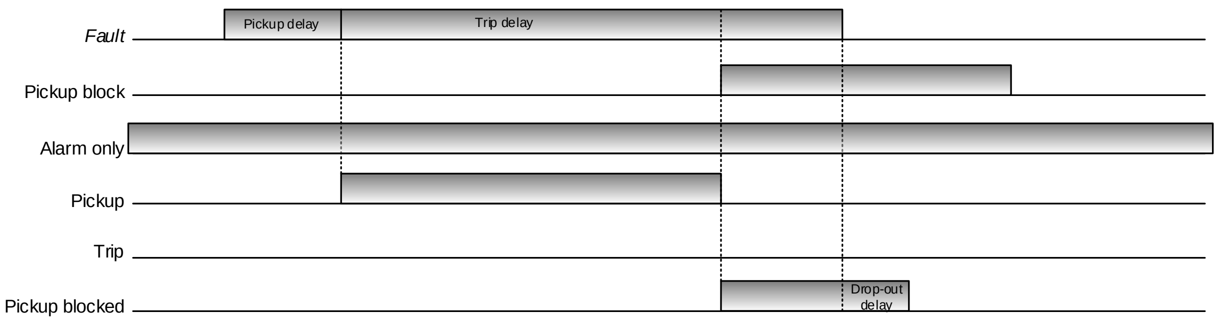

Figure 5.17: Alarm only

5.2.4 Direction detection

Directional protection is used for selective protection of lines in meshed networks and protection of parallel lines. For achievement of selectivity the protection must determine the direction of fault according to a reference direction.

An additional condition for fault detection is the correct direction of the fault, which must be within a range of directional characteristic. The protection can therefore operate only, if the fault value and direction is within the range of operation. Otherwise the protection is blocked. Fault direction is determined only on phases with faults. On other, healthy phases the direction is ignored.

Fault direction is determined with an angle between fault direction and reference direction. The range of operation is defined by **RCA Direction angle** and **RCA Correction angle** parameters.

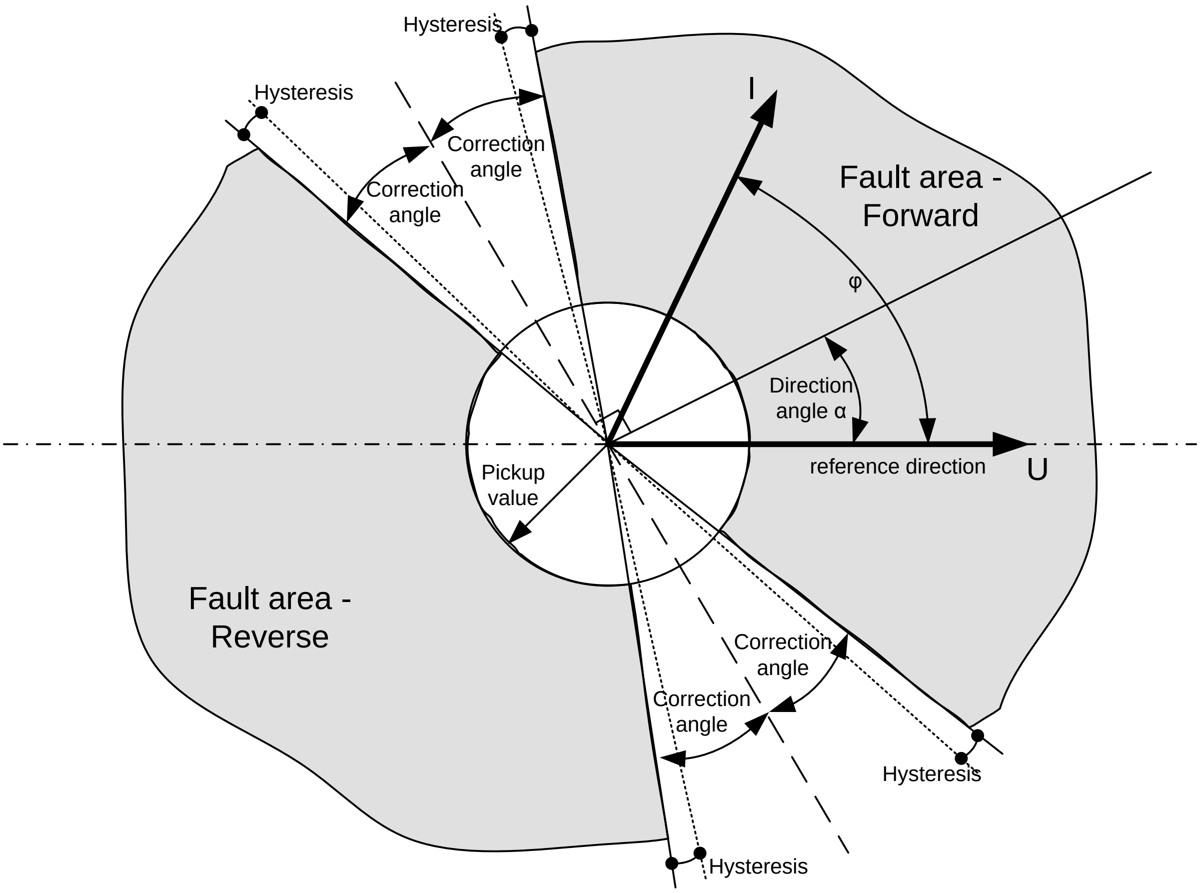

Figure 5.18: RCA direction, directional blocking

Directional mode can be enabled or disabled with the **Directional mode** parameter, selecting between *Off*, *RCA*, *Wattmetric* or *Varmetric* options.

The value of **Direction angle** is set in a range from *+90°* to *–90°*. The direction can be changed by 180° by setting the **Direction** parameter to *Forward* or *Reverse* for RCA, Wattmetric and Varmetric methods. Directional operating range can be modified to narrow range angle to less than *180°* using the **Correction angle** parameter.

In general, using the regular connection (where IE current and UE voltage are connected in the same direction) the following RCA characteristic angle settings are recommended:

- +90° - isolated networks,
- 0° - resistant or coil earthed networks and
- -7° - directly earthed networks.

In case of no special requirements, the recommended correction factor setting is between 5° and 10°. Of course, all this are recommendations only, and should be modified according to each specific requirements and application!

5.2.4.1 Wattmetric and Varmetric methods

These methods use sine or cosine amplitude component of the faulty current:

- $I_x = I_0 \cdot \cos(\varphi - \alpha)$ Wattmetric:
- $I_x = I_0 \cdot \sin(\alpha - \varphi)$ Warmetric:

Variables:

α............... **Direction angle** parameter
I_0............... measured faulty current
I_x............... fault amplitude
φ............... angle between the reference direction and faulty current

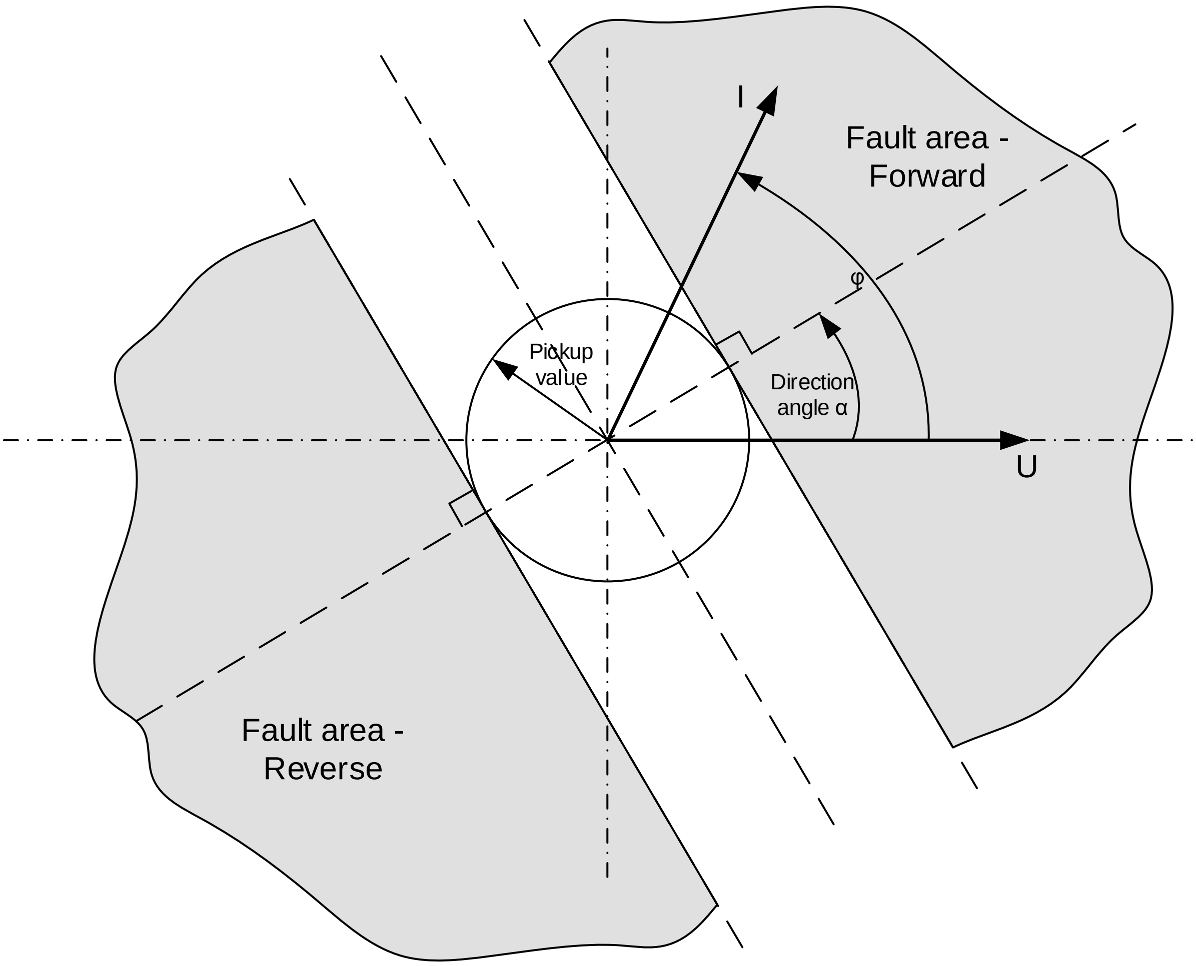

Figure 5.19: Wattmetric method operating range

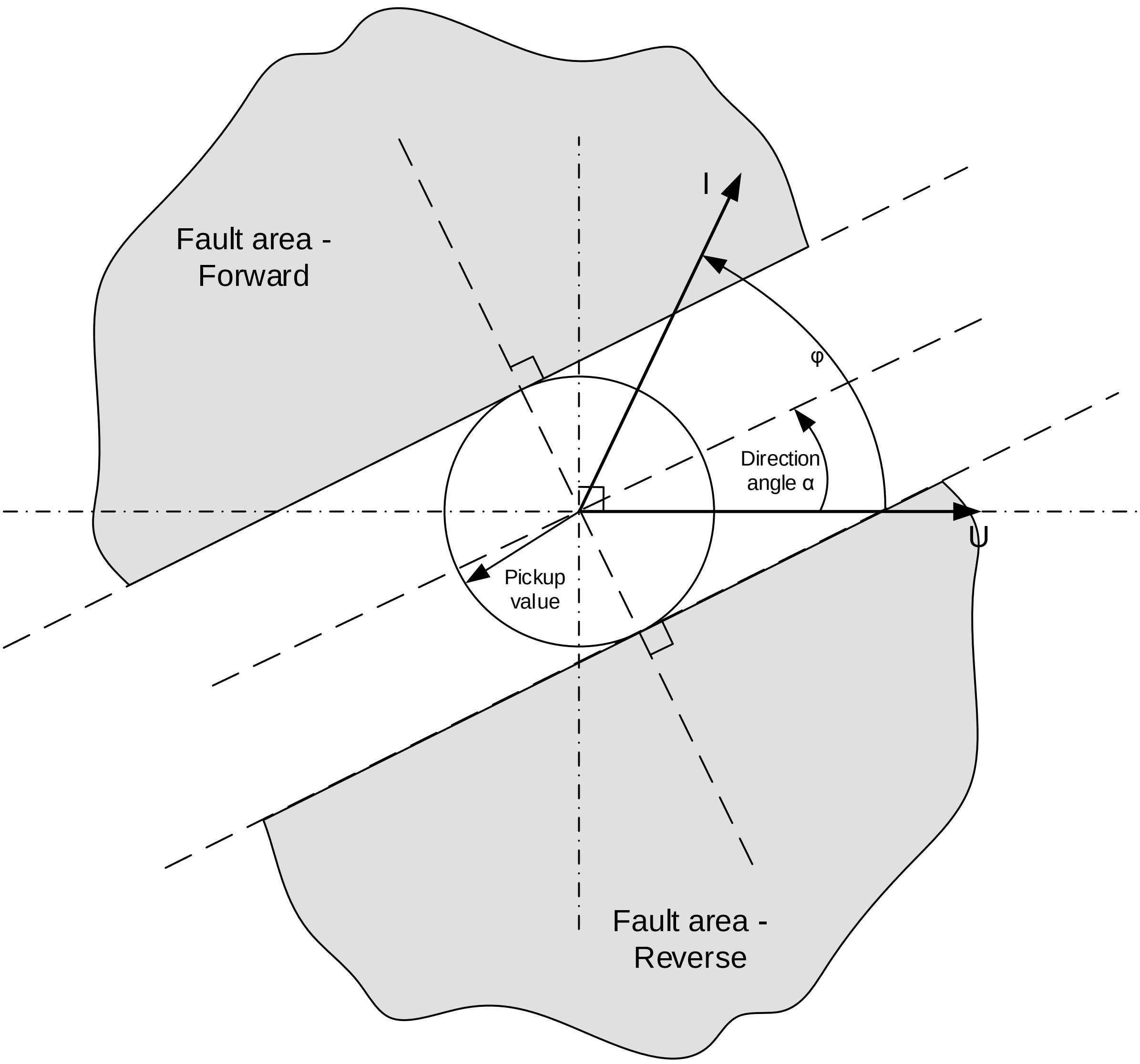

Figure 5.20: Varmetric method operating range

5.2.4.2 Reference direction

Fault direction is defined with the direction of earth fault voltage (UE) as a reference for determining the faulty current direction. In case when the reference voltage drops below the set **RCA Minimal voltage** value, the protection is blocked.

5.2.5 GFD function

In case of high impedance earth fault the earth fault current is too small for regular earth fault overcurrent protection to detect it. To avoid this problem, sensitive directional earth fault overcurrent protection is used, as one of the earth fault protection levels. Use of direction criteria is obligatory, because the amplitude of fault current caused by high impedance earth fault is comparable to capacitive currents, which are normaly present in the electrical system. Fault current differs only by its direction. The fault current as small as this is not a threat to electrical system operation, but it can harm humans and animals on fault location and that is why such line has to be disconnected. Time delay is usually current independent and is usually set to a higher value than in first two levels of earth fault protection.

The directional sensitive earth fault overcurrent protection is at high impedance faults sometimes not sensitive enough, because it is very difficult do determine the correct fault direction at primary currents below 3 A. The reason for this are very low UE voltage level and consequently measuring transformers phase angle errors. A GFD criteria uses s case, a non directional sensitive earth fault overcurrent protection operation in combination with additional operational condition delivered from sensitive overcurrent protection of transformer neutral current through a binary input can be used. It is named **External GFD** (*Ground fault* *detection*) input. The operation of earth fault overcurrent protection is allowed only if the **External GFD / Input** is set. The **External GFD** functionality is enabled with the **External GFD / Enabled** parameter.

The **GFD Delay** timer starts together with the **Pickup delay** timer. Conditions for protection operation are:

- current is in operating range
- the **Pickup delay** timer has elapsed
- the **GFD Input** is set within the time of **GFD delay**.

If the fault is still present, when **GFD delay** and **Pickup delay** timers elapse, and the GFD signal is not set, the **Pickup blocked** alarm sets.

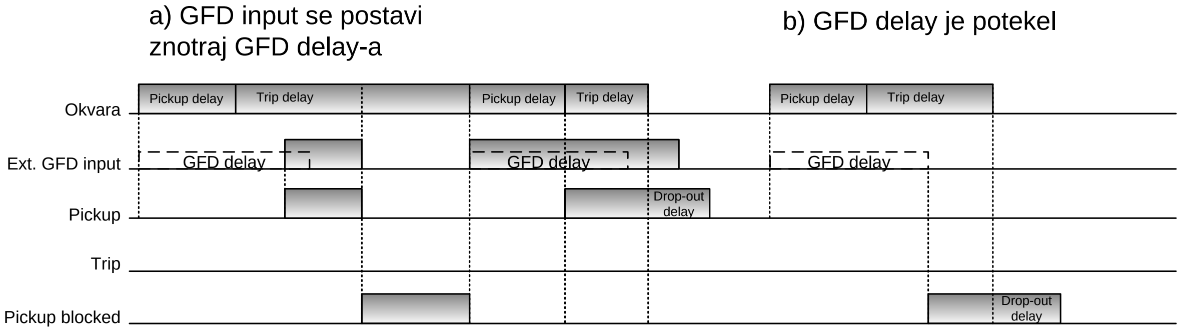

Figure 5.21: External GFD function operation

5.2.6 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.2.7 Module parameters, inputs and outputs

Group settings A…D

Operate mode Off Instantaneous Definite time Normal inverse Very inverse Extremely inverse Long-time inverse	Protection operation mode: *Off* – protection disabled *Instantaneous* – immediate operation *Definite time* – constant time of operation *... inverse* – selected IDMT characteristic
IDMT coefficient 0.05…1.00	Coefficient of the selected IDMT characteristic.
Pickup value 0.005...0.10…1.25 x In	Limit of monitored value, above which the protection starts.
Trip delay 0.00...2.00…300.00 sec	Fixed delay of **Trip** signal.

Directional mode Off RCA Wattmetric Varmetric	Directional criteria selection: *Off*– no directional condition
Direction Forward Reverse	*Forward*: Directional element operation mode forward. *Reverse*: Directional element operation mode reverse.
Direction angle -90...0…90 °	Reference angle for current direction according to reference voltage. 3° hysteresis.

Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.
Drop-out ratio 0.80...**0.95**...0.99	Drop-out value at which the protection drops.
RCA Correction angle **0**...90°	Angle correction for directional criteria.
RCA Minimal voltage 0.00...**0.65**…1.00 Un	The lowest reference voltage amplitude at which the directional protection still operates. If the reference voltage is lower than set, the protection is blocked.

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Block settings \ External GFD

Enabled **true**, false	Function enabling.
Input input (digital)	Status of external ground fault detection module. The condition for protection operation.
Delay 0.00...**0.05**…60.00 sec	Blocking activation delay.

Inputs	
Current amplitude Io input (analog)	Earth current amplitude.
Current angle Io input (analog)	Earth current angle.
Voltage UE input (analog)	Earth fault voltage amplitude, voltage asymmetry.
Voltage angle UE input (analog)	Earth fault voltage, asymmetry voltage angle.
Nominal current constant input (analog)	Nominal earth fault current (raw).
Nominal voltage constant input (analog)	Nominal earth fault voltage (raw).
Unit angle constant input (analog)	1° angle unit value (raw).

Outputs	
Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**...1000 ms	Minimal time of **Trip** output signal.

Counters	
Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.3 Negative sequence protection (I2>)

Negative sequence protection detects unbalanced loads in the electrical system. For its operation, the negative sequence of the three phase system symmetrical component has to be calculated. The asymmetrical load can cause uneven distribution of currents in the network, which is caused due to uneven load, asymmetrical (single or two phase) earth faults, line disconnections and irregular switching operations.

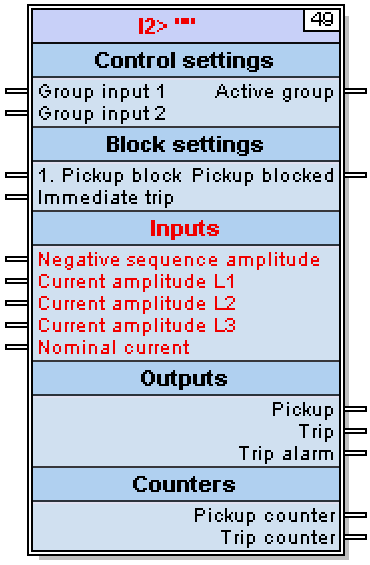

Figure 5.22: Negative sequence protection function block

5.3.1 Protection operation

The monitored value used for protection operation is the **Negative sequence amplitude**, which is the symmetrical component of the negative sequence of three phase system currents. The value of the negative sequence is defined by the asymmetry of the electrical system, and is used to achieve sensitivity needed on asymmetrical faults.

The protection can operate with the *Definite time* independent time delay or with inverse time characteristics.

Several negative sequence protection modules can run independently at the same time. Usually, two levels of protection are set, one with time independent and one with inverse time characteristic.

To prevent the protection malfunction and to achieve better selectivity the protection has additional operation conditions, otherwise the protection is blocked:

- at least one phase current has to be above the set **Minimal current** value and
- all of phase currents have to be below the set **Maximal current** value.

To achieve protection selectivity, the Trip delay time has to be set to higher value than the one set in main protections, such as overcurrent protection.

5.3.2 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

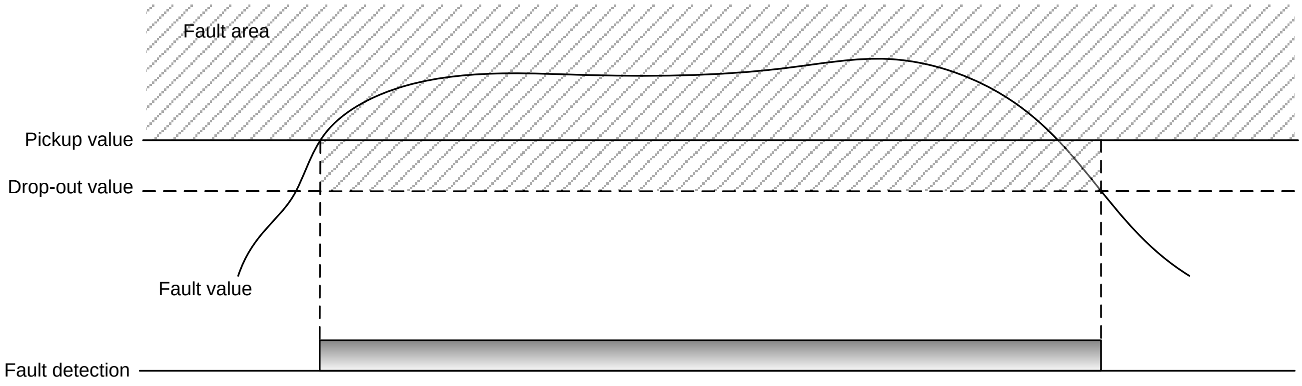

Figure 5.23: Protection operating range - fault area

5.3.2.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

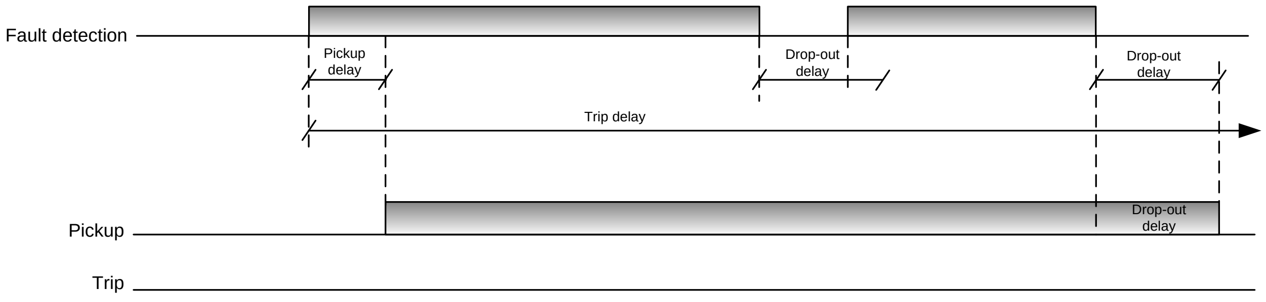

Figure 5.24: **Pickup** signal

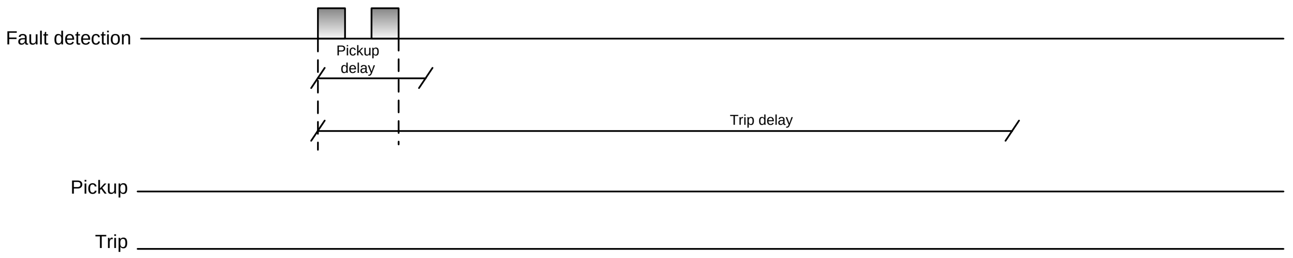

Figure 5.25: Fault confirmation time (**Pickup delay**)

5.3.2.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

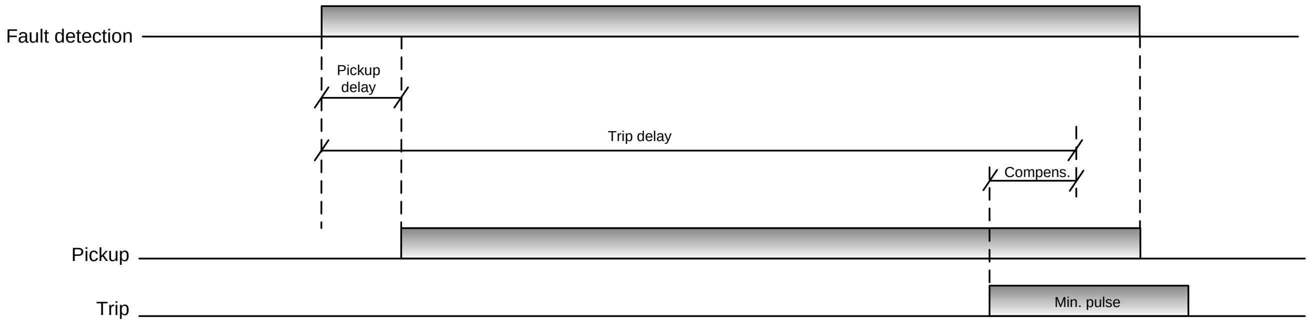

Figure 5.26: Protection operation

5.3.2.3 Time characteristics

Inverse time characteristics (*IDMT – Inverse Definite Minimum Time*) are selected according to IEC 60255-4: 1974 and British Standard B.S.142:1966 standards regulations. The main purpose of characteristics is to enable shorter time of protection trip when the fault amplitude is greater. At a set fault value the protection must trip in time that can be read out from a characteristic.

The available area of inverse time characteristic is defined in a range between 1.1 and 20 x I_p, where I_p stands for **Pickup value** limit. Amplitudes above 20 x I_p have an equal trip delay as the amplitude at 20 x I_p . Amplitudes from 1.1x I_p and lower have an equal trip delay as the amplitude at 1,1 x I_p.

The type of time characteristic can be chosen with the **Operate mode** parameter. It is necessary to set the **Pickup value** and **IDMT coefficient** parameters. Values are used with all types of time characteristics. The **IDMT coefficient** factor defines the time delay level. Lower values indicate faster operation at equal fault values. With inverse characteristics the **Open compensation** parameter is not used.

The fault amplitude is not always constant and can change during fault duration. For this reason the algorithm dynamically integrates parts of time during the fault according to particular characteristic and when the sum reaches the switch off limit the protection trips.

$$T = \frac{k \cdot \beta}{\left(\frac{I}{I_P}\right)^{\alpha} - 1}$$

Table 5.7: Coefficients of IEC characteristics

Name of characteristic	α	β
Normal inverse	0.02	0.14
Very inverse	1	13.5
Extremely inverse	2	80
Long time inverse	1	120

T .... protection trip time
k .... **IDMT coefficient** factor
α, β .... table factors according to IEC standard
I .... fault amplitude
I_P .... set limit of fault range, **Pickup value**

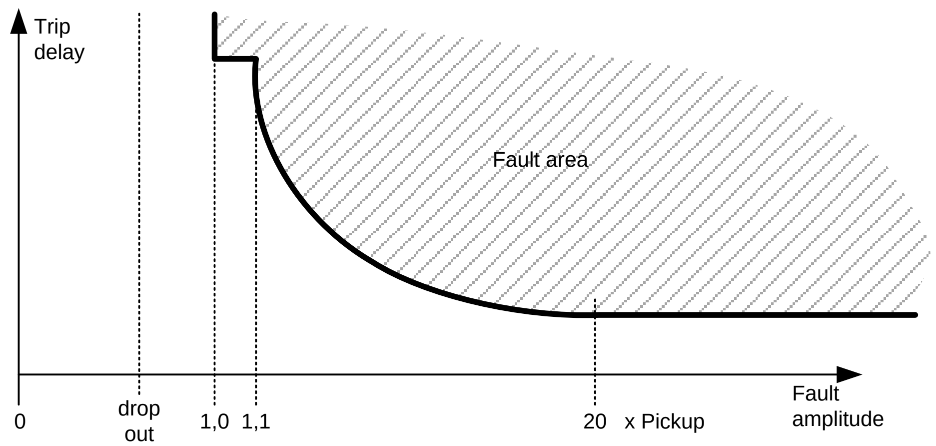

Figure 5.27: Time inverse characteristic

5.3.3 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.8: Selection of setting group

Group input 1	Group input 2	Selected group

0	0	A
1	0	B
0	1	C
1	1	D

5.3.4 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

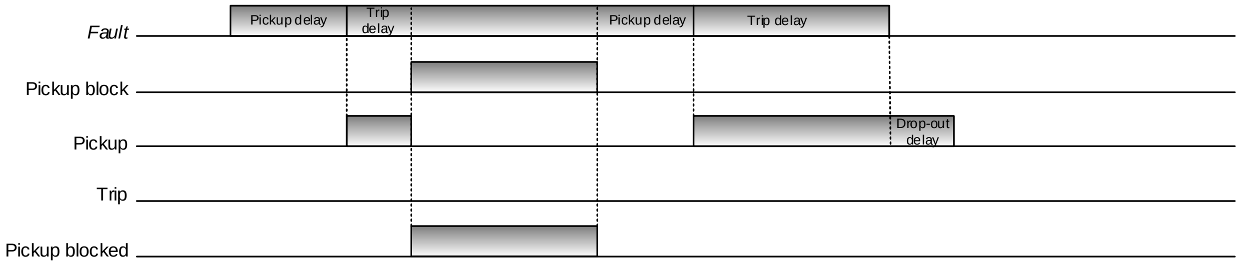

Figure 5.28: Protection blocking

5.3.4.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

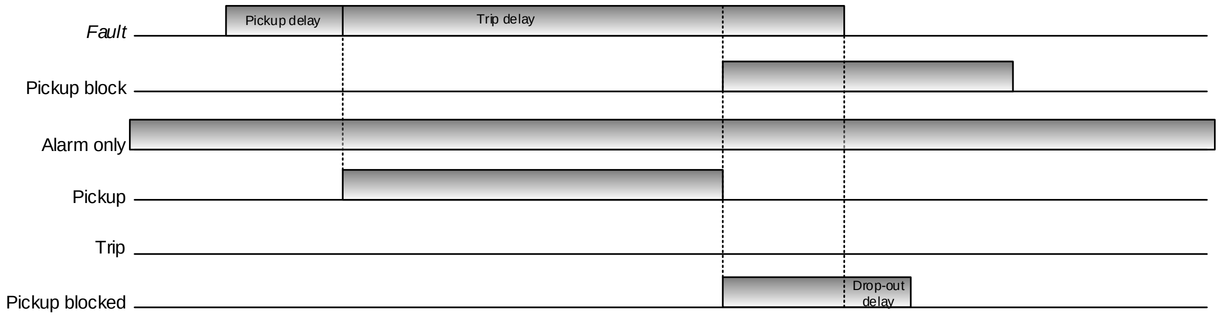

Figure 5.29: Alarm only

5.3.5 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.3.6 Module parameters, inputs and outputs

**\ Group settings A…D **

Operate mode Off Instantaneous Definite time Normal inverse Very inverse Extremely inverse Long-time inverse	Protection operation mode: *Off* – protection disabled *Instantaneous* – immediate operation *Definite time* – constant time of operation *... inverse* – selected IDMT characteristic
IDMT coefficient **0.05**…1.00	Coefficient of selected IDMT characteristic.
Pickup value 0.10...**0.10**…3.00 In	Limit of monitored value, above which the protection starts.
Trip delay 0.00...**1.50**…300.00 sec	Fixed delay of **Trip** signal.

.Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.

Drop-out ratio 0.80...**0.95**...0.99	Drop-out value below which the protection drops.

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).

Pickup blocked output (digital)	Signalization of protection operation blocking.

Minimal current 0.10...**0.10**…2.00 x In	Minimal current above which the protection still operates. If all phase currents are below the set value, protection is blocked.
Maximal current 0.10...**4.00**…8.00 x In	Maximal current below which the protection still operates. If any of phase currents is above, the protection is blocked.

\ Inputs \

Negative sequence amplitude input (analog)	Negative sequence amplitude
Current amplitude L1 input (analog)	Current L1 amplitude.
Current amplitude L2 input (analog)	Current L2 amplitude.
Current amplitude L3 input (analog)	Current L3 amplitude.
Nominal current constant input (analog)	Nominal current.

Outputs

Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**…1000 ms	Minimal time of **Trip** output signal.

Counters

Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.4 Thermal overload protection (TOP)

Thermal overload protection is used to protect lines, cables, transformers and other machines from thermal overload. The protection function creates a model of the thermal profile of the object being protected and takes into account the history of the load for its operation.

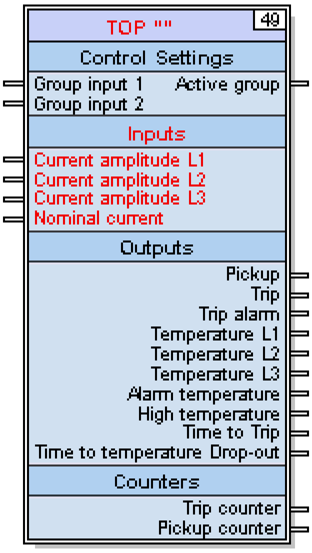

Figure 5.30: Thermal overload protection function block

5.4.1 Protection operation

The algorithm calculates the relative temperature of protected device based on current measurement. The temperature is calculated for each phase separately. The monitored value for protection is the highest calculated temperature. The equations below are used in protection algorithm.

5.4.1.1 Heating and cooling equation:

$$\frac{d\Theta}{dt} + \frac{1}{\tau} \cdot \Theta = \frac{\Theta_I}{\tau}$$

… heating and cooling differential equation

$$I_{alm} = \sqrt{\Theta_{alm}} \cdot k \cdot I_n$$

… current value, at which the alarm limit is reached

$$\Theta_I = \left(\frac{I}{k \cdot I_n} \right)^2$$

… temperature, which would be reached at specific current

$$\Theta = \Theta_I + (\Theta_0 - \Theta_I) \cdot e^{-\frac{t}{\tau}}$$

… temperature, which would be reached at specific current I in specific time t, started from Θ_0 temperature.

5.4.1.2 Equation for time to Trip calculation:

$t = \tau \cdot \ln\left(\frac{\Theta_I - \Theta}{\Theta_I - 1} \right)$; if $abs(\Theta_I - 1) > 0$; $I > k \cdot I_n$; $\Theta_{alm} < \Theta < 1$; are valid

5.4.1.3 Equation for Drop-out time calculation:

$t = \tau \cdot \ln\left(\frac{\Theta_I - \Theta}{\Theta_I - \Theta_{alm}} \right)$; if $abs(\Theta_I - \Theta_{alm}) > 0$; $I < I_{alm}$; $\Theta_{alm} < \Theta$; are valid

When the **Alarm temperature value** is reached, the **Alarm temperature** warning signal is set. The **Alarm temperature value** parameter is set in per cent, relative to the tripping temperature. In order to make the calculation of time to trip possible, the **Heating time constant** parameter must be set. Information about the heating constants can be found in device tables or acquired from the manufacturer of the protected equipment. For electrical lines, the cooling constant is equal to the heating constant.

The protection detects the fault, when the maximal allowed permanent thermal current I_{max}, which causes the start of overheating of protected element, is exceeded. The **k-factor** constant has to be set. The constant is defined as $k=I_{max}/I_N$, where the I_{max} is maximal thermal current and the I_N is nominal current of protected device.

The maximal thermal current is determined by materials used, construction properties and it is defined according to the environment where the device is used. Usually it is available from property tables supplied by the manufacturer.

When the **High temperature value** limit is exceeded and the current is still above the allowed value (**Pickup** signal is set), the protection will operate (signal **Trip** is set), which causes the disconnection of the protected device from the power source. The **Trip** signal resets, when the current is back below the maximal thermal current limit.

The **High temperature** signal is set according to **High temperature mode** setting:

- *Start on trip* - **High temperature** signal is set at the same time as the **Trip** signal, and it resets when the temperature falls below the set **High temperature value** value.
- *Start on high temperature* - **High temperature** signal is set constantly when the temperature is above the set **High temperature value** value.

*Note: When the circuit breaker disconnects the line because of thermal protection, the **Trip** signal resets, otherwise the CBFP protection of the circuit breaker Switch module would operate.*

*The closing of circuit breaker has to be inhibited until the temperature fall below the set **High temperature value** value. This limit can be different than the alarm limit. Therefore the **High temperature** signal can be used to block the circuit breaker close command in the circuit breaker Switch module.*

Current overtemperature values are written to **Temperature Lx** outputs separately for each phase. The value is written as a relative value, where 100% represents that the maximal allowed overtemperature is reached. By reseting values on outputs, their start values can be set by user interface. At the device startup, this outputs are reseted to zero, which represents no overtemperature. This outputs can also be linked to permanent registers (to *Retentive registers* module). In this case, the values will be written to static memory in device and will in case of power supply failure keep the last written temperature value.

5.4.2 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.9: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.4.3 Alarm only blocking

In normal operating mode, the function is intended for opening the circuit breaker with the **Trip** signal, which is via the *ACQ* module linked to an auxiliary digital relay of the device. At protection operation the **Trip** and the **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for tripping. In the "Alarm only" mode only the **Trip alarm** signal can be set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

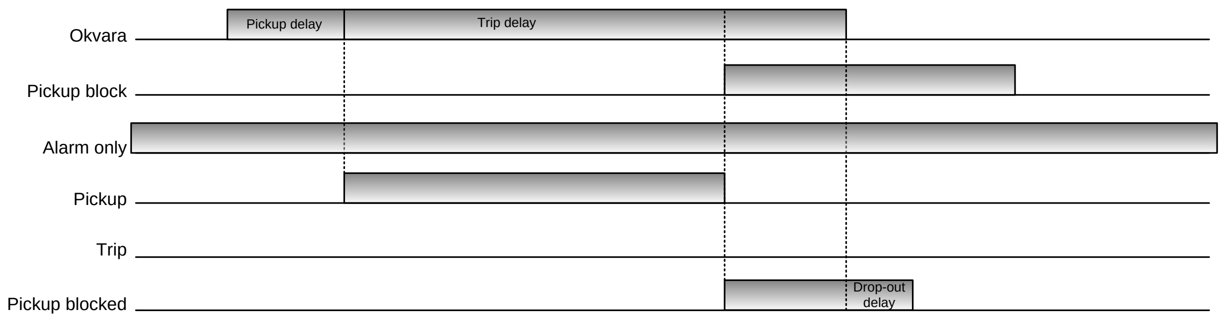

Figure 5.31: Alarm only

5.4.4 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)
-

5.4.5 Module parameters, inputs and outputs

Group settings A…D

Operate mode Off, On	*Off* – protection function is not active *On* – protection function is active
k-factor 0.10...**1.10**...4.00 x In	Maximal permanent thermal current allowed relative to the nominal current.
Alarm temperature value 45.0...**90.0**...99.0%	Alarm limit, Θ_{alm}.
High temperature value 45.0...**95.0**...99.0 %	Critical temperature limit.

Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected by **Group Input1** and **Group Input2** signals.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.

Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Heating time constant 1.0...**100.0**…1000.0 min	Heating and cooling time constant τ .
High temperature mode **Start on Trip**, Start on high temperature	**High temperature** signal mode.

Block settings

Alarm only true, **false**	**Trip** signal blocking.

Inputs

Current amplitude L1 input (analog)	Current L1 amplitude.
Current amplitude L2 input (analog)	Current L2 amplitude.
Current amplitude L3 input (analog)	Current L3 amplitude.
Nominal current constant input (analog)	Nominal current.

Outputs

Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**…1000 ms	Minimal time of **Trip** output signal.

Temperature L1 output (analog)	Current calculated relative overtemperature value, phase L1, 100% = 1000 raw value
Temperature L2 input-output (analog)	Current calculated relative overtemperature value, phase L2, 100% = 1000 raw value
Temperature L3 input-output (analog)	Current calculated relative overtemperature value, phase L3, 100% = 1000 raw value
Alarm temperature output (digital)	Temperature alarm limit is exceeded, any phase, 1% hysteresis.
High temperature output (digital)	Temperature maximal limit is exceeded, any phase, 1% hysteresis.
Time To Trip output (digital)	Time to reach the maximal temperature and Trip (the shortest time of all phases) in minutes.
Time To Drop-out output (digital)	Time in which the temperature drops below the alarm limit (the highest time of all phases) in minutes.

Counters

Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.5 Overvoltage protection (U>)

Overvoltage protection has the function to protect electrical equipment from overvoltage. The operational state is unfavourable as overvoltage may cause for example insulation problems, etc.

The overvoltage protection has the task of protecting the transmission lines and electrical machines against inadmissible overvoltage conditions that may cause insulation damage.

Several overvoltage protections with different settings can run at the same time and are included in the operation independently of one another. The overvoltage protection has two protection levels. Between them, voltage or time criteria can be used. In case of high overvoltage, tripping is performed with a short time delay and in case of less severe overvoltages, the tripping with a longer time delay is performed. The same module is used for all protection levels.

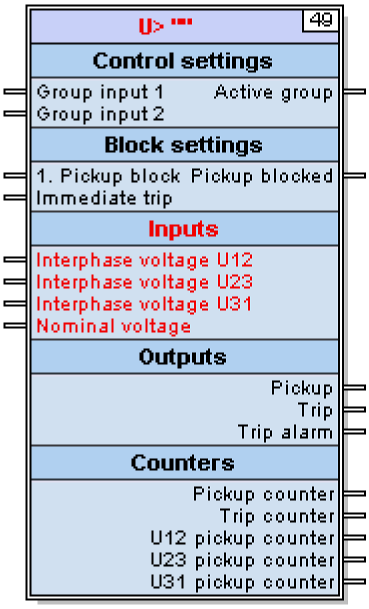

Figure 5.32: U> overvoltage protection function block

5.5.1 Protection operation

For its operation, the overvoltage protection uses three line-to-line voltages, calculated from phase voltages. Therefore, the voltages from **Interphase voltage L12**, **Interphase voltage L23** and **Interphase voltage L31** inputs are monitored. For protection operation, the one with the highest amplitude is used.

5.5.2 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

Example: The ***Pickup value*** *1.1 at 300 A nominal current means the protection will pick up above 330 A. At* ***Drop-out*** *hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

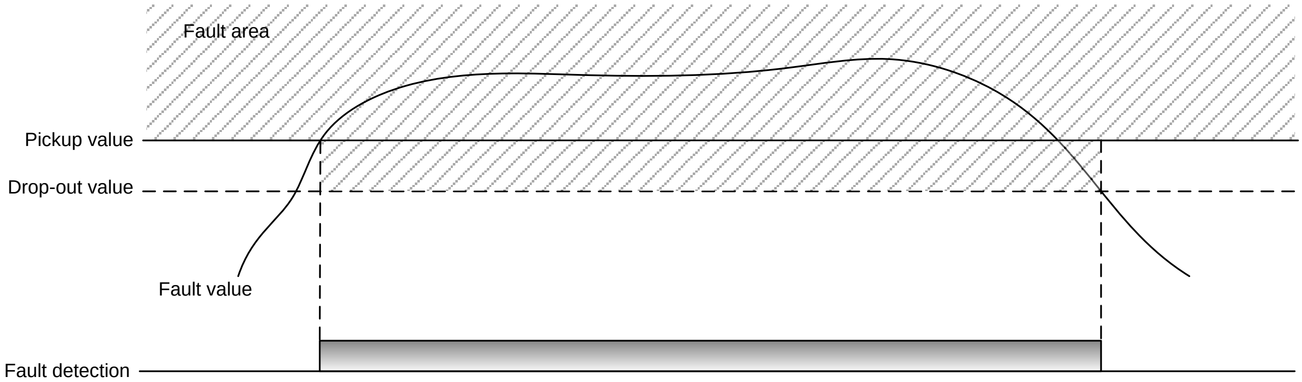

Figure 5.33: Protection operating range - fault area

5.5.2.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

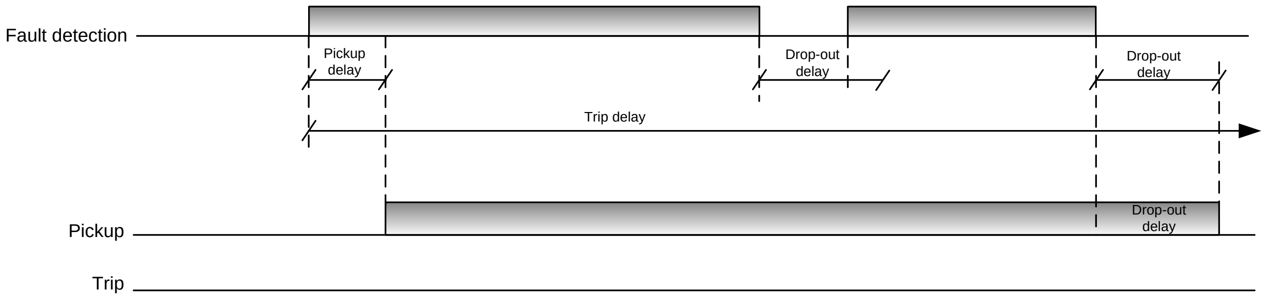

Figure 5.34: **Pickup** signal

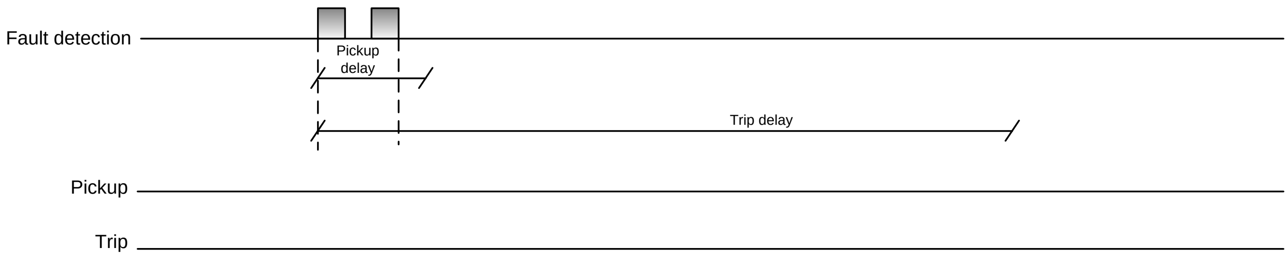

Figure 5.35: Fault confirmation time (**Pickup delay**)

5.5.2.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

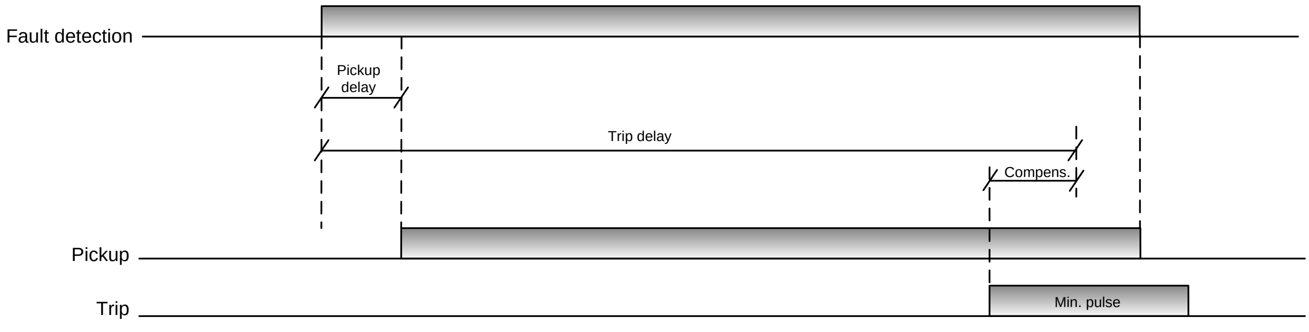

Figure 5.36: Protection operation

5.5.2.3 Three-phase operation

A protection algorithm is executed separately and independently for each individual phase. If a fault detection occurs at least on one phase and there is no blocking a joint **Pickup** signal is set. In case a fault is detected on one or more phases and at the same time a blocking is present a **Pickup blocked** signal is set.

5.5.3 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.10: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.5.4 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

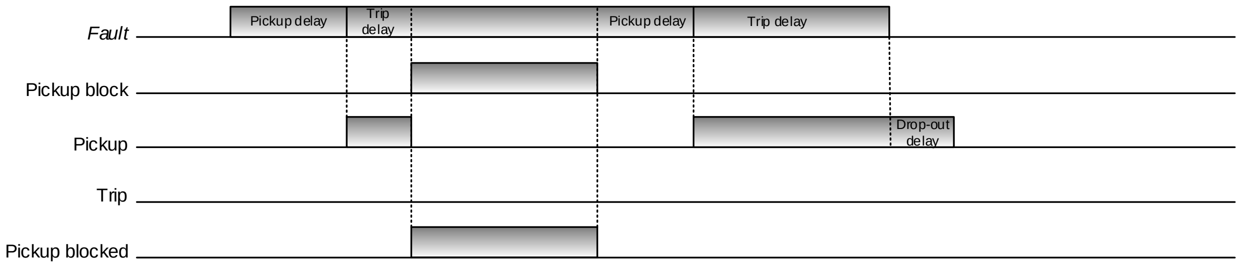

Figure 5.37: Protection blocking

5.5.4.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

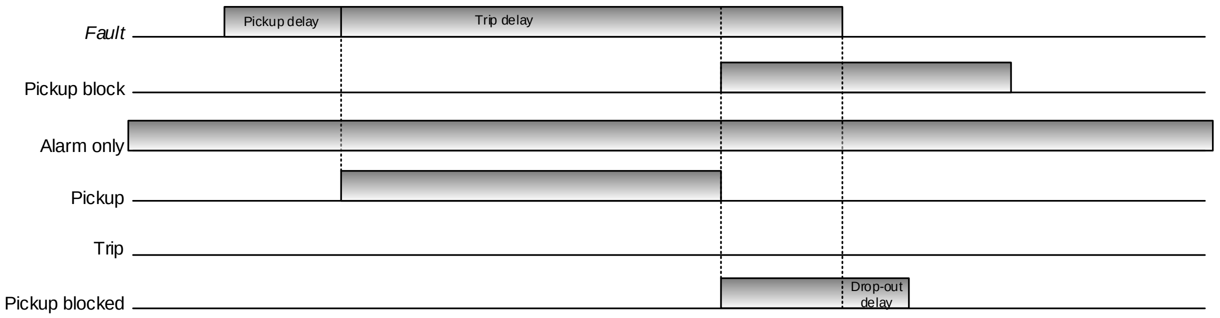

Figure 5.38: Alarm only

5.5.5 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.5.6 Module parameters, inputs and outputs

Group settings A…D	
Operate mode Off, On	*Off* – protection function is not active *On* – protection function is active
Pickup value 0.05...**1.10**…2.00 x Un	Limit of monitored value, above which the protection starts.
Trip delay 0.00...**0.50**…300.00 sec	**Trip** signal delay after the detection of fault.

Control settings	
Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.
Drop-out ratio 0.80...**0.95**...0.99	Drop-out value at which the protection drops.

Block settings	
Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Inputs	
Interphase voltage L12 input (analog)	U12 line-to-line voltage amplitude.
Interphase voltage L23 input (analog)	U23 line-to-line voltage amplitude.
Interphase voltage L31 input (analog)	U31 line-to-line voltage amplitude.
Nominal voltage constant input (analog)	Nominal line-to-line voltage.

Outputs	
Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**…1000 ms	Minimal time of **Trip** output signal.

Counters	
Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

L12 pickup counter counter	Voltage L12 pickup counter.
L23 pickup counter counter	Voltage L23 pickup counter.
L13 pickup counter counter	Voltage L31 pickup counter.

5.6 Undervoltage protection (U<)

Undervoltage protection has the function to protect electrical equipment from undervoltage. Operational state is unfavourable as undervoltage may cause system stability problems.

The undervoltage protection detects voltage drops on transmission lines and electrical machines and prevents the persistence of inadmissible operating states and a possible loss of system stability.

Several undervoltage protections with different settings can run at the same time and are included in an operation independently of one another. The overvoltage protection has two protection levels. The same module is used for all protection levels.

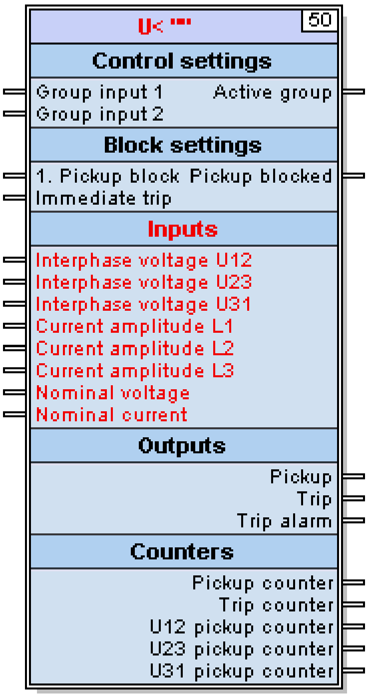

Figure 5.39: U< undervoltage protection function block

5.6.1 Protection operation

For its operation the undervoltage protection uses three line-to-line voltages, which are calculated from phase voltages. Therefore, the voltages from **Interphase voltage L12**, **Interphase voltage L23** and **Interphase voltage L31** inputs are monitored. For protection operation, the one with the lowest amplitude is used.

5.6.1.1 Current criteria

The operation and parametrizing of the undervoltage protection depends on the measuring transformer connection type. It can be connected on the bus bar side or on the line side, just behind the circuit breaker. In later case, after the undervoltage protection operation, and line disconection, the voltage does not return back to its nominal value, so the protection would stay in the operation area. In order to avoid this problem, the current criteria is used as a protection operation condition. The protection can operate only if the current is above the set **Zero current level** value. For current criteria, the highest of phase currents is used.

5.6.1.2 Bus bar connected voltage transformers

The Figure 5.40 shows operation of the undervoltage protection at a typical fault where the voltage transformer is connected to bus bar.

After the circuit breaker operation the voltage returns back to its nominal value, therefore the use of current criteria is not necessary. When voltage drops below the set **Pickup** value and after the timeout elapses, the protection will operate. Protection has an independent time delay. After the voltage rises back above the **Drop-out ratio** value the line is re-energized, ususally by the ARC function or manually.

Note

When setting the Minimal trip pulse time in the CB module, be careful that this time is shorter than the Dead time in the ARC module.

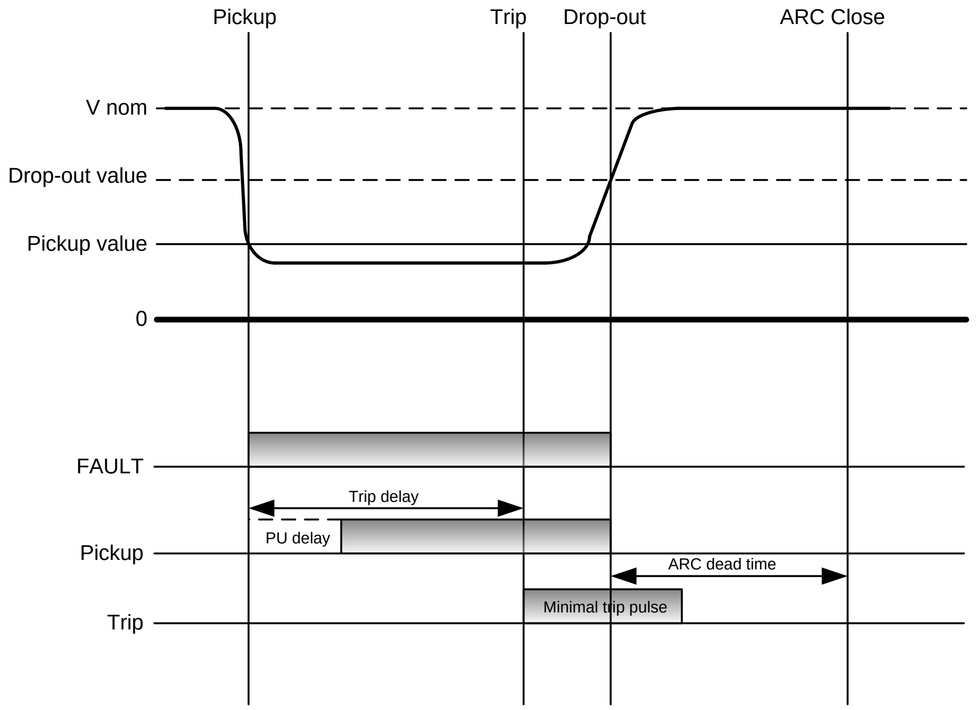

Figure 5.40: Operation of the undervoltage protection - voltage transformer on bus bar side

5.6.1.3 Line side connected voltage transformers

The Figure 5.41 shows the operation of the undervoltage protection at a typical fault where voltage transformer is connected to the line side.

After the circuit breaker operation, and line disconection, the voltage stays below the protection operational voltage. Because of that, the **Zero current level** current criteria has to be activated, which forces the **Pickup** signal to drop when the load current drops below the set value.

When the voltage drops below the set **Pickup** value and after the timeout has elapsed, the protection will operate. When as a consequence of opened circuit breaker the current drops below the set **Zero current level** value, the **Current supervision** blocking is set. This causes the **Pickup** and **Trip** signals to drop (after the **Minimal pulse** time elapses) and the **Pickup blocked** signal sets. Usually the ARC function is triggered at that time which re-energizes the line. After the successful line closing operation and after the current is above the set **Zero current value** value, the **Current supervision** blocking is extended for another 60 ms. During this time, the voltage has to raise above the **Drop-out value**, otherwise the undervoltage protection will operate again.

Note

When setting the Minimal trip pulse time in the CB module, be careful that this time is shorter than the Dead time in the ARC module.

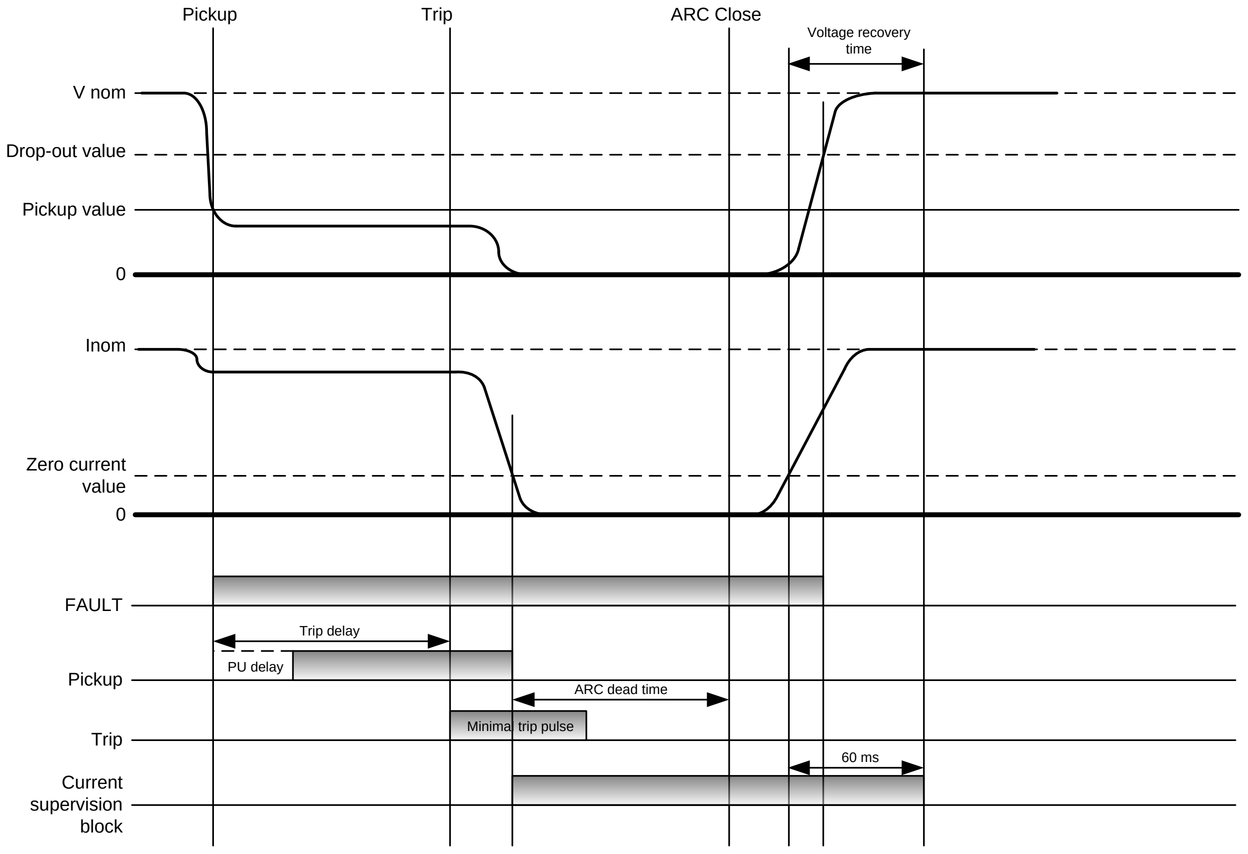

Figure 5.41: Operation of the undervoltage protection - voltage transformer on the line side

5.6.2 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

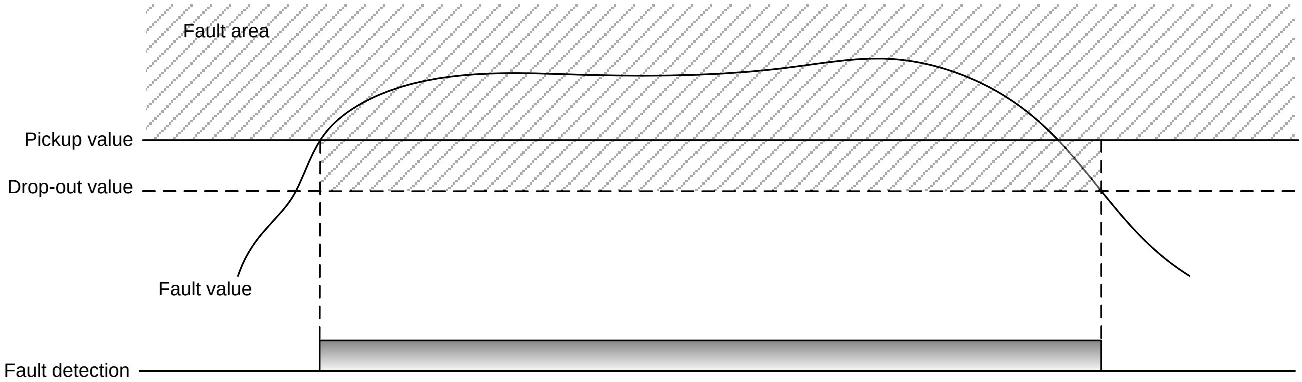

Figure 5.42: Protection operating range - fault area

5.6.2.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

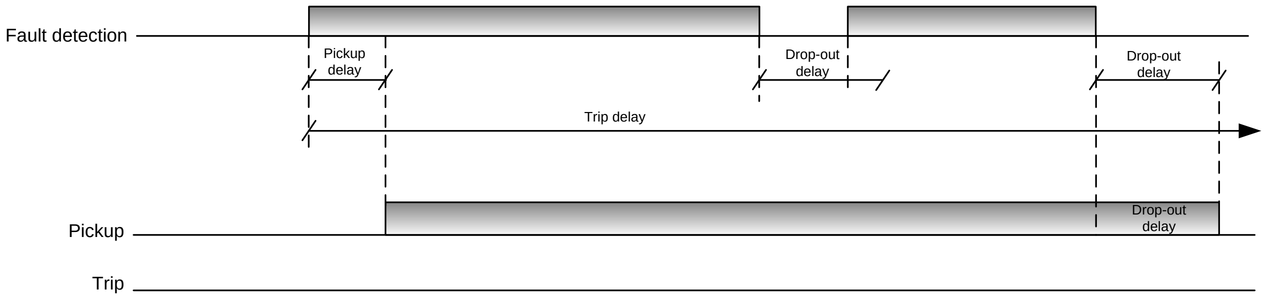

Figure 5.43: **Pickup** signal

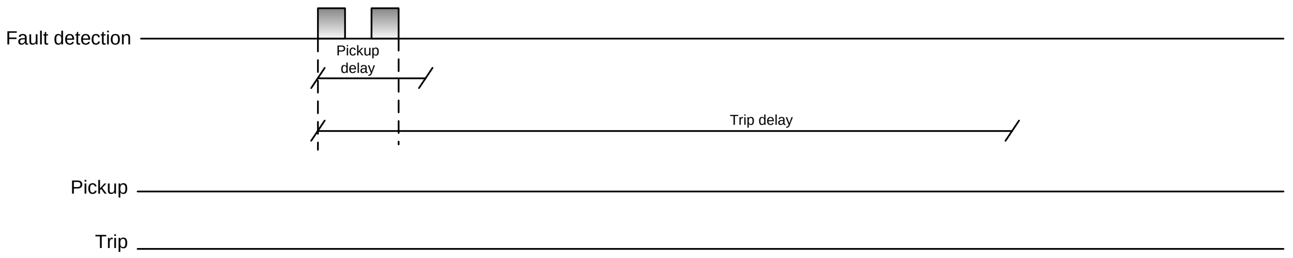

Figure 5.44: Fault confirmation time (**Pickup delay**)

5.6.2.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

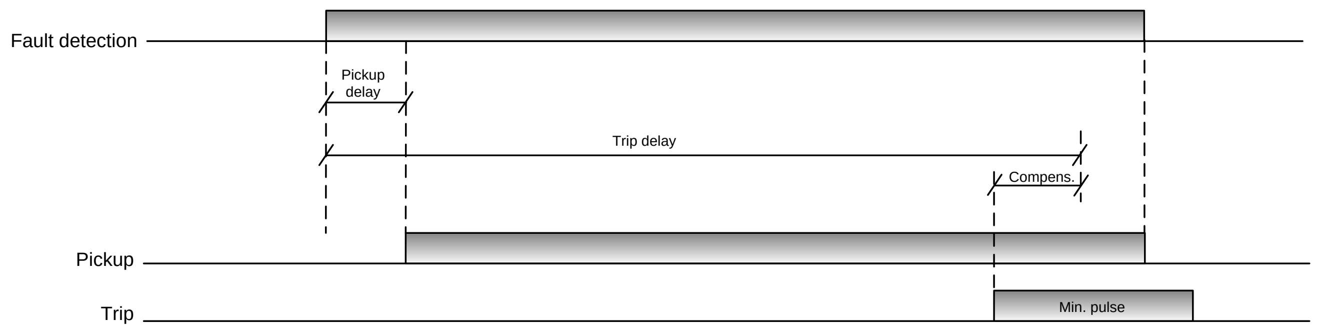

Figure 5.45: Protection operation

5.6.2.3 Three-phase operation

A protection algorithm is executed separately and independently for each individual phase. If a fault detection occurs at least on one phase and there is no blocking a joint **Pickup** signal is set. In case a fault is detected on one or more phases and at the same time a blocking is present a **Pickup blocked** signal is set.

5.6.3 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.11: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.6.4 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

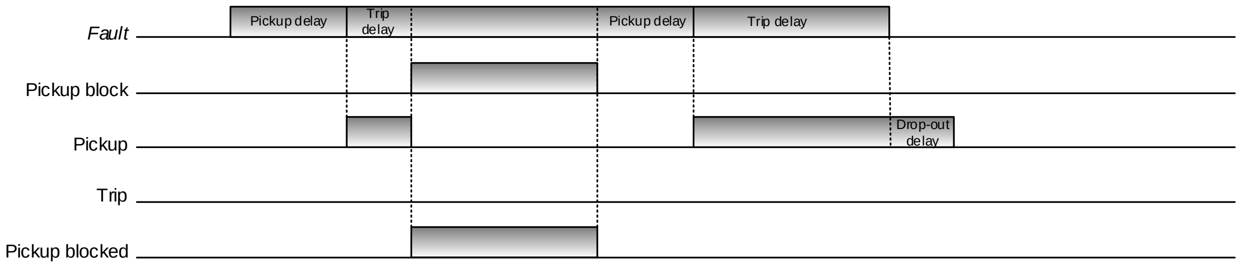

Figure 5.46: Protection blocking

5.6.4.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

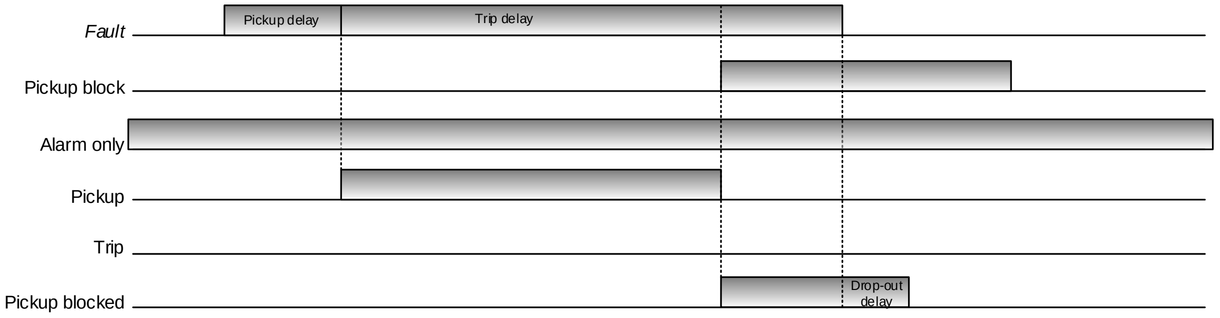

Figure 5.47: Alarm only

5.6.5 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.6.6 Module parameters, inputs and outputs

Group settings A…D

Operate mode Off, On	*Off* – protection function is not active *On* – protection function is active
Pickup value 0.10...**0.75**…2.00 x Un	Limit of monitored value, below which the protection starts.
Trip delay 0.00...**0.50**…300.00 sec	**Trip** signal delay after the detection of fault.

Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.

Drop-out ratio 1.01...**1.20**…3.00 Pickup	Drop-out value under which the protection drops.

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Current supervision

Enabled **true**, false	Function enabling.
Zero current level **0.04**...1.00 x In	Current level, below which the protection operation is blocked.

Inputs

Interphase voltage L12 input (analog)	U12 line-to-line voltage amplitude.
Interphase voltage L23 input (analog)	U23 line-to-line voltage amplitude.
Interphase voltage L31 input (analog)	U31 line-to-line voltage amplitude.
Nominal voltage constant input (analog)	Nominal line-to-line voltage.
Current angle L1 input (analog)	Current L1 angle.
Current angle L2 input (analog)	Current L2 angle.
Current angle L3 input (analog)	Current L3 angle.
Nominal voltage constant input (analog)	Nominal line-to-line voltage.
Nominal current constant input (analog)	Nominal current.

Outputs

Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**...1000 ms	Minimal time of **Trip** output signal.

Counters

Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

U12 pickup counter counter	Voltage L12 pickup counter.
U12 pickup counter counter	Voltage L23 pickup counter.
U12 pickup counter counter	Voltage L31 pickup counter.

5.7 Residual overvoltage protection (UE>)

Residual overvoltage protection is used for detection of earth faults and to protect lines from this faults and is mostly present in isolated networks. The residual voltage is also used to determine the direction for sensitive current earth fault protection.

Several residual overvoltage protections with different settings can run at the same time and are independent of one another.

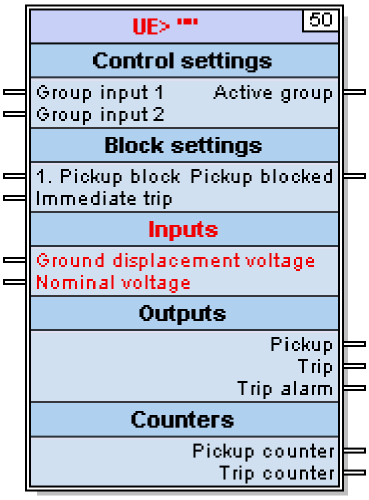

Figure 5.48: UE> residual overvoltage protection function block

5.7.1 Protection operation

Residual overvoltage protection monitors the special analog input for residual voltage or a sum of phase voltages. Protection has an fault independent time curve.

5.7.2 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

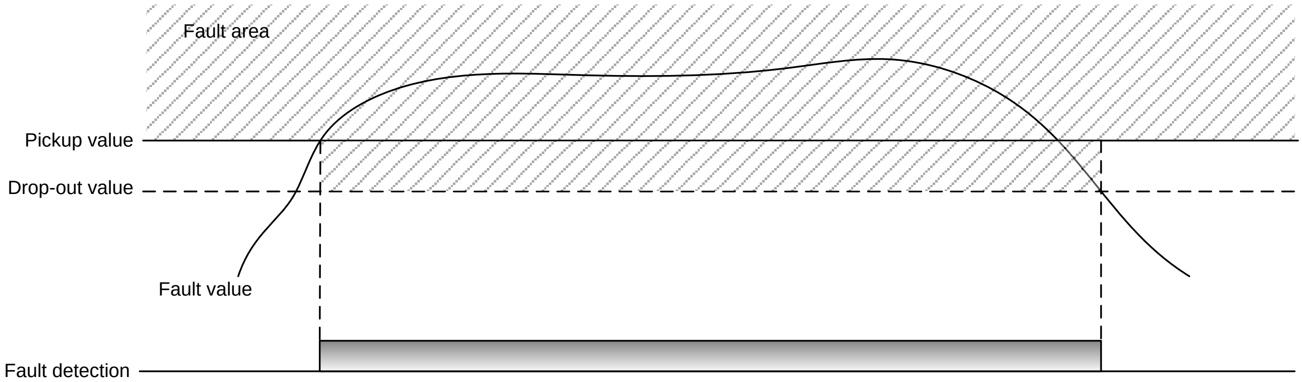

Figure 5.49: Protection operating range - fault area

5.7.2.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

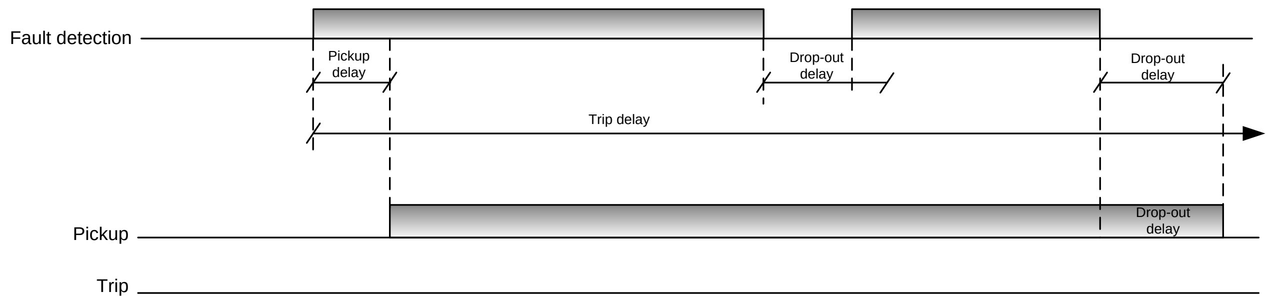

Figure 5.50: **Pickup** signal

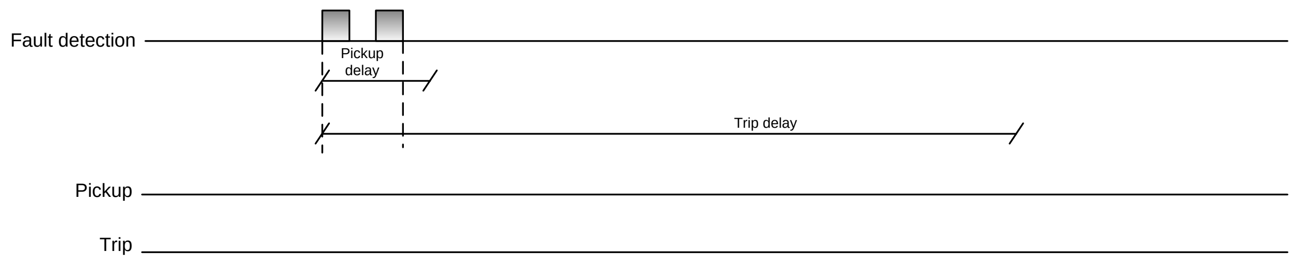

Figure 5.51: Fault confirmation time (**Pickup delay**)

5.7.2.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and

- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** = *0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

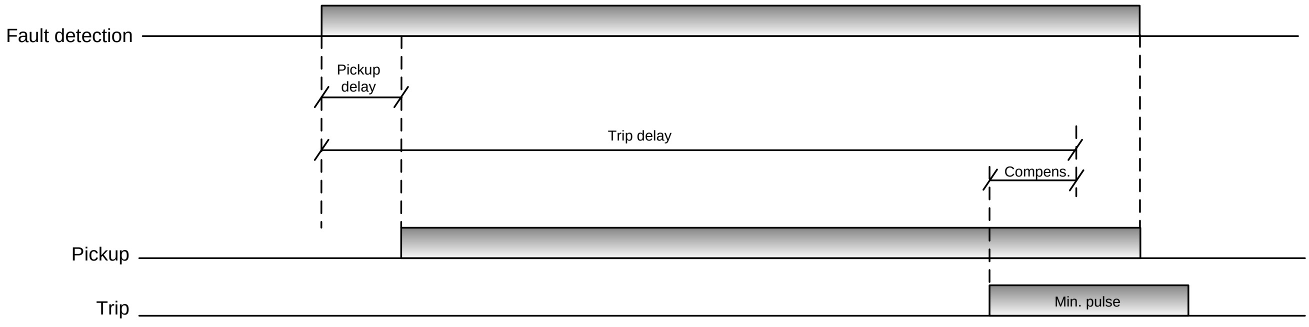

Figure 5.52: Protection operation

5.7.3 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.12: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.7.4 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

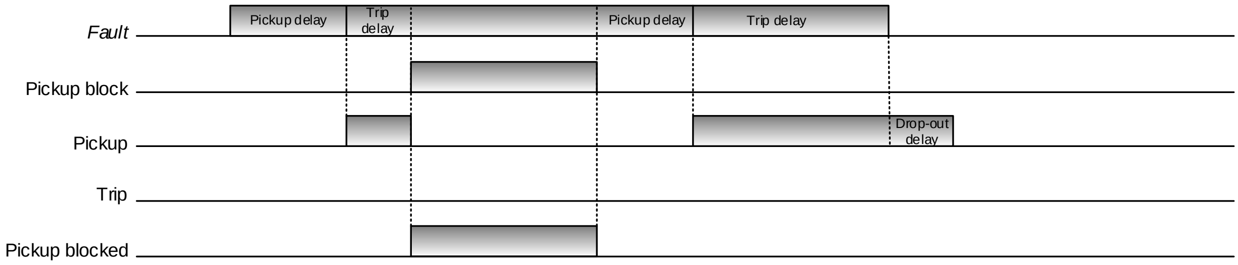

Figure 5.53: Protection blocking

5.7.4.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

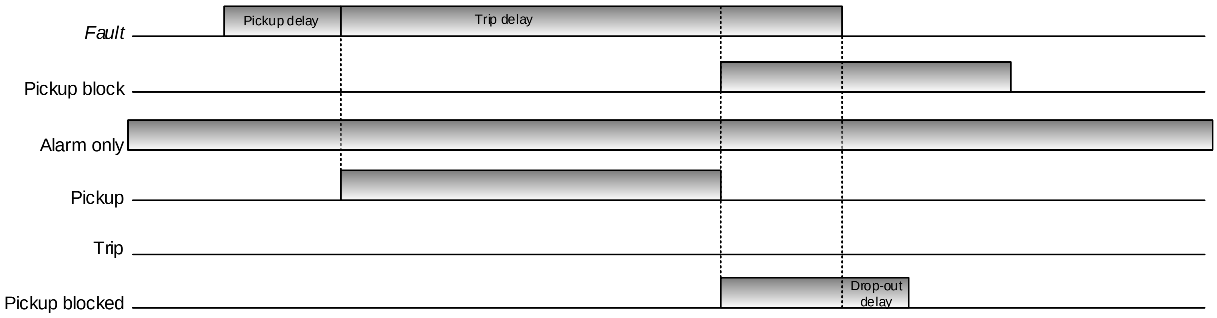

Figure 5.54: Alarm only

5.7.5 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)
-

5.7.6 Module parameters, inputs and outputs

Group settings A…D	
Operate mode Off, On	*Off* – protection function is not active *On* – protection function is active
Pickup value 0.01...**0.40**…2.00 x Un	Limit of monitored value, above which the protection starts.
Trip delay 0.00...**0.50**…300.00 sec	**Trip** signal delay after the detection of fault.

Control settings	
Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.
Drop-out ratio 0.80...**0.95**...0.99	Drop-out value at which the protection drops.

Block settings	
Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Inputs	
Ground displacement voltage input (analog)	Earth fault voltage amplitude.
Nominal voltage constant input (analog)	Nominal earth fault voltage (raw).

Outputs	
Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.

Minimal Trip pulse 0...**20**...1000 ms	Minimal time of **Trip** output signal.

Counters	
Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.8 Frequency protection: f>, f<

Frequency protection detects abnormally high or low frequencies in the electrical system. If the frequency lies outside of the allowable range, appropriate actions are initiated, such as load shedding or separating a generator from the system.

A decrease in system frequency occurs when the system experiences an increase in the real power demand, or when a malfunction occurs on generating system, etc.

An increase in system frequency occurs when for example large loads are disconnected from the system or a malfunction occurs on generator governor.

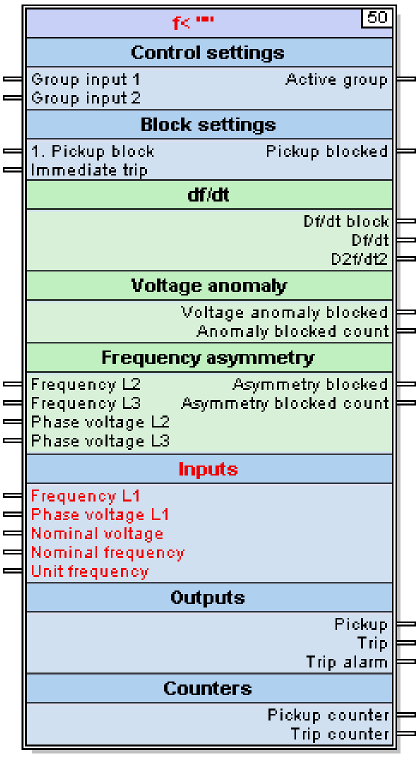

Figure 5.55: Frequency protection function block, example for f<

5.8.1 Protection operation

Monitored value, used for protection is system frequency, measured on UL1 phase voltage input. Frequency measurement is acquired every 10 ms. Protection has an independent time curve.

Drop-out value is a value above or below the **Pickup value** limit value. For example if the **Pickup value** is set to 48 Hz and **Drop-out value** is set to *0.5 Hz*, the protection drops at *48.5 Hz*.

Protection settings include reference **Minimal voltage** amplitude setting, at which the protection still operates. If reference voltage is lower than the set value, protection operation is blocked.

5.8.2 Underfrequency and overfrequency protection

Several frequency protections with different settings can run at the same time and are included in an operation independently of one another. The frequency protection can operate as underfrequency or overfrequency protection. Usually one or two overfrequency and one or two underfrequency levels are set.

For underfrequency protection the **Pickup value** parameter is set under the nominal system frequency. Protection operation range is under the **Pickup value** limit. For overfrequency protection the **Pickup value** parameter is set over the nominal system frequency. Protection operation range is over the **Pickup value** limit. If the **Pickup value** is set exactly to nominal frequency, the protection function is not active.

5.8.3 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

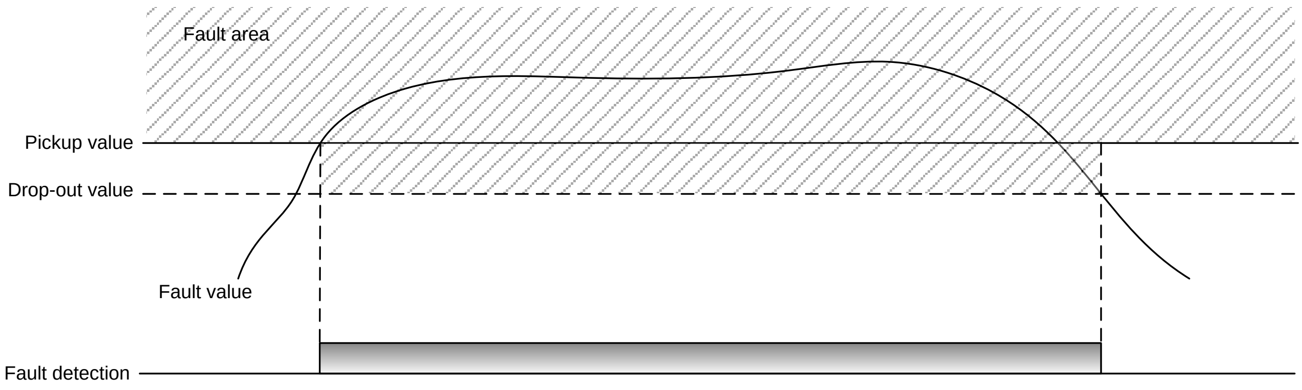

Figure 5.56: Protection operating range - fault area

5.8.3.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

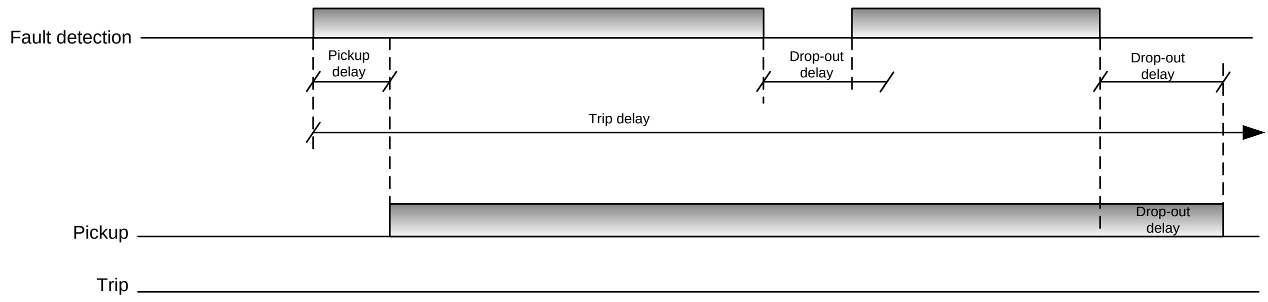

Figure 5.57: **Pickup** signal

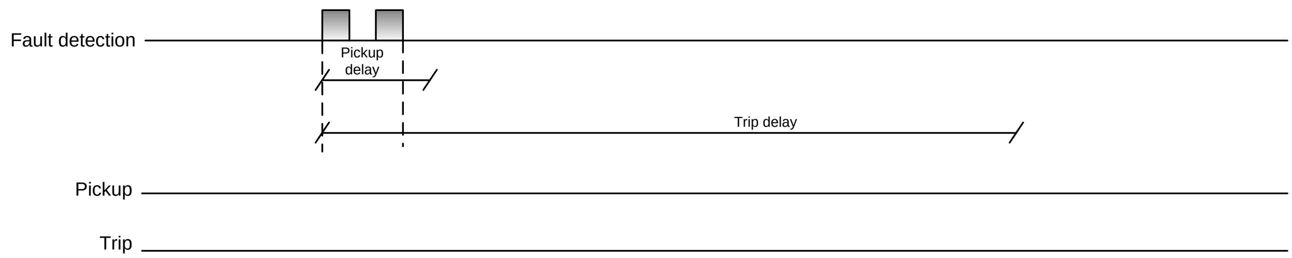

Figure 5.58: Fault confirmation time (**Pickup delay**)

5.8.3.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

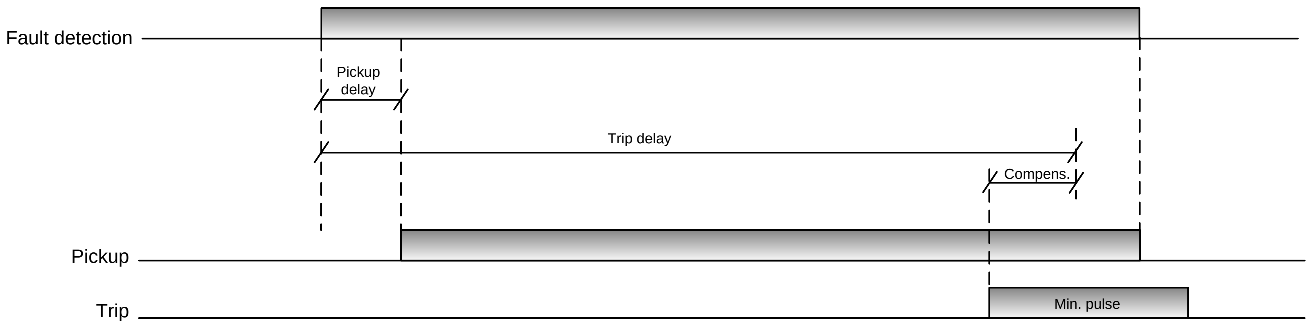

Figure 5.59: Protection operation

5.8.4 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.13: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.8.5 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

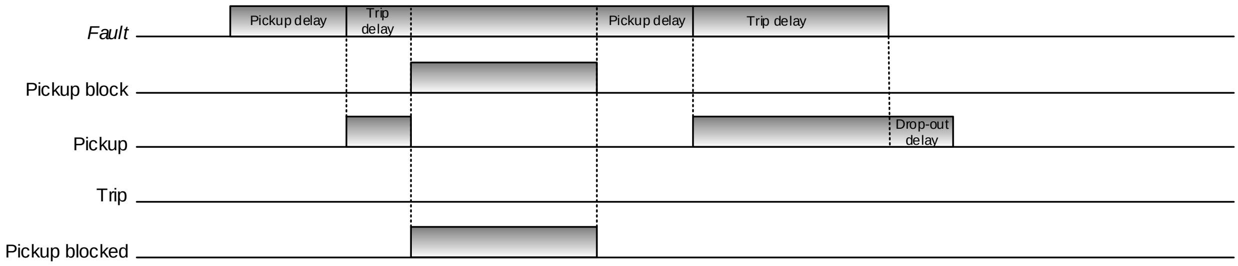

Figure 5.60: Protection blocking

5.8.5.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

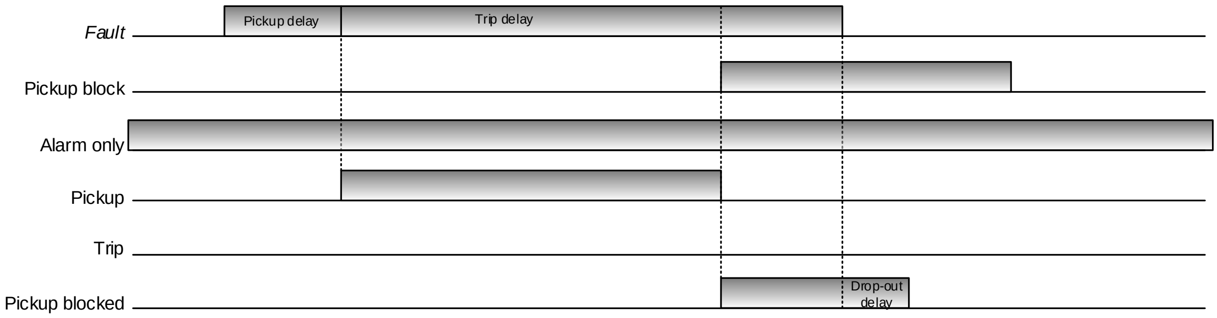

Figure 5.61: Alarm only

5.8.5.2 df/dt blocking

A df/dt blocking is used to block protection operation at temporary occurrences where frequency swings vastly and could trigger protection malfunctions. Such instances can occur at earth faults where Peterson coil is used for earthing which results in second order RLC circuit.

The first and second derivative of frequency with a 20 ms time window are measured and are written to **df/dt** and **d2f/dt2** outputs.

Blocking condition is set when:

- absolute value of **df/dt** is above the **df/dt level** set value, or
- absolute value of **d2f/dt2** amplitude value is above the **df/dt level** X **d2f/dt2 factor** value.

Blocking is active, when blocking condition is set and extends for **Block drop-off delay** timer. The **Block drop-off delay** timer starts when blocking condition disappears. It is intended for blocking stabilisation. When blocking is active, the **df/dt block** and the **Pickup blocked** signals are set. The **df/dt block count** counter counts protection operation blockings occurrences.

5.8.5.3 Voltage anomaly blocking

Anomaly of the phase voltage happens, when the amplitude value between two consecutive samples rises too fast - the step is bigger than set in **Anomaly level** parameter.

If the function detects such anomaly, the **Pickup** and **Trip** timers pause. The pause starts after the **Block delay** time and lasts for **Block duration** time. During this time the **Voltage anomaly blocked** signal is set. Such occurrences are counted with **Anomaly blocked count** counter.

If a new anomaly occurs before the previous one elapses it is considered the same way as the first one according to the settings. Therefore, blockings can overlap. In such case, the total time of blocking would be the combined time from the moment when the first blocking starts until the time when the second one is completed (the **Block duration** time elapses after the second blocking).

Another indicator of voltage anomaly is frequency asymmetry between the three voltage phases. A blocking caused by frequency asymmetry is set in **Frequency asymmetry** segment. The frequency asymmetry is present when any of two frequencies of **Frequency L1, Frequency L2, Frequency L3** inputs differ for more than the set **Asymmetry level** value and all three voltages are higher than set **Minimal voltage** value.

If a function detects frequency asymmetry, the **Pickup** and **Trip** timers are paused and the **Asymmetry blocked** signal is set. Such occurrences are counted with **Asymmetry blocked count** counter.

5.8.6 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.8.7 Module parameters, inputs and outputs

**\ Group settings A…D **

Operate mode **Off**, On	*Off* – protection function is not active *On* – protection function is active
Pickup value 45.00...**49.50**…55.00 Hz	Limits of monitored value, above/below which the protection starts.
Trip delay 0.00...**60.00**…300.00 s	**Trip** signal delay after the detection of fault.

Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.

Minimal voltage 0.00...**0.65**…1.00 Un	The lowest reference voltage amplitude at which the protection still operates. If the reference voltage is lower than set, the protection is blocked. 10% hysteresis.
Drop-out value **0.01**…1.00 Hz	Drop out value at which the protection drops relative to **Pickup value** setting.

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Block settings / df/dt

Enabled true, **false**	Function enabling.
df/dt level 0.2…**10.0** Hz/s	Limit for df/dt blocking condition.
d2f/dt2factor 0…**100**...500	Limit for blocking condition, relative to **df/dt level** setting. Value 0 means that this condition is ignored.
Block drop-off delay 0…**20**…2000 ms	Time after the disappearance of blocking condition when the blocking is still active
df/dt block output (digital)	Blocking is active.
df/dt output (analog)	First derivative value of frequency in time.
d2f/dt2 output (analog)	Second derivative value of frequency in time.
df/dt block count counter	Counter of blocked **Pickup** signals caused by this blocking.

Block settings / Voltage anomaly

Enabled true, **false**	Function enabling.
Anomaly level 0…**1200**…65000	Minimal raw value of the step.
Block delay 0…**70**…1000 ms	Maximal blocking delay.
Block duration 0…**180**…1000 ms	Minimal interlock duration time.
Voltage anomaly blocked output (digital)	Blocking active signal.
Anomaly blocked count counter	Blocking occurrences counter.

Block settings / Frequency asymmetry

Enabled true, **false**	Function enabling.
Asymmetry level 0.00…**0.10**…5.00 Hz	Maximal difference between two frequencies.
Frequency 2 input (analog)	Voltage L2 frequency.
Frequency 3 input (analog)	Voltage L3 frequency.
Voltage amplitude 2 input (analog)	Voltage L2 amplitude.
Voltage amplitude 3 input (analog)	Voltage L3 amplitude.

Asymmetry blocked output (digital)	Blocking active.
Asymmetry blocked count counter	Blocking occurrences counter.

Inputs	
Frequency L1 input (analog)	Phase voltage L1 frequency.
Phase voltage L1 input (analog)	Phase voltage L1 amplitude.
Nominal frequency constant input (analog)	Nominal frequency.
Unit frequency constant input (analog)	Frequency unit value.

Outputs	
Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**…1000 ms	Minimal time of **Trip** output signal.

Counters	
Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.9 External protection (ExtP)

External protection function is intended for connection of other protection relay outputs to binary input of the device.

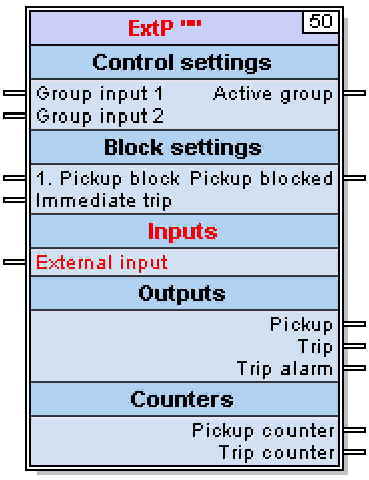

Figure 5.62: External protection function block

5.9.1 Protection operation

External protection algorithm is realised in a similar way as other protections, except that the monitoring input is not an analog but a digital value, normally of external digital input.

5.9.2 Detection element (pickup element)

Fault condition is when the monitored value enters the protection operating range or fault area. When setting the protection operating range the hysteresis characteristics must be considered. The starting operating range lies above the **Pickup value** limit and after it is crossed the protection operating range is changed so that the new limit lies above the **Drop-out value**. The drop-out hysteresis is normally set relative to the **Pickup value**.

*Example: The **Pickup value** 1.1 at 300 A nominal current means the protection will pick up above 330 A. At **Drop-out** hysteresis of 0.95 the protection will drop at 313.5 A.*

When the monitored value is in the protection operating range we say the protection picks up or starts. When the value falls out of the operation range we say the protections drops or resets.

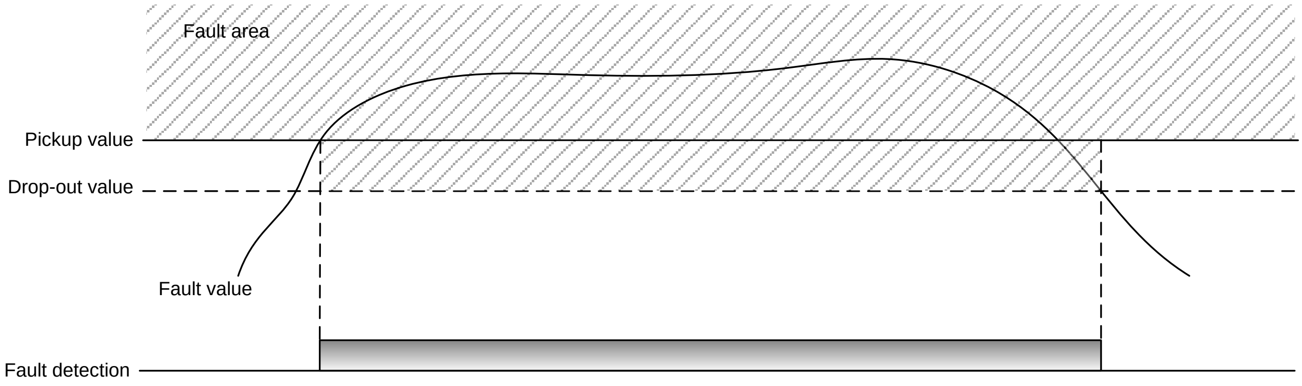

Figure 5.63: Protection operating range - fault area

5.9.2.1 Pickup signal

The **Pickup** output is an indicator that a fault occurred. The **Pickup delay** confirmation time is intended for fault signalling stabilization and prevents the very short-lived disturbances in the measuring part of the system from being reported as faults.

The **Pickup** is set:

- when a fault is present and
- the **Pickup delay** confirmation time runs out and
- there is no blocking.

The **Pickup** drops:

- when there is no fault and the **Drop-out delay** runs out, if the signal **Trip** is not set yet or
- when there is no fault, if the signal **Trip** is already set or
- when an blocking occurs.

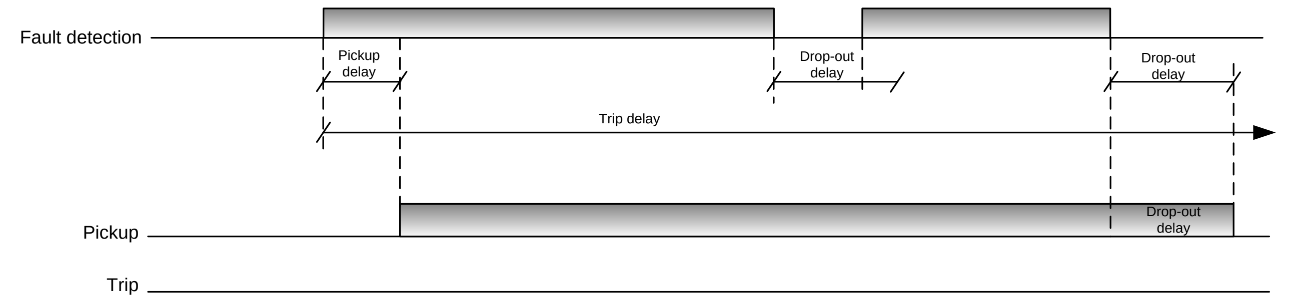

Figure 5.64: **Pickup** signal

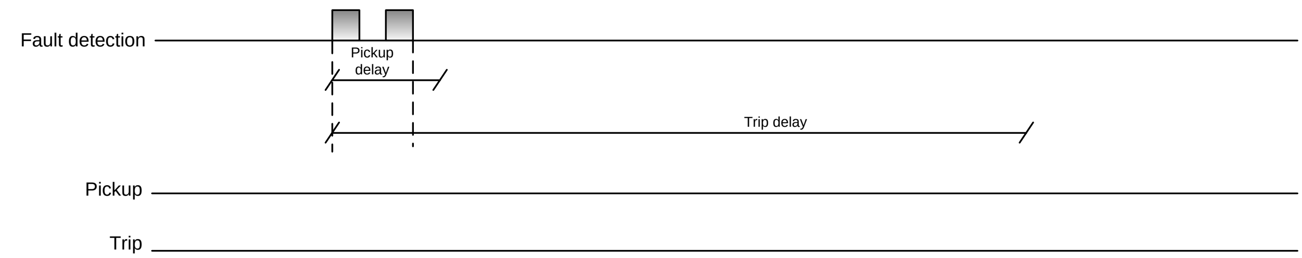

Figure 5.65: Fault confirmation time (**Pickup delay**)

5.9.2.2 Trip signal

The **Trip** signal is intended for opening of circuit breaker, which eliminates faulty element from electrical system. A major proportion of faults have transient character and disappear spontaneously very quickly. In such cases opening of circuit breaker is not necessary, so the Trip signal is usually delayed. Another reason for delaying Trip signal in to ensure selectivity along an electrical line. The delay is set with the **Trip delay** parameter. In case the protection is blocked the **Trip** signal will not set.

Trip sets in following conditions:

- when a fault is present and
- the **Pickup** signal is set and
- **Trip delay** time runs out and
- there is no blocking.

Trip signal drops:

- when the **Pickup** drops and
- **Minimal Trip pulse** time runs out.

The protection can temporarily operate without delay **Trip delay** *= 0*. For this purpose the protection has a special **Immediate trip** input that sets the protection operation mode with an immediate trip - the **Trip** signal is set at the same time as the **Pickup**. It can be used, for example, for connection with the *ARC* function, where we want the protection to trip immediately in the second ARC cycle.

When the protection trips there are some particular delays on detection and trip execution levels. The device needs some time to detect the fault and after the Trip signal, several milliseconds of delay can pass during the transfer of signal to external output relay and forward to the breaker switch off circuit. To compensate that lost time the **Open compensation** parameter must be set.

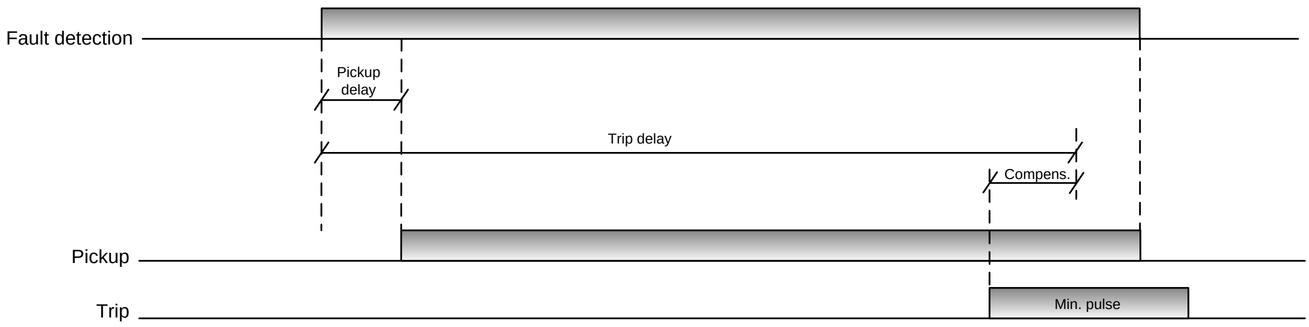

Figure 5.66: Protection operation

5.9.3 Setting groups

Setting groups enable dynamic switching between different settings during device operation and switching between different modes of system operation. Up to four different groups can be set. Each of setting groups includes key and specific settings enabled by the protection function. The parameters located in setting groups can therefore be set in four different variations, or a group that is not used can be set to *"Off"*.

Switching is executed via two digital inputs (**Group input 1** and **Group input 2**), so we can set different options. The request for group switching can be executed via two external digital inputs (**Group input 1** and **Group input 2**) or through communication via a remote command. Switching between groups can only be executed if the protection is in idle state when there is no fault detected. If a request for switching occurs, while the protection is in operation, the switching executes only after the protection is in idle state again. Switching is performed instantaneously.

If a group in the control settings is disabled (**Operate mode =** *Off*) and the user selects this group with the **Group selection** parameter or with *Input select*, the protection function is disabled. Group selection settings are located in **Control settings** parameter group.

Table 5.14: Selection of setting group

Group input 1	Group input 2	Selected group
0	0	A
1	0	B
0	1	C
1	1	D

5.9.4 Blocking

For the blocking purposes the protection function has up to 10 digital inputs that can be arbitrary connected via other function modules outputs. In this way it is possible for example to block the protection with any external digital input or other output signals like: bay interlocking result, various logic functions, etc.

The protection is blocked when any of **Pickup block …** inputs is set. If the protection is blocked, instead of **Pickup** signal the **Pickup blocked** signal is set. If blocking occurs during a fault, blocking drops the eventually set **Pickup** signal and resets the **Trip delay** timer. In case when blocking disappears and a fault still exists, the protection function starts again from the beginning as new fault.

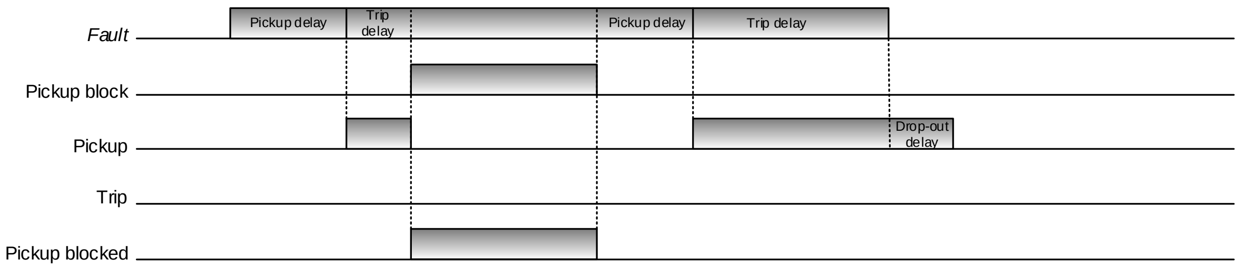

Figure 5.67: Protection blocking

5.9.4.1 Alarm only

In the normal operation mode, protection function is intended for switching off the faulty element via the **Trip** signal that is connected to external digital relay of the device through the *ACQ* module. When the protection is operational both **Trip** and **Trip alarm** signals are set.

The "Alarm only" is a special mode of protection function operation in which the protection function is intended for signalling and not for switching off. In the "Alarm only" mode, only **Trip alarm** signal is set, whereas the **Trip** signal is blocked. This mode is enabled with the **Alarm only** parameter.

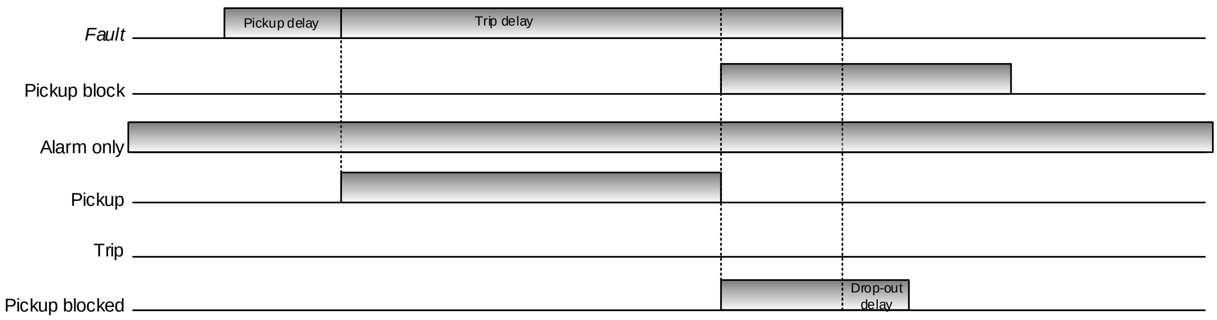

Figure 5.68: Alarm only

5.9.5 Statistical counters

For the purposes of statistical analysis of fault detection and protection operation the module includes counters for counting the operations. The counters can be used for analysing the wear of primary elements and determining the most frequent fault types that can occur on the network.

Note: For more detailed contacts wear measuring there is an I2t function in the Circuit Breaker Control (CB) *module, which is more accurate as it arithmetically determines the thermal wear of breaker contacts according to fault tripping current.*

On its outputs, the module counts:

- number of fault starts (**Pickup counter** output)
- number of protection trips (**Trip counter** output)

5.9.6 Module parameters, inputs and outputs

Group settings A…D

Operate mode Off, On	*Off* – protection function is not active *On* – protection function is active
Trip delay 0.00...**0.50**...300.00 sec	**Trip** signal delay after the detection of fault.

Control settings

Group selection **A**, B, C, D, Input select	A-D: group selection Input select: group is selected according to **Group Input1** and **Group Input2**.
Group input 1 input (digital)	First input for *Input select* group selection.
Group input 2 input (digital)	Second input for *Input select* group selection.
Active group output (analog)	Currently active setting group: 0: A, 1: B, 2: C, 3: D
Open compensation 0...**25**…1000 ms	**Trip delay** time compensation due to device external output relay own time of operation.
Pickup delay 0...**5**…1000 ms	Time stabilization of fault detection and as filter of short disturbances on measuring circuits. Time before protection start.
Drop-out delay 0.00...**0.20**...60.00 s	Time stabilization of **Pickup** signal. Time when the monitored value is outside the protection operating range, but the protection does not drop yet.

Block settings

Alarm only true **false**	**Trip** signal blocking.
Pickup block 1…10 input (digital)	Protection operation blocking.
Immediate trip input (digital)	Activation of immediate trip (**Trip delay**= *0*).
Pickup blocked output (digital)	Signalization of protection operation blocking.

Inputs

External input input (digital)	Digital monitored value.

Outputs

Pickup output (digital)	Fault detection, start of protection.
Trip output (digital)	Protection operation signal intended for switching the faulty element off.
Trip alarm output (digital)	Protection operation signal intended for signalization only.
Minimal Trip pulse 0...**20**…1000 ms	Minimal time of **Trip** output signal.

Counters

Pickup counter counter	Fault detection counter.
Trip counter counter	Protection trip operation counter.

5.10 Trip circuit supervision (TCS)

The device autonomously executes the function of the trip circuit supervision *(TCS)*. The function uses two binary inputs (**Input1** and **Input2**), which have to be galvanically isolated, not connected to a common potential. The inputs shall be connected as shown on the figure (Figure 5.70). The result of the TCS function is a status or an alarm on a digital output.

Figure 5.69: Trip circuit supervision function block

Table 5.15: Operation of trip circuit supervision function

Input1	Input2	Alarm
0	0	After the **Delay00** time elapses
0	1	without
1	0	without
1	1	After the **Delay11** time elapses

Module operation is shown in the Table 5.15 above: The TCS state is normal, if exactly one of the **Input1** or **Input2** inputs has value 1. Invalid states are *00* and *11*. The delay is set for each of the invalid states (**Delay00**, **Delay11**), and after the time of each of the delay elapses, the **Alarm** signal is set.

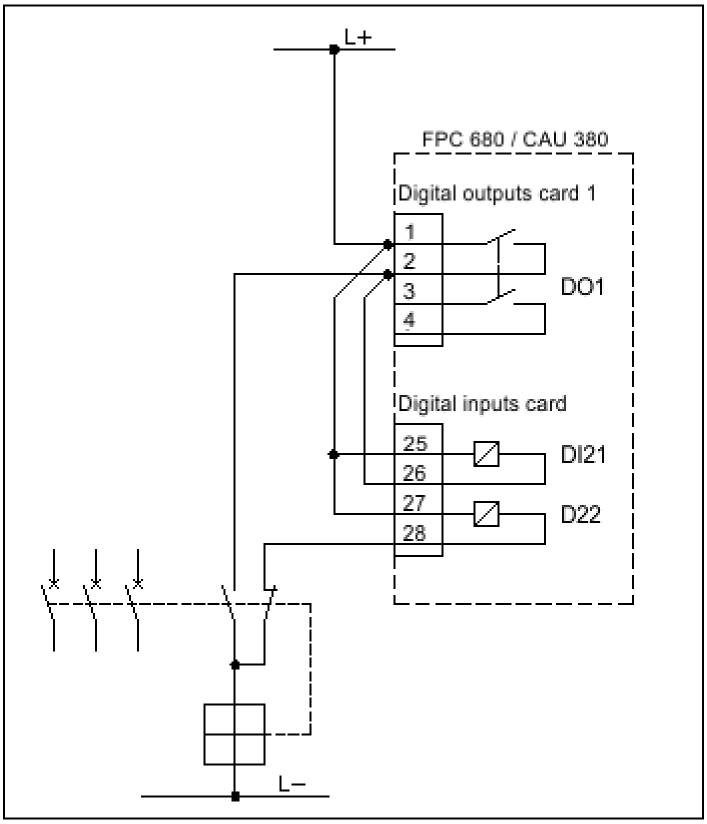

Figure 5.70: A sample of trip circuit supervision connection

5.10.1 Module parameters, inputs and outputs

Delay for 00 0...**1000**...60000 ms	Delay of *00* state alarm.
Delay for 11 0...**5**...10000 ms	Delay of *11* state alarm.
Input1 input (digital)	First digital input.
Input2 input (digital)	Second digital input.
Alarm output (digital)	Invalid state alarm

6 Control functions

6.1 Circuit breaker control (Switch)

The *Switch* module is the central control module for complete control and execution of commands on the primary switch - circuit breaker. The device constantly monitors the switch state. If more than one circuit breaker or switch needs to be monitored, separate modules have to be configured.

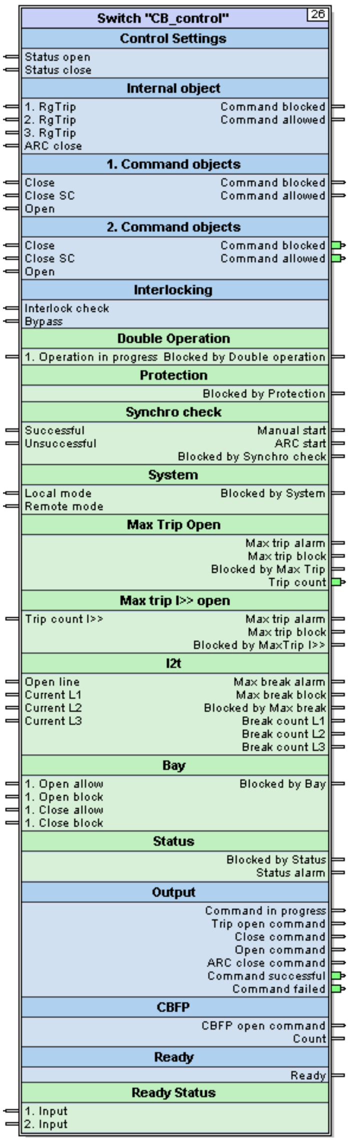

Figure 6.1: Circuit breaker control block

The main module function is circuit breaker command execution with interlock check. Therefore, the command process is divided to several phases:

- Command receipt: the module distinguishes between close, open, local, remote, *ARC*, *Synchro Check* and *Trip* commands.
- Interlock check, part 1: check for any command already in progress or *Trip* present.
- Interlock check, part 2: all other interlockings are checked: synchrocheck, system interlock, bay interlock, maximum trip number, maximum overcurrent instantaneous trip number, contact wear I2t, invalid status.
- Command execution: command signal to output relay

- Execution check: success check, circuit breaker failure control and event counting.

6.1.1 Continuous monitoring processes

Several continuous processes are running in the module which constantly monitor the breaker state and immediately reporting the irregularities:

- **Max trip alarm** exceeding detection
- Overcurrent instantaneous protection (**I>> max trip alarm**) exceeding detection
- Incorrect position of circuit breaker detection (**Status alarm**)
- Circuit breaker **Ready** state

6.1.1.1 Exceeding the protection trip number limit

This process monitors exceeding of allowed protection tripping number. The **Trip count** tripping counter is compared with two set limit values: alarm and blocking limit. The alarm limit is an indication that the circuit breaker is close to its maximum tripping number limit. The **Max break alarm** signal is set, when the tripping counter reaches the alarm limit, and the **Max trip block** signal is set, when the counter reaches the blocking limit. Settings, inputs and outputs are in the **/ Interlocking / Max trip open** parameter section.

6.1.1.2 Exceeding the I>> tripping limit

The operation of this process is similar to the previous one, except that it monitors the short circuit protection (I>>) tripping number by **Trip count I>>** input.

This functionality is used to differ between the number of trips caused by short circuit protection and number of trips caused by other protection functions. At overcurrent instantaneous protection, usually very high currents occur, which wear the circuit breaker contacts more severely than at lower current tripping. Therefore, the number of allowed overcurrent instantaneous protection trips is usually lower. Settings, inputs and outputs are in the **/ Interlocking / Max trip I>> open** parameter section.

6.1.1.3 Status monitoring

This process monitors and signalizes the faulty circuit breaker position status through the **Status alarm** output. The **Status alarm** output is set:

- when the circuit breaker position is in invalid 11 state or
- when the circuit breaker position is 00 state for more than **Command Timeout** time.

The circuit breaker status set with the **Input / Status...** inputs. Settings, inputs and outputs are in the **/ Interlocking / Status** parameter section.

6.1.1.4 Alert status monitoring

The switch alert status describes whether a switch is ready for operation. It consists of several signals, which have to be in ready state, either through external digital inputs or through internal signalization. If any of individual states is signalize not ready state, the switch state is reported as not ready.

Individual signals are linked to the **Status / Input** inputs, their ready state values are set by **Ready value** parameter and then they are enabled with the **Enable** parameter.

Settings, inputs and outputs are in the **/Ready** parameter section.

Example of signals that can be used for circuit breaker ready status:

- *Max trip open* blocking limit reached status
- *Max trip I>> open* blocking limit reached status
- *I2t* contact wear blocking limit reached status
- spring charge fail status
- trip circuit supervision (*TCS*) status
- incorrect circuit breaker status

- incorrect circuit breaker gas pressure status

6.1.2 Command receipt

Through this module different remote and local commands are executed: Command requests arrive to the inputs located in the **Internal object** and **Command object...** parameter section. Besides other checks, the **Close SC** command also passes through the synchro check. At command receipt, the **Command in progress** signal indicating the command currently being executed is set.

Manual commands can be executed in the following ways:

- remote close or open over communication from the control centre or SCADA
- local close or open over external digital input

6.1.2.1 Command objects

In the device, the **Internal object** command object and multiple external **Command object...** are available. In the internal command object, the device generated commands are the *Trip* and *ARC* commands. In external command objects, the manual, local or remote commands are handled.

A command object represents the source of the command which is important for further processing of command. The command object has several command inputs and two interlock status outputs - the **Command blocked** and **Command allowed**. With the **Source** parameter, the local or remote command source is defined.

Note: Command objects are intended for separating the feedback signals, which have to be separated for each command object that executed a command and is then waiting for an answer.

6.1.2.2 Trip command

The **Trip** signal is the most important command in the device and it is executed immediately, bypassing all other commands and interlocking. It is issued from the protection module after it detects a fault on the line. The **Trip** input is present as long as the fault condition exists. The **Trip** signal has priority above other commands. If during any command execution, the **Trip** command appears, all other commands are immediately cancelled regardless their execution phase or state.

Important!

The Trip command cancels execution of other commands! Trip is executed unconditionally and bypasses the interlock check!

6.1.2.3 Priority of commands

Commands are usually executed in a way that the one that comes first is executed first. Only one command can be executed at a time. Any command received during execution of first command is blocked by *Double operation* blocking.

6.1.3 Interlocking

The interlocking function is intended for safe execution of different commands or blocking of commands that because of different conditions must not be executed. The interlocking condition is checked at the moment of receipt of a command request. For example, if after the receipt of a command request the interlocking conditions are changed, they do not influence the command execution. The function of individual blocking is enabled or disabled with the **Enable** parameter.

The following interlocks are possible:

- *Double operation* blocking,
- *Protection* blocking,
- *Synchro check* blocking,
- Control mode interlocking (*System interlocking*),
- Blocking on bay level (*Bay interlocking*),

- Blocking due to exceeded number of protection tripping (*Max trip open*),
- Blocking due to exceeded number of overcurrent instantaneous protection tripping (*Max I>> trip open*),
- Blocking due to contact wear (*I2t interlocking*),
- Blocking because of already correct breaker position (*Status interlocking*)

The *Interlocking* is checked in two parts. In the first part, module check if another command is already executing or if any of the **Trip** inputs is set.

The second part of interlock check is executed only, if the command was not blocked in the first part of the interlock check.In the second part, all other interlocks are checked independently. One command can be blocked by more than one interlock at the same time.

If the command is blocked, the **Blocked by...** and **Command blocked** outputs are set after the interlock check completion. Otherwise, when the command is allowed, the **Command allowed** output is set. Outputs are only set on the command object that issued the command.

Only one command at a time can be received on a single command object. All further commands on the same command object, received during the first command execution time are rejected.

In case a command was blocked, the **Command in progress** output drops after the second part of interlock check procedure is complete.

6.1.3.1 Interlock check only

If only the status of interlocking is required, the **Interlock check** input should be set prior the command request. In that case, all of the interlocks are checked except the synchro check. The command is not executed. This functionality is used for Select-Check-Before-Execute (*SCBO*) command types located in the communication control driver.

6.1.3.2 Interlock bypass

The command interlock checking can be bypassed, if **Bypass** input is set before a command is sent. Interlock bypass doesn't applies to:

- *Double operation* blocking,
- *Protection* blocking,
- Control mode interlocking (*System interlocking*),

6.1.4 Interlocking types

6.1.4.1 Double operation blocking

This interlock prevents simultaneous execution of two commands. Only one command can be executed at a time. In case when during a command execution another command arrives, this interlock will be triggered. Usually, commands are executed in a way that the command arriving first is executed first and the other commands are blocked until the first command is executed completely. Settings, inputs and outputs are in the **/Interlocking / Double operation** section. When this interlock activates the **Double operation blocked** output is set.

This blocking is activated at the time of new command request in two cases:

- If any of the **Operation in progress** input is set or
- another command is in the middle of the execution.

Usually, the **Command in progress** outputs from other modules are linked to the **Operation in progress** input of this module.

6.1.4.2 Protection blocking

Blocking due to protection operation activation, where one or more of the **Trip** input signals are present. This blocking is very important. It is always active and can't be switched off or bypassed. The trip command has the highest priority and must always override other commands. Output is in the **/Interlocking / Protection** section. When this interlock activates, the **Blocked by Protection** output is set.

6.1.4.3 Synchro check blocking

Blocking due to asynchronism while attempt to connect two electrical systems. Settings, inputs and outputs are in the **/ Interlocking / Synchro check** section. This function is enabled with the **ARC enabled** parameter. Manual commands will pass through the separate synchronism check procedure. Synchro check blocking is activated only through the **Close SC** input.

The synchro check function is executed outside of this module. *Synchro-check* function can either be processed by *Synchro-check* module in this device or by independent external standalone device. If the synchro check is executed by an external device, the appropriate signals must be connected through external digital inputs to the this module inputs, shown in Figure 6.2.

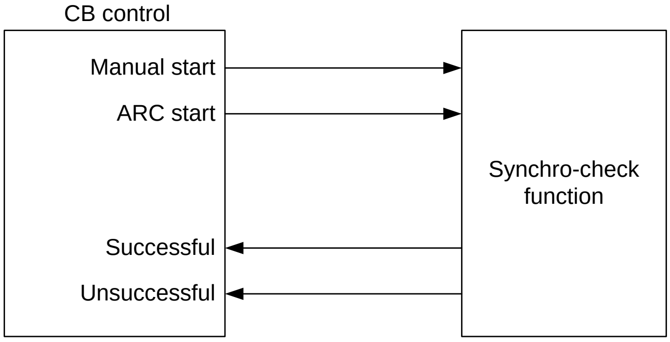

Figure 6.2: Linking of Switch control module inputs and outputs to Synchro-check function

The synchro check function is started by setting one of the **Manual start** outputs or **ARC start** signal, depending on the received command (ARC or manual). The request pulse is active until the feedback information is received. Feedbacks is received on **Successful** or **Unsuccessful** inputs.

The command is allowed, if after the synchro check request the **Successful** signal is set. The command is blocked, if after the synchro check request the **Unsuccessful** signal is set or the **Timeout** timer elapses. In latter case, a **Blocked by Synchro check** output is set.

6.1.4.4 Control mode blocking

The control mode blocking checks for local/remote control mode status. In local mode the remote commands are blocked, and in remote mode the local commands are blocked. The control mode switch is usually located on the front LDU panel. If the control mode status is not valid (ie. in state 00 or 11), the local and remote commands are also blocked. Settings, inputs and outputs are in the **/ Interlocking / System** section. If the **Local mode** and **Remote mode** inputs are not configured, the default mode is local mode. This blocking is active for closing and opening commands and it cannot be bypassed. When this interlock activates, the **Blocked by System** output is set.

There is an option to set the operation mode, where the local commands are always allowed and only remote commands are blocked. This feature is set by **Local always allowed** parameter.

Table 6.1: Detailed blocking operation, according to the control mode and parameters

Local mode	Remote mode	Local always allowed	Local command	Remote command
0	0	x	blocked	allowed
1	1	x	blocked	blocked
0	1	0	blocked	allowed
0	1	1	allowed	allowed
1	0	x	allowed	blocked

6.1.4.5 Bay interlock

The interlock in a bay is used for interlocking on basis of internal and external signals from various electrical elements e.g. switch positions. Usually, the condition for this interlocking is calculated from complex logical operations, performed by logical functions blocks. For example, a condition for the circuit breaker close or open command is calculated. The result of this logical equation is then connected the input of this interlocking. Settings, inputs and outputs are in the **/ Interlocking / Bay** section. To the **...Allow** inputs, all the signals that need to be set in order for the command is allowed are linked, and to the **...Block** inputs, all signals for blocking the command are linked.

The validity of the interlocking is also checked. In case the interlocking is not valid the command will be blocked. The interlocking separately blocks open and close commands. When this interlock activates, the **Blocked by Bay** output is set.

6.1.4.6 Correct circuit breaker status

The state of circuit breaker position is checked before executing command. If the breaker is already closed, the close command is blocked, and if the breaker is already opened, the open command is blocked. The commands are also blocked when the switch is in undefined or in fault position (position 00 or 11). This interlock blocks both trip and close commands. Settings, inputs and outputs are in the **/ Interlocking / Status** section. When this interlock activates, the **Blocked by Status** output is set.

6.1.4.7 Number of trips too high

Blocking due to exceeded number of protection tripping. The blocking that blocks only the close command is activated when the **Max trip block** signal is set. The **Max trip block** is calculated by a continuous process in this module, and it means that the number of trips reached or exceeded the set blocking value. Settings, inputs and outputs are in the **/ Interlocking / Max trip open** section. When this interlock activates, the **Blocked by Max Trip** output is set.

6.1.4.8 Number of short circuit trips (I>>) too high

Blocking due to exceeded number of short circuit protection tripping. The blocking blocks only the close command when the **Max trip block** signal is set. The **Max trip block** is calculated by a continuous process in this module, and it means that the number of trips reached or exceeded the set blocking value. Settings, inputs and outputs are in the **/ Interlocking / Max trip I>> open** section. When this interlock activates, the **Blocked by Max Trip** output is set.

This functionality is used to distinguish between the number of trips caused by the overcurrent instantaneous protection and the number of trips caused by other protection functions. At short circuit protection, usually very high currents occur, which wear the circuit breaker contacts more severely than at low amplitude current tripping. Therefore, the number of allowed overcurrent instantaneous protection trips is usually lower.

6.1.4.9 Contact wear I2t

Blocking due to contact wear, which is constantly monitored by the process in this module. The blocking blocks only the close command when the **Max break block** signal is set. The set **Max break block** signal means that the calculated contact wear exceeded the set blocking value. Settings, inputs and outputs are in the **/ Interlocking / I2t** parameters section. When this interlock activates, the **Blocked by Max break** output is set.

This functionality is used for very accurate measuring of contact wear at all protection types, at small and big currents. This functionality replaces the previously described blockings due to exceeded tripping number.

6.1.5 Command execution

After the receipt phase and successful interlock check, the command is executed. According to requested command, the appropriate output is set (Table 6.2) and then the command execution detection is started. In case of an open command, the contact wear counters are increased. At Trip open commands, the Circuit Breaker Failure Protection (CBFP) timer is started.

Table 6.2: List of outputs according to requested command

Output	Description
Trip open command	Open command by protection function (Trip).
Close command	Manual local or remote close command.
Open command	Manual local or remote open command.
ARC close command	Auto reclose function close command.

CBFP open command	Circuit Breaker Failure Protection (CBFP) function open command.

At command execution the corresponding output is set for **Minimal pulse time**. Outputs for open commands are usually connected to the outgoing digital output (relay) which sends an electrical signal to the open command circuit breaker coil.

6.1.5.1 Command execution success detection

This functionality provides information if the circuit breaker stalled, and it is executed after the command is executed. After the command execution, the **Command timeout** timer defining the time in which the command must be executed, and the command success checking process are started. While the command is in execution the **Command in progress** output signal is set.

The circuit breaker can stall and the command can fail. Failure is detected through the following conditions:

- after any command, the circuit breaker position is not correct inside the **Command timeout** time frame or
- the circuit breaker status gets is in fault position 11 or
- operation of circuit breaker failure protection (CBFP)

If the circuit breaker executes command successfully and it is in the correct position within the **Command timeout** time, the **Command successful** output is set. Otherwise, if it stalls, the **Command failed** output is set. In Figure 6.3, a successful command execution is shown.

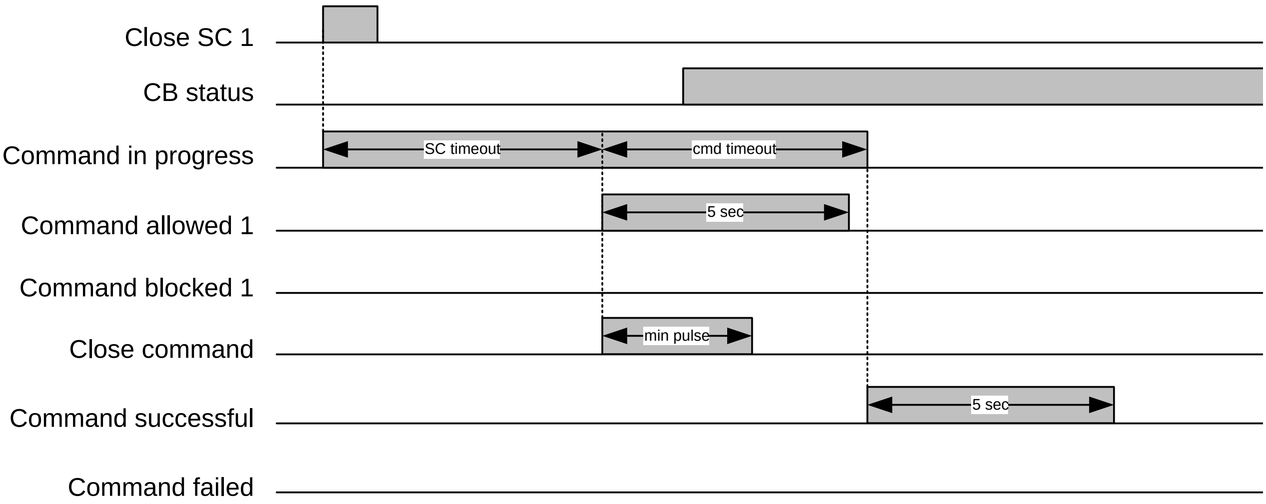

Figure 6.3: Successful execution of allowed command

6.1.5.2 Circuit breaker failure protection (CBFP)

The Circuit breaker failure protection (CBFP) functionality is intended for protection against problems when protection function issues the circuit breaker open command and command is not executed correctly. When the **Trip** open command is issued, the **CBFP Delay** timer starts. In this time, the **Trip** signal has to reset, otherwise the **CBFP open command** signal is set for at least the **Minimal pulse time** duration. Settings, inputs and outputs are in the **/CBFP** section.

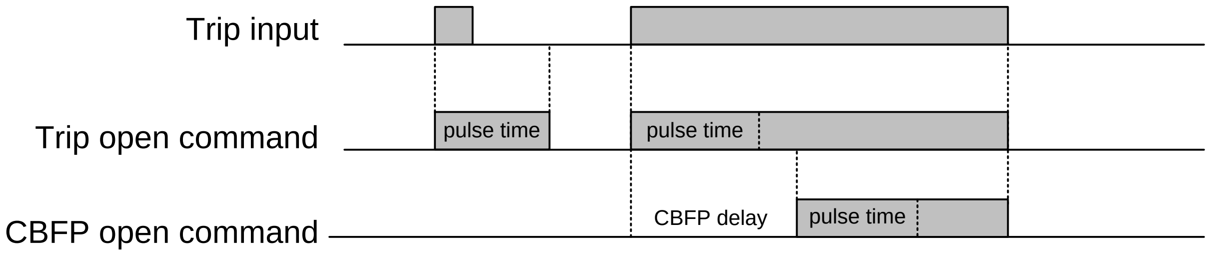

Figure 6.4: Trip and CBFP command

6.1.5.3 Trip counter

After each trip open command the **/Interlocking / Max trip open / Trip count** value is increased by 1.

6.1.5.4 Contact wear I2t

This functionality is used for very accurate measurement of contact wear at all protection types, at small and big currents. The basic idea is counting and appropriate evaluation of each circuit breaker open operation. The tripping current at the moment of contacts disconnection is used, and the wear using the "2p" method is calculated through its value.

This function also records the breaker opening in normal, no-fault condition by evaluating each operation, as it would be executed at nominal current. Circuit breaker lifetime is specified with mechanical lifetime as well. When the wear is approaching the maximum number, two warnings are available: alarm and blocking.

Settings, inputs and outputs are in the **/ Interlocking / I2t** section. The alarm and blocking levels can be set with the **Alarm set** and **Block set** parameters.

Wear is calculated only when the **Open line** input is set during command execution. In case the **Open line** is not connected, the calculation is always executed. After the calculation, the new contact wear is added to the cumulative **Break count L...** contact wear value, for each phase separately.

The **Current L...** phase currents values used in equations are read at the moment when the circuit breaker contacts disconnect. For exact calculation of that moment, the **DO close time** and **CB operation time** parameters must be set.

Usually, the characteristic of the contact wear is given from the manufacturer's catalogue in amperes and double logarithm scale. The characteristic has a shape of a straight line and is specified with two points, the start and the end point, Figure 6.5.

Each contact wear calculation is rounded up and its minimal value is 1. If the current is higher than the maximum allowed circuit breaker current, the wear equals the maximum circuit breaker contact wear (the **Block set** parameter). The **CB nominal current**, **CB max break current**, **Num of ops at nominal curr** and the **Num of ops at max break curr** parameters define the characteristic points in a double logarithm scale.

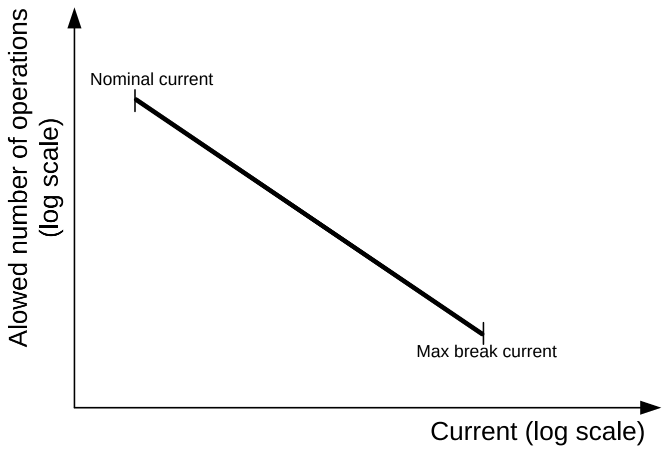

Figure 6.5: Circuit breaker characteristic example in double logarithm scale

6.1.6 Parameters, inputs and outputs table

/ Control settings	
Command timeout 0.00…**0.20**...1000.00 s	Max. time length of command execution.
CB operation time 0…**100**...2000 ms	Circuit breaker operation own time, the time between the DO contact closing and start of circuit breaker contacts disconnection.
DO close time 0…**9**...100 ms	Device DO relay operation own time, the time between the open command execution and the DO contact closing.
Status open input (digital)	Circuit breaker position open bit (bit 0).
Status close input (digital)	Circuit breaker position close bit (bit 1).

/ Internal object	
Trip 0…50 input (digital)	Protection open signal.
ARC close input (digital)	ARC function close signal.
Command blocked output (digital)	Command blocked. One or more interlocks are activated (5 second pulse).
Command allowed output (digital)	Command allowed. None of the interlocks are activated (5 second pulse).

/ Command object 1...6	
Source **Local**, Remote	Local or remote command.
Close input (digital)	Close command signal.
Close SC input (digital)	Synchro-check close command signal.
Open input (digital)	Open command signal.
Command blocked output (digital)	Command blocked. One or more interlocks are activated (5 second pulse).
Command allowed output (digital)	Command allowed. None of the interlocks are activated (5 second pulse).

/ Interlocking	
Interlock check input (digital)	Interlock check-only mode.
Bypass input (digital)	Interlock bypass mode. Some of the interlocking is not checked.

/ Interlocking / Double Operation	
Operation in progress 0...10 input (digital)	Command operations already in progress.
Blocked by Double operation output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / Protection

Blocked by Protection output (digital)	Close command was blocked (5 second pulse).

/ Interlocking / Synchro check

ARC enabled true, **false**	Enabling the synchro check with ARC close command.
Manual start output (digital)	Command for starting the synchro check with manual commands.
ARC start output (digital)	Command for starting the synchro check with ARC commands.
Timeout 0.00…**10.00**...100.00 s	Maximum allowed synchro check time.
Successful input (digital)	Synchro check function feedback signal: close command allowed.
Unsuccessful input (digital)	Synchro check function feedback signal: close command blocked.
Blocked by Synchro check output (digital)	Close command was blocked (5 second pulse).

/ Interlocking / System

Enabled true, **false**	Control mode interlock enabling.
Local always allowed true, **false**	Enabling the local command to be always allowed.
Local mode input (digital)	Control mode local signal (default).
Remote mode input (digital)	Control mode remote signal.
Blocked by System output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / Max trip open

Enabled true, **false**	Max trip interlock enabling.
Alarm set 1…**1.000**...100.000	Trip number alarming limit.
Block set 1…**1.010**...100.000	Trip number blocking limit.
Max trip alarm output (digital)	The **Trip count** has reached or exceeded the set **Alarm set** value.
Max trip block output (digital)	The **Trip count** has reached or exceeded the set **Block set** value.
Blocked by Max Trip output (digital)	Close command was blocked (5 second pulse).
Trip count counter	Trip counter.

/ Interlocking / Max trip I>> open

Enabled true, **false**	Max trip I>> interlock enabling.
Trip count I>> input (analog)	Short circuit protection (I>>) trip counter.

Alarm set 0…**1.000**...100.000	Trip number alarming limit.
Block set 0…**1.010**...100.000	Trip number blocking limit.
Max trip alarm output (digital)	The **Trip count I>>** has reached or exceeded the set **Alarm set** value.
Max trip block output (digital)	The **Trip count I>>** has reached or exceeded the set **Block set** value.
Blocked by Max Trip I>> output (digital)	Close command was blocked (5 second pulse).

/ Interlocking / I2t

Enabled true, **false**	I2t wear interlock enabling.
Alarm set 0…**24.000**...100.000	Alarming limit setting.
Block set 0…**30.000**...100.000	Blocking limit setting.
CB nominal current 0.00…**0.60**...50.00 kA	Nominal circuit breaker current.
CB max break current 0.00…**30.00**...150.00 kA	Maximum circuit breaker tripping current.
Num of ops at nominal curr 0…**30.000**...100.000	Number of allowed operations at circuit breaker nominal current.
Num of ops at max break curr 0…**50**...100.000	Number of allowed operations at circuit breaker maximum current.
Open line input (digital)	Disconnected state detection.
Current L1 input (analog)	Phase current L1.
Current L2 input (analog)	Phase current L2.
Current L3 input (analog)	Phase current L3.
Nominal current constant input (analog)	Nominal device current.
Primary nominal current constant input (analog)	Primary nominal current in raw value.
Max break alarm output (digital)	Alarm limit reached or exceeded.
Max break block output (digital)	Blocking limit reached or exceeded.
Blocked by Max break output (digital)	Close was blocked (5 second pulse).
Break count L1 static (analog)	L1 contact wear counter
Break count L2 static (analog)	L2 contact wear counter
Break count L3 static (analog)	L3 contact wear counter

/ Interlocking / Bay

Enabled true, **false**	Bay interlock enabling.
Open allow 0…10 input (digital)	Open command is allowed if all linked inputs are set.
Open block 0…10 input (digital)	Close command blocked if at least one input is set.

Close allow 0…10 input (digital)	Close command allowed, if all linked inputs are set.
Close block 0…10 input (digital)	Close command is blocked if at least one input is set.
Blocked by Bay output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / Status

Enabled true, **false**	Status interlock enabling.
Blocked by Status output (digital)	Close or open command was blocked (5 second pulse).
Status alarm output (digital)	Current circuit breaker status is not correct.

/ Output

Minimal pulse time 0.00…**0.20**...100.00 s	Minimum output pulse length.
Command in progress output (digital)	The command is in progress.
Trip open command output (digital)	Open command caused by protection.
Close command output (digital)	Manual local or remote close command.
Open command output (digital)	Manual local or remote open command.
ARC close command output (digital)	ARC close command.
Command successful output (digital)	A command was successful (5 second pulse).
Command failed output (digital)	Circuit breaker command failed (5 second pulse).

/ CBFP

Enabled true, **false**	CBFP function enabling.
CBFP delay 0.00…**0.20**...100.00 s	CBFP open command delay.
CBFP open command output (digital)	CBFP open command. Pulse with minimum length.
Count counter	CBFP open command counter.

/ Ready

Enabled true, **false**	Ready function enabling.
Ready output (digital)	Circuit breaker is ready.

/ Ready / Status 1…20

Enabled true, **false**	State monitoring enabling.

Input input (digital)	Current status value.
Ready value 0, **1**	Status value at which the circuit breaker is ready.

6.2 Disconnector control

The *Disconnector* module is the control module for complete control and execution of commands on the disconnector. The device constantly monitors the disconnector state. If more than one disconnector needs to be monitored, separate modules have to be configured.

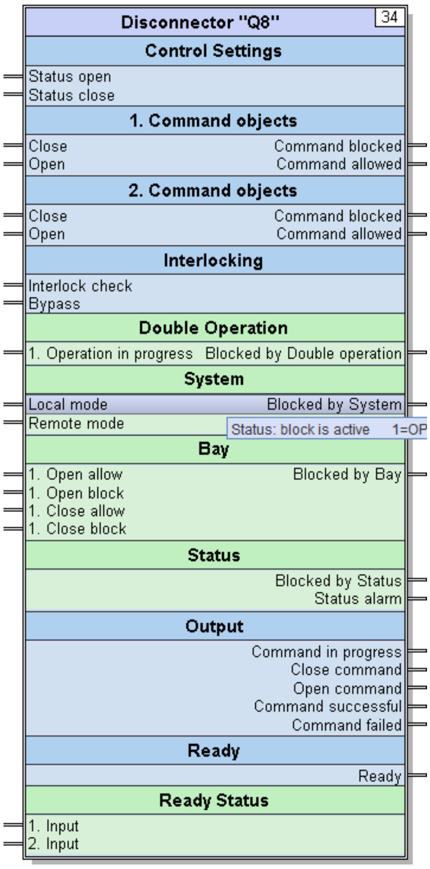

Figure 6.6: Disconnector control block

The main module function is disconnector command execution with interlock check. Therefore, the command process is divided to several phases:

- Command receipt: the module distinguishes between close, open, local and remote commands.
- Interlock check, part 1: check for any command already in progress present.
- Interlock check, part 2: all other interlocking are checked: system interlock, bay interlock, invalid status.
- Command execution: command signal to output relay
- Execution check: success check, disconnector failure control and event counting.

6.2.1 Continuous monitoring processes

Several continuous processes are running in the module which constantly monitor the breaker state and immediately reporting the irregularities:

- Incorrect position of disconnector detection (**Status alarm**)

- Disconnector **Ready** state

6.2.1.1 Status monitoring

This process monitors and signalizes the faulty disconnector position status through the **Status alarm** output. The **Status alarm** output is set:

- when the disconnector position is in invalid 11 state or
- when the disconnector position is 00 state for more than **Command Timeout** time.

The disconnector status set with the **Input / Status...** inputs. Settings, inputs and outputs are in the **/ Interlocking / Status** parameter section.

6.2.1.2 Alert status monitoring

The disconnector alert status describes whether a disconnector is ready for operation. It consists of several signals, which have to be in ready state, either through external digital inputs or through internal signalization. If any of individual states is signalize not ready state, the disconnector state is reported as not ready.

Individual signals are linked to the **Status / Input** inputs, their ready state values are set by **Ready value** parameter and then they are enabled with the **Enable** parameter.

Settings, inputs and outputs are in the **/Ready** parameter section.

Example of signals that can be used for disconnector ready status:

- incorrect disconnector status
- incorrect disconnector gas pressure status

6.2.2 Command receipt

Through this module different remote and local commands are executed: Command requests arrive to the inputs located in **Command object...** parameter section. Besides other checks, the **Close SC** command also passes through the synchro check. At command receipt, the **Command in progress** signal indicating the command currently being executed is set.

Manual commands can be executed in the following ways:

- remote close or open over communication from the control centre or SCADA
- local close or open over external digital input

6.2.2.1 Command objects

In the device, multiple external **Command object...** are available. In external command objects, the manual, local or remote commands are handled.

A command object represents the source of the command which is important for further processing of command. The command object has several command inputs and two interlock status outputs - the **Command blocked** and **Command allowed**. With the **Source** parameter, the local or remote command source is defined.

Note: Command objects are intended for separating the feedback signals, which have to be separated for each command object that executed a command and is then waiting for an answer.

6.2.2.2 Priority of commands

Commands are usually executed in a way that the one that comes first is executed first. Only one command can be executed at a time. Any command received during execution of first command is blocked by *Double operation* blocking.

6.2.3 Interlocking

The interlocking function is intended for safe execution of different commands or blocking of commands that because of different conditions must not be executed. The interlocking condition is checked at the moment of receipt of a command request. For example, if after the receipt of a command request the interlocking conditions are changed, they do not influence the command execution. The function of individual blocking is enabled or disabled with the **Enable** parameter.

The following interlocks are possible:

- *Double operation* blocking,
- Control mode interlocking (*System interlocking*),
- Blocking on bay level (*Bay interlocking*),
- Blocking because of already correct breaker position (*Status interlocking*)

The *Interlocking* is checked in two parts. In the first part, module check if another command is already executing.

The second part of interlock check is executed only, if the command was not blocked in the first part of the interlock check.In the second part, all other interlocks are checked independently. One command can be blocked by more than one interlock at the same time.

If the command is blocked, the **Blocked by...** and **Command blocked** outputs are set after the interlock check completion. Otherwise, when the command is allowed, the **Command allowed** output is set. Outputs are only set on the command object that issued the command.

Only one command at a time can be received on a single command object. All further commands on the same command object, received during the first command execution time are rejected.

In case a command was blocked, the **Command in progress** output drops after the second part of interlock check procedure is complete.

6.2.3.1 Interlock check only

If only the status of interlocking is required, the **Interlock check** input should be set prior the command request. In that case, all of the interlocks are checked except the synchro check. The command is not executed. This functionality is used for Select-Check-Before-Execute (*SCBO*) command types located in the communication control driver.

6.2.3.2 Interlock bypass

The command interlock checking can be bypassed, if **Bypass** input is set before a command is sent. Interlock bypass doesn't applies to:

- *Double operation* blocking,
- Control mode interlocking (*System interlocking*),

6.2.4 Interlocking types

6.2.4.1 Double operation blocking

This interlock prevents simultaneous execution of two commands. Only one command can be executed at a time. In case when during a command execution another command arrives, this interlock will be triggered. Usually, commands are executed in a way that the command arriving first is executed first and the other commands are blocked until the first command is executed completely. Settings, inputs and outputs are in the **/Interlocking / Double operation** section. When this interlock activates the **Double operation blocked** output is set.

This blocking is activated at the time of new command request in two cases:

- If any of the **Operation in progress** input is set or
- another command is in the middle of the execution.

Usually, the **Command in progress** outputs from other modules are linked to the **Operation in progress** input of this module.

6.2.4.2 Control mode blocking

The control mode blocking checks for local/remote control mode status. In local mode the remote commands are blocked, and in remote mode the local commands are blocked. The control mode switch is usually located on the front LDU panel. If the control mode status is not valid (ie. in state 00 or 11), the local and remote commands are also blocked. Settings, inputs and outputs are in the **/ Interlocking / System** section. If the **Local mode** and **Remote mode** inputs are not configured, the default mode is local mode. This blocking is active for closing and opening commands and it cannot be bypassed. When this interlock activates, the **Blocked by System** output is set.

There is an option to set the operation mode, where the local commands are always allowed and only remote commands are blocked. This feature is set by **Local always allowed** parameter.

Table 6.3: Detailed blocking operation, according to the control mode and parameters

Local mode	Remote mode	Local always allowed	Local command	Remote command
0	0	x	blocked	allowed
1	1	x	blocked	blocked
0	1	0	blocked	allowed
0	1	1	allowed	allowed
1	0	x	allowed	blocked

6.2.4.3 Bay interlock

The interlock in a bay is used for interlocking on basis of internal and external signals from various electrical elements e.g. switch positions. Usually, the condition for this interlocking is calculated from complex logical operations, performed by logical functions blocks. For example, a condition for the disconnector close or open command is calculated. The result of this logical equation is then connected the input of this interlocking. Settings, inputs and outputs are in the **/ Interlocking / Bay** section. To the **...Allow** inputs, all the signals that need to be set in order for the command is allowed are linked, and to the **...Block** inputs, all signals for blocking the command are linked.

The validity of the interlocking is also checked. In case the interlocking is not valid the command will be blocked. The interlocking separately blocks open and close commands. When this interlock activates, the **Blocked by Bay** output is set.

6.2.4.4 Correct disconnector status

The state of disconnector position is checked before executing command. If the breaker is already closed, the close command is blocked, and if the breaker is already opened, the open command is blocked. The commands are also blocked when the disconnector is in undefined or in fault position (position 00 or 11). This interlock blocks both open and close commands. Settings, inputs and outputs are in the **/ Interlocking / Status** section. When this interlock activates, the **Blocked by Status** output is set.

6.2.5 Command execution

After the receipt phase and successful interlock check, the command is executed. According to requested command, the appropriate output is set (Table 6.2) and then the command execution detection is started. In case of an open command, the contact wear counters are increased.

Table 6.4: List of outputs according to requested command

Output	Description
Close command	Manual local or remote close command.
Open command	Manual local or remote open command.

At command execution the corresponding output is set for **Minimal pulse time**. Outputs for open commands are usually connected to the outgoing digital output (relay) which sends an electrical signal to the open command disconnector coil.

6.2.5.1 Command execution success detection

This functionality provides information if the disconnector stalled, and it is executed after the command is executed. After the command execution, the **Command timeout** timer defining the time in which the command must be executed, and the command success checking process are started. While the command is in execution the **Command in progress** output signal is set.

The disconnector can stall and the command can fail. Failure is detected through the following conditions:

- after any command, the disconnector position is not correct inside the **Command timeout** time frame or
- the disconnector status gets is in fault position 11 or

If the disconnector executes command successfully and it is in the correct position within the **Command timeout** time, the **Command successful** output is set. Otherwise, if it stalls, the **Command failed** output is set. In Figure 6.3, a successful command execution is shown.

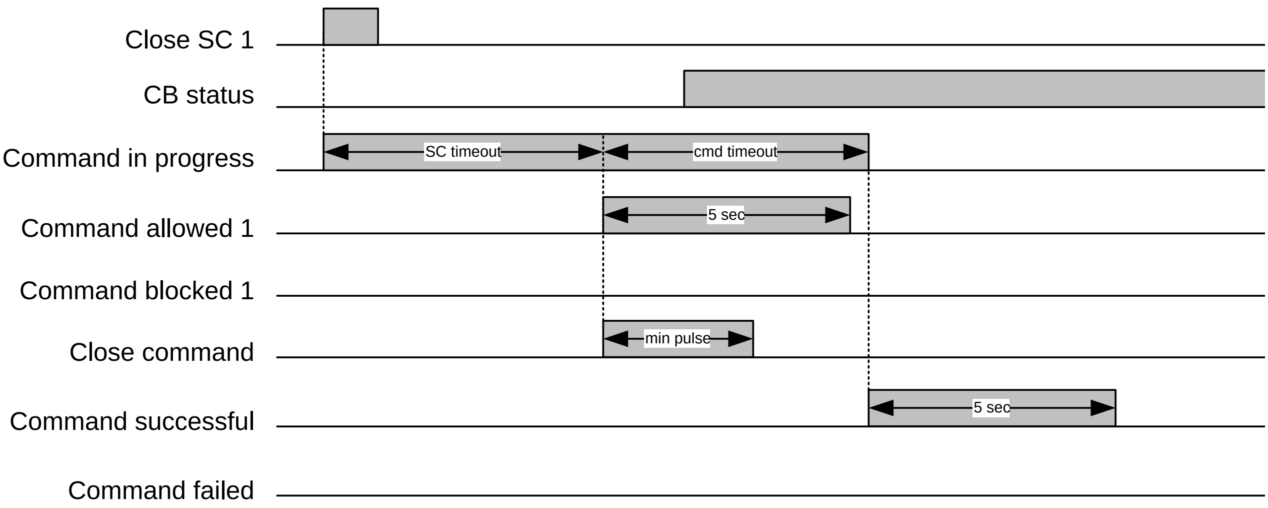

Figure 6.7: Successful execution of allowed command

6.2.6 Parameters, inputs and outputs table

/ Control settings	
Command timeout 0.00…**0.20**...1000.00 s	Max. time length of command execution.
CB operation time 0…**100**...2000 ms	Disconnector operation own time, the time between the DO contact closing and start of disconnector contacts disconnection.
DO close time 0…**9**...100 ms	Device DO relay operation own time, the time between the open command execution and the DO contact closing.
Status open input (digital)	Disconnector position open bit (bit 0).
Status close input (digital)	Disconnector position close bit (bit 1).

/ Command object 1...6	
Source **Local**, Remote	Local or remote command.
Close input (digital)	Close command signal.
Open input (digital)	Open command signal.

Command blocked output (digital)	Command blocked. One or more interlocks are activated (5 second pulse).
Command allowed output (digital)	Command allowed. None of the interlocks are activated (5 second pulse).

/ Interlocking

Interlock check input (digital)	Interlock check-only mode.
Bypass input (digital)	Interlock bypass mode. Some of the interlocking is not checked.

/ Interlocking / Double Operation

Operation in progress 0...10 input (digital)	Command operations already in progress.
Blocked by Double operation output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / System

Enabled true, **false**	Control mode interlock enabling.
Local always allowed true, **false**	Enabling the local command to be always allowed.
Local mode input (digital)	Control mode local signal (default).
Remote mode input (digital)	Control mode remote signal.
Blocked by System output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / Bay

Enabled true, **false**	Bay interlock enabling.
Open allow 0…10 input (digital)	Open command is allowed if all linked inputs are set.
Open block 0…10 input (digital)	Close command blocked if at least one input is set.
Close allow 0…10 input (digital)	Close command allowed, if all linked inputs are set.
Close block 0…10 input (digital)	Close command is blocked if at least one input is set.
Blocked by Bay output (digital)	Close or open command was blocked (5 second pulse).

/ Interlocking / Status

Enabled true, **false**	Status interlock enabling.
Blocked by Status output (digital)	Close or open command was blocked (5 second pulse).
Status alarm output (digital)	Current disconnector status is not correct.

/ Output	
Minimal pulse time 0.00…**0.20**...100.00 s	Minimum output pulse length.
Command in progress output (digital)	The command is in progress.
Close command output (digital)	Manual local or remote close command.
Open command output (digital)	Manual local or remote open command.
Command successful output (digital)	A command was successful (5 second pulse).
Command failed output (digital)	Disconnector command failed (5 second pulse).

/ Ready	
Enabled true, **false**	Ready function enabling.
Ready output (digital)	Disconnector is ready.

/ Ready / Status 1…20	
Enabled true, **false**	State monitoring enabling.
Input input (digital)	Current status value.
Ready value 0, **1**	Status value at which the disconnector is ready.

6.3 Auto reclose function (ARC)

Statistically, approx. 85% of all faults occurring at overhead lines are temporary short circuits that disappear after the protection operation. This means that after the protection operation a line is switched back into operation. Reclosing is executed after a set dead time through the *Auto Reclose Function* module (*ARC*). If after the reclosing the fault is still present, the protection function will operate again. In many cases, several attempts of reclosing are set.

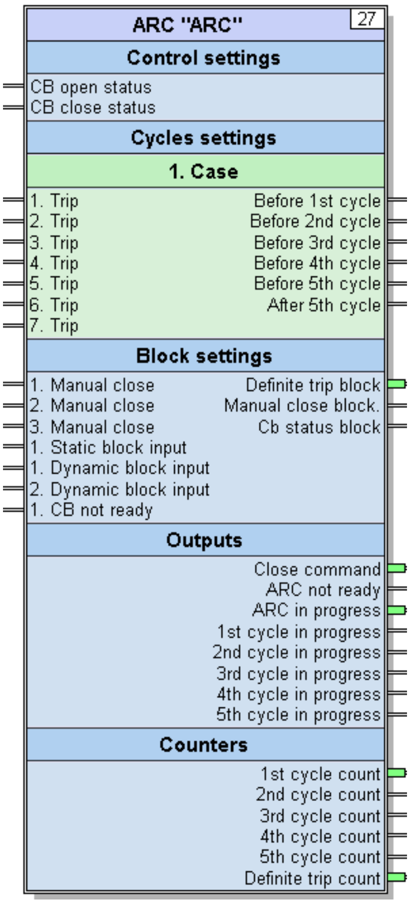

Figure 6.8: Auto reclose function block

The function of automatic reclosing is connected to the protection functions by their **Trip** signals.

ARC function includes:

- Option of setting trip priority in case of multiple simultaneous trips,
- Coordination of operation on the level of Trips and levels through signals **Before 1st, 2nd, 3rd …cycle** back to protections, like:
  - protection block
  - immediate trip after protection
- Possible closing through the *Synchro check* function
- Static blocks at standby mode (eg. state and position of a breaker, external block)
- Dynamic blocks during the reclosing sequence (eg. unsuccessful reclosing, closing on fault, invalid circuit-breaker state or position, manual command, external block signal)
- Statistical counters
- Signals of operation state: like **ARC not ready**, **ARC in progress**, **1st cycle in progress**, etc.

6.3.1 Operation

If the ARC function is enabled (**Operate mode** = *On*) and there are no static blocks, the ARC is set and in standby mode at the module start-up. The function monitors the input **Trip** signals. When any of them is set, it starts to operate according to the defined scenario.

If no new **Trip** signal appears after the last re-close during the **Reclaim time**, the re-closing is considered successful and the scenario is reset to beginning. After that, the scenario is restarted if new Trip occurs.

6.3.1.1 Table of cycles and scenarios

The main part of the automatic reclosing operation is defined by means of the table of cycles and case scenarios (**Cycles settings**).

Up to 10 different case scenarios can be defined (in settings groups **1.Case**...**10.Case**). In each scenario it is defined which protections will trigger an individual scenario. A priority is set for each scenario and up to 5 cycles of reclosing with the pre-defined dead times

Dead time is time without voltage after which the ARC function re-closes and put the line back into operation. The number of cycles is equal to the number of consecutive cycles with the set **Dead time**. Set value of **Dead time** parameter equal to zero means that this and all further cycles are made impossible. Closing is executed through the **Close command** output signal.

The ARC scenario is activated when one of its **Trip** inputs is set in standby state of ARC and there is no dynamic block present. The operation of the ARC scenario is indicated by the **Arc in progress** output signal which is set while the scenario is in progress. On the first **Trip** signal the first cycle is activated, and each further **Trip** activates the next cycle. The operation of each cycle is indicated by a corresponding output signal **... cycle in progress**. The procedure and successful closing is shown in Figure 6.9.

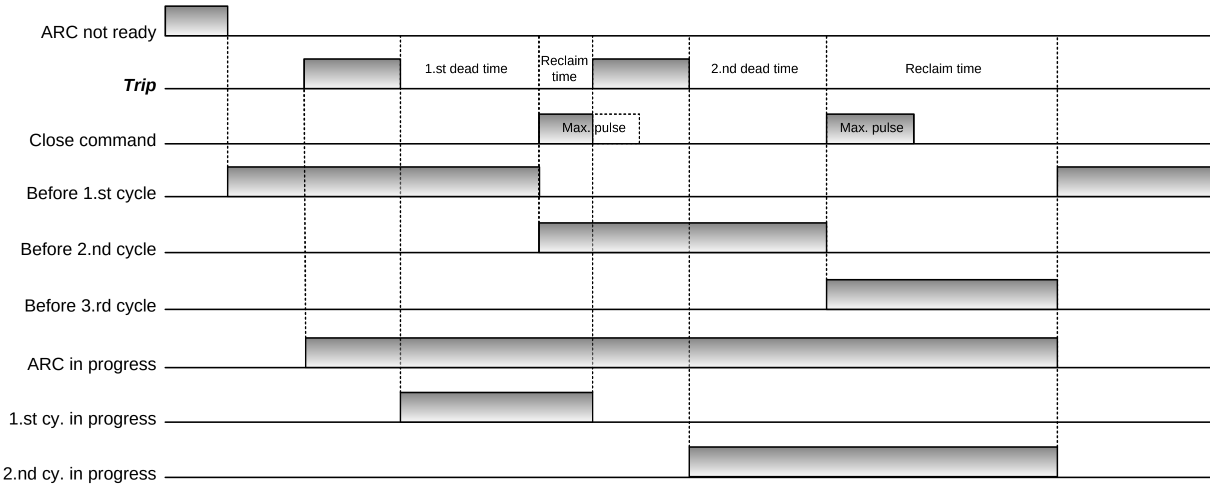

Figure 6.9: ARC operation: Second successful automatic reclosing

6.3.1.2 Operation with asynchronous synchro-check function

If ARC function is linked with the *Synchro-check* function, a certain delay occurs between the re-close command of the ARC function and a circuit breaker (Switch module) closing because of the time needed by the *Synchro-check* function at asynchronous closing. In this time the circuit breaker remains open while in the ARC function the **Reclaim time** timer is in progress. Maximal time of asynchronous reclosing is limited and should be considered at the **Reclaim time** timer parameter setting.

6.3.2 Scenarios overlapping

If scenario 1 in the first cycle (**Case 1**) is in progress and then another scenario 2 Trip is activated, the ARC switches to scenario 2 to 1st Cycle.

In case a certain cycle is in progress and several trips occur in different scenarios, even if they are not at the same time, the trip with a higher priority is selected for scenario. The **Dead time** timer is started after all Trip signals drop.

6.3.3 Coordination with protection functions

For setting of more complex scenarios, **Before ... cycle** output signals are available. With these signals it is possible to influence on the operation of protection functions through corresponding of **Block** and **Immediate trip** inputs in protection functions. For the first cycle the **Before 1st cycle** output is set when the ARC is at standby mode. For second cycle a corresponding **Before 2nd cycle** output is set at automatic reclosing in first cycle, etc.

*Example 1: all protections with the **Before 2.nd cycle** ARC signal connected to the **Block input** will be blocked in the second cycle of the ARC operation.*

*Example 2: all protections with the **Before 3.rd cycle** ARC signal connected to the **Immediate Trip** input will operate immediately in the third cycle, irrespective of their **Trip delay** settings.*

6.3.4 Blocking

There are two types of blocking used at the ARC function: static and dynamic.

6.3.4.1 Static blocking

Static blocking occur when the ARC is in standby mode or in idle state, or when a **Block delay** timer expires. A static blocking deactivates the ARC function and **ARC not ready** output is set. In case **Trip** is set, while the ARC is not ready, the ARC scenario is not activated.

Static blocking occurs in the following examples:

- A circuit breaker is not ready (thru **CB not ready** input).
- A circuit breaker is not closed (thru **CB status...** inputs). In that case a **CB status block** output is set.
- Any input of **Static block input…** is set, usualy used for external block signals.

6.3.4.2 Dynamic blocking

Dynamic blocking occur when the ARC scenario is in progress (**ARC in progress** output is set).

When a dynamic blocking occurs, the ARC scenario terminates, **ARC in progress** output drops, a common **Definite trip block** output is set and a **Block delay** timer is started. On the expiry of this timer, it is first checked if any static block is present. If this is the case, the static block is activated, otherwise it is checked if any of dynamic blocks is present. If this is the case, the **Block delay** timer is restarted, otherwise **Definite trip blocked** and all other status outputs drop and the ARC goes to standby mode.

Dynamic blocking comprises:

- Any **Trip** is present during the last **Reclaim time**, when all of unsuccessful closing cycles have expired (Figure 6.10).
- Any **Trip** during **Dead time** is present.
- Any **Trip** is set during a **Manual close block time**, if the **Manual close block enable** parameter is enabled. In that case the **Manual close block** is set.
- Any **Dynamic block input...** is set at any time.
- The circuit breaker is not ready (**CB not ready** input is set) during a time of automatic reclosing.
- Any manual command for **Manual close...** is set.
- The circuit breaker is closed or has a wrong state during **Dead time.**
- After the **Dead time,** the circuit breaker status is not open. In such case the **CB status block** output is set.
- The circuit breaker is opened or has a wrong state during **Reclaim time.**
- After the **Reclaim time** the circuit breaker status is not closed. In such cases the **CB status block** output is set.

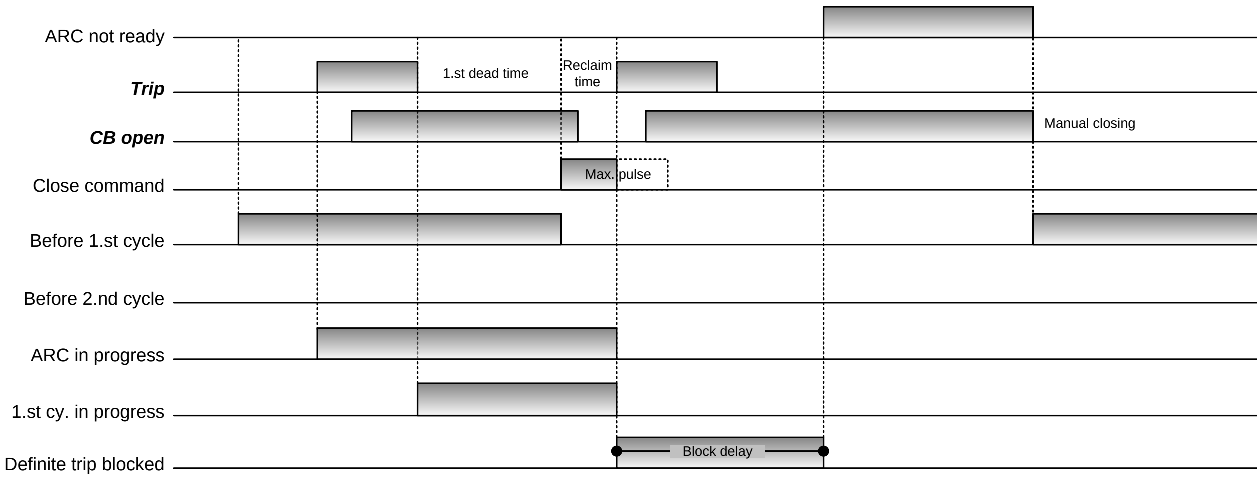

Figure 6.10: Unsuccessful automatic reclosing, a dynamic block

Important signals that influence on valid ARC operation and should be monitored closely are manual closing and manual opening of circuit breaker. The commands for manual closing are connected to a special **Manual close** input, while the commands for the manual opening are connected to the common **Dynamic block input**.

For setting the blocking to closing-on-fault, the **Manual close block enable** and **Manual close block time** parameters should be set. The **Manual close block time** timer is started when the ARC is in standby and the circuit breaker closes, which is detected by:

- Circuit breaker status is set to close or
- Manual closing through the **Manual close** input.

Up to 10 external blocks can be defined. External signals can be connected to the **Dynamic block inputs** where appropriate. A dynamic block usually includes circuit breaker failure protection signal (*CBFP* function in *CB module)*, unsuccessful circuit breaker closing (*CB failed* signal in *CB module*), a manual command for a circuit breaker opening (*Manual open command*), a command blocked signal for a circuit breaker closing (*Command blocked*), the operation of certain protection functions which blocks the ARC, external blocking, etc. Since some of these signals are short events, the block is activated at a positive signal change.

The circuit breaker is usually not ready due to an unwound spring or other faults on a circuit breaker, such as gas pressure fail. The circuit breaker is ready when it is capable to perform at least one open-close-open cycle. When the cycle is performed, the circuit breaker restoring is started (e.g. spring winding). At that time, the circuit breaker is not ready to perform a new close-open cycle, therefore the ARC must be blocked. The signal indicating that a circuit-breaker is not ready is connected to the **CB not ready** input.

6.3.5 Parameters table

Control settings	
Operate mode On, **Off**	Off – function is switched off On – operation enabled
Reclaim time 0,5...**3,0**…300,0 sec	Reclaim time: time that should pass after the last ARC closing without a new Trip in order to be considered as successful.
CB open status input (digital)	Circuit breaker position: open.
CB close status input (digital)	Circuit breaker position: close.

Cycles settings \ Case 1…10

Trip 1 … 10 input (digital)	OR function between Trip signals. Any Trip activates the operation of the ARC according to this scenario.
Priority 1...**10**…100	The priority of the scenario in case of more simultaneous trips. A smaller number indicates a higher priority.
1st Dead time **0,00**…300,00 sec	Dead time of the 1st cycle. Value 0 indicates that this and any subsequent cycles are disabled.
Before 1st cycle output (digital)	Output for reverse connection to protection. The signal is set before the cycle operation.
2nd Dead time **0,00**…300,00 sec	Dead time of the 2nd cycle. Value 0 indicates that any subsequent cycles are disabled.
Before 2nd cycle output (digital)	Output for reverse connection to the protection. The signal is set before the cycle operation.
3rd Dead time **0,00**…300,00 sec	Dead time of the 3nd cycle. Value 0 indicates that any subsequent cycles are disabled.
Before 3rd cycle output (digital)	Output for reverse connection to protection. The signal is set before the cycle operation.
4th Dead time **0,00**…300,00 sec	Dead time of the 4nd cycle. Value 0 indicates that any subsequent cycles are disabled.
Before 4th cycle output (digital)	Output for reverse connection to protection. The signal is set before the cycle operation.
5th Dead time **0,00**…300,00 sec	Dead time of the 5nd cycle. Value 0 indicates that any subsequent cycles are disabled.
Before 5th cycle output (digital)	Output for reverse connection to protection. The signal is set before the cycle operation.

Block settings

Block delay 0,01...**0,50**…300,00 sec	Time of block when the condition occurs for a dynamic block at which the standby conditions are checked again.
Manual close block enable **true**, false	Block enabled after manual closing for a certain **Manual close block time**.
Manual close block time 0,20...**1,00**…300,00 sec	Time after manual closing when the ARC is in the block state.
Manual close 0...10 input (digital)	Manual circuit breaker closing.
Static block input 0…10 input (digital)	Conditions for a static block of the ARC standby.
Dynamic block input 0…10 input (digital)	Conditions for a static block of the ARC scenario.
CB not ready input (digital)	Indication that the circuit breaker is not ready.
Definite trip block output (digital)	Block status: ARC is in the dynamic block state. The ARC function is deactivated.
Manual close block output (digital)	Block status: ARC is blocked dynamically due to the block after manual closing of the circuit breaker.
CB status block output (digital)	Block status: ARC is blocked due to incorrect position of the circuit breaker.

Outputs

Close command output (digital)	A command for the circuit breaker reclosing (**Maximal close pulse time**)
Maximal close pulse time 0,00…**0,10**…100,00 sec	Maximal length of **Close command** output pulse
ARC not ready output (digital)	ARC function is not at standby mode due to a static block.
ARC in progress output (digital)	ARC operation is in progress.

1st cycle in progress output (digital)	1st cycle in progress
2nd cycle in progress output (digital)	2nd cycle in progress
3rd cycle in progress output (digital)	3rd cycle in progress
4th cycle in progress output (digital)	4th cycle in progress
5th cycle in progress output (digital)	5th cycle in progress

Counters	
1st cycle count counter	1st cycle counter.
2nd cycle count counter	2nd cycle counter.
3rd cycle count counter	3rd cycle counter.
4th cycle count counter	4th cycle counter.
5th cycle count counter	5th cycle counter.
Definite trip count counter	A definite trip counter.

6.4 Synchro check

The *Synchro check* module is used for safe synchronised connection of two live electrical systems - networks. Circuit breaker closing is allowed only when the frequency, amplitude and phase differences are within the set limits and consequently imply only minimal temporary transients on the network.

The synchro check function consists of the following sections:

- connection type, one or two bus system
- line and bus bar voltage detection,
- starting mode, manual or ARC
- synchronizing mode: synchronous or asynchronous.

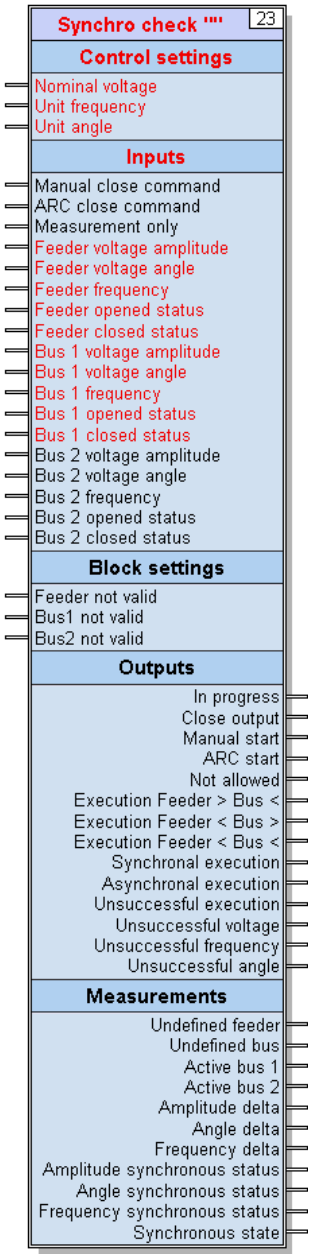

Figure 6.11: Synchro check module

6.4.1 Operation description

6.4.1.1 Measurements

The measurement calculation process is started with **Manual close command**, **ARC close command** or **Measurement only** command and lasts until the end of the command process or at least for 5 seconds. All values defined in **Measurements** output group are calculated periodically. After the procedure is finished, the measurements stop, the measurement values and disconnectors statuses are reset to 0 values. Active bus bar voltage is used as a reference for all calculations.

The undefined disconnector status and zero voltage level are signalled with **Undefined feeder** and **Undefined bus** alarms from **Measurement** outputs group. Cases of undefined status are:

- Disconnector's statuses are invalid, therefore **.... not valid** output signals are set or
- any of disconnectors is not defined, i.e. has value 00 or 11 or
- active *bus* bar voltage or *feeder* line voltage is between set values of **Dead level U<** and **Live level U>** parameters.

If the disconnector 1 status is valid and closed, the **Active bus 1** signal is set. Same applies for disconnector 2. If both disconnectors are opened, none of the statuses is set. If both disconnectors are valid and closed, both statuses are set, and the disconnector 1 is used as active bus. In case any of the disconnector is undefined, the **... delta** measurements and their **... synchronous status** statuses are set to 0.

6.4.1.2 Measurements only mode

This mode of operation is intended for monitoring the synchronous state of synchronism between two electrical systems without any commands. Only measurements are calculated. This mode is active when the **Measurement only** input is set.

6.4.2 Synchro check function

Manual close command or **ARC close command** starts the synchro check function (SC function) and **In progress** signal is set. The start of the SC function is not affected with the **Measurement only** mode already active. If the user sends a command when the SC function is already **In progress**, the command is rejected since the SC function is not possible to be interrupted with another command.

6.4.3 Operation steps

Step 1:

Start: According to **Manual close command** and **ARC close command** inputs one of the **Manual start** or **ARC start.** outputs is set.

Step 2:

Undefined voltages or disconnectors: If the disconnectors or voltages are undefined, the **Unsuccessful execution** signal is set. The procedure is stopped.

Step 3:

Disconnector status conditioned execution: If at least one of the disconnectors on the line or bus bar is opened, the **Close output** command is executed. The procedure is completed.

Step 4:

Dead voltage execution: According to the location (line or bus bar) of dead voltages the **Execution Feeder< Bus<** or **Execution Feeder> Bus<** or **Execution Feeder< Bus>** are set.

Step 5:

If operation mode **Block settings** parameters cause blocking to be active, the **Not allowed** and **Unsuccessful execution** signals are set. The procedure is stopped.

Step 6:

Dead voltage execution: If there is no blocking, the **Close output** is executed. The procedure is completed.

Step 7:

Live voltage execution: The frequency difference is calculated: $DeltaFrek = Frek1 - Frek2$.

If the absolute $DeltaFrek$ is below the set **Max delta frequency sync.** value or the asynchronous mode is disabled then the **Synchronous execution** signal and synchronous mode are set.

If the asynchronous execution is enabled and the $deltaFrek$ is above the set synchronous frequency **Max delta frequency sync.**, the **Asynchronous execution** signal and asynchronous mode are set.

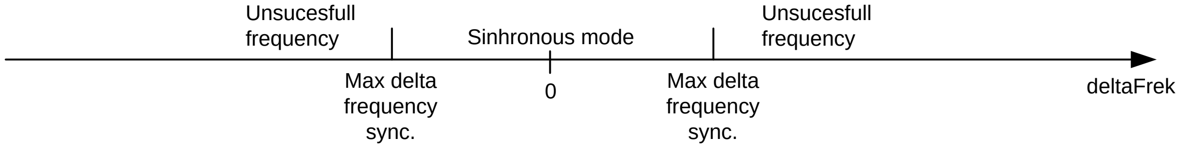

Figure 6.12: Operation mode at **Synchronous mode** = off

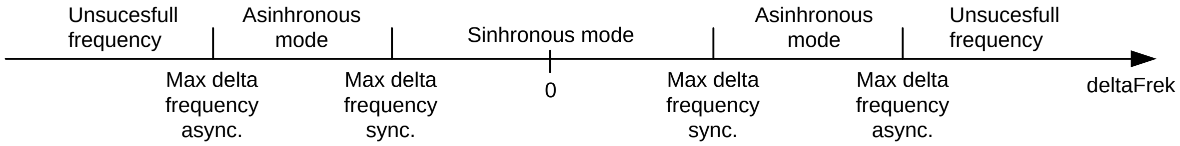

Figure 6.13: Operation mode at **Asynchronous mode** = on

The measurement calculations start and the measurements are calculated to the module outputs in **Measurement** section. Depending on the *deltaFrek* value, synchronous or asynchronous mode is started:

Step 8a: Synchronous mode execution:

The voltage, angle and frequency conditions are checked only once:

Frequency check: If the frequency difference is above the set synchronous frequency tolerance, the **Unsuccessful frequency** signal is set.

Voltages check: If the voltage difference is above the set voltage tolerance, the **Unsuccessful voltage** signal is set.

Angle check: If the angle difference is above the set angle tolerance, the **Unsuccessful angle** signal is set.

If all of the above conditions are successful, the **Close output** command is executed and the procedure is completed.

Step 8b: Asynchronous mode execution:

The voltage, angle and frequency conditions are checked until all are successful or the **Max. duration** time elapses. If all of the conditions are successful within this time, the **Close output** command is executed and the procedure is completed. When the **Max. duration** time elapses, the output signals are set according to the final voltage, angle and frequency condition state:

Frequency check: If the frequency difference is out of asynchronous frequency tolerance, the **Unsuccessful frequency** signal is set.

Voltage check: If the voltage difference is above the set voltage tolerance, the **Unsuccessful voltage** signal is set.

Angle check: If the angle difference is above the set angle tolerance, the **Unsuccessful angle** signal is set.

Step 9:

If any of the voltage, angle and frequency conditions in previous step is unsuccessful, the **Unsuccessful execution** signal is set, the **In progress** signal drops and the procedure stops

6.4.4 Asynchronous mode angle shifting:

In asynchronous mode, the **Close output** command is executed a small fraction of time before feeder and bus are in synchronous state. The cause for this is the fact that closing takes some time to finish. That time is set with the **CB close time** parameter.

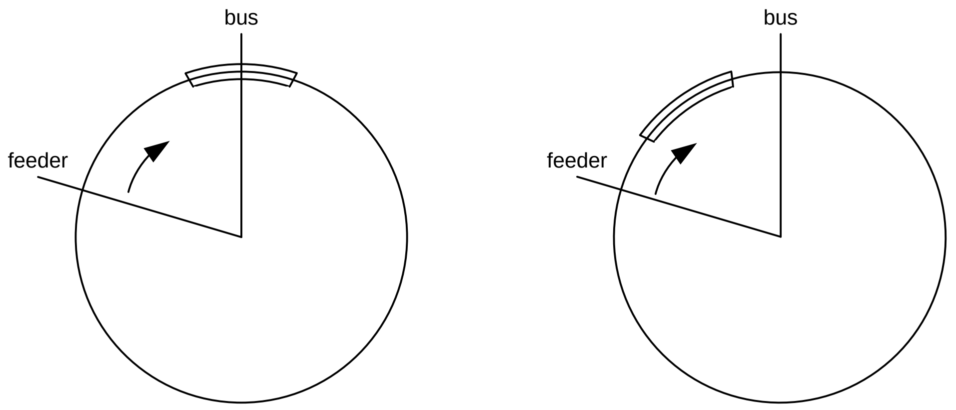

Figure 6.14: Operating range for synchronous and asynchronous execution

6.4.5 Module parameters

**\ Control settings **

Operate mode On, Off	*Off* – function inactive *On* - function active
Live level U> 0.03…**0.80**…1.00 Un	Voltage limit above which the voltage is regarded as present.
Dead level U< 0.03…**0.05**…1.00 Un	Voltage limit below which the voltage is regarded as not present.
Max delta voltage sync. 3…**5**…100 %	Maximum synchronous mode amplitude tolerance.
Max delta angle 3…**10**…80°	Maximum angle tolerance.
Max delta frequency sync. 0.01…**0.10**…2.00 Hz	Maximum synchronous mode frequency tolerance.
Asynchronous mode **On**, Off	*On* – asynchronous more enabled.
Max delta voltage async. 3…**5**…100 %	Maximum asynchronous mode amplitude tolerance.
Max delta frequency async. 0.01…**0.10**…2.00 Hz	Maximum asynchronous mode frequency tolerance.
CB close time 0.00…**0.30**…3.00 s	Circuit breaker closing time.
Max. duration 0.00…**0.30**…3.00 s	Maximum duration time of synchronous closing procedure.
Nominal voltage constant input (analog)	Nominal voltage amplitude in raw value.
Unit frequency constant input (analog)	Frequency 1 Hz in raw value.
Unit angle constant input (analog)	1° angle in raw value.

Inputs

Manual close command input (digital)	Manual synchro-check close command.
ARC close command input (digital)	ARC synchro-check close command.
Measurement only input (digital)	Measurements only mode.

Feeder voltage amplitude input (analog)	Feeder voltage amplitude.
Feeder voltage angle input (analog)	Feeder voltage angle.
Feeder frequency input (analog)	Feeder frequency.
Feeder opened status input (digital)	Feeder opened status.
Feeder closed status input (digital)	Feeder is closed status.
Bus 1 voltage amplitude input (analog)	Bus 1 voltage amplitude.
Bus 1 voltage angle input (analog)	Bus 1 voltage angle.
Bus 1 frequency input (analog)	Bus 1 frequency.
Bus 1 opened status input (digital)	Bus 1 disconnector opened status.
Bus 1 closed status input (digital)	Bus 1 disconnector closed status.
Bus 2 voltage amplitude input (analog)	Bus 2 voltage amplitude.
Bus 2 voltage angle input (analog)	Bus 2 voltage angle.
Bus 2 frequency input (analog)	Bus 2 frequency.
Bus 2 opened status input (digital)	Bus 2 disconnector opened status.
Bus 2 closed status input (digital)	Bus 2 disconnector closed status.

Block settings

Sync. close enabled man. **true**, false	synchronous mode enabled, manual close
Async. close enabled man. true, **false**	asynchronous mode enabled, manual close
Feeder < Bus < enabled man. **true**, false	close command is enabled when the feeder and the bus bar are without voltage, manual close
Feeder > Bus < enabled man. **true**, false	close command is enabled when the feeder has voltage and the bus bar is without voltage, manual close
Feeder < Bus > enabled man. **true**, false	close command is enabled when the feeder is without voltage and the bus bar has voltage, manual close
Sync. close enabled ARC **true**, false	synchronous mode enabled, ARC
Async. close enabled ARC true, **false**	asynchronous mode enabled, ARC
Feeder < Bus < enabled ARC **true**, false	close command is enabled when the feeder and the bus bar are without voltage, ARC
Feeder > Bus < enabled ARC **true**, false	close command is enabled when the feeder has voltage and the bus bar is without voltage, ARC
Feeder < Bus > enabled ARC **true**, false	close command is enabled when the feeder is without voltage and the bus bar has voltage, ARC
Bus2 enabled true, **false**	Bus bar 2 is enabled.
Feeder not valid input (digital)	Feeder voltage is not valid.
Bus1 not valid input (digital)	Bus bar 1 voltage is not valid.
Bus2 not valid input (digital)	Bus bar 2 voltage is not valid.

Outputs

In progress output (digital)	Synchro-check is in progress.
Pulse time 0.00…**0.50**…100.00 s	Length of the **Close output** pulse.
Close output output (digital)	Close command.
Manual start output (digital)	Pickup after the manual close (5 seconds signal).
ARC start output (digital)	Pickup after the ARC close (5 seconds signal).
Not allowed output (digital)	SC command is not allowed (5 seconds signal).
Execution Feeder> Bus< output (digital)	*Feeder> Bus<* execution (5 seconds signal).
Execution Feeder< Bus> output (digital)	*Feeder< Bus>* execution (5 seconds signal).
Execution Feeder< Bus< output (digital)	*Feeder< Bus<* execution (5 seconds signal).
Asynchronous execution output (digital)	Synchronous execution mode (5 seconds signal).
Asynchronous execution output (digital)	Asynchronous execution mode (5 seconds signal).
Unsuccessful execution output (digital)	The execution failed (5 seconds signal).
Unsuccessful voltage output (digital)	The execution failed due to voltage amplitude (5 seconds signal).
Unsuccessful frequency output (digital)	The execution failed due to frequency (5 seconds signal).
Unsuccessful angle output (digital)	The execution failed due to angle (5 seconds signal).

Measurements

Undefined feeder output (digital)	Feeder voltage is undefined.
Undefined bus output (digital)	Bus bar voltage is undefined.
Active bus 1 output (digital)	Bus bar 1 is active.
Active bus 2 output (digital)	Bus bar 2 is active.
Amplitude delta output (analog)	Voltage amplitude difference.
Angle delta output (analog)	Voltage angle difference.
Frequency delta output (analog)	Frequency difference.
Amplitude synchronous status output (digital)	Amplitude is synchronous.
Angle synchronous status output (digital)	Angle is synchronous.
Frequency synchronous status output (digital)	Frequency is synchronous.
Synchronous state output (digital)	Synchronous state.

6.5 Function blocks

For execution of simple logical operations e.g. logical AND, OR, etc. logical function blocks are used. Blocks allow simple linking of two or more signals to inputs of a specific operator, calculation of a logical **Output** function and its inverted value (**Inverted output**).

The blocks selection includes a broad spectrum of operators: from simple ones, such as the choice and comparison operators (*AND*, *OR,...*), to the complex ones, such as the conversion blocks (BCD and BS coding). Blocks are divided in the following categories:

- Choice and comparison elements
  - AND, OR, XOR, NOT
  - MIN, MAX
  - GT, GE, EQ, LE, LT, NE
  - SEL
- Bistable elements
  - RS-FF
  - SR-FF
  - D-FF
  - T-FF
- Conversion elements
  - BCD encoder, BCD decoder
  - BS decoder, BS encoder
- Counters
  - CTU
  - CTD
  - CTUD
- Timers
  - TP
  - TON
  - TOF
- Numeric functions
  - ABS
  - SQRT
  - Live zero
- Arithmetic operations
  - ADD, SUB
  - MUL, DIV
  - AVRG

If not stated otherwise, the following rules apply:

- the non-linked inputs are ignored,
- if only one input is linked, the output result equals the input.
- if an overflow happens on the output, the output gives the highest possible value,
- the **Inverted output** is the **Output** inverted value.

6.5.1 Choice and comparison elements

6.5.1.1 Element: AND

The AND operation is performed between all the **Input...** signals and the result is written on the **Output**.

Input 1…32 input (digital)	Inputs of the function.
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.1.2 Element: OR

The OR operation is performed between the **Input...** and the result is written on the **Output**.

Input 1…32 input (digital)	Inputs of the function.
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.1.3 Element: XOR

The XOR operation is performed between the **Input...** and the result is written on the **Output**.

Input 1…4 input (digital)	Inputs of the function.
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.1.4 Element: NOT

The **Input** is inverted and the result is written on the **Output**.

Input input (digital)	Function input
Output output (digital)	Result of the function

6.5.1.5 Element: MIN

The **Output** is the minimal value of all **Input...**.

Input 1...32 input (analog)	Inputs of the function.
Output output (analog)	Minimal value.

6.5.1.6 Element: MAX

The **Output** is the maximal value of all **Input...**.

Input 1...32 input (analog)	Inputs of the function.
Output output (analog)	Maximal value.

6.5.1.7 Element: GT

The **Output** is set, if each **Input...** is larger than its lower neighbour. If only one input is linked, the comparison is made with a zero.

Input 1...4 input (analog)	Inputs of the function.
Output output (digital)	Each input is larger than its lower neighbour.

6.5.1.8 Element: GE

The **Output** is set, if each **Input...** is larger than or equals its lower neighbour. If only one input is linked, the comparison is made with a zero.

Input 1...4 input (analog)	Inputs of the function.

Output output (digital)	Each input is larger than or equals its lower neighbour.

6.5.1.9 Element: EQ

The **Output** is set, if all **Input...** are equal. If only one input is linked, the output is always set.

Input 1...32 input (analog)	Inputs of the function.
Output output (digital)	All inputs are equal.

6.5.1.10 Element: LE

The **Output** is set, if each **Input...** is smaller than or equals its lower neighbour. If only one input is linked, the comparison is made with a zero.

Input 1...4 input (analog)	Inputs of the function.
Output output (digital)	Each input is smaller than or equals its lower neighbour.

6.5.1.11 Element: LT

The **Output** is set, if each **Input...** is smaller than its lower neighbour. If only one input is linked, the comparison is made with a zero.

Input 1...4 input (analog)	Inputs of the function.
Output output (digital)	Each input is smaller than its lower neighbour.

6.5.1.12 Element: NE

The **Output** is set, if **Input1** and **Input 2** are not same.

Input 1 input (analog)	Input 1 of the function.
Input 2 input (analog)	Input 2 of the function.
Output output (digital)	The inputs are not same.

6.5.1.13 Element: SEL

If the **Selector** equals 0, the **Output** has the same value as **Input 0**. If not, it has the same value as **Input 1**.

Input 0 input (analog)	The value when selector value is 0.
Input 1 input (analog)	The value when selector value is 1.
Selector input (digital)	The input for selector.
Output output (analog)	Selected value.

6.5.2 Bistable elements

6.5.2.1 Element: RS-FF

The **Input S** sets the **Output**, and the **Input R** drops it. In case when both inputs are present at the same time, the **Output** is dropped.

Table 6.5: RS flip flop

Set	Reset	Output
1	0	1

0	1	0
1	1	0

Input R input (digital)	Function input - Reset
Input S input (digital)	Function input - Set
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.2.2 Element: SR-FF

The **Input S** sets the **Output**, and the **Input R** drops it. In case when both inputs are present at the same time, the **Output** is set.

Table 6.6: SR flip flop

Set	Reset	Output
1	0	1
0	1	0
1	1	1

Input R input (digital)	Function input - Reset
Input S input (digital)	Function input - Set
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.2.3 Element: D-FF

When the **Trigger** sets (rising edge), the **Output** is overwritten by **Input D** value.

Input D input (digital)	Input.
Trigger input (digital)	Function trigger.
Output output (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.2.4 Element: T-FF

When the **Input T** is set and the **Trigger** sets (rising edge), the **Output** value is inverted.

Input T input (digital)	Input.
Trigger input (digital)	Function trigger.
Output static (digital)	Result of the function
Inverted output output (digital)	Inverted result of the function

6.5.3 Conversion

6.5.3.1 Element: BCD encoder

Block calculates a BCD8421 code into a decimal value. The **Output** with 8 bits can have values between 0 and 99.

If an invalid combination is set on **Bit n** inputs, the **Invalid** output is set and the old value remains on the **Output**. Invalid value is a state, where number is larger than 9 in one quadruple of bits.

Usually, the input signals is set from some mechanical element. The **Freeze** input is used for prevention of false calculation at temporary states where the input bits are not all changed at the same time, but a certain time is need for the change to be made. As long as **Freeze** input is set, the output value is frozen on the last calculated value, irrespective of input bits. When **Freeze** input drops, the output is calculated.

This element is usually used when reading tap changer positions.

Table 6.7: BCD coding for the first four bits

Bit 1	Bit 2	Bit 4	Bit 8	Output
0	0	0	0	0
1	0	0	0	1
0	1	0	0	2
1	1	0	0	3
0	0	1	0	4
1	0	1	0	5
0	1	1	0	6
1	1	1	0	7
0	0	0	1	8
1	0	0	1	9

Bit 1 input (digital)	BCD code first bit.
Bit 2 input (digital)	BCD code second bit.
Bit 4 input (digital)	BCD code third bit.
Bit 8 input (digital)	BCD code fourth bit.
Bit 10 input (digital)	BCD code fifth bit.
Bit 20 input (digital)	BCD code sixth bit.
Bit 40 input (digital)	BCD code seventh bit.
Bit 80 input (digital)	BCD code eighth bit.
Freeze input (digital)	Freezes the **Output**.
Output output (analog)	BCD code value.
Invalid output (digital)	There is an invalid combination present on the inputs.

6.5.3.2 Element: BCD decoder

BCD8421 code calculation from the decimal value into individual output bits. This element is an inverse function of the BCD encoder. If an invalid value is set on the **Input** , the **Over range** output is set, and the old value remains on the **Bit n** outputs. Invalid value is a state, where **Input** is outside 0..99 range.

Example: This element is for example used when determining Setting groups. The analog output value is transformed into two bits: A = 0 = 00, B = 1 = 01, C = 2 = 10, D = 3 = 11.

Input input (analog)	BCD code value.
Bit 1 output (digital)	BCD code first bit.
Bit 2 output (digital)	BCD code second bit.
Bit 4 output (digital)	BCD code third bit.
Bit 8 output (digital)	BCD code fourth bit.
Bit 10 output (digital)	BCD code fifth bit.
Bit 20 output (digital)	BCD code sixth bit.
Bit 40 output (digital)	BCD code seventh bit.
Bit 80 output (digital)	BCD code eighth bit.
Over range output (digital)	The input value is outside the allowed limits 0...99.

6.5.3.3 Element: BS decoder 4,3,2

Decoding a binary number into one consecutive **Output...** signal. Binary number is connected to inputs **Input bit...** bit by bit. The **Analog out** output is the analog value of the binary number. Number of inputs and outputs may vary, depending on element used.

Table 6.8: BS decoding

In 1	In 2	...	Out 1	Out 2	Out 3	Out 4	...	Analog out
0	0	...	1	0	0	0	...	0
1	0	...	0	1	0	0	...	1
0	1	...	0	0	1	0	...	2
1	1	...	0	0	0	1	...	3
...	...	...	...	...	...	...	...	...

Example: If there is 0101 value on the Input bit..., there is 0000 0000 0010 0000 value on the Output... and a 5 value on the Analog Output.

Input bit 0 input (digital)	Input string bits.
...	...
Input bit 3 input (digital)	Input string bits.
Output 0 output (digital)	Input value indicator.
...	...
Output 15 output (digital)	Input value indicator.
Analog output output (analog)	Input analog value.

6.5.3.4 Element: BS encoder 4

Coding of one consecutive input **Input...** signal into **Out...** binary number and an **Analog out** output decimal number. This element is an inverse function of the BS decoder. In case an invalid value appears on the input, the outputs are not changed and the old value remains on outputs. Number of inputs and outputs may vary, depending on element used.

Table 6.9: BS encoding

In 1	In 2	In 3	In 4	...	Out 1	Out 2	...	Analog out
1	0	0	0	...	0	0	...	0
0	1	0	0	...	1	0	...	1
0	0	1	0	...	0	1	...	2
0	0	0	1	...	1	1	...	3
...	...	...	...	...	...	...	...	...

Example: If there is 0000 0000 0010 0000 value on the Input..., there is 0101 value on the Output bit... and a 5 value on the Analog Output.

Input 0 input (digital)	Input string bits.
...	...
Input 15 input (digital)	Input string bits.
Output bit 0 output (digital)	Input value indicator.
...	...
Output bit 3 output (digital)	Input value indicator.
Analog output output (analog)	Input analog value.

6.5.4 Counters

6.5.4.1 Element: CTU

The **Count up** counter counts the changes on input signal (rising edge). The number of changes is counted on the **Value** output. When the counter value is larger than or equals **Set value** setting, the **Greater than Set** output is set. If the **Reset to zero** input is set, the **Value** counter value is reset to 0. The counter operates when the **Value** is smaller than the **Max value** set.

Count up input (digital)	Trigger.
Reset to zero input (digital)	Resetting the counter to 0.
Set value input (analog)	The value for comparison.
Max value 0...**1000**...	The counter maximal value.
Value counter (analog)	Counter value.
Greater than Set output (digital)	The counter value is larger than or equals the **Set value**.

6.5.4.2 Element: CTD

Similar as the CTU, but the counter counts downwards.

Count down input (digital)	Trigger.
Reset to Set input (digital)	Resetting the counter to **Set value**.
Set value input (analog)	The value for comparison.
Min value ...-1000...**0**	The counter minimal value.
Value counter (analog)	Counter value.

Less than zero output (digital)	The counter value is smaller than or equals 0.

6.5.4.3 Element: CTUD

Similar as the CTU, but the counter counts up- and downwards.

Count up input (digital)	The trigger for counting upwards.
Count down input (digital)	The trigger for counting downwards.
Reset to zero input (digital)	Resetting the counter to 0.
Reset to Set input (digital)	Resetting the counter to **Set value**.
Set value input (analog)	The value for comparison.
Max value 0...**1000**...	The counter maximal value.
Min value ...-1000...**0**	The counter minimal value.
Value counter (analog)	Counter value.
Greater than Set output (digital)	The counter value is larger than or equals the **Set value**.
Less than zero output (digital)	The counter output value is smaller than or equals 0.

6.5.5 Timers

A timer can be set in minutes **Set minutes** and in seconds **Set seconds**. The join time of a timer is a sum of both parameters. The elapsed time of a timer is written on the **Elapsed minutes** and **Elapsed seconds** outputs.

All timers have the same set of parameters:

Input input (digital)	Trigger.
Set minutes **0**...10.080	Timer setting for minutes.
Set seconds 0.000...**1.000**...59.999	Timer setting for seconds.
Elapsed minutes counter	Timer value for minutes.
Elapsed seconds counter	Timer value for seconds.
Output output (digital)	Timer output.

6.5.5.1 Element: TP

The timer starts when the **Input** sets. The **Output** is set while the timer is running. The **Output** drops when the timer runs out. The timer cannot be interrupted. Timer operation diagram is shown in Figure 1.1.

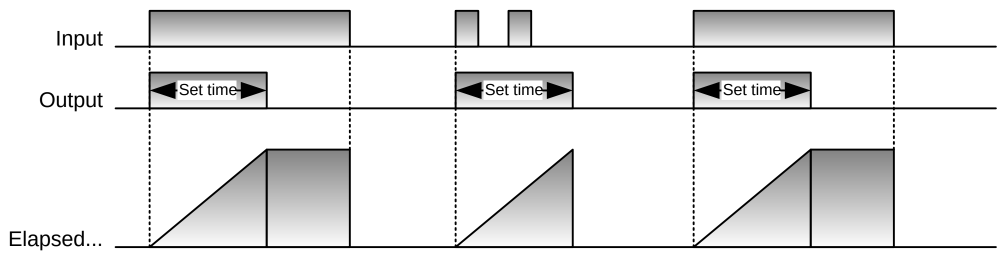

Figure 6.15: TP timer operation diagram

6.5.5.2 Element: TON

The timer is running when the **Input** is set. The **Output** is set when the timer runs out. The **Output** drops when the **Input** drops. Timer operation diagram is shown in Figure 1.2.

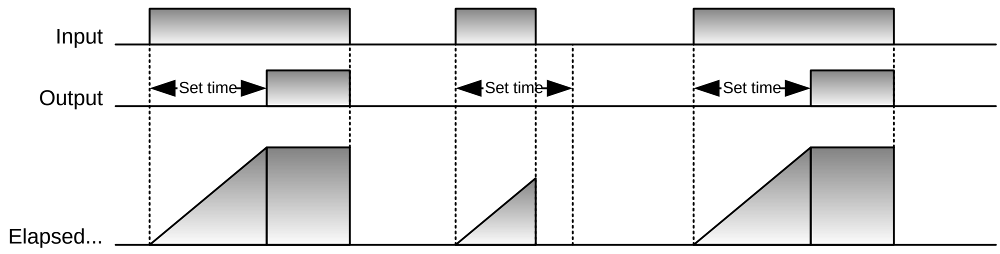

Figure 6.16: TON timer operation diagram

6.5.5.3 Element: TOF

The timer starts when the **Input** drops, and is running while the **Input** is dropped. The **Output** is set when the **Input** is set. The **Output** drops when the timer runs out. Timer operation diagram is shown in Figure 1.3.

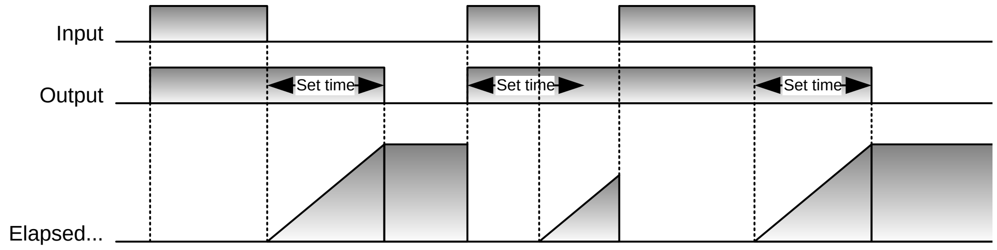

Figure 6.17: TOF timer operation diagram

6.6 Processing digital signals

The module is intended for advanced multiple digital signals processing. Usually it is used for advanced digital inputs or outputs configuration.

To every signal brought on **Input** it is possible to set additional values and in what way its changes should be reflected on **Output**.

For the input time delay on the output a parameter **Minimal output time** should be set. This setting is useful when an alarm should be set on a signal, which must be present for a fixed time, e.g. spring charge fail alarm.

Signal operation mode is set with **Type** parameter. It is possible to choose from monostable (*Mono)*, *Bistable*, *Latched* and *Direct* operation mode. At device start-up all module outputs are down, their value is 0. Time diagrams of individual operation mode are shown in following figures:

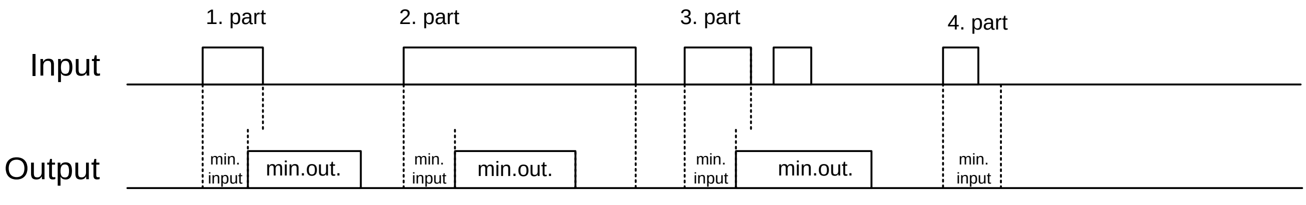

Figure 6.18: Pulse signals - Monostable operation

Monostable operation: **Output** is pulse with constant length of **Minimal output time**, irrespective of **Input** signal length.

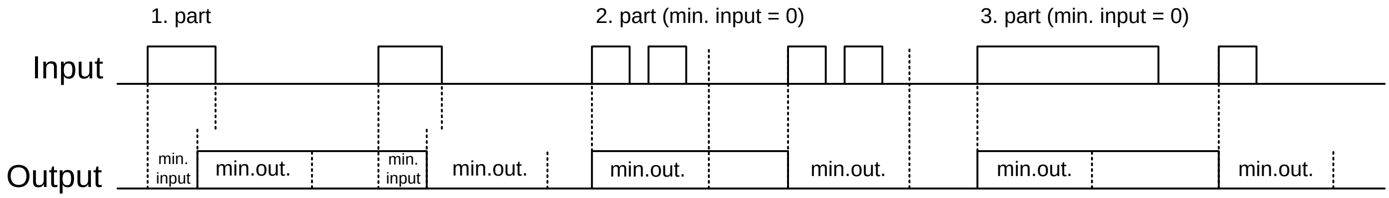

Figure 6.19: Pulse signals - Bistable operation

Bistable operation: **Output** alternately changes its value (it alternates) with each pulse on **Input**. **Output** can change its value only after **Minimal output time** since the last change.

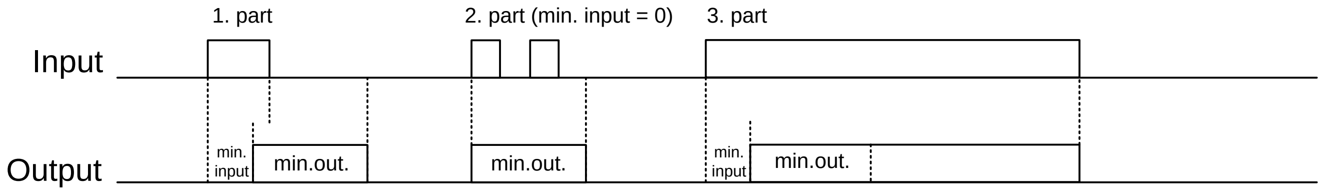

Figure 6.20: Pulse signals - Direct operation

Direct operation: **Output** si set for the same time as **Input**, but at least for **Minimal output time**.

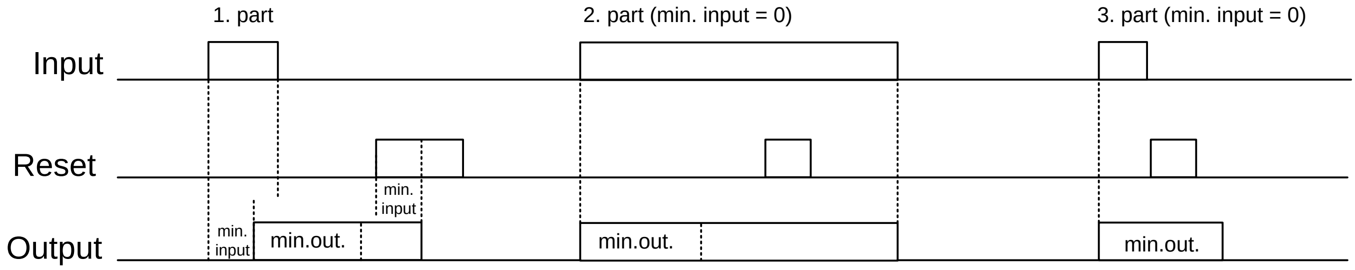

Figure 6.21: Pulse signals - Latched operation

Latched operation: **Output** is set with a pulse on **Input** and drops with a pulse on input **Reset** and fallen **Input**. Operation is similar to logical FlipFlop element with priority set input.

Input input (digital)	Command request (one-bit or 1st input of two-bit)
Input 2 input (digital)	Command request (2nd input of two-bit)
Reset input (digital)	Request for locked one-bit command reset.
Type ***Mono***, Bistable, Direct, Latched, DoubleBit	*Mono* - monostable command *Bistable* – bistable command *Direct* – direct command *Latched* – locking *DoubleBit* – two-bit command
Minimal input time **0.00**…100.00 s	Minimal input pulse length (**Input, Input2, Reset**). If the input pulse is shorter, it is rejected.

Minimal output time 0.00…**0.50**…100.00 s	Minimal output pulse length (**Output**, **Output2**).
Output output (digital)	Command execution (one-bit or 1st output of two-bit)
Output 2 output (digital)	Command execution (2nd output of two-bit)

6.6.1 Numeric functions

6.6.1.1 Element: ABS

Input input (analog)	Input.
Output output (analog)	The output absolute value.

6.6.1.2 Element: SQRT

Input input (analog)	Input.
Output output (analog)	The output square root value.

6.6.1.3 Element: Live zero

Live zero element converts input signal by two different linear factors, depending in inputs value. Output characteristics are set by parameters for zero start by **Live zero** parameter and knee point by **Input knee** and **Output knee** parameters.

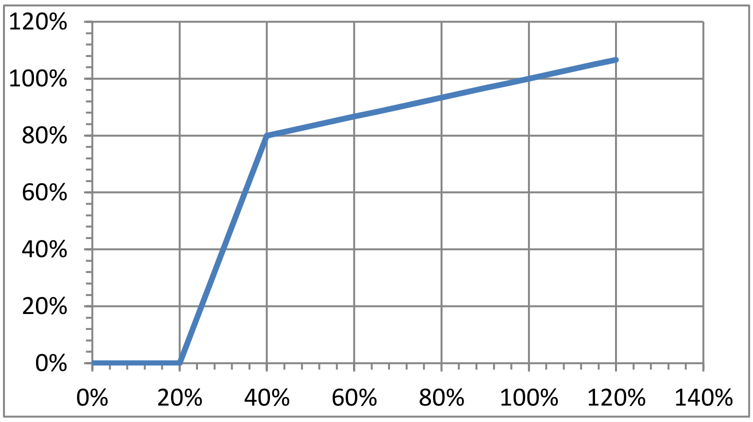

Figure 6.22: Example of Live zero transformation

The **Invalid output** is set when value of **Input** is less than input zero value **Live zero**.

Live zero 0.0...**20.0**...99.0% nom	Input zero value.
Input knee 0.0...**50.0**...99.0% nom	Knee input value.
Output knee 0.0...**70.0**...99.0% nom	Knee output value.
Input input (analog)	Input value.
Nominal value constant input (analog)	Nominal input value in bits.
Output output (analog)	Output value.
Invalid output output (digital)	Input value is outside of range.

6.6.1.4 Element: Scale

Input value is scaled and relayed to same indexed **Output…**, by following equations:

$$Y = kX + n$$

$$k = \frac{Y_2 - Y_1}{X_2 - X_1}$$

$$n = Y_1 - k \cdot X_1 = Y_2 - k \cdot X_2$$

Where:

X.............. **Input** value
Y.............. **Output** value
X_1, X_2 .... parameters **Min input value, Max input value**
Y_1, Y_2......... parameters **Min output value, Max output value**

Min input value -1000,00 … **1,00**…1000,00 x nom	Minimum value of input value.
Max input value -1000,00 … **10,00**…1000,00 x nom	Maximum value of input value.
Min output value -1000,00 … **1,00**…1000,00 x nom	Minimum value of output value.
Max output value -1000,00 … **10,00**…1000,00 x nom	Maximum value of output value.
Nominal input input (analog)	Nominal input value. Default value is 1 if not connected.
Nominal output input (analog)	Output factor. Default value is 1 if not connected.

Value 1…20	
Input input (analog)	Input value.
Output output (analog)	Output value.
Valid output (analog)	Indication of input value inside valid range.

6.6.1.5 Element: Dead band

On start-up, **Input** value is relayed to **Output**. On every change of **Output** value the **±Dead band** range is re-set. When **Input** value reaches or exceeds dead band limits, the **Input** value is relayed to **Output**.

If the value of **Input** value reaches within zero dead band range, the **Outputs** value is zero and the **±Zero Dead band** applies.

Dead time is the minimum time between two changes of the **Output** value.

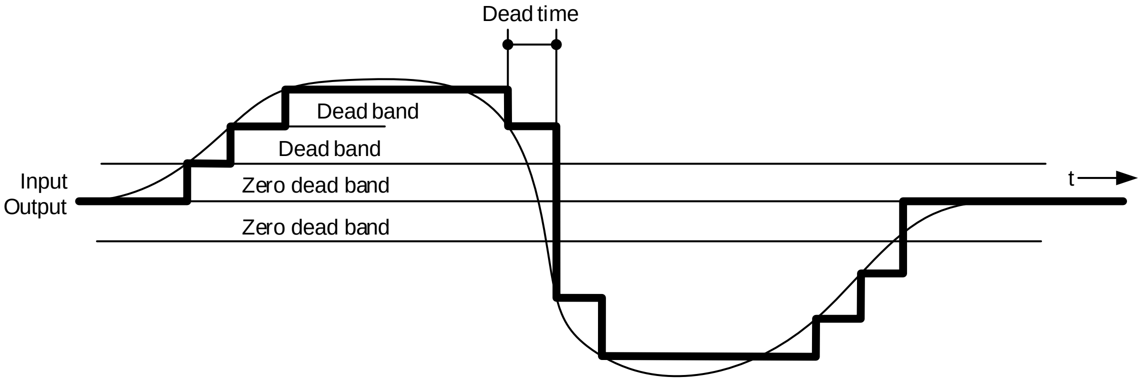

Figure 6.23: Dead band function

Dead band 1…**5**…10000	Dead band limits in raw value.
Zero dead band 1…**10**…10000	Dead band limits around zero in raw value.
Dead time 0…**100**…10.000 ms	Dead time between output changes.

Value 1…10

Input input (analog)	Input value.
Output output (analog)	Output value.

6.6.2 Arithmetic operations

6.6.2.1 Element: ADD

The sum of all **Input...** is calculated on the **Ouput**.

$$OUT = IN_1 + IN_2 + \cdots$$

Input 1...32 input (analog)	Inputs.
Output output (analog)	The sum of all inputs.

6.6.2.2 Element: MUL

The product of all **Input...** is calculated on the **Ouput**.

$$OUT = Scale \cdot IN_1 \cdot IN_2 \cdot \ldots$$

Input 1...32 input (analog)	Inputs.
Scale 0.000001...**1**...1000.000000	Product calculation.
Output output (analog)	Calculated product of all inputs.

6.6.2.3 Element: SUB

The difference of inputs is calculated on the **Output**.

$$OUT = IN_1 - IN_2$$

Input 1 input (analog)	1st input.

Input 2 input (analog)	2nd input.
Output output (analog)	The difference of inputs.

6.6.2.4 Element: DIV

The scaled quotient of inputs is calculated on the **Output**. If the **Input 2** value is 0, the **Output** equals 0.

$$OUT = Scale \cdot \frac{IN_1}{IN_2}$$

Input 1 input (analog)	1st input.
Input 2 input (analog)	2nd input.
Scale 0.001...**1.000**...1000,000.000	Quotient scaling.
Output output (analog)	Scaled inputs quotient.

6.6.2.5 Element: AVRG

The average value of all linked inputs is calculated in the **Output**.

$$OUT = \frac{\sum_{n}^{i=1} IN_i}{n}$$

Input 1...32 input (analog)	Inputs.
Output output (analog)	The average value of all linked inputs.

7 Communication

7.1 General notes on communication

The NEO 3000 devices can have several communication protocols which enable communication via serial and network connections. All settings are written into the device configuration, that is transferred to the device through the *Initialization* procedure. You can find the communication settings in the following files on device: *iec61850.cid*, *inputs.xml*, *Settings.xml*, *neo3000.conf* and *system_settings.xml*.

7.1.1 Network interfaces settings

During the project design, the project network configuration, services for time synchronization and file transfer service are set. On the device the desired network typology through which the device will communicate is chosen and the addresses are set.

7.1.1.1 Star network topology

The default setting of the NEO 3000 devices topology setting is of star type. In case when the device has two network interfaces, the settings for both are the same. Only one network interface can be used at a time, while the second one is a backup. In case of a failure or defect of the first network interface. or during testing, a simple switch to the second interface in possible.

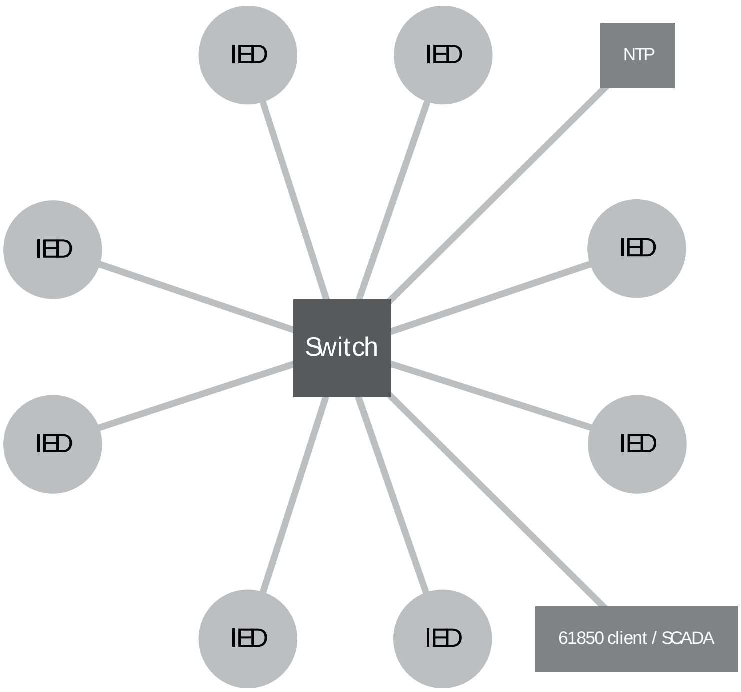

Figure 7.1: Network Topology: star

7.1.1.2 Double star network topology

Double star topology enables redundant communication with the master systems and isolation of horizontal communication between the devices in one branch. It also enables complete physical isolation between different control systems, e.g. when you want to enable simultaneous communication with the device for two, in terms of business, strictly separated subjects, which demand this separation in their security policy.

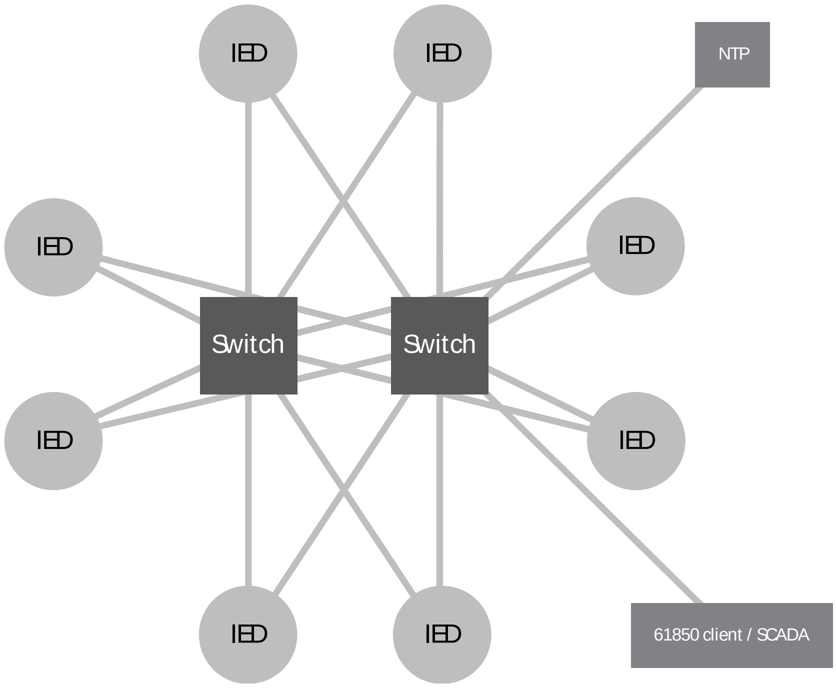

Figure 7.2: Network Topology: double star

7.1.1.3 RSTP ring network typology

The Rapid Spanning Tree Protocol (RSTP) enables automatic redundant network connection between devices. All network equipment must support the use of this protocol.

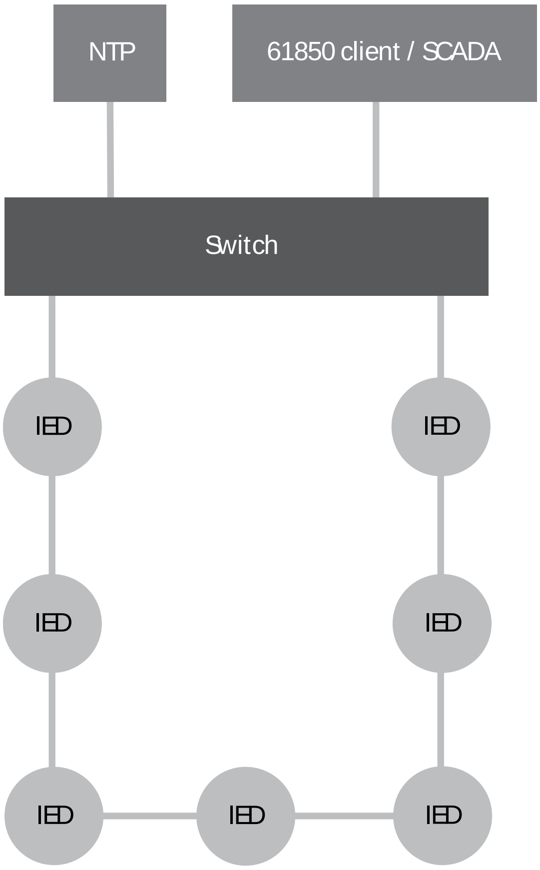

Figure 7.3:Network Topology: ring (RSTP)

7.1.2 Clock synchronization

The device measures time on the basis of a quartz oscillator or with a dedicated integrated circuit with a built-in calendar. Time measuring on the device runs independently of the master systems. Typically every clock has a certain drift relative to the real time. By clock synchronization, the clock between devices is synchronized.

When a TCP/IP network connection is available, recommended use is the NTP protocol (Network Time Protocol) for the project devices time synchronization, which is the default synchronization mode. The synchronization mode is chosen with the section *Time synchronization* parameters in the device properties. With **Protocol** parameter, we can choose between the NTP protocol, SNTP protocol, which is simpler, less accurate and the SCU protocol. The latter enables clock synchronization via standard protocols: IEC 50870-101, 104, DNP3 or Modbus. The source is chosen in communication protocol settings. Use *Communication* tab, right-click in the main window on the root, e.g. DNP3 protocol, command *Time synchronization source*. In the device properties under the **Protocol** parameter the **SCU source** = *DNP3* should be set. In this mode the **Device local time** = *Enable* should be set. The simultaneous synchronization with the NTP servers in the SCU mode is not possible. Actual clock synchronization period according to protocol must always be shorter than the **Refresh period** parameter, or else the good time synchronization state will not be achieved. The clock synchronization system inside the device automatically averages the time and compensates for the drift. To achieve reliable and stable synchronization, synchronization process may take from several minutes to several hours.

7.1.3 Parameters

7.1.3.1 Parameters for network project settings and services

/ SubStation / Project network	
Network name String	Network name.
Address 255.255.255.255	Network IP address.
Subnet mask 255.255.255.255	Network mask IP address.
Broadcast address 255.255.255.255	Broadcast IP address.
Default gateway 255.255.255.255	Communication gateway IP address.
Virtual LAN ID 0..4095	Virtual network identifier.

/ SubStation / Time synchronisation	
Time zone Location, GMT +/-, Others	Time zone. Location: Choice of all countries in the world. GMT +/-: GMT-12 to GMT+14. Others: Choice of named timezones.
NTP server IP1...IPn 255.255.255.255	NTP server IP address.

/ Device / Network settings	
Topology Star, Double star, Ring (RSTP)	Choice of the network topology.
Network 255.255.255.255	Sub-network name. Only the choice between those, defined on the substation level is possible.
Network address 255.255.255.255	IP address, limited according to the chosen sub-network (Network).

/ Device / Network settings / Alias	
Network 255.255.255.255	Choice of Subnetwork address, which are defined on the substation level.
Network address 255.255.255.255	IP address, limited according to the chosen sub-network (Network).

/ Device / Time synchronisation	
Protocol NTP, SNTP, SCU	Chosing the protocol for time synchronization.
Device local time NTP, SNTP	Choosing the device stabilization protocol for SCU synchronization.
NTP server 255.255.255.255	IP address of servers for NTP, SNTP synchronization protocol.
SCU source <protocol>	The chosen communication protocol for SCU synchronization.

Refresh period 8, 16, 32, 64, 128, 256, 512, 1024, 2048, 4096, 8192, 16384, 32768, 65536, 131072	Refresh time period for SCU synchronization.

7.2 Communication hardware

7.2.1 Communication network port (ETH)

Network port connector is a standard RJ45 connector. The device can be connected into the LAN network or directly to a computer via a standard UTP cable. If the computer does not support cable detection, a CROSSOVER UTP cable should be used for direct connection between device and computer.

Table 7.1: Description of ETHx connector pins according to EIA/TIA 568B diagram

Pin	100 Mb/s	1 Gb/s
1	TX+	TX+
2	TX-	TX-
3	RX+	RX+
4	n.c.	BI+
5	n.c.	BI-
6	RX-	RX-
7	n.c.	BI+
8	n.c.	BI-

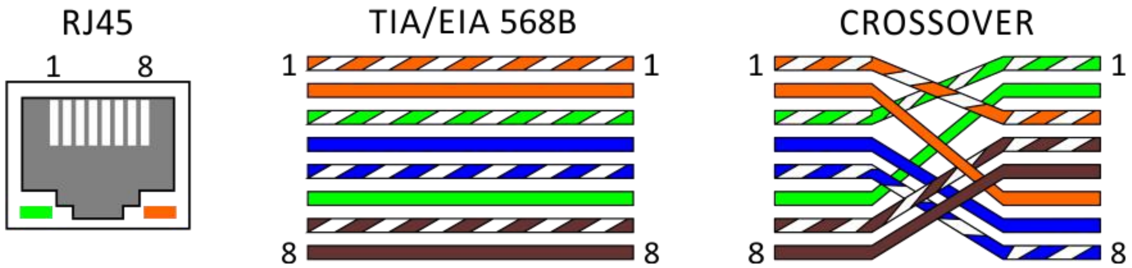

Figure 7.4: ETH RJ45 network port connector and wiring

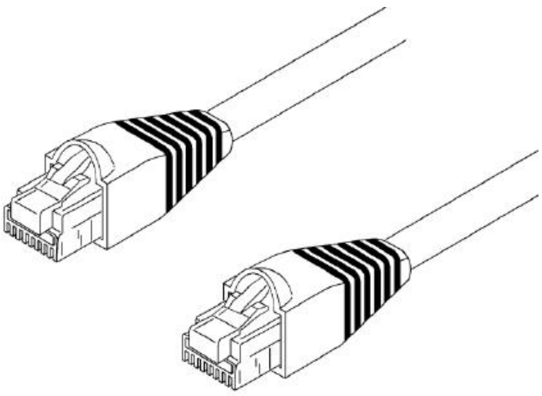
Figure 7.5: ETH cable for ETH1 network port

7.2.2 PSM – LDU network port

Network port connector is a standard RJ45 connector. The device can be connected into the LAN network or directly to a computer via a standard UTP cable. If the computer does not support cable detection, a CROSSOVER UTP cable should be used for direct connection between device and computer.

Device initialisation with NEO3000 Power System Manager (PSM) can be done only thru LDU or PSM network adapter. On LDU is placed on a bottom left side and on connection side of the device it is on the bottom of communication card. Connector is a standard RJ45 connector.

Wiring is reduced to two pairs (100Mb/s, Crossover). Connector on communication card contains two Ethernet connections, one for remote LDU, the other for PC connection with PSM. It must be specially wired as shown in next picture:

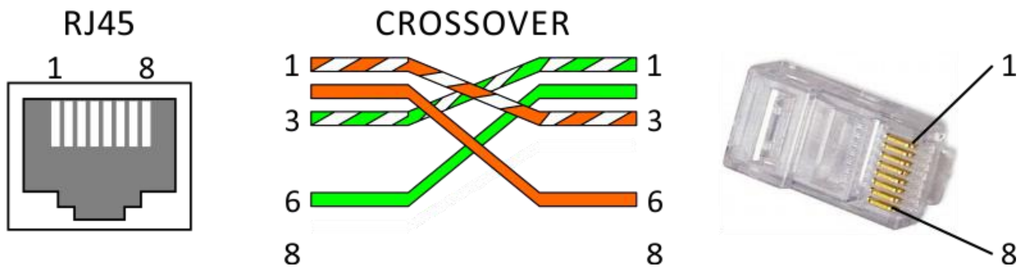

Figure 7.6: LDU-PSM RJ45 network port connector and wiring

7.2.3 RS-232 serial port (COM1 and COM2)

Serial port connector is a standard DB9 connector. Both serial ports COM1 and COM2 support all modem signals. A standard 2x DB9M cable is used for connection to a modem, and a DB9 extension cable (1x DB9F, 1x DB9M) is used for connection to a computer.

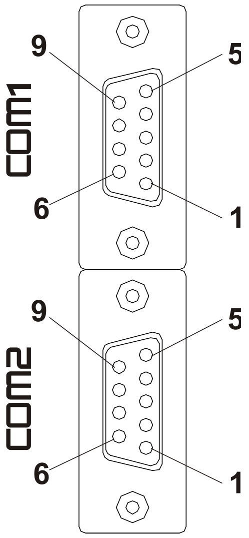

Figure 7.7: Connector of RS232 serial COM1 and COM2 DB9F port

Table 7.2: COM1 and COM2 connection pins description

Pin	Description
1	DCD
2	RXD
3	TXD
4	DTR
5	GND
6	DSR

7	RTS
8	CTS
9	RI

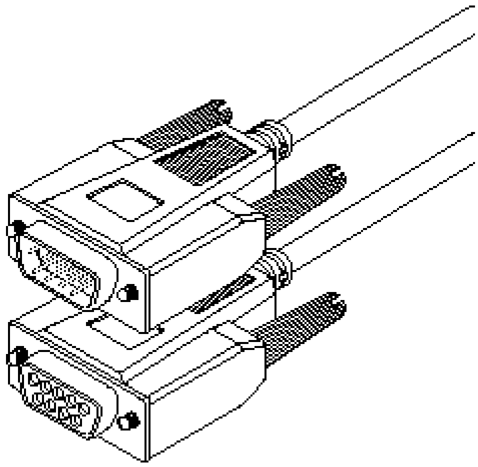

Figure 7.8: Serial cable DB9

7.2.4 RS-485 serial port (COM2)

Serial port connector is a standard MSTB 2,5/ 3-ST-5,08 connector.

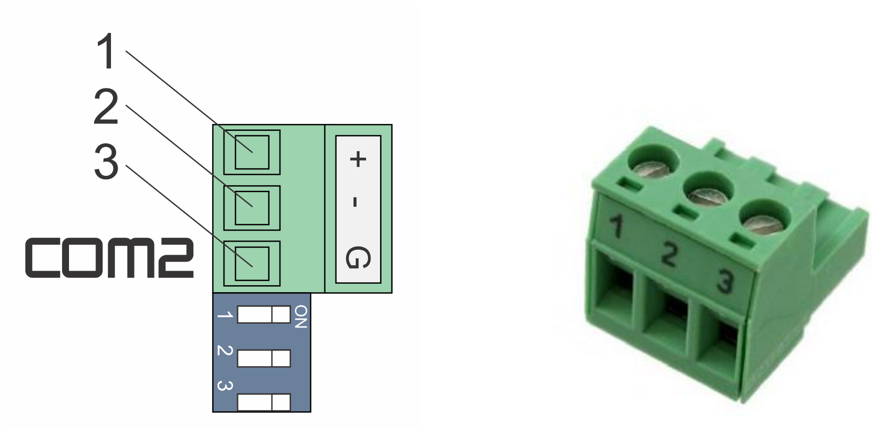

Figure 7.9: Connector MSTB of RS485 COM2 port

Table 7.3: COM2 connection pins description

Pin	Description
1	B (+)
2	A (-)
3	C (G)

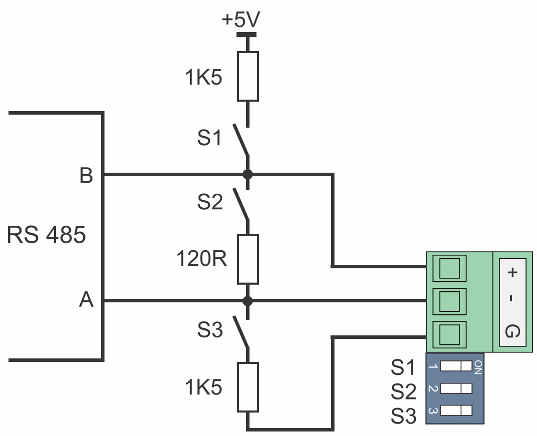

Figure 7.10: 485 stabilization and termination scheme

Table 7.4: Switch description

Switch	Description
S1	B line stabilization
S2	Termination between lines
S3	A line stabilization

Termination between RS485 lines is necessary to switch on the first and the last node in row (S2 switch).

For better performance switch line stabilization on in last node in row (S1 and S3 switch).

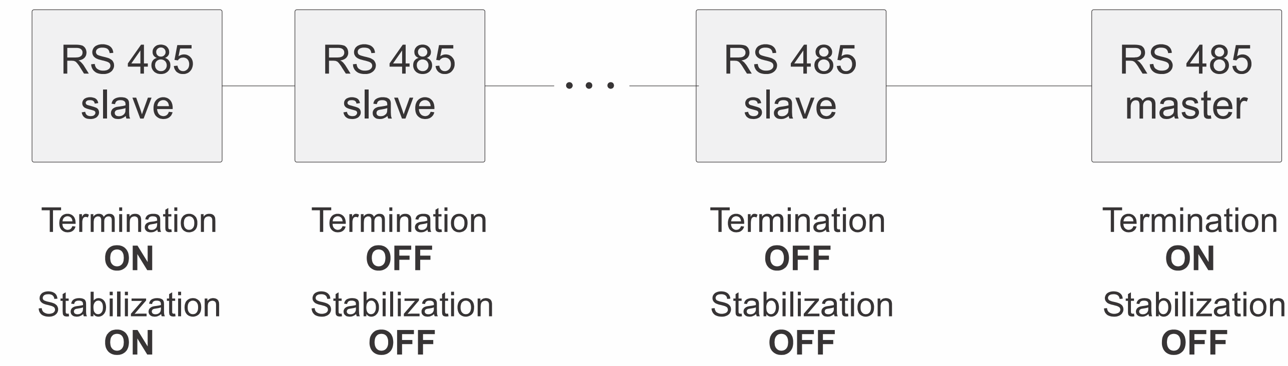

Figure 7.11: 485 stabilization and termination

7.2.5 Service system port (SYS)

The connector is a 4-pin RJ14. It enables two modes of device access: access to device system terminal and software installation access to FPGA IC memory map with the »FPGA Tester« special tool (for service access only). Each access mode requires a different cable. The cable wiring diagram is shown in figures (Figure 1.5 and Figure 1.6).

Table 7.5: Description of SYS port pins (RJ14)

Pin	Description
1	Enable FPGA communication
2	RS232 RXD
3	RS232 TXD

4	GND

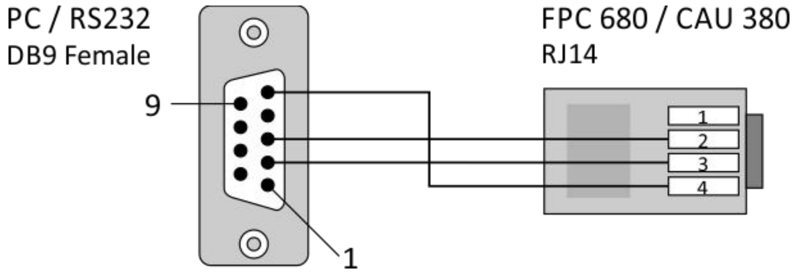

Figure 7.12: Connector of SYS/RJ45 - DB9 system serial port

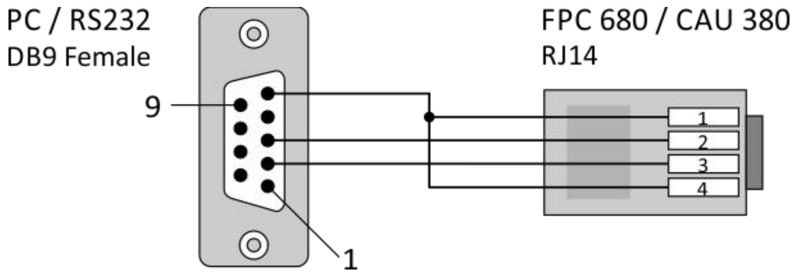

Figure 7.13: Connector of SYS/RJ45 - DB9 FPGA serial port

7.3 Modbus protocol

7.3.1 Introduction

Modbus communication protocol enables communication of the device with the supervising control system or to another device with a Modbus master mode. It enables sending of information out of the device and receiving commands into it. Device operates in the slave mode, as server. Modbus protocol supports transfer of digital values, analog measurements and commands in format of single or more bits, words, events and time synchronization data.

Modbus includes and enables:

- Implementation of general Modbus standard data types.
- Serial interface support.
- Analog measurements reading.
- Digital statuses reading.
- Direct commands execution.
- Device clock synchronization.
- Holding of digital values.

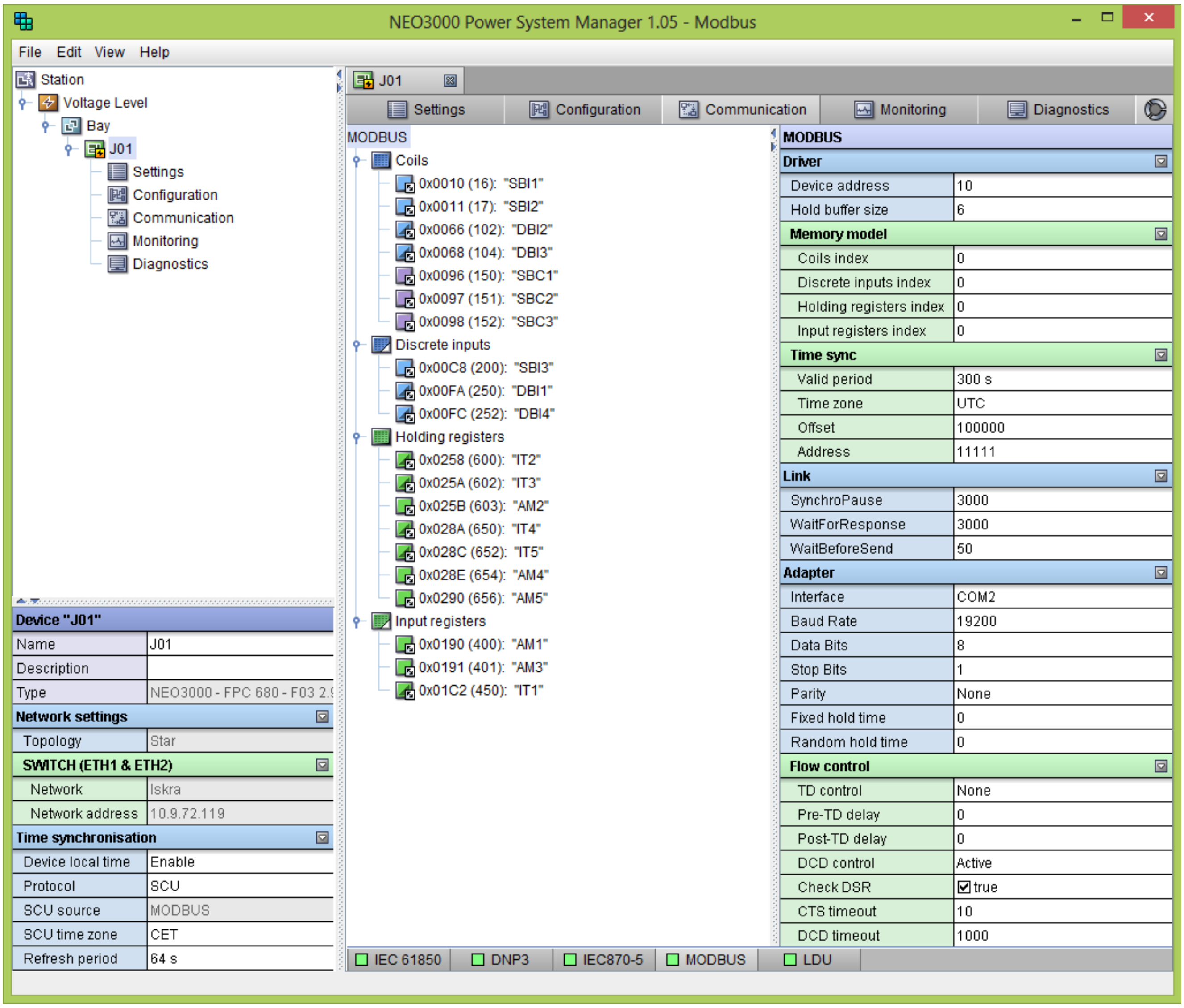

Figure 7.14: Modbus module parametrizing with the Power System Manager tool.

7.3.2 Supported Modbus functions

The requests function codes are limited according to type of an object linked to the table. Modbus protocol of the device supports the following functions or codes from the RTU Modbus protocol set:

Table 7.6: Supported data formats and Modbus function codes

Object type	Supported function codes	Supported formats	Table
SBI	1, 2, 5, 15	1 bit	*Coils, Discrete Inputs*
DBI	1, 2, 5, 15	2 bits	*Coils, Discrete Inputs*
AM	3, 4, 6, 16	INT16, UINT16, FLOAT32	*Holding Registers, Input Registers*
IT	3, 4, 6, 16	INT32, UINT32	*Holding Registers, Input Registers*
SBC	1, 2, 5, 15	1 bit	*Coils*

Legend:

- 01 (0x01) *Read Coils* (reading of n output or internal bits).
- 02 (0x02) *Read Discrete Inputs* (reading of n input bits).

- 03 (0x03) *Read Holding Registers* (reading of n output or internal words).
- 04 (0x04) *Read Input Registers* (reading of n output words).
- 05 (0x05) *Write Single Coil* (writing of one bit).
- 06 (0x06) *Write Single Register* (writing of one word).
- 15 (0x0F) *Write Multiple Coils* (writing of n bits).
- 16 (0x10) *Write Multiple Registers* (writing of n words).

7.3.3 Exception codes

Device supports the following exception codes, according to Modbus standard:

01 – ILLEGAL FUNCTION (unknown exception code)

02 – ILLEGAL DATA ADDRESS (incorrect address)

03 – ILLEGAL DATA VALUE (incorrect data)

04 – SLAVE DEVICE FAILURE (request cannot be processed)

7.3.4 Data model

Data model is presented to the master system with four data tables, according to Modbus standard:

- *Coils* (one bit table, read-write, e.g. switches settings, set-point)
- *Discrete Inputs* (one bit table, read only, e.g. digital inputs and outputs from functions: Pickup, Trip, etc.)
- *Holding Registers* (analog table, 16-bit word, read-write, e.g. analog measurements)
- *Input Registers* (analog table, 16-bit word, read only)

Each device address is set with **Application / Device Address** parameter. Values from 1 to 247 are allowed. The buffer size or the number of held changes on the data level can be set with **Hold buffer size** parameter.

7.3.4.1 Memory space and mirroring

All four Modbus tables are linked to the device memory via the **Application / Memory model** parameter. The device has 4 separated memory spaces marked with indexes (**… index**) from 0 to 3. Each memory space can accept 65535 addresses.

If two tables are linked to the same memory space, they have data linked to identical memory space. This is called "data mirroring between tables". It is possible to access the same data with the request for different data types. When mirroring analog and digital tables the rule applies that the first 16 bits from a digital tables is mirrored in the first analog data, and the second 16 bits are mirrored in the second analog data, etc. Then for the addresses the rule applies that the XXX0…XXXF addresses in the digital tables are mirrored in the 0XXX address in the analog table and vice versa.

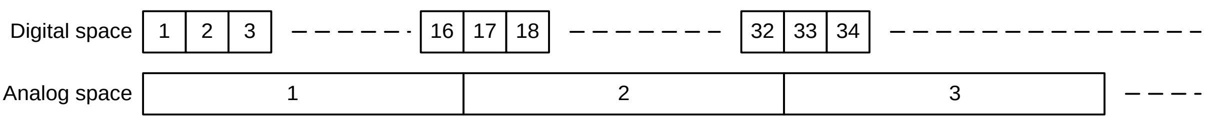

Figure 7.15: Mirroring between analog and digital table

Example 1:
In this case the same data can be accessed in four different tables. This means that the same data can be read with different function codes – the tables are mirrored.

- *Coils index*: 0
- *Discrete inputs index*: 0

- *Holding registers index*: 0
- *Input registers index*: 0

Example 2:
In this case different data are stored in each table, which are in separate memory space - the tables are not mirrored.

- *Coils index*: 0
- *Discrete inputs index*: 1
- *Holding registers index*: 2
- *Input registers index*: 3

7.3.4.2 Data mapping

Different data types in the **Objects** section are available for mapping the driver data tabels with the device real time data. Single bit information are mapped by **SBI** objects, double bit information are mapped by **DBI** objects, and analog information are mapped by **AM** and **IT** objects. Commands are mapped by **SBC** objects.

The **SBI** and **DBI** object are used for single and double bit information mapping (statuses and alarms). The description of an individual signal is entered in the **Name** field. The table with data is selected from the **Bank table** parameter. For digital data the option *Coils* (default) or *Discrete inputs* can be set. The address of the table data is set in the **Address** parameter. References to the data bits are set with the **Value bit 0** and **Value bit 1** inputs.

The **AM** object is used for analog values mapping. The data description is entered into the **Name** field. The table with data is selected from the **Bank table**, which can be of *Coils, Discrete inputs, Holding registers* or *Input registers* type. The address in the table with data is determined in the **Address** field. The format in which the analog value is written is set with the **Type** parameter, and can be: *INT16, INT32, UINT16, UINT32, FLOAT32*. Additionally, the refresh period for the measurement is set with **Refresh period**. The reference to device data is selected with the **Value** field.

The **IT** object is used for counters mapping. It is set in the same way as the **AM** object. It has no scaling.

7.3.4.3 Analog values scaling

Two different modes are available for analog value scaling. Scaling can be set as a range scale or with a linear function.

Range scaling is set in parameter section **Range scale**. Scaling is executed with the mode which is more user-friendly. The user knows the range of a value - given or received by the device function (raw value), and he knows the corresponding scaled range that should be given or received by the communication driver (scaled value). Scaling is set with the **Range scale (Raw Lo, Raw Hi, Scaled Lo, Scaled Hi)**.

Example: The current value given by the AI module is between 0 and X in raw value, but a scaled value between 0 and Y bits must be transferred to communication.

The second scaling mode is set in **Linear scale** parameter section and is set with the k and n parameters. Scaling is done by expression: $Y=kX+n$, where Y is the scaled value and X is the raw value. Parameters are set in **Linear scale / k, n**.

7.3.5 Protocol operation principle

Transfer is triggered by a control system request after which the device respond. Each telegram exchange includes two messages: the master request and the NEO3000 device response. All exchanged messages have the same structure. Each message contains 4 sections:

Slave Number	Function Code	Data Zones	CRC 16 Check Zone

- Slave Number (1 byte): address or ID of the NEO3000 slave device (1…247 decimal).
- Function Code (1 byte): it is used for setting the request type (function: read, write, bit, word) and for checking the response accuracy.

- Data Zones (n bytes): the zone includes parameters referring to the function (bit address, word address, bit value, word value, number of bits, number of words).
- Check Zone (2 bytes): This zone is used for detecting transfer errors.

7.3.6 Holding of data changes

Normally the supervising system reads the device data with a set period. As a consequence there is a possibility of losing the fast changing events values. Therefore, the function of events changes values holding is integrated into the device. It enables the control master to receive all values witch are stored in device hold buffer. The buffer operates on the data level. This means that each event has its own hold buffer.

The device receives and records the changes of digital information in its internal buffer, witch size is set by **Hold buffer size** parameter. Only information with the set **Hold** parameter is written in the buffer. Once the buffer is full all new changes are no longer recorded. Device writes the values of changes one after another from this buffer into a digital table and holds that value until it is read by the supervising system, then the value in the table changes to the value of next event.

7.3.7 Commands

The control system sends a request for command execution by writing value 1 on the command coil bit in the *Coils* digital table. Address of command coil bit is set with **SBC / Operate bit address** parameter.

If any other command is already in the execution process, the command is blocked. Otherwise, the **Close** output in form of a pulse is set.

If the **Command successful** and the **Command failed** are set, the execution success is checked:

- The **Command check timeout** timer, in which the whole execution procedure must be executed, starts. If **Command check timeout** timer expires, the command is not successful.
- The module checks the **Command successful** and **Command failed** input values:
  - if the **Command failed** is set, the command is not successful,
  - if the **Command successful** is set, the command is successful,
  - if none or both are set, the command is not successful.

If the command is successful, it resets the set command coil bit. If the command fails, the command coil bit remains set.

Commands are mapped by **SBC** objects. A command description is entered in the **Name** field. Command executes by the **Value reference** output.

7.3.8 Device clock synchronization

The time synchronization parameters are set in the **Application / Time sync** parameters section. With the **Valid period** parameter the time period in which the device expects a synchronization telegram is set in seconds. If the device does not receive the telegram in this time period, the time in device is not valid. If the **Valid period** parameter is set to 0, this function is switched off.

The time zone of the time received through synchronization telegram is set with the **Time zone** parameter, and can be set to: *UTC* or *Local time* option.

The *Holding registers* table has a space for clock writing. The device is synchronized from this clock. The clock is written according to IEC 60870-5-4, Binary Time 2a standard and consists of 8 characters structure:

Word	MSB Byte	LSB Byte
1	0	Year: 0...99
2	Month: 1...12	Day: 1...31
3	Hour: 0...23	Minute: 0...59
4	Millisecond: 0...59999	

The address fo time structure in *Holding registers* table is set with the **Address** parameter.

At device start-up the clock is not correct. When the control system sends a new time to the device, it is checked for validity. If the time is valid, the device clock is synchronized. The **Offset** parameter value is added to the sent time to compensate for the telegram transfer delay. Then the control system periodically sends a new time and the device periodically synchronizes internal clock. The device expects a new time to be received within the period set with the **Valid period** parameter.

7.3.9 Event recorder

Device stores SBI and DBI types of connected digital status changes (events) in its internal buffer. Only events with **Enable SOE** parameter set, are logged into the buffer. We can set up to 5 independent buffers **Events 1…5**, size of which are set with parameter **Buffer size**. If any of the buffers gets full, all new events in that buffer are not recorded anymore.

Events are equipped with time running in the device. Type of time is the same as at clock-synchronization – parameter **Time zone**. As long as the device clock is not synchronized, all events carry wrong time. It is anticipated that the control system will take care of the clock synchronization in due time at device boot time.

Event is stored into analog table *Holding registers* at the starting address (set with parameter **Address**). It occupies 33 words (1 + 4x8). Events are not sorted by the time of occurrence.

7.3.9.1 Structure

The device displays up to four events at the same time for each buffer and one control word. Structure of data in the table looks as follows:

```
Control word + Event 1 + Event 2 + Event 3 + Event 4
```

The function of control word is to ensure correct reception of all data, even in case of trouble and loss of data at communication. To ensure this, it includes number of transactions and number of events. On device boot, number of transactions is 0.

Events are recorded in 8 word structure. Each event consists of the following information:

- Address where the data is stored
- Exact time of the event
- Value of the event

Control word structure:

	MSB Byte	**LSB Byte**
1	Number of transaction: 0..255	Number of events: 0..4

Single event structure:

	MSB Byte	**LSB Byte**
1	Type of event: 08	Type of event: 00
2	Address: 1..65535	
3	00	00
4	00	Value: 0..3
5 6 7 8	Time of the event, see chapter 7.3.8	

7.3.9.2 Reading of events

Monitoring system periodically reads the control word and checks whether there are new events available. Only reading of control word is allowed or reading of the whole 33 word block. For all other requests, the device returns an error (Wrong data).

On the arrival of new events in the buffer, the device writes the values of events into the structure in the analog table and increases the number of transactions in the control word by 1 and sets the number of written events (maximum 4).

Monitoring system reads the values of the events, checks for any reception errors and validity of the data. If events are present, device stops to write new events in the buffer and waits for confirmation for those that were sent last.

Monitoring system confirms correct reception to device with writing into control word the same transaction number and number of events is reset to 0.

Upon confirmation of successful reception from the monitoring system, the device erases the transferred events from buffer, in analog table all words for the events are set to 0, writes new events and sets a new control word, as previously described. Deletion of events is only allowed if a request to read the entire block of events has previously been issued. Namely, the monitoring system can't confirm events, if it did not read them previously.

When device sends all events and clears its buffer, it does not change the control word anymore even after the monitoring system reads the control word.

7.3.9.3 Remote deletion of events

Monitoring system has the ability to delete all events in the device and in the buffer and in the analog table, by writing control word which has the number of events set to FF. In this case, the number of transactions is reset to 0.

7.3.10 Parameters, inputs and outputs

/ Application	
Device Address **1**… 247	Modbus communication device address.
Hold buffer size 1…**5**…16	Number of saved changes in hold buffer.

/ Application / Memory model	
Coils index 0...3	Index of memory space, where the stated table is being saved.
Discrete inputs	…
Holding registers index	…
Input registers index	…

/ Application / Time sync	
Valid period 0.0...**1800.0**... s	Time period in which the device expects a synchronization telegram. 0 value means the function is switched off.
Time zone UTC, **Local time**	Time zone of the time, received via synchronization telegram: *UTC* – received time is in UTC time zone. *Local time* - received time is in local time zone.
Offset -999999...**0**...999999 µs	Fixed compensation for transfer delay.
Address **1**…65535	Address in *Holding registers* table with the clock.

Application / Events 0…5	
Name tekst	Event instance name.

Buffer size 1…**100**…256	Buffer size.
Address **1**…65535	Address of events table.

Coils / SBI …
Discrete inputs / SBI …

Name text	Signal description.
Address **1**…65535	Address in table with a data.
Hold true, **false**	Are the values withheld at writing into the table: true – new value is holded false – new value is changed immediately
Value bit input (digital)	Value in the table.

Coils / DBI …
Discrete inputs / DBI …

Name text	Signal description.
Address **1**…65535	Address in table with a data.
Hold true, **false**	Are the values withheld at writing into the table: true – new value is holded false – new value is changed immediately
Value bit 0…1 input (digital)	Bits of value in the table.
Transit time 0,00…**1,00**…3600 sec	Dead time of 00 state where until data is refreshed in table.

Holding registers / AM / …
Input registers / AM / …
Holding registers / IT / …
Input registers / IT / …

Name text	Analog measurement description.
Address **1**…65535	Initial address in table with a data.
Type INT16, **INT32**, UINT16, UINT32, FLOAT32	Format of analog value input.
Refresh period 1…**5**…86400 sec	Refresh period.
Value input (analogue)	Measurement source.
Conversion **None**, Linear, Range scale	Scaling of analog value.

… / AM / Range scale

Raw Lo decimal number	Bottom limit of the raw value in the device.
Raw Hi decimal number	Upper limit of the raw value in the device.
Scaled Lo decimal number	Bottom limit of the scaled value in table.
Scaled Hi decimal number	Upper limit of the scaled value in table.

… / AM / Linear scale

k decimal number	Input raw value scaling, k factor.
n decimal number	Input raw value scaling, n factor.

/ Coils / SBC …

Name text	Command description.
Operate bit address **1**…65535	Bit address in the *Coils* table for command execution.
Command reference output (digital)	Command output.
Pulse **true**, false	Pulse signal on command output.
Command timeout 1…**10**…65535 sec	Command timeout after which command is unsuccessful.
Command successfull vhod (digitalni)	Response for successful command.
Command failed vhod (digitalni)	Response for unsuccessful command.

7.4 IEC 61850

The IEC 61850 is intended for the vertical communication of the device with the master control systems and for the horizontal communication between the devices (interconnection – IEC 61850 GOOSE).

It consists of two connected main parts:

- function modules, executed in real time – Real time modules
- IEC 61850 server (MMS, GOOSE)

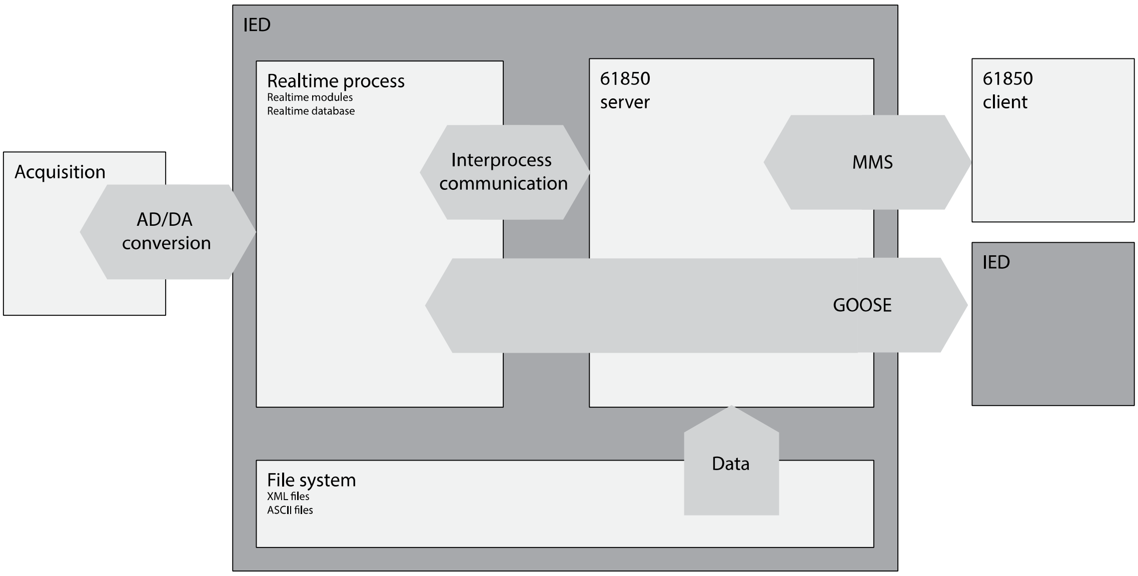

Figure 7.16: Communication system

The data flows between physical inputs and device processes through the acquisition modules like *AI and DI.* The changes flow between the real-time process and the IEC 61850 server with help internal communication. GOOSE messages flow between the devices directly to real-time processes, for speed purpose. The IEC 61850 server sends and receives the messages in the MMS format (Manufacturing Message Specification). The IEC 61850 server can read the data from files in XML and TXT format.

The settings are a component of the system. They consist of several files which are stored in device. The real-time process operation is determined by the *Settings.xml* file, the IEC 61850 server operation is determined by the *iec61850.cid* (MMS) and *inputs.xml* (GOOSE) files, and the software start mode is determined with the *neo3000.conf* file.

7.4.1 MMS communication

The data exchange between the device and the SCADA control system is executed via the IEC 61850 server inside the device and the IEC 61850 client, e.g. on SCADA workstation. The communication is carried out by MMS format messages exchange.

The 61850 standard defines the described language that is intended for configuration of devices, incorporated into the electrical system – configuration language of the substation (Substation Configuration Description Language - SCL). It is used for the device (IED - Intelligent Electronic Device) configuration and communication according to regulations in the IEC 61850-5 and IEC 61850-7-x standard. It allows a formal description of relations between the automation systems and the substation device. On the applicative level it enables description of relations between the substation device and logical nodes (Logical Node, LN).

The data structures are determined with the IEC 61850-7-3 standard.

Structures consisting of logical nodes (LN) are used for describing the physical world inside the substation. The nodes consist of data objects, and these contain the data (Attribute). All information is formatted in the SCL language and saved in an XML file.

7.4.2 Data model

Device server supports the following logical nodes:

Table 1: List of supported LNs.

L: System Logical Nodes
LPHD (Physical device information) Information about the device physical characteristics. Hardware version, software version.
LLN0 (Logical node zero) It contains data regarding the IED, independently of all other LN (device identification, diagnostic messages)

P: Logical Nodes for protection functions
PDIF (Differential) Differential protection relay is a protection relay that functions independently of the percentage difference or phase angle or other quantitative differences between two currents.
PFRC (Rate of change of frequency) Frequency protection. Frequency relay is a relay that responds according to the frequency of electrical value. It operates in cases when the frequency or the frequency changes are outside the specified ranges.
PHIZ (Ground detector) Earth fault overcurrent relay is a relay that operates when the earthed device becomes faulty.
PIOC (Instantaneous overcurrent) Instantaneous overcurrent protection is a protection that operates at the exact time of overcurrent detection or extremely fast current change.
PTOC (Time overcurrent) Time overcurrent protection.
PTOF (Overfrequency) Overfrequency protection.
PTOV (Overvoltage) Overvoltage protection.
PTTR (Thermal overload) Thermal overload protection.
PTUV (Undervoltage) Undervoltage protection.
PTUF (Underfrequency) Underfrequency protection.

R: Logical nodes for protection related functions
RBRF (Breaker failure) Breaker failure protection.
RDIR (Directional element) Directional element.
RREC (Autoreclosing) Autoreclosing.
RSYN (Synchronism-check or synchronising) Checking of synchronism.

C: Logical Nodes for control
CALH (Alarm handling) Grouping of alarms.

CILO (Interlocking) Interlocking at feeder level or substation level.
CSWI (Switch controller) Control of switching element.

G: Logical Nodes for generic references
GAPC (Generic automatic process control) General node for all non-defined complex functions executed in form of sequences (load limiting, transformer change over, bus bar change over, automatic network restoration).
GGIO (Generic process I/O) General process data. All that is not included in other logical nodes.

A: Logical Nodes for automatic control
ATCC (Automatic tap changer controller) Tap changer regulation.
AVCO (Voltage control) Voltage regulation.

M: Logical Nodes for metering and measurement
MMTR (Metering) Energy counters.
MMXN (Non-phase related Measurement) Calculated measurements, which are phase independent.
MMXU (Measurement) Phase measurements.

X: Logical Nodes for switchgear
XCBR (Circuit breaker) Circuit breaker.
XSWI (Switch) Load switch.

7.4.3 Mapping with process

When mapping data from functional modules to places in a logical node, those nodes are used that most accurately represent the chosen function inside the device.

Example: for mapping the overcurrent protection function, the PIOC logical node is used.

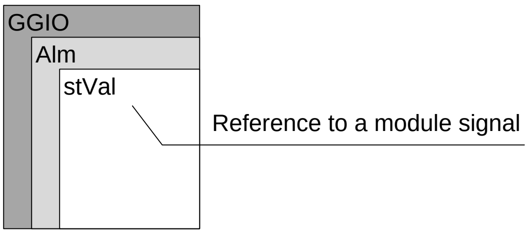

Figure 7.17: Simple alarm mapping

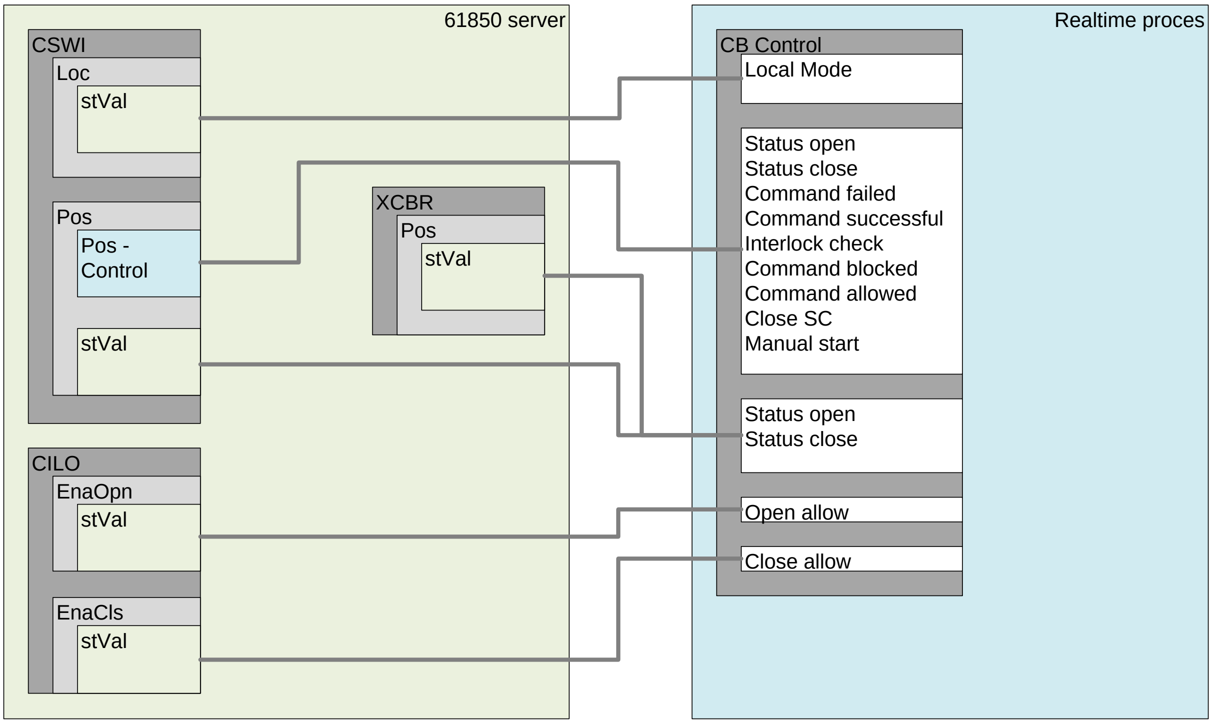

Figure 7.18: Breaker function mapping

7.4.3.1 Statuses and measurements mapping

/ Data Attribute Instance

Description text	Data description.
Path text	Path to the data in SCL format. The value cannot be changed.
Name text	Data name. The value cannot be changed.
Functional Constraint ST, MX, CO, SP, SV, CF, DC, SG, SE, EX, BR, RP, LG, GO, GS, MS, US, XX	Functional constraint of a data according to standard. It is determined with an element and cannot be changed.

/ Data Attribute Instance / Triggers

Data Change true, false	Enabling of sending at a change. The setting cannot be changed.

Support Data Update true, false	Enabling of sending at value refresh. The setting cannot be changed.
Support Quality Change true, false	Enabling of sending at data quality feature change (q). The setting cannot be changed.

/ Data Attribute Instance / Value Attributes

Is Array true, false	If the data type is array (string), the value is set to true. If not the value is set to false.
Base Type BOOLEAN, Dbpos, INT32	Basic data type according to the selected attribute.
Enum Type BOOLEAN, Dbpos, INT32	Enum data type according to the selected attribute.
Value Kind	Value type.
Value enum	Chosen value in enumeration.

/ Data Attribute Instance / Mapping

sAddr text	Reference to process (real-time) data in form of characters string.
Info source No, Rtdb, Xml file, Raw File	Data source from where the data is read or to where they are written.
Bit conversion No, 1N code, Gray code, Bcd code, Bit string	Way of data conversion into other types.
Num of bits integer	Bit number or number of all signals to which sAddr is addressed.
Refresh Polling, Event	Data transfer mode. Polling: The 61850 server periodically requests process data. Event: At a change the process sends a data to the 61850 server.
Event type SINGLE_BIT, DOUBLE_BIT	Event type.
Transit time [ms] integer	In case of two bit event the transit time, in which the state will be equal to 00, can be set.

/ Data Attribute Instance / Mapping / Info

Bit Index integer	Multi-bit data bit index
Rtdb Properties Output/input	Input or output to any module

7.4.3.2 Commands mapping

/ Private

Type text	Command type.
Source	Selection is not possible.
Value text	Mapping reference to process data.

/ Private / Control / Commands	
Open Input (digital)	Open command.
Close Input (digital)	Close command.
Commands / Timeout 1...**30**... ms	Time in which a command must be executed or an error is reported.
Commands / Pulse true, false	Pulse execution of a command.

/ Private / Control / Statuses	
Command Failed output (digital)	Signal name to which the server writes the command execution failure.
Command Successful output (digital)	Signal name to which the server writes the command execution success.

/ Private / Control / Interlock	
Interlock Check input (digital)	Interlocking check command, at request for command execution with interlocking check (Check[10] request)
Command Blocked output (digital)	Feed-back information after the interlocking result: Command is blocked. The device signals: »Blocked by Interlocking«.
Command Allowed output (digital)	Feed-back information after the interlocking result: The command is allowed. The device signals: »Command Allowed«.

… / Private / Control / Synchro Check	
Synchro Check output (digital)	Synchro Check Interlocking check command, at request for command execution with interlocking check (Check[01] request)
Synchronized output (digital)	Feed-back information after the interlocking result: The command is allowed.

7.4.4 Services mapping

7.4.4.1 Dataset mapping

/ LLN0 / DataSet / »Name«	
Description text	Data set contents description.
Name text	Name
Data attributes: current / max integer	The number of currently used data in the dataset and the maximum allowed number of data in one set.

/ LLN0 / DataSet / Functional Constraint Data »Attribute«	
Logical device instance text	Logical device instance name.
Logical node prefix text	Prefix at the beginning of a logical node.
Logical node class text	Logical node type.

Logical node instance integer	Logical node instance number.
Data Object Name text	Data object name.
Functional constraint text	Functional constraint of a data. If the element is a data object, then this parameter can be changed, and if the element is a data (attribute) the selection is not possible.

7.4.4.2 Report control block mapping

/ LLN0 / Report Control / »Name«	
Description text	Any description of a report control block.
Name text	Report control block name.
Buffered true, false	Enabling of control block accumulative type. Buffer size is 20.000 reports / report.
Buffer Time Integer	Accumulation time.
Integrity Period Integer	Report integrity time interval.
Report ID Integer	Report identification number.
Configuration Revision Integer	Configuration change version.
Data Set text	Data set reference.

/ LLN0 / Report Control / Trigger Options	
Data Changed true, false	Enabling of report sending at a data change in a set.
Quality Changed true, false	Enabling of report sending at a data quality tag change.
Data Updated true, false	Enabling of report sending at a value freeze. It also enables value sending when the new value does not differ from the previous one.
Integrity true, false	Enabling of report sending after the time interval of report integrity has timed out.

/ LLN0 / Report Control / Option Fields	
Sequence Number true, false	Sending the SqNum in a report.
Time Stamp true, false	Sending the TimeOfEntry in a report.
Data Set Name true, false	Sending the DatSet in a report.
Reason Code true, false	Sending the ReasonCode in a report.
Data Reference true, false	Sending the DataRef or DataAttributeReference in a report. Setting is not possible.
Entry ID true, false	Sending the EntryID in a report.
Configuration Revision true, false	Sending the ConfRev in a report.

/ LLN0 / Report Control / Report Enabled	
Description text	Description.
Max No Of Clients integer	The maximal permitted number of simultaneous clients.

7.4.5 GOOSE communication

The IEC 61850 GOOSE communication are used in the substations automatization systems and for exchange of statuses between the devices (IED interconnection) and the process with help of communication via copper of fibre optic Ethernet. It substitutes the classical method of using binary inputs/outputs and hard wires. GOOSE stands for *Generic Object Oriented Substation Events*.

There are two types of GOOSE messages: output and input. Each output GOOSE message must belong to a dataset to which the GOOSE control block refers to.

Each data (attribute), to which the input GOOSE will be mapped, must have a reference to a real-time *Input block* module. The output GOOSE data from one device can be sent to several different input GOOSE inside a second device. Only one output GOOSE can be mapped to one GOOSE input data.

7.4.5.1 GOOSE control block

The output messages parameters are set with the GOOSE control block.

/ GSE Control	
MAC-Address 01-0C-CD-01-XX-XX	MAC address that will be included into the GOOSE message.
Name String	GOOSE control block name.
Description String	Any description.
Application ID String	Identification in form of path to the DataSet element (e.g. J02FPC680/LLN0GOtest).
Data Set Data Set choice list	Dataset selection. You can choose only between those that include data (not data objects).
Configuration Revision Integer	Configuration version number.
VLAN-APPID Integer	according to 61850 standard
VLAN-PRIORITY Integer	according to 61850 standard
VLAN-ID Integer	according to 61850 standard
Min Time Integer	The shortest time until GOOSE resending.
Max Time Integer	The longest time until GOOSE resending.

8 Mounting and commissioning

8.1 Safety warnings

Safety instructions and warnings should be considered before commencing any works on the device. They are provided for device proper installation, handling and maintenance and to provide guidelines for safe operation conditions. It is the user's responsibility that equipment is installed, operated and used in accordance with its intended function and in the manner specified in user manual. Failure to comply with these manual's instructions may impair the operational safety function of the device.

WARNING!

Hazardous voltages possible of causing death can be present on the exposed electrical elements. Failure to observe the safety regulations during installation, commissioning, operation and maintenance can result in severe personal injury and/or equipment damage.

WARNING!

The device housing must be correctly earthed before it is connected to power supply. Earthing is executed with a flat braid which is screwed on the device with a designated screw and a washer. Non-earthed operating devices are hazardous to persons.

WARNING!

Never open the secondary circuits of current transformer (CT) secondary circuit when the current transformer is energized. Before disconnecting the current circuits, always short circuit the CT secondary circuit. Omitting that instruction can result in lethal hazard and equipment insulation deterioration due to high voltage inductions!

WARNING!

Opening of the device and changing its parts or electronic components during device operation is strictly prohibited. There is a possibility of high voltage stroke into a person or equipment damage.

WARNING!

Only qualified personnel familiar with the warnings and safety information stated in this document and other safety regulations are permitted to handle this device.

WARNING!

When handling devices with optic communication the user should not look directly into the optical heads. There is a possibility of eye injuries.

8.2 Removing the packaging

When removing the packaging the user is obliged to thoroughly inspect the device to assure no physical damages occurred during the transport. A damaged device should not be assembled, but returned to the supplier together with the original packaging for further inspection.

8.3 Mounting

8.3.1 Procedure

- See chapter "Technical data" regarding the device measurement ranges.
- Select location of the device, see chapter 8.3.5. Around the device there should be at least 30 mm of free space for conveying the heat, see Figure 8.1.
- Drill 4 holes of 3.2 mm diameter into the mounting plate and make M4 screw threads.
- Loosely screw the screws into the prepared threaded holes.
- Mount the device onto the screws.
- Tighten the screws.
- Connect the earthing connection, which must be made of a minimum 40 mm2 flat copper tinned braided wire and screwed with at least one M5 screw with corresponding earthing washers, on the device side as well as on the copper earthing bar side.
- Execute the wiring.

8.3.2 Recommendations

- A device in operation should only be accessible to the qualified personnel.
- The device should only operate when in an enclosed cabinet or a cell.
- The device must be mounted in a vibration-free environment.
- Temperature of the device in its direct surrounding area should be within the prescribed limits, see Technical data.
- A damaged device should not be put into commissioning, but returned to the manufacturer for inspection.
- Any physical modifications of the device are prohibited.
- Before connecting to the power supply the device must be earthed. During operation the earthing should not be interrupted.
- The device power supply should be executed via an installation miniature circuit breaker type 2 AT or 4 AT (2 A fuse) which should be installed near the device.
- Power supply wiring should be made out of individual 0.5 – 2.5 mm2 section wires. In case the braided wires are used, the wires should be finished with insulated cable shoes measuring 5 mm in length and executed with a suitable tool.
- When executing optical communication connections the permitted radius of bends should be observed.
- Wire communication connections should be made with armoured cables earthed on both sides.

8.3.3 Recommended external protection elements

- Power supply: K2 or C2
- Voltage inputs: Z2
- Digital inputs: B2
- Digital outputs: B6

8.3.4 Mandatory free space around the device

It is necessary to provide 30 mm of free space around the device to assure adequate cooling of the device.

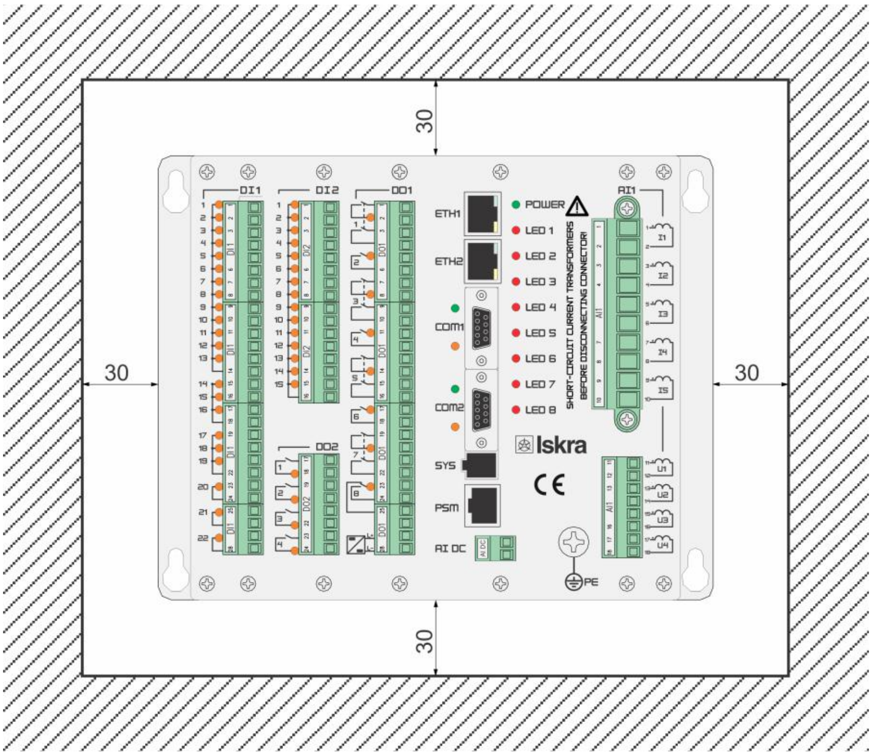

Figure 8.1: Free space around the device for its cooling

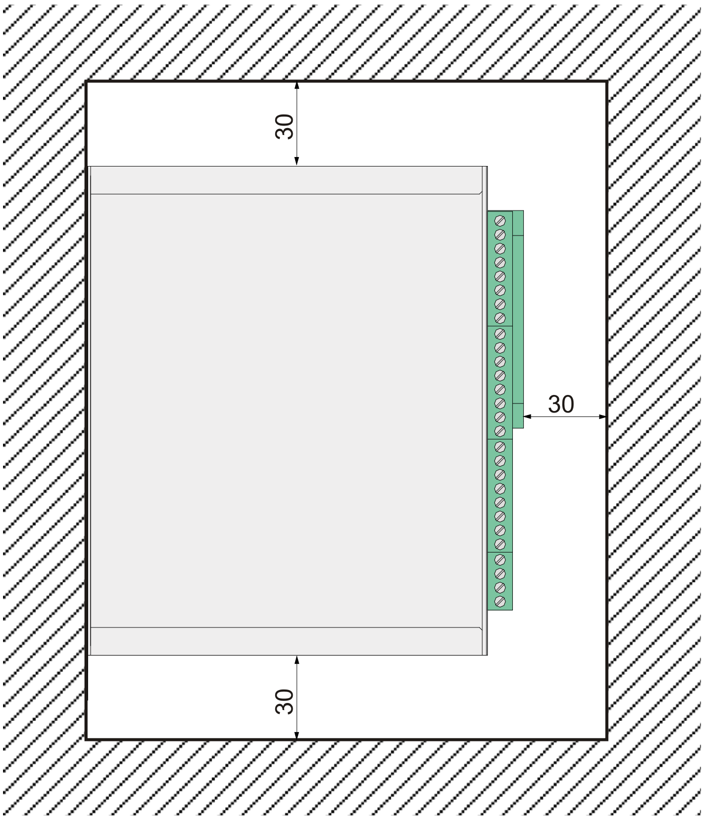

Figure 8.2: Free space in front of the device for cables

8.3.5 Correct device location in the cabinet

In case a device is mounted into a cabinet exposed to direct environmental influences, mounting in the bottom part of the cabinet is recommended where the temperatures are lower.

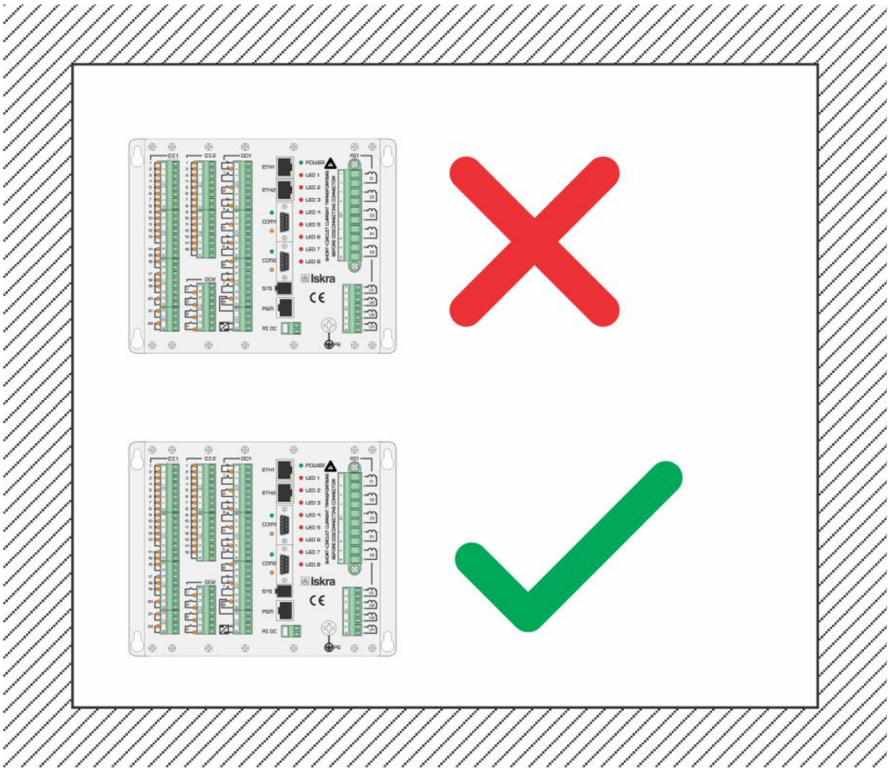

Figure 8.3: Recommended device mounting into the cabinet

8.3.6 Mounting of the device with an LDU on the cabinet door

Device with an LDU (local control panel) should be installed into the cut-out in the door – from the front side - and screwed on it with four M4 screws from the door back side. The LDU then protrudes 3 cm outside of the door.

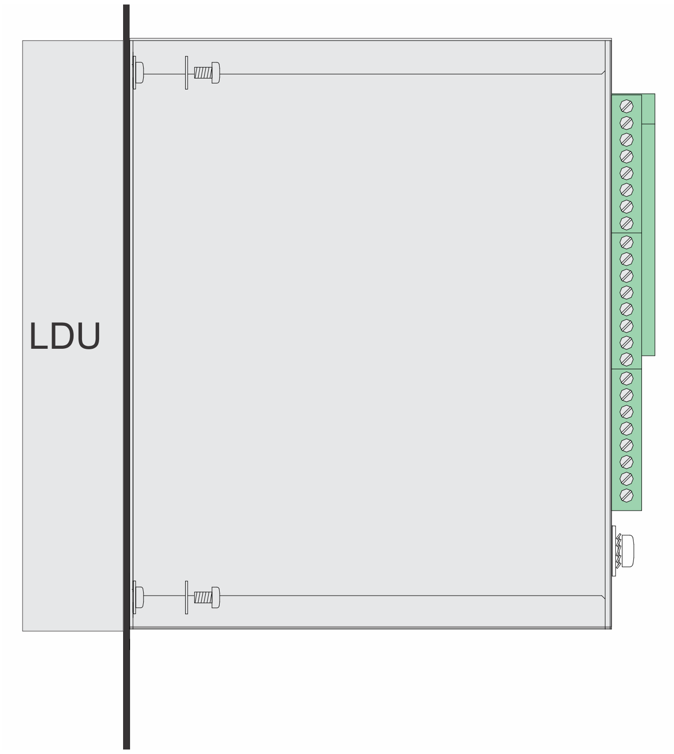

Figure 8.4: Mounting of the device with an LDU on the cabinet door.

8.3.7 Mounting of the device with an LDU inside a cabinet on the rear panel

Device with an LDU (local control panel), should be mounted on the rear panel of a cabinet with four M4 screws from the front side.

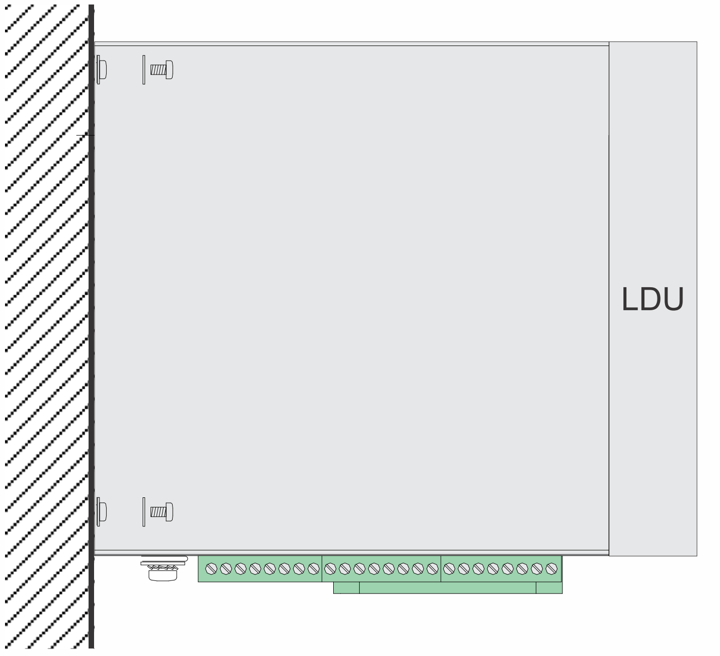

Figure 8.5: Mounting of the device with an LDU in the cabinet on the rear panel.

8.3.8 Mounting of the device without LDU inside a cabinet on the rear panel

Device without LDU, should be mounted on the rear panel of a cabinet with four M4 screws from the front side.

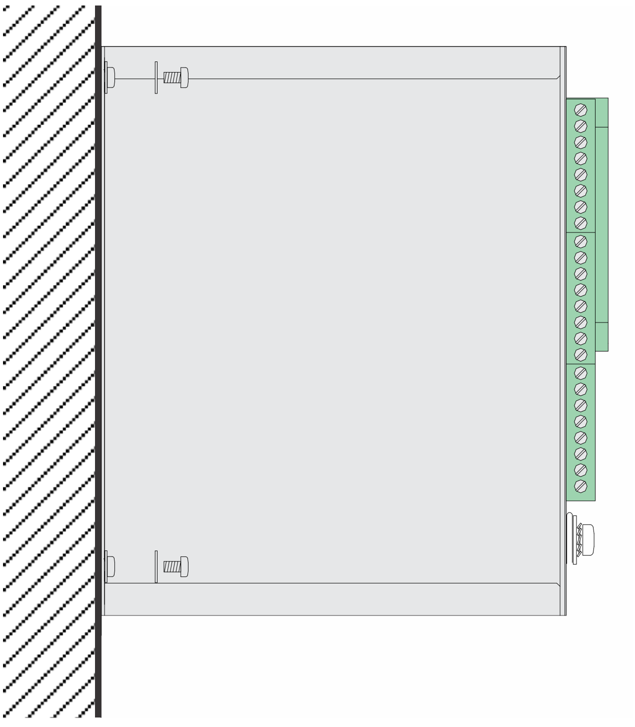

Figure 8.6: Mounting of the device without LDU in the cabinet on the rear panel

8.4 Device wiring

WARNING!

It is the user's duty to provide a suitable earthing of the device before executing the wiring. It is user's responsibility to check device technical data and get familiar with the instructions for use and mounting before connecting the device, commissioning or maintenance work.

WARNING!

Before connecting the device, commissioning or maintenance work the user must secure the terminals and install terminal short links according to instructions.

Only braided or single strand wires can be used for the wiring. The braided wires must be correctly finished with cable ends and executed with a suitable tool. The ends must not be soldered. At the end of the wiring process a correct overvoltage insulation should be assured at all places.

Recommended wire dimensions for the individual device connection types with a secondary wiring of the electrical bay (feeder):

- for earthing, min. φ 40 mm2 flat copper-tinned cross braided wire (recommended length up to 30 cm)
- power supply, at least 0.75 mm2, 500 V (recommended: 1.5 mm2, 500 V)
- current measurements, at least 1.5 mm2, 500 V (recommended: 2.5 mm2, 500 V)
- voltage measurements, at least 0.75 mm2, 500 V (recommended: 1.5 mm2, 500 V)
- for digital inputs collection, min. φ 0.75 mm2, 500 V
- digital outputs, depending on the command circuits voltages and currents, recommended at least: 1.5 mm2, 500 V

8.4.1 Earthing

Earthing must be executed with a copper-tinned cross braided wire with a min. φ 40 mm^2 and screwed down with two M5 screws with a normal and tooth lock or spring washer.

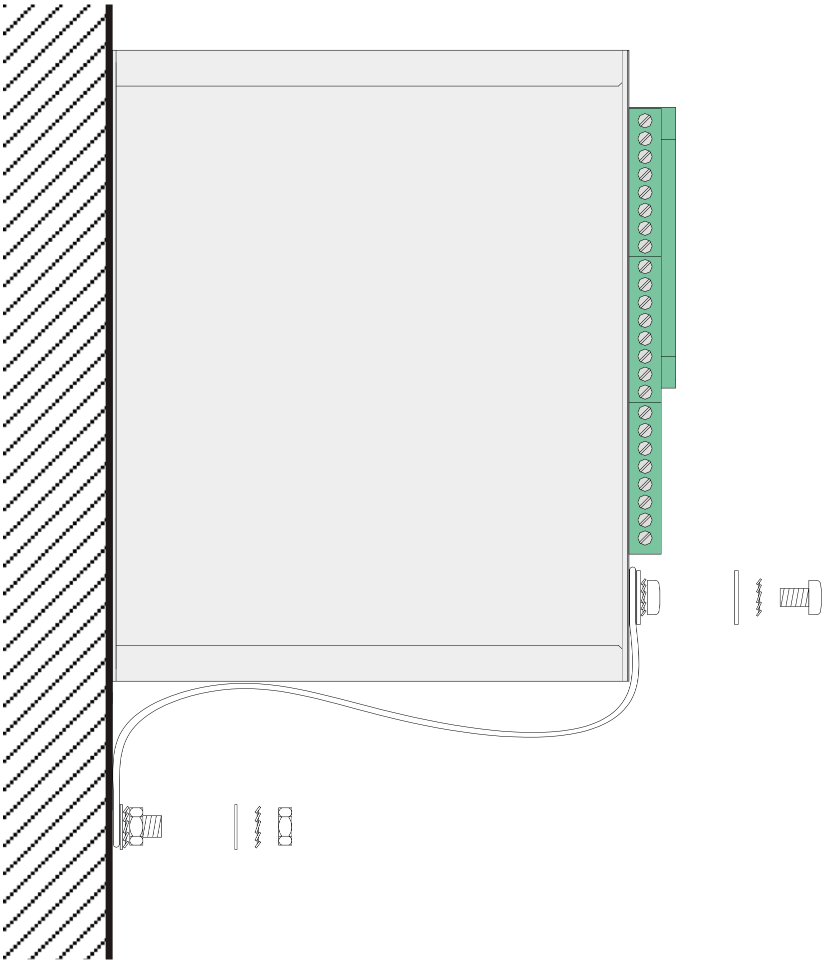

Figure 8.7: Device earthing with braided wire

8.5 Connection with the device

Connection with devices can be established with PSM user interface and corresponding PSM project. The user interface distinguishes individual devices by name; therefore, names in the PSM project should not be duplicated. Devices are searched by network addresses. An individual device has several network addresses, which can be added and configured in the device properties for all networks listed in the project properties.

On the PSM network connection port, all the devices have the same network address. This makes it possible to establish initial connection with the device and the corresponding PSM project. This procedure is called device initialization.

Po inicializaciji naprave je omogočen vpis in branje nastavitev tudi neposredno iz komunikacijskega omrežja postaje, preko ETH mrežnih priključkov. Pri inicializaciji naprave je v kontekstnem meniju izpisano tudi ime naprave, s katero smo povezani preko prednjega vhoda (porta.)

8.5.1 Basic equipment for operating the device

For operating the device, the following simulation environment is required:

- Personal computer with LAN and serial COM port
- Power supply of corresponding voltage and power of at least 30 W as required by the device type (e.g. 110 VDC, etc.)
- Power cable
- Communication cables (serial communication cable RJ45 – RS232, network LAN cable)
- Optional: network switch

Software:

- Windows XP or newer
- User interface Iskra Sistemi NEO 3000 Power System Manager

8.5.2 Power supply

Connect the device to DC power supply by connecting cable on the clip of the connector DO1, pin 27(+), 28(–). Power supply voltage of the device is labelled on the data plate. For voltage 24 V, a dedicated power supply with a capacity of at least 1.5 A should be used. When the device is connected to the power supply, a LED diode “Power” lights-up, and after about one minute “Ready” diode also lights-up.

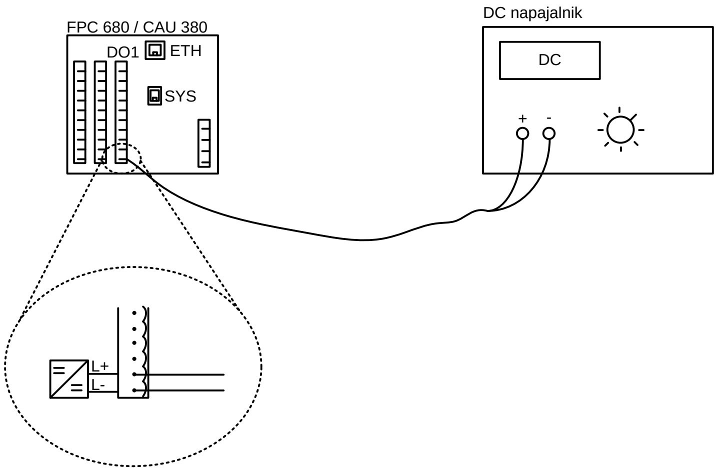

Figure 8.8: Connection of the device to power supply

8.5.3 Connection via LDU ETH port

To connect via the front LDU ETH port you need a cross-over network cable. Newer network interfaces on PCs support automatic detection of the cable: normal or cross-over, so in this case you may also use a normal network cable (TIA / EIA 568B).

Connect network cable to LDU ETH port on the front of LDU panel of the device. Connect the other side of the cable to the ETH port on the PC. You can only connect PC to company network or the internet via another ETH port.

LDU ETH port on the device has IP address 192.168.100.101; DHCP server assigns addresses in the range 192.168.100.103…110. Reserved address for LDU is 192.168.100.102.

Configure the ETH port on the PC to:

- automatic DHCP setting
  For detailed instructions on how to configure ETH port see Microsoft documentation, chapter "Configure TCP/IP for automatic addressing - Microsoft"
- set to static IP:
  - IP address: 192.168.100.100
  - mask: 255.255.255.240

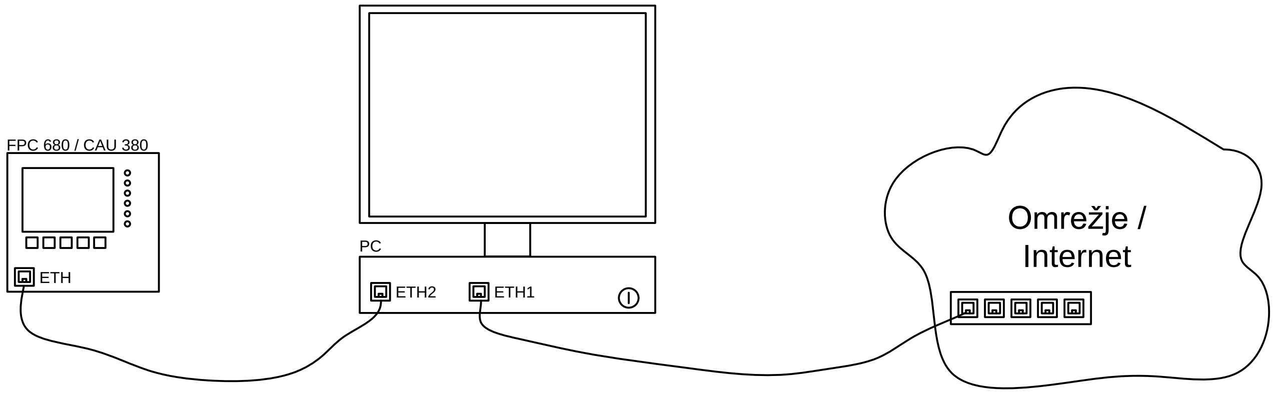

Figure 8.9: Connection to the device via LDU ETH port

WARNING!

The device includes DHCP server, which provides IP addresses to computers connected via local interface. Via local network port, the device should not be connected to a corporate network, which usually has its own DHCP server.

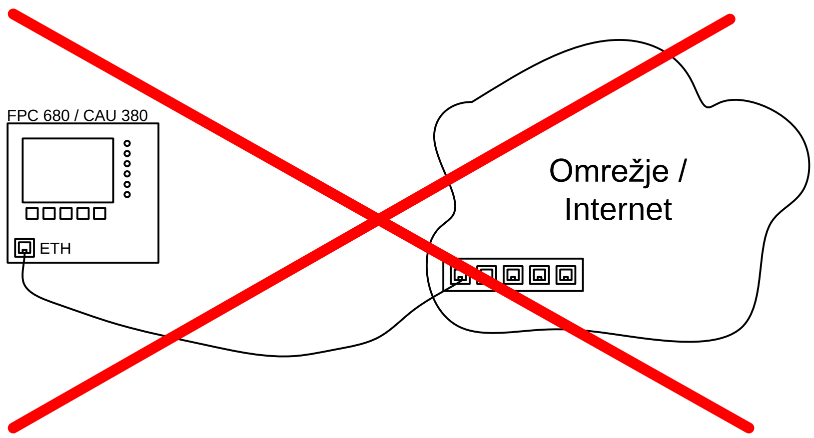

Figure 8.10: Prohibited connection to the front port

8.5.4 Connection via ETH communication ports

Connect network cable to the ETH1 connector on the back side of the device. Connect PC via the ETH port to the same network as the device. Set the ETH port on the PC to same network parameters as device. PC and device should have its unique IP address.

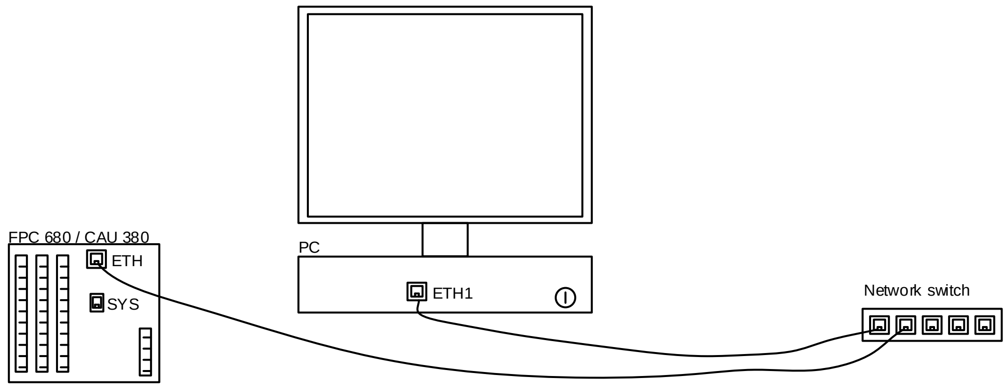

Figure 8.11: Connection to the device via ETH1 port on the back side

WARNING!

The device should not be connected in a way to allow simultaneous connection of both (front and back) ETH ports. In this case, a loop is created and communication is broken (Figure 8.12).

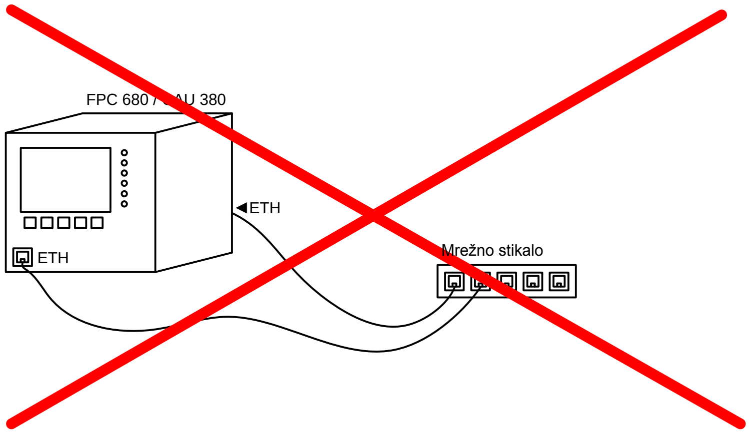

Figure 8.12: Prohibited simultaneous connection

8.5.5 Connection via SYS port

This port is designed for service and diagnostic interventions into devices by trained service engineers. It enables terminal access to the operating system or monitoring of FPGA signals of the circuit with dedicated tools. Details of serial service connection are described in the service manual.

8.6 Commissioning

This chapter describes typical procedures during the commissioning of the device. Procedures used have to be adapted to the actual application. In order to complete this task, a good knowledge of the project, device, necessary tools and consistent safety warnings consideration are needed.

8.6.1 Safety warnings

The first condition before the start of commissioning is to correctly set and connect the device. At commissioning the certain instructions and warnings apply.

WARNING!

In case a feeder can't be switched off, at least two qualified persons should be present at the test. They should also be qualified for medical reanimation of a person being hit by a stroke of electrical current.

Before connecting the current or voltage source to the device you should make sure the measuring transformers are actually disconnected from the protection device.

WARNING!

During the commissioning procedure the device should not be modified.

WARNING!

Before connecting the power supply, the suitability of power supply voltage and polarity should be checked according to device nominal values and terminals.

WARNING!

Testing on a protection device in a bay under load is not advised. The protected element will have no protection during the test!

WARNING!

During the testing is should be assured the continuous current does not exceed 4x nominal device current, otherwise the current inputs can be damaged.

If the current exceeds 4x nominal device current, a pause should be done between individual tests, allowing the current loops within the device to cool down. Otherwise damages of the protection device may occur!

WARNING!

Voltages and currents injecting into the protection device can result in manipulation of device relays operation and by this manipulation of primary elements!

If no action on breaker is desired when testing inside the bay, the switch off circuits should also be disconnected from the breaker. This is executed on terminals or with a testing socket.

8.6.2 Operating conditions

WARNING!

Only operation within the allowed limits of electrical and environmental influences described in the device technical data is permitted for the device.

WARNING!

All circuits connected to device should be properly protected using fuse-links or low voltage circuit breakers except current circuits.

WARNING!

After equipment insulation testing the capacitors can be left charged to hazardous voltage. Before disconnection of test leads from terminals, testing voltage should be gradually reduced to zero, to discharge device internal capacitors.

8.6.3 Testing ground wiring

The figure below shows device connection with inputs and outputs simulators and PC computer.

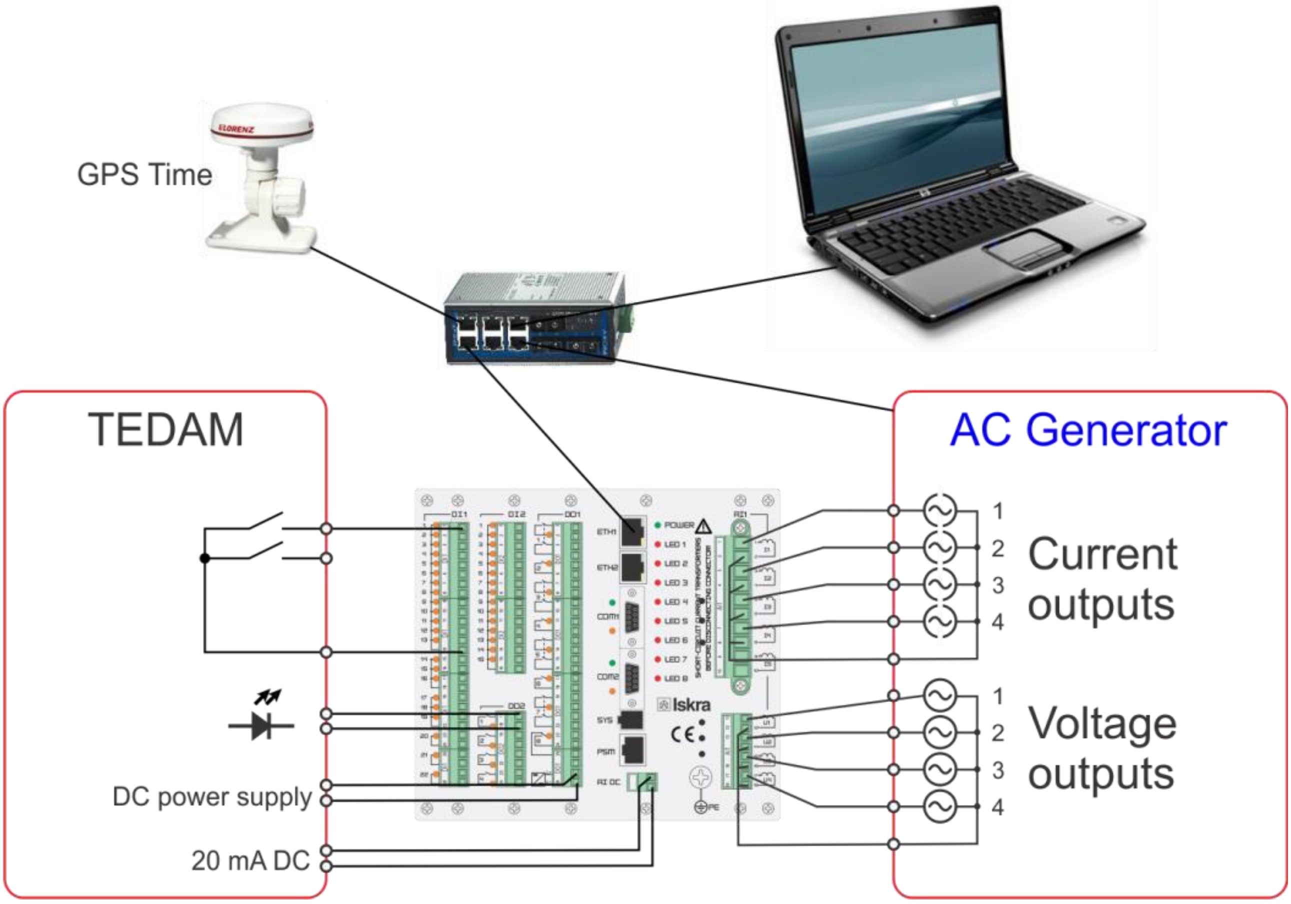

Figure 8.13 Device wiring diagram

8.6.4 Digital inputs test

For their operation the digital inputs need a voltage level that is normally the same as the power supply voltage. For the correct digital input operation the PIN of the chosen input should be connected to positive voltage, and this inputs group common point should be connected to negative. To facilitate the work see connection diagram on the connection board of the device. On devices with integrated digital input LEDs, a corresponding LED will illuminate for the tested input.

In the user interface go to *DI card* module and enable On-line mode. The module output of the tested input is set to 1.

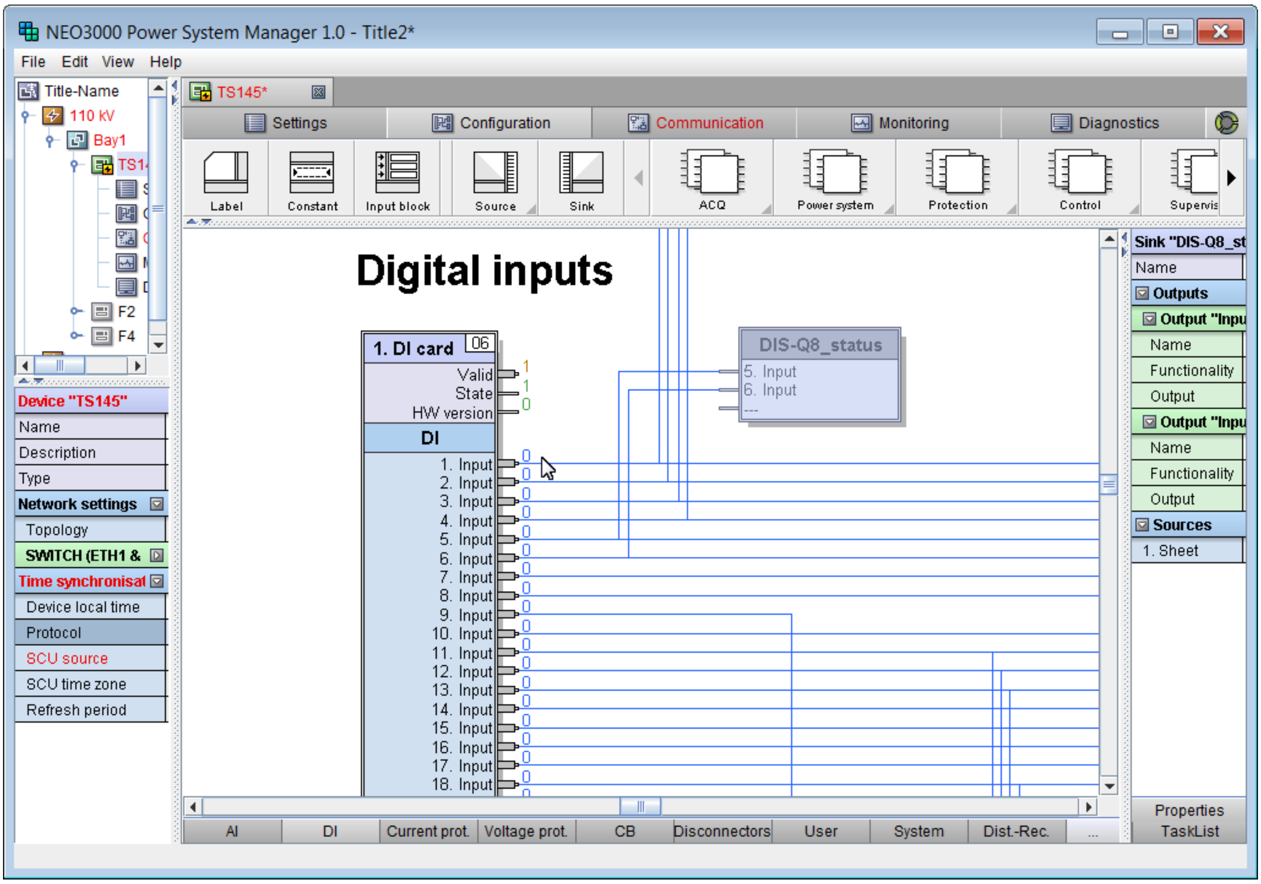

Figure 8.14 Digital inputs status control

8.6.5 Analog measurements test

Measurement inputs are checked with the current and voltage generator. When connecting to a device terminals, be careful to consider a correct polarity. Input line should be connected to the analog input terminal which is marked with a dot. To facilitate the work there is a connection diagram on the device connection board. In case there are no other restrictions the nominal analog values can now be applied to the inputs.

In the user interface go to *AC fundamental* module and enable On-line mode. The module output of the tested input are set to correct raw value.

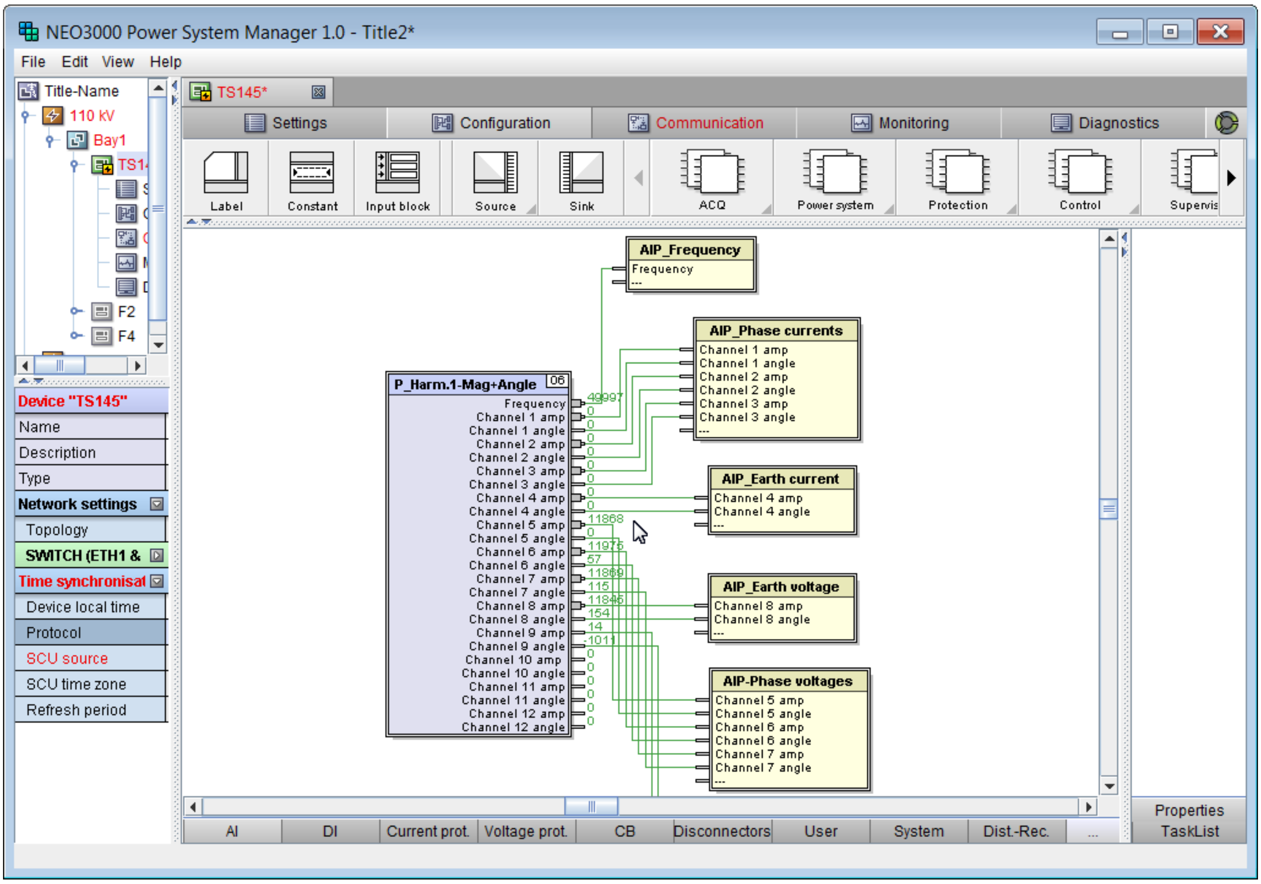

Figure 8.15 Analog inputs status control

8.6.6 Digital output relays test

Command outputs are tested with the *TEDAM* testing set or with universal instrument with the resistance measuring function. Output triggering is done through the communication protocol, LDU panel or from the user interface.

Through a user interface set value 1 to the input of the *DO card* module. With this an output relay is triggered. Its operation is confirmed with zero resistance between relay contacts. If the device has LEDs integrated on the connection board, a corresponding LED should illuminate.

In the user interface it is not possible to write to the module's input terminals. The module with its outputs connected to the tested relay outputs has to be found and test values must be written to these outputs.

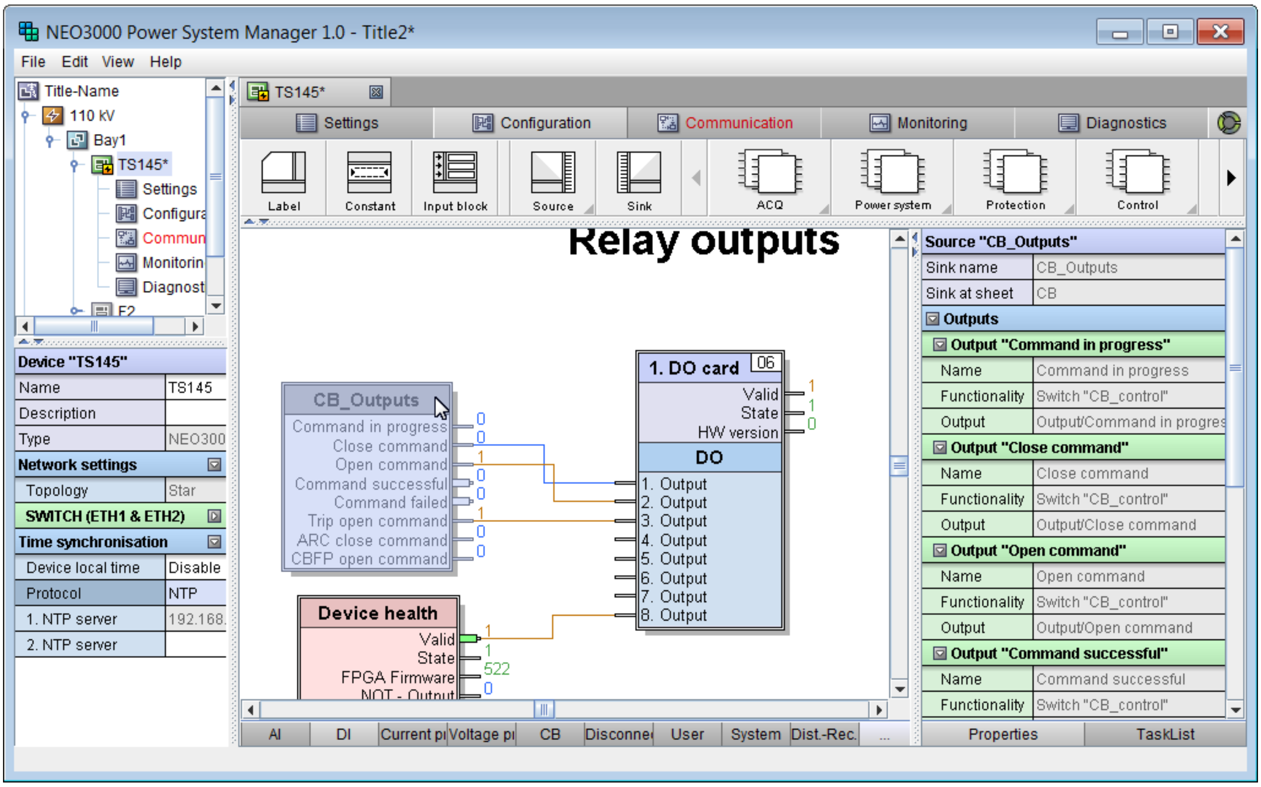

Figure 8.16 Command triggering

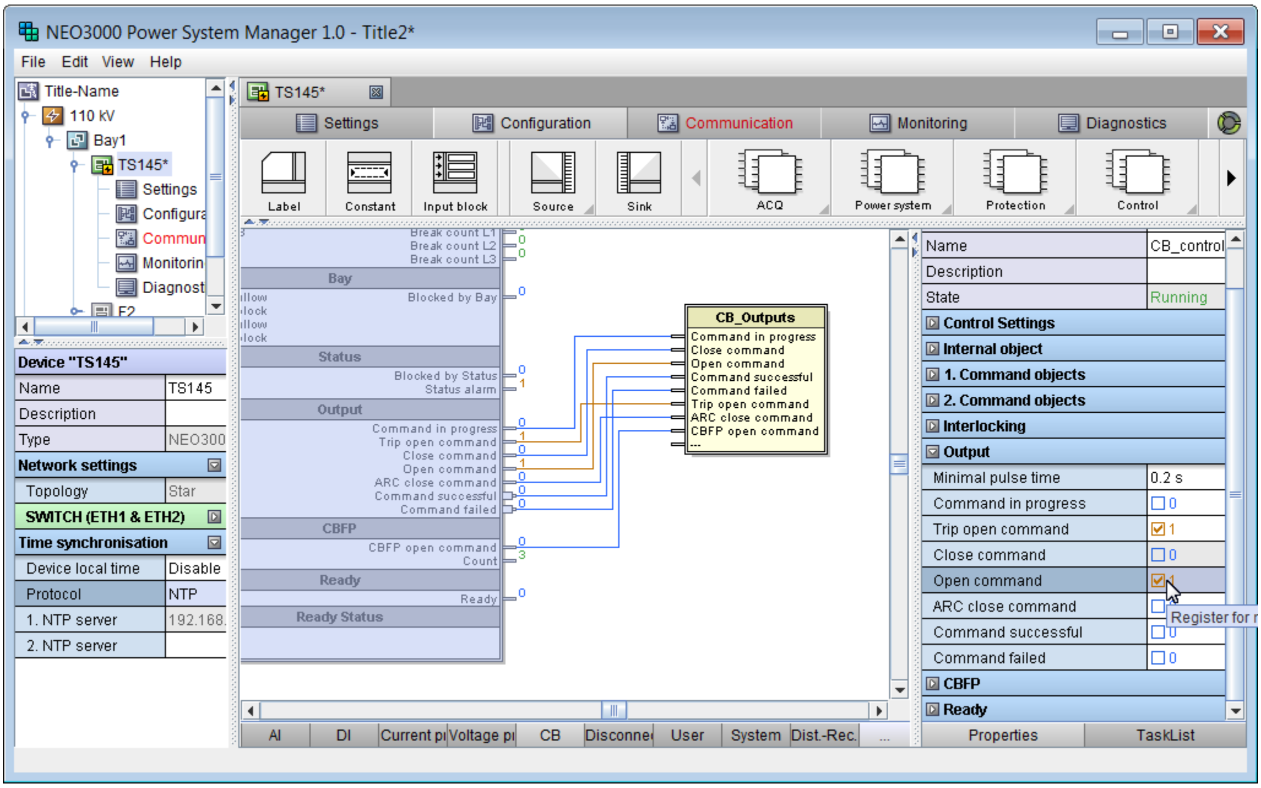

Figure 8.17 Command triggering

8.6.7 Communication protocol test

The device can have several communication protocols (IEC 104, DNP3, Modbus) and communication adapters (RS232, Fibre Optic, LAN). Communication protocol and adapter operation is tested with the protocol simulator, like ASE 2000 tool or any other. Figure below displays an ASE2000 simulator interface.

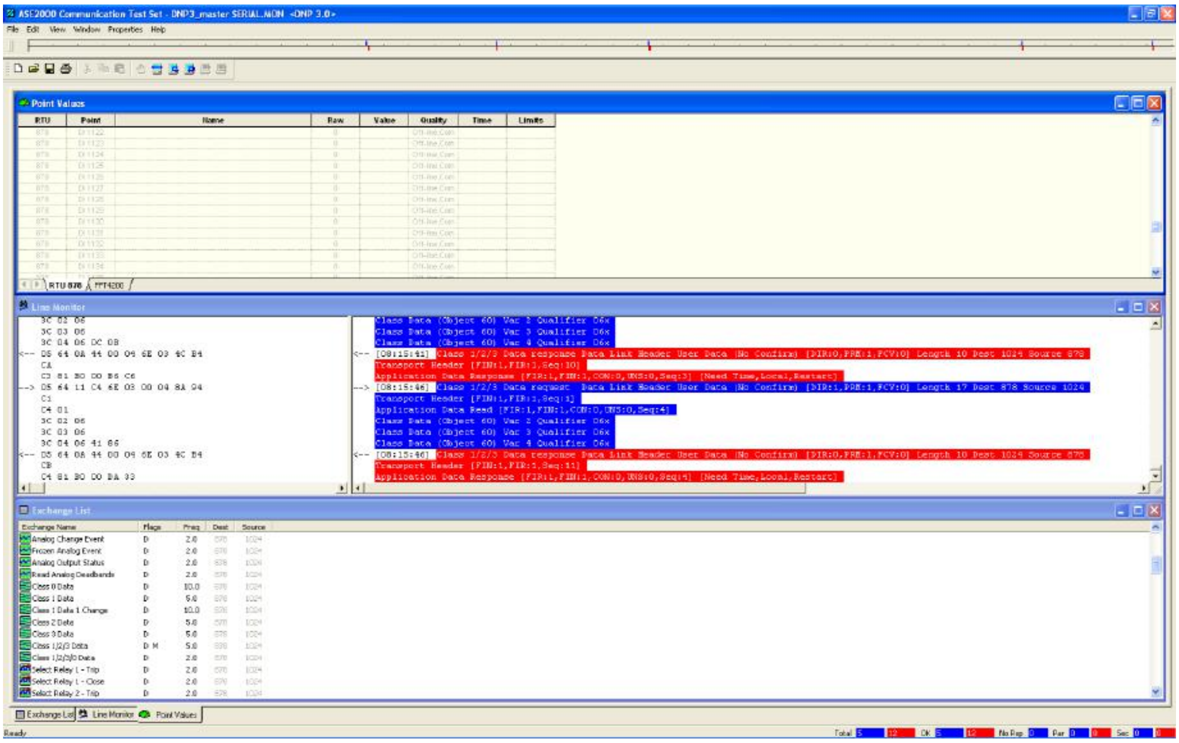

Figure 8.18: ASE2000 communication protocol simulator

The device must have the communication interface and protocol configured. On PC with a protocol simulator, connect to the device via a desired communication adapter and cable. Set the communication parameters and run the start procedure. On device, simulate data changes, which are transferred over communication. On protocol simulator issue all commands and verify successful execution on device.

8.6.8 Function tests

When testing control and protection functions, the conditions needed to cause the function to operate has to be simulated. It can be done through a communication, physical inputs or manually with user interface.

For protection functions, the monitored analog value is set to protection operating area and then the function can be tested:

- The protection has to operate and activate the **Trip** output signal, which closes the digital relay on the DO card.
- Disturbance records should be recorded and can be viewed with the user interface.
- **Pickup** and **Trip** signal events have to be sent over the communication.
- On the LDU local panel, an alarm is displayed and recorded to the event list.

Other functions connected to external digital inputs have to trigger the set relays when the conditions for individual function are fulfilled. All events included in communication protocols and local control panel LDU are written to a communication event list and can be viewed with the user interface tool. Control centre confirms the receiving of the triggered events.

8.6.8.1 Sample of a protection function test (Overcurrent protection)

For function test execution the function must be active and set correctly. Detailed instructions can be found in respective functions chapters.

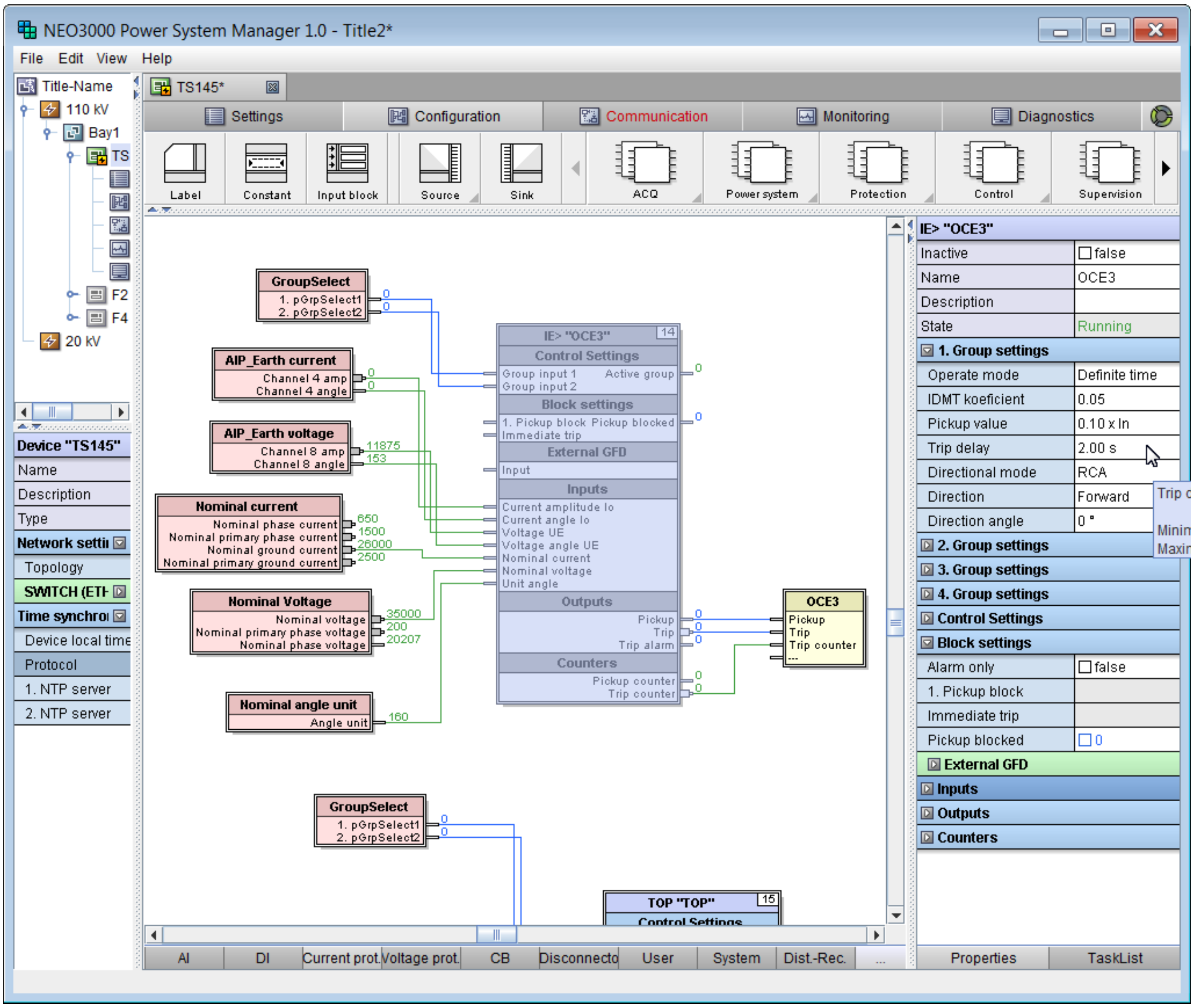

Figure 8.19 Function settings and its outputs

The test is performed with one- or three-phase AC values generator and a simulation of switching elements and change-over switch state that affect function operation. For the test execution it is best to prepare a test sequence for the AC values generator as this is the easiest way to simulate the actual real time occurrences on the line.

On the inputs it is necessary to inject the current exceeding the set value (in the example above: 1.0 x In - see figure above left). When all conditions for operation are met, the signals of detected faults are set on the outputs: **Pickup** and **Trip**.

There are multiple modules of overcurrent protection in device, which have different Pickup value and Trip delay parameters. All modules is tested the same way, but with a different fault values..

9 Technical data

Remark: All given parameters refer to recommended operating conditions in a range from -10°C to +55°C, except if specified otherwise. Specification can be changed without prior notice.

9.1 Mechanical characteristics

Dimensions (Width x Height x Depth)	Small housing	176*220*142 mm
	Middle-sized housing	176*270*142 mm
	Size 170 x 190	170*190*172 mm
	Size 220 x 190	220*190*172 mm
Weight	Small housing	≤ 3.5 kg
	Middle-sized housing	≤ 5 kg
Material		Stainless steel
Graphical display unit (Width x Height x Depth)	Small housing (1/2 19” 4U)	220 x 176 x 30 mm
	Middle-sized housing (1/3 19” 4U)	290 x 176 x 30 mm
IP protection level	Housing	IP 40
	Housing for extended temperature range	IP 20
	LDU graphical	IP 42
	LDU textual	IP 54
	Terminal side	IP 40

Operating conditions

Storage temperature	-20°C to +70°C
Operating temperature	-10°C to +55°C -10°C to +70°C (housing for extended temp. range)
Humidity	up to 95% non-condensing (29g/m^3 at 30°C)
Environmental conditions	Up to 2000 m of height above sea level

9.2 Device power supply

Rated voltage	24 / 48 / 110 / 220 V_{DC} and 230 V_{AC}
Permissible tolerance	-20…+30%
Power consumption	≤ 20 W, typical 15 W
Voltage loss hold up time	20 ms (100% drop)
Permanent memory type	Flash
Permanent data storing time	permanently

9.3 Analog inputs

AC current and voltage performance

Sampling rate	128 samples per cycle
AD converter digital resolution	16 bits (15 bits plus sign)

AC current inputs (FPC device)

Nominal frequency (f_N)	50 Hz
Nominal current (I_N)	1 A / 5 A
Current inputs range (I_{FS})	80 I_N 2 I_N (sensitive input)
Accuracy – amplitude	≤ ±0,5% I_N (0.1 I_N ≤ I ≤ 4 I_N; 50 Hz; 25°C) ≤ ±3% I_N (4 I_N ≤ I ≤ 80 I_N; 50 Hz; 25°C) ≤ ±0.1% I_N (0.001 I_N ≤ I ≤ 2 I_N; 50 Hz; 25°C; sensitive input)
Accuracy – angle	≤ ±0,5° (0.1 I_N ≤ I ≤ 80 I_N; 50 Hz; 25°C) ≤ ±0.1° (0.001 I_N ≤ I ≤ 2 I_N; 50 Hz; 25°C; sensitive input)
Accuracy – harmonics amplitude	≤ ±0.2% I_N (0.01 I_N ≤ I ≤ 0.5 I_N; H2…H40)
Temperature stability	≤ ±0.1% I_N / 10°C (amplitude) ≤ ±0.1° / 10°C (angle)
Consumption	≤ 0.07 VA (at I_N), ≤ 0.1 VA (at 20 I_N)
Thermal overload	4 I_N (continuous), 15 I_N (10 s), 100 I_N (1 s), 250 I_N (10 ms)
Response time	25 ms (0 - 100%)

AC current inputs (CAU device)

Nominal frequency (f_N)	50 Hz
Nominal current (I_N)	1 A / 5 A
Current inputs range (I_{FS})	20 I_N
Accuracy – amplitude	≤ ±0.2% I_N (0.01 I_N ≤ I ≤ 20 I_N; 50 Hz; 0-60°C)
Accuracy – angle	≤ ±0.5° (0.05 I_N ≤ I ≤ 20 I_N; 50 Hz; 0-60°C)
Accuracy – harmonics amplitude	≤ ±0.2% I_N (0.01 I_N ≤ I ≤ 0.5 I_N; H2…H40)
Consumption	≤ 0.07 VA (at I_N), ≤ 0.1 VA (at 20 I_N)
Thermal overload	4 I_N (continuous), 15 I_N (10 s), 100 I_N (1 s), 250 I_N (10 ms)
Linearity	≤ ±0.03%

AC voltage inputs

Nominal frequency (f_N)	50 Hz
Nominal voltage (U_N)	100 V / 200 V
Voltage inputs range (U_{FS})	150% U_N
Accuracy – amplitude	≤ ±0.1% U_N (0.005 U_N ≤ U ≤ 1.5 U_N; 50 Hz; 25°C)
Accuracy – angle	≤ ±0.2° (0.01 U_N ≤ U ≤ 1.5 U_N; 50 Hz; 25°C)
Accuracy – harmonics amplitude	≤ ±0.2% U_N (0.01 U_N ≤ U ≤ 0.5 U_N; H2…H40)
Temperature stability	≤ ±0.1% / 10°C (amplitude) ≤ ±0.1° / 10°C (angle)
Consumption	≤ 0.23 VA (at 150 V), ≤ 0.40 VA (at 300 V)
Maximum input voltage	150% U_N (continuous)
Response time	25 ms (0 - 100%)

DC analog inputs

Nominal value	±2 / ±10 / ±20 mA (DC current inputs, $I_{FS\text{-}DC}$) ±0.5 / ±2.5 / ±5 / ±10 V (DC voltage inputs, $U_{FS\text{-}DC}$)
Input resistance	100 kΩ (DC voltage inputs), 110 Ω (20 mA), 220 Ω (2 mA or 10 mA)
Accuracy	≤±0.08% (0.02 $I_{FS\text{-}DC}$≤ I ≤ $I_{FS\text{-}DC}$; 25°C) ≤±0.08% (0.02 $U_{FS\text{-}DC}$≤ U ≤ $U_{FS\text{-}DC}$; 25°C)
Temperature stability	≤±0.2% / 10°C (DC voltage inputs) ≤±0.3% / 10°C (DC current inputs) ≤±0.04% / 10°C (option)
Common mode rejection ratio (CMRR)	66 dB (at 50 / 60 Hz)
Normal mode rejection ratio (NMRR)	26 dB (at 50 / 60 Hz)
Maximum input voltage	±11 V (DC voltage inputs), ±6 V (DC current inputs), continuous
Maximum input current	±25 mA (DC voltage and DC current inputs), continuous
Galvanic isolation	2000 V $_{(AC,\ DC)}$

9.4 Digital inputs

DC digital inputs

Nominal voltage ($U_{N\text{-}DI}$**)**	24 / 48-60 / 110 / 220 V_{DC}
Upper logic level	0.8 $U_{N\text{-}DI}$ ≤ U ≤ 1.2 $U_{N\text{-}DI}$
Lower logic level	-1.2 $U_{N\text{-}DI}$ ≤ U ≤ 0.5 $U_{N\text{-}DI}$
Input current	≤ 0.5 mA
Maximum input voltage	±1.2 $U_{N\text{-}DI}$ (continuous)
Galvanic isolation	2000 V $_{(AC,\ DC)}$

AC digital inputs

Nominal voltage($U_{N\text{-}DI}$**)**	230 V_{AC}
Upper logic level	0.8 $U_{N\text{-}DI}$ ≤ U ≤ 1.2 $U_{N\text{-}DI}$
Lower logic level	U ≤ 0.5 $U_{N\text{-}DI}$
Input current	≤ 0.5 mA
Maximum input voltage	1.2 $U_{N\text{-}DI}$ (continuous)
Galvanic isolation	2000 V $_{(AC,\ DC)}$

9.5 Digital (relay) outputs

Number of outputs per DO module	8 (1x switching relay+ 3x single contact + 4x double contact)
Switching capacity	8 A (continuous) 14 A (max. 4 s at D=10%)
Number of switching cycles	10^6
Maximum switching voltage	250 V $_{(DC,AC)}$
Maximum number of simultaneously switched relays	16 (regardless of the number of relays in the device)

Response time	≤ 12 ms

9.6 Communication

COM1 and COM2

Use	data transfer from the device and commands execution
Type	RS232 or RS485 or FO (optical interface)

COM RS232

Connector	rear, DB9
Cable	TBD
Transfer speed	300, 600, 1.200, 2.400, 4.800, 9.600, 19.200, 38.400, 57.600, 115.200 bit/s (full modem)
Range	15 m (RS232)
Galvanic isolation	500 V (AC, DC)

COM RS485

Connector	rear, MSTB 3
Cable	120 Ω STP or UTP (twisted pair)
Transfer speed	300, 600, 1.200, 2.400, 4.800, 9.600, 19.200, 38.400, 57.600, 115.200 bit/s
Range	according to EIA-485
Galvanic isolation	500 V (AC, DC)

COM FO

Connector	rear, ST
Cable	multi-mode, 62.5/125 μm, 50/125 μm, 100/140 μm, 200 μm
Wavelength	820 nm
Transfer speed	300, 600, 1.200, 2.400, 4.800, 9.600, 19.200, 38.400, 57.600, 115.200 bit/s
Range	1700 m
Transmitter optical power	-15 dBm
Receiver sensitivity	-34 dBm
Allowed optical loss	≤ 6.8 dB (62.5/125 μm, 1700 m, -15 dBm / -34 dBm)

ETH1 and ETH2

Use	data transfer from the device and commands execution
Type	10BASE-T/100BASE-TX (RJ45) or 100BASE-FX (ST)

ETH 10BASE-T / 100BASE-TX

Connector	rear, RJ45
Cable	100 Ω STP or UTP - CAT5E crossover
Transfer speed	10/100 Mbit/s FDX/HDX
Range	100 m

Galvanic isolation	500 V (AC, DC)

ETH 100BASE-FX

Connector	rear, ST
Cable	multi-mode, 62.5/125 µm, 50/125 µm
Wavelength	1300 nm
Transfer speed	100 Mbit/s FDX/HDX
Range	2000 m (IEEE 802.3u)
Transmitter optical power	-23.5 dBm
Receiver sensitivity	-35 dBm
Allowed optical loss	≤ 7.2 dB (62.5/125 µm, 2000m, -23.5 dBm/-35 dBm)

PSM interface

Use	exclusively for connection of a remote LDU device or service access to a device – not installed in devices with a built-in LDU module
Type	10BASE-T / 100BASE-TX (RJ45)
Connector	rear, RJ45
Cable	100 Ω STP or UTP - CAT5E crossover (LDU), special local access service cable
Transfer speed	10/100 Mbit/s
Range	100 m
Galvanic isolation	500 V (AC, DC)

LDU ETH front network interface

Use	local service access to a device
Type	10BASE-T / 100BASE-TX (RJ45)
Connector	front, RJ45
Cable	100 Ω STP or UTP - CAT5E crossover (LDU),
Transfer speed	10/100 Mbit/s
Range	100 m
Galvanic isolation	500 V (AC, DC)

Service system port

Connector	rear, RJ11
Cable	TBD
Transfer speed	9.600, 19.200, 38.400, 57.600, 115.200 bit/s
Range	15 m (RS232)
Galvanic isolation	None

Supported protocols

Ethernet ports	IEC 61850 DNP 3.0 over TCP/IP IEC 60870-5-104

Serial ports	DNP 3.0 over serial IEC 60870-5-101 IEC 60870-5-103
Undetected bit error probability **DNP3, IEC 60870-5**	10^{-18} (BER 10^{-3}) 10^{-36} (BER 10^{-5})
Undetected bit error probability **Modbus**	10^{-5} (BER 10^{-3}) 10^{-11} (BER 10^{-5})

9.7 Control functions

Clock synchronization

Way of synchronizing	Communication protocol, NTP

Autorecloser (ARC)

Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Synchro-check (SC)

Accuracy – angle	≤ ±0.6°
Accuracy – amplitude	≤ ±0.3%
Accuracy – frequency	≤ ±10 mHz
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Programmable timer

Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Scheduler

Accuracy – timer	≤ ±1 s

Voltage regulator

Accuracy – angle	≤ ±0.6°
Accuracy – voltage	≤ ±0.3%
Accuracy – current	≤ ±1.0%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

9.8 Calculation functions

Phase-to-phase voltages

Accuracy - amplitude	< 0,5% Un (U > 0,5 Un; 50 Hz; 25°C)
Accuracy - angle	< ±0,75°

Symmetrical components

Accuracy – current amplitude	< 0,5% In (50 Hz; 25°C)
Accuracy – voltage amplitude	< 0,1% Un (50 Hz; 25°C)

Power and energy

Accuracy – power (P, Q, S)	< 0,5% Pn (U > 0,5 Un; I > 0,1 In; PF > 0,7; 50 Hz; 25°C)

Power quality

Accuracy – current RMS	< 1% In (I > 0,1 In; 50 Hz; 25°C)
Accuracy – voltage RMS	< 0,2% Un (U > 0,05 Un; 50 Hz; 25°C)
Accuracy – current THD	< 2 pp (I > 0,5 In; 50 Hz; 25°C)
Accuracy – voltage THD	< 1 pp (U > 0,1 Un; 50 Hz; 25°C)
Accuracy – current H2…H40	< 0,5% In (I > 0,01 In; 50 Hz; 25°C)
Accuracy – voltage H2…H40	< 0,2% Un (U > 0,01 Un; 50 Hz; 25°C)

Fault locator (FPC device only)

Line resistance/inductance	0.00 … 10.00 ohm/km
Accuracy – fault distance	< ±0,5 km
Accuracy – fault resistance	< ±2 ohm

9.9 Protection functions (FPC device only)

Overcurrent protection (I>)

Pickup level range	0.05 … 40 I_N
Accuracy – amplitude	≤ ±1,0% I_N (0.1 I_N ≤ I ≤ 20 I_N; 50 Hz; 25°C) ≤ ±3% I_N (20 I_N ≤ I ≤ 80 I_N; 50 Hz; 25°C)
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms
Accuracy – Invers time delay	≤ ±1000 ppm of t_{IDMT} ±5 ms

Earth fault overcurrent protection (Ie>)

Pickup level range	0.05 … 1.25 I_N
Accuracy – amplitude	≤ ±0.2%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms
Accuracy – Invers time delay	≤ ±1000 ppm of t_{IDMT} ±5 ms

Overvoltage protection (U>)

Pickup level	0.05 … 2 U_N
Accuracy – amplitude	≤ ±0.3%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Undervoltage protection (U<)

Pickup level	0.1 … 2 U_N
Delay	0.00 … 300.00 s
Accuracy – amplitude	≤ ±0.3%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Residual overvoltage protection (Ue>)

Pickup level	0.01 … 2 U_N
Delay	0.00 … 300.00 s

Accuracy – amplitude	≤ ±0.3%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Frequency protection: (f>, f<)

Pickup level	45 … 55 Hz
Delay	0.00 … 300.00 s
Accuracy – frequency	≤ ±5 mHz (U ≥ 0.6 U_{FS}) ≤ ±10 mHz (0.1 U_{FS}< U < 0.6 U_{FS})
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

External protection (EXT>)

Delay	0.00 … 300.00 s
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Trip circuit supervision (TCS)

Delay	0 … 60000 ms
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Negative sequence protection (I2>)

Pickup level	0.1 … 3 I_N
Accuracy – amplitude	≤ ±1,0%
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

Thermal overload protection (TOP)

Pickup level	45.00 … 99.99%
Accuracy – amplitude	≤ ±1,0%
Accuracy – temperature	≤ ±3°C
Accuracy – timer	≤ -50 ppm of t_{SET} ±5 ms

9.10 Device dimensions

Drill holes mounting dimensions. Dimensions in figures are in millimetres.

9.10.1 FPC 680 / CAU 380 – xxx / N1(4) / ... device dimensions

FPC 680 / CAU 380 - N1 (surface mount without LDU – small housing ½ of 19", 4U) housing dimensions (WxHxD): 220 mm x 176 mm x 144 mm (157 mm with connectors).

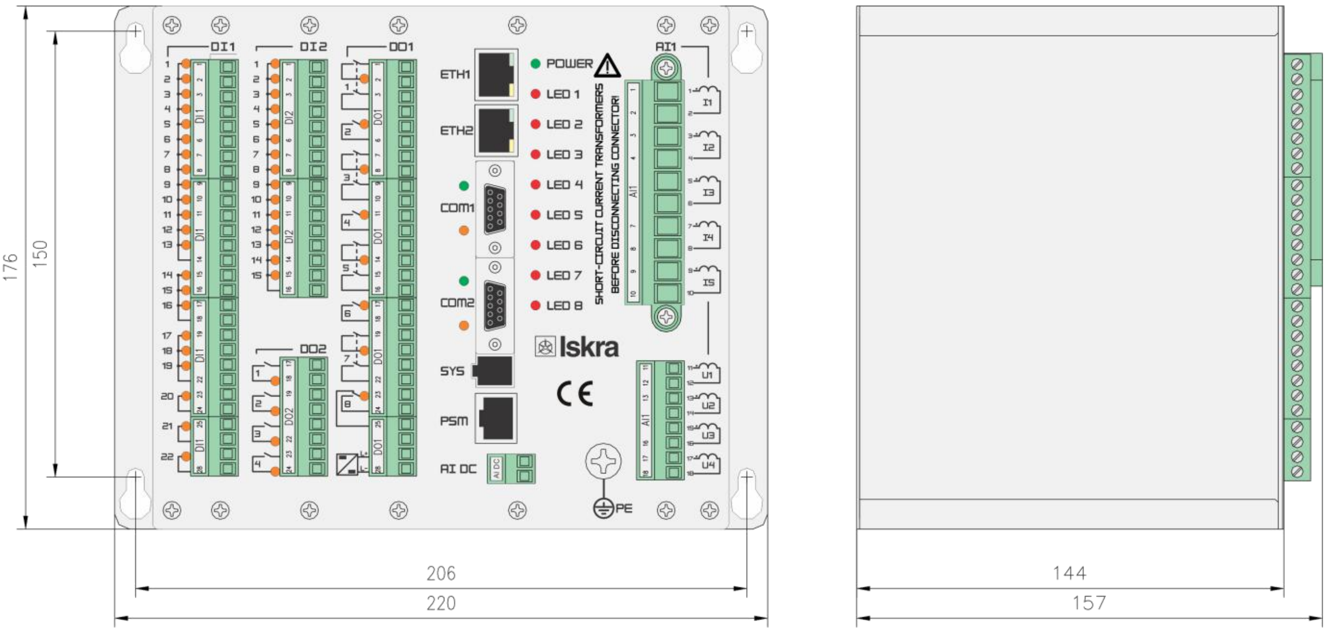

Figure 9.1: FPC 680 / CAU 380 - N1(4) device mounting dimensions

9.10.2 FPC 680 / CAU 380 – xxx / L1(4) / ... device dimensions

FPC 680 / CAU 380 - L1 (flush mount with LDU integration – small housing ½ of 19", 4U) housing dimensions (WxHxD): 220 mm x 176 mm x 174 mm (187 mm with connectors).

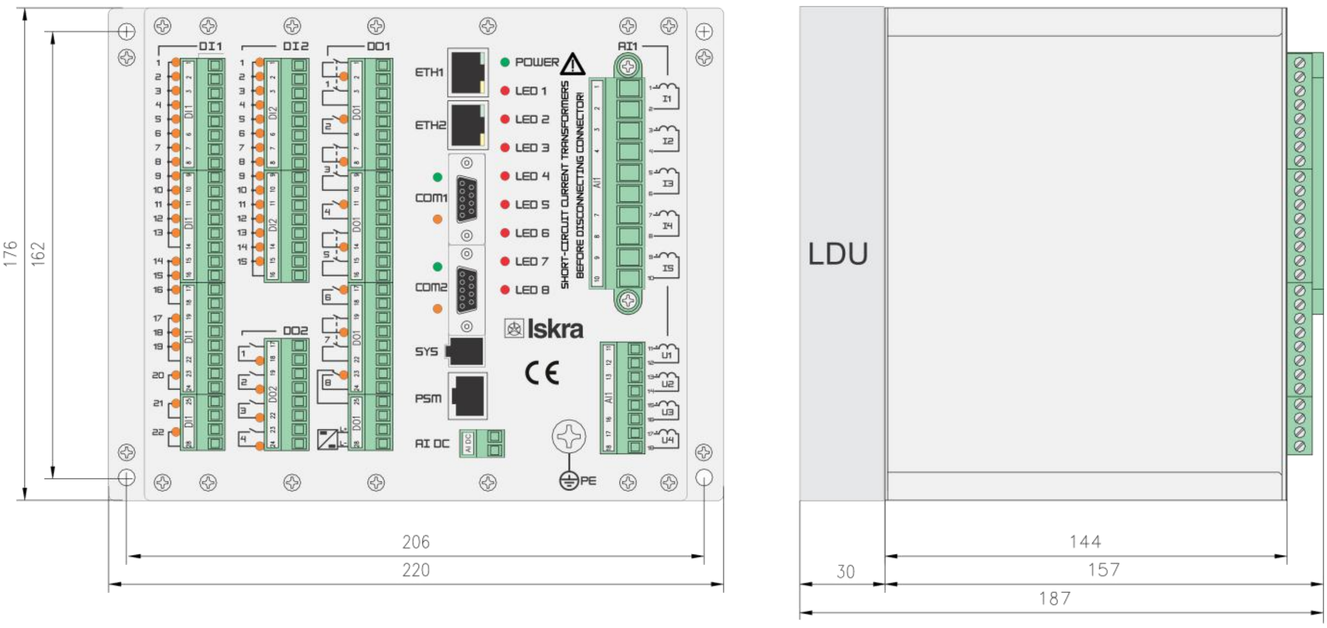

Figure 9.2: FPC 680 / CAU 380 - L1(4) device mounting dimensions

9.11 Cut-out dimensions

Measurements of cut-outs and drill holes for mounting. All measurements on pictures are in millimetres.

9.11.1 Cut-out for FPC 680 / CAU 380 – xxx / L1(4) /…

For FPC 680 / CAU 380 - L1(4) (mounting with an integrated LDU – small housing ½ of 19”, 4U) the recommended mounting cut-out dimensions are 196 mm x 177 mm and space between screw holes is 206 mm on horizontal axis and 162 on vertical axis.

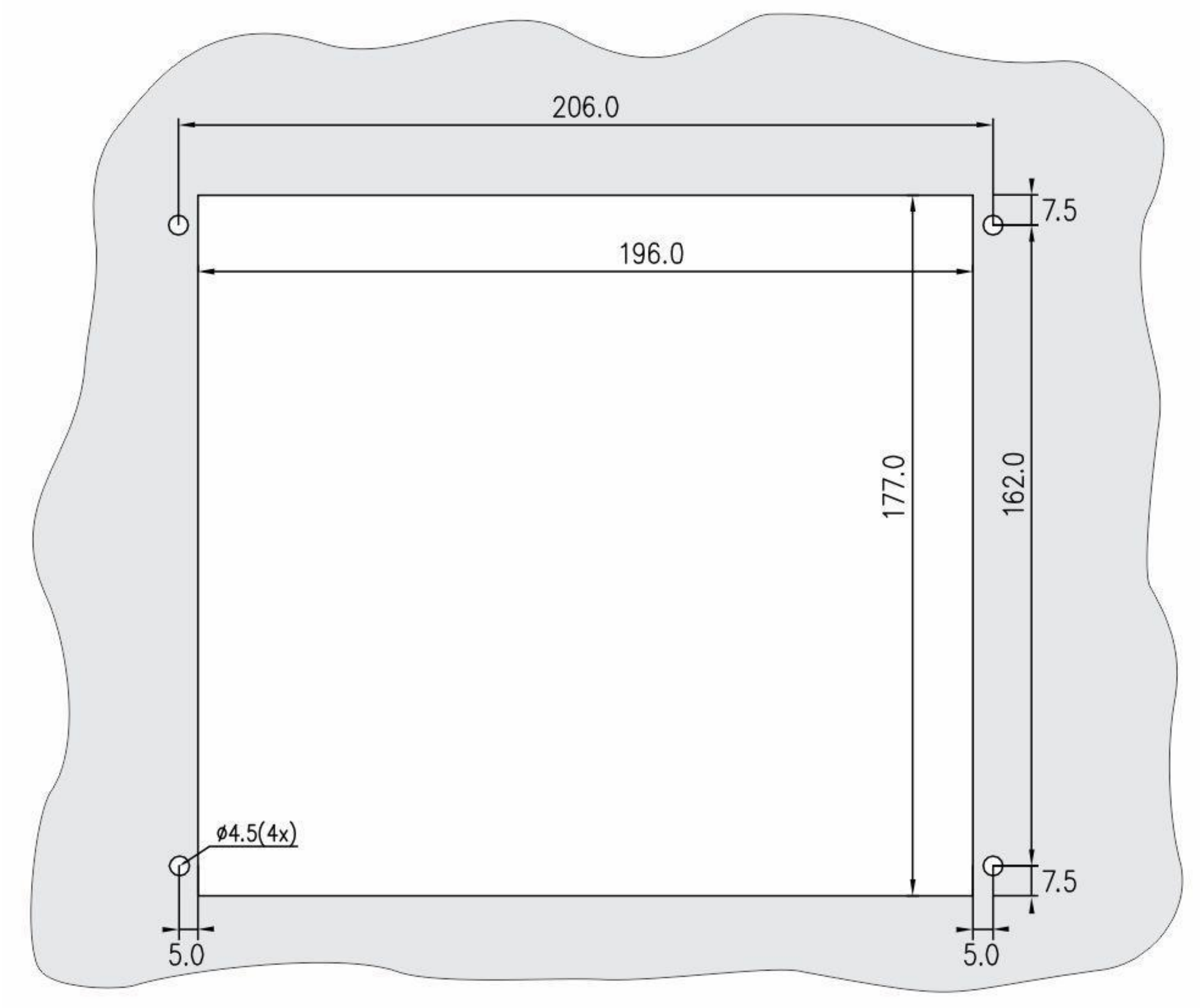

Figure 9.3: Recommended cut-out dimensions for FPC 680 / CAU 380 - L1(4)

9.12 Storing and maintenance

The device is maintenance-free. Cleaning can only be performed when the device is switched-off from the power supply and disconnected from the secondary electrical system. Use of liquid cleaning agents is not allowed.

The device can only be stored in its original packaging in a dry and dust-free environment in conditions described in the technical data.

Appendix A: FPC 680 ordering code

FPC 680 - SW / H / AI / C1 / C2 / C3 / C4 / PS / S1 / S2 / S3 / S4

|--------------------- Small housing ---------------------------------|

|--------------------- Medium housing ---|

- **SW** – Software type
  - FPC 680
    - F01 – Current protection
    - F02 – Voltage protection
    - F03 – Current and Voltage protection
    - F04 – Current and Voltage protection with Synchro check
    - F05 – Current and Voltage protection with Shunt protection
    - F06 – Current and Voltage protection with IuB protection
    - F07 – Current and Voltage protection with Differential protection
    - T01 – Transformer Current protection
    - T03 – Transformer Current and Voltage protection
    - M01 – Current protection for motors
    - M03 – Current and Voltage protection for motors

- **H** – Housing layout
  - Housing type
    - T – flush mounting with integrated Textual LDU
    - L – flush mounting with integrated Graphical LDU
    - N – surface mounting without LDU
    - D – surface mounting with detachable Graphical LDU
    - Z – surface mounting with integrated Graphical LDU
  - Housing size
    - 1 – Small housing (1/2 19”, 4U) (slots S1 … S2)
    - 2 – Medium housing (2/3 19”, 4U) (slots S1 … S4)
    - 4 – Small housing for extended temp. range (1/2 19”, 4U) (slots S1 … S2)
    - 5 – Medium housing for extended temp. range (2/3 19”, 4U) (slots S1 … S4)
    - 7 – Size 170 x 190 for extended temp. range
    - 8 – Size 220 x 190 for extended temp. range (slots S1, S2)

- **AI** - AI AC configuration
  - AC board type
    - N – none
    - D – 3 CT + 1 CTs (1) + 4 VT
    - E – 3 CT + 2 CTs (1) + 4 VT
    - F – 4 CT + 1 CTs (1) + 4 VT
    - G – 3 CT + 1 CTs (1) + 5 VT
    - H – 3 CT + 1 CTs (1) + 4 VT + 3 CT + 1 CTs (1)
    - K – 3 CT + 1 CTs (1)
    - L – 4 VT
    - M – 4 CT + 1 CTs (1) + 7 VT
  - Current measuring inputs
    - N – none
    - 1 – 1 A current input
    - 5 – 5 A current input
    - M – mixed 1 A and 5 A current input
  - Voltage measuring inputs
    - N – none
    - 1 – 150 V voltage input
    - 3 – 300 V voltage input

- DC measuring inputs (1 input)
  - N – none
  - C – 1 AI DC Current measuring inputs 20 mA
  - V – 1 AI DC Voltage measuring inputs +/- 10 V

- **C1, C2** - Ethernet communication ports
  - Connector
    - N – none (only system)
    - E – 100BaseTX (RJ45)
    - F – 100BaseFX (ST Glass F.O.)
  - Communication protocol
    - N – none
    - G – IEC 61850 MMS with GOOSE
    - 4 – IEC 60870-5-104
    - D – DNP3 over TCP/IP

- **C3, C4** – Serial communication ports
  - Connector
    - N – none (only system)
    - 2 – RS232 (DB9 female)
    - F – ST Glass F.O.
    - 5 – RS485
  - Communication protocol
    - N – none
    - 1 – IEC 60870-5-101
    - 3 – IEC 60870-5-103
    - D – DNP3
    - M – Modbus RTU

- **PS** – Auxiliary supply voltage
  - 1 – 19…30 V DC with 8 DO
  - 2 – 38…72 V DC with 8 DO
  - 3 – 88…150 V DC with 8 DO
  - 4 – 176…300 V DC with 8 DO
  - 5 – 170…330 V AC with 8 DO
  - M1 – 19…30 V DC with 5 DO and 8 DI
  - M2 – 38…72 V DC with 5 DO and 8 DI
  - M3 – 88…150 V DC with 5 DO and 8 DI
  - M4 – 176…300 V DC with 5 DO and 8 DI
  - M5 – 170…330 V AC with 5 DO and 8 DI

- **S1..S8** – Slot configuration
  - NN - none
  - R8 - DO board (8 digital outputs) (2) (3) (5 or 8 digital output are default on PS board)
  - B1 - DI board (22 digital inputs) 24 V DC (with LEDs) (3)
  - B2 - DI board (22 digital inputs) 48 V DC (with LEDs) (3)
  - B3 - DI board (22 digital inputs) 110 V DC (with LEDs) (3)
  - B4 - DI board (22 digital inputs) 220 V DC (with LEDs) (3)
  - B5 - DI board (22 digital inputs) 230 V AC (with LEDs) (3)
  - M1 - DIO board (15 digital inputs, 4 digital outputs) 24 V DC (with LEDs) (3a)
  - M2 - DIO board (15 digital inputs, 4 digital outputs) 48 V DC (with LEDs) (3a)
  - M3 - DIO board (15 digital inputs, 4 digital outputs) 110 V DC (with LEDs) (3a)
  - M4 - DIO board (15 digital inputs, 4 digital outputs) 220 V DC (with LEDs) (3a)
  - M5 - DIO board (15 digital inputs, 4 digital outputs) 230 V AC (with LEDs) (3a)
  - D8 – AI DC board (8 inputs) (4)
  - T8 – AI RTD board (8 inputs) – for direct PT100 (4)

Legend:

(1) – CTs – sensitive Current input for sensitive earth current protection stages

(2) – up to 2 boards max

(3) – sum of all DI and DO boards up to 7

(3a) – DIO board uses addressing of two boards: DI and DO

(4) – one board max

Ordering code examples:

FPC 680 – F04 / L1 / D11N / FG / FG / NN / NN / 3 / B3 / B3

FPC 680 – F03 / L1 / D11N / FG / FG / NN / NN / 3 / B3

Appendix B: Software type classification

Base modules:

- Access to HW cards (Acquisition module)
- Function blocks (AND, OR, NOT, GT, LT, …)
- CB control
- Disconnector control
- Line state detection
- Symmetrical components calculation
- Power and Energy metering
- Energy counters
- Disturbance recorder
- Pulse signals
- Event recorder

Control:

- Dips and swells
- Analog over-range
- Programmable timer

Current protection:

- Over-current protection with IDMT, Cold Load,..
- Over-current earth protection with IDMT, Cold Load,..
- Negative sequence over-current protection
- Thermal overload protection
- External protection
- Trip Circuit Supervision
- ARC – Automatic Recloser Control
- Restricted earth fault
- Inrush Restraint

Voltage protection:

- Over voltage protection
- Under voltage protection
- Over voltage earth protection
- Over frequency protection
- Under frequency protection
- External protection
- Trip Circuit Supervision

Synchro check:

- Synchro check control function

Voltage regulator:

- Voltage regulation function

Fault Current Detection:

- Fault current detection function

Shunt protection:

- Shunt protection
- NGR failure detection

Iub protection:

- Iub protection

Transformer protections

- Machine control, running hours
- Temperature monitoring (up to 8 sensors)
- Advanced thermal overload protection for machines

Protections for motor

- Machine control, running hours
- Temperature monitoring (up to 8 sensors)
- Locked rotor, excessive starting time
- Starts per hour
- Advanced thermal overload protection for machines

Appendix C: Directives, standards and tests

Table C.1: Environmental test standards list.

Test	Standard	Description
Temperatures	IEC 60068-2-1, IEC 60068-2-2	from 0 °C to 60 °C
Temperature gradient	IEC 60068-2-14	up to 30 °C
Humidity	IEC 60068-2-30	up to 95% at 40 °C drop from 40 °C to 25 °C at 95% relative humidity up to 29 g/m3
Damp heat, steady state	IEC 60068-2-78	In compliance with IEC60255-27, chapter 10.5.1.5

Vibration (sinusoidal)	IEC 60068-2-6	2 g acceleration, from 9 to 350 Hz
Shock and bump	IEC 60068-2-27	15 g, 11 ms test
Seismic	IEC 60068-21-3	under voltage, in compliance with IEC60255-27, chapter 10.5.2.1.4

Table C.2: Insulation test standards list.

Test	**Standard**	**Description**
Rated insulation voltage	IEC 60255-5, table 1	500 V
Dielectric voltage	IEC 60255-5, table 1, series B, chapter 6	2.0 kV RMS
Insulation resistance	IEC 60255-5, chapter 7	100 MΩ at 500 VDC
Impulse voltage	IEC 60255-5, chapter 8	5 kV, 1.2/50 µs, 0.5 J

Table C.3: Electromagnetic compatibility test standards list.

Test	**Standard**	**Description**
Electrical disturbances	IEC 60255-22-1, class 3	2.5 kV common mode, 1.0 kV differential mode
Electrostatic discharge immunity	IEC 61000-4-2, level 4	15 kV air discharge, 8 kV direct discharge
Radiated immunity	IEC 61000-4-3, level 3 IEC 60255-22-3, class 3 IEC 61000-4-3, class 3 ENV 50204 (GSM), level 3	80 MHz to 1 GHz 27 to 500 MHz 50 kHz to 1 GHz 10 V/m, 2 W at 0.6 m
Fast transient/burst immunity	IEC 61000-4-4, level 4 IEC 60255-22-4, class 4 ANSI/IEEE C.37.90.1	4 kV 4 kV 4–5 kV
Surge immunity	IEC 61000-4-5, level 4	2 kV / 4 kV
Conducted immunity	IEC 61000-4-6, level 3	10 V
Power frequency magnetic field immunity	IEC 61000-4-8, level 4	30 A/m
Pulse magnetic field immunity	IEC 61000-4-9, level 5	1000 A/m
Damped oscillatory magnetic field immunity	IEC 61000-4-10, level 4	30 A/m
Oscillatory transient immunity	IEC 61000-4-12, level 4 IEC 61000-4-18, level 3 ANSI/IEEE C.37.90.1	Ring wave Damped oscillatory wave 2.5 kV
Emissions test	IEC 60255-25	20 to 1000 MHz
Power interruption test	IEC 60255-11	20 ms, 12% ripple
Power frequency immunity test	IEC 60255-22-7 IEC 61000-4-16	In compliance with IEC 60255-16, table 6

Table C.4: List of standards for communication protocols tests.

Test	**Standard**	**Description**

61850 communication	IEC 61850-6 IEC 61850-7-1 IEC 61850-7-2 IEC 61850-7-3 IEC 61850-7-4 IEC 61850-8-1	IEC 61850-10 Ed1