TPU L500

Product Manual

Edition 1

AS16002284, Rev. 01, November 2016

The content of this manual has been carefully revised, however, the full compliance of its content with the technical and functional characteristics of the product it is referred to cannot be assured, as typing or other errors cannot be completely ruled out. The information given is regularly reviewed and any necessary correction or additional explanation will be included in future revisions of this document.

Due to continuous development, the content of this manual can be changed without notice.

We appreciate any correction or improvement suggestion.

PREFACE

Objective

This manual describes the installation, configuration, operation and maintenance of the TPU L500.

Focus

This manual is intended for protection and automation power system engineers, specialized personnel responsible for the installation, configuration and commissioning of the equipment and staff from the energy transmission and distribution companies in charge of its operation.

Application

The information in this manual is valid for the following equipment of EFACEC Automation:

- TPU L500, Edition 1

Safety Instructions

This manual does not cover all safety measures required to operate the equipment because additional procedures can be necessary in specific circumstances. Yet, all safety instructions given in this manual must be followed.

Any intervention regarding the equipment's installation, commissioning or operation must be carried out by authorized technical personnel.

The equipment shall not be used for purposes other than those specified in this document.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel and/or equipment damage.

CE

This product complies with the Directive of the European Parliament and of the Council 2006/95/EC (Low Voltage Directive) as well as with the Directive of the European Parliament and of the Council 2004/108/EC (Electromagnetic Compatibility Directive).

The conformity is proved by several actions including the tests conducted by EFACEC and by independent entities, in accordance with the standards EN 61000-6-2 (2005), EN 61000-6-4 (2007) and EN 50263 (1999) concerning Electromagnetic Compatibility Directive and in accordance with the standards EN 60950-1: 2006 + A1: 2010 + A11: 2009 + A12: 2011, EN 60255-5 (2001) and EN 60255-27 (2005) concerning Low Voltage Directive.

Organization

This manual is organized in chapters so that it is easier to find the desired information and it is adjusted to the different target readers it is meant for:

- **Chapter 1 - Introduction**: summary of the device characteristics and functions;
- **Chapter 2 - Installation**: instructions for the unit correct installation and the execution of all required connections;
- **Chapter 3 - Human Machine Interface**: guide for the use of the local and web-based human-machine interfaces;
- **Chapter 4 - Device Configuration**: description of the base device configurations;
- **Chapter 5 - Application Functions**: description of the operating principle, configuration and interface for each built-in function;
- **Chapter 6 - Communications**: application of communication protocols and their configuration;
- **Chapter 7 - Operation**: operation guide with procedure to perform supported tasks;
- **Chapter 8 - Annexes**: additional information about the device.

This manual contains warnings related to specific aspects of the equipment's installation, configuration or operation with different importance levels:

The failure to comply with the safety instruction may endanger the correct operation and cause personnel injuries and/or equipment damage.

The failure to comply with the safety or operational instruction may endanger the correct operation of the equipment.

Additional information with special interest for an easier configuration or operation, not relevant for personnel and/or equipment safety.

Answer to a frequent question about the equipment's configuration or operation for quick problem solving.

Related Documents

Reference	Document	Number
[1]	TPU L500 Data-sheet	AS16001230
[2]	Automation Studio User Manual	ASID12000061
[3]	Automation Studio User Manual – Efacec Devices	ASID12000065
[4]	Automation Studio User Manual – IEC 61131-3 Programming	ASID12000066
[5]	Automation Studio User Manual – IEC 61850 and Third-Party Devices	ASID12000064

Manual Revisions

Revision	Date	Changes
01	2016-11-02	Document release.

GLOSSARY

a.c.	Alternating Current
A/D	Analogue / Digital
ANSI	American National Standards Institute
AS	Automation Studio
BCD	Binary-Coded Decimal
BCU	Bay Control Unit
CB	Circuit Breaker
CDC	Common Data Class (from IEC 61850)
CID	Configured IED Description (from IEC 61850)
COMTRADE	IEEE Standard Common Format for Transient Data Exchange
CPU	Central Processing Unit
CT	Current Transformer
d.c.	Direct Current
DNP	Distributed Network Protocol
DSP	Digital Signal Processor
EHV	Extra High Voltage
EMC	Electro-Magnetic Compatibility
FBD	Function Block Diagram (from IEC 61131)
FO	*Fermeture-Ouverture* auto-reclose cycle
FTP	File Transfer Protocol
GOOSE	Generic Object Oriented Substation Event
GPS	Global Positioning System
HMI	Human Machine Interface
HTTP	HiperText Transfer Protocol
HV	High Voltage
I/O	Input/ Output
ICD	IED Capability Description (from IEC 61850)
IEC	International Electrotechnical Committee
IEC 61131-3	IEC Standard for Programmable controllers
IEC 61850	IEC Standard for Communication networks and systems for power utility automation
IEC 60870-5-101	Companion standard for basic telecontrol tasks
IEC 60870-5-103	Protection communication companion standard
IEC 60870-5-104	Network access for IEC 60870-5-101 using standard transport profiles
IED	Intelligent Electronic Device
IEEE	Institute of Electrical and Electronics Engineers
IP	Internet Protocol

IRIG-B	Inter-Range Instrumentation Group code format B
LAN	Local Area Network
LCD	Liquid Cristal Display
LD	Logical Device (from IEC 61850)
LED	Light Emitting Diode
LN	Logical Node (from IEC 61850)
MAC	Media Access Control address
MCB	Miniature Circuit Breaker
MV	Medium Voltage
OFO	*Ouverture-Fermeture-Ouverture* auto-reclose cycle
PC	Personal Computer
PLC	Programmable Logic Controller
RMS	Root Mean Square
RS-232	Serial link according to EIA standard RS-232
RS-485	Serial link according to EIA standard RS-485
RTC	Real-Time Clock
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SCL	Substation Configuration description Language (from IEC 61850)
SI	*Système International d'Unités*
SNTP	Simple Network Time Protocol
ST	Structured Text (from IEC 61131)
STP	Shielded Twisted Pair
TCP	Transmission Control Protocol
TPU	Terminal Protection Unit
UART	Universal Asynchronous Receiver/Transmitter
UTC	Universal Time Coordinated
UTP	Unshielded Twisted Pair
VT	Voltage Transformer
XML	Extensible Markup Language

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Chapter 1

INTRODUCTION

In this chapter, the TPU L500 line distance protection and control relay is introduced. The device main characteristics and range of application are presented. The chapter also includes a brief description of the basic operation principle and built-in application functions.

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1.1 APPLICATION

The TPU L500 is a high-end line distance protection relay that provides a high performing solution for power system protection while offering additional control, measurement and recording functions for an easy and reliable power system management.

Used standalone or in a duplicated protection scheme, in parallel with a redundant line differential protection such as TPU D500, the TPU L500 can be applied to all overhead lines or underground cables in transmission and sub-transmission networks, with single or three-phase tripping.

The TPU L500 provides a six-zone full-scheme distance protection, with quadrilateral and/or mho characteristics, that can be configured independently for phase-to-phase or phase-to-earth faults. Its excellent phase selection algorithm ensures correct loop discrimination for every fault type, without compromising speed and sensitivity. Other important features include load compensation in case of heavily loaded lines, stability during open-pole conditions or stable power swing blocking.

Additional directional earth-fault protection increases sensitivity for low-level earth faults. Complete communication scheme logic is implemented for both distance and directional earth fault protection. Several other current, voltage and frequency protection functions are also available.

Several control and supervision functions extend the application of the relay, with option for additional user-defined automation functions and logic (for example, interlocking logic or load transfer and restoration schemes). Accurate measured and metered values and a wide range of records and other stored information add value to the base application.

High configurability via flexible binary and analog I/O configurations, advanced user-programmable functions and a comprehensive library of selectable built-in firmware functions allows the user to adapt the device to different substation topologies as well as protection and control schemes. Integration in a state of the art engineering toolset allows straightforward engineering throughout the system life-cycle without compromising user requirements.

Designed with IEC 61850 and other open standards in mind the TPU L500 is flexible, future-proof and can be seamlessly integrated in multivendor distributed protection, automation and control systems.

Figure 1.1. TPU L500.

1.2 Architecture

The TPU L500 is an Intelligent Electronic Device (IED) consisting of a microprocessor-based platform, with fully numerical processing of all its functions. Figure 1.2 schematically represents the internal architecture of the protection relay.

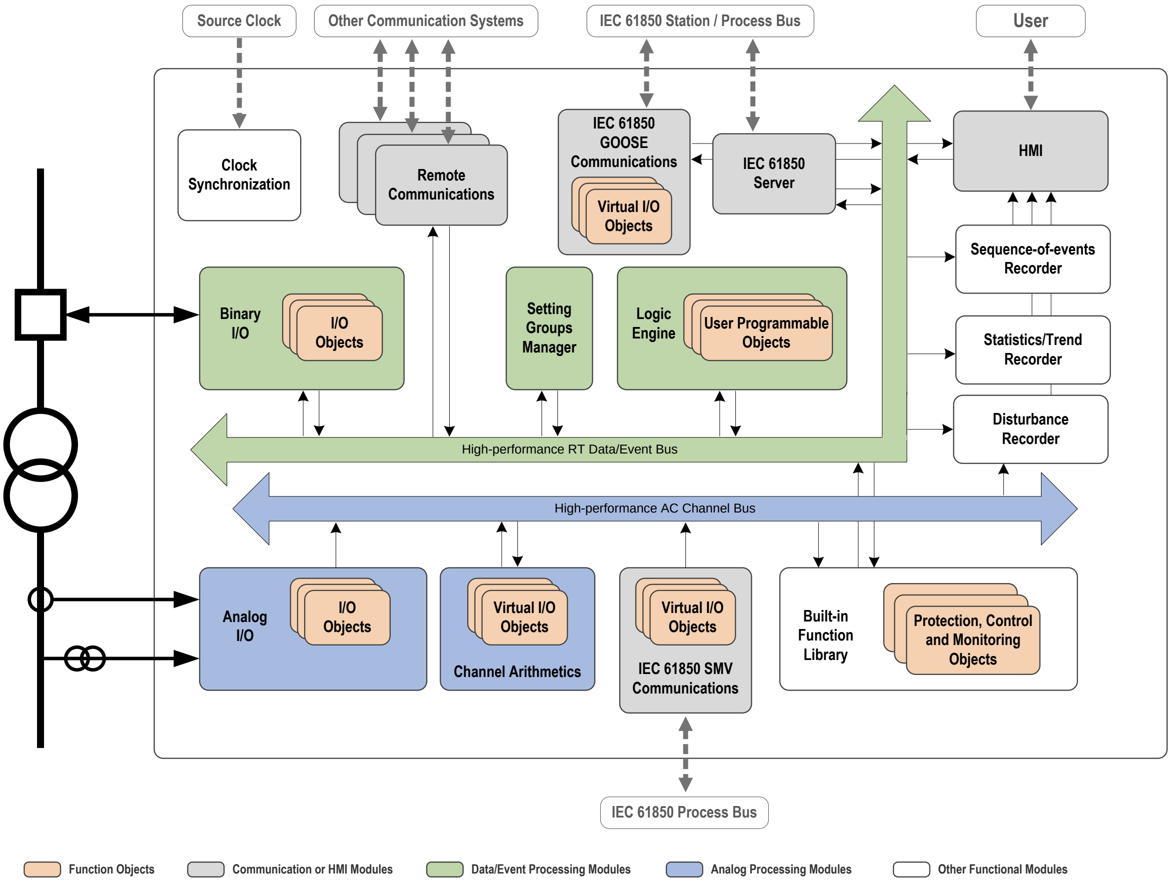


Figure 1.2. TPU L500 architecture.

The acquisition and analogue/digital conversion system guarantees the galvanic insulation from the outside of the relay; it also guarantees current and voltage inputs conditioning, in order to match these signals to the admissible levels for internal electronics.

This sub-system is also responsible for signal filtering and sampling, for subsequent processing by protection and measurement algorithms. A set of low-pass analogue and digital filters were dimensioned to ensure adequate bandwidth for protection functions, together with several estimation algorithms specially designed to remove harmonic and transient components present in the signals.

The IED is able to perform several operations over the base sampled analogue signals, such as current summation or bus voltage switching, which allows adapting the IED to complex bus topologies and multiple breaker arrangements without the need for additional external connections.

The results from these sampling and estimation processes are made available to a built-in library of protection, control and monitoring functions through a high performance and dedicated a.c. channel bus. Those results are periodically evaluated to support the protection relay decision-making process. This approach ensures an adequate time response of all time critical functions.

Besides analogue input acquisition, the relay interface with the process includes binary inputs and outputs responsible for the interaction with external equipment, like circuit breakers and other apparatus.

A logic engine allows implementation of user-defined PLC logic and additional automation functions to complement the base library functions.

A generic data and event internal bus provides very fast information exchange between IED modules, whether they are user-defined logic modules, built-in library functions or binary I/O objects. Data exchanged includes outputs from user-defined and built-in application functions, information acquired from binary inputs and commands issued to external switching devices.

The central processing system is also responsible for the management of other IED interfaces, namely the local and remote human-machine interface and communication systems.

The human-machine interface includes the front panel display where diverse power system and device data can be accessed, and a set of configurable alarms and function keys. An embedded webserver is also available.

Communication interfaces include an IEC 61850 server and GOOSE publish/subscribe mechanism for integration in an IEC 61850 station bus, along with several other protocol options, either serial or over Ethernet. GOOSE messages provide an alternative to binary input / output objects, allowing information exchange with other IEC 61850 compliant devices through the communication interface.

Dedicated communication interfaces supporting the IEEE C37.94 standard enable remote communications with other substations. The internal architecture is also already prepared for future integration in an IEC 61850 compliant process bus.

The IED design includes other modules responsible for auxiliary and management tasks, such as: setting management and change of setting groups; diagnostic and self-tests, with watchdog supervision; different recording functions, like disturbance recorder or event log. An independent clock synchronization module ensures correct time tagging of all events and records.

1.3 General Characteristics

The TPU L500 relay is part of the TPU 500 Protection, Automation and Control IED series from EFACEC. All IEDs of this series are characterised by a similar set of features and are based on a common platform which provides uniform and highly integrated solutions, easy to specify, configure, troubleshoot and maintain.

- High performing architecture, based on an 800 MHz state-of-the-art processor and other specialized cores, including built-in digital signal processing.
- 6U height, 19'' (84HP) width case, rack- or flush-mounted.
- Acquisition up to a maximum of 24 a.c. analogue inputs with 24 bit resolution analogue/digital conversion at a rate of 80 samples per cycle (sampling frequency of 4 kHz for a rated frequency of 50 Hz).
- Flexible analogue channel configuration and built-in channel operations for direct support of complex bus topologies and multiple breaker arrangements.
- Maximum number of 264 binary inputs with built-in input filtering or 136 binary outputs with output pulse shape configuration.
- Flexible I/O configuration, allowing low-level implementation of single and double, n-bits or pulse-counting points as well as multiple contact operation via single or double controls.
- Wide range of protection, control, supervision and monitoring built-in library functions, covering several power system applications.
- Further application extension and customization via user-defined functions and PLC logic, fully programmed in IEC 61131-3 languages.
- Boolean or integer logic and arithmetic available together with blocks such as flip-flops, counters and timers.
- Flexible function assignment to a maximum of sixteen internal logical devices, with independent operation mode and switching hierarchy management.
- Eight independent setting groups for each logical device, interchangeable by programmable logic condition or user's command.
- Battery powered real-time clock, with time zone configuration according to the device location.
- Accurate time synchronization performed in option via SNTP, IRIG-B or by communication protocol.
- One millisecond resolution event log, with user-defined set of recorded entities and multiple trigger options.
- Large non-volatile memory capacity, for storage of several device records, such as event logs, disturbance records, load diagrams and fault reports.
- Up to four IEEE C37.94 communication interfaces, supporting transfer rates from 64 kbit/s to 2 Mbit/s, for remote communication with other substations.
- Three Ethernet ports and up to three serial ports, with multiple communication options available.
- Up to four simultaneous server/slave or client/master communication protocols, serial or over Ethernet.
- Optional IEC 61850 server ready for integration in an IEC 61850 station bus, with GOOSE publish/subscribe mechanism supporting complex distributed automation schemes.
- Front Ethernet port for configuration, diagnostic and maintenance actions.
- Local human-machine interface including an optional large graphic LCD, easy to use keypad for menu navigation and setting edition and relay operation status indicators.
- 16 programmable alarms and 9 programmable function keys with several configuration options.
- Embedded webserver, accessible at the front and rear Ethernet ports.
- Plug-and-play identification of internal hardware and software components.
- Internal watchdog, watchdog output and self-supervision of all hardware components and software modules.

- Integrated engineering in the Automation Studio toolset, featuring configuration deployment, handling of operational settings, simulation, online device monitoring and data extraction and analysis.
- Highly configurable and flexible design and type-tested configuration templates.

1.4 APPLICATION FUNCTIONS

1.4.1 PROTECTION FUNCTIONS

Distance

- **ANSI**: 21
- **IEC 61850**: PDIS
- **Number of independent functions**: 1
- Six independent impedance measuring zones available, configurable as forward, reverse or non-directional stages.
- One of the measuring zones enabled by external logic condition, for use in zone extension schemes.
- Six separate protection elements for each zone, three for the phase-to-phase fault loops and three for the phase-to-earth fault loops (full scheme).
- Accurate phase and fault loop selection according to the fault type, including during open pole conditions.
- Optional criteria for selection of measuring loops for phase-to-phase-to-earth faults.
- Selectable mho or quadrilateral characteristic.
- Optional combination of mho impedance elements for phase-to-phase fault loops and of quadrilateral impedance elements for phase-to-earth fault loops.
- Distinct resistive reach for phase-to-phase and phase-to-earth faults, when quadrilateral characteristic is used.
- Distinct operational time for phase-to-phase and phase-to-earth faults.
- Earth-fault compensation factor configured independently for each protection zone.
- Optional compensation of parallel line mutual zero sequence impedance.
- High stability for heavy loaded systems and large fault resistances.
- Additional compensation for the effect of non-homogeneous systems.
- Enhanced sensitivity even in the case of weak infeed line ends.
- Load encroachment zone, independently configured for forward and reverse load flows, balanced or unbalanced.
- Adjustable minimum and maximum directional characteristic angles.
- Positive and negative sequence voltage polarization and pre-fault voltage memory to ensure adequate directional selectivity for all types of faults.
- Additional directional supervising element for mho impedance measuring elements.
- Optional directional criteria for series compensated lines.
- Additional configurable delay to deal with CCVT transients.
- Independent block input for each protection zone.

Power Swing Blocking / Out-Of-Step Tripping

- **ANSI**: 68, 78
- **IEC 61850**: RPSB
- **Number of independent functions**: 1
- Reliable detection of both fast and slow power swings based on the variation of the swing centre voltage.
- Adaptive operation principle, without blinder configuration or other user settings.
- Ability to detect power swings during open pole or other asymmetrical operating conditions.

- Fast blocking of distance protection measuring zones in case of stable power swing conditions.
- Unblocking if asymmetrical or symmetrical faults occur during a power swing.
- Optional trip due to unstable out-of-step conditions.
- Selectable trip on the way in (TOWI) or out (TOWO) the system characteristic angle, with configurable trip angles.
- Independent block input.

Distance Teleprotection Schemes

- **ANSI**: 85(21), 27WI
- **IEC 61850**: PSCH
- **Number of independent functions**: 1
- Suitable for the implementation of one of several communication schemes associated to Distance Protection, for lines with two or three ends.
- Transmission logic prepared to be associated to any local Distance Protection stage.
- Transmission of general or phase-segregated pickup and/or trip signals.
- Built-in Permissive Underreach Transfer Trip (PUTT), Permissive Overreach Transfer Trip (POTT) and Directional Comparison Blocking (DCB) logic schemes.
- Complementary current reversal logic for parallel lines.
- Optional unblocking logic associated with the supervision of the channel guard signal.
- Optional echo logic.
- Optional weak infeed trip supervised by built-in undervoltage stage.
- Prepared for several communication interfaces or association with binary inputs and outputs.
- Independent block input.

Directional Earth-Fault Teleprotection Schemes

- **ANSI**: 85(67N), 59NWI
- **IEC 61850**: PSCH
- **Number of independent functions**: 1
- Suitable for the implementation of one of several communication schemes associated to Directional Earth-Fault Protection, for lines with two or three ends.
- Transmission logic prepared to be associated to any local Directional Earth-Fault Overcurrent Protection stage.
- Built-in Directional Comparison (DC), and Directional Comparison Blocking (DCB) logic schemes.
- Complementary current reversal logic for parallel lines.
- Optional unblocking logic associated with the supervision of the channel guard signal.
- Optional echo logic.
- Optional weak infeed trip supervised by built-in residual overvoltage stage.
- Prepared for several communication interfaces or association with binary inputs and outputs.
- Independent block input.

Remote Tripping

- **ANSI**: 85
- **IEC 61850**: PSCH
- **Number of independent functions**: 1
- Suitable for the implementation of direct transfer trip protection schemes.

- General or phase-segregated trip signals.
- Two independent modules, one for transmitting to and one for receiving from remote substations.
- Transmission logic prepared to be associated to any local protection function or stage trip.
- Configurable prolongation time of the transmitted signal and optional time delay after receiving a remote trip.
- Prepared for several communication interfaces or association with binary inputs and outputs.
- Independent inputs for blocking transmission and receiving logic.

Stub

- **ANSI**: 87STB
- **IEC 61850**: PDIF
- **Number of independent functions**: 1
- Suitable for application in multiple breaker substation topologies.
- Activated by logic condition corresponding to line (or transformer) switch open.
- One restrained differential stage with an adjustable two-section stabilization characteristic.
- Separate protection elements for the three phases and for the residual component (full scheme).
- Phase and residual protection elements with independent stabilization characteristic settings and operational time.
- Optional instantaneous trip, activated by user-defined logic condition.
- High stability against CT saturation, even in the case of close-in external faults and large fault currents.
- Independent block input.

(Directional) Phase Overcurrent Protection

- **ANSI**: 50, 51, 67
- **IEC 61850**: PTOC / RDIR / PHAR
- **Number of independent functions**: 1
- Four independent time overcurrent stages available: two definite time stages and two definite or inverse time stages.
- Separate protection elements for the three phases (full scheme).
- Optional instantaneous tripping.
- Several selectable time curve characteristics, according to IEC and ANSI/IEEE standards.
- Optional dynamic reset when inverse time option is selected.
- Configurable current threshold multiplier, activated by user-defined logic condition, for example in interaction with external cold load pickup logic.
- Second harmonic inrush restraint, activated independently for each stage, with cross-block option between distinct phases.
- Optional directional operation, in the forward or reverse direction, configured independently for each stage.
- Directional characteristic angle with wide setting range to allow best adaptation to system characteristic impedance angle.
- Positive and negative sequence voltage polarization and pre-fault voltage memory to ensure adequate directional selectivity for all types of phase-to-phase faults.
- Optional function block or non-directional trip in case of voltage transformer failure.
- Independent block input for each protection stage.
- Configurable blocking of high-speed stage by downstream protection pickup.

(Directional) Earth-Fault Overcurrent Protection

- **ANSI**: 50N, 51N, 67N, 50G, 51G, 67G
- **IEC 61850**: PTOC / RDIR / PHAR
- **Number of independent functions**: 2
- Four independent time overcurrent stages available: two definite time stages and two definite or inverse time stages.
- Optional instantaneous tripping.
- Several selectable time curve characteristics, according to IEC and ANSI/IEEE standards.
- Additional logarithmic time inverse curve.
- Optional dynamic reset when inverse time option is selected.
- Operational quantity configurable as residual current (calculated sum of the three phase currents) or neutral current, obtained from a separate phase-balance neutral current transformer.
- Large resistance earth-fault detection if the function is associated with an optional high sensitivity current input.
- Phase current stabilization to prevent errors due to CT saturation.
- Configurable current threshold multiplier, activated by user-defined logic condition, for example in interaction with external cold load pickup logic.
- Second harmonic inrush restraint, activated independently for each stage.
- Optional directional operation, in the forward or reverse direction, configured independently for each stage.
- Directional characteristic angle with wide setting range to allow best adaptation to several system characteristic impedance angles and neutral connections.
- Residual voltage and/or neutral current polarization to ensure adequate directional selectivity for all types of phase-to-earth faults.
- Optional fault direction discrimination based on negative sequence components.
- Optional function block or non-directional trip in case of voltage transformer failure or polarization absence.
- Independent block input for each protection stage.
- Configurable blocking of high-speed stage by downstream protection pickup.

(Directional) Negative Sequence Overcurrent Protection

- **ANSI**: 46, 67
- **IEC 61850**: PTOC / RDIR
- **Number of independent functions**: 1
- Four independent time overcurrent stages available: two definite time stages and two definite or inverse time stages.
- Optional instantaneous tripping.
- Several selectable time curve characteristics, according to IEC and ANSI/IEEE standards.
- Optional dynamic reset when inverse time option is selected.
- Optional directional operation, in the forward or reverse direction, configured independently for each stage.
- Directional characteristic angle with wide setting range to allow best adaptation to system characteristic impedance angle.
- Negative sequence voltage polarization to ensure adequate directional selectivity for all types of asymmetrical faults.
- Optional function block or non-directional trip in case of voltage transformer failure or polarization absence.
- Independent block input for each protection stage.

Thermal Overload Protection

- **ANSI**: 49

- **IEC 61850**: PTTR
- **Number of independent functions**: 1
- Thermal model of the protected equipment, based on the calculated heat losses according to the I^2t characteristic.
- Continuous evaluation of the RMS value of the current signals, accounting for the effect of the load current prior to the overload.
- Independent measurement for the three phases, with operation based on the largest of the three temperatures.
- Trip characteristic according to the IEC 60255-8 standard.
- Separate temperature settings for alarm and reset (permission to reclose) stages.
- Settable default environment temperature.
- Independent block input.

Switch-Onto-Fault Protection

- **ANSI**: 50HS
- **IEC 61850**: RSOF / PIOC
- **Number of independent functions**: 1
- Prepared to be activated by external order, for example in case of CB close command.
- Integrated dead line detection based on current and voltage absence, in alternative.
- Configurable confirmation time for dead line condition.
- Configurable time interval that the function remains active after CB closed.
- Independent high-speed overcurrent stage available, with instantaneous trip.
- Prepared to be associated to any stage of other protection function.

Directional Earth-Fault Overcurrent for Non-Earthed Systems

- **ANSI**: 32N
- **IEC 61850**: PSDE
- **Number of independent functions**: 2
- Independent definite time earth-fault protection with several trip options available.
- Residual (or neutral) overvoltage pickup stage.
- Function trip by overvoltage or overcurrent criteria, selectable by user.
- Operational quantity configurable as residual current (calculated sum of the three phase currents) or neutral current, obtained from a separate phase-balance neutral current transformer.
- Large resistance earth-fault detection if the function is associated with an optional high sensitivity current input.
- Optional directional operation, in the forward or reverse direction.
- Directional discrimination based on current phase angle measurement (minimum current magnitude) or wattmetric principle (minimum power).
- Specially shaped directional characteristic, with residual voltage polarization, prepared for application in systems with isolated or compensated neutral.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.
- Independent alarm level based on phase voltage unbalance.

Directional Power

- **ANSI**: 32
- **IEC 61850**: PDOP / PDUP

- **Number of independent functions**: 1
- Four independent definite time directional power stages: two overpower stages and two underpower stages.
- Several CT and VT arrangements supported, with different power calculation methods.
- Directional characteristic angle with wide setting range to allow any operational quantity (real or reactive power or a combination of both) or direction (forward or reverse).
- Configurable dropout ratio and reset time.
- Optional block in case of circuit breaker open and configurable time interval that the function remains blocked after CB closed.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.
- Independent block input for each protection stage.

Phase Undervoltage Protection

- **ANSI**: 27
- **IEC 61850**: PTUV
- **Number of independent functions**: 1
- Two independent time undervoltage stages available: one definite time stage and one definite or inverse time stage.
- Separate protection elements for the three phases (full scheme).
- Prepared to use phase-to-earth or phase-to-phase voltages as operational quantities.
- Extended setting range, allowing operation thresholds below or above rated voltage.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.
- Independent block input for each protection stage.
- Configurable load shedding and restoration schemes, freely programmable by user.

Phase Overvoltage Protection

- **ANSI**: 59
- **IEC 61850**: PTOV
- **Number of independent functions**: 1
- Two independent time overvoltage stages available: one definite time stage and one definite or inverse time stage.
- Separate protection elements for the three phases (full scheme).
- Prepared to use phase-to-earth or phase-to-phase voltages as operational quantities.
- Extended setting range, allowing operation thresholds below or above rated voltage.
- Independent block input for each protection stage.

Residual Overvoltage Protection

- **ANSI**: 59N
- **IEC 61850**: PTOV
- **Number of independent functions**: 1
- Two independent time overvoltage stages available: one definite time stage and one definite or inverse time stage.
- Operational quantity configurable as residual voltage (calculated sum of the three phase voltages) or neutral voltage, obtained from a separate open-delta connected winding.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.
- Independent block input for each protection stage.

Negative Sequence Overvoltage Protection

- **ANSI**: 47
- **IEC 61850**: PTOV
- **Number of independent functions**: 1
- Two independent time overvoltage stages available: one definite time stage and one definite or inverse time stage.
- Prepared to use phase-to-earth or phase-to-phase voltages as operational quantities.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.
- Independent block input for each protection stage.

Underfrequency Protection

- **ANSI**: 81U
- **IEC 61850**: PTUF
- **Number of independent functions**: 1
- Five independent definite time underfrequency stages available.
- Frequency measurement from phase-to-earth or phase-to-phase voltages.
- Extended setting range, allowing operation thresholds below or above rated frequency.
- Configurable undervoltage block threshold.
- Independent block input for each protection stage.
- Configurable load shedding and restoration schemes, freely programmable by user.

Overfrequency Protection

- **ANSI**: 81O
- **IEC 61850**: PTOF
- **Number of independent functions**: 1
- Five independent definite time overfrequency stages available.
- Frequency measurement from phase-to-earth or phase-to-phase voltages.
- Extended setting range, allowing operation thresholds below or above rated frequency.
- Configurable undervoltage block threshold.
- Independent block input for each protection stage.
- Configurable load shedding and restoration schemes, freely programmable by user.

Frequency Rate-of-Change Protection

- **ANSI**: 81RC
- **IEC 61850**: PFRC
- **Number of independent functions**: 1
- Five independent definite time frequency rate-of-change stages available.
- Extended operation threshold setting range, for both positive and negative frequency rate-of-change.
- Frequency measurement from phase-to-earth or phase-to-phase voltages.
- Optional frequency supervision threshold.
- Configurable observation time for frequency rate-of-change average calculation.
- Configurable undervoltage block threshold.
- Independent block input for each protection stage.

- Configurable load shedding and restoration schemes, freely programmable by user.

1.4.2 Control and Supervision Functions

Three-Phase / Single-Phase Trip Logic

- **ANSI**: 94
- **IEC 61850**: PTRC
- **Number of independent functions**: 1
- Three-phase or single-phase circuit breaker trip conditioning and block.
- Multiple breaker arrangements supported.
- General and per phase protection pickup and trip indications.
- Instantaneous trip with Switch-Onto-Fault active, for selected protection function stages.
- Circuit breaker trip counter.

Automatic Reclosure

- **ANSI**: 79
- **IEC 61850**: RREC
- **Number of independent functions**: 2
- Up to five reclosing cycles, with independent parameterizations per cycle.
- Capable of single-pole and/or three-pole reclosures (configurable per cycle).
- Independent dead times for single-pole reclosures, three-pole reclosures, and evolving fault situations (configurable per cycle).
- Supervision of protection trip, after pickup, and of circuit breaker operation, after open and close commands.
- Optional reclosing with synchronism check.
- Optional wait for master logic.
- Optional voltage level verification (live line or dead line check).
- Number of successful and unsuccessful reclosing sequences available.

Synchronism and Voltage Check

- **ANSI**: 25
- **IEC 61850**: RSYN
- **Number of independent functions**: 2
- Independent parameterizations for manual and automatic circuit breaker close commands.
- Configurable phase-to-phase or phase-to earth operating voltages.
- Several operating modes, independently activated: voltage check modes (Dead / Dead, Dead / Live, Live / Dead) and synchronism check mode (Live / Live).
- Settable dead and live voltage thresholds and maximum permitted voltage for close operations.
- Continuous evaluation of voltage magnitude and frequency, for all voltage and synchronism check operating modes.
- Continuous evaluation of magnitude difference, phase angle difference and frequency difference, for synchronism check operating mode.
- Optional close command release at asynchronous system conditions, taking into account circuit breaker close time and frequency rate-of-change.
- Independently activated unconditional release operating mode.

- High accuracy in an extended measuring range, for all operating quantities.
- Fast verification of release conditions for all operating modes, with optional user-defined confirmation time.
- Magnitude, phase angle and frequency difference measurements available.

Circuit Breaker Failure

- **ANSI**: 50BF
- **IEC 61850**: RBRF
- **Number of independent functions**: 2
- One or two definite time stages: only external trip; both re-trip and external trip enabled.
- Optional single-phase re-trip in case of phase-to-earth faults.
- Independent time delay settings for single-phase and three-phase circuit breaker operation.
- Monitoring of phase current in each pole of the circuit breaker.
- Distinct current thresholds for pickup (protection trip) and reset (detection of circuit breaker open).
- Supervision of circuit breaker position in alternative to phase current monitoring.
- Optional instantaneous trip after protection trip, due to faulty circuit breaker circuit.

Trip Circuit Supervision

- **ANSI**: 74TC
- **IEC 61850**: STRC
- **Number of independent functions**: 6
- Up to two supervised circuit breaker trip circuits (main and backup trip coils) via dedicated binary inputs.
- Supervision only with circuit breaker closed, in option.
- Configurable alarm delay and reset time.

Lockout

- **ANSI**: 86
- **IEC 61850**: RCBL
- **Number of independent functions**: 1
- Latched (resettable by user), unlatched or timed blocking of circuit breaker close operations.
- User-defined block conditions for each mode of operation.

VT Supervision

- **ANSI**: 60
- **IEC 61850**: RVTS
- **Number of independent functions**: 1
- Voltage transformer MCB status supervision via binary input.
- Additional criteria for detection of voltage transformer secondary circuit failures based on voltage and current signals.
- Negative sequence and zero sequence monitoring for detection of asymmetrical failures.
- Three-phase undervoltage and current variation monitoring for detection of symmetrical failures.
- Voltage absence check after circuit breaker close.
- Polarity and phase sequence check.

CT Supervision

- **IEC 61850**: RCCS
- **Number of independent functions**: 2
- Detection of current circuit failures based on reference residual current and/or voltage.
- Polarity and phase sequence check.

Open Pole Detection

- **IEC 61850**: ROPD
- **Number of independent functions**: 1
- Distinct options for monitoring open pole condition after single-phase trip, based on the supervision of voltage and current signals.
- Additional supervision criterion based on the comparison of symmetrical components in the several line ends.
- Multiple breaker arrangements supported.

Broken Conductor Check

- **ANSI**: 46BC
- **IEC 61850**: RBCD
- **Number of independent functions**: 1
- Independent alarm stage based on negative sequence / positive sequence current ratio.
- Configurable alarm delay and reset time.

Circuit Breaker Control

- **IEC 61850**: CSWI
- **Number of independent functions**: 2
- Independent block inputs for circuit breaker open and close commands.
- Different block conditions depending on the control origin: local manual, remote manual or automatic commands.
- User-defined monitoring of interlocking conditions and optional synchronism check for close commands.
- Multi-level switching authority management.
- Circuit breaker open command counter.

Circuit Breaker Supervision

- **ANSI**: 89
- **IEC 61850**: XCBR / SGCB
- **Number of independent functions**: 2
- Circuit breaker single-phase or three-phase control execution and status update.
- Configurable fixed or adaptive pulse duration, for circuit breaker open and close commands.
- Optional intermediate state filtering, with configurable filter time.
- Supervision of the circuit breaker opening and closing time.
- Circuit breaker open operation counter.
- Last switched current and accumulated sum of the square currents switched by each circuit breaker pole.
- Configurable alarms for maximum number of open operations and accumulated sum of the square switched currents.
- Open pole alarm with configurable timer.

Circuit Switch Control

- **IEC 61850**: CSWI
- **Number of independent functions**: 10
- Independent block inputs for circuit switch open and close commands.
- Different block conditions depending on the control origin: local manual, remote manual or automatic commands.
- User-defined monitoring of interlocking conditions.
- Multi-level switching authority management.
- Circuit switch open command counter.

Circuit Switch Supervision

- **ANSI**: 52
- **IEC 61850**: XSWI
- **Number of independent functions**: 10
- Circuit switch control execution and status update.
- Configurable fixed or adaptive pulse duration, for circuit switch open and close commands.
- Optional intermediate state filtering, with configurable filter time.
- Supervision of the circuit switch opening and closing time.
- Circuit switch open operation counter.
- Configurable alarm for maximum number of open operations.

1.4.3 Monitoring and Recording Functions

Three-Phase Measurements

- **IEC 61850**: MMXU / MSQI
- **Number of independent functions**: 1
- Accurate three-phase system instantaneous measurements of current, voltage (phase-to-earth and phase-to-phase), power (real, reactive and apparent), power factor, impedance and frequency.
- Additional measurements of neutral current and voltage, if available.
- Additional measurements of current and voltage symmetrical components.
- Magnitude and phase angle information available.
- Several CT and VT arrangements supported, with different power calculation methods.
- Configurable CT orientation in forward (towards line) or reverse (towards bus) direction, independent from protection functions.

Three-Phase Measurements (Currents only)

- **IEC 61850**: MMXU / MSQI
- **Number of independent functions**: 6
- Accurate three-phase system instantaneous measurements of current and frequency.
- Additional measurements of neutral current, if available.
- Additional measurements of current symmetrical components.
- Magnitude and phase angle information available.

Single-Phase Measurements

- **IEC 61850**: MMXN
- **Number of independent functions**: 3
- Accurate instantaneous measurements of current, voltage, power (real, reactive and apparent), power factor, impedance and frequency.
- Magnitude and phase angle information available.
- Available for non-phase related signals, such as additional neutral current or bus voltage for synchronism check.
- Configurable CT orientation in forward (towards line) or reverse (towards bus) direction, independent from protection functions.

Three-Phase Metering

- **IEC 61850**: MMTR
- **Number of independent functions**: 1
- Accurate real and reactive energy counters in forward and reverse direction, based on three-phase voltage and current signals.
- Additional total real, reactive and apparent energy counters.
- Start/stop and reset control over metering function.
- Several CT and VT arrangements supported, with different energy calculation methods.
- Configurable CT orientation in forward (towards line) or reverse (towards bus) direction, independent from protection functions.

Fault Locator

- **ANSI**: 21FL
- **IEC 61850**: RFLO
- **Number of independent functions**: 1
- Triggered by the pickup of user-selectable protection functions.
- Measuring algorithm completely independent from protection functions.
- Prepared for application in overhead lines or underground cables with up to three distinct line sections.
- Fault location results presented in ohm, in kilometres (or miles) and in percentage of line length, including calculation of the fault resistance.
- Identification of the fault type and of the fault loop used for distance calculation.
- Compensation of the load current.
- Enhanced fault location based on information from the remote line ends.
- Optional compensation of parallel line mutual zero sequence impedance.
- High accuracy in an extended measuring range, for all calculated quantities.
- Optional block in case of voltage transformer failure, according to voltage transformer supervision function.

Disturbance Recorder

- **IEC 61850**: RDRE
- **Number of independent functions**: 1
- Up to 36 analogue channels and 96 binary channels.
- Disturbance record files according to COMTRADE standard.
- Configurable pre-fault time, post-fault time and maximum record duration.
- Manual trigger available, by user command or logic condition, with independent configurable record duration.

- Multiple internal trigger conditions, user-defined, for both analogue and binary channels.
- Optional record retrigger during post-fault time.
- Indication of actual record number and percentage of memory used.

Chapter

2

INSTALLATION

This chapter describes how to install the TPU L500. It details the case, mounting, constitution and installation of the TPU L500. It also describes its connections, as well as the type of connectors to be used.

TABLE OF CONTENTS

Total of pages of the chapter: 35

2.1 PRESENTATION AND DIMENSIONS

The TPU L500 is presented in a 6U height proprietary enclosure for flush mounting or for 19'' panel (rack) mounting. This section describes the enclosure and presents its dimensions.

2.1.1 ENCLOSURE

The TPU L500 has a proprietary enclosure with a width of 19'' rack and a height of 6U. It has a front panel with the local user interface and a back panel with the connectors for interface to the installation.

To access the interior of the TPU L500, all connectors must be disconnected to avoid the risk of electrical shock and afterwards it is necessary to remove its back panel. This warning is also applicable for the removal of the front panel (user interface).

Any intervention in the interior of the TPU L500 shall be carried out by authorised technical personnel.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel injuries and/or equipment damage.

Figure 2.1 and Figure 2.2 present respectively the front panel and the back panel of the TPU L500. The panels are briefly described.

Front Panel

Figure 2.1 presents the front panel of the TPU L500. This panel is fixed to the TPU L500 body by sixteen screws at the sides and top and bottom of the front frame. The front panel is covered by a film of silk screened polycarbonate where the user interface is located.

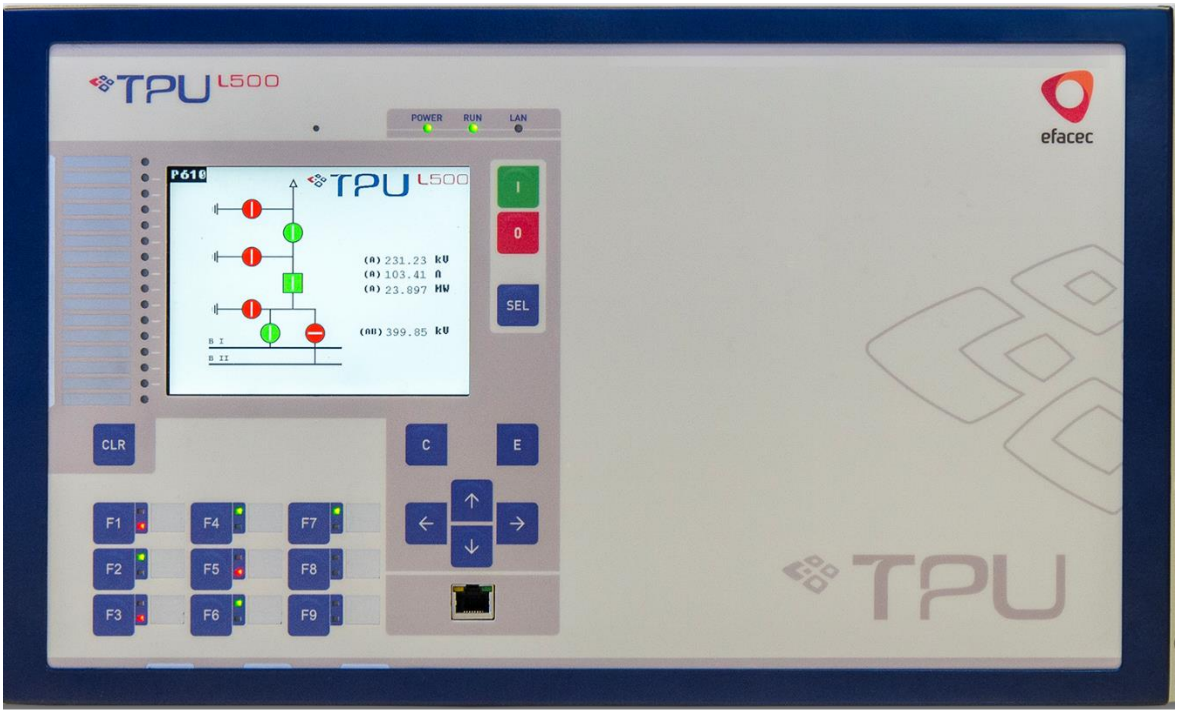


Figure 2.1. Front view of the TPU L500.

The user interface is constituted by a large graphic display, 16 programmable alarm LEDs, 3 LEDs indicating the operation status of the TPU L500 and of the LAN, as well as 18 LEDs associated to the function keys.

There are 6 navigation keys, 3 keys for selection and operation of apparatus, 9 function keys for selection of operation modes or other pre-defined actions and one last key for alarm acknowledgement.

Finally there is a front Ethernet port (RJ-45 connector) to be used as a Service Interface. This Interface is dedicated to communication with the Automation Studio application running in a PC for configuration, settings change, data collection and firmware update of the TPU L500.

Back Panel

Figure 2.2 presents the back panel of the TPU L500. It shows the back connectors arrangement with their respective identification. Table 2.1 briefly describes the connectors. Details on the connectors are given in section 2.4 - Connections.

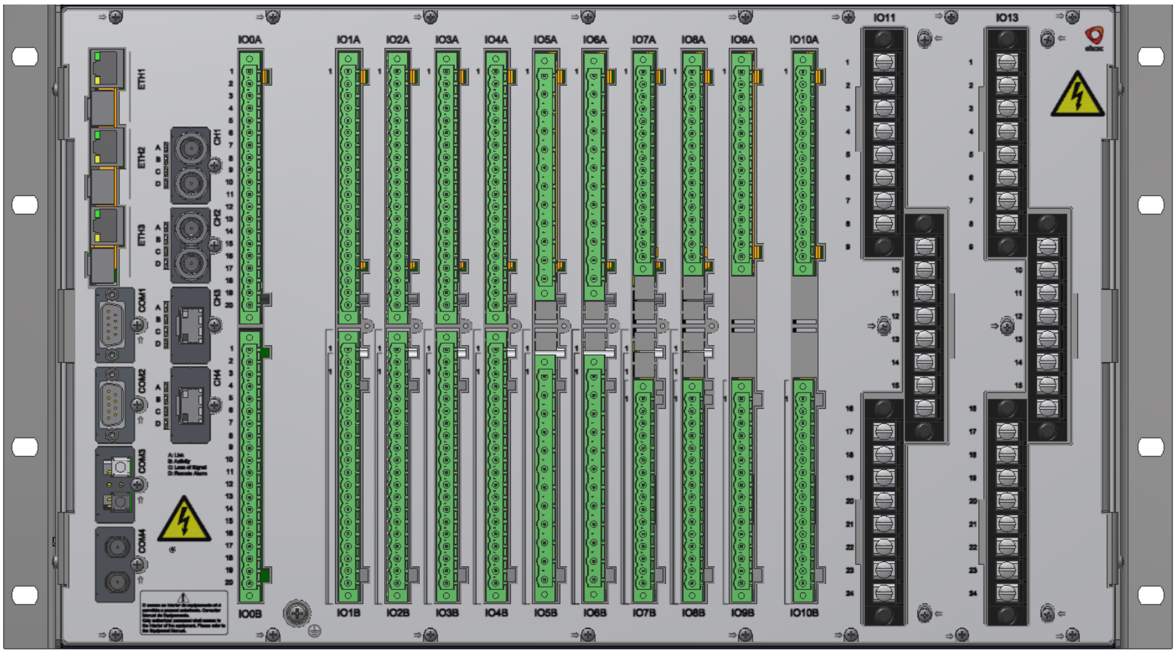


Figure 2.2. Back view of the TPU L500.

Table 2.1. Connectors description.

Connector	Description	Observations
ETH1, ETH2, ETH3	RJ-45 connectors for dual LAN connection (twisted pair) LC Duplex connectors for dual LAN connection (optical fibre)	See section 2.4
COM1, COM2, COM3	Serial ports	See section 2.4
COM4	Input for demodulated IRIG-B synchronization signal	See section 2.4
CH1, CH2, CH3, CH4	ST or LC Duplex connectors for remote communication interfaces	See section 2.4
IO0A, IO0B	Connections of power supply and base binary I/O board	See section 2.4
IO1A, IO1B … IO10A, IO10B	Connections of expansion binary and analogue d.c. I/O boards	See section 2.4
IO11A, IO11B IO13A, IO13B	Current and/or voltage a.c. analogue inputs	See section 2.4

2.1.1 DIMENSIONS

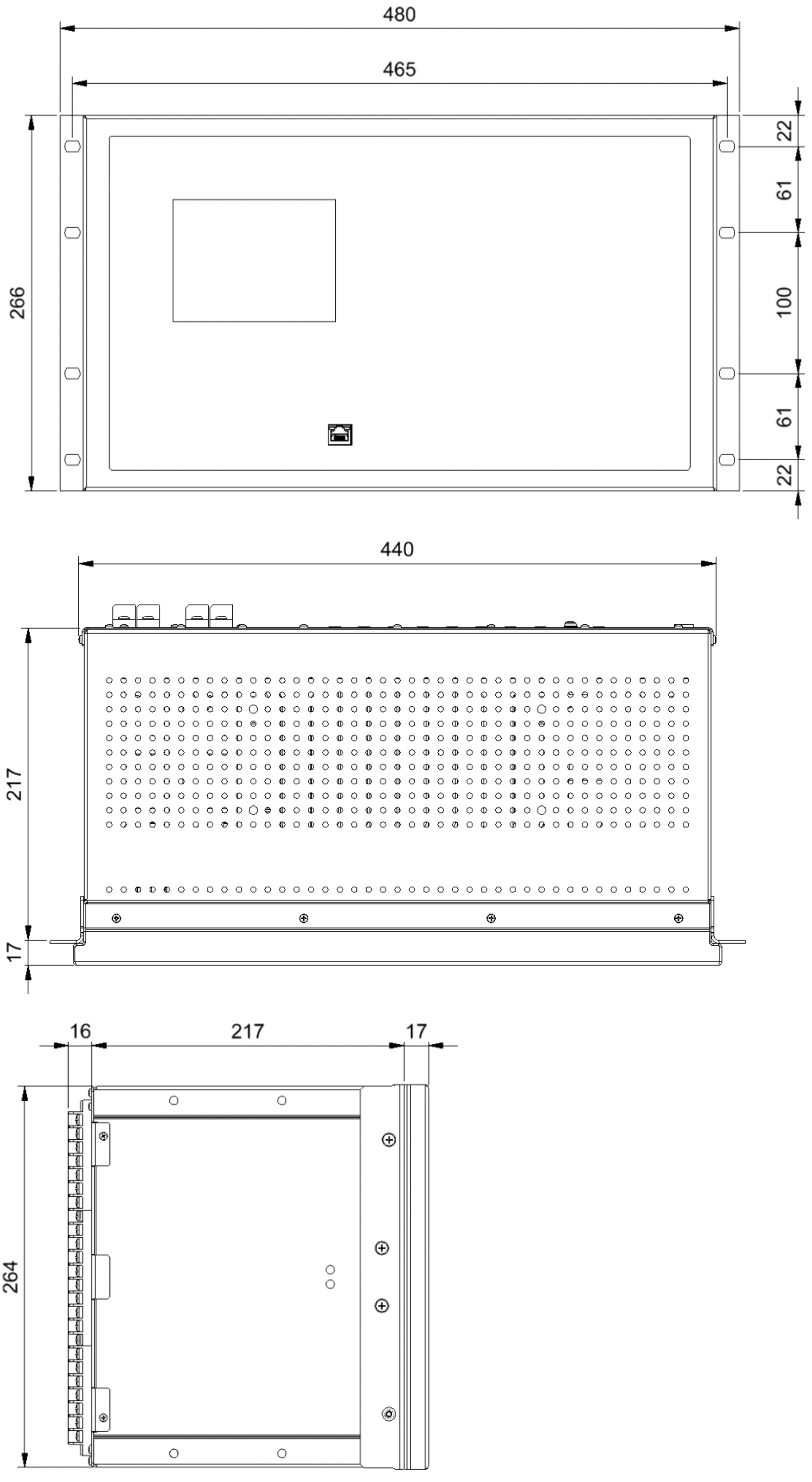


Figure 2.3. External dimensions (in mm) of the TPU L500.

2.2 HARDWARE DESCRIPTION

This section describes the hardware that constitutes the TPU L500, and presents the possible configurations in terms of electronic modules.

2.2.1 GENERAL DESCRIPTION

The TPU L500 architecture is modular and multiprocessing, using 32-bit processors and a floating point digital signal processor, in order to achieve very high performance from the TPU L500. A hard real-time operating system is used to guarantee the demanding time requirements necessary to its correct operation.

The technology and components used allow meeting and exceeding the electromagnetic compatibility and security standards applicable. All signals that interface with the installation are properly isolated from the most sensitive electronics and are physically separated as all connections to the installation are made in the back of the unit, and the sensitive internal signals circulate in a Front-Plane that interconnects all boards and is located immediately behind the local user interface.

2.2.2 MODULE DESCRIPTION

MAP8061 - Front-End Board

This board supports the local interface of the TPU L500. It is associated to the front panel and is only accessible by the front. It contains a graphic display, all LEDs, keys and the front Ethernet port. The large graphic display has a 640×480 resolution, and is LED backlighted. The Ethernet media type is 10/100BASE-TX.

This board should only be accessed for maintenance purposes because it does not have any accessible configuration.

MAP8001 - CPU Module

This module performs all central processing of the TPU L500. It integrates an 800 MHz state-of-the-art processor and other specialized cores, including a 32-bit floating point Digital Signal Processor (DSP), along with associated RAM and FLASH memories for operation data, settings, firmware, etc.

It provides three Ethernet ports, 10/100BASE-TX or 100BASE-FX. It provides LC Duplex type connectors for optical fibre or RJ-45 for twisted pair (UTP or STP, Cat.5). It also provides an optional IRIG-B time synchronization input (COM4), which receives optically isolated demodulated synchronization signals.

Up to three serial ports are provided (COM1, COM2 and COM3) available as optional Piggy-Back modules. RS-232, RS-485 and optical fibre (1mm thick plastic optical fibre for distances up to 45m, or 62,5µm/125µm thick glass optical fibre for distances up to 1700m) media may be chosen. The default media type is RS-232.

This board has several configuration jumpers. Its access is possible after removing the back lid of the TPU L500.

MAP8074 - Remote Communication Module

This module contains up to 4 channels for remote communication with IEDs situated at distances up to 100km, enabling analogue and binary signal transfer. Four options are provided: 2km (multimode optical fibre), 40km, 60km and 100km (single-mode optical fibre). This module is mainly used for the line differential protection but it can be used in other applications such as teleprotection schemes and direct transfer trip. The IEEE/ANSI C37.94 standard format is used.

MAP8011 Power Supply and Base I/O Module – 8 Binary Inputs and 8 Binary Outputs

This module contains a switched mode power supply that generates voltages of +5V and +12V respectively for, logic + analogue, and relay-based binary outputs. It has galvanic isolation and filtering from external disturbances. There are several options depending on the range of supply voltage.

The module contains 8 independent, optically isolated binary inputs, and 7 binary outputs plus one dedicated watchdog output. Four of the binary outputs are of the changeover type, one of which is the watchdog output. The operating voltage of the binary inputs is configurable by user. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Every input and output is galvanically isolated against each other, which allows any type of cabling. They have high immunity against external disturbances given by optical isolation and suppression of transient in the binary inputs, and by using optical couplers for the command of output relays, as well as the use of a separate supply voltage.

MAP8020 Expansion Module – 16 Binary Inputs

This module contains 16 independent, optically isolated binary inputs. The operating voltage of the binary inputs is configurable by user. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8021 Expansion Module – 32 Binary Inputs

This module contains 32 optically isolated binary inputs, arranged in four groups of 8 inputs, each group having one common return. The operating voltage of the binary inputs is configurable by user. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8030 Expansion Module – 8 Binary Inputs and 8 Binary Outputs

This module contains 8 independent, optically isolated binary inputs, and 8 relay-based binary outputs, being four of the changeover type. The operating voltage of the binary inputs is configurable by user. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8031 Expansion Module – 16 Binary Inputs and 8 Binary Outputs

This module contains 16 optically isolated binary inputs, arranged in one group with a common return, and 8 relay-based binary outputs, being four of the changeover type. The operating voltage of the binary inputs is configurable by user. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8051 Expansion Module – 16 Binary Outputs

This module contains 16 relay-based binary outputs, being four of the changeover type.

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8052 Expansion Module – 8 High-Speed Binary Outputs

This module contains 8 static, high-speed binary outputs. These outputs combine high speed requirements (≤ 50µs, resistive load) with high current interruption (10 A, L/R = 40 ms), and are implemented by means of an IGBT device paralleled with a relay. This results in high speed high breaking capacity, along with very low burden in steady state operation.

Accessing this board is only possible after removing the back panel of the TPU L500.

Table 2.2. Types of binary expansion modules.

Option	Board type	Number of binary inputs	Number of binary outputs
A	MAP8020	16	-
B	MAP8021	32	-
C	MAP8030	8	8
D	MAP8031	16	8
E	MAP8051	-	16

F	MAP8052	-	8 (high-speed)

MAP8081 Expansion Module – 8 d.c. Analogue Input

This module contains 8 independent d.c. analogue inputs. There are several options of rated current and/or rated voltage of the inputs, depending on the application. Each input can be independently programmed as voltage or current input, including different rated values. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

This module contains isolation, analogue filtering and high resolution A/D conversion, as well as a dedicated processor to control the module. It has been especially designed in order to provide a very high rejection degree at the power system frequency (50 and 60 Hz).

Accessing this board is only possible after removing the back panel of the TPU L500.

MAP8082 Expansion Module – 12 a.c. Analogue Inputs

This module contains 12 a.c. analogue inputs. There are several options of this module, with different combinations of current and voltage inputs. There are also several options of rated current and/or rated voltage of the inputs, depending on the application. These options are detailed in subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

This module contains the auxiliary current and/or voltage transformers, analogue filtering and high resolution A/D conversion.

Table 2.3. Analogue input expansion board options.

Option	Analogue inputs	Description
J	8 d.c.	8 current or voltage d.c. inputs
O	6 I + 6 U	6 a.c. analogue current inputs + 6 a.c. analogue voltage inputs
P	12 I	12 a.c. analogue current inputs
Q	8 I + 4 U	8 a.c. analogue current inputs + 4 a.c. analogue voltage inputs
R	5 I + 1 I sensitive + 6 U	6 a.c. analogue current inputs (one of them sensitive) + 6 a.c. analogue voltage inputs
S	6 I + 2 I sensitive + 4 U	8 a.c. analogue current inputs (two of them sensitive) + 4 a.c. analogue voltage inputs

Expansion modules must be correctly configured to work properly. Wrong configuration, besides causing malfunction in the TPU L500, may cause permanent damage in the expansion boards and/or processing board.

Any intervention in the interior of the TPU L500 shall be carried out by authorised technical personnel. The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel injuries and/or equipment damage.

2.2.3 Configuration of the Supply Voltage and I/O

It is necessary to make sure that the correct options of the operating voltages of the power supply and of the binary inputs are chosen. Incorrect choice can cause malfunction and even damage the TPU L500. The same applies to the rated values of a.c. current and voltage inputs.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel injuries and/or equipment damage.

A copy of the ordering form is in the back panel of the TPU L500, in the tag with the CE Marking symbol.

Supply Voltage Ranges

Table 2.4 shows three options for the operating ranges of the power supply.

Table 2.4. Ranges of operating voltages for the power supply.

Rated voltages	Operating ranges	Power consumption
24 / 48 / 60 V d.c.	d.c.: 19 – 72 V	< 50 W (d.c.) / < 80 VA (a.c.)
110 / 125 / 220 / 250 V d.c. 115 / 230 V a.c.	d.c.: 88 – 350 V a.c.: 80 – 265 V	
48 / 60 / 110 / 125 V d.c.	d.c.: 38 – 150 V	

Operating Voltages of Binary Inputs

There are four options for the operating voltage of binary inputs in order to adjust their operating range to the supply voltage used. The operating voltage must be chosen according to the rated voltage in order to assure an operation threshold high enough to avoid unexpected operation of the inputs. The rated voltages and operating ranges are specified in Table 2.5.

Binary inputs will only work properly if a continuous voltage is applied. Make sure the polarity of binary inputs is correct; otherwise they will not work properly.

Table 2.5. Rated voltages and operating ranges of binary inputs.

Rated voltages	Voltage thresholds	Maximum permitted voltage	Consumption
24 V d.c.	$V_{LOW} \leq 8$ V d.c. $V_{HIGH} \geq 20$ V d.c.	300 V d.c.	< 0.05 W (1.5 mA @ 24 V d.c.)
48/60 V d.c.	$V_{LOW} \leq 26$ V d.c. $V_{HIGH} \geq 38$ V d.c.		< 0.1 W (1.5 mA @ 48 V d.c.)
110/125 V d.c.	$V_{LOW} \leq 66$ V d.c. $V_{HIGH} \geq 85$ V d.c.		< 0.2 W (1.5 mA @ 125 V d.c.)
220/250 V d.c.	$V_{LOW} \leq 132$ V d.c. $V_{HIGH} \geq 170$ V d.c.		< 0.4 W (1.5 mA @ 250 V d.c.)

Analogue d.c. inputs configuration

The analogue d.c. current and voltage inputs have three different hardware scales. There are four wiring connections for each input, three for the different hardware scales and one common point. The wiring connections define the hardware scale used.

Each hardware scale support multiple operating ranges, according to Table 2.6. The exact operating range for each input can then be set by software configuration. The adequate gain factors in the acquisition circuit will be automatically adjusted in order to guarantee the defined accuracy and resolution.

Table 2.6. Scales of analogue d.c. inputs.

Scale	Operating ranges	Thermal withstand
Voltage (high)	± 150V; ± 300V	360 V continuous 420 V for 1 s
Voltage (low)	± 1V; ± 5V; ± 10V	20 V continuous 50 V for 1 s
Current	± 1mA; ± 5mA; ± 10mA; ± 20mA / 0 .. 1 mA / 0 .. 5 mA / 0 .. 10 mA / 0 .. 20mA / 4.. 20mA	0.1 A continuous 0.5 A for 1 s

Analogue a.c. Inputs Configuration

The rated value of the analogue a.c. current and voltage inputs are configured by user. The configuration must be in accordance with the external CT and VT connected to the TPU L500.

Table 2.7 shows the different options and technical data for a.c. current inputs. The choice between standart and sensitive a.c. current options is made by the analogue a.c. module installed.

One or more extra sensitive current inputs are available in some of the options of the analogue a.c. module. This option enables increased sensitivity for neutral current measurement and can be used for detection of high resistance phase-to-earth faults.

Table 2.7. Rated values and operating ranges of a.c. current inputs.

Option	Rated value	Operating ranges	Thermal withstand	Consumption
Standard	I_r = 1 A I_r = 5 A	[0,05 .. 50,0] × I_r	500 A for 1 s 20 A continuous	< 0,05 VA @ I_r = 1 A < 0,15 VA @ I_r = 5 A
Sensitive	I_r = 1 A I_r = 5 A	[0,005 .. 5,0] × I_r	250 A for 1 s 10 A continuous	< 0,05 VA @ I_r = 1 A < 0,25 VA @ I_r = 5 A

Table 2.8 shows the different options and technical data for a.c. voltage inputs.

Table 2.8. Rated values and operating ranges of a.c. voltage inputs.

Rated value	Operating ranges	Thermal withstand	Consumption
U_r = 100/3, 110/3, 115/3 or 120/3 V (residual)	[0,25 .. 220,0] V_{rms}	500 V for 1 s	< 0,05 VA @ U_r

Ur = 100/√3, 110/√3, 115/√3 or 120/√3 V (phase-earth)		460 V continuous	
Ur = 100, 110, 115 or 120 V (phase-phase)			
Ur = 100/√3, 110/√3, 115/√3 or 120/√3 V (residual)	[0,50 .. 440,0] V_{rms}	500 V for 1 s 460 V continuous	< 0,25 VA @ U_r
Ur = 100, 110, 115, 120 V or 230 V (phase-earth)			
Ur = 100×√3, 110×√3, 115×√3, 120×√3 V or 400 V (phase-phase)			

2.3 MOUNTING

This section describes the options available to mount the TPU L500. The TPU L500 can be installed on a 19'' rack type panel or cabinet, or flush-mounted directly on the switchgear. Instructions and relevant information for mounting are provided below. Mounting shall be permanent, internal and made on a dry place.

2.3.1 MOUNTING IN A 19" PANEL RACK

Figure 2.4 shows the mounting procedure of the TPU L500 in a 19'' panel rack or cabinet.

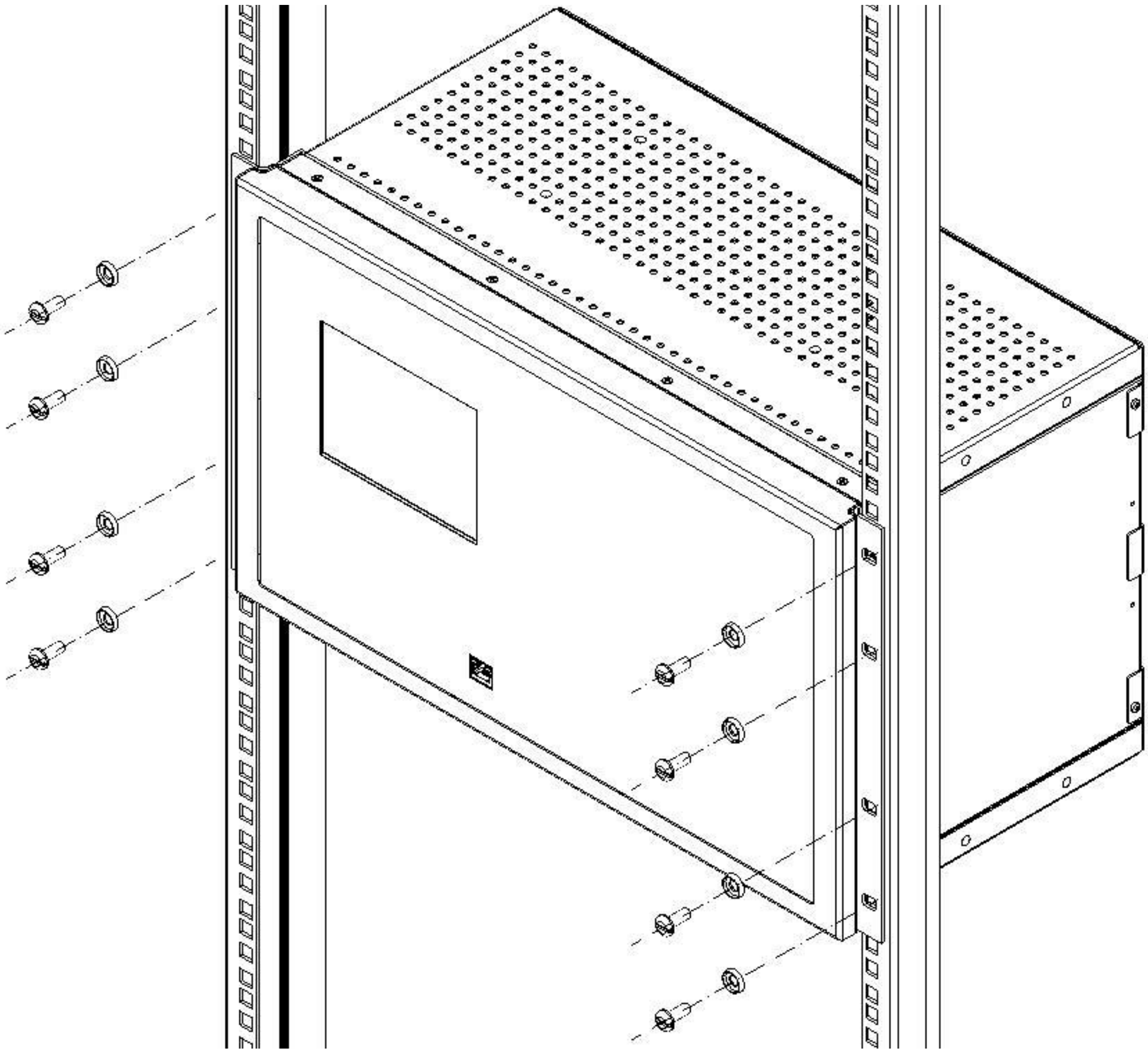


Figure 2.4. Assembly of the TPU L500 in a 19" panel rack or cabinet.

2.3.2 FLUSH-MOUNTING

Figure 2.5 shows the flush-mounting of the TPU L500 directly on a switchgear cubicle.

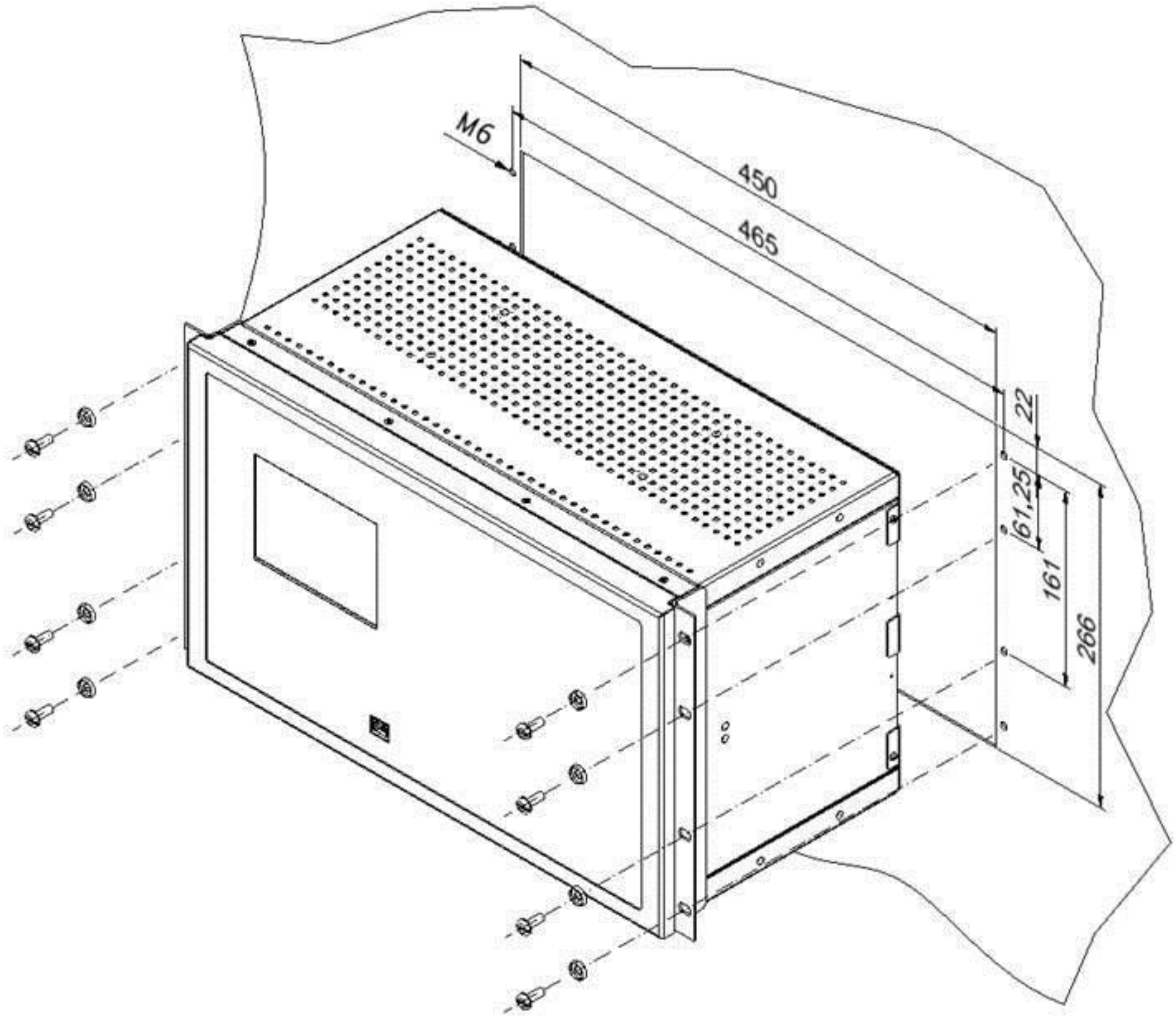


Figure 2.5. Flush-mounting of the TPU L500 on a switchgear cubicle.

2.4 CONNECTIONS

The voltages in the connections of the TPU L500 are high enough to present a high risk of electrical shock. As such, precaution shall be taken to avoid situations that may endanger the physical health of the technical personnel.

Technical personnel shall be adequately trained to handle this type of equipment. The following shall be considered:

- A solid earth protection connection shall be the first to be made, before any other connections are made;
- Any connection may carry dangerous voltages;
- Even when the unit's supply is off, it is possible to have dangerous voltages present.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel injuries and/or equipment damage.

Figure 2.6 shows the connectors present in the back of the TPU L500.

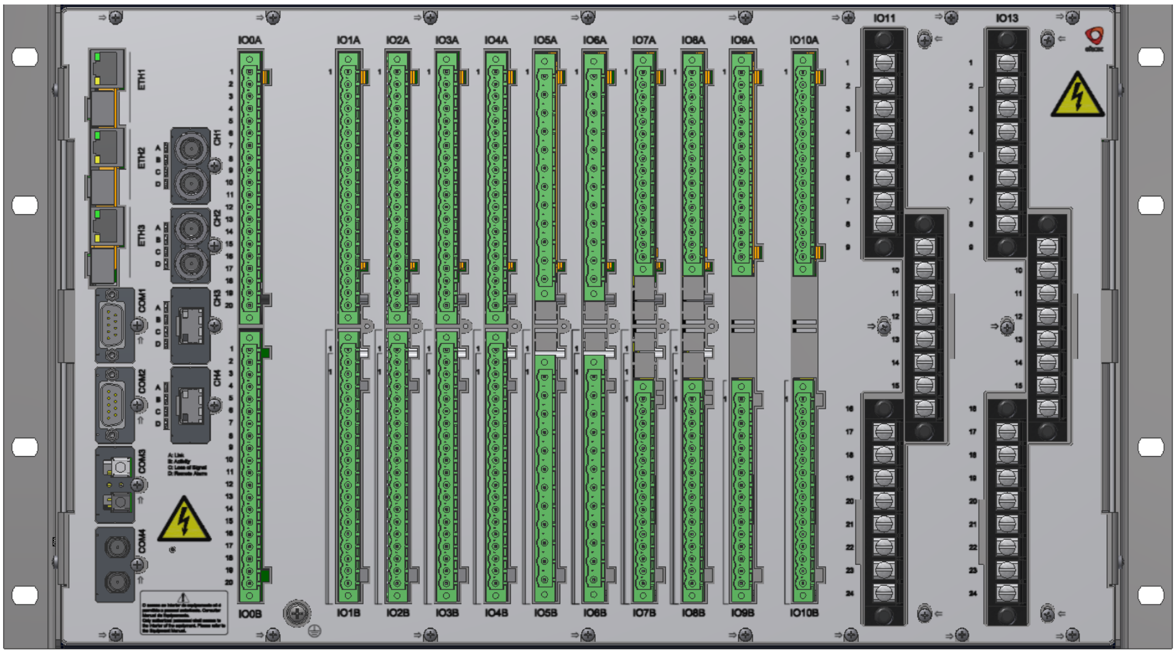
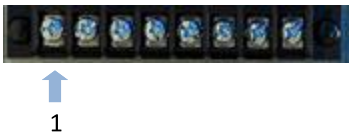


Figure 2.6. Connectors in the back of the TPU L500.

2.4.1 Connectors Description

The next table list all the external connectors included and supplied with the equipment:

Connector for power supply, binary inputs and standard binary outputs	
	Phoenix Front-MSTB 2.5/20-STF-5,08 (1777976) type connector, 20 contacts. Accepts conductors with section from 0.2 mm² to 2.5 mm². The connection is made by screw with the help of a screw driver size 0.6 x 3.5 mm. Torque: 0.5 – 0.6 Nm.
Connector for high-speed binary outputs	
	Phoenix Front-GMSTB 2.5/12-STF-7.62 (1806106) type connector, 12 contacts. Accepts conductors with section from 0,2 mm² to 2,5 mm². The connection is made by screw with the help of a screw driver size 0,6 x 3,5 mm. Torque: 0,5 – 0,6 Nm.
Connector for d.c. analogue inputs	
	Phoenix Front-MSTB 2.5/16-STF-5.08 (1777934) type connector, 16 contacts. Accepts conductors with section from 0.2 mm² to 2.5 mm². The connection is made by screw with the help of a screw driver size 0.6 x 3,5 mm. Tightening torque: 0.5 – 0.6 Nm.
Terminal for connection of a.c. analogue inputs	
	Terminal Barrier type connector, 8 contacts. Accepts M3.5 or M4 ring-type lug terminals (max. 8 mm external diameter) for conductors with cross-sections from 1.5 to 4.0 mm². The connection is made by DIN 5.5 x 1.0 screwdriver or a PZ2 screwdriver. Tightening torque: 0.8 – 1.0 Nm.
Terminal for earth protection connection	
	Terminal to be fitted by M4 screw, for connection to Earth Protection. This connection is essential for the correct operation of the TPU L500. It should be solid for security reasons.

2.4.2 Wiring Diagrams

Figure 2.7 to Figure 2.15 present the general wiring connection diagrams for the TPU L500.

Base Wiring Diagram

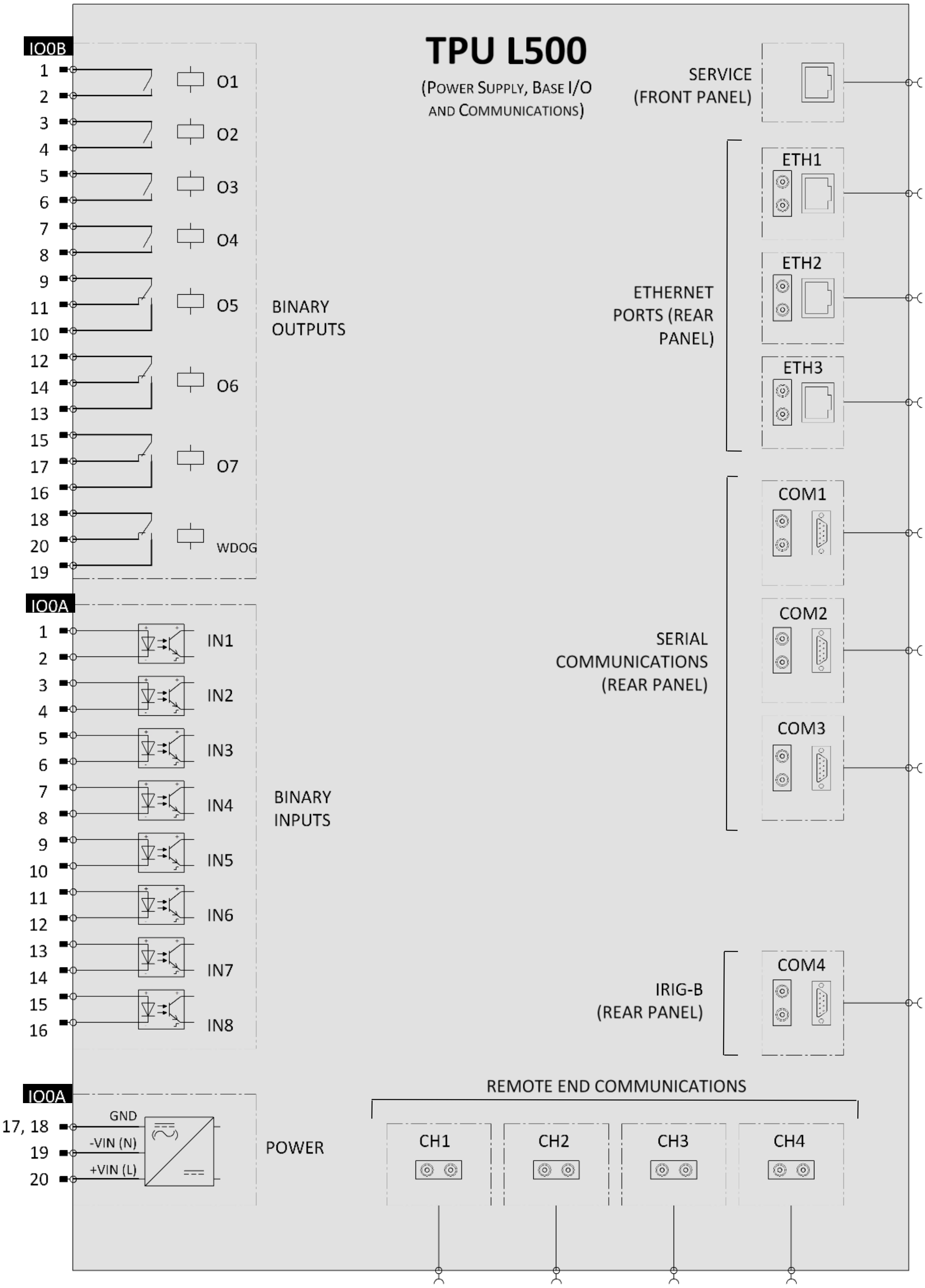


Figure 2.7. Base wiring diagram.

MAP8020 Expansion Module Wiring Diagram

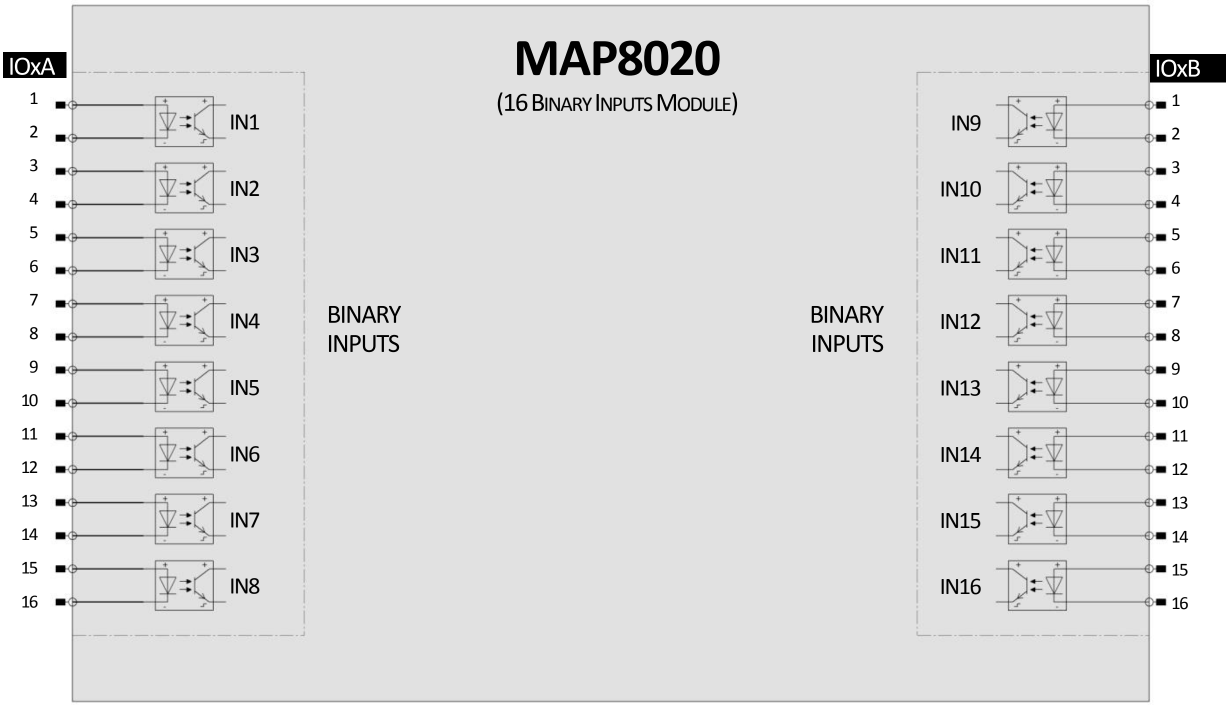


Figure 2.8. MAP8020 expansion module wiring diagram.

MAP8021 Expansion Module Wiring Diagram

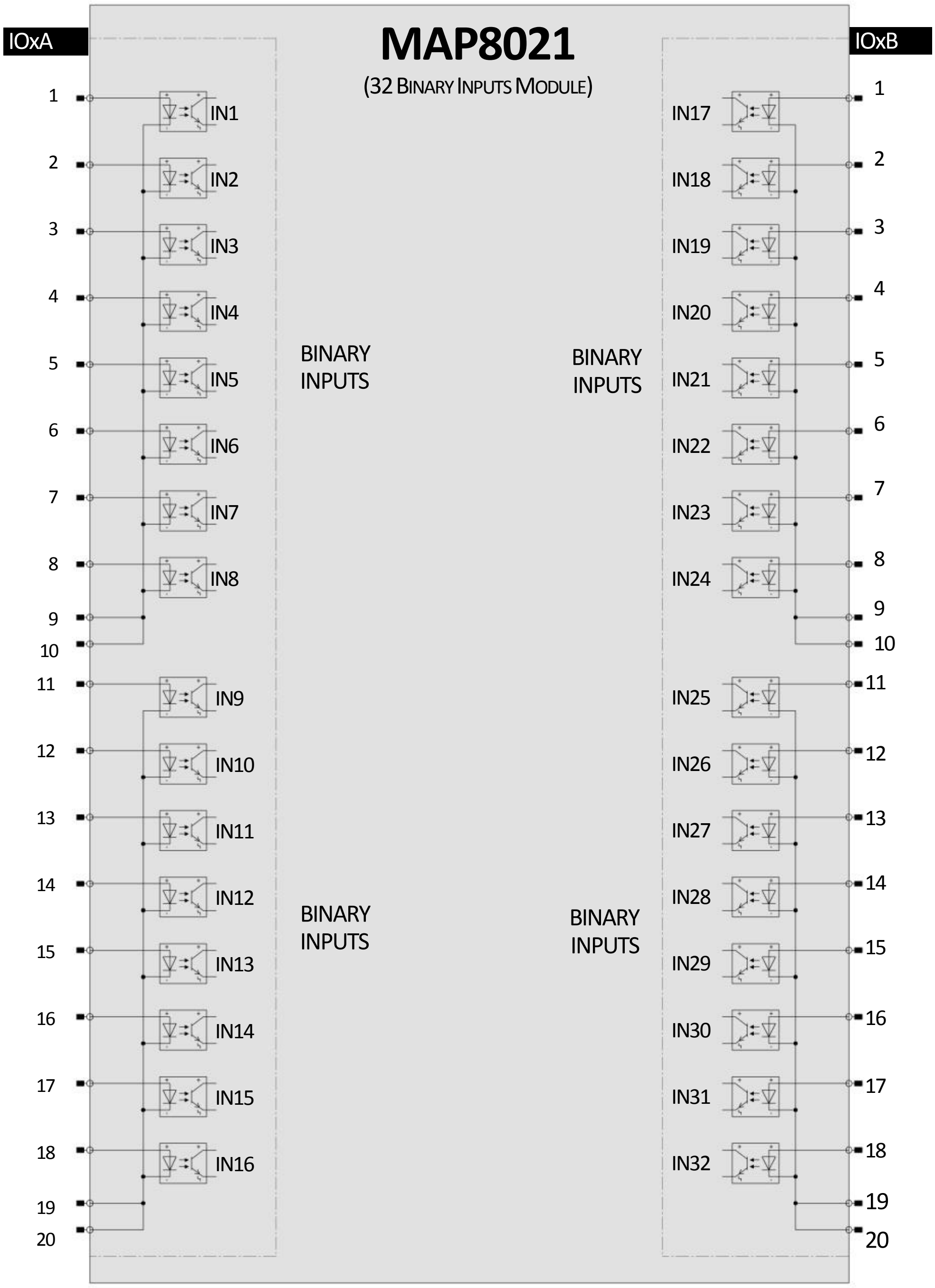


Figure 2.9. MAP8021 expansion module wiring diagram.

MAP8030 Expansion Module Wiring Diagram

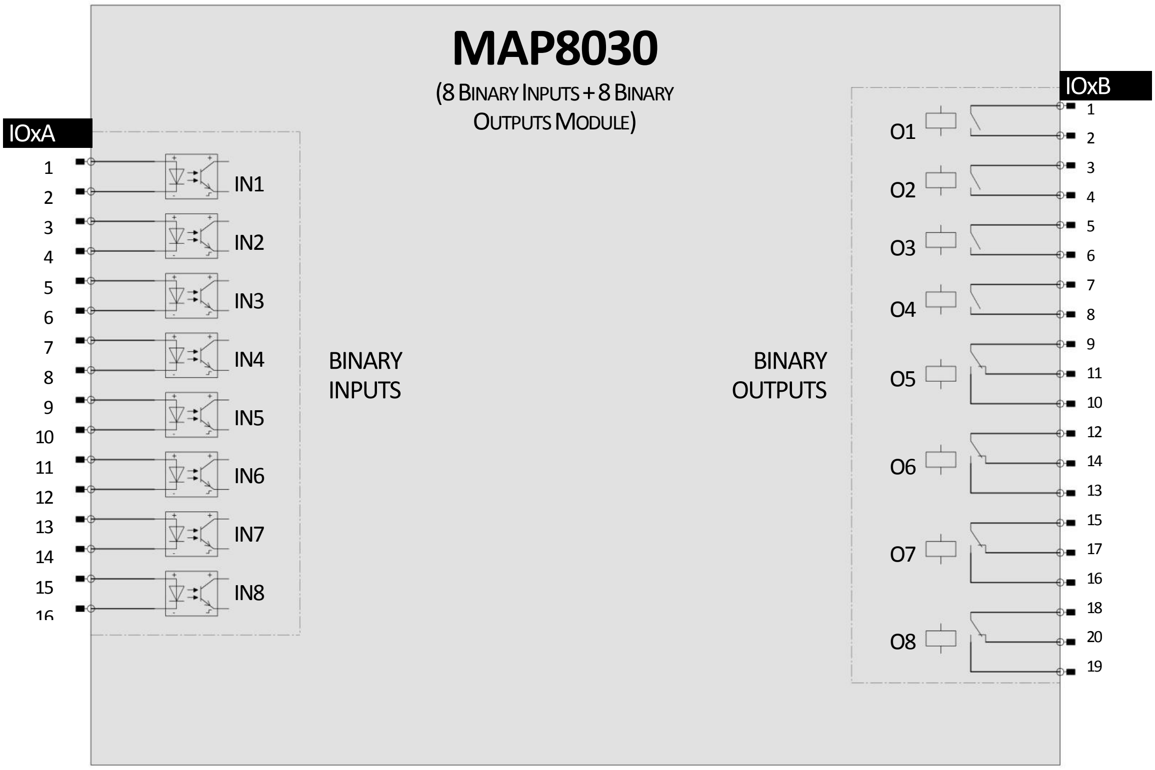


Figure 2.10. MAP8030 expansion module wiring diagram.

MAP8031 Expansion Module Wiring Diagram

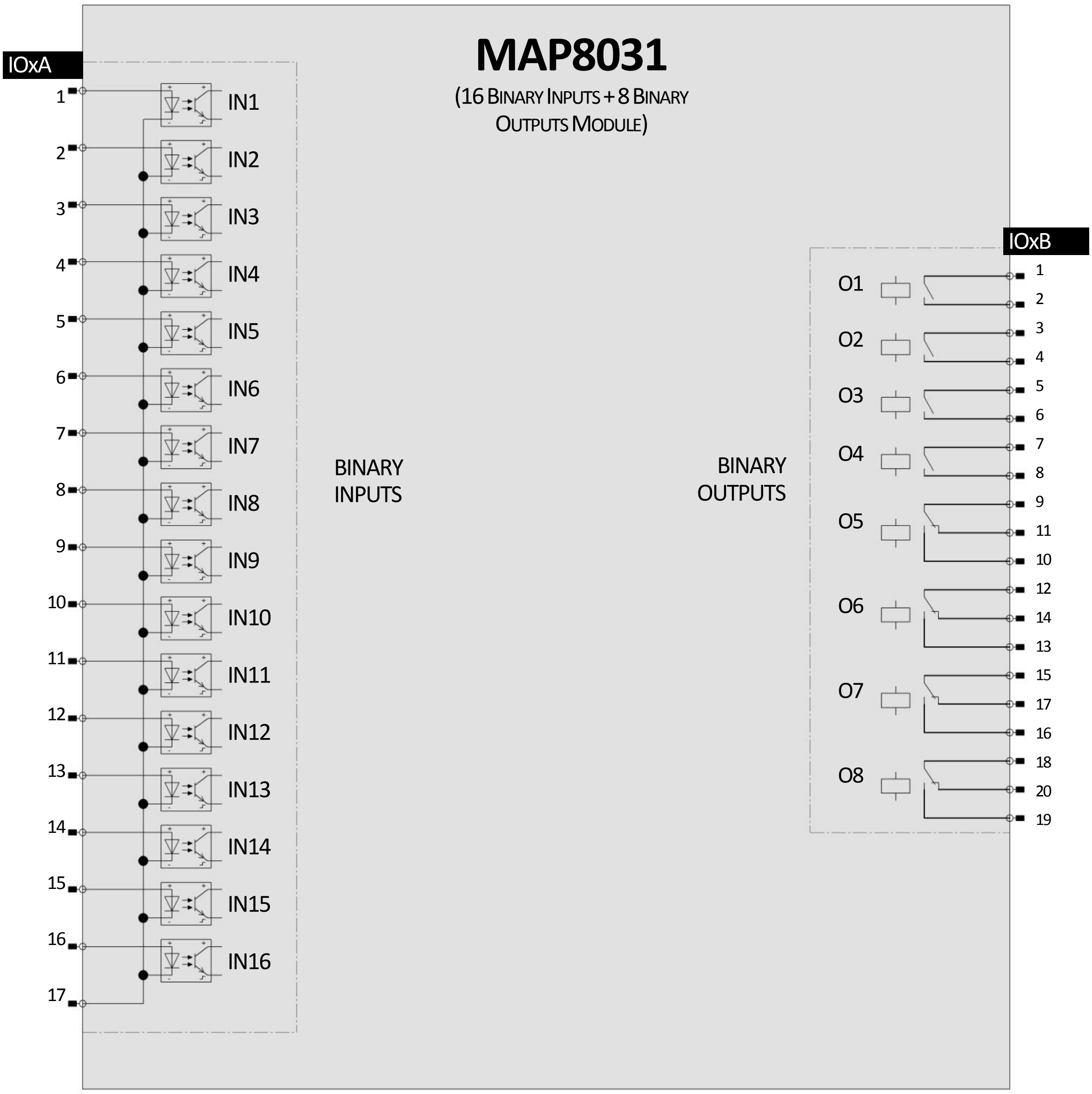


Figure 2.11. MAP8031 expansion module wiring diagram.

MAP8051 Expansion Module Wiring Diagram

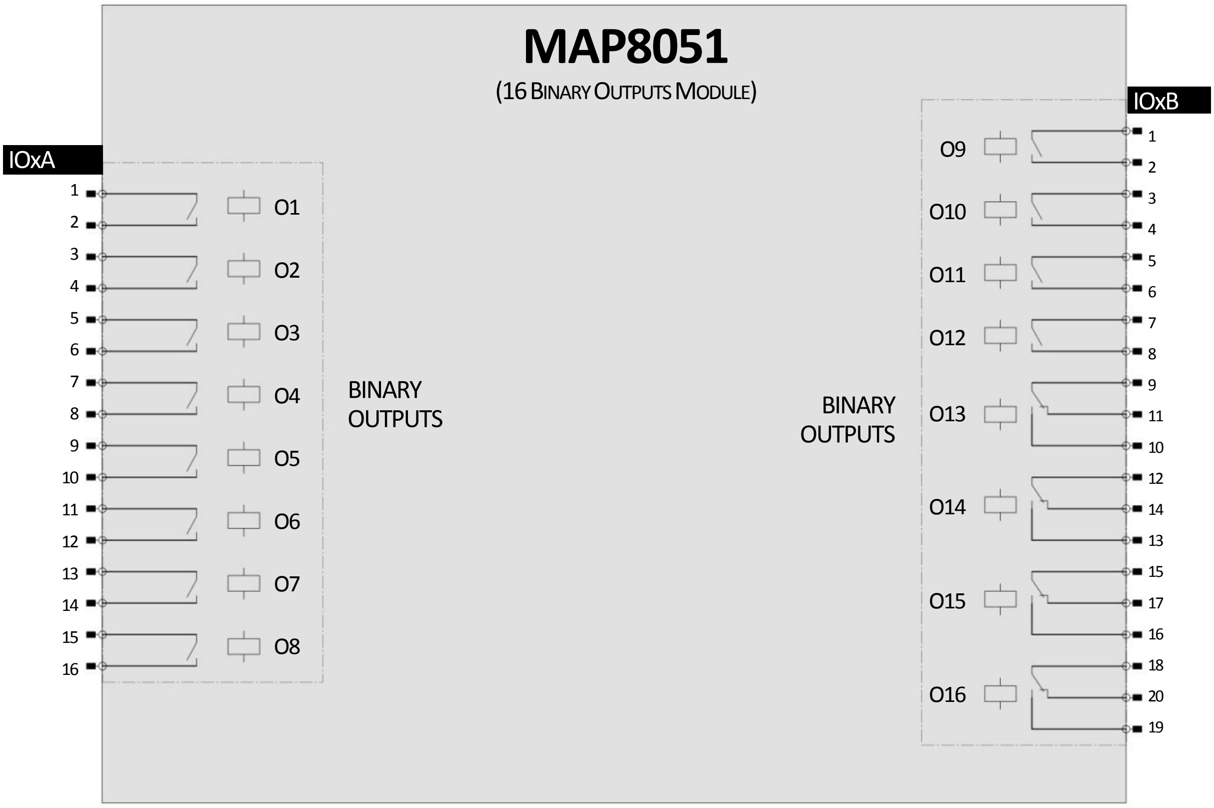


Figure 2.12. MAP8051 expansion module wiring diagram.

MAP8052 Expansion Module Wiring Diagram

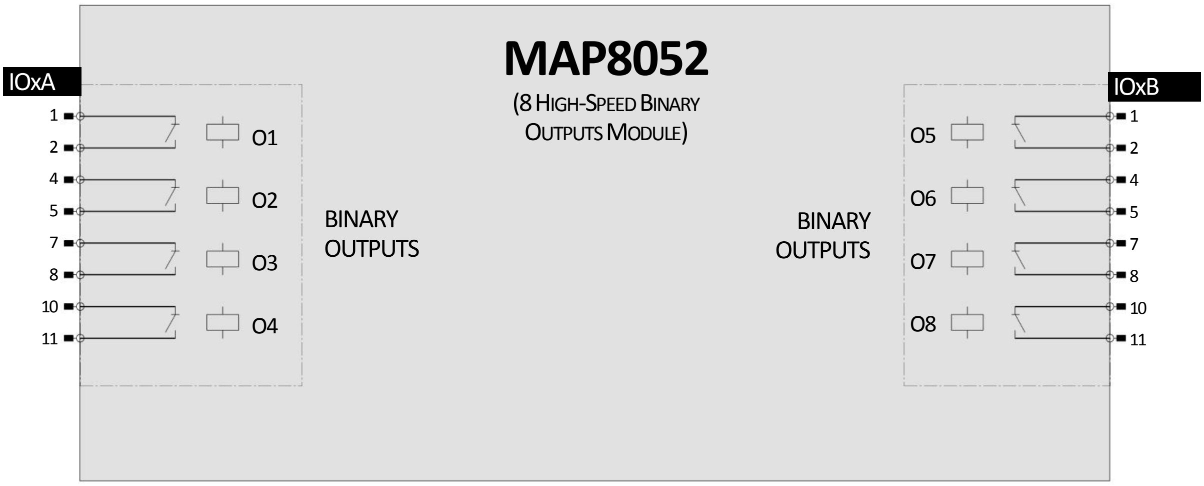


Figure 2.13. MAP8052 expansion module wiring diagram.

MAP8081 Expansion Module Wiring Diagram

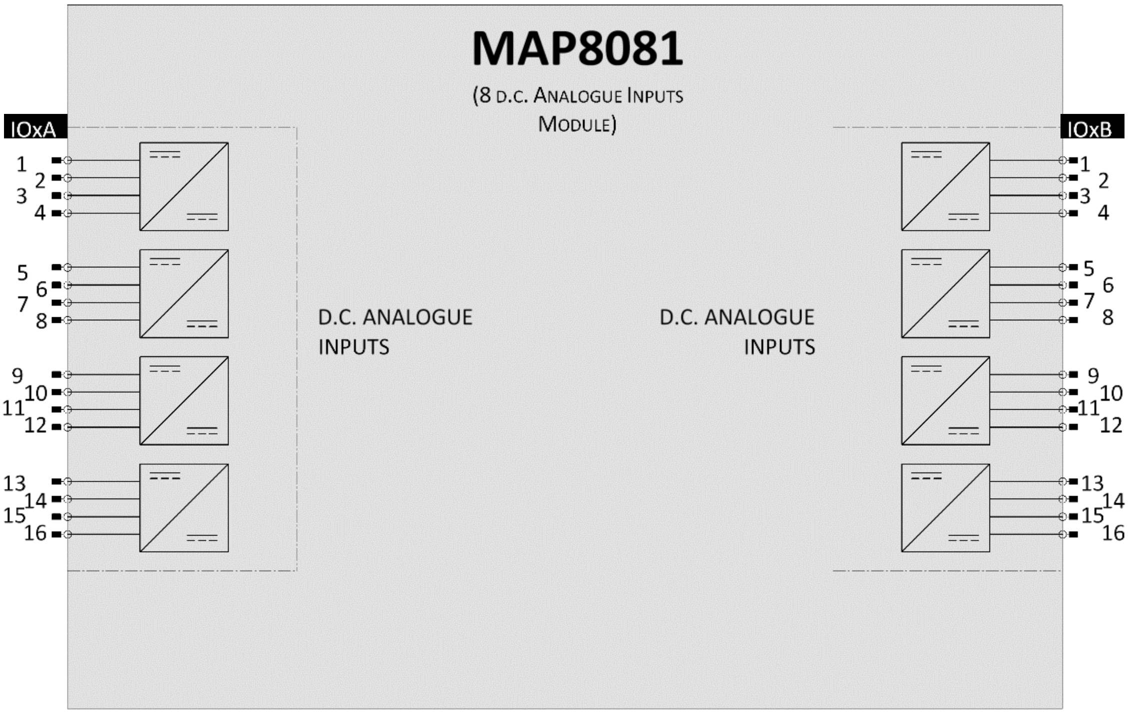


Figure 2.14. MAP8081 expansion module wiring diagram.

MAP8082 Expansion Module Wiring Diagram

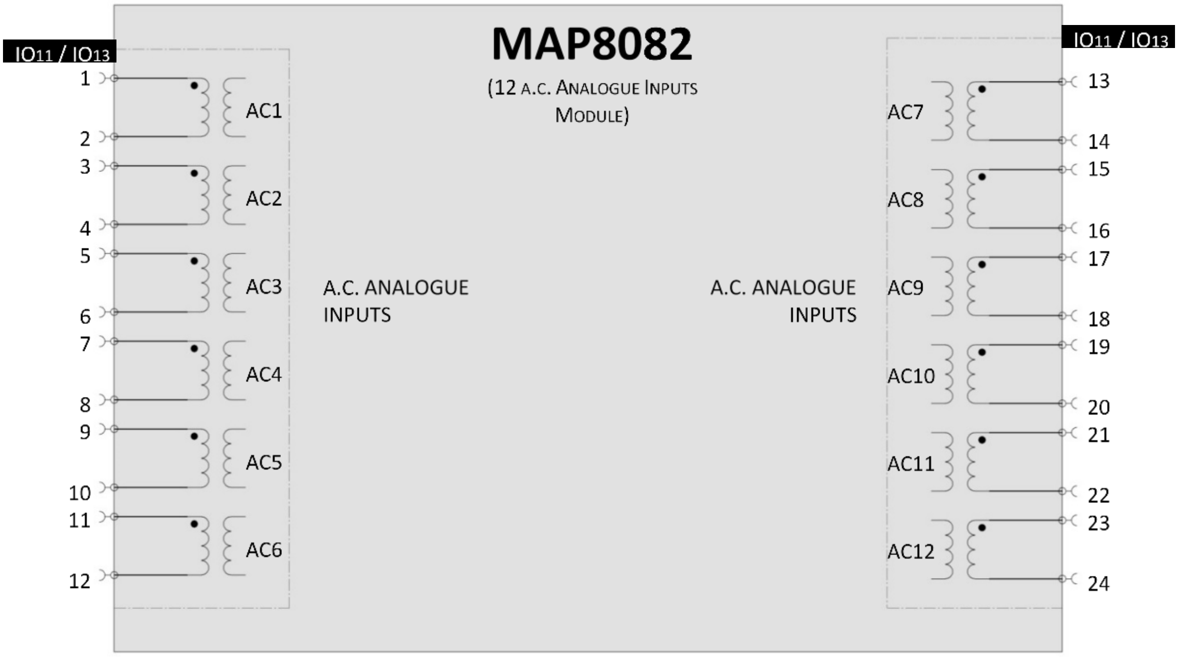


Figure 2.15. MAP8082 expansion module wiring diagram.

2.4.3 Power Supply Connection

According to security regulations a suitable device shall be installed to turn on and off the power supply (main and auxiliary) that shall cut both poles simultaneously.

Protection device against over-currents in both poles of supply (main and auxiliary) shall also be installed. Due to the fact that both input poles are protected by fuses, an earth fault protection device shall also be used.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

Safety Earth Ground shall be directly connected to the earth system using the shortest possible path. Earth protection symbol is:

Conductor with a minimum section of 4 mm^2, preferably of copper braided wire should be used.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500, and cause personnel injuries and/or equipment damage.

After connecting the Safety Earth Ground with a conductor with 4 mm^2 minimum section, which shall be the first connection to be made, connect the remaining earth ground connections. See relevant wiring connections diagrams for details and Figure 2.16. These connections shall be made with at least 1,5 mm^2 cross-section conductor.

The two supply poles, after passing the protection device against over-currents and the switch device, shall be connected to the respective terminals of the POWER connector, taking polarity into account. Both poles are fluctuating in regard to earth and have full galvanic isolation.

Supply voltage shall be within the acceptable range for the version in question – see the tag in the back panel of the TPU L500. The use of incorrect supply voltage may cause the TPU L500 to malfunction and/or damage.

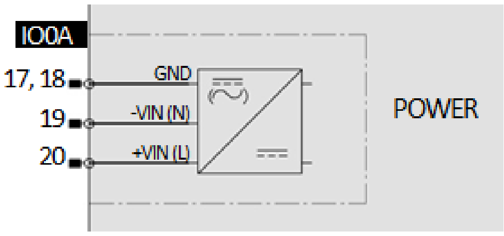


Figure 2.16. Power supply connections of the TPU L500.

2.4.4 Current and Voltage Connections

The secondary circuits of current transformers must be short-circuited before connecting or disconnecting the respective terminals in the TPU L500! If there are test terminals that automatically short circuit the secondary circuits of the current transformers, they may be put to test position as long as their correct operation has been previously verified.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

It is mandatory to check the nominal values of the a.c. analogue current and voltage inputs before they are put to operation. Incorrect nominal values may cause the unit to malfunction and/or damage.

The acceptable thermal capacity shall also be verified for each of the input nominal values, both for permanent and short-time values. Subjecting analogue inputs to values higher than those specified will cause permanent damage to the inputs.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

Typical Connections for a.c. Current Inputs

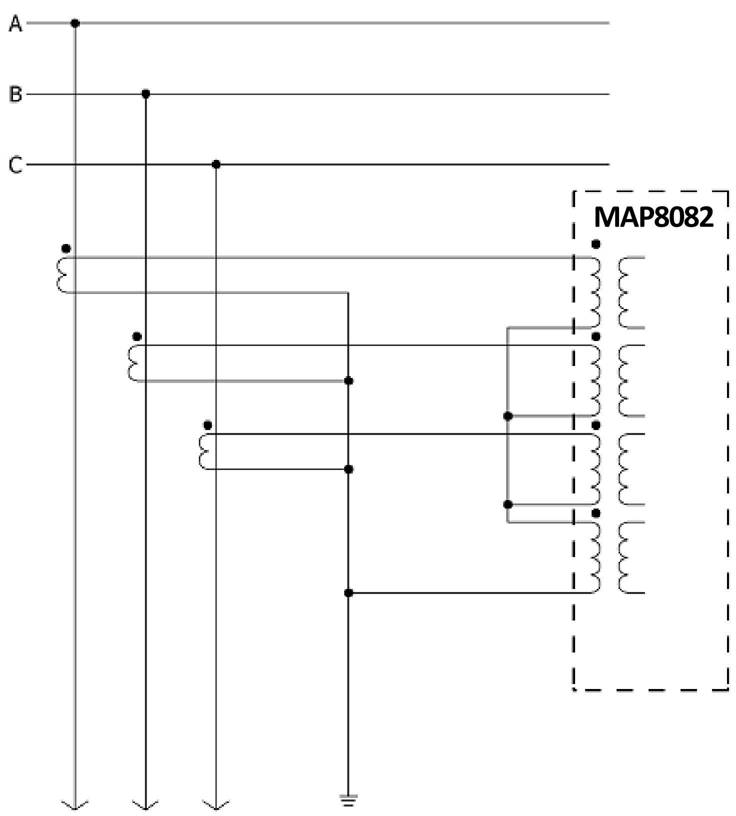


Figure 2.17. First example of connections of current inputs.

Figure 2.17 presents phase and earth current inputs connection, with residual current obtained from the phase currents by external Holmgreen circuit. This type of connection is typical for low-impedance earthed systems.

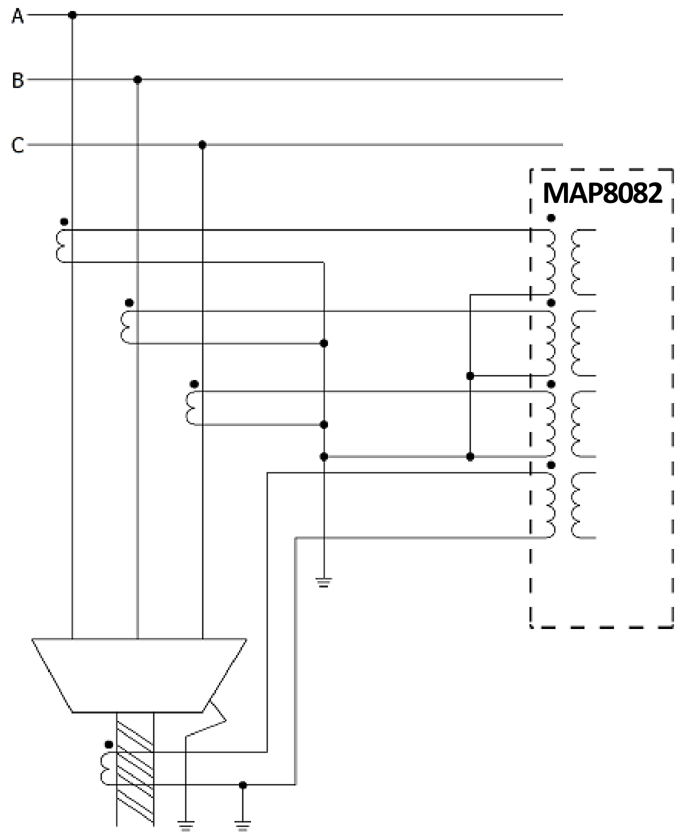


Figure 2.18. Second example of connections of current inputs.

Figure 2.18 shows phase and earth current inputs connection, when an independent phase-balance neutral current transformer for earth current measurement is available. This type of connection is usually required in the case of isolated or compensated networks and for sensitive earth-fault detection.

Typical Connections for a.c. Voltage Inputs

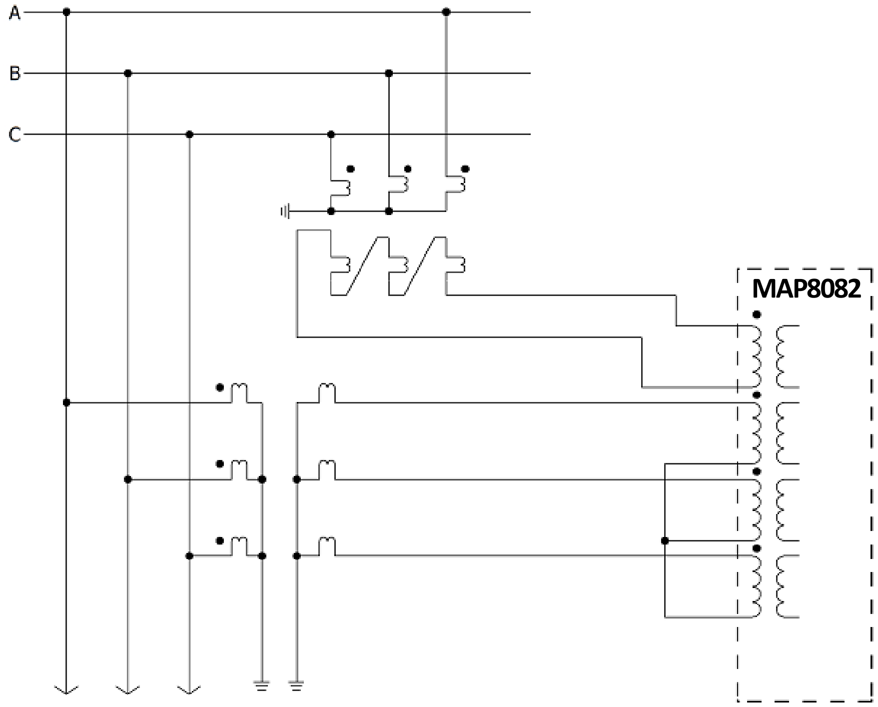


Figure 2.19. First example of connections of voltage inputs.

Figure 2.19 shows three phase-to-earth voltage transformer connection, with an independent open-delta connected winding for residual voltage measurement. The fourth voltage input can provide polarization for directional earth-fault protection.

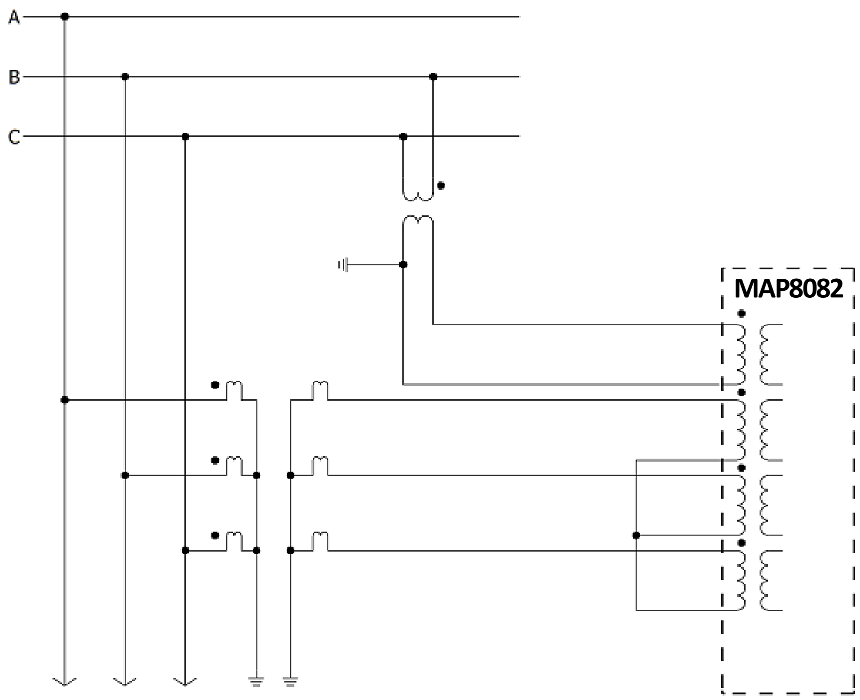


Figure 2.20. Second example of connections of voltage inputs.

Figure 2.20 shows three phase-to-earth voltage transformer connection and an additional phase-to-phase voltage input for busbar voltage measurement. Fourth voltage connection is required for synchro-check applications. Polarization for directional earth-fault protection can be obtained from internal sum of phase-to-earth voltages.

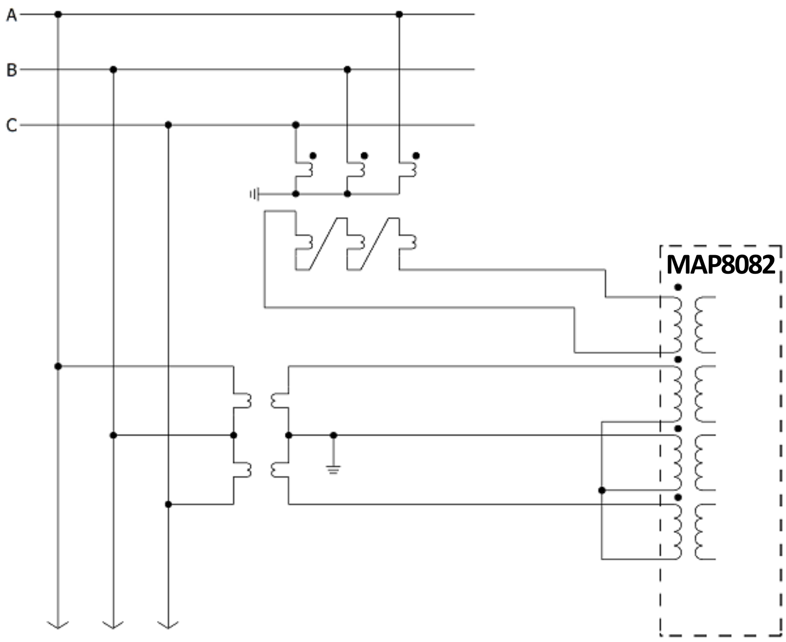


Figure 2.21. Third example of connections of voltage inputs.

Figure 2.21 is an alternative voltage connection, with three phase-to-earth voltages obtained from two phase-to-phase voltage transformers (Aron circuit). An independent open-delta connected winding is required for residual voltage measurement.

Table 2.9. Pin assignment for MAP8082 expansion board.

IO 11 (or 13)		
1	AC Input 1	IN1A
2		IN1B
3	AC Input 2	IN2A
4		IN2B
5	AC Input 3	IN3A
6		IN3B
7	AC Input 4	IN4A
8		IN4B
9	AC Input 5	IN5A
10		IN5B
11	AC Input 6	IN6A
12		IN6B

IO 11 (or 13)		
13	AC Input 7	IN7A
14		IN7B
15	AC Input 8	IN8A
16		IN8B
17	AC Input 9	IN9A
18		IN9B
19	AC Input 10	IN10A
20		IN10B
21	AC Input 11	IN11A
22		IN11B
23	AC Input 12	IN12A
24		IN12B

Table 2.10. Type of analogue inputs.

Option	Current inputs	Sensitive current inputs	Voltage inputs
O	IN1, IN2, IN3, IN4, IN5, IN6	-	IN7, IN8, IN9, IN10, IN11, IN12
P	IN1, IN2, IN3, IN4, IN5, IN6, IN7, IN8, IN9, IN10, IN11, IN12	-	-
Q	IN1, IN2, IN3, IN4, IN5, IN6, IN7, IN8	-	IN9, IN10, IN11, IN12
R	IN1, IN2, IN3, IN4, IN5	IN6	IN7, IN8, IN9, IN10, IN11, IN12
S	IN1, IN2, IN3, IN5, IN6, IN7	IN4, IN8	IN9, IN10, IN11, IN12

2.4.5 Binary Input and Output Connections

It is necessary to assure the correct polarity of binary inputs, otherwise they will not work. Also check that the option of operating voltage and operation set is according to the used control voltage.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

The TPU L500 has binary inputs that may vary in number depending on the configuration of binary input/output expansion module used. Inputs have high galvanic isolation and are completely independent among each other. It is also necessary to make sure that their operating voltage (and respective operating range) is according to the used control voltage. See Table 2.5 and subsection 2.2.3 - Configuration of the Supply Voltage and I/O.

Binary outputs may vary in number (besides the dedicated watchdog output) depending on the configuration of input/output modules. See subsection 2.2.3 - Configuration of the Supply Voltage and I/O for details. Output contacts are dry and completely independent among each other. There are normally opened contacts and of change-over type, as can be seen in the wiring diagrams.

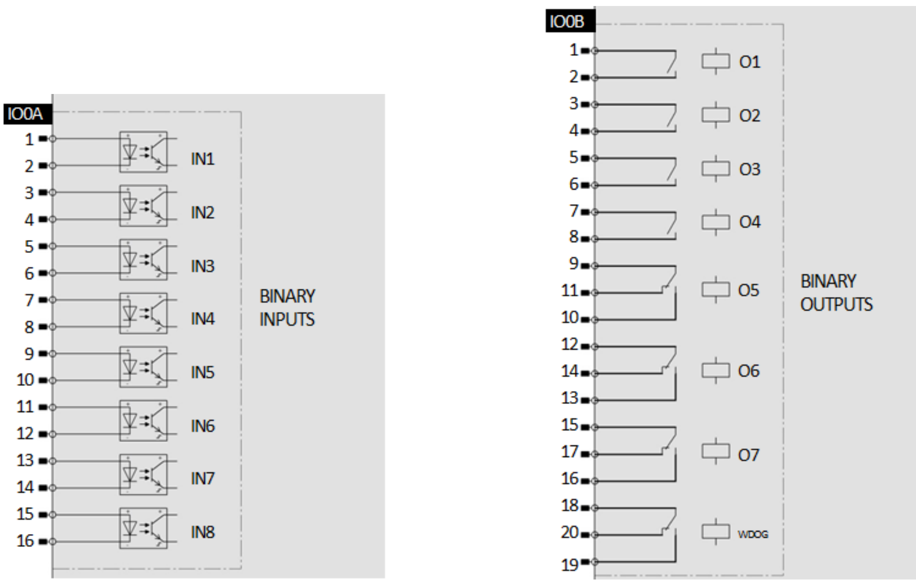


Figure 2.22. Binary I/O connections of the TPU L500 (base module).

Table 2.11. Pin assignment for MAP8011 base board.

IO 0A		
1	Binary Input 1	+
2		-
3	Binary Input 2	+
4		-
5	Binary Input 3	+
6		-
7	Binary Input 4	+
8		-
9	Binary Input 5	+
10		-
11	Binary Input 6	+
12		-
13	Binary Input 7	+
14		-
15	Binary Input 8	+
16		-
17	Earth	
18		
19	Power Supply	-
20		+

IO 0B		
1	Binary Output 1	Normally Open
2		
3	Binary Output 2	Normally Open
4		
5	Binary Output 3	Normally Open
6		
7	Binary Output 4	Normally Open
8		
9	Binary Output 5	Common
10		Normally Open
11		Normally Closed
12	Binary Output 6	Common
13		Normally Open
14		Normally Closed
15	Binary Output 7	Common
16		Normally Open
17		Normally Closed
18	Watchdog	Common
19		Normally Open
20		Normally Closed

Table 2.12. Pin assignment for MAP8020 expansion board.

IO xA (x = 1 to 8)		
1	Binary Input 1	+
2		-
3	Binary Input 2	+
4		-
5	Binary Input 3	+
6		-
7	Binary Input 4	+
8		-
9	Binary Input 5	+
10		-
11	Binary Input 6	+
12		-
13	Binary Input 7	+
14		-
15	Binary Input 8	+
16		-
17	Not Connected	
18	Not Connected	
19	Not Connected	
20	Not Connected	

IO xB (x = 1 to 8)		
1	Binary Input 9	+
2		-
3	Binary Input 10	+
4		-
5	Binary Input 11	+
6		-
7	Binary Input 12	+
8		-
9	Binary Input 13	+
10		-
11	Binary Input 14	+
12		-
13	Binary Input 15	+
14		-
15	Binary Input 16	+
16		-
17	Not Connected	
18	Not Connected	
19	Not Connected	
20	Not Connected	

Table 2.13. Pin assignment for MAP8021 expansion board.

IO xA (x = 1 to 8)		
1	Binary Input 1	+
2	Binary Input 2	+
3	Binary Input 3	+
4	Binary Input 4	+
5	Binary Input 5	+
6	Binary Input 6	+
7	Binary Input 7	+
8	Binary Input 8	+
9	Common (binary inputs 1 to 8)	-
10		-
11	Binary Input 9	+
12	Binary Input 10	+
13	Binary Input 11	+
14	Binary Input 12	+
15	Binary Input 13	+
16	Binary Input 14	+
17	Binary Input 15	+
18	Binary Input 16	+
19	Common (binary inputs 9 to 16)	-
20		-

IO xB (x = 1 to 8)		
1	Binary Input 17	+
2	Binary Input 18	-
3	Binary Input 19	+
4	Binary Input 20	-
5	Binary Input 21	+
6	Binary Input 22	-
7	Binary Input 23	+
8	Binary Input 24	+
9	Common (binary inputs 17 to 24)	-
10		-
11	Binary Input 25	+
12	Binary Input 26	+
13	Binary Input 27	+
14	Binary Input 28	+
15	Binary Input 29	+
16	Binary Input 30	+
17	Binary Input 31	+
18	Binary Input 32	+
19	Common (binary inputs 25 to 32)	-
20		-

Table 2.14. Pin assignment for MAP8030 expansion board.

IO xA (x = 1 to 8)		
1	Binary Input 1	+
2		-
3	Binary Input 2	+
4		-
5	Binary Input 3	+
6		-
7	Binary Input 4	+
8		-
9	Binary Input 5	+
10		-
11	Binary Input 6	+
12		-
13	Binary Input 7	+
14		-
15	Binary Input 8	+
16		-
17	Not Connected	
18	Not Connected	
19	Not Connected	
20	Not Connected	

IO xB (x = 1 to 8)		
1	Binary Output 1	Normally Open
2		
3	Binary Output 2	Normally Open
4		
5	Binary Output 3	Normally Open
6		
7	Binary Output 4	Normally Open
8		
9	Binary Output 5	Common
10		Normally Open
11		Normally Closed
12	Binary Output 6	Common
13		Normally Open
14		Normally Closed
15	Binary Output 7	Common
16		Normally Open
17		Normally Closed
18	Binary Output 8	Common
19		Normally Open
20		Normally Closed

Table 2.15. Pin assignment for MAP8031 expansion board.

IO xA (x = 1 to 8)			IO xB (x = 1 to 8)		
1	Binary Input 1	+	1	Binary Output 1	Normally Open
2	Binary Input 2	+	2		
3	Binary Input 3	+	3	Binary Output 2	Normally Open
4	Binary Input 4	+	4		
5	Binary Input 5	+	5	Binary Output 3	Normally Open
6	Binary Input 6	+	6		
7	Binary Input 7	+	7	Binary Output 4	Normally Open
8	Binary Input 8	+	8		
9	Binary Input 9	+	9	Binary Output 5	Common
10	Binary Input 10	+	10		Normally Open
11	Binary Input 11	+	11		Normally Closed
12	Binary Input 12	+	12	Binary Output 6	Common
13	Binary Input 13	+	13		Normally Open
14	Binary Input 14	+	14		Normally Closed
15	Binary Input 15	+	15	Binary Output 7	Common
16	Binary Input 16	+	16		Normally Open
17	Common	-	17		Normally Closed
18	Not Connected		18	Binary Output 8	Common
19	Not Connected		19		Normally Open
20	Not Connected		20		Normally Closed

Table 2.16. Pin assignment for Type 2 Expansion Board (MAP8051).

IO xA (x = 1 to 8)			IO xB (x = 1 to 8)		
1	Binary Output 1	Normally Open	1	Binary Output 9	Normally Open
2			2		
3	Binary Output 2	Normally Open	3	Binary Output 10	Normally Open
4			4		
5	Binary Output 3	Normally Open	5	Binary Output 11	Normally Open
6			6		
7	Binary Output 4	Normally Open	7	Binary Output 12	Normally Open
8			8		
9	Binary Output 5	Normally Open	9	Binary Output 13	Common
10			10		Normally Open
11	Binary Output 6	Normally Open	11		Normally Closed
12			12	Binary Output 14	Common
13	Binary Output 7	Normally Open	13		Normally Open
14			14		Normally Closed
15	Binary Output 8	Normally Open	15	Binary Output 15	Common
16			16		Normally Open
17	Not Connected		17		Normally Closed
18	Not Connected		18	Binary Output 16	Common
19	Not Connected		19		Normally Open
20	Not Connected		20		Normally Closed

Table 2.17. Pin assignment for MAP8052 expansion board.

IO xA (x = 1 to 8)		
1	Binary Output 1	Normally Open (+)
2		Normally Open (-)
3	Not Connected	
4	Binary Output 2	Normally Open (+)
5		Normally Open (-)
6	Not Connected	
7	Binary Output 3	Normally Open (+)
8		Normally Open (-)
9	Not Connected	
10	Binary Output 4	Normally Open (+)
11		Normally Open (-)
12	Not Connected	

IO xB (x = 1 to 8)		
1	Binary Output 5	Normally Open (+)
2		Normally Open (-)
3	Not Connected	
4	Binary Output 6	Normally Open (+)
5		Normally Open (-)
6	Not Connected	
7	Binary Output 7	Normally Open (+)
8		Normally Open (-)
9	Not Connected	
10	Binary Output 8	Normally Open (+)
11		Normally Open (-)
12	Not Connected	

2.4.6 D.C. ANALOGUE INPUT CONNECTIONS

It is mandatory to check the nominal values of the d..c.. analogue inputs before they are put to operation. Incorrect nominal values may cause the unit to malfunction and/or permanent damage.

The acceptable thermal capacity shall also be verified for each of the input nominal values, both for permanent and short-time values. Subjecting analogue inputs to values higher than those specified may cause permanent damage to the inputs.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

Table 2.18. Pin assignment for MAP8081 expansion board.

IO xA (x = 7 to 10)		
1	DC Input 1	High Voltage (+)
2		Low Voltage (+)
3		Current (+)
4		Common (-)
5	DC Input 2	High Voltage (+)
6		Low Voltage (+)
7		Current (+)
8		Common (-)
9	DC Input 3	High Voltage (+)
10		Low Voltage (+)
11		Current (+)
12		Common (-)
13	DC Input 4	High Voltage (+)
14		Low Voltage (+)
15		Current (+)
16		Common (-)

IO xB (x = 7 to 10)		
1	DC Input 5	High Voltage (+)
2		Low Voltage (+)
3		Current (+)
4		Common (-)
5	DC Input 6	High Voltage (+)
6		Low Voltage (+)
7		Current (+)
8		Common (-)
9	DC Input 7	High Voltage (+)
10		Low Voltage (+)
11		Current (+)
12		Common (-)
13	DC Input 8	High Voltage (+)
14		Low Voltage (+)
15		Current (+)
16		Common (-)

2.4.7 Remote Communication Connections

The TPU L500 may be equipped with up to 4 remote communication channels, for analogue and binary signal transfer with remote IEDs. Four options are provided: up to 2 km (62,5/125 μm or 50/125 μm, 800nm wavelength multimode type glass optical fibre, equipped with ST type connectors), up to 40 km (9/125μm, 1310nm wavelength single-mode type glass optical fibre, equipped with LC duplex type connectors), from 30 km to 60 km (9/125 μm, 1310nm wavelength single-mode type glass optical fibre, equipped with LC duplex type connectors) or from 50 km to 100 km (9/125 μm, 1511nm wavelength single-mode type glass optical fibre, equipped with LC duplex type connectors). The IEEE/ANSI C37.94 standard format is used.

Optical fibre connectors are supplied with protecting covers to avoid dust from entering and contaminating the optical components. The covers can be easily removed.

Remote Communication Interface LEDs

In the back panel of the TPU L500, next to each Remote Communication interface, there is a set of four LEDs to signal the status of the remote connections, described in Table 2.20. The external LEDs are visible in the back panel of the TPU L500.

Table 2.19. LEDs of the Remote Communication interfaces.

LED	Colour	Channel	Indication
A	Green	CH1, CH2 CH3, CH4	Link status
B	Green		Activity (Transmission/Reception of packets)
C	Green		Loss of Signal
D	Green		Remote Alarm

2.4.8 Local Area Network Connections

Ethernet Interface

The TPU L500 is equipped with a dual and a single Fast Ethernet Local Area Network communication interfaces to be connected to two Ethernet networks. The dual-interface uses the physical ports ETH1 and ETH2 and the single-interface is associated to the physical port ETH3. Media type is independently selected by interface and can be 10/100BASE-TX or 100BASE-FX.

Copper port option uses RJ-45 connectors with UTP or STP Cat.5/Cat.6 cable.

Optical fibre option supports multimode type glass optical fibre (62,5/125 μm or 50/125 μm) by the use of SFP modules equipped with LC Duplex type connectors. Wavelength is 1300 nm for 100Mbps. Fibre length can be up to 2000m, depending on the SFP module used.

Optical fibre connectors are supplied with protecting covers to avoid dust from entering and contaminating the optical components. The covers can be easily removed.

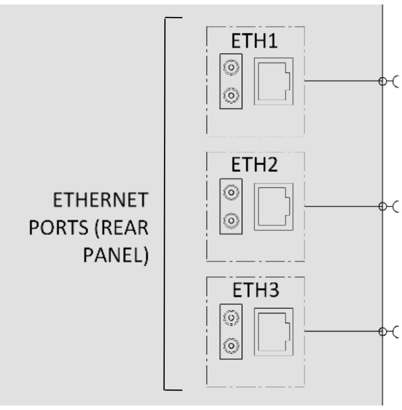


Figure 2.23. Connections of the Ethernet interface.

Ethernet Interface LEDs

In the back panel of the TPU L500, next to the Ethernet interface, there are two LEDs to signal the status of the connection to the Ethernet network, described in Table 2.20. The external LEDs are visible in the back panel of the TPU L500.

Table 2.20. LEDs of the Ethernet interface.

LED	Colour	Transceiver	Indication
LNK	Green	TP1, FO1 TP2, FO2	Link status
ACT	Yellow		Activity (Transmission/Reception of packets)

2.4.9 Front Service Interface

Fast Ethernet Front Service Interface is dedicated to communication with the Automation Studio application running in a PC for configuration, settings change, data collection and firmware update of the TPU L500.

2.4.10 Serial Ports

The TPU L500 provides up to three serial ports (COM1 to COM3) located on the back of the unit. The serial ports provide galvanic isolation and protection against electrostatic discharges. The TPU L500 is supplied with protective covers in the serial ports to protect them from dust and other environmental agents.

Serial ports can be used to support serial communication protocols. There are four types of communication interface for serial ports: RS-485/RS-232 (settable by jumper) or optical fibre (glass or plastic).

RS-232/RS-485 Interfaces

This interface provides connection to a RS-232 serial link or RS-485 bus. Maximum baud rate is 57200 baud. This serial interface has galvanic isolation and immunity against electrostatic discharges.

Table 2.21. Pin allocation for RS-232/RS-485 serial ports.

COM1 to COM3	RS232	RS485
1	Not Connected	Not Connected
2	RxD (Input Receive Data)	DATA-

3	TxD (Output Transmit Data)	Not Connected
4	Not Connected	Not Connected
5	GND (Ground)	GND
6	Not Connected	Not Connected
7	RTS (Output Request To Send)	DATA+
8	CTS (Input Clear To Send)	Not Connected
9	Not Connected	Not Connected

IRIG-B Synchronisation

COM4	IRIG-B, Galvanic Option
1	Not Connected
2	Not Connected
3	5 V Level Input
4	12 V Level Input
5	GND (Ground)
6	Not Connected
7	24 V Level Input
8	Not Connected
9	Not Connected

Optical Fibre Interface

There are two options in optical fibre: plastic optical fibre, with snap-in type connector, for connections up to 45 m; or glass optical fibre, with ST connector, for connections up to 1700 m. This type of ports can be used in a point to point or ring configuration. Protective covers for the connectors are supplied to protect them from dust and other environmental agents.

Chapter

3

HUMAN MACHINE INTERFACE

After reading this chapter, the reader will obtain important information on the components, characteristics and features of the Human Machine Interface as well as knowledge on how to operate it. An introduction is also given on the information available for consultation and edition in the menu structure, with references to other sections in the manual where this knowledge can be expanded.

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Total of pages of the chapter: 17

3.1 Local HMI

3.1.1 Front Panel Description

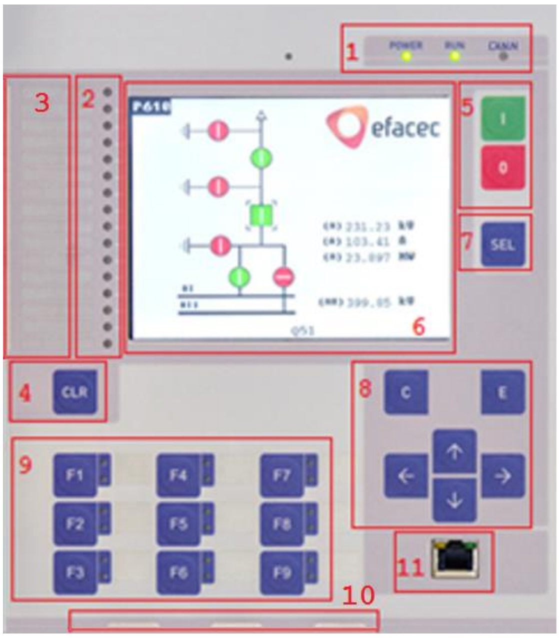
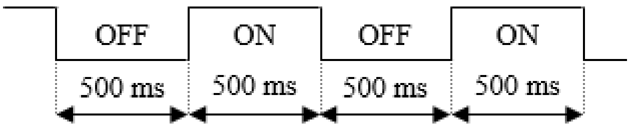


Figure 3.1. Front panel and Local Human Machine Interface.

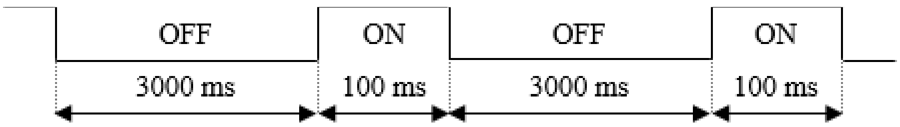
1) State LEDs:

LEDs used to represent the unit state.

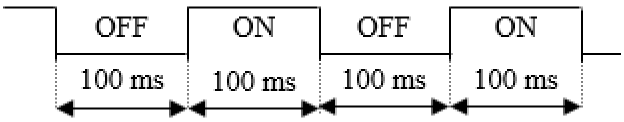
- POWER LED (green) is static if the unit is energized.
- RUN LED reflects the device's health (green OK; orange WARNING; red ALARM) and blinks or not depending on the configuration. The run led can blink differently accordingly with the IED following modes:
  - User configuration blink pattern (normal mode);



  - Factory configuration blink pattern (empty configuration);



  - Test mode blink pattern.



- COMM LED (yellow) indicates Ethernet communications status.

2) Alarm LEDs:

LEDs associated with the current state of each programmable alarm.

3) Alarm descriptive windows:

Windows associated with the descriptive paper tag of each programmable alarm.

4) CLR Key:

Key that allows the acknowledgment of active alarms.

5) Command keys:

Keys used to operate selected objects in a mimic page.

6) LCD:

Colour graphic display (640x480 pixels).

7) Selection key:

Key used to enter Mimic mode and to select objects in a mimic page.

8) Navigation Keys:

Keys that allow navigation in menus, selection of options and commands as well as settings change.

9) Function Keys:

Programmable keys that can have different meanings depending on the configuration.

10) Function Keys descriptive windows:

Windows associated to each programmable keys descriptive paper tags.

11) Local Access:

Ethernet port used to access the unit locally in order to change firmware, to configure the unit and to check the event log, among others.

3.1.2 Startup Sequence

During the startup sequence, Local HMI goes through several different stages that allow the correct identification of each step until the unit resumes normal operation. With this, it is possible to identify in which step a possible failure occurred.

When the unit is energized, state LED POWER and LED COMM will light up with the colour yellow while LED RUN will display the colour orange. All remaining LEDs will be in the off state, indicating that the unit is in boot mode, as seen in Figure 3.2.

Figure 3.2. Local Human Machine Interface in boot mode.

If boot mode procedure is successful, the LCD will display the EFACEC Logo image and all alarms and function keys LEDs will light up while Run LED and COMM LED will be turned off, as seen in Figure 3.3.

Figure 3.3. Local Human Machine Interface while waiting for startup sequence conclusion.

Unit will remain in this state while the startup sequence concludes. In case of failure the local interface will display the cause in a message and the RUN LED will light up with the colour red (Figure 3.4). If the failure is on the main hardware only the RUN LED will change its state, as showed in the Figure 3.5.

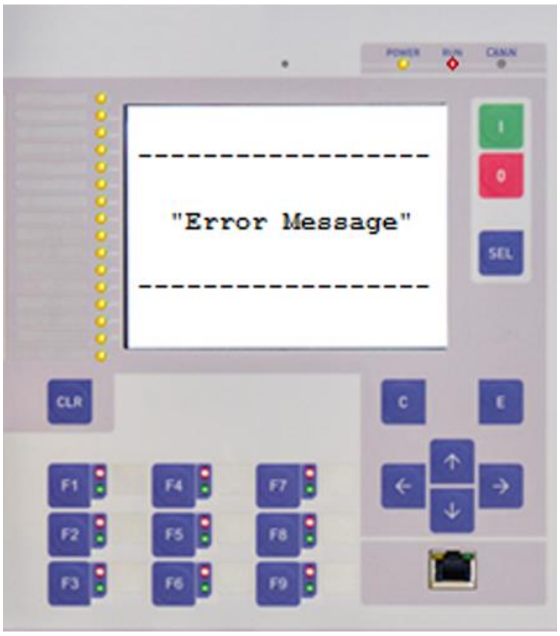


Figure 3.4. Local Human Machine Interface showing the message that indicates the reason of the startup failure.

Figure 3.5. Local Human Machine Interface with the red RUN LED marking a complete main hardware failure.

In a normal startup the LCD will change from the EFACEC logo image to the first mimic page or to the main menu if a firmware update or a configuration deploy was performed. Additionally, POWER LED will display the colour green, RUN LED will reflect the device's health (green OK; orange WARNING; red ALARM) and COMM LED will reflect the actual state of the communications. Alarm and function keys LEDs will change to reflect their configuration and entities that they are associated with. Figure 3.1 represents the conclusion of a normal startup.

3.1.3 KEYPAD

Each key has unique characteristics and features, as described below, that allow for optimal interaction with the unit, nevertheless, it is important to emphasize some aspects of using the keypad such as:

- If two keys are pressed simultaneously, none will be recognized unless it is an established key configuration with a defined meaning (e.g. E and C keys pressed together will restart the Local Human Machine Interface);

- If a key is continuously pressed, the associated action will be repeated. There are exceptions to this, such as continuously pressing navigation key up or down during the edition of a parameter. This will increase the rate in which the parameter changes thus making edition more user-friendly.

Navigation keys

Navigate up in a menu.

Increase the value of a selected parameter.

Paging up the options lists.

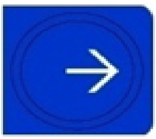
Navigate to the next mimic page.

Navigate down in a menu.

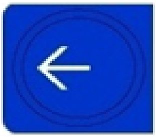
Decrease the value of a selected parameter.

Paging down the options lists.

Navigate to the previous mimic page.



Navigate right during parameter edition.



Navigate left during parameter edition.

Go to the selected menu.

Starts and ends the process of parameter changing.

Confirm the parameter value change.

Confirm an instruction.

Exit Mimic mode and enter Menu mode

Go back to the previous menu.

Interrupt the process of parameter changing.

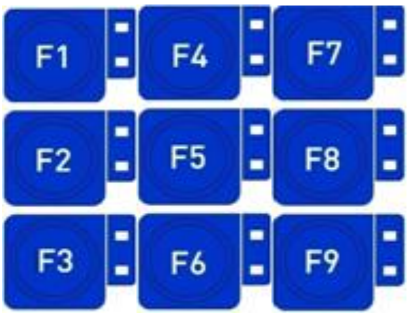
Cancel the parameter value change.

Cancel an instruction.

Alarm cancellation key

Acknowledge active alarms. If the logical state of the entities, associated to an alarm, is inactive, the corresponding LED will be turned off.

Function keys



The operation mode associated with each key is programmable.

Key behaviour will depend on whether key was configured as:

- Status Key
- Control Key
- Status and Control Key
- Shortcut

For more in-depth information on this feature, please refer to subsection 4.6.3 - Function Keys.

Selection key

Exit Menu mode and enter Mimic mode.

Select a controllable object in a mimic page.

Command keys

Operate a selected object of a mimic page.

3.1.4 MENU

The LCD present in the unit can be used in Menu mode which will display information in menu format and offer a range of functionalities, in conjunction with the navigation keys, such as editing parameters, change between options and allow sending commands to the unit and seeing if those commands were executed or blocked.

Menu Format

Menu format was designed to allow for a more intuitive and user friendly interaction with the unit. With this in mind, some distinguishing features were defined in order to give the user all the information required for a smooth navigation in the menu tree.

Figure 3.6 shows the appearance of a typical menu, in this case, the first page of the Main Menu.

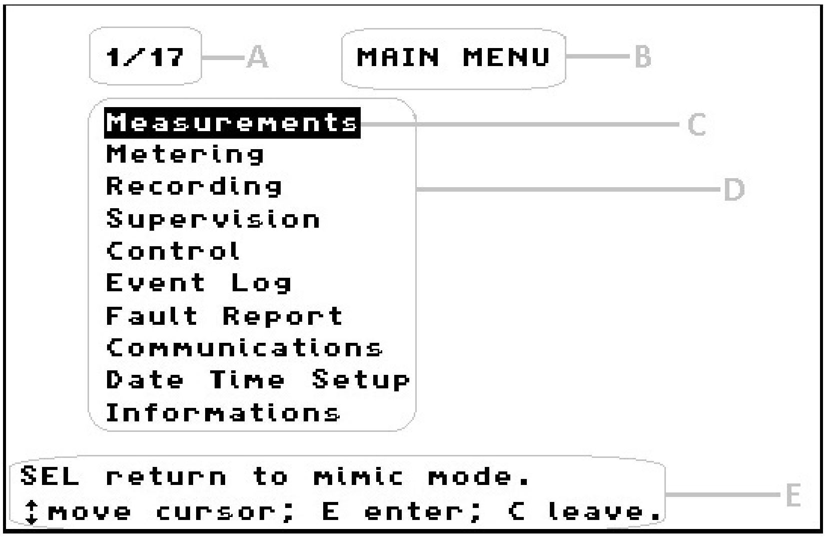


Figure 3.6. Menu Interface: Main Menu appearance.

(A) and (B) give information on the current menu such as the index of the element selected, the total number of navigable elements and the menu title. In this example, **1/17** indicates that the first element of the menu is selected and there are, in total, seventeen navigable elements that can be accessed in this menu. The menu title is **Main Menu**.

The selection bar (C) is used to identify the object selected and can be identified as the menu line with the colour inverted regarding the remaining display. Throughout the menu tree, a selected object can vary from a new navigable menu to an editable parameter or an option or a command that can be given. Lines on the menu that don't allow selection are read only or are protected with a particular access level that prevents a lower level user of becoming aware that they are an editable or selectable object.

The menu content (D) is made up of a group of objects whose meaning varies greatly depending on the menu selected. They can merely be information displayed, new navigable menus, editable parameters and options or commands, among others.

Finally, the last two lines (E) of any page are reserved for instructions on what can be performed in the current menu or in the selected object of that menu.

Menu Navigation

The interaction with the Menus Interface only uses the 4 navigation keys and thus is very easy to use.

Navigation keys ↑ and ↓ can be used to navigate up and down in a menu, allowing moving the selection bar to the item one wants to access. There are menus constituted by several pages so when reaching the first or final line in the menu content, it is possible to go to the previous page or to the next page, respectively.

When pressing key E, access is given to the selected menu while C key allows going back to the previous menu.

Menu Edition

In order to start parameter edition, do as follows:

A. Access the Menu with the parameter(s) to be changed using the procedure described previously;
B. Place the selection bar on the line containing the parameter;
C. Press E key to begin edition mode.

At this point one of two things can happen, parameter edition can start at which point the parameter will start blinking or authentication will be required. Nevertheless, the procedure to change a parameter is identical to the one used for user authentication since both are, in essence, parameter edition. In Table 7.1 we can see the permissions for each ID access.

In case of authentication, the user will be redirected to **Authentication** menu and the procedure described in subsection Start Session will have to be performed.

If authentication was successfully performed for that particular element, menu will jump to the menu that originated the need for authentication in the first place and the user can proceed with parameter edition. On the other hand, if an invalid ID/password combination was inserted, a menu will appear giving this information and containing the option to press C to try again. At any time, user can press C to cancel authentication or edition.

It is important to note that after an authentication is performed, it won't be necessary to perform it again in the same session. A session ends when screensaver/hibernation starts or when user selects option **Quit** in **Security** menu.

Having passed the authentication phase, we are back to step B:

C. Press E key to begin edition mode;
D. Press ↑ / ↓ to change the parameter by increasing/decreasing its value or in case of a list of options, paging up/down the list until reaching the desired option;
E. Press E to end edition.

While on the menu, user can edit the remaining parameters by repeating steps B through E. After having changed all intended values it will be necessary to confirm changes. To do this, press key C as if intending to return to previous menu and, after being prompted, press key E to accept changes or key C to cancel changes.

During edition, the TPU L500 will use the most recent group of valid data and only after the user confirms the new parameters will it perform the update. The success of this procedure can be confirmed if the menu displays the new values, otherwise, it will display the original ones.

When changes are accepted, all the settings in the menu will be deployed so make sure that all changes have been done before accepting them. Don't edit and accept changes for one setting at the time.

Main Menu

The TPU L500 is equipped with a user-friendly interface using menus. When unit starts, the **Main Menu** can be shown by pressing the E key, which allows accessing all other menus through the respective item. This menu is longer than one page and it is, therefore, necessary to move from page to page to access the full content.

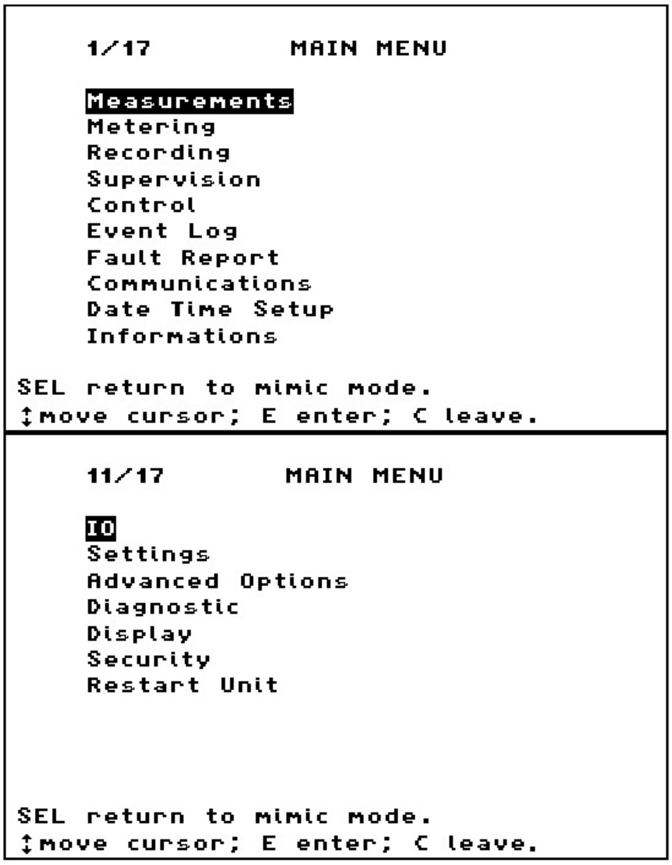


Figure 3.7. Main Menu.

Next is a description of each submenu present in the **Main Menu**.

- **Measurements / Metering / Recording / Supervision / Control:**

  Each one of these menus is composed of relevant data from built-in functions and their format varies depending on the number of functions present in the configuration. Additionally, while navigating in these menus, it is possible to find several outputs, identified by the selection arrow, in which it is possible for the user to execute a control.

  For more detailed information on these menus please refer to sections 7.7 - Built-in Functions - Visualization and 7.8 - Built-in Functions - Controls. For more detailed information on available built-in functions, please refer to chapter 5 - Application Functions.

- **Event Log**

  Visualization of events logged in the Event Log. For more information on the elements and operations supported in this menu, please refer to section 7.14 - Event Log. For more information on the configuration of the event log, please refer to section 4.7 - Event Log.

- **Fault Report**

  Information and operations related with the Fault Report module. For more information on the elements and operations supported in this menu, please refer to section 7.15 - Fault Report. For more information on the Fault Report module, please refer to section 4.8 - Fault Report.

- **Communications**

  Contain information on the Network and Local Access. For more information please refer to section 7.4 - Network Configuration.

- **Date Time Setup**

  Current date and time can be viewed and edited. For more information please refer to section 7.5 - Date and Time Configuration.

- **Informations**

Important information related with the TPU L500. For more information please refer to section 7.3 - Device Information.

- **IO**

  Contains general information related to all I/O boards in the unit such as serial numbers and the number of voltages, currents, digital inputs and digital outputs of each board. A list of Digital and Analogue I/O Boards present in the unit can also be found here. By selecting a digital board, the user can see the state of its inputs and its outputs. For Analogue boards the user can check if the board is calibrated (OK) or not (NOK) and the reason why the board isn't considered calibrated.

  For more information please refer to section 7.6 - I/O Diagnostic and Information.

- **Settings**

  Parameterization of all built-in and user functions, selection of the active group for each logical device and configuration of the logical device mode.

  For more information please refer to sections 7.9 - Operational Settings, 7.10 - Active Setting Group and 7.11 - Logical Device Mode. For more detailed information on available firmware functions and their settings, please refer to chapter 5 - Application Functions

- **Advanced Options**

  Option to restore factory configuration, to restore factory operational settings and to delete records in the device. For more information on these options, please refer to sections 7.17 - Delete Records, 7.12 - Restore Factory Configuration and 7.13 - Restore Factory Operational Settings.

- **Diagnostic**

  Tests supported by the TPU L500 are grouped here. For more information on this, please refer to section 7.21 - Diagnostic and Tests.

- **Display**

  Options to personalize the display such as:

  - **Language**: select from the supported languages;
  - **Screensaver** time: amount of time the unit has to be idle for screensaver to start;
  - **Hibernation** time: amount of time the unit will stay in screensaver mode until changing to hibernation mode;
  - **Brightness:** level of brightness of the graphic display (1-10).

  In this menu it is also possible to access menu **Diagnostic** that contains tests for the display and all the keys and LEDs. Each test includes instructions on how to start and end it.

- **Security**

  Here it is possible to access menu **Authentication** and menu **Change Password** where the user can start a security session or change the password for an ID access level. For more information on this please refer to section 7.1 - User Management.

- **Restart Unit**

  Command to restart unit. For more information please refer to section 7.19 - Restart Device.

3.1.5 Mimic

The TPU L500 supports the configuration of up to six mimic pages where additional information can be added for consultation and objects can be configured as controllable. By accessing a mimic page, the unit enters the Mimic mode.

Mimic Page

The content of each mimic page depends entirely on what was configured.

Mimic Navigation

By default the TPU L500 starts in mimic mode unless a configuration deploy or a firmware update was performed. Otherwise, mimic mode can be activated by pressing selection key SEL at which time the LCD will display the first mimic page, if this is the first time entering this mode, or the last mimic page that was accessed, if not. Having done this, it is possible to change the visible mimic by using the navigation keys ↑ and ↓ which will navigate to the next and previous page, respectively.

At any point, pressing navigation key E will return the Local HMI to Menu mode which will result in the last accessed menu being displayed.

Mimic Operation

Objects in a mimic page that were configured as controllable can be operated using the command keys to execute a command. With this in mind, do as follows:

A. Enter Mimic mode;
B. Access the desired page using the procedure described previously;
C. Press selection key SEL as many times as needed to select the desired object;
D. Press the command key that executes the desired order.

If the order was unsuccessful the reason for the failure will appear in the mimic page.

3.1.6 Screensaver and Hibernation

If the unit is idle for a configurable amount of time (1 to 60 min) the screensaver will activate and the display will automatically rotate through the mimic pages configured. After being in Screensaver Mode for a configurable amount of time (1 to 60 min), Hibernation Mode will activate and the display will reset to main menu while the LCD light will be turned off. By cofiguring the screensaver time to zero minutes, the unit will enter Hibernation mode directly after being idle for the configured Hibernation time.

To exit screensaver or hibernation mode, it is necessary to press one of the navigation keys or the selection key SEL LCD will display the first mimic page.

3.2 WEB-BASED HMI

The TPU L500 provides an embedded webserver that can be accessed by any device that has a web browser and is connected to the relay, be it directly through the Local Access Ethernet port or through one of the rear Ethernet ports. The webserver is very simple to access and with it is possible to obtain relevant information and perform a range of tasks in a very intuitive and user friendly way.

3.2.1 ACCESS

To access the webserver, open your web browser of choice and type the IP address for the TPU L500. This IP can be for the Local Access Ethernet port that is by default 192.168.0.100 or one of the rear Ethernet ports, depending on which you have access to. The IP address for each rear Ethernet port will depend on the configuration.

Having done this, the Login window will appear where a successful login will be necessary to access the webserver content. For more detailed information on this, please refer to section 7.1 - User Management.

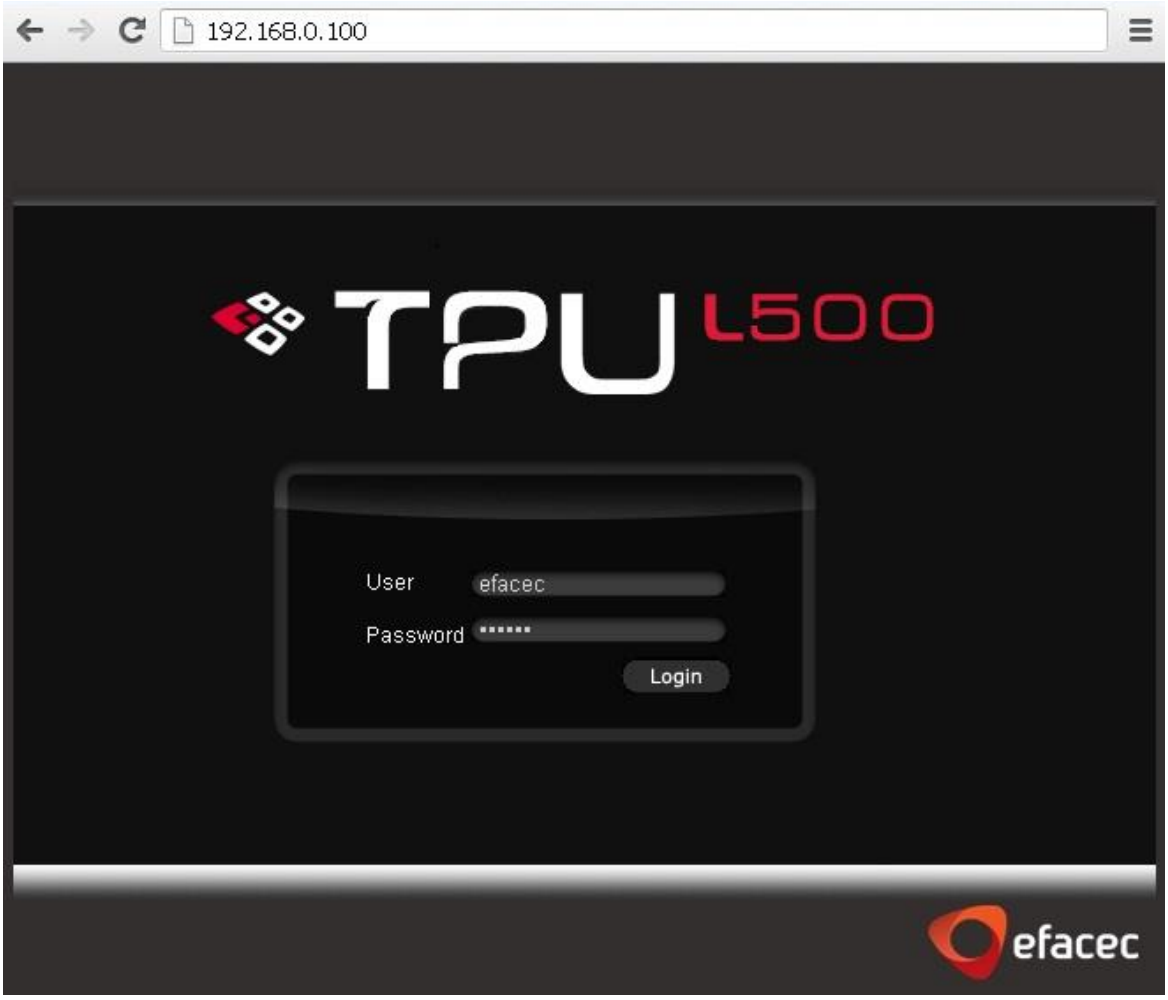


Figure 3.8. Login Window.

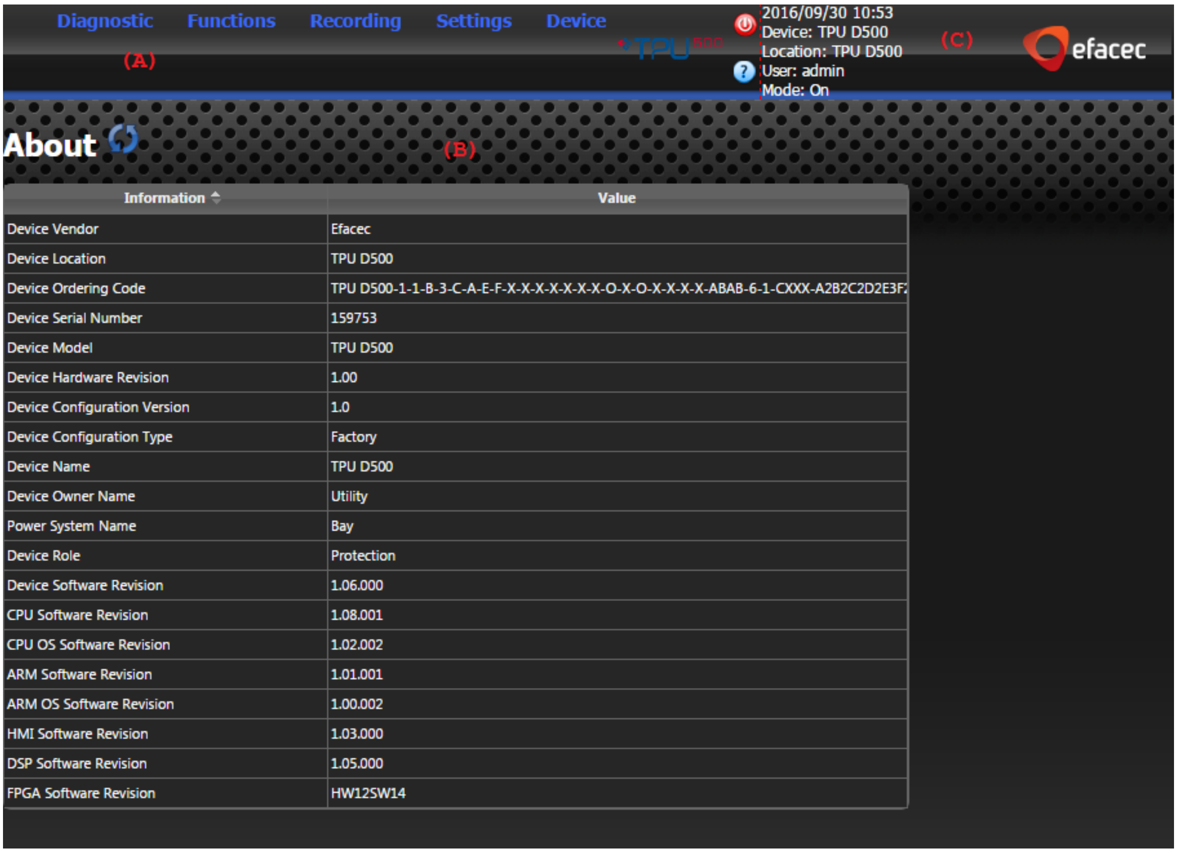


Figure 3.9. First contact.

3.2.2 Layout

From Figure 3.9 we can see that the webserver is organized in three distinct areas:

- **(A) Navigation**: The home page contains a menu at the top of the screen where the main menus are located;
- **(B) Content**: large area in the centre where the information of the current menu is displayed;
- **(C) Status Bar**: Gives information on the firmware version of the TPU L500 as well as the local time and date. Current user is also displayed.

Additionally, it is also possible to access the following menus:

Help menu;

Shutdown menu.

In some menus, information can be refreshed by selecting the refresh button:

While not mandatory, it is highly advised to always perform logout to end the session, by accessing the shutdown menu and selecting **Logout** option.

3.2.3 Content

Navigation menu consist of the main menus through which is possible to access all the relevant information of the TPU L500. These menus are:

- **Diagnostic:**

  Diagnostic related information and functionalities will be present here. Currently composed of:

  - **System Monitor**: information on the state of the device (eg. memory used)
  - **IO**: information and state of digital and analogue IO;
  - **Modules**: information on the main modules running in the device;
  - **Application Modules**: information on the built-in functions running in the device;
  - **Protocols**: information concerning the configured protocols;
  - **Traces**: visualization of protocol traces;
  - **RTDB**: information on the state of any RTDB element.

  For more information on this, please refer to section 7.21 - Diagnostic and Tests.

- **Functions:**

  Relevant data from Built-in functions, separated in the following categories:

  - Measurements
  - Metering
  - Recording
  - Supervision
  - Control

  For more detailed information on available built-in functions, please refer to chapter 5 - Application Functions. On how to access the information in these menus, please refer to section 7.7 - Built-in Functions - Visualization.

- **Recording**

  Displays all records performed by the TPU L500. Currently Fault Report and Event Log are available. For a more in-depth description on the Fault Report please refer to section 4.8 - Fault Report and for a more in-depth description on the Event Log please refer to section 4.7 - Event Log. On how to consult and interpret the information provided in this menu, please refer to section 7.15 - Fault Report and section 7.14 - Event Log.

- **Settings**

  TPU L500 settings are grouped here;

  Current only operational settings are available as well as information on active setting group and the current logical device mode. For more detailed information on available built-in functions and their settings, please refer to chapter 5 - Application Functions. On how to access the information in this menu, please refer to sections 7.9 - Operational Settings, 7.10 - Active Setting Group and 7.11 - Logical Device Mode.

- **Device**

  Currently composed of menus:

  - **About**: contains important Information on the TPU L500characteristics. For more information on this menu, please refer to section 7.3 - Device Information.
  - **System log**: information reported by the device that can be used for troubleshooting;
  - **Application log**: information reported by the built-in functions that can be used for troubleshooting.

3.2.4 Shutdown Menu

By accessing the shutdown menu, the menu in Figure 3.10 will appear with the options to **Logout**, **Reboot** the TPU L500 and **Reset Configuration** by restoring the factory one.

For more detailed information on these functionalities, please refer to sections 7.12 - Restore Factory Configuration and 7.19 - Restart Device.

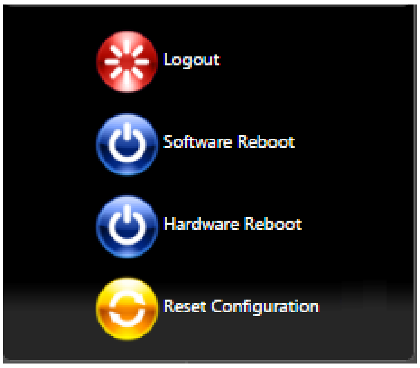


Figure 3.10. Shutdown menu.

For additional information please check menu help. Here you can also find a list of web browsers supported by the webserver.

If you experience problems with the webserver after a firmware update or after having accessed webservers in devices with different firmware versions, please clear you browser cache and history and restart it.

Chapter

4

DEVICE CONFIGURATION

This chapter explains the base configuration of the TPU L500, namely the internal clock synchronization and time management, the application of user programmable automation and base recording functions, such as event log. The configuration of the process interface, including analogue inputs and binary inputs and outputs, is described as well as the general device description and diagnostic information. An introductory section, dedicated to the characterization of the several internal entity data types, contains important information necessary for the subsequent chapters.

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4.1 Data Types

All the real-time information available in the TPU L500 is contained in an internal database that allows the exchange of data among built-in application functions, device interfaces and user-defined modules. Each piece of information (*i.e.* data object) corresponds to one of the supported data types that are listed in Table 4.1.

Table 4.1. Data types.

Type	IEC 61850 Correspondence	Reference	Description
Digital	SPS, (ACT), (ACD)	DIG	Single Point Status entities
DoubleDigital	DPS	DB DIG	Double Point Status entities
IntegerValue	INS, ENS	INT	Integer Status entities
AnalogueValue	MV	ANL	Real Analogue Measurement entities
ComplexAnalogueValue	CMV, (WYE), (DEL), (SEQ)	CPX ANL	Complex Analogue Measurement entities
Counter	BCR	CNT	Binary Counter entities
Control	SPC	DIG CTRL	Controllable Single Point Status entities
DoubleControl	DPC	DB CTRL	Controllable Double Point Status entities
IntegerControl	INC, ENC	INT CTRL	Controllable Integer Status entities
StepPositionControl	BSC	STEP CTRL	Controllable Step Position Status entities
IntegerStepPositionControl	ISC	ISTEP CTRL	Integer Controllable Step Position Status entities
AnalogueControl	APC	ANL CTRL	Controllable Analogue Measurement entities
OptionListSetting	SPG, ENG	OPT SET	Enumerated Settings entities
IntegerSetting	ING	INT SET	Integer Settings entities
AnalogueSetting	ASG	ANL SET	Analogue Settings entities
SettingGroups	-	SET GRP	Setting Groups entities

Each of them is a complex type that aggregates a set of related fields (*i.e.* data attributes) that can be updated during runtime or correspond to configuration properties. They are described in detail in the next subsections, together with the expected behaviour.

Each data type also provides a straightforward correspondence with one or more CDC defined in the IEC 61850 standard, as indicated in Table 4.1. The exact mapping depends on the specific data object. It is also possible in some cases that an IEC 61850 object corresponds to more than one internal data object, like for example a set of three-phase related trip signals or measurements. These special cases are indicated inside parentheses. Although all data types have been conceived with the intent of providing a coherent mapping with IEC 61850 types, they are sufficiently generic to be used in any other kind of application.

The column Reference in Table 4.1 contains an acronym for each internal data type for simplified reference elsewhere in this document.

4.1.1 Status Entities

Status entities correspond to data acquired from the process or generated internally to the device, excluding the analogue interface. These entities may also be outputs from user-defined functions (please refer to section 4.5 - User Programmable

Automation), in which case user code should be responsible for their update and management. There are three basic types: **Digital** (Table 4.2), **DoubleDigital** (Table 4.3) and **IntegerValue** (Table 4.4).

Table 4.2. Digital entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	BOOL	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

Table 4.3. DoubleDigital entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	UINT8	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

Table 4.4. IntegerValue entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	INT32	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

The **VALUE** field, that represents the status value of the data, depends on the specific entity type:

- Boolean value, if the entity type is **Digital**;
- Enumerated value with four options (see Table 4.5), if the entity type is **DoubleDigital**;
- Numeric value, if the entity type is **IntegerValue**.

Table 4.5. Options for DoubleDigital value.

Identifier	Value	Binary Value	Description
INTERMEDIATE	0	00	Switch in movement (intermediate position)
OFF	1	01	Switch is open
ON	2	10	Switch is closed
BAD STATE	3	11	Invalid switch position

The **QUALITY** field indicates if the information contained in **VALUE** is valid, *i.e.* if the information source is trustworthy and there is no abnormal condition detected in the acquisition process or function responsible for its update. Three distinct options should be considered for **QUALITY**, as in Table 4.6. An additional qualifier is added to **QUALITY** field in the case it is **INVALID** or **QUESTIONABLE**, detailing the reason for that. The possible qualifiers are listed in Table 4.7. More than one qualifier can be simultaneously active. Their specific use is described throughout this document whenever applicable. The **QUALITY** field also includes a **TEST** flag indicating whether the function responsible for its update is in test mode.

Table 4.6. Options for QUALITY field.

Identifier	Value	Description
GOOD	0	No abnormal condition detected; the value is valid
INVALID	1	Abnormal condition detected; the value is invalid
QUESTIONABLE	3	Abnormal condition detected; however, the value may still be valid

Table 4.7. Detail qualifier of QUALITY field.

Identifier	Description
OVERFLOW	Value beyond the capability of being represented properly
OUT OF RANGE	Value beyond a predefined range
BAD REFERENCE	Value originated from a source with reference out of calibration
OSCILLATORY	Oscillating value
FAILURE	Internal or external failure
OLD DATA	Value not updated during a specific time interval
INCONSISTENT	Inconsistent value
INACCURATE	Value originated from an inaccurate source

The **TIMETAG** field is automatically updated by the device whenever **VALUE** or **QUALITY** changes (even for user-defined functions).

Originator

The status-only data types may have an additional field with relevance in specific cases: **ORIGIN**. It contains information about the hierarchical level of the originator of the data change. This is for example used when the value of the entity reflects the control issued on a control type entity (please refer to subsection 4.1.3 - Control Entities for more details on this kind of entities). A typical application is the circuit breaker open and close commands. The possible options for the field **ORIGIN** are listed in Table 4.8. The default value of this field for every **Digital**, **DoubleDigital** and **IntegerValue** entity is **NOT SUPPORTED**.

Table 4.8. Options for ORIGIN field.

Identifier	Value	Description
NOT SUPPORTED	0	Not defined
BAY CONTROL	1	Manual control – bay level
STATION CONTROL	2	Manual control – station level
REMOTE CONTROL	3	Manual control – remote level
AUTOMATIC BAY	4	Automatic control – bay level
AUTOMATIC STATION	5	Automatic control – station level

Identifier	Value	Description
AUTOMATIC REMOTE	6	Automatic control – remote level
MAINTENANCE	7	Control from a maintenance / service tool
PROCESS	8	Status changed without control action

4.1.2 Measurement Entities

Measurement entities correspond to data acquired from the process or generated internally to the device, mainly from the analogue interface. These entities may also be outputs from user-defined functions (please refer to section 4.5 - User Programmable Automation), in which case user code should be responsible for their update and management. There are three basic types: **AnalogueValue** (Table 4.9), **ComplexAnalogueValue** (Table 4.10) and **Counter** (Table 4.11).

Table 4.9. AnalogueValue entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
MAGNITUDE	mag.f	FLOAT32	Deadbanded value of the data
INSTMAGNITUDE	instMag.f	FLOAT32	Instantaneous value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
UNITS	units.SIUnit	INT8	SI unit in which the data value is represented
MULTIPLIER	units.multiplier	INT8	Multiplier value of the SI unit
RANGE	range	INT8	Range in which the current data value is
MAGDEADBAND	db	UINT32	Deadband used for value calculation
ZERODEADBAND	zeroDb	UINT32	Range around zero where the data value is forced to zero
HHLEVEL	rangeC.hhLim.f	FLOAT32	Threshold above which the data value is in high-high range
HLEVEL	rangeC.hLim.f	FLOAT32	Threshold above which the data value is in high range
LLEVEL	rangeC.lLim.f	FLOAT32	Threshold below which the data value is in low range
LLLEVEL	rangeC.llLim.f	FLOAT32	Threshold below which the data value is in low-low range
MINIMUM	rangeC.min.f	FLOAT32	Minimum admissible data value
MAXIMUM	rangeC.max.f	FLOAT32	Maximum admissible data value
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

Table 4.10. ComplexAnalogueValue entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
MAGNITUDE	cVal.mag.f	FLOAT32	Deadbanded magnitude of the data
ANGLE	cVal.ang.f	FLOAT32	Deadbanded phase angle of the data

Identifier	IEC 61850 Correspondence	Type	Description
INSTMAGNITUDE	instCVal.mag.f	FLOAT32	Instantaneous magnitude of the data
INSTANGLE	instCVal.ang.f	FLOAT32	Instantaneous phase angle of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
UNITS	units.SIUnit	INT8	SI unit in which the data value is represented
MULTIPLIER	units.multiplier	INT8	Multiplier value of the SI unit
RANGE	range	INT8	Range in which the current data magnitude is
MAGDEADBAND	db	UINT32	Deadband used for magnitude calculation
ZERODEADBAND	zeroDb	UINT32	Range around zero where the data magnitude is forced to zero
ANGDEADBAND	dbAng	UINT32	Deadband used for phase angle calculation
HHLEVEL	rangeC.hhLim.f	FLOAT32	Threshold above which the data magnitude is in high-high range
HLEVEL	rangeC.hLim.f	FLOAT32	Threshold above which the data magnitude is in high range
LLEVEL	rangeC.lLim.f	FLOAT32	Threshold below which the data magnitude is in low range
LLLEVEL	rangeC.llLim.f	FLOAT32	Threshold below which the data magnitude is in low-low range
MINIMUM	rangeC.min.f	FLOAT32	Minimum admissible data magnitude
MAXIMUM	rangeC.max.f	FLOAT32	Maximum admissible data magnitude
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

Table 4.11. Counter entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	actVal	INT64	Actual value of the counter
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
UNITS	units.SIUnit	INT8	SI unit in which the data value is represented
MULTIPLIER	units.multiplier	INT8	Multiplier value of the SI unit
PULSE	pulsQty	FLOAT32	Magnitude step of the counted value per count
FROZENVALUE	frVal	INT64	Frozen value of the counter
FREEZETIMETAG	frTm	TIME	Time of the last counter freeze
FREEZEENABLE	frEna	BOOL	Indication if freezing process shall occur
STARTTIME	strTm	TIME	Starting time of the freeze process
PERIOD	frPd	INT32	Time interval between freeze operations
RESET	frRs	BOOL	Indication if the counter is to be automatically reset to zero after each freezing process
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value

AnalogueValue entities correspond to real valued (floating point) measurements whereas **ComplexAnalogueValue** entities correspond to complex valued measurements, with both magnitude and angle information. **INSTMAGNITUDE** field (and **INSTANGLE** field for complex measurements) represent the instantaneous status value of the data. **QUALITY**, **TIMETAG** and **ORIGIN** fields are managed identically to the equivalent fields of status entities.

Additional enumerated fields allow the indication of the SI unit (**UNITS**) and its corresponding multiplier (**MULTIPLIER**) in which the measurement is represented. These are configuration fields, only updated during the device startup, and are compliant with the enumerations defined in the IEC 61850 standard.

Deadbanded Value Calculation

A deadbanded value is available in **MAGNITUDE** field, based on a deadband calculation from the instantaneous value. It is mainly used for the IEC 61850 interface. **MAGNITUDE** is only updated to the current **INSTMAGNITUDE** value if it changes more than a certain configurable deadband, defined in **MAGDEADBAND** field, when compared to the last value reported. This prevents overloading in event driven channels, eliminating excessive analogue values reported. The same feature is available for **ANGLE**, being its corresponding deadband **ANGDEADBAND**.

It is also possible to define a configuration value (**ZERODEADBAND**) below which **MAGNITUDE** is forced to zero. This prevents reporting noisy values if the measurements are very small.

All deadband configurations are set in percentage of the difference between the configured **MAXIMUM** and **MINIMUM** values (*i.e.* the measurement full scale), in 0,001% steps, according to equation (4.1). For instance, a deadband of 0,5% of the full scale corresponds to a configured value of 500. The full scale for angles is fixed and equal to 360°.

$$Deadband_{real} = Deadband_{config} \times 0{,}00001 \cdot (Maximum - Minimum) \tag{4.1}$$

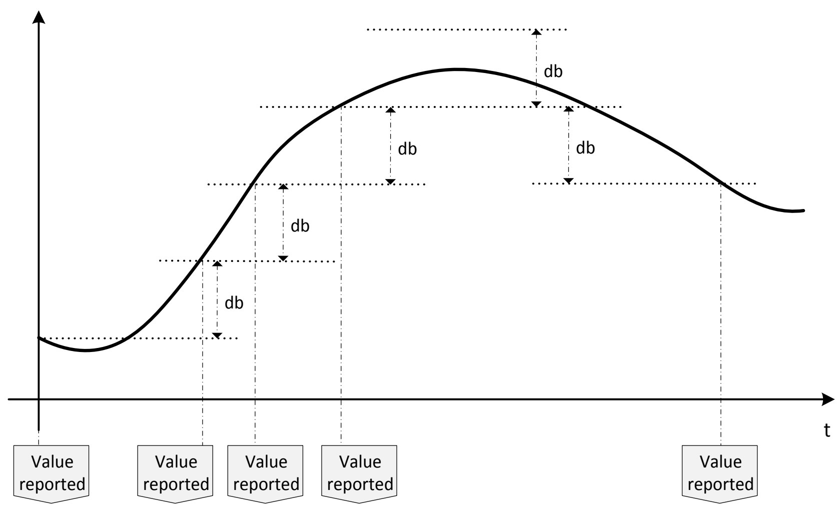

Figure 4.1. Deadbanded value calculation.

Range

Measurements can also be continuously monitored and additional magnitude range information provided, both for **AnalogueValue** and **ComplexAnalogueValue** entities, according to Table 4.12. The **RANGE** field is calculated by comparing the instantaneous magnitude with four distinct thresholds, which are configuration fields defined by the user: **HHLEVEL**, **HLEVEL**, **LLEVEL** and **LLLEVEL**. This behaviour is illustrated in Figure 4.2.

Table 4.12. Options for RANGE field.

Identifier	Value	Description
NORMAL	0	Between low and high levels

Identifier	Value	Description
HIGH	1	Between high and high-high levels
LOW	2	Between low-low and low levels
HIGH-HIGH	3	Above high-high level
LOW-LOW	4	Below low-low level

If **RANGE** is not to be evaluated all its configuration fields should be zero and its value will always be **NORMAL**. Otherwise, the relation defined in (4.2) must be observed.

$$LLLevel \leq LLevel < HLevel \leq HHLevel \quad (4.2)$$

In general, all these configuration fields will be positive or zero. In this case, for **AnalogueValue** entities that can be negative, the range will be calculated based on the modulus of the measurement. This is the most usual option (for example, an active power which range is evaluated irrespective of the power flow direction). However, for **AnalogueValue** entities that can be negative, some range configuration fields can be defined as negative values, in which case the range will be calculated based on the actual value of the measurement.

Moreover, if the magnitude is above **MAXIMUM** or below **MINIMUM**, the measurement is considered as out of range, and its **QUALITY** field updated accordingly (becoming **QUESTIONABLE**, with detail qualifier **OUT OF RANGE**). Factory values for the minimum and maximum thresholds are provided when the measurements are built-in application function outputs, but they can be changed by the user.

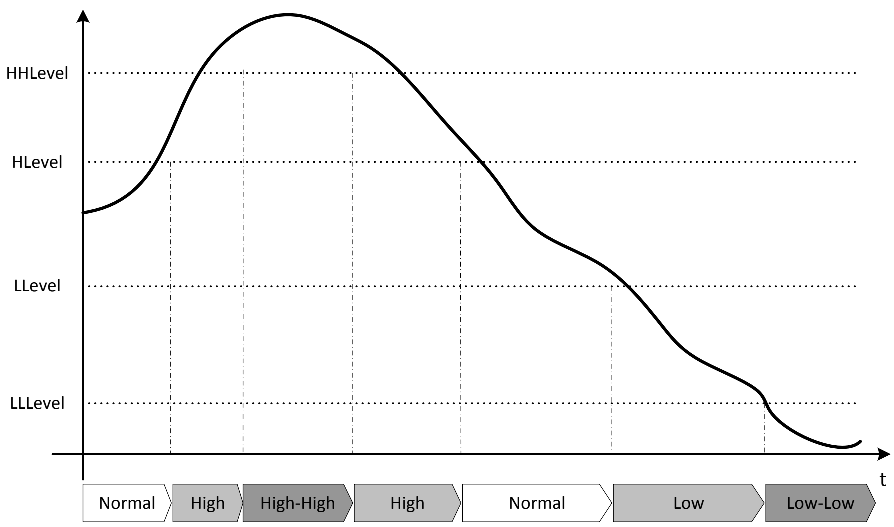

Figure 4.2. Range calculation.

Counters

Counter is a special data type. Its **VALUE** is a 64-bit integer field, which enables the representation of very large numbers, suitable for metering and other specific counter applications. To obtain the real value of the entity, its integer representation should be multiplied by the configuration field **PULSE**, which corresponds to the magnitude of the counted value per count, in other words the counter resolution.

$$Value_{real} = Value \times Pulse \quad (4.3)$$

Other fields, like **QUALITY**, **TIMETAG**, **ORIGIN**, **UNITS** and **MULTIPLIER** are managed as for other entity types.

4.1.3 Control Entities

Control entities correspond to data acquired from the process or generated internally to the device but their state, unlike status-only entities, can be controlled manually or by an automatic function. These entities may also be outputs from user-defined functions (please refer to section 4.5 - User Programmable Automation), in which case user code should be responsible for their update and management. There are five basic types: **Control** (Table 4.13), **DoubleControl** (Table 4.14) **IntegerControl** (Table 4.15), **StepPositionControl** (Table 4.16), **IntegerStepPositionControl** (Table 4.17) and **AnalogueControl** (Table 4.18).

Table 4.13. Control entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	BOOL	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
CONTROL	Oper.ctlVal	BOOL	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
TYPE	pulseConfig.cmdQual	INT8	Indication if the control output is pulsed or persistent
ONDUR	pulseConfig.onDur	UINT32	Duration of each pulse of the control output
OFFDUR	pulseConfig.offDur	UINT32	Duration between consecutive pulses
NUMPULSES	pulseConfig.numPls	UINT32	Number of pulses generated
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	BOOL	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	BOOL	Cancel value
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

Table 4.14. DoubleControl entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	UINT8	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value

Identifier	IEC 61850 Correspondence	Type	Description
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
CONTROL	Oper.ctlVal	BOOL	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
TYPE	pulseConfig.cmdQual	INT8	Indication if the control output is pulsed or persistent
ONDUR	pulseConfig.onDur	UINT32	Duration of each pulse of the control output
OFFDUR	pulseConfig.offDur	UINT32	Duration between consecutive pulses
NUMPULSES	pulseConfig.numPls	UINT32	Number of pulses generated
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	BOOL	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	BOOL	Cancel value
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

Table 4.15. IntegerControl entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	stVal	INT32	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
CONTROL	Oper.ctlVal	INT32	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command

Identifier	IEC 61850 Correspondence	Type	Description
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
MIN	minVal	INT32	Minimum data value
MAX	maxVal	INT32	Maximum data value
STEP	stepSize	UINT32	Step between consecutive data values
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	INT32	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	INT32	Cancel value
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

Table 4.16. StepPositionControl entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	valWTr.posVal	INT8	Status value of the data
TRANSIENT	valWTr.transInd	BOOL	Indication of data in transient state
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
CONTROL	Oper.ctlVal	UINT8	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
PERSISTENT	persistent	BOOL	Indication if the activation of the output is to be persistent
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
MIN	minVal	INT8	Minimum data value
MAX	maxVal	INT8	Maximum data value
STEP	stepSize	UINT8	Step between consecutive data values
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	UINT8	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	UINT8	Cancel value

Identifier	IEC 61850 Correspondence	Type	Description
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

Table 4.17. IntegerStepPositionControl entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	valWTr.posVal	INT8	Status value of the data
TRANSIENT	valWTr.transInd	BOOL	Indication of data in transient state
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
CONTROL	Oper.ctlVal	INT8	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
MIN	minVal	INT8	Minimum data value
MAX	maxVal	INT8	Maximum data value
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	INT8	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	INT8	Cancel value
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

Table 4.18. AnalogueControl entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
VALUE	mxVal.f	FLOAT32	Status value of the data
QUALITY	q	QUALITY	Quality information associated to the data value
TIMETAG	t	TIME	Timestamp of the last change in the data value or in its quality
ORIGIN	origin.orCat	INT8	Originator of the last change in the data value
UNITS	units.SIUnit	INT8	SI unit in which the data value is represented
MULTIPLIER	units.multiplier	INT8	Multiplier value of the SI unit
MAGDEADBAND	db	UINT32	Deadband used for value calculation

Identifier	IEC 61850 Correspondence	Type	Description
ZERODEADBAND	-	UINT32	Range around zero where the data value is forced to zero
CONTROL	Oper.ctlVal	FLOAT32	Control value
CONTROLORIGIN	Oper.origin.orCat	INT8	Originator of the control
TEST	Oper.Test	BOOL	Indication of test control
MODEL	ctlModel	INT8	Indication of the control state machine behaviour
OPERTIMEOUT	operTimeout	UINT32	Timeout used to supervise an operation according to the control model
SELTIMEOUT	sboTimeout	UINT32	Timeout between a select and an operate command
CLASS	sboClass	INT8	Indication if the data can be operated more than once after selection or not
MIN	minVal	FLOAT32	Minimum data value
MAX	maxVal	FLOAT32	Maximum data value
STEP	stepSize	FLOAT32	Step between consecutive data values
CAUSE	-	INT8	Cause of rejection of the last control operation
SELECTED	stSeld	BOOL	Indication if the control is selected
SELECT	SBOw.ctlVal	FLOAT32	Select value
SELECTORIGIN	SBOw.origin.orCat	INT8	Originator of the control selection
CANCEL	Cancel.ctlVal	FLOAT32	Cancel value
CANCELORIGIN	Cancel.origin.orCat	INT8	Originator of the cancellation

The status part of the entity is composed of the **VALUE**, **QUALITY**, **TIMETAG** and **ORIGIN** fields, as for status-only entities.

The control part is composed of **CONTROL**, **CONTROLORIGIN** and **TEST** fields. The control order should be issued on the **CONTROL** field by an external process. **CONTROLORIGIN** and **TEST** should also be filled at the same time, indicating respectively the hierarchical level of the originator of the data change and an optional test attribute.

It is the responsibility of the application that updates the entity status to accept or reject the control order based on several distinct criteria. If the control order is rejected, the field **CAUSE** will be updated with the corresponding reason for rejection (see Table 4.19 for possible options). If the control order is accepted, an action will be initiated (*e.g.* operate a binary output) to trigger the status change; or the status will be automatically updated in the case of an internal entity. **CAUSE** will also be updated indicating the success and the end of the control action.

Table 4.19. Options for CAUSE field.

Identifier	Value	Description
UNKNOWN	0	Unknown cause
BLOCKED BY SWITCHING HIERARCHY	2	At least one level with lower switching hierarchy in local mode
SELECT FAILED	3	Cancelled due to an unsuccessful selection
POSITION REACHED	5	Switch already in the intended position
BLOCKED BY MODE	8	Blocked by actual operation mode
BLOCKED BY PROCESS	9	Blocked due to some external event at process level
BLOCKED BY INTERLOCKING	10	Blocked due to interlocking of switching devices
BLOCKED BY SYNCHRO-CHECK	11	Blocked by synchronism check function

Identifier	Value	Description
COMMAND ALREADY IN EXECUTION	12	Control action already in execution
BLOCKED BY HEALTH	13	Blocked due to some internal event that prevents a successful operation
ABORTION BY CANCEL	15	Cancelled
TIME LIMIT OVER	16	Aborted; time limit exceeded
OBJECT NOT SELECTED	18	Rejected because control object is not selected
OBJECT ALREADY SELECTED	19	Control object already selected
NONE	25	No cause of rejection; control executed
INCONSISTENT PARAMETERS	26	Rejected because the parameters between successive control services are not consistent

The **VALUE** and **CONTROL** fields depend on the specific entity type:

- Both value and control order are Boolean, if the entity type is **Control**;
- Enumerated value with four options (see Table 4.5), if the entity type is **DoubleControl**; the control order is Boolean (only open and close commands allowed);
- Both value and control order are numeric integer values, if the entity type is **IntegerControl**;
- Numeric integer value, if the entity type is **StepPositionControl**; **HIGHER** (increment data value) and **LOWER** (decrement data value) are the alternatives for the control order;
- Both value and control order are numeric floating point values, if the entity type is **AnalogueControl**.

For **StepPositionControl** entities there is also an indication that the data is in a transient state (**TRANSIENT** field).

Control Model

Several control model options, with different state machine implementations, are allowed. They are listed in Table 4.20.

Table 4.20. Options for control MODEL field.

Identifier	Value	Description
STATUS ONLY	0	No control order allowed; equivalent to status entity
DIRECT WITH NORMAL SECURITY	1	Direct execution without selection; no supervision of the status value
SELECT BEFORE OPERATE WITH NORMAL SECURITY	2	Selection before execution; no supervision of the status value
DIRECT WITH ENHANCED SECURITY	3	Direct execution without selection; with supervision of the status value
SELECT BEFORE OPERATE WITH ENHANCED SECURITY	4	Selection before execution; with supervision of the status value

Control Pulse

In the case of entities with a Boolean control order, that can be associated with binary outputs, the shape of the output pulse is defined by the configuration fields **ONDUR**, **NUMPULSES** and **OFFDUR** that represent respectively the pulse duration, the number of pulses and the time between pulses (in case more than one pulse is configured).

Control Range

In the case of control entities with a numeric control order (**IntegerControl**, **StepPositionControl** and **AnalogueControl** data types), a range of possible control order values must be defined. The configuration fields **MIN**, **MAX** and **STEP** specify this range. Built-in application functions have predefined ranges for their specific control entities.

4.1.4 Setting Entities

Operational settings also correspond to database entities. They are usually associated with built-in application functions but they can also be created for user-defined functions (please refer to section 4.5 - User Programmable Automation), in which case user code should be responsible for the definition of their behaviour. There are three basic types: **OptionListSetting** (Table 4.21), **IntegerSetting** (Table 4.22) and **AnalogueSetting** (Table 4.23).

Only operational settings belonging to the interface of built-in application functions or user-defined modules correspond to data entities. Settings corresponding to base device modules and communication protocols belong to the device configuration and are managed in a different way.

Table 4.21. OptionListSetting entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
ACTIVE	setVal	UINT8	Actual value of the setting, corresponding to the active setting group
EDIT	-	UINT8	Value of the setting corresponding to the setting group currently in edition
MIN	minVal	UINT8	Minimum of the setting range
MAX	maxVal	UINT8	Maximum of the setting range
STEP	stepSize	UINT8	Step between consecutive values of the setting range

Table 4.22. IntegerSetting entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
ACTIVE	setVal	INT32	Actual value of the setting, corresponding to the active setting group
EDIT	-	INT32	Value of the setting corresponding to the setting group currently in edition
MIN	minVal	INT32	Minimum of the setting range
MAX	maxVal	INT32	Maximum of the setting range
STEP	stepSize	INT32	Step between consecutive values of the setting range
UNITS	-	INT8	SI unit in which the data value is represented
MULTIPLIER	-	INT8	Multiplier value of the SI unit

Table 4.23. AnalogueSetting entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
ACTIVE	setMag	FLOAT32	Actual value of the setting, corresponding to the active setting group

Identifier	IEC 61850 Correspondence	Type	Description
EDIT	-	FLOAT32	Value of the setting corresponding to the setting group currently in edition
MIN	minVal	FLOAT32	Minimum of the setting range
MAX	maxVal	FLOAT32	Maximum of the setting range
STEP	stepSize	FLOAT32	Step between consecutive values of the setting range
UNITS	units.SIUnit	INT8	SI unit in which the data value is represented
MULTIPLIER	units.multiplier	INT8	Multiplier value of the SI unit

Settings are managed under the concept of setting groups (please refer to subsection 5.1.5 - Setting Groups Management). **ACTIVE** field indicates the setting value the function is working with at that moment, *i.e.*, the value corresponding to the active setting group; **EDIT** field indicates the value of the setting for the setting group being edited at the moment. This last feature is useful when the possibility of value change of specific settings by the communication protocol is required.

The setting value depends on the specific entity type:

- Enumerated value (includes Boolean settings), if the entity type is **OptionListSetting**;
- Numeric integer value, if the entity type is **IntegerSetting**;
- Numeric floating point value, if the entity type is **AnalogueSetting**.

The configuration fields **MIN**, **MAX** and **STEP** specify the setting range. Built-in application functions have predefined ranges for their specific settings.

Additional enumerated fields allow the indication of the SI unit (**UNITS**) and its corresponding multiplier (**MULTIPLIER**) in which the setting is represented, for **IntegerSetting** and **AnalogueSetting** entities.

4.1.5 Setting Group Entities

SettingGroup (Table 4.24) is a special data type. It allows the access to some information relative to the device setting groups (please refer to subsection 5.1.5 - Setting Groups Management).

To change the active group during runtime, the value of the field **ACTIVEGROUP** should be edited. To edit the value of the settings for a specific group during runtime, the value of the field **EDITGROUP** should be edited.

Table 4.24. Setting Groups entity fields.

Identifier	IEC 61850 Correspondence	Type	Description
NUMGROUPS	-	UINT8	Number of setting groups
ACTIVEGROUP	-	UINT8	Index of the active setting group
EDITGROUP	-	UINT8	Setting group currently in edition
TIMETAG	-	TIME	Timestamp of the last change of setting group

4.1.6 Module Interface Structure

The interface of each built-in application function or device base module includes a set of inputs and a set of outputs that correspond to database entities (for application functions, there is also a set of operational settings) When these entities are described throughout this document they are presented in separate tables with the following information:

- **Id**: the internal name that is used as a fixed reference for each entity;

- **Title**: a short description of each entity, language specific and user-configurable, used for example in the Local HMI or event log files;
- **Description**: a long description, containing a succinct explanation of the entity semantics or behaviour;
- **Type**: the acronym of the specific entity type;
- **Multiplicity**: the maximum number of entities that can be associated (only applicable for module inputs);
- **NV**: an indication that the corresponding entity is non-volatile, *i.e.* its status data is not lost between device restarts (only applicable for module outputs);
- **Range**: the setting range (only applicable for function settings);
- **Factory value**: the default value (only applicable for function settings).

4.2 Device General Data

The TPU L500 provides several device identification and diagnostic information. This section describes the information that corresponds to the device as a whole. Other diagnostic information, relative to specific modules running in the device, such as communication ports and protocols, can be found in the corresponding sections.

An independent watchdog module supervises all hardware and software components and operates in case a major failure of the device is detected.

4.2.1 Device Identification And Diagnostics

Table 4.25 lists general device information, including device identification and diagnostic entities. This information can be accessed through the webserver, toolset or communication interfaces and is also available in the local user interface.

Table 4.25. General device information.

Identifier	Title	Type	NV	Description
Vendor	Vendor	TEXT	-	Device vendor
Model	Model	TEXT	-	Device model
SerialNumber	Serial Number	TEXT	-	Device serial number
HWRevision	HW Revision	TEXT	-	Device hardware revision
SWRevision	SW Revision	TEXT	-	Device software revision
Version	Version	TEXT	-	Device configuration version
ConfigurationType	Configuration Type	INT	-	Device configuration type
Description	Description	TEXT	-	Device general description
OrderingCode	Ordering Code	TEXT	-	Device ordering code
Location	Location	TEXT	-	Location where the device is installed
Owner	Owner	TEXT	-	Owner of the device
PowerSystemName	Power System Name	TEXT	-	Name of the electric power system the device is connected to
Role	Role	TEXT	-	Role of the device
Health	Health	INT	-	Device health
NumPowerUps	Num Power Ups	INT	Yes	Number of device power up operations
NumWarmStarts	Num Warm Starts	INT	Yes	Number of device warm start operations
ResetStatistics	Reset Statistics	DIG CTRL	-	Reset statistics of the device
OperationTime	Operation Time	INT	-	Number of hours since last startup
SimulationMode	Simulation Mode	INT CTRL	-	Device in simulation mode

Device Identification

Some of the entities corresponding to the device identification have fixed values. **Vendor** has always the value “Efacec” and **Model** the value “TPU L500”. Other entities also have fixed values, but are dependent on the specific device: it is the case of **SerialNumber**, **HWRevision**, **SWRevision** and **OrderingCode**.

Version reflects the configuration version, which can be set by the user when configuring the device through the engineering toolset. It is also incremented automatically each time the configuration is built and deployed to the device. The **ConfigurationType** entity indicates the type of configuration currently loaded.

Table 4.26. Configuration type.

Status	Value	Description
None	1	No configuration loaded
Factory	2	Factory configuration
User	3	User configuration

Other identification properties should be set by the user, namely those indicated in Table 4.27. They correspond to the particular application of the TPU L500.

Table 4.27. General device configuration settings.

Identifier	Title	Range	Factory value	Description
Description	Description	Max 255 Char.	Description	Device general description
Location	Location	Max 32 Char.	Location	Location where the device is installed
Owner	Owner	Max 32 Char.	Owner	Owner of the device
PowerSystemName	Power System Name	Max 32 Char.	PowerSystemName	Name of the electric power system the device is connected to
Role	Role	Max 32 Char.	Role	Role of the device

Device Diagnostics

Health represents the global status of the device. Its possible values and meanings are described in the following table.

Table 4.28. Health status.

Status	Value	Description
Ok	1	No problems; normal operation
Warning	2	Minor problems; operation possible
Alarm	3	Severe problem; no operation possible

Device Statistics

Specific entities are available with the purpose of device statistics, namely **NumPowerUps**, **NumWarmStarts** and **OperationTime**. The control **ResetStatistics** enables the user to clear this information.

4.2.2 Hardware Modules Identification And Diagnostics

Each main hardware module has also a set of identification and diagnostic data.

CPU Board Information

Description is the name of the board and has always the value “MAP8001”. **HWRevision** is dependent on the specific board. Individual entities identify the software revision of each board processor.

For correct identification of the software version running in the TPU L500, the device global **SWRevision** entity should be used instead of any specific processor software revision.

In the context of CPU board information, **Health** is the operation status of this particular component. Other board status information is also available.

Table 4.29. CPU board information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	CPU board description
HWRevision	HW Revision	TEXT	-	CPU board hardware revision
Cpu.SWRevision	CPU SW Revision	TEXT	-	Main CPU software revision
CpuOS.SWRevision	CPU OS SW Revision	TEXT	-	Main CPU operating system software revision
Dsp.SWRevision	DSP SW Revision	TEXT	-	DSP software revision
Fpga.SWRevision	FPGA SW Revision	TEXT	-	FPGA software revision
Arm.SWRevision	ARM SW Revision	TEXT	-	ARM software revision
ArmOS.SWRevision	ARM OS SW Revision	TEXT	-	ARM operating system software revision
Health	Health	INT	-	CPU board health
Temperature	Temperature	ANL	-	CPU board temperature
Voltage1	Voltage 1	ANL	-	CPU board first internal voltage level
Voltage2	Voltage 2	ANL	-	CPU board second internal voltage level
CpuUser	Cpu User Usage	ANL	-	Percentage of normal processes executed in user mode, every three seconds
CpuSys	Cpu Sys Usage	ANL	-	Percentage of processes executed in kernel mode, every three seconds
Load1Min	Load 1 Min	ANL	-	System load (number of processes in the system run queue) averaged for one minute
Load5Min	Load 5 Min	ANL	-	System load (number of processes in the system run queue) averaged for five minutes
Load15Min	Load 15 Min	ANL	-	System load (number of processes in the system run queue) averaged for fifteen minutes
MemFree	Mem Free	INT	-	Free memory in kilobytes (KB)
MemUsed	Mem Used	INT	-	Memory used in kilobytes (KB)
DiskFree	Disk Free	INT	-	Free disk space in megabytes (MB)
DiskUsed	Disk Used	INT	-	Disk space used in megabytes (MB)

HMI Board Information

The available HMI board information is similar to the one described in the case of CPU board. **Description** is the name of the board and has always the value "MAP8061".

Table 4.30. HMI board information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	HMI board description
HWRevision	HW Revision	TEXT	-	HMI board hardware revision
SWRevision	SW Revision	TEXT	-	HMI CPU software revision
Health	Health	INT	-	HMI board health
Temperature	Temperature	ANL	-	HMI board temperature
Voltage1	Voltage 1	ANL	-	HMI board first internal voltage level
Voltage2	Voltage 2	ANL	-	HMI board second internal voltage level

I/O Boards Information

For each I/O board, a similar set of information is available. In the case of boards with analogue inputs, the status entity **Calibrated** indicates the result of its calibration process. For other I/O boards, this output has no associated meaning.

Table 4.31. I/O board information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	I/O board description
HWRevision	HW Revision	TEXT	-	I/O board hardware revision
SWRevision	SW Revision	TEXT	-	I/O CPU software revision
Health	Health	INT	-	I/O board health
Temperature	Temperature	ANL	-	I/O board temperature
Voltage1	Voltage 1	ANL	-	I/O board first internal voltage level
Voltage2	Voltage 2	ANL	-	I/O board second internal voltage level
Calibrated	Calibrated	DIG	-	I/O board calibrated

4.2.3 Watchdog

In addition to self-supervision of all its hardware and software components, the TPU L500 includes an independent watchdog module that operates in case of major internal failure.

Two levels of operation are provided:

- An alarm level is triggered in case of device failures, when operation is still possible but with restrictions. It does not involve device reset, only signalization of the failure condition.
- A reset level operates in case of major failures, when no device operation is possible. In this case, the internal watchdog resets all processors in order to try to re-establish normal operating conditions.

A specific watchdog output, with a change-over contact, is available in the base I/O board (see subsection 2.4.5 - Binary Input and Output Connections). This output actuates for both internal watchdog levels: alarm and reset. It also remains actuated whenever the power supply is switched off.

Table 4.32. Watchdog module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Status	Status	DIG	-	Watchdog status
OpCounter	Op Counter	INT CTRL	Yes	Number of watchdog operations

The watchdog alarm level is also available in the entity **Status**. It can be used to report the global device health to other equipment, through a communication link.

4.3 Time Synchronization

An independent real time clock provides accurate date and time information to all modules and application functions. It allows the correct time tagging of internal and external events and recorded data files. If this clock is synchronized by an external high accuracy time source, the comparison of events between different devices in the same substation is possible. Several time synchronization alternatives are available.

4.3.1 Time Model

The TPU L500 internal clock has a UTC based time model that allows, together with the technology and components used, correct time tagging of all events with one millisecond resolution. The built-in time model is prepared to handle calendar information through 2100, including leap year correction.

Besides the internal UTC clock representation, the corresponding local time is calculated whenever date and time need to be displayed, for example in the Local HMI, event log and disturbance record files or the embedded webserver. For this purpose, several settings must be defined by the user, according to Table 4.33, Table 4.34 and Table 4.35.

Table 4.33. Local time configuration settings.

Identifier	Title	Range	Factory value	Description
StdOffset	Standard Offset	± [00h00m.. 14h59m]	00h00m	Offset of local time from UTC during standard time
DayLightSavings > Status	DayLight Savings Active	OFF / ON	ON	Location using daylight savings time
DayLightSavings > Offset	DayLight Savings Offset	± [00h00m.. 14h59m]	01h00m	Offset of local time from UTC during daylight savings time
DayLightSavings > Start	DayLight Savings Start	See Table 4.34	-	Local time of next change to daylight savings time
DayLightSavings > End	DayLight Savings End	See Table 4.35	-	Local time of next change to standard time

Table 4.34. Next change to daylight savings time configuration settings.

Identifier	Title	Range	Factory value	Description
Format	Format	DAY OF YEAR / DAY OF WEEK	DAY OF WEEK	Date format
DayOfYear	Day Of Year	[0.. 364]	90	Day of the year
DayOfWeek > Day	Day Of Week > Day	SUNDAY / … / SATURDAY	SUNDAY	Day of the week
DayOfWeek > Week	Day Of Week > Week	FIRST / SECOND / THIRD / FOURTH / LAST	LAST	Week of the month
DayOfWeek > Month	Day Of Week > Month	JANUARY / … / DECEMBER	MARCH	Month
Time	Time	[00:00:00.. 23:59:59]	01:00:00	Time of change

Table 4.35. Next change to standard time configuration settings.

Identifier	Title	Range	Factory value	Description
Format	Format	DAY OF YEAR / DAY OF WEEK	DAY OF WEEK	Date format
DayOfYear	Day Of Year	[0.. 364]	300	Day of the year
DayOfWeek > Day	Day Of Week > Day	SUNDAY / … / SATURDAY	SUNDAY	Day of the week
DayOfWeek > Week	Day Of Week > Week	FIRST / SECOND / THIRD / FOURTH / LAST	LAST	Week of the month
DayOfWeek > Month	Day Of Week > Month	JANUARY / … / DECEMBER	OCTOBER	Month
Time	Time	[00:00:00.. 23:59:59]	01:00:00	Time of change

The model enables the definition of the appropriate time zone and the optional handling of daylight savings time. Standard and daylight savings time offset are both relative to the UTC time zone. The date and time of change to daylight savings time (and the corresponding change back to standard time) can also be defined. The user can set the days these changes happen in one of two distinct formats: day of year or day of week.

Day of week is the typical format for most countries. Its configuration only needs to be done once, since the TPU L500 will calculate the corresponding calendar day from the settings every year.

Alternatively, the device also supports the day of year format, which is a simple sequential number starting at 0 (January 1st) and ending in 364 (December 31st). Leap years are not supported in these sequence, which means March 1st is always day 60 and that it not possible to set the start or end of daylight savings time to February 29th (which is in any case rather unusual). In this date format, the configuration must be redefined in the beginning of every year, before the change to daylight savings time occurs.

The factory settings are adjusted to the current time zone configuration of continental Portugal, as an example, but they can be changed in order to represent any other country configuration.

4.3.2 Real Time Clock

The TPU L500 has a real time clock (RTC) component with backup power provided by a lithium battery. The RTC ensures the time is kept for at least one month during device power off and startup. The first time the device starts up or whenever it has been switched off for a long time and the RTC power has been lost, the date and time will start at 00:00:00 of January 1st 1984.

The clock design provides 30 ppm accuracy, which means that a maximum drift of 3 seconds per day is expected when the device is switched off or there is no time synchronization source available.

The RTC also guarantees that the time tag field of all data entities is initialized with the date and time of the TPU L500 startup, after the device is switched on and before it is synchronized again.

4.3.3 Synchronization

To compensate for the natural drift of the clock in stand-alone mode, the TPU L500 should always be synchronized from an external time source in normal operation conditions. The device is prepared for several synchronization methods. There may be more than one synchronization protocol configured simultaneously but the device will select only one at each moment, depending on its availability and defined priority.

The synchronization procedure is similar for all protocols. All of them consist in the periodic reception of synchronization messages from an external master clock. The first time this message is received, the device internal clock is adjusted. In general, the full accuracy will not be reached immediately after this first incoming message but it will increase as more messages are received and the internal clock is fine tuned.

From that moment on, subsequent messages are expected to have a small difference from the already adjusted internal clock. If the time difference is less than the acceptable error, nothing is done. As time goes by, that difference will increase due to the drift and the clock should be readjusted. To avoid wrong resynchronization due to errors or delays in the transmission between the device and the time server, a message filter is implemented. In general, sporadic messages with large offsets from the internal clock will be automatically discarded because they do not correspond to the natural clock drift. Even smaller offsets will not be accepted immediately but will have to be confirmed with subsequent messages. The filter details depend on the specific protocol.

When the device stops receiving synchronization messages for more than the configured timeout, which also depends on the specific protocol, the device resumes stand-alone mode. The synchronization procedure will be restarted after the reception of a new synchronization message. The entity **Status** referred in Table 4.36 continuously indicates if the device is synchronized by an external master clock or not.

There is also a data entity representing if daylight savings time is in effect or not.

Table 4.36. Synchronism module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Status	Status	DIG	-	Device synchronized by master clock
DayLightSavings	Day Light Savings	DIG	-	Indication if daylight savings is in effect

Synchronization by SNTP

SNTP protocol provides a method of synchronization using the Ethernet interface. It is the standard option to be used when the TPU L500 is integrated in an IEC 61850 station bus, but it can also be used whenever the device is connected to an Ethernet network.

The SNTP priority should be defined relative to other synchronization methods, in a scale from 1 to 5 where 1 is the highest priority and 5 the lowest, according to the explained above. Table 4.37 presents other general SNTP settings.

Table 4.37. SNTP configuration settings.

Identifier	Title	Range	Factory value	Description
Priority	Priority	[1..5]	2	SNTP priority relative to other synchronization protocols
Mode	Mode	BROADCAST / UNICAST	BROAD.	Synchronization mode
Period	Period	[1..86400] s	10	Time between requests to the server in unicast mode
Timeout	Timeout	[1..3600] s	12	Maximum allowed time for server response in unicast mode
Count	Count	[1..25]	5	Required number of correct server responses in unicast mode
Error	Error	[1..1000] ms	5	Maximum allowed time difference

Two operation modes are possible: **UNICAST** and **BROADCAST**.

In broadcast operation mode, the device just listens to SNTP messages present in the network and synchronizes its clock by them.

In unicast operation mode, a "ping-pong" mechanism is used, in which the client (*i.e.* the device) periodically requests the time to the server (*i.e.* the master clock). The TPU L500 executes a sequence of more than one request in order to select the most accurate response. At least the number of correct server responses specified in **Count** should be received. The time between those sequences of requests is defined by setting **Period**. The maximum allowed time for server response is defined in setting **Timeout**.

The setting **Error** defines the maximum time difference allowed and is valid for any of the two operation modes.

Up to five distinct SNTP servers can be configured in unicast mode. Each one is identified by its corresponding IP address and can be independently enabled / disabled. The user can define a different priority for each server, from a list of five levels where 1 has the highest priority and 5 the lowest. This indicates the order the different servers should be requested time information. If two servers have identical priority, the device will give preference to the server with the highest stratum (*i.e.* the one that is nearest from the reference clock and therefore has the smaller time delay). The list of settings concerning each server is shown in Table 4.38.

Table 4.38. SNTP server configuration settings.

Identifier	Title	Range	Factory value	Description
IP	IP	Max 16 Char.	192.1.1.1	IP address of the server
Status	Status	OFF / ON	OFF	Server enabled / disabled
Priority	Priority	[1..5]	1	Server priority relative to the other servers
MaxStratum	Maximum Stratum	[1..15]	15	Maximum stratum level that is considered has a valid synchronism source.

The synchronism messages are also checked for consistency and they are only accepted if the server indicates that it is synchronized and does not have an invalid stratum. The TPU L500 periodically supervises if each configured server is available in the network and synchronized. The current state of each server is indicated in the corresponding data entity **Status**, as can be seen in Table 4.39.

Table 4.39. SNTP server information.

Identifier	Title	Type	NV	Description
Status	Status	DIG	-	Server supervision status

Broadcast operation mode is not recommended and should only be used for test purposes. In normal operation conditions, unicast should be used instead, because the "ping-pong" mechanism provides a means of compensating the network delay between the client and the server.

A time accuracy of 1 ms can be reached with SNTP synchronization. However some conditions apply:

- The time server should be an adequate real-time master clock with high performance and accuracy, and directly synchronized from a GPS source.
- Unicast operation mode should always be used.
- The number of network active components (*e.g.* switches) between the device and the server should be

limited in order to guarantee the correct network response; the client and the server should be preferably in the same LAN.

The general SNTP module information is listed in Table 4.40. **Status** indicates if the device is synchronized by SNTP protocol, *i.e.* if there is at least one time server ON. The numerical id of the time server that is providing the time to the device is also indicated in the entity **Server**.

Table 4.40. SNTP module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Status	Status	DIG	-	Device synchronized by SNTP protocol
Server	Server	INT	-	Number of the server that is the current master clock

Synchronization by IRIG-B

The TPU L500 has a fibre optics IRIG-B interface, prepared to receive a demodulated signal of the format IRIG-B 00x, x=0 to 7. It can be used to synchronize all digital signals and internal state transitions of the device with 1 ms accuracy. It is also required to synchronize the sampling of the analogue signals by GPS signal with up to 1 μs accuracy. This option requires a dedicated network infrastructure for time synchronization. Synchronism messages are received with a fixed period of one second, together with a PPS signal that ensures the adequate time accuracy.

The synchronization by IRIG-B input can be activated in the corresponding setting **Status**. The IRIG-B priority should be defined relative to other synchronization methods, in a scale from 1 to 5 where 1 is the highest priority and 5 the lowest, according to the explained above. Table 4.41 presents other general IRIG-B settings.

Table 4.41. IRIG-B configuration settings.

Identifier	Title	Range	Factory value	Description
Status	Status	OFF / ON	OFF	IRIG-B status
Time	Time	UTC / TZ / TZ+DLS / IEEE1344	UTC	Time format sent by the server
Priority	Priority	[1..5]	1	IRIG-B priority relative to other synchronization protocols
Timeout	Timeout	[1..3600] s	20	Maximum allowed time to wait for IRIG-B signal

The TPU L500 is prepared to handle different types of time server configuration:

- If the server time information is available in UTC format, setting **Time** should be set to **UTC**; the TPU L500 calculates the local time.
- If the server time information is available in local time format, but the server does not handle daylight savings time, setting **Time** should be set to **TZ**; the TPU L500 calculates the UTC time.
- If the server time information is available in local time format and daylight savings time is also handled by the server, setting **Time** should be set to **TZ+DLS**; the TPU L500 calculates the UTC time.

- If the time server is compliant with the standard IEEE 1344, the corresponding option of **Time** should be selected; the synchronism message includes all required information to calculate the local time, including daylight savings time.

If **Time** is set as **TZ** or **TZ+DLS**, the time model of the TPU L500 should be adequately configured (please consult subsection 4.3.1 - Time Model).

Information of the year is not included in the synchronism message in case of IRIG-B 00x signals, with x = 0, 1, 2 or 3. The year should be set once directly in the TPU L500.

By the contrary, in case of IRIG-B 00x signals, with x = 4, 5, 6 or 7, information of the year is already included in the synchronism message.

The general IRIG-B module information is listed in Table 4.42. **Status** indicates if the synchronization by IRIG-B is enabled.

If the IRIG-B signal is detected, **SignalDetected** is indicated, however the time synchronization will only be performed if the device is able to interpret the synchronism message (**SignalOK**). **FormatReceived** indicates the type of IRIG-B received (IRIG-B 00x, x = 0 to 7) and **IEEE1344OK** signals that the message is compliant with the standard.

If the synchronization by IRIG-B is enabled, the signal is being correctly received and interpreted, and it is the time source with the highest priority, the device will be synchronized by IRIG-B, and the **Sync** indication will be active. If the IRIG-B signal fails for more than the time specified in setting **Timeout**, the IRIG-B message will cease to be considered a valid time source.

Table 4.42. IRIG-B module information.

Identifier	Title	Type	NV	Description
Info	Info	TEXT	-	General information
Status	Status	DIG	-	Synchronization by IRIG-B input enabled
SignalDetected	Signal Detected	DIG	-	IRIG-B signal detected
SignalOK	Signal OK	DIG	-	IRIG-B signal OK
Sync	Sync	DIG	-	Device synchronized by IRIG-B input
FormatReceived	Format Received	TEXT	-	Time format received
IEEE1344OK	IEEE 1344 OK	INT	-	IEEE 1344 time message OK

Synchronization by Communication Protocol

As an alternative to the previous options, the TPU L500 can be synchronized by the communication protocol, if it supports synchronism messages. This method only allows coarse time synchronization and therefore it should only be used if no alternative is available or as a low priority synchronism method in the event all other options fail. For more details, please consult chapter 6 - Communications.

4.4 Process Interface

An independent module, with high execution priority, is dedicated to the interface of the TPU L500 with the process, *i.e.* the cyclic acquisition of binary and analogue inputs and the control of binary outputs. Analogue inputs are processed independently of binary inputs and outputs, due to the different time restrictions associated to each type of interface. Table 4.43 presents the general information about the I/O module.

Table 4.43. I/O module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version

The configuration of the interface with the process has two distinct levels:

- The physical configuration of each I/O point for every board present in the device;
- The logical configuration of I/O entities, modules and analogue channels.

4.4.1 Physical Configuration

The description in this subsection is applicable to every input and output of either base or expansion I/O boards. Each type of input or output has specific settings, according to the processing associated with it.

Binary Inputs

All binary inputs are simultaneously acquired every millisecond. The acquisition is synchronized by the internal clock of the device.

Each binary input has independent configurations. Table 4.44 describes the settings for each binary input. These settings allow the configuration of independent debounce and chatter filters that eliminate false state transitions due to noise in the cabling or contact chatter.

Table 4.44. Binary input configuration settings.

Identifier	Title	Range	Factory value	Description
DebounceTime	Debounce Time	[1..128] ms	20	Filter time
OscillationTime	Oscillation Time	[2..10000] ms	100	Minimum oscillation period
MaxNumChanges	Max Num Changes	[2..255]	5	Maximum number of changes in oscillation mode

Each input can be subjected to a filter time. A state transition is declared only if the input remains in the new state for more than **DebounceTime**. All other transitions are suppressed. This filtering mechanism does not affect the correct time tagging of each new state, which always corresponds to the time instant of the first transition of the input. Figure 4.3 illustrates the results of this filter operation.

In order to prevent overloading in event driven channels, a chatter filter is also provided to eliminate excessive binary input operations. If an input changes twice in the same direction in less than **OscillationTime**, it is defined as oscillatory. This corresponds to setting the quality of the associated data entity to **QUESTIONABLE**, with a detail qualifier of **OSCILLATORY**.

The **OscillationTime** should be inferior to the minimum oscillation period that is expected in the corresponding signal in actual operating conditions.

If this oscillatory behaviour persists for a number of state transitions greater than the value defined in **MaxNumChanges**, the quality of the entity is then set to **INVALID** and no more events are generated for that input as long as the signal is oscillating. If **MaxNumChanges** is equal to the minimum of the setting range (2), the **INVALID** state is immediately confirmed at the same time the input is declared as oscillatory (no intermediate **QUESTIONABLE** state is reported). The entity remains in **INVALID** (or **QUESTIONABLE**) state until its state stops changing for more than **OscillationTime**. The chatter filter is illustrated in Figure 4.4.

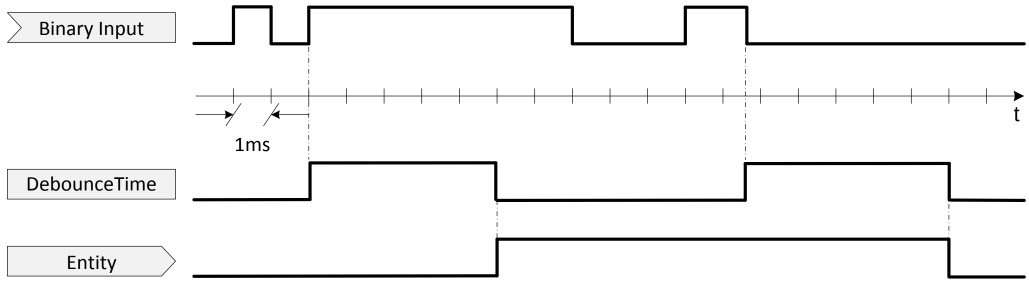

Figure 4.3. Debounce filter.

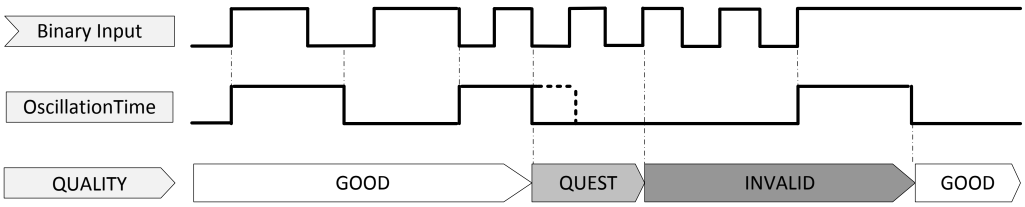

Figure 4.4. Chatter filter.

Binary inputs can be accessed and associated with data base entities through I/O modules, as seen in subsection 4.4.2 - I/O Modules.

Binary Outputs

Binary outputs are operated and its state refreshed at the same rate binary inputs are acquired. Binary outputs can be associated with data base entities through I/O modules, and can be configured as status or controls, as seen in subsection 4.4.2 - I/O Modules. For status outputs, the settings presented in Table 4.45 apply and define the shape of the output pulse. When the output is associated with the control value of the entity, the output pulse is directly defined by the specific characteristics of the entity, namely its fields **NUMPULSES**, **ONDUR** and **OFFDUR** (see subsection 4.1.3 - Control Entities).

Table 4.45. Binary output configuration settings.

Identifier	Title	Range	Factory value	Description
PulseTime	Pulse Time	[0..60000] ms	0	Duration of the output pulse
DelayTime	Delay Time	[0..60000] ms	0	Time delay to operate output
ResetTime	Reset Time	[0..60000] ms	0	Time delay to reset output

If all three settings are set to zero, the output pulse follows exactly the state of the data entity (or entities) it is associated to. Additional settings can be defined to implement a delay in relay operation (**DelayTime**) and a delay in relay dropout (**ResetTime**). If the output should remain actuated for a fixed time interval, even if the data entity it is associated to resets before, **PulseTime** should be configured instead. In the case **PulseTime** has a value different from zero **ResetTime** is not taken into account. The behaviour of the output pulse is shown in Figure 4.5 and Figure 4.6.

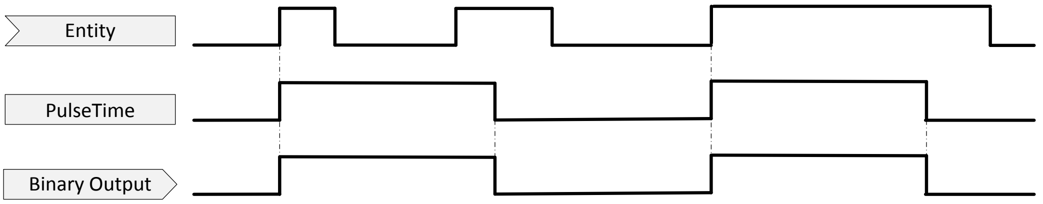

Figure 4.5. Output pulse shape (pulse time).

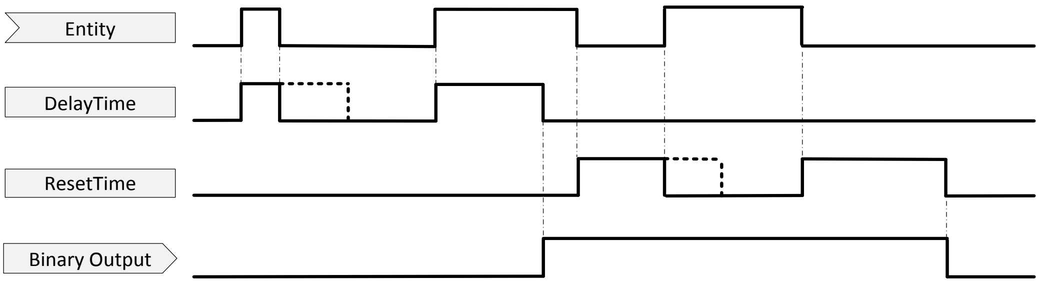

Figure 4.6. Output pulse shape (delay and reset time).

d.c. Analogue Inputs

Each d.c. analogue input, like the binary inputs and outputs, has an independent configuration. Both current and voltage input options are supported. Table 4.46 shows the settings corresponding to each d.c. analogue input.

Table 4.46. d.c. analogue input configuration settings.

Identifier	Title	Range	Factory value	Description
Range	Range	-1..1 mA / -5..5 mA / -10..10 mA / -20..20 mA / 0..1 mA / 0..5 mA / 0..10 mA / 0..20 mA / 4..20 mA / -5..5 V / -10..10 V / -150..150 V / -300..300 V / -1..1 V	-1..1 mA	Input range of operation
FilterTime	Filter Time	[100..2000] ms	1000	Filter time

Range enables the configuration of the exact scale for each input, to adjust it to the range of the external converter with maximum accuracy and resolution.

Besides setting **Range**, a specific hardware configuration, as described in subsection 2.2.3 - Configuration of the Supply Voltage and I/O, must also be changed. The setting value must be supported by the actual hardware external wiring, namely the selection between current and voltage inputs.

If an input value is outside its defined range, the quality of the associated data entity is set as **QUESTIONABLE**, with a detail qualifier of **OUT OF RANGE**.

All d.c. analogue inputs are sampled at a rate of 10 samples per second. A filter consisting of the average of *n* consecutive samples can be configured in setting **FilterTime** in order to further enhance the accuracy of the measurement. The d.c. analogue input value will be available periodically with a period equal to **FilterTime**.

All d.c. analogue inputs are calibrated in factory to ensure adequate accuracy, according to the TPU L500 specification.

a.c. Analogue Inputs

All a.c. analogue inputs are synchronously sampled at a very high rate. Different sampling rates (submultiples from the original one) and different digital filters are then implemented with distinct purposes (measurement, protection, fault disturbance records).

All a.c. analogue inputs are calibrated in factory to ensure adequate accuracy, according to the TPU L500 specification.

The adaptation of the rated value of each analogue input is done exclusively by software configuration, as described in subsection 4.4.3 - Channels.

Each a.c. analogue input, like the binary inputs and outputs, has an independent configuration. Table 4.47 and Table 4.48 show, respectively, the settings corresponding to each a.c. current and voltage analogue input.

Table 4.47. Current input configuration settings.

Identifier	Title	Range	Factory value	Description
AngleRef	Angle Ref	OFF / ON	OFF	Input used as phase angle reference

Table 4.48. Voltage input configuration settings.

Identifier	Title	Range	Factory value	Description
AngleRef	Angle Ref	OFF / ON	OFF	Input used as phase angle reference

If **AngleRef** has the value **ON**, it indicates that the particular analogue signal should be selected to be the reference phase angle input. In that case, its phase angle measurement will always indicate zero, whereas the phase angle measurement of all other quantities will be referred to that reference.

Only one analogue input (voltage or current) should be configured as the reference phase angle input.

If more than one input is configured as the reference phase angle input at the same time, the configuration is discarded.

If no input is configured as the reference phase angle input, the first of all inputs (the first input of the first board, relatively to the physical order in the device) will be considered automatically.

There is also a general I/O setting, impacting on all a.c. analogue inputs, in particular on its sampling rate, which is the frequency rated value, and that must match the applicable power system frequency.

Table 4.49. General I/O configuration settings.

Identifier	Title	Range	Factory value	Description
RatedFreq	Rated Freq	50 Hz / 60 Hz	50 Hz	Power system rated frequency

4.4.2 I/O MODULES

Binary inputs and outputs as well as d.c. analogue inputs are associated with data base entities through I/O modules.

I/O modules allow the user the creation of functional units, directly implemented using I/O points. Besides allowing the connection of I/O points to other internal modules, communication protocols or HMI objects (*e.g.*, alarms or function keys), they provide an effective resource to implement configurable functional modules, equivalent to built-in application functions (refer to chapter 5 - Application Functions) or user-defined functions (refer to section 4.5 - User Programmable Automation) when no built-in or user code is needed, only data representation and/or control.

Different types of I/O points from distinct boards can be associated to the same I/O module, with no restriction (except a.c. analogue inputs that are managed in a different way, described in subsection 4.4.3 - Channels), which provides highly flexible configurations. Different data types can be mapped, according to the following description.

Single Status Entities

When this option is selected, the state of the associated data entity corresponds exactly to the state of the binary input. This is the typical configuration for Boolean (digital) status entities.

Double Status Entities

This option enables the mapping of double status entities (normally for the representation of circuit breaker and other apparatus status) directly in I/O modules, extending the ones provided by built-in application function. Two consecutive binary inputs from the same board must be assigned for this effect. The first one must correspond to the **OFF** state of the entity (the one that is active when the circuit breaker is open, for instance) and the last one to the **ON** state (the one that is active when the circuit breaker is closed). For the exact representation of double entities, see section 4.1 - Data Types.

An optional filter can be configured to enable the suppression of the intermediate state (when both inputs have the value zero). It is activated when setting **IntermediateState** is **ON**. If, during a transition, the result of the two inputs remains in the intermediate state less than **FilterTime** this state does not generate an event (the entity changes directly from one final state to the other one). When **FilterTime** expires, if the result of the two inputs is still in the intermediate state, that value is then reported; the time tag of this event is the exact time instant of the transition to the intermediate state. This filter has no effect on supressing the invalid state (both inputs active), which is always immediately reported. Figure 4.7 illustrates the action of this filter.

Table 4.50. Double status entity configuration settings.

Identifier	Title	Range	Factory value	Description
IntermediateState	Intermediate State	OFF / ON	OFF	Show intermediate position
FilterTime	Filter Time	[0..30000] ms	10000	Intermediate position filtering time

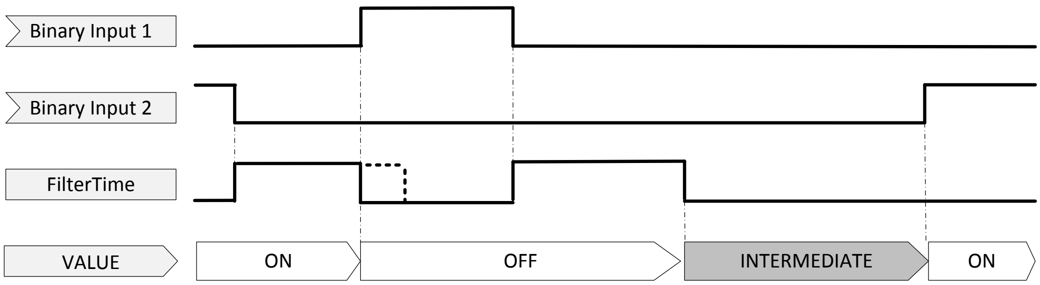

Figure 4.7. Intermediate state filter.

Integer Status Entities

This option enables the representation of integer entities directly in I/O modules (for instance, for use in the representation of tap changer position). This requires *n* consecutive binary inputs from the same board, as defined in the setting **NumBits**. The first input must correspond to the least significant bit, the last one to the most significant bit. Several integer encodings are supported: standard binary code, gray code, BCD, 1-of-N.

Table 4.51. Integer status entity configuration settings.

Identifier	Title	Range	Factory value	Description
NumBits	Num Bits	[1..6] or [1..32][1] bit	1	Number of bits to represent integer value
Code	Code	BINARY / GRAY / BCD / 1-OF-N / SIGNED BCD	BINARY	Coding of integer value

Pulse Counters Entities

This option enables the use of the binary input to count pulses. This allows to use entities of the type Counter to count the number of pulses sampled by the binary input. The count can be done in the rising edge, falling edge or both according with the setting **PulseType.** The counter behaviour is defined by the counter entity attributes **UNITS, MULTIPLIER, PULSE, FREEZEENABLE, STARTTIME, PERIOD** and **RESET**.

Table 4.52. Pulse counter entity configuration settings.

[1] The 32 bits are only available with the 1-OF-N code. All the remaining codes have a maximum of 6 bits.

Identifier	Title	Range	Factory value	Description
PulseType	Pulse Type	RISING EDGE/ FALLING EDGE/ BOTH	RISING EDGE	Signal edge used for counting.

Status Outputs

This option is used to assign digital entities to binary outputs that will operate according to the entity state. It is useful, for example, in the case of protection pickup and trip signals.

Up to 16 different entities can be assigned to a single binary output, in which case the output will react to the logical OR of the aggregated entities' values. It is possible to negate function inputs; in input multiplicity cases, each associated entity may be negated independently.

The shape of the output pulse is defined by the corresponding output time settings.

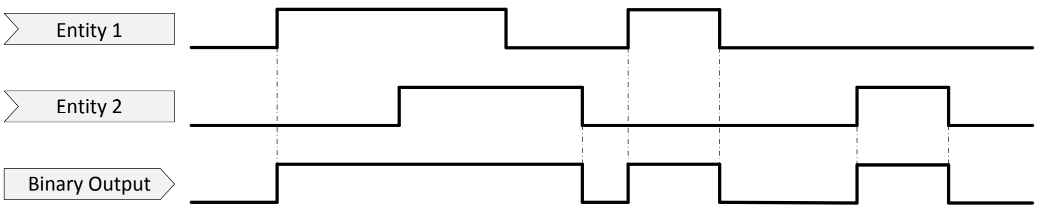

Figure 4.8. Output pulse shape in the case of a logical OR of several entity status.

Control Entities

This option is used to assign controllable data entities to both binary inputs and outputs. Both single and double status entities are supported.

The status of the entity, acquired from the process, is mapped on binary inputs, in the same manner as for single or double status entities (not controllable).

Each assigned output is actuated for a specific (configurable) value of the control order. The shape of the output pulse is defined by the corresponding entity attributes **NUMPULSES**, **ONDUR** and **OFFDUR**.

Multiple values of the control order can be assigned to the same output (maximum 16). In this case, the output pulse is the logical OR of output pulses for individual control values. This is especially useful, for instance, when assigning a common output for both circuit breaker open and close commands, as in Figure 4.9.

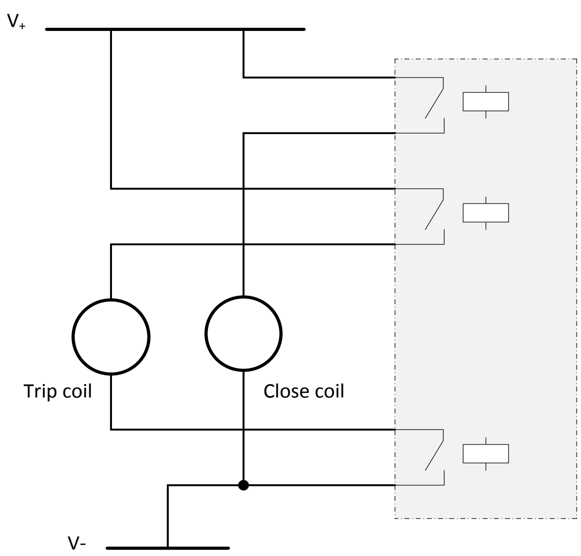

Figure 4.9. Example of circuit breaker open and close commands with a common output.

Step Position Control Entities

This option is used to assign integer controllable data entities directly in I/O modules (for instance, to control and represent tap changers). The status of the entity, acquired from the process, is mapped on binary inputs, in the same manner as for integer status entities (not controllable).

Each assigned output is actuated for a specific (configurable) value of the control order. The value 2 (H) is used to raise the tap and the value 1 (L) is used to lower the tap position. All the orders are given with one pulse with one second duration on the outputs.

d.c. Analogue Entities

This option is used to assign measurement data entities to d.c. analogue inputs.

The value of the measurement can be directly read from the input or a conversion function can be configured. Two types of conversion functions are supported: polynomials and piecewise linear interpolation.

If setting **ConversionFunction** is set to **POLINOMIAL**, the measurement value is given by equation (4.4), corresponding to a polynomial up to the seventh order with its coefficients defined by settings **A7** to **A0**. The linear conversion is a particular case of the polynomial one.

$$Y = a_7 \cdot X^7 + a_6 \cdot X^6 + a_5 \cdot X^5 + a_4 \cdot X^4 + a_3 \cdot X^3 + a_2 \cdot X^2 + a_1 \cdot X + a_0 \qquad (4.4)$$

X is the input value and Y the output measurement value.

If all settings but **A1** and **A0** are equal to zero, a linear conversion can be programmed. If only **A1** is different than zero and its value is 1, a direct reading of the input is obtained.

If setting **ConversionFunction** is set to **PIECEWISE LINEAR**, the measurement value is defined by a set of points with coordinates defined by pairs of settings (**Xi**, **Yi**), with i = 1 to 8. The number of data points is defined in setting **NumPoints**. A linear interpolation is performed between consecutive points.

Table 4.53. d.c. analogue entity configuration settings.

Identifier	Title	Range	Factory value	Description
ConversionFunction	Conversion Function	POLINOMIAL / PIECEWISE LINEAR	POLINO MIAL	Type of conversion function
Polinomial > A7 .. A0	Polinomial > A7 .. A0	[-99999..99999]	0,0	Coefficient of n^{th} order of the polynomial
Piecewise > NumPoints	Piecewise > NumPoints	[2..8]	2	Number of points of the piecewise interpolation
Piecewise > X1 .. X8	Piecewise > X1 .. X8	[-99999..99999]	0,0	Coordinate of the n^{th} data point in the x axis
Piecewise > Y1 .. Y8	Piecewise > Y1 .. Y8	[-99999..99999]	0,0	Coordinate of the n^{th} data point in the y axis

4.4.3 Channels

In an equivalent way to I/O modules, channels allow the association of a.c. analogue inputs to functional modules. Only specific built-in application function inputs can be associated with channels. They cannot be used in I/O modules or user-defined functions; they are not directly available in communication interfaces or in the user interface; they are only available through the results of each application function.

Base Channels

Each base channel should correspond to a specific set of associated external CT or VT, typically a three-phase current or voltage system. They can also be used in other scenarios, like for instance:

- Incomplete three-phase current systems (only one or two phase current signals available);
- Incomplete three-phase voltage systems (only one or two voltage signals available, either phase-to-earth or phase-to-phase), for example in the case of a separate voltage for synchro-check applications;
- A separate neutral current input, obtained from an independent phase-balance neutral current transformer or external Holmgreen circuit;
- A separate neutral current input, obtained from an independent open-delta connected winding.

For the reasons stated, the maximum number of a.c. analogue inputs for each channel is three. The following restrictions apply:

- No channel is allowed with both current and voltage signals;
- No phase-to-earth and phase-to-phase signals should be mixed in the same channel (only A-B-C, AB-BC-CA channels allowed, or subsets of the previous two);
- No neutral signal should be mixed with other signals (only N channels allowed, with a single input).

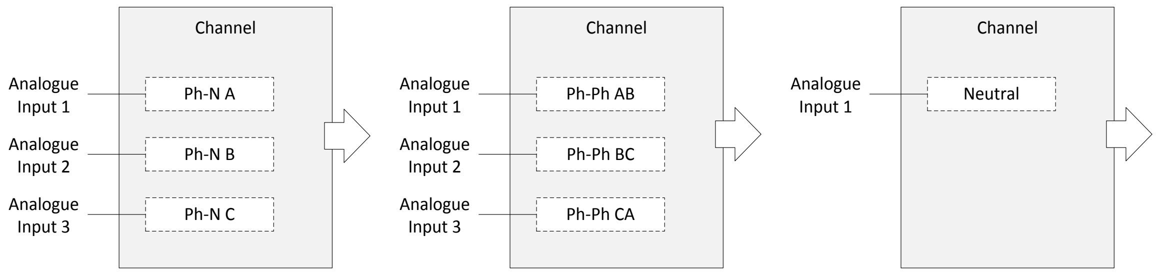

Figure 4.10. Possible channel configurations.

Table 4.54 lists the settings that must be configured for each channel.

Table 4.54. Base channel configuration settings.

Identifier	Title	Range	Factory value	Description
Id	Id	[1..20]	20	Channel id
Orientation	Orientation	FORWARD / REVERSE	FORW.	Polarity inversion
Ratio	Ratio	[1,0..20000,0]	100,0	External transformer ratio
PrimaryRatedValue	Primary Rated Value	[0,0..10000,0]	0.0	Rated CT (or VT) primary value

Ratio is the external CT or VT ratio. It allows the presentation of measurement outputs, or fault records, with the correct power system primary values. This setting can also be required for the proper operation of some application functions. All input instantaneous values and calculated quantities are made available to application functions in primary values.

PrimaryRatedValue is the rated CT (or VT) primary value. In the case of voltage inputs, the primary rated value always refers to the primary VT phase-to-phase voltage.

PrimaryRatedValue is used by all protection, control and monitoring functions using that particular a.c. input as the base reference for its operation threshold settings, if their value is set in p.u. (value per unit).

- When applied to current signals, 1 p.u. corresponds to **PrimaryRatedValue**, in primary values.
- When applied to phase-to-phase voltage signals, 1 p.u. corresponds to **PrimaryRatedValue**, in primary values.
- When applied to phase-to-earth voltage signals, 1 p.u. corresponds to **PrimaryRatedValue** / $\sqrt{3}$, in primary values.

For more detailed information on each specific setting, please refer to chapter 5 - Application Functions.

Orientation enables the user to reverse the polarity of the a.c. analogue signal relatively to the input polarity. This is especially useful for current analogue signals. The current direction depends directly on the connection of the CT. The star point of a three-phase system of star connected CTs can be connected to the object or from the object. The same applies to the earth connection of an independent neutral CT. The setting **Orientation** enable the correct configuration of each channel according to the TPU L500 convention.

All TPU L500 application functions assume the direction into the power system object is the forward direction and the direction out from the power system object is the reverse direction. So:

- If CTs star point is connected to the object, the channel setting **Orientation** should be set to Forward.
- If CTs star point is connected from the object, the channel setting **Orientation** should be set to Reverse.

For measurement and metering functions, a separate setting is available, which provides additional configuration flexibility. For example, it is possible to display power system measurements in the reverse direction (out from the power system object), if it is a user requirement, even if all other application functions should use the forward direction as the reference for its operation.

Derived Channels

Derived channels are obtained from base channels after applying some pre-defined arithmetic operations. They allow the internal calculation of additional analogue signals required by protection, control and monitoring functions in complex bus topologies and multiple breaker arrangements without the need for additional external connections.

Table 4.55. Derived channel configuration settings.

Identifier	Title	Range	Factory value	Description
Id	Id	[21..32]	21	Channel id
Type	Type	SUM / SELECTOR	SUM	Type of derived channel

The **SUM** channel is most suited to current channels in multiple breaker arrangements, when two sets of current transformers must be summed to calculate the current signals flowing in the power equipment. It can be applied both to single and three-phase systems. Two base channels must be associated to the new derived channel. Each signal in the derived channel is the sum of the corresponding signals in the base channels.

The **SELECTOR** channel, by the contrary, is most suited to voltage channels in multiple bus topologies and provides an easy way of selecting the voltage signals among two different buses. It can also be applied both to single and three-phase systems. Two base channels must be associated to the new derived channel. Each signal in the derived channel is the corresponding signal of one of the base channels, selected according to a binary condition associated to the input **Selector**.

When two base channels are combined in one derived channel, they must be of the same type (current or voltage) and they must group the same number and type of input quantities.

4.5 User Programmable Automation

The TPU L500 provides an IEC 61131-3 compliant logic engine which allows the implementation of additional user-defined automation functions, using the Structured Text (ST) and/or Function Block Diagram (FBD) programming languages.

Instructions on how to configure and implement user-defined automation programs are described in detail in [4].

User programs can interact directly with application functions, I/O modules, and HMI interface entities. In order to create the necessary additional data base entities, it is possible to add user functions containing the required entities to the existing logical devices (any of the standard data types can be selected when defining the user function interface).

Operational settings can be added to user functions, making this feature accessible for user-implemented programs as well. Operational setting configuration and management is detailed in subsection 5.1.5 - Setting Groups Management.

Table 4.56. Logic engine module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Mode	Mode	INT CTRL	Yes	Module controllable operation mode
Behavior	Behavior	INT	-	Module operation mode

4.5.1 Task Management and Program Execution

The logic engine is comprised of eight pre-emptive tasks with settable priorities (**High**, **Above Normal**, **Normal, Below Normal** and **Low**). Programs implemented by the user must be assigned to one of these tasks. There is no pre-emption between programs running in the same task, regardless of the program scheduling options.

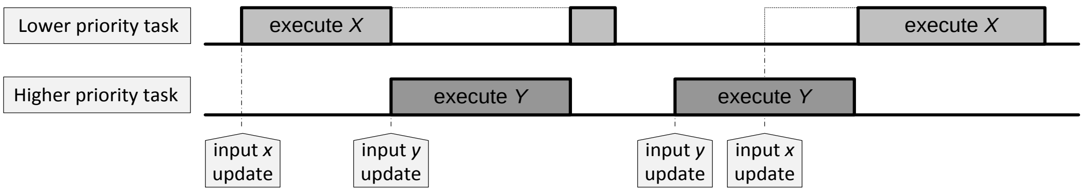

Figure 4.11. Task pre-emption example.

Table 4.57. Task information.

Identifier	Range	Description
Description	-	Task description
Name	-	Task name
Priority	High / Above Normal / Normal / Below Normal / Low	Task priority
On-Event Execution	Buffered	On-event execution policy

Identifier	Range	Description
Use Source Time	True / False	Output time stamps correspond to the instant the program was triggered

Program scheduling is a program property (it is task-independent); therefore programs running in the same task may have different scheduling options. The TPU L500 logic engine supports three non-mutually-exclusive scheduling configurations: **Cyclic**, **OnEvent** and **Startup**.

- **Cyclic execution:** programs are executed periodically, independently of input changes. The period of execution can be configured by adjusting the **Cycle** setting. If this parameter is set to 0, program cadence will correspond to the minimum task period, which varies according to the task priority (see Table 4.61).
- **Event-triggered execution:** program execution is triggered by input updates (*i.e.*, programs are executed whenever the value associated to one of their inputs is updated, even if it does not change). These programs are executed immediately and are not affected by the task cadence. On-event execution is buffered, implying that, in the case of simultaneous events (several inputs being updated at the same time), all updates are preserved and the programs are executed once for each stored value.
- **Startup execution:** programs are executed one time, at startup. This scheduling policy may be combined with on-event execution in order to ensure program initialization.

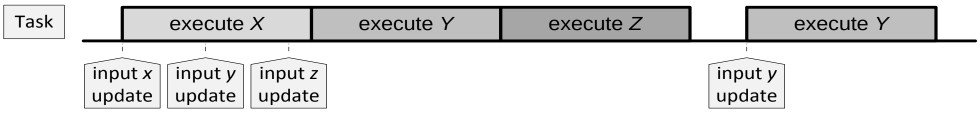

Figure 4.12. On-event buffered execution example.

The actual execution period of programs configured for cyclic execution corresponds to the parameterized **Cycle** value rounded to the closest lower multiple of the minimum task period.

Program execution is carried out in the following order:

1. all input values are read;
2. program code is processed;
3. output values are updated in the device data base.

By default, outputs are time stamped the moment their values are updated in the device data base. However, if the **Use Source Time** option is activated, output time tags will correspond to the time stamp of the input that triggered the program execution (*n.b.*, this feature only affects on-event programs).

Table 4.58. Program information.

Identifier	Range	Description
Description	-	Program description
Name	-	Program name
Language	Function Block Diagram / Structured Text	Program language
Scheduling	OnEvent / Cyclic / Startup	Program scheduling
Cycle	[0.. 9223372036854] ms	Cyclic program period

4.5.2 Program Implementation

User programs can be implemented either in ST or FBD languages (defined in the IEC 61131-3 standard). In order to allow the user to take the most advantage of both programming languages, the use of ST functions in FDB programs and of FBD functions and function blocks in ST programs is straightforward.

Program interface variables (*i.e.*, program inputs and outputs) must be associated to data base entities. It is necessary to specify the input scheduling policy by activating or deactivating the **OnEvent** setting, so that it matches the corresponding program scheduling. This is particularly important in programs that are executed both cyclically and on-event, since the program portions that are executed according to each policy are determined by the corresponding input configuration.

The logic engine supports a limitless number of on-delay, off-delay, and pulse timers, as defined by IEC 61131-3. It is possible to configure up to ten of these timers as real-time (1 ms resolution). For a timer to be processed as real-time, the program must be capable of on-event execution and the input that triggers the timer must be configured as **OnEvent**.

Table 4.59. Variable information.

Identifier	Range	Description
Description	-	Variable description
Name	-	Variable name
Type	Specified in [4]	Variable type
Initial value	Specified in [4] (dependent of variable type)	Initial value
Kind	Input / Output / Internal / Return	Interface type
On-Event	True / False	Variable scheduling policy
Device Id	-	Device data base correspondence

4.5.3 Automation System Library

The logic engine counts with an automation system library that provides several pre-set functions. The functions supported by the TPU L500 are listed in Table 4.60.

Table 4.60. System function blocks.

Identifier	Class	Description
NOT	Boolean algebra	Negation
AND	Boolean algebra	Conjunction
OR	Boolean algebra	Disjunction
XOR	Boolean algebra	Exclusive or
ADD	Arithmetic	Addition
SUB	Arithmetic	Subtraction
MUL	Arithmetic	Multiplication
DIV	Arithmetic	Division
MOD	Arithmetic	Modulo
SHL	Bit-Shift	Shift left
SHR	Bit-Shift	Shift right

Identifier	Class	Description
ROL	Bit-Shift	Rotate left
ROR	Bit-Shift	Rotate right
EQ	Comparison	Equal
NE	Comparison	Not equal
GT	Comparison	Greater than
GE	Comparison	Greater or equal
LT	Comparison	Lower than
LE	Comparison	Lower or equal
SEL	Selection	Selector
MAX	Selection	Maximum
MIN	Selection	Minimum
LIMIT	Selection	Limiter
MUX	Selection	Multiplexer
TP	Timers	Pulse timer
TON	Timers	On-delay timer
TOF	Timers	Off-delay timer
SR	Standard	Bistable (set dominant)
RS	Standard	Bistable (reset dominant)
R_TRIG	Standard	Rising edge detector
F_TRIG	Standard	Falling edge detector
CTU	Standard	Up counter
CTD	Standard	Down counter
CTUD	Standard	Up/down counter
ABS	Mathematical	Absolute value
SQRT	Mathematical	Square root
EXP	Mathematical	Exponential
LN	Mathematical	Natural logarithm
LOG	Mathematical	Base 10 logarithm
SIN	Mathematical	Sine
COS	Mathematical	Cosine
TAN	Mathematical	Tangent
ASIN	Mathematical	Arcsine
ACOS	Mathematical	Arccosine
ATAN	Mathematical	Arctangent
RAND_INT32	Non-standard	Random 32-bit signed integer
RAND_FLOAT32	Non-standard	Random 32-bit floating point number
SET_ACTIVE_GROUP	Device	Set/get active group
CTL_IN_BOOL	Controls	Boolean control reception

Identifier	Class	Description
CTL_IN_INT32	Controls	32-bit integer control reception
CTL_OUT_BOOL	Controls	Boolean control execution
CTL_OUT_INT32	Controls	32-bit integer control execution
CLOCK	Time functions	Current time and date information
TIMEINFO	Time functions	Separates time and date information into different fields
INT8_TO_*	Type conversion	8-bit signed integer conversion
INT16_TO_*	Type conversion	16-bit signed integer conversion
INT32_TO_*	Type conversion	32-bit signed integer conversion
INT64_TO_*	Type conversion	64-bit signed integer conversion
UINT8_TO_*	Type conversion	8-bit unsigned integer conversion
UINT16_TO_*	Type conversion	16-bit unsigned integer conversion
UINT32_TO_*	Type conversion	32-bit unsigned integer conversion
UINT64_TO_*	Type conversion	64-bit unsigned integer conversion
FLOAT32_TO_*	Type conversion	32-bit floating point number conversion
FLOAT64_TO_*	Type conversion	64-bit floating point number conversion

4.5.4 Good Programming Practices

User programs should be implemented with care, since they can have an impact in the functioning of the device as a whole. There are some common mistakes that can easily be avoided by the user.

- Although possible in ST programming, the use of loops (FOR, WHILE, or REPEAT instructions) is not advisable. If necessary, it must be done with caution – loops with a large number of iterations may compromise the functioning of other device modules.

The use of infinite loops in user programs will cause some device modules to stop working.

- Programs with strict time requirements should be configured as **OnEvent** and associated to one of the higher priority tasks, since higher priority tasks cannot be pre-empted by lower priority task (this situation is exemplified in Figure 4.11).
- In order to avoid unexpected behaviours at system startup, initial values should be assigned to output variables by the user.

4.5.5 Logic Engine Limits

Table 4.61. Logic engine limits.

Description	Overall	High priority	Above Normal priority	Normal priority	Below Normal priority	Low priority
Maximum number of tasks	8	1	1	2	2	3
Maximum number of programs	150	4	4	64	128	150

Description	Overall	High priority	Above Normal priority	Normal priority	Below Normal priority	Low priority
Maximum number of program variables	2048	2048	2048	2048	2048	2048
Maximum number of instructions	32000	1000	32000	32000	32000	32000
Minimum cycle	-	50 ms	100 ms	250 ms	500 ms	1 s
Maximum number of real-time timers	64	64	64	64	64	64

4.6 Local HMI

4.6.1 Display

Table 4.62 shows the settings present in the configuration concerning the display as well the range of values permitted and their default values. As referred previously, these settings can be changed while the unit is running in menu **Display**, present in the Local HMI. Additionally, it is also possible to configure up to six mimic pages with objects that can be selected and operated in runtime.

Table 4.62. Display configuration settings.

Identifier	Title	Range	Factory value	Description
Screensaver	Screensaver	[0..60] min	5	Timeout to screensaver mode
Hibernation	Hibernation	[1..60] min	10	Timeout to hibernation mode
Contrast	Contrast	[0..100] %	50	Display contrast
Brightness	Brightness	[0..100] %	50	Display brightness
Language	Language	PORTUGUESE / ENGLISH / SPANISH / FRENCH / ROMANIAN[2]/ RUSSIAN	ENGLISH	Display language.

Selecting the desired language in setting **Language** is not enough. One has to add it to the Automation Studio project in order for it to be available.

4.6.2 Alarms

The TPU L500 supports sixteen configurable alarms that, as seen in Table 4.66, can be:

- **Latched** - Persistent alarm. After a trigger the LED will remain active until the clear key is pressed (Table 4.65).
- **Unlatched** – The state of the LED will follow the entities state associated to it.

For each alarm, it is possible to associate sixteen different entities of different types, as seen in Table 4.63. For more information on these types please refer to section 4.1 - Data Types.

Table 4.63. Alarm inputs.

[2] Still under development

Identifier	Title	Type	Mlt	Description
Status	Status	DIG / DB DIG / INT / DIG CTRL / DB CTRL / INT CTRL	16	Alarm inputs

Table 4.64. Alarm information.

Identifier	Title	Type	NV	Description
Led	LED	DIG	Yes	Red colored led alarm status
YellowLed	YELLOWLED	DIG	Yes	Yellow colored led alarm status

Table 4.65. Clear key information.

Identifier	Title	Type	NV	Description
ResetLeds	Reset LEDs	DIG CTRL	-	LED reset control

When more than one entity is associated with one particular alarm, the alarm state will reflect the result of the logical OR of the state of the entities. As seen in Table 4.66, where settings concerning the alarms are shown, the user can select if an alarm is latched or unlatched, if the alarm will blink or not and the data value associated to the red LED and the yellow LED which represents the value the entity or the logical OR must have for the alarm LED to light up. It is also possible to specify the alarm label. It is also possible to specify the alarm label.

It is not possible to define the same value to light up the red and yellow led in the same alarm. Unlached alarms cannot be configured to blink because the user may interpret that behaviour as a toggle of the data base entity that is associated to the alarm.

For Boolean (DIG) entities, it is possible for the state of the LED to be negated relatively to the state of the Boolean entity (logical or included) that it represents. Finally, the alarm can also be used to represent the quality of entities which means that the LED will light up if the quality is invalid. For that, the value associated to the red LED will have to be i or I.

Table 4.66. Alarm configuration settings.

Identifier	Title	Range	Factory value	Description
Red	Red	-	-	Data value that lights up the red LED
Yellow	Yellow	-	-	Data value that lights up the yellow LED
Type	Type	UNLATCHED / LATCHED	UNLATCH.	Alarm operation mode
Blink	Blink	NONE/ SLOW/ FAST	NONE	Alarm blink mode
Text	Text	Max 16 Char.	Alarm	Alarm label

4.6.3 Function Keys

Function keys are programmable by the user and can take the form of:

- **Control key**:

  The action of pressing the key will give a defined control order in the entity associated to it.

- **Status key**:

  The key toggles the states defined in the LEDs.

- **Status and control key**:

  The key toggles the control orders based on the current led state.

- **Shotcut key**:

  The key will display the menu chosen by the user from an enumerated list.

The status shown in the LEDs and the control order can be mapped in different entities of different types as seen in Table 4.67. For more information on these types please refer to section 4.1 - Data Types.

Table 4.67. Function key information.

Identifier	Title	Type	NV	Description
Control	Control	DIG / DB DIG / INT / DIG CTRL / DB CTRL / INT CTRL	-	Entity controlled by the function key
Status	Status	DIG / DB DIG / INT / DIG CTRL / DB CTRL / INT CTRL	-	Entity displayed by the function key LEDs

Table 4.68. Function key configuration settings.

Identifier	Title	Range	Factory value	Description
Red	Red	-	-	Data value that lights up the red LED
Green	Green	-	-	Data value that lights up the green LED
Type	Type	STATUS/ CONTROL/ STATUS CONTROL/ SHORTCUT	STATUS	Function key operation mode

Identifier	Title	Range	Factory value	Description
Shortcut	Shortcut	MEASUREMENTS / METERING/ RECORDING/ SUPERVISION/ CONTROL/ EVENT LOG/ FAULT REPORT/ SETTINGS/ FUNCTION HEALTH/ FUNCTION SETTINGS/ FUNCTION STATUS/	MEASUR EMENTS	List of menus that can be associated by the user to the shortcut key

4.7 EVENT LOG

The TPU L500 is prepared to continuously log a set of configurable internal and/or external events, *i.e.* data entity transitions. All events are recorded with one millisecond resolution time tag information.

The event log is kept in non-volatile memory. The device can keep up to 25000 events, providing long-term recording, which is, in general, enough to guarantee the events can be retrieved manually or automatically before being overwritten by more recent information. For the sake of easier memory management, the event log is organized in individual and smaller files in the device memory, up to a maximum of 50 files, with typically 500 events each. This reduces the amount of information replaced with the most recent one when the memory is full since only the last file is lost and overwritten by the file containing the new events.

Because the rate of creation of new files during power system disturbances can be slower than the rate at which new information is generated, the last events are temporarily maintained in a circular buffer. To avoid the loss of information in any situation, even this buffer is located in an independent, non-volatile memory. This ensures that, even in the case of an inadvertent device restart, the information is not lost before it is saved permanently in a file.

Despite the measures taken, if some events are lost due to a flood of information, the indication **BufferOverflow** is generated, as seen in Table 4.69.

Table 4.69. Event log module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Health	Health	INT	-	Module health
Mode	Mode	INT CTRL	-	Mode control
MemClear	Memory Clear	DIG CTRL	-	Clear memory control
EraseFiles	Erase Files	DIG CTRL	-	Erase log files control
ForceFile	Force File	DIG CTRL	-	Force creation of log file control
NewLogFile	New Log File	DIG	-	New log file creation indication
NumberEvents	Number Events	INT	Yes	Number of events recorder
BufferOverflow	Buffer Overflow	DIG	-	Loss of information in event log buffer
EventsLost	Events Lost	INT	Yes	Number of events lost

Table 4.70. Event log configuration settings.

Identifier	Title	Range	Factory value	Description
HMIOrdering	HMI Ordering	ASCENDING / DESCENDING	ASCEND.	Order of presentation of events in local HMI
HMIMaxEvents	HMI Max Events	[1..100]	50	Maximum number of events in local HMI

The event log can be accessed from the engineering tool or the embedded webserver. For convenience, the last events are also available in the Local HMI. The maximum number of events displayed in the Local HMI is configurable as well as the order of presentation, as seen in Table 4.70. This allows the user to organize the information to be displayed in the most convenient way, when the device is being tested in the absence of any software tool. Note that the user also has the option to change, in the Local HMI, the settings related to the visualization of events; however, in this case it will only be possible to select the number of displayed elements up to the maximum number of events selected in the configuration. On the other hand, the webserver allows the visualization of all the events. For more information on this, please refer to section 7.14 - Event Log.

Up to 3000 different data entities can be configured to be logged, of any of the supported data types. For each entity, the user can select the trigger type which, depending on the data type, can be:

- Data-Update;
- Data-Change;
- Quality-Change;
- Range-Change.

Keyword *Change* indicates that the trigger value has to change for an event to be generated while keyword *Update* indicates that the trigger value only has to be updated for the event to be generated.

When an entity is selected to be logged, all trigger types will be enabled by default with the exception of trigger Data-Update when the entity is a control. In this case, user intervention is necessary to enable it. Table 4.71 shows the types of trigger supported by each entity and which fields are enabled for trigger when they are selected. When an event occurs, all the fields that were selected as trigger, will be recorded even when they aren't responsible for generating the event. Apart from these fields, there are additional fields that will also be recorded when an event occurs.

Table 4.71. Triggers supported and information recorded for each data type.

Type	Reference	Trigger Type	Field Used as Trigger	Fields Recorded
Digital	DIG	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN
		Quality-Change	QUALITY	
DoubleDigital	DB DIG	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN
		Quality-Change	QUALITY	
IntegerValue	INT	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN
		Quality-Change	QUALITY	
AnalogueValue	ANL	Quality-Change	QUALITY	MAGNITUDE INSTMAGNITUDE QUALITY TIMETAG RANGE ORIGIN
		Range-Change	RANGE	
ComplexAnalogueValue	CPX ANL	Quality-Change	QUALITY	MAGNITUDE ANGLE INSTMAGNITUDE INST ANGLE QUALITY TIMETAG RANGE ORIGIN
		Range-Change	RANGE	
Counter	CNT	Quality-Change	QUALITY	QUALITY TIMETAG PULSE FROZENVALUE FREEZETIMETAG ORIGIN
		Data-Update	FROZENVALUE	

Control	DIG CTRL	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
		Quality-Change	QUALITY	
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	
DoubleControl	DB CTRL	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
		Quality-Change	QUALITY	
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	

IntegerControl	INT CTRL	Data-Change	VALUE	VALUE QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
		Quality-Change	QUALITY	
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	
StepPositionControl	STEP CTRL	Data-Change	VALUE	VALUE TRANSIENT QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
			TRANSIENT	
		Quality-Change	QUALITY	
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	

IntegerStepPositionControl	ISTEP CTRL	Data-Change	VALUE	VALUE TRANSIENT QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
			TRANSIENT	
		Quality-Change	QUALITY	
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	
AnalogueControl	ANL CTRL	Quality-Change	QUALITY	VALUE QUALITY TIMETAG ORIGIN CONTROL CONTROLORIGIN TEST CAUSE SELECT SELECTORIGIN CANCEL CANCELORIGIN
		Data-Update	CONTROL	
			CAUSE	
			SELECT	
			CANCEL	
OptionListSetting	OPT SET	-	-	-
IntegerSetting	INT SET	-	-	-
AnalogueSetting	ANL SET	-	-	-
SettingGroups	SET GRP	Data-Update	ACTIVEGROUP	TIMETAG

4.8 Fault Report

4.8.1 Introduction

The Fault Report module is responsible for creating a detailed report of a fault occurrence, which can be used to assist the post-fault analysis. This report will aggregate the most relevant information in a block called **Summary**, display a chronological list of events in a block called **Timeline** and record the pre-fault and fault measurements in a block called **Measurements**. While the first block of information is always present in a Fault Report, the presence of the last two depends on the configuration.

The information present in a report will be automatically obtained from the functions present in the configuration which removes the need for a complex configuration by the user. If disturbances are recorder by the Disturbance Recorder, during the timeframe of a Fault Report, this information will be present in the Fault Report.

The TPU L500 can store up to 50 reports.

4.8.2 Operation Method

A Fault Report is triggered by the start of the **Three/Single-Phase Trip Logic** function which makes its presence mandatory in the configuration. Moreover, one or more of the following protection functions must be connected to the Three/Single-Phase Trip Logic in order for a report to occur:

- **Distance**
- **Distance Teleprotection**
- **Earth-Fault Overcurrent**
- **Earth-Fault Overcurrent for Non-Earthed Systems**
- **Earth-Fault Teleprotection**
- **Negative Sequence Overcurrent**
- **Phase Overcurrent**
- **Remote Tripping**
- **Stub**
- **Switch-Onto-Fault**

Additionally, Information can be used from the following functions:

- **Automatic Reclosure**
- **Circuit Breaker Failure**
- **Circuit Breaker Supervision**
- **CT Supervision**
- **Fault Locator**
- **Three-Phase Measurements**
- **VT Supervision**

Only information from protection functions connected to the Three/Single-Phase Trip Logic function will be used in the report while information provided by the remaining functions, during an occurrence, will be used without limitation in the **Summary** and / or the **Timeline** blocks. Exceptions to this are the functions Circuit Breaker Failure and Circuit Breaker Supervision that also have to be connected to the Three/Single-Phase Trip Logic function, as seen in Figure 4.13.

In order for the report to be as complete as possible, all the above functions should be present in the configuration and the connections in Figure 4.13 followed. Missing functions or functions that don't comply with the mandatory connections will lead to blocks of information that will not be present in the report.

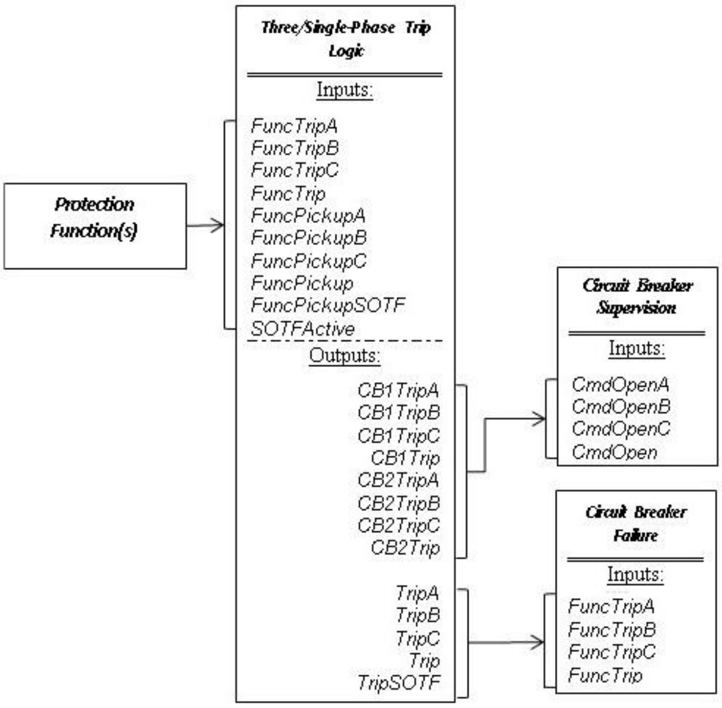

Figure 4.13. Fault Report mandatory connections.

Regarding the information provided in a Fault Report, there are some aspects of how that information is obtained that require a more detailed examination. This is done below.

Fault direction information will only appear in the **Summary** block if the value, obtained from all the protection functions that were active in the Fault Report, is the same. Nevertheless, even if this information is not provided, it is possible to see the value obtained from each function in the **Timeline**. Note that if the value of a function oscillates during a Fault Report, the fault direction displayed in the **Timeline**, for that function, will be unknown.

Fault type and fault loop are obtained primarily from the Fault Locator, nevertheless, if this function is not available, their value can be obtained by the Distance function; however, while fault type information will appear on the **Summary** block, fault loop information will only appear in the **Timeline** block.

Fault time is the time elapsed from the instant a protection function starts (assuming it is connected to the Three/Single-Phase Trip Logic function) until the first dropout of the Three/Single-Phase Trip Logic or, in case of Automatic Reclosure, the last dropout of the Three/Single-Phase Trip Logic that occurred before the recloser ended. Furthermore, while a report start time is also the instant a protection function starts, its conclusion depends on several factors, identified bellow:

- None of the protection functions tripped (without Automatic Reclosure):

  Dropout of the Three/Single-Phase Trip Logic function;

- At least one of the protection functions tripped (without Automatic Reclosure):

  Reception of the state of all the circuit breakers connected with the Three/Single-Phase Trip Logic function (open, invalid or circuit breaker open failure) or time elapsed reached the maximum value allowed to wait for this information;

- Automatic Reclosure started:

  It can end with final state successful / aborted or only with the reception of the state of all the circuit breakers connected with the Three/Single-Phase Trip Logic function (open, invalid or circuit breaker open failure) when the final state is unsuccessful. In the last case, a maximum allowed time was stipulated to receive this information.

In block **Summary**, a list of all the functions that tripped is given as well as information regarding Circuit Breaker Failure, namely the date and time with a millisecond resolution of each failure occurrence. Additional, if Automatic Reclosure occurred, the number of cycles and its final state will also be displayed here.

Finally, it is important to note that, in case one Automatic Reclosure started, Fault Type, Loop, Impedance, Location and Fault Measurements displayed are only of the first cycle

4.8.3 Interface

Table 4.73 and Table 4.74 list the information that can be included in the **Summary** and the **Measurements** blocks, respectively.

Timeline displays the most relevant events in a chronologic order that can be divided in three categories:

- **Pickup**

  Information regarding the start of a protection function is aggregated with the format:

  <Function Title> pickup stage(s) x, x phase(s) x, x. Fault Direction x

- **Trip**

  Information regarding the trip of a protection function is aggregated with format:

  <Function Title> trip stage(s) x, x phase(s) x, x

- **Registers**

  Important events displayed with format:

  <Date / time > <Function Title> <Element Title> <Element Value>

  Date / Time will only appear in some events while element value will only appear if it is relevant.

Table 4.72 displays additional information on the TPU L500 and the report itself that doesn't belong to any of the blocks but is, nevertheless, included in the report.

Apart from the information in the report itself, the Fault Report module also provides the information listed in Table 4.75.

Table 4.72. Report additional information.

Information	Description
Report Number	Number of the report created with current configuration
Model Device	Device Model
Serial Number	Device serial number
Configuration Version	Version of the configuration present in the device when the fault occurred
Firmware Version	Firmware version of the device
Role	Role of the device
Owner	Owner of the device
Location	Location where the device is installed
Power System Name	Name of the electric power system the device is connected to
Start Date	Report start date and time with a millisecond resolution
End Date	Report end date and time with a millisecond resolution
Disturbance Recorder Files	Disturbance Recorder records that occurred during the Fault Report timeframe

Table 4.73. Report Summary.

Information	Function(s)	Description
Fault Type	Fault Locator / Distance	Fault Type
Fault Loop	Fault Locator	Fault Loop

Information	Function(s)	Description
Fault Direction	Protection Functions	Fault direction given by the protection functions that started as long as their values match
Fault Time	-	Fault duration
Fault Location	Fault Locator	Fault Distance in Km
Fault Impedance	Fault Locator	Fault Impedance
Functions	Protection Functions	List of protection functions that tripped
1Ph Auto Reclosure	Automatic Reclosure	Number of cycles and final state (successful or unsuccessful). Since more than one Automatic Reclosure function is supported, more than one indication can be displayed.
1Ph CB Failure	Circuit Breaker Failure	Indication that circuit breaker failure occurred with date and time with a millisecond resolution. Since more than one Circuit Breaker Failure function is supported, more than one indication can be displayed.

Table 4.74. Report Measurements.

Identifier	Title	Type	Function	Description
CurrentA	IA	Pre-Fault Measurement	Three-Phase Measurements	Phase A current
CurrentB	IB	Pre-Fault Measurement	Three-Phase Measurements	Phase B current
CurrentC	IC	Pre-Fault Measurement	Three-Phase Measurements	Phase C current
ResidualCurrent	Ires	Pre-Fault Measurement	Three-Phase Measurements	Residual current
NeutralCurrent	Ineut	Pre-Fault Measurement	Three-Phase Measurements	Neutral current
VoltageA	UA	Pre-Fault Measurement	Three-Phase Measurements	Phase A voltage
VoltageB	UB	Pre-Fault Measurement	Three-Phase Measurements	Phase B voltage
VoltageC	UC	Pre-Fault Measurement	Three-Phase Measurements	Phase C voltage
ResidualVoltage	Ures	Pre-Fault Measurement	Three-Phase Measurements	Residual voltage
NeutralVoltage	Uneut	Pre-Fault Measurement	Three-Phase Measurements	Neutral voltage
VoltageAB	UAB	Pre-Fault Measurement	Three-Phase Measurements	AB phase-to-phase voltage
VoltageBC	UBC	Pre-Fault Measurement	Three-Phase Measurements	BC phase-to-phase voltage
VoltageCA	UCA	Pre-Fault Measurement	Three-Phase Measurements	CA phase-to-phase voltage
PositiveSeqCurrent	I1	Pre-Fault Measurement	Three-Phase Measurements	Positive sequence current

Identifier	Title	Type	Function	Description
NegativeSeqCurrent	I2	Pre-Fault Measurement	Three-Phase Measurements	Negative sequence current
ZeroSeqCurrent	I0	Pre-Fault Measurement	Three-Phase Measurements	Zero sequence current
PositiveSeqVoltage	U1	Pre-Fault Measurement	Three-Phase Measurements	Positive sequence voltage
NegativeSeqVoltage	U2	Pre-Fault Measurement	Three-Phase Measurements	Negative sequence voltage
ZeroSeqVoltage	U0	Pre-Fault Measurement	Three-Phase Measurements	Zero sequence voltage
SwitchCurrA	Switch IA	Fault Measurement	Circuit Breaker Supervision	Current interrupted during last open operation, phase A
SwitchCurrB	Switch IB	Fault Measurement	Circuit Breaker Supervision	Current interrupted during last open operation, phase B
SwitchCurrC	Switch IC	Fault Measurement	Circuit Breaker Supervision	Current interrupted during last open operation, phase C

Table 4.75. Fault Report module information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Module description
SWRevision	SW Revision	TEXT	-	Module software revision
Version	Version	TEXT	-	Module configuration version
Health	Health	INT	-	Module health
Mode	Mode	INT CTRL	-	Mode control
ReportStarted	Report Started	DIG	Yes	Report started indication
ReportEnd	Report End	DIG	-	Report end indication
MemClear	Memory Clear	DIG CTRL	-	Clear memory control
ReportNumber	Report Number	INT	Yes	Number of reports recorder
ReportsLost	Reports Lost	INT	Yes	Number of reports lost

4.8.4 Settings

The Fault Report settings are listed in Table 4.76.

Table 4.76. Fault Report configuration settings.

Identifier	Title	Range	Factory value	Description
ReportFaultType	Report Fault Type	All / With trip	All	Record a report every time a fault occurs or only in case a protection function tripped

Identifier	Title	Range	Factory value	Description
Timeline	Timeline	OFF / ON	ON	Enable or disable the Timeline block
Measurements	Measurements	OFF / ON	ON	Enable or disable the Measurements block

Chapter
5

APPLICATION FUNCTIONS

This chapter describes the protection, control, supervision and monitoring functions available in the TPU L500. For each built-in function, the operation principle and the scope of application are described. The chapter analyses the operation characteristics, the function interface and the associated logic schemes. It also includes the meaning of each configurable parameter as well as the corresponding factory values and regulation ranges.

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5.1 General Function Data

5.1.1 Application Functions

The TPU L500 provides a set of highly configurable protection, control, supervision, and monitoring functions. Their modular interface has been specifically designed with the aim of favouring function interconnection and simplifying the configuration process. All application functions have been conceived with the intent of providing a straightforward correspondence to the IEC 61850 standard, although they are not constrained by this.

The application function interface consists of a set of inputs, a set of outputs, and, in most cases, a set of settings. It is possible to interconnect application functions, and connect them to user-defined functions, I/O modules, and HMI objects (*e.g.*, alarms or function keys).

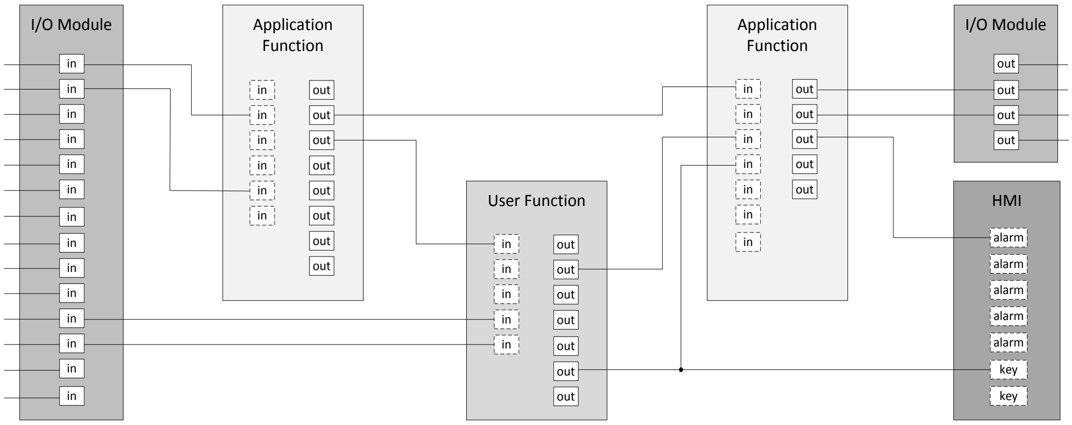

Figure 5.1. Example of connections between application functions, user functions, I/O modules, and HMI objects.

Input multiplicity is supported (*i.e.*, it is possible to assign several entities to a single input), in which case the considered input value corresponds to the logical OR of the aggregated entities' values. It is possible to negate function inputs; in input multiplicity cases, each associated entity may be negated independently.

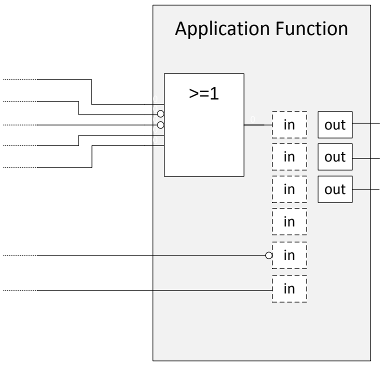

Figure 5.2. Input multiplicity and negation.

All application functions have a **Health** output, indicating whether they are functioning normally (**OK**), functioning with certain limitations (**WARNING**), or unable to function at all (**ALARM**). Factors that affect function health (usually wrong input configuration and/or setting values) are function specific and are described in the present chapter throughout the application function sections.

5.1.2 Logical Devices

Application functions, user-defined functions, and I/O modules are organized in logical devices. The TPU L500 supports up to sixteen logical devices among which all functions may be freely distributed. Each logical device has specific parameters which affect all functions associated to it.

As detailed throughout the present section, function management is also logical device specific (*i.e.*, functions within a given logical device can be handled simultaneously, independently of the remaining logical devices).

Table 5.1. Logical device inputs.

Identifier	Title	Type	Mlt	Description
LocalKey	Local Key	DIG	1	Local control behavior at bay level
LocalStationKey	Local Station Key	DIG	1	Control authority at station level

Table 5.2. Logical device information.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Logical device description
Mode	Mode	INT CTRL	Yes	Logical device controllable operation mode
Behavior	Behavior	INT	-	Logical device operation mode
Health	Health	INT	-	Logical device health
Local	Local	DIG	-	Local control behavior at bay level
LocalStation	Local Station	DIG CTRL	Yes	Control authority at station level
SettingGroups	Setting Groups	SET GRP	-	Logical device setting group management
ActiveGroup	Active Group	INT	-	Active setting group
EditGroup	Edit Group	INT	-	Setting group in edition

Table 5.3. Logical device configuration settings.

Identifier	Title	Range	Factory value	Description
Description	Description	Max 255 Char.	Logical Device	Logical device description
Multilevel	Multilevel	OFF / ON	OFF	Mode of switching authority for local control

5.1.3 Operation Mode Management

Operation modes allow enabling or disabling application functions and specify how they behave towards incoming data and command execution requests. Operation mode management is only provided for built-in application functions – it has no effect on I/O modules and must be programmed by the user in order to affect user-defined functions (see section 4.5 - User Programmable Automation).

The TPU L500 supports three different operation modes: on, off, and test. Operation modes can be set per logical device by issuing commands on the corresponding **Mode** entity. All application functions are affected by their logical device operation mode. Currently selected logical device operation modes are always displayed in the **Mode** and **Behavior** entities.

Several functions have **Operation** and/or **Test** settings, sometimes one for each stage, making it possible to switch operation mode independently of the logical device. Application functions that contain any of these settings have a dedicated **Behavior** output that indicates their current operation mode. Functions that have distinct **Operation** and/or **Test** settings for each stage also have separate **Behavior** outputs for all stages. Table 5.4 shows how function behaviour is calculated based on these settings and the logical device operation mode.

The quality of function outputs is updated according to the function behaviour. When a function is turned off, output quality is set to invalid. The output quality of a function operating in test mode remains valid, but its test flag is activated.

Command execution requests and incoming data quality are evaluated before being processed by an application function (see Table 5.5). Commands that cannot be executed due to a function's operation mode report **BLOCKED BY MODE** as the cause of rejection.

Table 5.4. Function behaviour hierarchy.

	Logical device mode on	Logical device mode test	Logical device mode off
Function mode on	ON	TEST	OFF
Function mode test	TEST	TEST	OFF
Function mode off	OFF	OFF	OFF

Table 5.5. Application function operation mode and behaviour.

Operation Mode / Behavior	on	test	off
Function operation	ON	ON	OFF
Output quality	Not affected	Test	Invalid
Response to normal command	Accepted	Rejected	Rejected
Response to test command	Rejected	Accepted	Rejected
Incoming data (good quality)	Processed as valid	Processed as valid	Not processed
Incoming data (test quality)	Processed as invalid	Processed as valid	Not processed
Incoming data (invalid quality)	Processed as invalid	Processed as invalid	Not processed

5.1.4 Control Authority Management

Control authority is handled per logical device, affecting all application functions associated to it. For it to be enforced in user functions, it must be user-implemented in programmable logic (see section 4.5 - User Programmable Automation). I/O modules are not subject to control authority.

Commands issued on controllable entities can be validated according to their origin (*i.e.*, whether they were executed manually or automatically, and where they were issued from). Manual and automatic control sources can be categorized into three distinct levels: bay level (local), station level (local station), and control centre level (remote). Commands blocked by control authority report **BLOCKED BY SWITCHING HIERARCHY** as the cause of rejection.

A vast number of control authority configurations are provided, easily adapting to a plurality of distinct scenarios (see Table 5.6). Control authority switching is possible by acting on the logical device **LocalKey** and **LocalStationKey** entities. These entities' status are reflected on the **Local** and **LocalStation** entities, respectively.

Acting on the **LocalKey** entity sets the device to local mode, ensuring that bay level commands are accepted. Activating the **LocalStationKey** input causes station level commands to be accepted (this is subject to further validation, as indicated in Table 5.6). In order to grant greater flexibility, it is possible not to configure the **LocalKey** and/or **LocalStationKey** inputs, thus creating additional control authority management configurations.

It is possible to configure the logical device control authority so that commands from more than one level are accepted at the same time. This can be achieved by setting the **Multilevel** parameter to **ON**. In this case, if control authority is set to remote, commands from all levels are accepted, if it is set to local station, only control centre level commands are rejected.

This setting only applies to manual commands; control authority for automatic commands is always multi-level (it is not possible to deactivate it). Unlike function settings (see subsection 5.1.5 - Setting Groups Management), **Multilevel** is part of the device configuration and cannot be edited in runtime.

Table 5.6. Control origin validation.

Multilevel	LocalStationKey	LocalKey	Bay Level Commands	Station Level Commands	Control Center Level Commands
OFF	OFF	OFF	Rejected	Rejected	Accepted
OFF	OFF	ON	Accepted	Rejected	Rejected
OFF	OFF	not connected	Rejected	Rejected	Accepted
OFF	ON	OFF	Rejected	Accepted	Rejected
OFF	ON	ON	Accepted	Rejected	Rejected
OFF	ON	not connected	Accepted	Accepted	Rejected
OFF	not connected	OFF	Rejected	Accepted	Accepted
OFF	not connected	ON	Accepted	Rejected	Rejected
OFF	not connected	not connected	Accepted	Accepted	Accepted
ON	OFF	OFF	Accepted	Accepted	Accepted
ON	OFF	ON	Accepted	Rejected	Rejected
ON	OFF	not connected	Accepted	Accepted	Accepted
ON	ON	OFF	Accepted	Accepted	Rejected
ON	ON	ON	Accepted	Rejected	Rejected
ON	ON	not connected	Accepted	Accepted	Rejected
ON	not connected	OFF	Accepted	Accepted	Accepted
ON	not connected	ON	Accepted	Rejected	Rejected
ON	not connected	not connected	Accepted	Accepted	Accepted

5.1.5 Setting Groups Management

Most application functions have user-configurable parameters. This feature is also available to user-defined functions (see section 4.5 - User Programmable Automation).

The TPU L500 counts with eight setting groups, allowing the creation of eight distinct protection profiles that can be switched to at any time. It is possible to select the active setting group independently for each logical device, affecting all associated application and user-defined functions that contain settings. The logical device **SettingGroups** and **ActiveGroup** entities indicates which group is currently active.

It is possible to change the active setting group at runtime manually, using the local HMI or the engineering tool, and automatically via programmable automation. The default active group is setting group 1, and this value will be used until another is selected. It is not possible to define a different default value when configuring the device.

Function settings and active setting groups are persistent even through configuration changes. This allows further configuration improvements and corrections made by the user without losing previously configured setting values. The only exception takes place when a new device configuration with a different number of logical devices is deployed to the unit. In this case the default value of the active setting group is restored for all logical devices (even under these circumstances, configured function settings are not lost).

5.2 Distance

5.2.1 Introduction

The Distance Protection function in TPU L500 is designed to fulfill the needs for line protection in transmission systems and meshed distribution systems. With its enhanced sensitivity and accuracy it is perfectly suited for detect any type of fault and to reliably determine it location. The main algorithm of Distance Protection is based on measuring the impedance from the measurement location to the fault location, which in most cases, is proportional to the distance to the fault. Its profile, widely independent from generation and load conditions, make this type of protection very versatile in adapting to the given system conditions. Distance Protection, being a non-unit type of protection, is widely used not only as main protection for overhead lines and cables but also has backup protection for further feeders, busbars and transformers.

5.2.2 Operation Method

Six independent distance measuring zones are available (each corresponding to one stage). Each zone can be separately activated and configured in reach, directionality and time of operation. In addition, zone six can be dynamically activated by input. Two types of characteristic can be chosen for all stages, quadrilateral and mho. Furthermore, a combination of this two characteristics can be chosen, in which case, the type of fault will determine the type of characteristic used (quadrilateral for phase-to-earth faults and mho for phase-to-phase faults).

The pickup and trip signals are always selective in phase (from fault type) and zone (from fault location). There are also general pickup and trip outputs for each zone. They correspond to the logical OR of the phase outputs, that is, they are activated, respectively, if at least one phase pickup or trip is active in the respective zone. Moreover, there are general pickup and trip outputs for the whole function correspondent to the logical OR of the zones outputs, including phase selective outputs.

This generic interface allows a user defined interaction with different applications, such as Distance Teleprotection Schemes and Triplogic, and therefore the function general tripping behavior is fully user configurable.

Measuring Principle

The Distance Protection function continuously monitors the three phase current signals and three phase-to-earth voltage signals in the two analogue channels, connected to the function inputs **I** and **U**, respectively. With these quantities, it is estimated the line positive sequence impedance, from the measurement point to the fault, which is then compared to the active protection zones. The protection function is executed in full-scheme mode, which means that there are separate protection elements for monitoring each one of the six possible loops: three phase-to-phase (AB, BC and CA) and three phase-to-earth (A0, B0 and C0).

During a fault condition the healthy loops impedance can also breach active protection zones, this phenomenon would compromise the application selectivity tripping. To prevent this occurrence, a dedicated phase and loop selector mechanism is included in the function. This mechanism uses multiple criteria to discriminate the type of fault and the loops involved, blocking the healthy loop calculations (See **Loop Selection**).

In case of loops phase-to-phase the positive sequence impedance can be estimated by (fault between phase x and phase y):

$$Z_{xy} = \frac{V_x - V_y}{I_x - I_y} \tag{5.1}$$

For loops phase-to-earth, with reference to Figure 5.3 the positive sequence impedance can be estimated by (fault in phase x):

$$V_x = n \cdot Z_1 \cdot (I_x + k_0 \cdot 3I_o) + I_f \cdot R_f \tag{5.2}$$

Where:

V_x = phase voltage measured at relay.

n = per-unit distance to fault from the relay.

Z_1 = positive sequence line impedance.

I_x = phase current measured from relay.

$k_0 = \frac{Z_0 - Z_1}{3Z_1}$ (Z_0 = zero sequence line impedance)

I_f = fault current.

R_f = fault resistance.

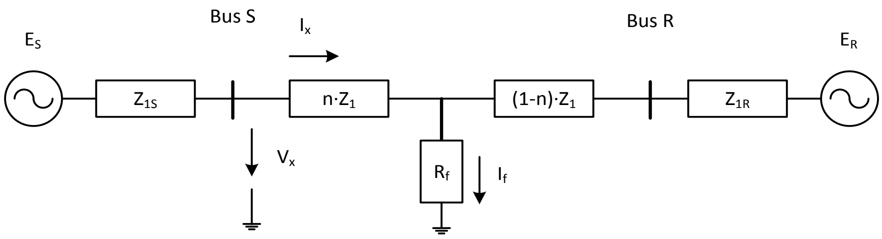

Figure 5.3. Two machine equivalent system.

The positive line impedance (Z_1) angle is defined in setting **LineAngle**. In order to allow a fully versatile application, capable of adapting to most different systems, the compensating factor k_0 is independent per zone and available in settings **StxK0Mag** and **StxK0Angle** (x = 1, 2, 3, 4, 5 or 6).

The accuracy of the Distance Protection results depends largely on the accuracy of line impedance values introduced by the user. It is therefore required that these values are obtained from experimental measurements when accurate values are not directly available from theoretical calculations. This is particularly relevant in the case of zero sequence impedances, where the influence of earth is usually difficult to estimate.

The Distance Protection application provides a very powerful algorithm of impedance estimation capable of eliminating the effect of fault resistance, eventual double end in-feed and load current seen in equation (5.2). Special polarization techniques are employed to achieve this goal. Due to this compensation, the exact loop reactance and fault resistance values can be estimated with very high accuracy.

Loop Selection

The loop selection algorithm will block any loop with a phase current involved lower than the threshold defined in setting **Imin**. On the other hand, any phase-to-earth loop shall be blocked if the residual current is lower than the threshold defined in setting **IresMin**. In both cases the threshold is set in values per unit, relative to the rated CT primary current. A built-in hysteresis of 2% guarantees the adequate stability in loop releasing.

$$I_{th}[A] = I_{th}[p.u.] \cdot I_r \qquad (5.3)$$

Current transformer saturation during faults without earth involvement or unsymmetrical load conditions could lead to secondary residual current arising. To prevent wrong releasing of loop involving earth in these cases, special restraining steps are taken to the earth loops release characteristics shown in Figure 5.4.

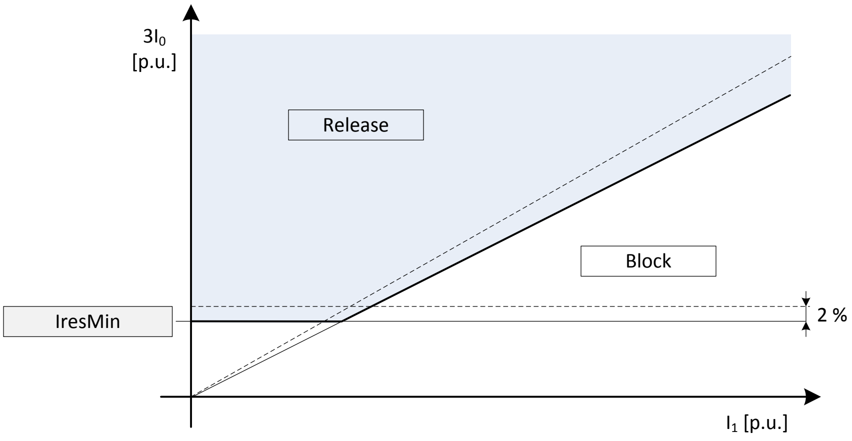

Figure 5.4. Earth loops release characteristics.

The phase and loop selector algorithm is capable of accurately determine the fault type from one of the listed in Table 5.7; this information is available during the general pickup of the function in the output **FaultType**. The default entity state while no fault is detected is **UNKNOWN**.

Table 5.7. Fault type options.

Value	Description
0	Unknown
1	Three-phase
2	Phase-earth
3	Phase-phase
4	Phase-phase-earth

If a phase-to-phase-to-earth fault is determined by the built-in loop selector the loops released can be determined by the setting **PPELoopSel** as described in Table 5.8.

Table 5.8. Released loops for phase-to-phase-to-earth fault.

Phases involved	Loops released for calculus	
	PPELoopSel = PHASE-PHASE	PPELoopSel = ALL
AB	AB	AB, A0, B0
BC	BC	BC, B0, C0
CA	CA	CA, C0, A0

The loop selection algorithm is capable of correctly detecting fault type and fault loop even in typically harsh conditions, like weak in-feed or heavy (unbalanced) load conditions. During these conditions the currents may drop below the pre-fault load level, making the signature fault current buried underneath the load current. The algorithm uses pre-fault phasors stored in memory to minimize these problems. For longer memories special arrangements are also made to compensate for the phase rotation due to frequency variations during the time the memory is active.

Directionality

Each zone can be independently complemented with a directional element, *i.e.* it can be set as non-directional or directional (forward or reverse). This is configurable in setting **StxDirection**.

> The forward direction is defined as the direction into the protected object, whereas the reverse direction is the direction out from the protected object. The CT polarity should be conveniently configured according to this convention (please consult the corresponding subsection 4.4.3 - Channels).

The directional characteristic is evaluated for the released loops from the loop selector. The polarization of the directional element is done with the positive sequence voltages - equation (5.4)(5.18). This quantity can be obtained from the three phase-to-earth voltage signals associated in one analogue channel connected to the function input **U**.

$$\overline{U}_{1\_A} = 1/3 \cdot \left(\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C\right), \quad a = e^{j120^\circ} \tag{5.4}$$

The relay evaluates the fault direction by taking into account the phase angle difference between the positive sequence voltage and the selected loop current, as described in Table 5.9.

Table 5.9. Quantities evaluated for directional decision.

Loop	Loop current	Polarization voltage
A0	$I_A+k_03I_0$	U_{1_A}
B0	$I_B+k_03I_0$	U_{1_B}
C0	$I_C+k_03I_0$	U_{1_C}
AB	I_A-I_B	U_{1_AB}
BC	I_B-I_C	U_{1_BC}
CA	I_C-I_A	U_{1_AC}

From these quantities a directional characteristic is constructed as in Figure 5.5. The two sections that limit the forward and reverse direction are configurable by user in setting **DirAngleR** and **DirAngleX**. A built-in hysteresis of 5° guarantees the adequate stability of the direction decision.

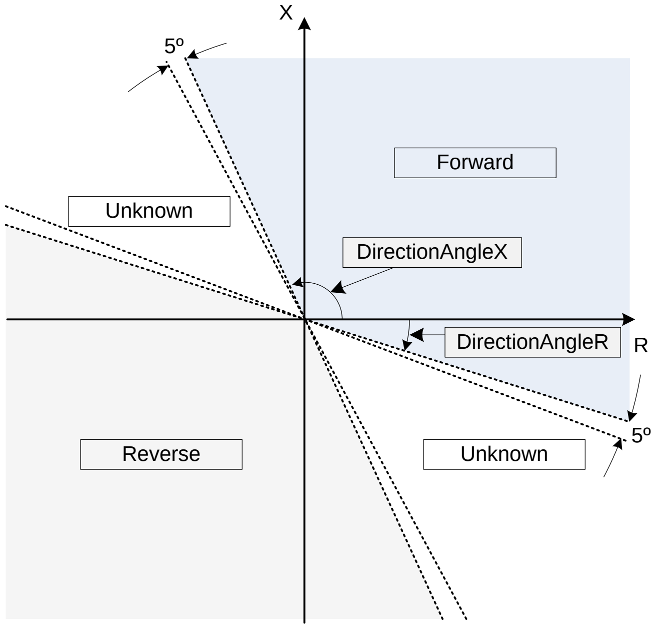

Figure 5.5. Distance directional characteristic.

In case of a close-in three-phase fault, if positive sequence voltage is not available for polarizing the directional element, the TPU L500 relies on the memory of the pre-fault voltage to determine fault direction. Besides that, the pre-fault voltage is always used for polarization immediately after fault inception, regardless of the type of fault, so that the relay decision is not affected by voltage signal transients. Special arrangements are also made to compensate for the phase rotation due to frequency variations during the time the memory is active. This type of polarization corresponds, in the impedance plane, to an impedance displacement dependent on line impedance (Z_1), equivalent impedance of the system upstream the line (Z_{1S}) and equivalent impedance of the system downstream of the line (Z_{1R}). So two faults close to the relay location, but one downstream (Figure 5.6 a) and another upstream (Figure 5.6 b), are correctly differentiated.

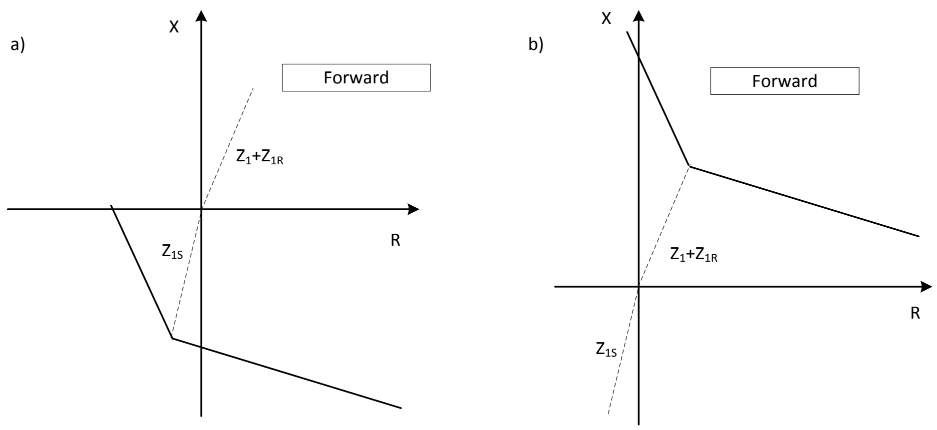

Figure 5.6. Polarization effect in directional characteristic for fault in front of the relay a) and behind the relay b).

The memory of the pre-fault voltages is kept during approximately two seconds; in real operating conditions, this is usually enough to guarantee a safe trip decision. If nonetheless the fault condition persists after the memory timeout elapses, the protection maintains the directional decision that was taken before. On the other hand if, at the time of fault inception, there is no voltage memory nor fault positive sequence voltage, the directional element cannot operate and the direction **FORWARD** is assumed for all loops so that a trip can be issued.

The threshold for positive sequence voltage to be considered viable for polarization, is 10% of the rated VT primary voltage. This threshold is used both for fault voltage polarization decision and for pre-fault voltage memory saving.

The fault direction is signaled in function output **FaultDirection**, which has three possible values: **UNKNOWN**, **FORWARD** and **REVERSE**. The default entity state while no fault is detected is **UNKNOWN**.

In case of fault being detected in **FORWARD** or **REVERSE** direction, the pickup loops will be signaled with the respective directions in the outputs **LoopABFwd**, **LoopABRv**, **LoopBCFwd**, **LoopBCRv**, **LoopCAFwd**, **LoopCARv**, **LoopAFwd**, **LoopARv**, **LoopBFwd** , **LoopBRv** , **LoopCFwd** and **LoopCRv**.

Load Encroachment

During heavy load level profile, common in networks nowadays, the wanted fault resistance coverage can be compromised. To overcome this problem the Distance Protection function in TPU L500 is equipped with a built-in load encroachment algorithm capable of blocking the user defined load zones represented in Figure 5.7..

There are four separate load zones: two evaluated for loops phase-to-phase (one in direction forward and one in direction reverse) and two evaluated for loops phase-to-earth (also one in direction forward and one in direction reverse). The angles of load zones are defined in settings **AngleLoadPE** (for loops phase-to-earth) and **AngleLoadPP** (for loops phase-to-phase). Resistive reaches are defined in settings **RLoadPEFwd** (for forward loops phase-to-earth), **RLoadPERv** (for reverse loops phase-to-earth), **RLoadPPFwd** (for forward loops phase-to-phase) and **RLoadPPRv** (for reverse loops phase-to-phase). A built-in hysteresis of 2° in angles and 4% (with a minimal of 50mΩ) in impedances guarantees the adequate stability of the decision.

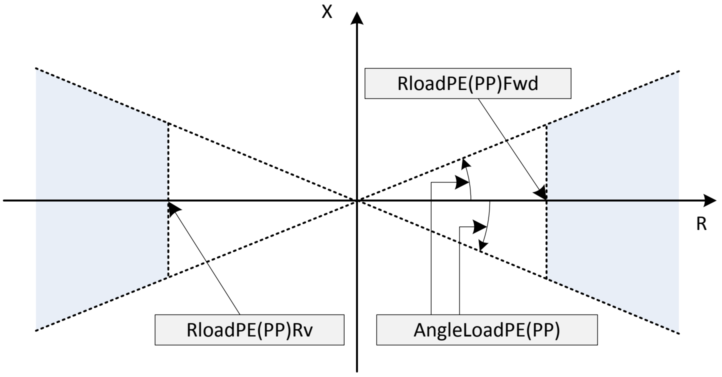

Figure 5.7. Load encroachment.

Blocking Conditions

The function provides an individual block input for each protection zone (**St1Block** to **St6Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition. The blocking condition is signaled in the corresponding stage output (**St1Blocked** to **St6Blocked**) and in case of a general block in output (**Blocked**).

In case of circuit breaker single-pole tripping capability, the Distance Protection should be informed of an open pole condition. Three independent inputs (**OpenPoleA**, **OpenPoleB** and **OpenPoleC**) are available for this purpose; they should be associated with the corresponding outputs of a separate open pole detector function. During open pole condition the loops that involve the open phase are blocked to prevent erroneous calculus.

TPU L500 provides an Open Pole function perfectly suited for detecting open pole conditions. (Please consult the corresponding subsection 5.30 - Open Pole Detection).

During power swing condition, Distance Protection application will see an oscillatory impedance measurement that can breach the protection zones. To prevent unwanted operations a dedicated input (**PSBlock**) is available to potentially block Distance Protection. The active zones behavior to this input (block or not block) is managed, individually by zone, according to the settings **St1PSBlock** to **St6PSBlock**. If the selected behavior is block (**StxPSBlock**=ON) during power swing conditions (**PSBlock** activated) the zone is prevented to pickup but not reseted, allowing non instantaneous tripping zones (that detected fault before the power swing condition) to provide normal backup duty.

TPU L500 provides a Power Swing detection function perfectly suited for detecting power swing conditions; the **DistBlock** output should be connected to **PSBlock** input (please consult the corresponding subsection 5.3 - Power Swing Blocking / Out-Of-Step Tripping).

A voltage transformer failure causes the loss of the polarization quantity. In case the MCB trips, no measuring voltage will be available for relay polarization in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, the positive sequence voltage cannot be calculated. In both cases, the impedance calculations will be compromised, so the Distance Protection should be immediately blocked. A dedicated input (**VTFail**) is available for this purpose.

TPU L500 provides a VT Fail detection function perfectly suited for detecting voltage transformer fail conditions (please consult the corresponding subsection 5.28 - VT Supervision).

Polygonal Characteristic

All protection zones are evaluated as polygonal type characteristics whenever the setting **OperatingChar** is **POL**, for all loops, or whenever the setting **OperatingChar** is **BOTH**, for loops phase-to-earth. This type of characteristic is represented in Figure 5.8 (example for a forward characteristic).

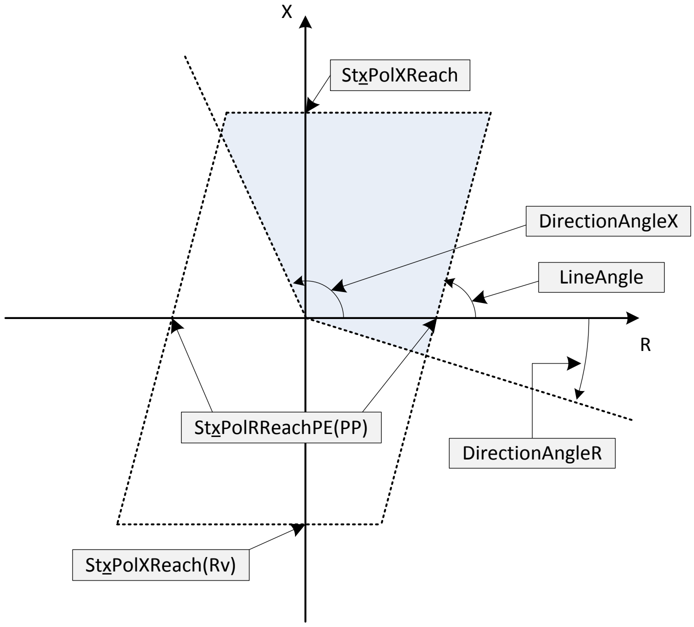

Figure 5.8. Polygonal forward characteristics.

The characteristic angle is defined for all zones in setting **LineAngle**. Reaches resistive and reactive are individually defined for each zone. The reactive reach is defined in settings **St1PolXReach** to **St6PolXReach** in primary ohms. Resistive reach is individually defined for loops phase-to-earth (settings **St1PolRReachPE** to **St6PolRReachPE**) and phase-to-phase (settings **St1PolRReachPP** to **St6PolRReachPP**) in primary ohms. A built-in hysteresis of 5% (with a minimal of 50mΩ) guarantees the adequate stability of the decision. The full characteristic is formed adding all zones characteristics and load encroachment as described in Figure 5.9.

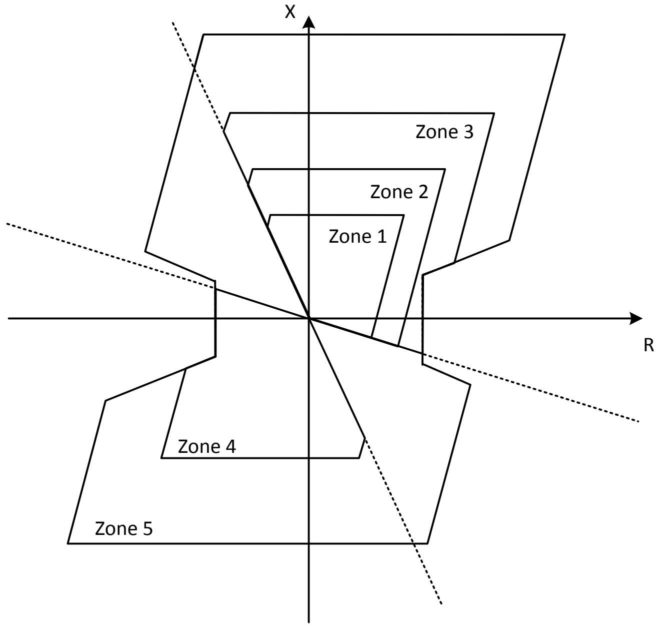

Figure 5.9. Complete polygonal characteristics.

Zone 5 was designed to be especially versatile, adapting to all desirable non directional characteristics, so the negative reactive reach can be independently defined (in setting **St5PolXReachRv**) from positive reactive reach (in setting **St5PolXReach**).

Distance Protection will evaluate the polygonal characteristics in different referential for loops phase-to-earth and phase-to-phase. In case of loops phase-to-phase, the widely known apparent impedance referential is used. For this reason, the resistive reach for this type of faults (**StxPolRReachPP**) should be half of intended fault resistance coverage. On the other hand, for loops phase-to-earth, special estimation techniques are employed to remove the influence of k_0. In this fully compensated referential it is plotted line impedance to fault plus fault resistance, without other influences, thus the resistive reach for this type of faults (**StxPolRReachPE**) should be the intended fault resistance coverage. It should be noted that the directional characteristic and the load encroachment are converted in order to be correctly plotted in the same compensated referential to form the full characteristic.

Mho Characteristic

All protection zones are evaluated as Mho type characteristics whenever the setting **OperatingChar** is **MHO**, for all loops, or whenever the setting **OperatingChar** is **BOTH**, for loops phase-to-phase. This type of characteristic is represented in Figure 5.10 (example of a non-directional characteristic).

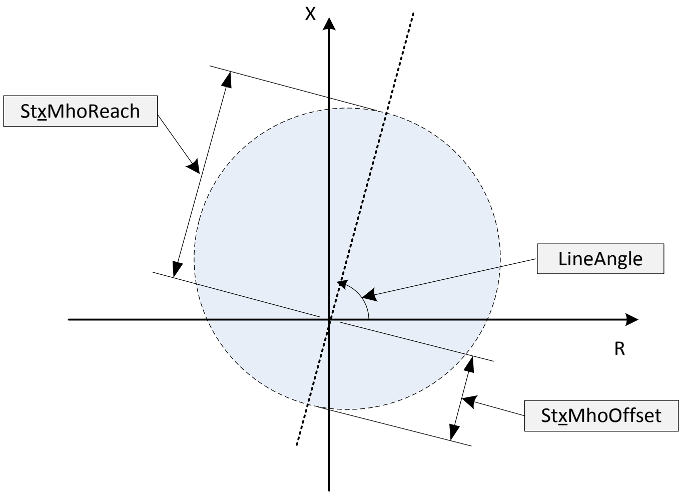

Figure 5.10. Mho non-directional characteristics.

The characteristic angle is defined for all zones in setting **LineAngle**. Reach is individually defined for each zone in settings **St1MhoReach** to **St6MhoReach**, in primary ohms. An offset, defined in setting **StxMhoOffset**, is added to the Mho characteristic for zones with **StxDirection** defined as **NON-DIRECTIONAL**. A built-in hysteresis of 5% (with a minimal of 50mΩ) guarantees the adequate stability of the decision. The full characteristic is formed adding load encroachment as described in Figure 5.11.

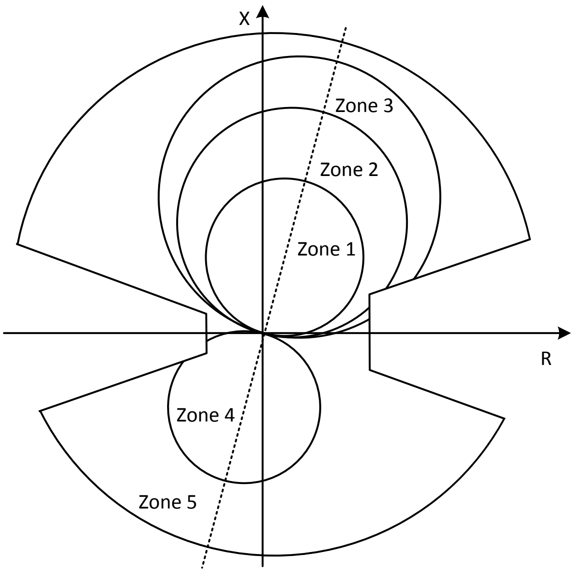

Figure 5.11. Complete Mho characteristics.

To prevent misoperation during close-in faults the directional Mho impedance comparator is polarized with positive sequence voltage. In case of a close-in three-phase fault, if positive sequence voltage is not available, the TPU L500 relies on the memory of the pre-fault positive sequence voltage to polarize the directional Mho impedance comparator. Besides that, the pre-fault voltage is always used for polarization immediately after fault inception, regardless of the type of fault, so that the relay decision is not affected by voltage signal transients. Special arrangements are also made to compensate for the phase rotation due to frequency variations during the time the memory is active.

The memory of the pre-fault voltages is kept during approximately two seconds; in real operating conditions, this is usually enough to guarantee a safe trip decision. If nonetheless the fault condition, with inexistent positive sequence voltage, persists after the memory timeout elapses, the protection maintains the pickup decisions for the directional Mho type characteristcs. On the other hand if, at the time of fault inception, there is no voltage memory nor fault positive sequence voltage, the directional Mho impedance comparator cannot operate and a pickup is issue for all F**ORWARD** zones.

Despite Mho type characteristics natural directional polarization, for security, the directional evaluation can be forced by setting **MhoDirElement**. When this setting is **ON** the directional evaluation is active, and loops with direction estimated different from the respective setting **StxDirection** will be blocked (please consult the corresponding subsection - Directionality).

Definite Time Characteristic

All protection zones (Zone 1 to zone 6) have definite time characteristic. The pickup is signaled when the measured impedance is inside the respective zone. It resets when the impedance is outside the respective reset zone, which is defined by the different reset elements of the characteristic combined.

The trip time is individually defined by zone and also by loop phase-to-earth and loop phase-to-phase (settings **St1TopPE** to **St6TopPE** and **St1TopPP** to **St1TopPP** respectively). If the operational time is set to zero, the trip will be instantaneous.

After a zone pickup both timers (for loop phase-to-earth and for loop phase-to-phase) are started, whatever the fault loop(s) detected. The zone trip will occur when the presently calculated fault loop timer has elapsed. This way, the tripping time is always measured from the beginning of the fault even if it has begun in a different loop. This behavior is particularly importante in case of evolving faults.

Timer Solidarity

There are two ways of configuring the start for zone trip timers. They can be started with the respective zone pickup (setting **TimerSolidarity** set to OFF), or with any zone pickup (setting **TimerSolidarity** set to ON). Both configurations are described in Figure 5.12.

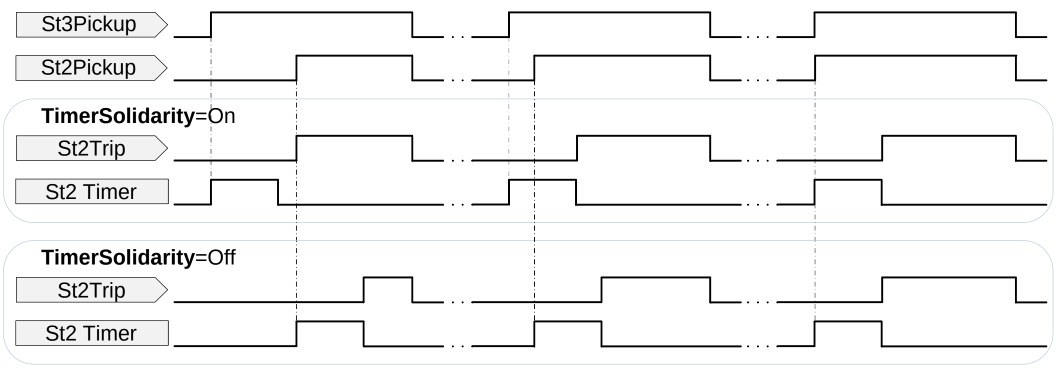

Figure 5.12. Timer solidarity.

Zone 1 and 6 Special Behavior

The Distance Protection algorithm available in TPU L500 is very fast and reliable in the detection and discrimination of faults. Zone 1 is especially fit to detect faults inside the protection line and to issue subcycle trip signals. In order to prevent unreliable subcycle operations, the algorithm is capable of dynamically tune the sensitivity of the function to the conditions of the system. This dynamic tuning allows the best possible distance vs. tripping time to fault distribution.

Zone 6 is suited for serve has Zone 1 overreach. For this purpose it has all the special features of Zone 1, and it can be dynamically activated from a dedicated input (**St6Enable**). If this input is signaled and the zone is not blocked by the inputs **St6Block** or **Block** the Zone 6 is activated and the output **St6Enabled** is signaled (provided that the Zone is active by the setting **St6Operation**). This flexible interface allows the Zone 6 to be used in any user defined configuration.

Compensation of Parallel Line

The main impedance estimation algorithm can take into account the mutual inductive coupling between the protected line and one parallel line, which may influence distance measurement for phase-to-earth faults. To enable the compensation of the zero sequence mutual coupling, the setting **ParallelLineCmp** should be set to ON and the residual current measured in the parallel line should be associated to the input **I0**. For a phase-to-earth fault in phase x, the algorithm compensates for the effect of the residual current in the protected line ($3I_0$) and in the parallel line ($3I_{0,parallel}$) according to equation (5.5).

$$V_x = n \cdot Z_1 \cdot \left(I_x + k_0 \cdot 3I_o + k_{0M} \cdot 3I_{o,parallel}\right) \tag{5.5}$$

Where:

$3I_{o,parallel}$ = residual current in the parallel line

$k_{0M} = \dfrac{Z_{0M}}{3Z_1}$ (Z_{0M} = zero sequence mutual impedance)

The compensating factor k_{0M} is equal for all protection zones and is available in settings **KmMag** and **KmAngle**.

Series Compensated Lines

During a fault behind a series capacitors bank, if the protective spark gap does not pickup, the fault voltage can be inverted thus the directional decision is severely compromised. To overcome this problem, the Distance Protection in TPU L500 uses stored voltage memory through the fault. With this polarization the directional characteristic (shown in Figure 5.6) is capable of correctly determine de direction, as long as the capacitors bank impedance is lower than source impedance (which is always true). Special arrangements are made to compensate for the phase rotation due to frequency variations during the time the memory is active. The setting **SeriesCompensated** is used to enable this compensation.

Non-homogeneous Systems

As shown in equation (5.2), remote in-feed and fault resistance can significantly influence the impedance estimation. The Distance Protection algorithm in TPU L500 is capable of compensating these effects, provided that the system is homogeneous. However, if the system is non-homogeneous, in order to reduce the impact of load or fault resistance, the device should be provided with a compensating angle (setting **NoHomogCompAngle**). This compensating angle should be calculated from the equivalent zero sequence impedance of the system upstream the line (Z_{0S}), the equivalent zero sequence impedance of the system downstream the line (Z_{0R}) and the line zero sequence impedance (Z_{0L}) as shown in equation (5.6).

$$\textbf{NoHomogCompAngle} = -\angle\left(\frac{\frac{Z_{0L}}{2} + Z_{0R}}{Z_{0S} + Z_{0L} + Z_{0R}}\right) \tag{5.6}$$

If this setting is other than zero, the non-homogeneous compensation will become active for Zone 1 and Zone 6.

Capacitive Voltage Transformers

Capacitive voltage transformers are common in high and very high voltages transmission lines. Typically these voltage transformers have a very adverse transient response that can compromise fast reliable tripping of Distance Protection. To overcome this problem the Distance Protection algorithm in TPU L500 implements a delay to accommodate the transient response of the CVT. This delay is configurable in setting **CVTDelay**. From the directional decision point of view, the transient response of the CVT can be disregarded because of the memory polarization.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I** or input **U**;
- The analogue channel associated to input **I** does not correspond to a group of three phase current signals;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals;

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There is one or more open pole inputs (**OpenPoleA**, **OpenPoleB**, and **OpenPoleC**) connected but not all three: the function will disregard the existing open pole information.
- The setting **ParallelLineCmp** is set to ON and there is no analogue group associated to input **I0** or it does not correspond to a neutral or to a group of three phase current signals: the compensation of the zero sequence mutual coupling with the parallel line is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.2.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.10 and Table 5.11, respectively.

Table 5.10. Distance function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
I0	I0	ANL CH	-	Neutral current
U	U	ANL CH	-	Phase voltages
Block	Block	DIG	4	Function block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
St5Block	St5 Block	DIG	2	Stage 5 block
St6Block	St6 Block	DIG	2	Stage 6 block
OpenPoleA	Open Pole A	DIG	2	Open pole, phase A
OpenPoleB	Open Pole B	DIG	2	Open pole, phase B
OpenPoleC	Open Pole C	DIG	2	Open pole, phase C
VTFail	VT Failure	DIG	2	Voltage transformer failure
PSBlock	PS Block	DIG	2	Power swing block
St6Active	St6 Active	DIG	4	Stage 6 enable

Table 5.11. Distance function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
St5Behavior	St5 Behavior	INT	-	Stage 5 operation mode

Identifier	Title	Type	NV	Description
St6Behavior	St6 Behavior	INT	-	Stage 6 operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St5Blocked	St5 Blocked	DIG	-	Stage 5 blocked
St6Blocked	St6 Blocked	DIG	-	Stage 6 blocked
Pickup	Pickup	DIG	-	Function general start
PickupA	Pickup A	DIG	-	Function general start, phase A
PickupB	Pickup B	DIG	-	Function general start, phase B
PickupC	Pickup C	DIG	-	Function general start, phase C
PickupN	Pickup N	DIG	-	Function general start, neutral
Trip	Trip	DIG	-	Function general trip
TripA	Trip A	DIG	-	Function general trip, phase A
TripB	Trip B	DIG	-	Function general trip, phase B
TripC	Trip C	DIG	-	Function general trip, phase C
LoopABFwd	Loop AB Fwd	DIG	-	Fault detected in loop AB, forward direction
LoopABRv	Loop AB Rv	DIG	-	Fault detected in loop AB, reverse direction
LoopBCFwd	Loop BC Fwd	DIG	-	Fault detected in loop BC, forward direction
LoopBCRv	Loop BC Rv	DIG	-	Fault detected in loop BC, reverse direction
LoopCAFwd	Loop CA Fwd	DIG	-	Fault detected in loop CA, forward direction
LoopCARv	Loop CA Rv	DIG	-	Fault detected in loop CA, reverse direction
LoopA0Fwd	Loop A0 Fwd	DIG	-	Fault detected in loop A0, forward direction
LoopA0Rv	Loop A0 Rv	DIG	-	Fault detected in loop A0, reverse direction
LoopB0Fwd	Loop B0 Fwd	DIG	-	Fault detected in loop B0, forward direction
LoopB0Rv	Loop B0 Rv	DIG	-	Fault detected in loop B0, reverse direction
LoopC0Fwd	Loop C0 Fwd	DIG	-	Fault detected in loop C0, forward direction
LoopC0Rv	Loop C0 Rv	DIG	-	Fault detected in loop C0, reverse direction
FaultType	Fault Type	INT	-	Fault type
FaultDirection	Fault Direction	INT	-	Fault direction indication
St1PickupA	St1 Pickup A	DIG	-	Stage 1 start, phase A
St1PickupB	St1 Pickup B	DIG	-	Stage 1 start, phase B
St1PickupC	St1 Pickup C	DIG	-	Stage 1 start, phase C
St1PickupN	St1 Pickup N	DIG	-	Stage 1 start, neutral
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St1TripA	St1 Trip A	DIG	-	Stage 1 trip, phase A
St1TripB	St1 Trip B	DIG	-	Stage 1 trip, phase B

Identifier	Title	Type	NV	Description
St1TripC	St1 Trip C	DIG	-	Stage 1 trip, phase C
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2PickupA	St2 Pickup A	DIG	-	Stage 2 start, phase A
St2PickupB	St2 Pickup B	DIG	-	Stage 2 start, phase B
St2PickupC	St2 Pickup C	DIG	-	Stage 2 start, phase C
St2PickupN	St2 Pickup N	DIG	-	Stage 2 start, neutral
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St2TripA	St2 Trip A	DIG	-	Stage 2 trip, phase A
St2TripB	St2 Trip B	DIG	-	Stage 2 trip, phase B
St2TripC	St2 Trip C	DIG	-	Stage 2 trip, phase C
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3PickupA	St3 Pickup A	DIG	-	Stage 3 start, phase A
St3PickupB	St3 Pickup B	DIG	-	Stage 3 start, phase B
St3PickupC	St3 Pickup C	DIG	-	Stage 3 start, phase C
St3PickupN	St3 Pickup N	DIG	-	Stage 3 start, neutral
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St3TripA	St3 Trip A	DIG	-	Stage 3 trip, phase A
St3TripB	St3 Trip B	DIG	-	Stage 3 trip, phase B
St3TripC	St3 Trip C	DIG	-	Stage 3 trip, phase C
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4PickupA	St4 Pickup A	DIG	-	Stage 4 start, phase A
St4PickupB	St4 Pickup B	DIG	-	Stage 4 start, phase B
St4PickupC	St4 Pickup C	DIG	-	Stage 4 start, phase C
St4PickupN	St4 Pickup N	DIG	-	Stage 4 start, neutral
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St4TripA	St4 Trip A	DIG	-	Stage 4 trip, phase A
St4TripB	St4 Trip B	DIG	-	Stage 4 trip, phase B
St4TripC	St4 Trip C	DIG	-	Stage 4 trip, phase C
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
St5PickupA	St5 Pickup A	DIG	-	Stage 5 start, phase A
St5PickupB	St5 Pickup B	DIG	-	Stage 5 start, phase B
St5PickupC	St5 Pickup C	DIG	-	Stage 5 start, phase C
St5PickupN	St5 Pickup N	DIG	-	Stage 5 start, neutral
St5Pickup	St5 Pickup	DIG	-	Stage 5 general start
St5TripA	St5 Trip A	DIG	-	Stage 5 trip, phase A
St5TripB	St5 Trip B	DIG	-	Stage 5 trip, phase B
St5TripC	St5 Trip C	DIG	-	Stage 5 trip, phase C
St5Trip	St5 Trip	DIG	-	Stage 5 general trip

Identifier	Title	Type	NV	Description
St6PickupA	St6 Pickup A	DIG	-	Stage 6 start, phase A
St6PickupB	St6 Pickup B	DIG	-	Stage 6 start, phase B
St6PickupC	St6 Pickup C	DIG	-	Stage 6 start, phase C
St6PickupN	St6 Pickup N	DIG	-	Stage 6 start, neutral
St6Pickup	St6 Pickup	DIG	-	Stage 6 general start
St6TripA	St6 Trip A	DIG	-	Stage 6 trip, phase A
St6TripB	St6 Trip B	DIG	-	Stage 6 trip, phase B
St6TripC	St6 Trip C	DIG	-	Stage 6 trip, phase C
St6Trip	St6 Trip	DIG	-	Stage 6 general trip
St6Active	St6 Active	DIG	-	Stage 6 enabled

5.2.4 Settings

The function settings are listed in Table 5.12.

Table 5.12. Distance function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
IMin	I Minimum	[0,05..10,0] × I_r	0,05	Minimal phase current for fault detection
IresMin	Ires Minimum	[0,05..10,0] × I_r	0,10	Minimal residual current for earth fault detection
RLoadPEFwd	R Load PE Fwd	[0,05..600,0] Ω	10,0	Phase earth load resistive reach for forward loops
RLoadPPFwd	R Load PP Fwd	[0,05..600,0] Ω	10,0	Phase phase load resistive reach for forward loops
RLoadPERv	R Load PE Rv	[0,05..600,0] Ω	10,0	Phase earth load resistive reach for reverse loops
RLoadPPRv	R Load PP Rv	[0,05..600,0] Ω	10,0	Phase phase load resistive reach for reverse loops
AngleLoadPE	Ang Load PE	[5,0..45,0] °	30,0	Phase earth load angle area
AngleLoadPP	Ang Load PP	[5,0..45,0] °	30,0	Phase phase load angle area
LineAngle	Line Angle	[30,0..90,0] °	80,0	Line angle
KmMag	Km Magnitude	[0,0..4,0]	1,0	Mutual compensation factor magnitude
KmAngle	Km Angle	[-180,0..180,0] °	0,0	Mutual compensation factor angle
PPELoopSel	PPE Loop Selection	PHASE-PHASE / ALL	PHASE-PHASE	Loop selection for phase-phase-earth faults
DirAngleR	Dir Angle Min	[-60,0..0,0] °	-30,0	Minimum angle in forward direction

Identifier	Title	Range	Factory value	Description
DirAngleX	Dir Angle Max	[90,0..150,0] °	110,0	Maximum angle in forward direction
OperatingChar	Operating Char	POL / MHO / BOTH	POL	Operating characteristic
MhoDirElemen	Mho Dir Oper	OFF / ON	OFF	Mho directional element operation
CVTDelay	CVT Delay	[0..40] ms	0	Delay due to capacitive voltage tranformer
NoHomogCompAngle	No Homog Comp Ang	[-40,0..40,0] °	0,0	Compensation angle for no homogeneous systems
SeriesCompensated	Series Compensated	OFF / ON	OFF	Series compensated operation
TimerSolidarity	Timer Solidarity	OFF/ON	OFF	Timer solidarity operation
ParallelLineCmp	Parallel Line Cmp	OFF/ON	OFF	Parallel line compensation
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1PSBlock	St1 PS Block	OFF / ON	OFF	Stage 1 power swing block
St1Dir	St1 Direction	NON-DIR / FORWARD / REVERSE	FORWARD	Stage 1 direction
St1K0Mag	St1 K0 Magnitude	[0,0..4,0]	1,0	Stage 1 earth compensation factor magnitude
St1K0Angle	St1 K0 Angle	[-180,0..180,0] °	0,0	Stage 1 earth compensation factor angle
St1TopPE	St1 Top PE	[0..60000] ms	0	Stage 1 operation delay time for phase earth loops
St1TopPP	St1 Top PP	[0..60000] ms	0	Stage 1 operation delay time for phase phase loops
St1PolXReach	St1 Pol X Reach	[0,05..500,0] Ω	4,0	Stage 1 polygonal reactive reach
St1PolRReachPE	St1 Pol R Reach PE	[0,05..500,0] Ω	8,0	Stage 1 polygonal resistive reach for phase earth loops
St1PolRReachPP	St1 Pol R Reach PP	[0,05..500,0] Ω	4,0	Stage 1 polygonal resistive reach for phase phase loops
St1MhoReach	St1 Mho Reach	[0,05..500,0] Ω	4,0	Stage 1 Mho characteristic polar reach
St1MhoOffset	St1 Mho Offset	[0,05..500,0] Ω	0,05	Stage 1 Mho characteristic offset
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2PSBlock	St2 PS Block	OFF / ON	OFF	Stage 2 power swing block
St2Dir	St2 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 2 direction
St2K0Mag	St2 K0 Magnitude	[0,0..4,0]	1,0	Stage 2 earth compensation factor magnitude
St2K0Angle	St2 K0 Angle	[-180,0..180,0] °	0,0	Stage 2 earth compensation factor angle
St2TopPE	St2 Top PE	[0..60000] ms	2500	Stage 2 operation delay time for phase earth loops

Identifier	Title	Range	Factory value	Description
St2TopPP	St2 Top PP	[0..60000] ms	2500	Stage 2 operation delay time for phase phase loops
St2PolXReach	St2 Pol X Reach	[0,05..500,0] Ω	16,0	Stage 2 polygonal reactive reach
St2PolRReachPE	St2 Pol R Reach PE	[0,05..500,0] Ω	32,0	Stage 2 polygonal resistive reach for phase earth loops
St2PolRReachPP	St2 Pol R Reach PP	[0,05..500,0] Ω	16,0	Stage 2 polygonal resistive reach for phase phase loops
St2MhoReach	St2 Mho Reach	[0,05..500,0] Ω	16,0	Stage 2 Mho characteristic polar reach
St2MhoOffset	St2 Mho Offset	[0,05..500,0] Ω	8,0	Stage 2 Mho characteristic offset
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3PSBlock	St3 PS Block	OFF / ON	OFF	Stage 3 power swing block
St3Dir	St3 Direction	NON-DIR / FORWARD / REVERSE	FORWARD	Stage 3 direction
St3K0Mag	St3 K0 Magnitude	[0,0..4,0]	1,0	Stage 3 earth compensation factor magnitude
St3K0Angle	St3 K0 Angle	[-180,0..180,0] °	0,0	Stage 3 earth compensation factor angle
St3TopPE	St3 Top PE	[0..60000] ms	0	Stage 3 operation delay time for phase earth loops
St3TopPP	St3 Top PP	[0..60000] ms	0	Stage 3 operation delay time for phase phase loops
St3PolXReach	St3 Pol X Reach	[0,05..500,0] Ω	4,0	Stage 3 polygonal reactive reach
St3PolRReachPE	St3 Pol R Reach PE	[0,05..500,0] Ω	8,0	Stage 3 polygonal resistive reach for phase earth loops
St3PolRReachPP	St3 Pol R Reach PP	[0,05..500,0] Ω	4,0	Stage 3 polygonal resistive reach for phase phase loops
St3MhoReach	St3 Mho Reach	[0,05..500,0] Ω	4,0	Stage 3 Mho characteristic polar reach
St3MhoOffset	St3 Mho Offset	[0,05..500,0] Ω	0,05	Stage 3 Mho characteristic offset
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4PSBlock	St4 PS Block	OFF / ON	OFF	Stage 4 power swing block
St4Dir	St4 Direction	NON-DIR / FORWARD / REVERSE	FORWARD	Stage 4 direction
St4K0Mag	St4 K0 Magnitude	[0,0..4,0]	1,0	Stage 4 earth compensation factor magnitude
St4K0Angle	St4 K0 Angle	[-180,0..180,0] °	0,0	Stage 4 earth compensation factor angle
St4TopPE	St4 Top PE	[0..60000] ms	0	Stage 4 operation delay time for phase earth loops
St4TopPP	St4 Top PP	[0..60000] ms	0	Stage 4 operation delay time for phase phase loops
St4PolXReach	St4 Pol X Reach	[0,05..500,0] Ω	4,0	Stage 4 polygonal reactive reach

Identifier	Title	Range	Factory value	Description
St4PolRReachPE	St4 Pol R Reach PE	[0,05..500,0] Ω	8,0	Stage 4 polygonal resistive reach for phase earth loops
St4PolRReachPP	St4 Pol R Reach PP	[0,05..500,0] Ω	4,0	Stage 4 polygonal resistive reach for phase phase loops
St4MhoReach	St4 Mho Reach	[0,05..500,0] Ω	4,0	Stage 4 Mho characteristic polar reach
St4MhoOffset	St4 Mho Offset	[0,05..500,0] Ω	0,05	Stage 4 Mho characteristic offset
St5Operation	St5 Operation	OFF / ON	OFF	Stage 5 operation
St5PSBlock	St5 PS Block	OFF / ON	OFF	Stage 5 power swing block
St5Dir	St5 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 5 direction
St5K0Mag	St5 K0 Magnitude	[0,0..4,0]	1,0	Stage 5 earth compensation factor magnitude
St5K0Angle	St5 K0 Angle	[-180,0..180,0] °	0,0	Stage 5 earth compensation factor angle
St5TopPE	St5 Top PE	[0..60000] ms	2500	Stage 5 operation delay time for phase earth loops
St5TopPP	St5 Top PP	[0..60000] ms	2500	Stage 5 operation delay time for phase phase loops
St5PolXReach	St5 Pol X Reach	[0,05..500,0] Ω	16,0	Stage 5 polygonal reactive reach
St5PolRReachPE	St5 Pol R Reach PE	[0,05..500,0] Ω	32,0	Stage 5 polygonal resistive reach for phase earth loops
St5PolRReachPP	St5 Pol R Reach PP	[0,05..500,0] Ω	16,0	Stage 5 polygonal resistive reach for phase phase loops
St5PolXReachRv	St5 Pol X Reach Rv	[0,05..500,0] Ω	8,0	Stage 5 polygonal reactive reach for reverse faults
St5MhoReach	St5 Mho Reach	[0,05..500,0] Ω	16,0	Stage 5 Mho characteristic polar reach
St5MhoOffset	St5 Mho Offset	[0,05..500,0] Ω	8,0	Stage 5 Mho characteristic offset
St6Operation	St6 Operation	OFF / ON	OFF	Stage 6 operation
St6PSBlock	St6 PS Block	OFF / ON	OFF	Stage 6 power swing block
St6Dir	St6 Direction	NON-DIR / FORWARD / REVERSE	FORWARD	Stage 6 direction
St6K0Mag	St6 K0 Magnitude	[0,0..4,0]	1,0	Stage 6 earth compensation factor magnitude
St6K0Angle	St6 K0 Angle	[-180,0..180,0] °	0,0	Stage 6 earth compensation factor angle
St6TopPE	St6 Top PE	[0..60000] ms	0	Stage 6 operation delay time for phase earth loops
St6TopPP	St6 Top PP	[0..60000] ms	0	Stage 6 operation delay time for phase phase loops
St6PolXReach	St6 Pol X Reach	[0,05..500,0] Ω	8,0	Stage 6 polygonal reactive reach

Identifier	Title	Range	Factory value	Description
St6PolRReachPE	St6 Pol R Reach PE	[0,05..500,0] Ω	16,0	Stage 6 polygonal resistive reach for phase earth loops
St6PolRReachPP	St6 Pol R Reach PP	[0,05..500,0] Ω	8,0	Stage 6 polygonal resistive reach for phase phase loops
St6MhoReach	St6 Mho Reach	[0,05..500,0] Ω	8,0	Stage 6 Mho characteristic polar reach
St6MhoOffset	St6 Mho Offset	[0,05..500,0] Ω	0,05	Stage 6 Mho characteristic offset

5.3 Power Swing Blocking / Out-Of-Step Tripping

5.3.1 Introduction

Routine exploration of power systems can originate disturbances capable of causing transient loss of stable operation between rotating machines. The most typical of these disturbances are load profile changes and network topology changes (caused either by faults and their clearance or switching actions). The loss of stable operation is characterized by an oscillatory power flow (power swing) as the rotating machines try to adjust to the new point of system operation. The impedance variation that occurs during power swing can jeopardize protection functions decisions which operate according to the impedance measurements as in Distance Protection. Power Swing Blocking is responsible for detecting power swing situations and prevents incorrect operation of Distance Protection.

Severe power swings can lead to a permanently unstable operation of the power system. Out-Of-Step Tripping is responsible for detecting this condition and determines the controlled disconnection of the line.

5.3.2 Operation Method

Power swing situations are normally detected by evaluations of impedance variations. This method is largely dependent of the correct determination of the system impedances; which is typically very difficult to achieve. Therefore the algorithm implemented in Power Swing Blocking / Out-Of-Step Tripping is largely independent of system parameters. The function can be activated by setting **Operation**. In particular, the Out-Of-Step Tripping can be activated be setting **OOSTripEnable**.

Measuring Principle

Power swing detection is based on the temporal evolution of the swing-centre voltage (Figure 5.13). The swing-centre is defined as the location of a two-source equivalent system where voltage is zero when the two sources are in phase opposition. This quantity can be estimated from the three phase local current and the three phase-to-earth local voltage, associated in two channels connected to inputs **I** and **U** respectively.

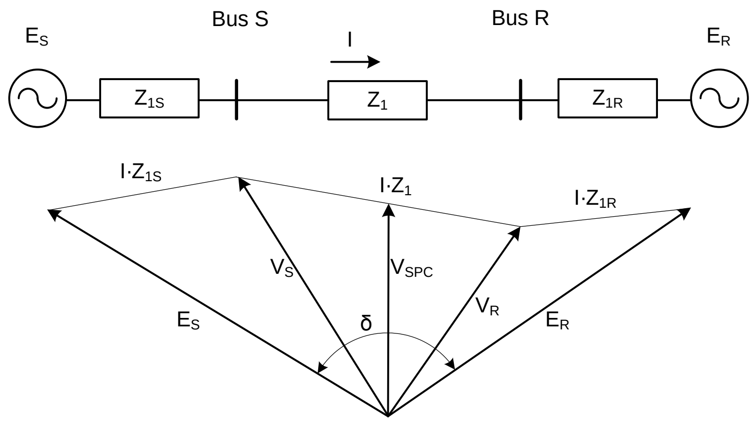

Figure 5.13. Phasor diagram of the two sources equivalent system.

The algorithm implemented in Power Swing function, is capable of detecting stable and unstable oscillations in a wide range of slip frequencies, even in particularly difficult system conditions like open pole dead time. The only system parameter necessary to do so is the system characteristic angle configured in setting **SystemAngle**; which in most applications can be approximated by the line angle.

In order to adapt to a single pole dead time condition, possible if the circuit breaker is capable of single-pole tripping, an external open pole detector must be provided and connected to dedicated input **OpenPole**.

TPU L500 provides an Open Pole function perfectly suited for detecting open pole conditions. (Please consult the corresponding subsection 5.30 - Open Pole Detection).

When a power swing condition is detected it is immediately signaled in the output **PSDetected**. At the same time, the function signals an independent output used for blocking Distance Protection (**DistBlock**).

The blocking of Distance Protection is made by user configuration. To do so, the output **DistBlock** shall be connected to Distance protection input **PSBlock**. The blocked zones are managed in Distance Protection (Please consult the corresponding subsection 5.2 - Distance).

Any fault occurring during a power swing condition should immediately lead to unblock of distance protection to ensure convenient tripping decision and fault elimination. The algorithm is capable of detecting every type of fault (phase-to-earth, phase-to-phase, phase-to-phase-to-earth and three-phase) in a broad type of system conditions, including open pole dead time, and rapidly unblock Distance Protection, by resetting the outputs **PSDetected** and **DistBlock**. Special measures are taken to ensure that even when a fault occurs in the system swing-center, and incepts exactly when the swing-center voltage is zero, it is properly detected and Distance Protection promptly unblocked.

Out-of-Step Tripping

The angle difference between the theoretical sources of a two-source equivalent system (δ in Figure 5.13 and Figure 5.14) can be estimated from the swing-center voltage. Whenever a power swing is detected this angle is calculated and compared with the desired trip angle. If the angle between the sources passes through 180° the system stability was definitely lost and will never recover so the out-of-step condition is signaled in the output **OOSDetected**.

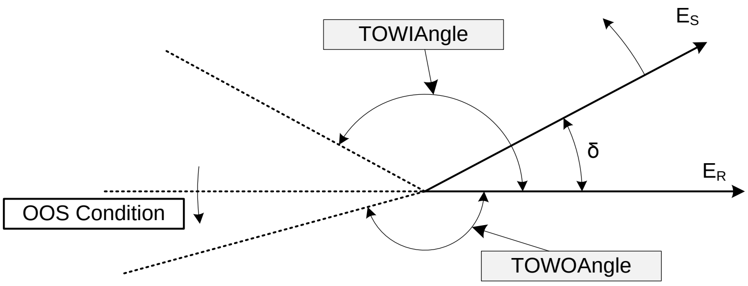

Figure 5.14. Phasor diagram of Out-of-Step condition.

The tripping order is issued according to setting **OOSTripEnable**. If out-of-step trip is enabled (**OOSTripEnable** = **ON**) the function offers two tripping options according to setting **OOSTripType** (as described in Figure 5.14): Trip can be issued before the out-of-step condition is reached and when the angle between the two sources passes **TOWIAngle** (selected if **OOSTripType** = **TOWI**); Trip can be issued after the out-of-step condition is reached and when the angle between the two sources passes **TOWOAngle** (selected if **OOSTripType** = **TOWO**).

If the tripping was issued (**OOSTripEnable** is **ON** and tripping conditions were met), the decision of power swing and out-of-step will only reset when the circuit breaker opens and the current disappears, this means that the outputs **OOSDetected**, **OOSTrip**, **PSDetected** and **DistBlock** will stay active until then. On the other hand, if out-of-step tripping is disabled or if the conditions of tripping were not yet met, the **OOSDetected** output will reset and possible out-of-step trip blocked if the power swing decision is reset.

Blocking Conditions

The function provides a general function block input (**Block**). It can be freely associated to any user-defined condition. The blocking condition is signaled in the corresponding output (**Blocked**).

A voltage transformer failure will result in unreliable line voltage measurement. If MCB trips, no measuring voltage will be available for relay in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, one or two of line voltages are not available. In both cases, the general operation method of the function will be compromised, so the Power Swing Blocking / Out-Of-Step Tripping should be immediately blocked. A dedicated input (**VTFail**) is available for this purpose.

TPU L500 provides a VT Fail detection function perfectly suited for detecting voltage transformer fail conditions (please consult the corresponding subsection 5.28 - VT Supervision).

Reset Time

After a stable power swing condition the reset of the power swing indications can be delayed according to setting **UnblockTime**.

The maximum time allowed for the Power Swing function to block Distance function is defined in setting **MaxBlockTime**. After this time has elapsed the function will reset all its outputs regardless of the system conditions (**MaxBlockTime** prevails over **UnblockTime**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I** or input **U**;
- The analogue channel associated to input **I** does not correspond to a group of three phase current signals;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals;

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There is no connection to the input **DistPickup**: the function will not become blocked when Distance pickups.

The configuration is valid and the function operates accordingly otherwise.

5.3.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.13 and Table 5.14, respectively.

Table 5.13. Power Swing Blocking / Out-of-Step Tripping function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
U	U	ANL CH	-	Phase voltages
Block	Block	DIG	4	Function block
OpenPole	Open Pole	DIG	1	Open pole
VTFail	VT Failure	DIG	1	Voltage transformer failure

Table 5.14. Power Swing Blocking / Out-of-Step Tripping function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health

Identifier	Title	Type	NV	Description
Blocked	Blocked	DIG	-	Function blocked
PSDetected	PS Detected	DIG	-	Power swing detected
DistBlock	Distance Block	DIG	-	Distance blocked
OOSDetected	OOS Detected	DIG	-	Out-of-step detected
OOSTrip	OOS Trip	DIG	-	Out-of-step trip

5.3.4 Settings

The function settings are listed in Table 5.15.

Table 5.15. Power Swing Blocking / Out-of-Step Tripping function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
OOSTripEnable	OOS Trip Enable	OFF / ON	OFF	Out-of-step trip enable
OOSTripType	OOS Trip Type	TOWI / TOWO	TOWI	Out-of-step trip type
SystemAngle	System Angle	[30,0..90,0] °	80,0	System characteristic angle
TOWOAngle	TOWO Angle	[30,0..180,0] °	120,0	TOWO angle
TOWIAngle	TOWI Angle	[30,0..180,0] °	180,0	TOWI angle
UnblockTime	Unblock Time	[0..10000] ms	0	Unblock time under stationary conditions
MaxBlockTime	Max Block Time	[0..60000] ms	60000	Maximum block time

5.4 Distance Teleprotection Schemes

5.4.1 Introduction

A very fast tripping time is required to preserve power system stability during the occurrence of network faults. However, in transmission lines, faults beyond the first distance zone reach can only be cleared by the second distance zone after a settable time delay, so that the selectivity with the protection relays in the adjacent lines is not compromised. On very short lines, a first instantaneous zone may not even be possible to set.

The purpose of Teleprotection Schemes associated with Distance Protection is to trip almost instantaneously irrespective of the location of the fault in the protected line, by exchanging directional information between the line terminals through communication channels. Distance Protection, which is inherently directional and quite immune to system impedance changes, is suitable for this application. Several options can be considered, ranging from permissive schemes, which tend to be faster and more secure against false tripping, to blocking schemes that by the contrary are usually more dependable.

5.4.2 Operation Method

The Distance Teleprotection Schemes function can be activated by setting change (setting **Operation**). Several logic schemes are available as built-in options that can be selected in setting **DisScheme**:

- Permissive Underreach Transfer Trip (PUTT) scheme logic: **DisScheme** = **PUTT**;
- Permissive Overreach Transfer Trip (POTT) scheme logic: **DisScheme** = **POTT**;
- Directional Comparison Blocking (DCB) scheme logic: **DisScheme** = **DCB**.

Additional logic options can be configured to complement the previous communication schemes:

- Directional Comparison Unblocking (DCUB) scheme logic;
- Current Reversal logic;
- Open Circuit Breaker logic.

Finally, special modes concerning weak infeed sources can be activated in setting **EchoMode**:

- Echo Transmission logic: **EchoMode** = **ECHO** or **ECHO+TRIP**;
- Weak Infeed (WI) Trip logic: **EchoMode** = **TRIP** or **ECHO+TRIP**.

The function can be used in association with different communication interfaces, according to the several options available in the TPU L500. It can also be associated with binary inputs and outputs.

Permissive Underreach Transfer Trip (PUTT) Scheme Logic

In the PUTT scheme, the trip of a forward underreach Distance measuring zone is sent as a permissive signal to the remote line ends. The reception of this signal initiates a remote trip if the presence of a fault inside the protected zone is confirmed by the pickup of a forward overreach measuring zone. The measuring principle is shown in Figure 5.15.

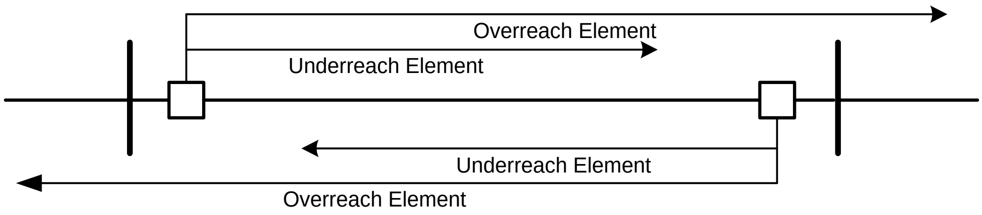

Figure 5.15. Permissive Underreach Transfer Trip (PUTT) scheme.

The transmission logic of the PUTT scheme is shown in Figure 5.16.

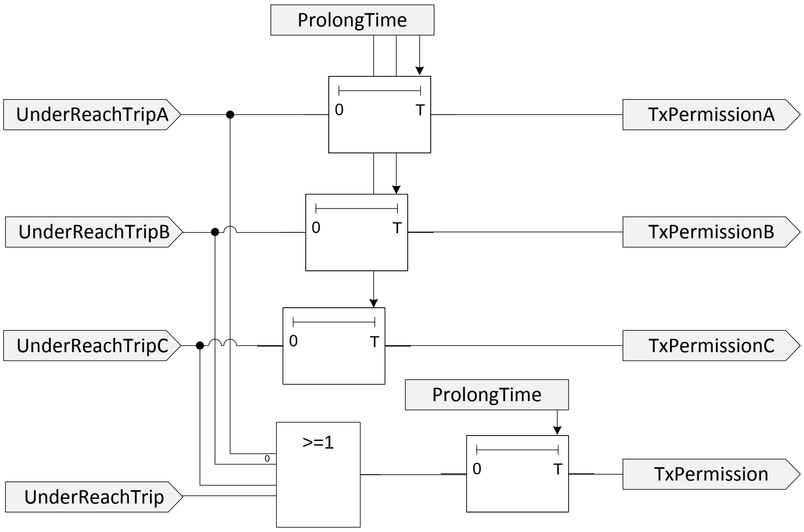

Figure 5.16. Permissive Underreach Transfer Trip (PUTT) transmission logic.

In most cases, this module can be activated by associating the trip signal from a selected Distance Protection zone (typically zone 1) to the function input **UnderReachTrip**. The output signal **TxPermission** should be associated to a remote end communication channel or to a binary output, depending on the communication interface being used. In case of three-end lines, **TxPermission** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs.

As an alternative, phase-segregated trip signals can be transmitted to the remote end if inputs **UnderReachTripA**, **UnderReachTripB** and **UnderReachTripC** are associated, for example, with the corresponding outputs of a Distance zone. The output signals **TxPermissionA**, **TxPermissionB** and **TxPermissionC** should be configured in the same way as **TxPermission** in the previous example. Phase segregated communication should be used when three communication channels are available and discrimination of simultaneous phase-to-earth faults is required. **TxPermission** will also be available to send to the remote end, as the logical OR of the three phase input signals.

Whatever the chosen option is, the transmitted signal or signals can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input trip signal. This guarantees a minimum duration of the pulse sent, compensating for eventual differences in the pickup time of the protection zones in the several line terminals.

The receive logic of the PUTT scheme function is shown in Figure 5.17.

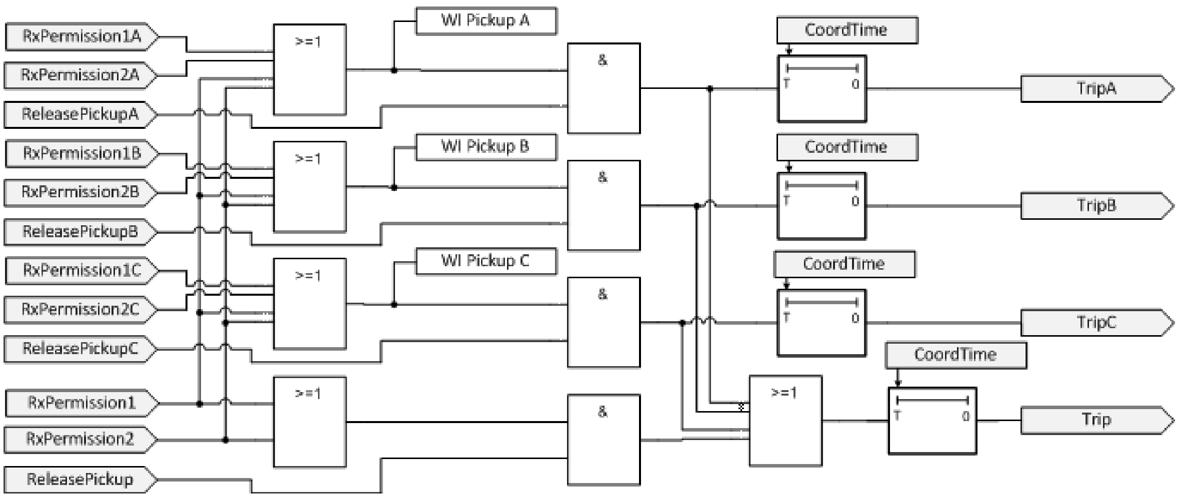

Figure 5.17. Permissive Underreach Transfer Trip (PUTT) receive logic (three line ends).

When only three-phase transfer trip signals are exchanged, function inputs **RxPermission1** and/or **RxPermission2** should be associated to remote end communication channels or to binary inputs, depending on the number of line ends. The reception of any of these signals leads to a function trip, if confirmed by the pickup of a forward overreach Distance zone. In three-pole tripping applications, that pickup should be associated with input **ReleasePickup**. If single-phase tripping is required, phase selection should be guaranteed by the local overreach Distance zone, by means of function inputs **ReleasePickupA**, **ReleasePickupB** and **ReleasePickupC**.

The reception of phase-segregated trip signals is also possible. For this purpose, **RxPermission1A**, **RxPermission1B** and **RxPermission1C** (as well as **RxPermission2A**, **RxPermission2B** and **RxPermission2C** in case of three-end lines) should be associated to remote end communication channels or to binary inputs.

The received signals are also available as function outputs for event log purposes.

The three-pole trip is available in function output **Trip**; the single-pole trip outputs in **TripA**, **TripB** and **TripC**. The general **Trip** will also be issued as the logical OR of the individual phase outputs.

The operation can be delayed for a defined amount of time. This time delay is constant and can be set by the user in setting **CoordTime**. If the operational time is set to zero, the trip will be instantaneous, as is typical in this scheme.

Permissive Overreach Trip (POTT) Scheme Logic

In the POTT scheme, the pickup of a forward overreach Distance measuring zone is sent as a permissive signal to the remote line ends. That pickup can also initiate an instantaneous trip if a fault inside the protected zone is confirmed by the reception of the corresponding signal from all remote ends. The measuring principle is shown in Figure 5.18.

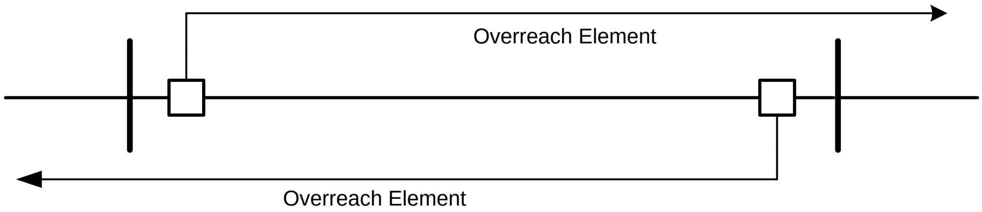

Figure 5.18. Permissive Overreach Transfer Trip (POTT) scheme.

The transmission logic of the POTT scheme is shown in Figure 5.19.

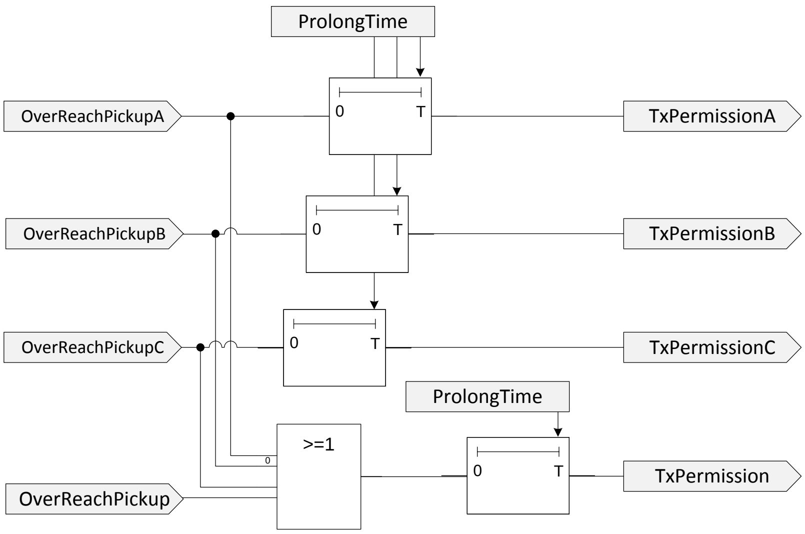

Figure 5.19. Permissive Overreach Transfer Trip (POTT) transmission logic.

In most cases, this module can be activated by associating the pickup signal from a selected Distance Protection zone (typically zone 2) to the function input **OverReachPickup**. The output signal **TxPermission** should be associated to a remote end communication channel or to a binary output, depending on the communication interface being used. In case of three-end lines, **TxPermission** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs.

As an alternative, phase-segregated pickup signals can be transmitted to the remote end if inputs **OverReachPickupA**, **OverReachPickupB** and **OverReachPickupC** are associated, for example, with the corresponding outputs of a Distance zone. The output signals **TxPermissionA**, **TxPermissionB** and **TxPermissionC** should be configured in the same way as **TxPermission** in the previous example. Phase segregated communication should be used when three communication channels are available and discrimination of simultaneous phase-to-earth faults is required. **TxPermission** will also be available to send to the remote end, as the logical OR of the three phase input signals.

Whatever the chosen option is, the transmitted signal or signals can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input pickup signal. This guarantees a minimum duration of the pulse sent even if one of the line terminals rapidly resets due to the trip of the independent zone 1.

The receive logic of the POTT scheme is shown in Figure 5.20.

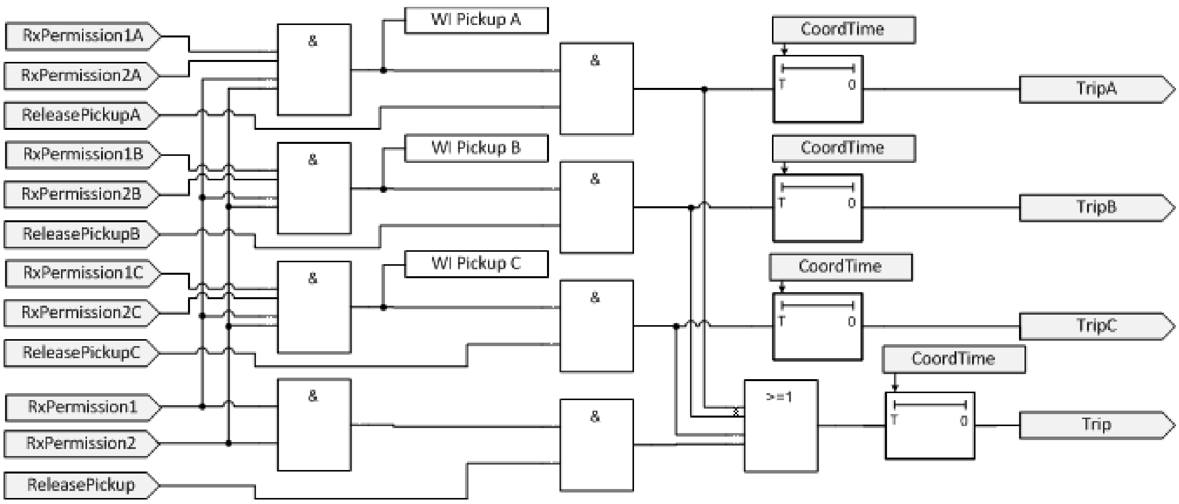

Figure 5.20. Permissive Overreach Transfer Trip (POTT) receive logic (three line ends).

When only three-phase transfer trip signals are exchanged, function inputs **RxPermission1** and/or **RxPermission2** should be associated to remote end communication channels or to binary inputs, depending on the number of line ends. The reception of the signal from all configured line ends, if confirmed by the pickup of the local forward overreach Distance zone, leads to the function trip. In three-pole tripping applications, that pickup should be associated with input **ReleasePickup**. If single-phase tripping is required, phase selection should be guaranteed by means of function inputs **ReleasePickupA**, **ReleasePickupB** and **ReleasePickupC**.

The reception of phase-segregated trip signals is also possible. For this purpose, **RxPermission1A**, **RxPermission1B** and **RxPermission1C** (as well as **RxPermission2A**, **RxPermission2B** and **RxPermission2C** in case of three-end lines) should be associated to remote end communication channels or to binary inputs.

The received signals are also available as function outputs for event log purposes.

The three-pole trip is available in function output **Trip**; the single-pole trip outputs in **TripA**, **TripB** and **TripC**. The general **Trip** will also be issued as the logical OR of the individual phase outputs.

The operation can be delayed for a defined amount of time. This time delay is constant and can be set by the user in setting **CoordTime**. If the operational time is set to zero, the trip will be instantaneous, as is typical in this scheme.

Directional Comparison Blocking (DCB) Scheme Logic

In the DCB scheme, unlike permissive schemes, the pickup of a reverse Distance measuring zone is sent as a blocking signal to the remote line ends. A forward overreach measuring zone will trip after a pre-defined coordination time, unless the blocking signal from one of the remote line ends is received before the timer elapses, indicating that the fault is outside the protected zone. The measuring principle is shown in Figure 5.21.

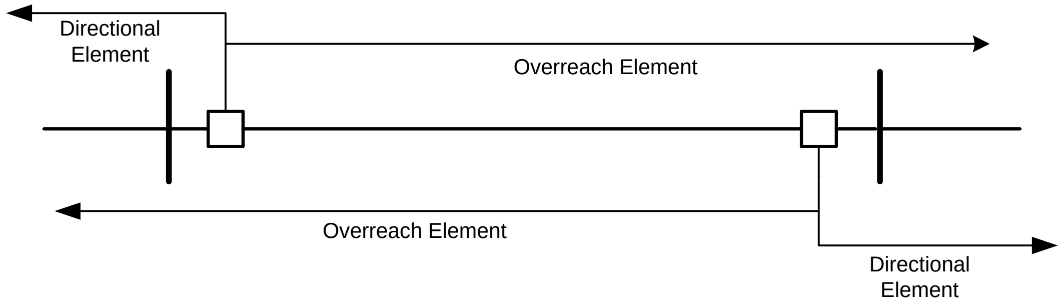

Figure 5.21. Directional Comparison Blocking (DCB) scheme.

The transmission logic of the DCB scheme is shown in Figure 5.22.

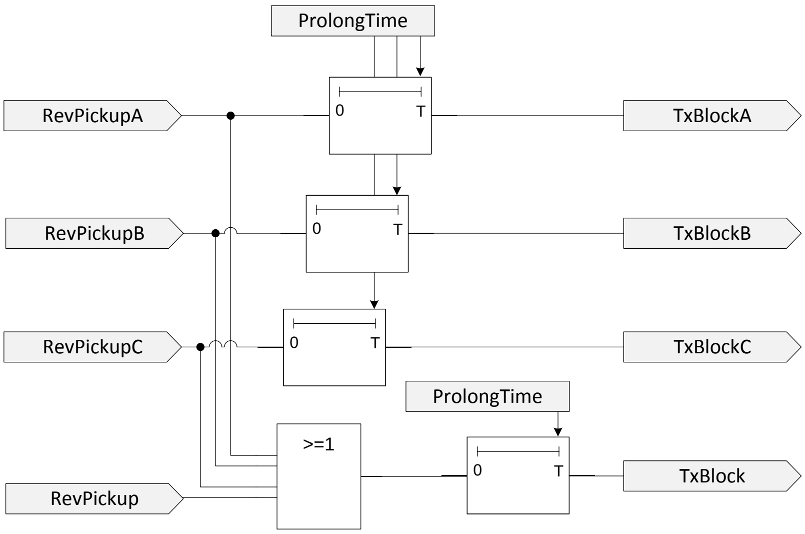

Figure 5.22. Directional Comparison Blocking (DCB) transmission logic.

In most cases, this module can be activated by associating the pickup signal from a selected reverse Distance Protection zone to the function input **RevPickup**. The output signal **TxBlock** should be associated to a remote end communication channel or to a binary output, depending on the communication interface being used. In case of three-end lines, **TxBlock** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs.

As an alternative, phase-segregated block signals can be transmitted to the remote end if inputs **RevPickupA**, **RevPickupB** and **RevPickupC** are associated, for example, with the corresponding outputs of a Distance zone. The output signals **TxBlockA**, **TxBlockB** and **TxBlockC** should be configured in the same way as **TxBlock** in the previous example. Phase segregated communication should be used when three communication channels are available and discrimination of simultaneous phase-to-earth faults is required. **TxBlock** will also be available to send to the remote end, as the logical OR of the three phase input signals.

Whatever the chosen option is, the transmitted signal or signals can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input pickup signal. This guarantees a minimum duration of the pulse sent after an external fault is cleared, compensating for eventual differences in the reset time of the protection zones in the several line terminals.

The receive logic of the DCB scheme is shown in Figure 5.23.

When only three-phase blocking signals are exchanged, function inputs **RxBlock1** and/or **RxBlock2** should be associated to remote end communication channels or to binary inputs, depending on the number of line ends. The reception of any of these signals blocks the function trip that otherwise is issued due to the pickup of a forward overreach Distance zone (typically zone 2). In three-pole tripping applications, that pickup should be associated with input **ReleasePickup**. If single-phase tripping is required, phase selection should be guaranteed by the local overreach Distance zone, by means of function inputs **ReleasePickupA**, **ReleasePickupB** and **ReleasePickupC**.

The reception of phase-segregated trip signals is also possible. For this purpose, **RxBlock1A**, **RxBlock1B** and **RxBlock1C** (as well as **RxBlock2A**, **RxBlock2B** and **RxBlock2C** in case of three-end lines) should be associated to remote end communication channels or to binary inputs.

The received signals are also available as function outputs for event log purposes.

The three-pole trip is available in function output **Trip**; the single-pole trip outputs in **TripA**, **TripB** and **TripC**. The general **Trip** will also be issued as the logical OR of the individual phase outputs.

The operation should be delayed for a defined amount of time, to allow the reception of the remote block signal. This time delay is constant and can be set by the user in setting **CoordTime**.

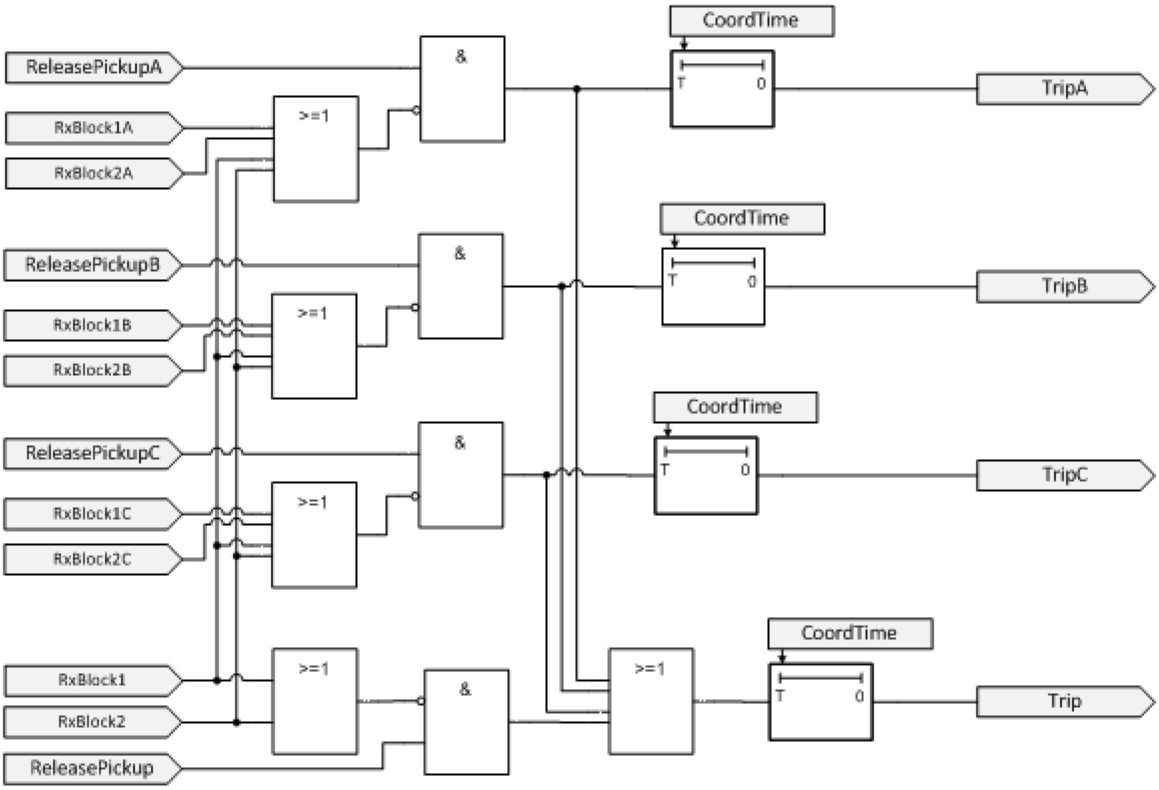

Figure 5.23. Directional Comparison Blocking (DCB) receive logic (three line ends).

Directional Comparison Unblocking (DCUB) Scheme Logic

In a permissive scheme, when the signal is sent directly over the protected line, using a conventional communication channel based on power line carrier (PLC) technology, it may be lost or severely attenuated as the result of a fault in the line. This may prevent the teleprotection scheme of tripping because the permissive signal will not be received by the remote line ends.

To overcome this limitation, specific unblocking logic is usually provided in the receiver so that tripping is possible even if the permissive signal is not received. It may be applied in association with both PUTT and POTT schemes.

The DCUB logic requires a guard signal to be keyed in a different transmit frequency from the one that is used for the trip signal. The guard signal is transmitted in permanence during load conditions or when a fault is detected in the reverse direction. When a fault is detected in the forward direction, the transmitter is keyed to the trip frequency. The channel can thus be monitored on a continuous basis.

Up to two guard signals corresponding to two distinct remote line ends can be connected to inputs **RxGuard1** and/or **RxGuard2**, and they may be associated to remote end communication channels or to binary inputs. The DCUB logic is presented in Figure 5.24.

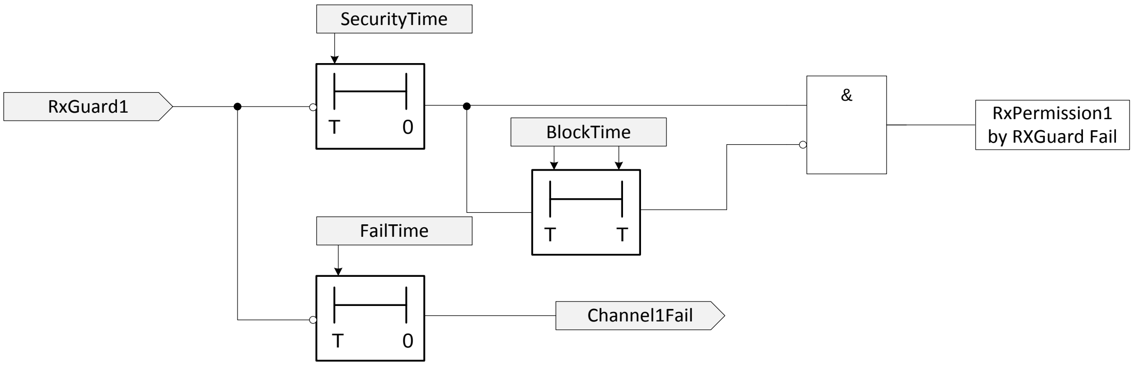

Figure 5.24. Directional Comparison Unblocking logic.

The loss of the guard signal for more than a pre-defined amount of time (setting **SecurityTime**) will lead to a temporary unblocking of the permissive scheme trip. Tripping is released during a short period of time, until a second timer, defined by setting **BlockTime**, elapses. If a fault is detected in the forward direction by the associated overreach Distance zone, a trip will be initiated, even if the remote signal is not received. After that, the unblocking logic remains inoperative and only after the guard signal is recovered again and remains stable for more than **BlockTime**, the quiescent state is reached again.

It is possible to set an additional time delay (setting **FailTime**), independently from the trip release logic, to signal channel failure due to loss of the guard signal. This indication is available in function outputs **Channel1Fail** and **Channel2Fail**.

Current Reversal Logic

The Current Reversal Logic is used in association with POTT scheme to prevent inadvertent tripping of the communication scheme logic in an unfaulted feeder due to the sequential opening of circuit breakers in a parallel line. This failure is caused by the change in current direction when one of the circuit breakers of the faulted line opens before the other end, and depends largely on the fault location and the system impedances.

The Current Reversal Logic can be activated if the pickup of a reverse Distance zone is connected to the input **RevPickup**. If the protection detects a fault in the reverse direction and that decision is maintained for more than **BlkConfirmTime**, the trip of the permissive scheme is blocked, irrespective of a permissive signal being sent by the relay in the other terminal, which is detecting the fault in the forward direction. Then, if the fault current changes direction, and the forward element picks up, the function remains blocked for an additional time delay, defined in setting **BlkBlockTime**. This timer is used to stabilize the relay decision during this fault current reversal, allowing the remote end to reverse direction and the transmitted permissive signal to reset.

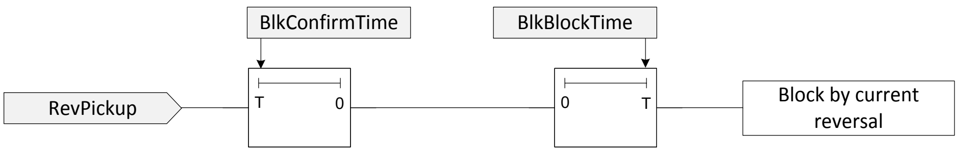

Figure 5.25. Current Reversal logic.

The PUTT scheme does not require this special logic because the permissive signal is issued by a measuring zone with limited reach. In blocking schemes, such as DCB, an equivalent result can be obtained by prolonging the block signal for a pre-set time, as explained in the respective section.

Open Circuit Breaker Logic

If the circuit breaker is open, an internal fault cannot be detected by the local protection and hence a pickup or trip signal cannot be sent as permissive signal to the remote line ends. To overcome this limitation, specific logic is usually provided in the transmitter so that the permissive signal is sent in permanence when the circuit breaker is open. It may be applied in association with both PUTT and POTT schemes. This logic is shown in Figure 5.26.

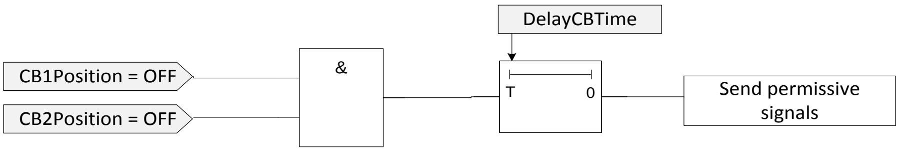

Figure 5.26. Open circuit breaker permissive logic.

This logic can be activated in setting **TxOpenCB**. The circuit breaker position should be associated to the function input **CB1Position**. To enable the application of this scheme logic in multiple breaker topologies, a second circuit breaker may be associated to input **CB2Position**. When the circuit breaker (or both circuit breakers) is (or are) detected open, a continuous permissive signal is sent to the remote line terminals. A confirmation time can be programmed in setting **DelayCBTime**.

Echo Transmission Logic

An instantaneous trip will be issued by POTT scheme only if a fault in the forward direction is detected by the protection relays in all line terminals at the same time. In case at least one of the line ends has a weak infeed or no infeed at all, Distance Protection may not pick up for some internal faults and a permissive signal will not be sent to the other ends, thus preventing the POTT scheme to trip even in the line ends with strong infeed. However, if Echo Transmission Logic is activated in association with POTT scheme, a permissive signal will be returned as an echo by the weak infeed terminal when the protection is not able to detect the fault, unblocking the trip in the other line ends, as represented in Figure 5.27.

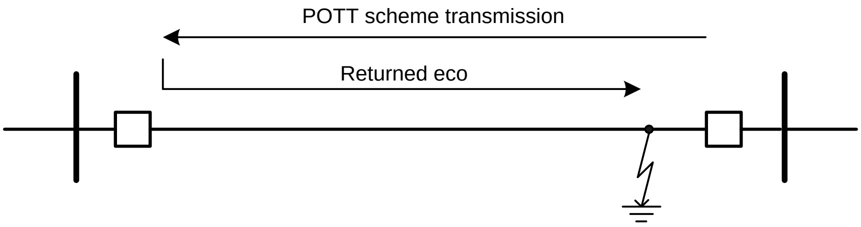

Figure 5.27. Echo transmission logic.

In order to the Echo Transmission Logic to be applied, the pickup signal from a selected reverse Distance Protection zone should be associated to the function input **GenPickup**, indicating that a fault was not detected in the reverse direction. The general Distance Protection pickup can be used for that purpose as an alternative, since forward faults that are detected by the weak infeed are already tackled by the POTT scheme logic. However, the absence of Distance Protection pickup will also occur if the function is blocked, for example due to a VT failure; to cover that possibility, the pickup of the Phase Overcurrent Protection used as emergency function should also be associated to the **GenPickup** input.

The sequence of events for some examples of application of the Echo Transmission Logic is represented in Figure 5.28.

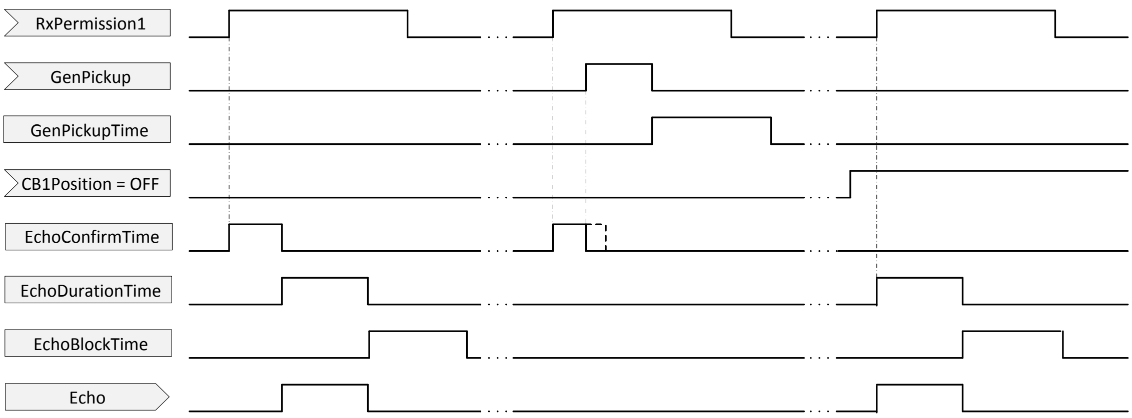

Figure 5.28. Sequence of events for echo signal transmission.

If the permissive signal is received from at least one of the remote ends, but the presence of a backward fault is not indicated by the **GenPickup** input, an echo signal will be transmitted to the other ends. A time delay, defined in setting **EchoConfirmTime**, is necessary before sending the echo signal, to deal with the possibility of a longer fault detection time in the weak infeed terminal due to unfavourable conditions. If the protection does not pick up until this timer elapses, an echo signal will be transmitted and its duration can be defined in setting **EchoDurationTime**. To avoid the repetition of the echo signal after the line is switched off an additional block time can be defined in setting **EchoBlockTime**. After a pulse is sent, a new signal will not be transmitted again until this timer has elapsed.

By the contrary, if **GenPickup** occurs while timer **EchoConfirmTime** is counting, the echo signal will not be transmitted. After the protection resets, the echo signal transmission will remain blocked for an additional time interval defined in setting **GenPickupTime**, to allow for the cancelation of the remote permissive signal and thus avoid a false echo signal.

The echo signal is transmitted without delay after the reception of the remote permissive signal if the circuit breaker is already open (or both circuit breakers in multiple breaker topologies) as indicated by **CB1Position** and **CB2Position**.

The echo signal is transmitted as a normal permissive signal, in output **TxPermission** (or in **TxPermissionA**, **TxPermissionB** and **TxPermissionC** in the case of phase-segregated pickup signals). Additionally, the function output **Echo** is also signalled.

The echo signal transmission can also be subject to confirmation by an undervoltage stage (same as used for Weak Infeed Tripp). If setting **EchoVoltageSup** is set to **ON**, the echo sgnal is only sent if the undervoltage stage picks up.

Weak Infeed (WI) Trip Logic

The Weak Infeed Trip Logic can be activated independently of the Echo Transmission Logic or it can complement it. The WI Trio Logic is necessary to accelerate the trip in the Weak Infeed terminal, in order to avoid a sequential delayed trip only after the remote circuit breakers open. It can be used in association with either POTT or PUTT schemes.

The built-in logic is similar to the Echo Transmission Logic: it operates when a permissive signal is received from the remote end and simultaneously Distance Protection does not pick up, either in the forward or in the reverse direction. Additionally, if a complementary protection element detects the fault, a local trip can be issued by the WI Trip Logic.

A built-in undervoltage stage is used as fault detector element. Three phase-to-earth voltage signals must be associated in one analogue channel connected to the function input **U**. The stage pickup is signalled when the measured voltage magnitude is lower than the threshold defined in the corresponding setting (**Uop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The pickup threshold is set in values per unit, relative to the rated VT primary voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \qquad (5.7)$$

The WI Trip Logic is depicted in Figure 5.29.

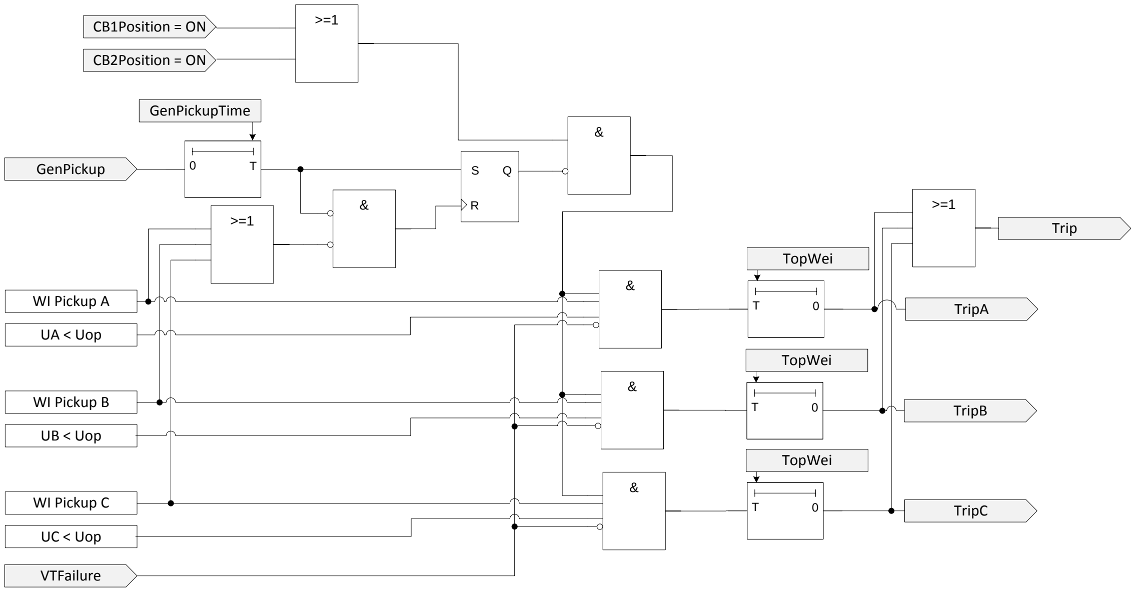

Figure 5.29. Weak Infeed (WI) trip logic.

If the permissive signal is received from the remote end and the presence of a backward fault is not indicated by the **GenPickup** input, a local trip can be issued if at the same time a fault is detected by the undervoltage condition in one or more of the phases. The operation should be delayed for a defined amount of time, to cope with the possibility of a longer fault detection time of the backward protection element in the weak infeed terminal due to unfavourable conditions. This time delay is constant and can be set by the user in setting **TopWei**. The trip due to the WI Trip Logic is signalled in function output **WeiOp**.

If **GenPickup** occurs while timer **TopWei** is counting, the trip will not be initiated. After the protection resets, the trip will remain blocked for an additional time interval defined in setting **GenPickupTime**, to allow for the cancelation of the remote permissive signal.

The trip will not be allowed in case a failure in the voltage measuring circuit is indicated in the **VTFailure** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision) or the trip indication of the MCB that protects the voltage transformer can be directly used.

The circuit breaker (or at least one of the circuit breakers in multiple breaker topologies) should also be closed, as indicated by **CB1Position** and **CB2Position**, so that a trip can be initiated.

Blocking Conditions

The function provides a general function block input (**Block**) and independent block inputs to block only transmission or only tripping (**BlockTx** and **BlockTrip**). It can be freely associated to any user-defined condition. The blocking conditions are signalled in the corresponding outputs (**Blocked, BlockedTx** and **BlockedTrip**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- For the selected scheme, neither the inputs of the receiving logic nor the inputs of the sending logic are connected;
- For any group of input entities, only one or two phase-segregated inputs are connected (for example, **RxBlock1A** and **RxBlock1B** are connected but **RxBlock1C** is not);
- PUTT or POTT schemes are selected, Weak Infeed Trip Logic is enabled and there is no analogue channel connected to function input **U**;
- PUTT or POTT schemes are selected, Weak Infeed Trip Logic is enabled and the analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- For the selected scheme, either the inputs of the receiving logic or the inputs of the sending logic are not connected;

- For any group of input entities, the general and any of the phase-segregated inputs are connected simultaneously (for example, **RxBlock1** and **RxBlock1A** are both connected);
- PUTT or POTT schemes are selected, Open Circuit Breaker Logic is enabled and both **CB1Position** and **CB2Position** inputs are disconnected;
- PUTT or POTT schemes are selected, Echo Transmission Logic and/or Weak Infeed Trip Logic is/are enabled and **GenPickup** input is disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.4.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.16 and Table 5.17, respectively.

Table 5.16. Distance Teleprotection Schemes function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Block function
BlockTx	Block Tx	DIG	4	Block transmission
BlockTrip	Block Trip	DIG	4	Block trip
VTFailure	VT Failure	DIG	2	Voltage transformer failure
RxPermission1A	Rx Permission 1 PhA	DIG	1	Receive permission indication from side 1 phase A
RxPermission1B	Rx Permission 1 PhB	DIG	1	Receive permission indication from side 1 phase B
RxPermission1C	Rx Permission 1 PhC	DIG	1	Receive permission indication from side 1 phase C
RxPermission1	Rx Permission 1	DIG	1	Receive permission indication from side 1
RxPermission2A	Rx Permission 2 PhA	DIG	1	Receive permission indication from side 2 phase A
RxPermission2B	Rx Permission 2 PhB	DIG	1	Receive permission indication from side 2 phase B
RxPermission2C	Rx Permission 2 PhC	DIG	1	Receive permission indication from side 2 phase C
RxPermission2	Rx Permission 2	DIG	1	Receive permission indication from side 2
RxBlock1A	Rx Block 1 PhA	DIG	1	Receive block indication from side 1 phase A
RxBlock1B	Rx Block 1 PhB	DIG	1	Receive block indication from side 1 phase B
RxBlock1C	Rx Block 1 PhC	DIG	1	Receive block indication from side 1 phase C
RxBlock1	Rx Block 1	DIG	1	Receive block indication from side 1
RxBlock2A	Rx Block 2 PhA	DIG	1	Receive block indication from side 2 phase A
RxBlock2B	Rx Block 2 PhB	DIG	1	Receive block indication from side 2 phase B

Identifier	Title	Type	Mlt	Description
RxBlock2C	Rx Block 2 PhC	DIG	1	Receive block indication from side 2 phase C
RxBlock2	Rx Block 2	DIG	1	Receive block indication from side 2
UnderReachTripA	Underreach Trip A	DIG	1	Underreach trip phase A
UnderReachTripB	Underreach Trip B	DIG	1	Underreach trip phase B
UnderReachTripC	Underreach Trip C	DIG	1	Underreach trip phase C
UnderReachTrip	Underreach Trip	DIG	1	Underreach trip
OverReachPickupA	Overreach Pickup A	DIG	1	Overreach pickup phase A
OverReachPickupB	Overreach Pickup B	DIG	1	Overreach pickup phase B
OverReachPickupC	Overreach Pickup C	DIG	1	Overreach pickup phase C
OverReachPickup	Overreach Pickup	DIG	1	Overreach pickup
RevPickupA	Rev Pickup PhA	DIG	1	Reverse pickup phase A
RevPickupB	Rev Pickup PhB	DIG	1	Reverse pickup phase B
RevPickupC	Rev Pickup PhC	DIG	1	Reverse pickup phase C
RevPickup	Rev Pickup	DIG	1	Reverse pickup
ReleasePickupA	Release Pickup PhA	DIG	1	Release pickup phase A
ReleasePickupB	Release Pickup PhB	DIG	1	Release pickup phase B
ReleasePickupC	Release Pickup PhC	DIG	1	Release pickup phase C
ReleasePickup	Release Pickup	DIG	1	Release pickup
GenPickup	Gen Pickup	DIG	32	General pickup
RxGuard1	Rx Guard 1	DIG	1	Receive guard signal from side 1
RxGuard2	Rx Guard 2	DIG	1	Receive guard signal from side 2
CB1Position	CB 1 Position	DBL DIG	1	Circuit breaker 1 position
CB2Position	CB 2 Position	DBL DIG	1	Circuit breaker 2 position

Table 5.17. Distance Teleprotection Schemes function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
BlockedTx	Blocked Tx	DIG	-	Transmission blocked
BlockedTrip	Blocked Trip	DIG	-	Trip blocked
TxPermissionA	Tx Permission PhA	DIG	-	Transmit permission signal phase A
TxPermissionB	Tx Permission PhB	DIG	-	Transmit permission signal phase B
TxPermissionC	Tx Permission PhC	DIG	-	Transmit permission signal phase C
TxPermission	Tx Permission	DIG	-	Transmit permission signal

Identifier	Title	Type	NV	Description
TxBlockA	Tx Block PhA	DIG	-	Transmit block signal phase A
TxBlockB	Tx Block PhB	DIG	-	Transmit block signal phase B
TxBlockC	Tx Block PhC	DIG	-	Transmit block signal phase C
TxBlock	Tx Block	DIG	-	Transmit block signal
TripA	Trip PhA	DIG	-	Phase A trip
TripB	Trip PhB	DIG	-	Phase B trip
TripC	Trip PhC	DIG	-	Phase C trip
Trip	Trip	DIG	-	General trip
Echo	Echo	DIG	-	Tx Permission is being sent as echo signal
WeiOp	Wei Op	DIG	-	Indication that Op is the operate from the weak end infeed function
Channel1Fail	Channel 1 Fail	DIG	-	Channel 1 fault alarm
Channel2Fail	Channel 2 Fail	DIG	-	Channel 2 fault alarm
RxPermission1A	Rx Permission 1 PhA	DIG	-	Permission indication received from side 1 phase A
RxPermission1B	Rx Permission 1 PhB	DIG	-	Permission indication received from side 1 phase B
RxPermission1C	Rx Permission 1 PhC	DIG	-	Permission indication received from side 1 phase C
RxPermission1	Rx Permission 1	DIG	-	Permission indication received from side 1
RxPermission2A	Rx Permission 2 PhA	DIG	-	Permission indication received from side 2 phase A
RxPermission2B	Rx Permission 2 PhB	DIG	-	Permission indication received from side 2 phase B
RxPermission2C	Rx Permission 2 PhC	DIG	-	Permission indication received from side 2 phase C
RxPermission2	Rx Permission 2	DIG	-	Permission indication received from side 2
RxBlock1A	Rx Block 1 PhA	DIG	-	Block indication received from side 1 phase A
RxBlock1B	Rx Block 1 PhB	DIG	-	Block indication received from side 1 phase B
RxBlock1C	Rx Block 1 PhC	DIG	-	Block indication received from side 1 phase C
RxBlock1	Rx Block 1	DIG	-	Block indication received from side 1
RxBlock2A	Rx Block 2 PhA	DIG	-	Block indication received from side 2 phase A
RxBlock2B	Rx Block 2 PhB	DIG	-	Block indication received from side 2 phase B
RxBlock2C	Rx Block 2 PhC	DIG	-	Block indication received from side 2 phase C
RxBlock2	Rx Block 2	DIG	-	Block indication received from side 2

5.4.4 Settings

The function settings are listed in Table 5.18.

Table 5.18. Distance Teleprotection Schemes function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Function operation
DisScheme	Distance Scheme	PUTT / POTT / DCB	PUTT	Distance teleprotection scheme
ProlongTime	Prolong Time	[0..10000] ms	50	Time delay after activation conditions are reset
CoordTime	Coord Time	[0..10000] ms	100	Coordination time for blocking schemes
SecurityTime	Security Time	[20..10000] ms	30	Security time for unblocking scheme
BlockTime	Block Time	[20..10000] ms	100	Block time used in unblocking scheme
FailTime	Fail Time	[50..60000] ms	10000	Delay time for channel fail alarm
BlkConfirmTime	Blk Confirm Time	[20..10000] ms	40	Confirm time for transient coditions block
BlkBlockTime	Blk Block Time	[20..10000] ms	100	Block time for transient conditions block
EchoMode	Echo Mode	OFF / TRIP / ECHO / ECHO+TRIP	OFF	Echo and week end infeed operation mode
EchoConfirmTime	Echo Confirm Time	[20..10000] ms	50	Confirmation time for echo send
EchoDurationTime	Echo Duration Time	[0..10000] ms	50	Echo signal duration time
EchoBlockTime	Echo Block Time	[20..10000] ms	30	Echo signal block time
GenPickupTime	Gen Pickup Time	[0..10000] ms	0	General pickup signal prolong time
Uop	Uop	[0,2..1,0] × U_r	0,50	Minimum voltage operation threshold
TopWei	Top Wei	[0..10000] ms	50	Week end infeed trip operation time
EchoVoltageSup	Echo Voltage Sup	OFF / ON	OFF	Enable voltage supervision for echo transmit
TxOpenCB	Tx Open CB	OFF / ON	OFF	Transmit permission signal on open circuit breaker
DelayCBTime	Delay CB Time	[0..1000] ms	100	Time delay for circuit breaker open permission signal
RemEnd2Operation	Rem End2 Operation	OFF / ON	OFF	Second remote end operation. If set to **OFF**, inputs **RxPermission2(ABC)** and **RxBlock2(ABC)** have no effect.

5.5 Directional Earth-Fault Teleprotection Schemes

5.5.1 Introduction

A very fast tripping time is required to preserve power system stability during the occurrence of network faults. However, in transmission lines, the selectivity of an instantaneous Earth-Fault Protection stage is difficult to guarantee because the reach of the function is affected by system impedance changes. Moreover, faults beyond that stage can only be cleared by a second stage after a settable time delay. On very short lines, a first instantaneous stage may not even be possible to set.

The purpose of Teleprotection Schemes associated with Directional Earth-Fault Protection is to trip almost instantaneously irrespective of the location of the fault in the protected line, by exchanging directional information between the line terminals through communication channels. These schemes can be applied to Directional Earth-Fault Protection, which is inherently more sensitive than Distance Protection for phase-to-earth faults. Several options can be considered, ranging from permissive schemes, which tend to be faster and more secure against false tripping, to blocking schemes that by the contrary are usually more dependable.

5.5.2 Operation Method

The Directional Earth-Fault Teleprotection Schemes function can be activated by setting change (setting **Operation**). Several logic schemes are available as built-in options that can be selected in setting **EFScheme**:

- Directional Comparison (DC) scheme logic: **EFScheme** = **DC**;
- Directional Comparison Blocking (DCB) scheme logic: **EFScheme** = **DCB**.

Additional logic options can be configured to complement the previous communication schemes:

- Directional Comparison Unblocking (DCUB) scheme logic;
- Current Reversal logic;
- Open Circuit Breaker logic.

Finally, special modes concerning weak infeed sources can be activated in setting **EchoMode**:

- Echo Transmission logic: **EchoMode** = **ECHO** or **ECHO+TRIP**;
- Weak Infeed (WI) Trip logic: **EchoMode** = **TRIP** or **ECHO+TRIP**.

The function can be used in association with different communication interfaces, according to the several options available in the TPU L500. It can also be associated with binary inputs and outputs.

Directional Comparison (DC) Scheme Logic

In the DC scheme, the pickup of a forward overreach Directional Earth-Fault stage is sent as a permissive signal to the remote line ends. That pickup can also initiate an instantaneous trip if a fault inside the protected zone is confirmed by the reception of the corresponding signal from all remote ends. The measuring principle is shown in Figure 5.30.

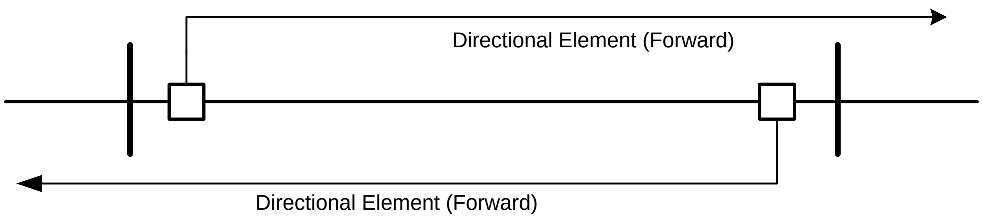

Figure 5.30. Directional Comparison (DC) scheme.

The transmission logic of the DC scheme is shown in Figure 5.31.

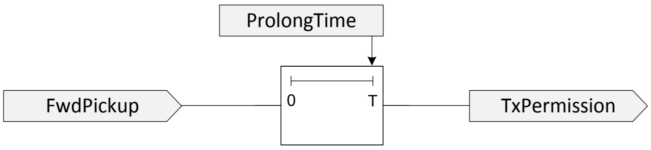

Figure 5.31. Directional Comparison (DC) transmission logic.

This module can be activated by associating the pickup signal from a selected Directional Earth-Fault Protection stage to the function input **FwdPickup**. The output signal **TxPermission** should be associated to a remote end communication channel or to a binary output, depending on the communication interface being used. In case of three-end lines, **TxPermission** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs.

The transmitted signal can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input pickup signal. This guarantees a minimum duration of the pulse sent even if one of the line terminals rapidly resets due to the trip of another high-speed protection function.

The receive logic of the DC scheme is shown in Figure 5.32.

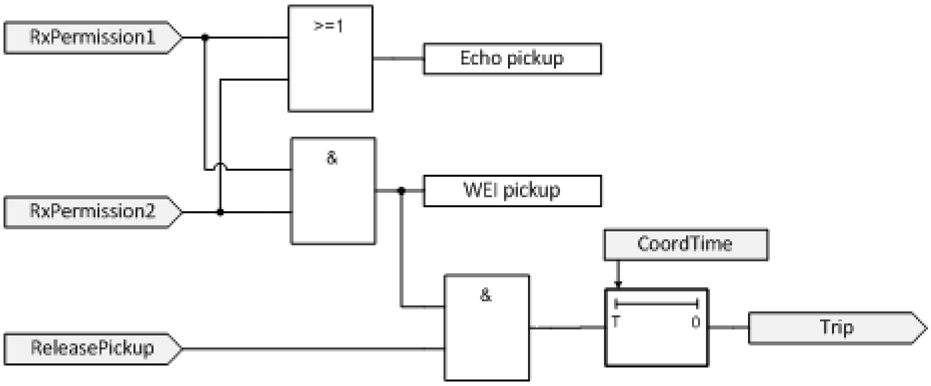

Figure 5.32. Directional Comparison (DC) receive logic (three line ends).

Function inputs **RxPermission1** and/or **RxPermission2** should be associated to remote end communication channels or to binary inputs, depending on the number of line ends. The reception of the signal from all configured line ends, if confirmed by the pickup of the local forward overreach Directional Earth-Fault stage, leads to the function trip. That pickup should be associated with input **ReleasePickup**.

The received signals are also available as function outputs for event log purposes. The three-pole trip is available in function output **Trip**.

The operation can be delayed for a defined amount of time. This time delay is constant and can be set by the user in setting **CoordTime**. If the operational time is set to zero, the trip will be instantaneous, as is typical in this scheme.

Directional Comparison Blocking (DCB) Scheme Logic

In the DCB scheme, unlike permissive schemes, the pickup of a reverse Directional Earth-Fault stage is sent as a blocking signal to the remote line ends. A forward stage will trip after a pre-defined coordination time, unless the blocking signal from one of the remote line ends is received before the timer elapses, indicating that the fault is outside the protected zone. The measuring principle is shown in Figure 5.33.

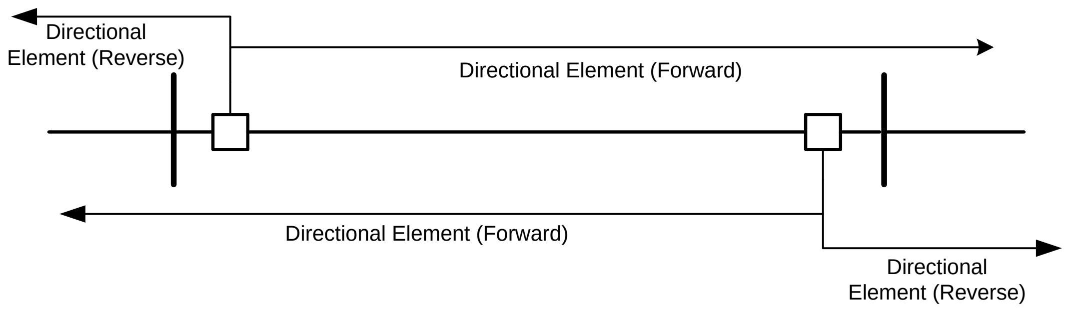

Figure 5.33. Directional Comparison Blocking (DCB) scheme.

The transmission logic of the DCB scheme is shown in Figure 5.34.

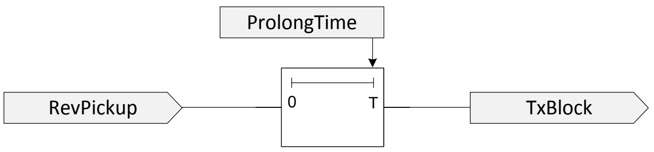

Figure 5.34. Directional Comparison Blocking (DCB) transmission logic.

This module can be activated by associating the pickup signal from a selected reverse Directional Earth-Fault Protection stage to the function input **RevPickup**. The output signal **TxBlock** should be associated to a remote end communication channel or to a binary output, depending on the communication interface being used. In case of three-end lines, **TxBlock** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs.

The transmitted signal can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input pickup signal. This guarantees a minimum duration of the pulse sent after an external fault is cleared, compensating for eventual differences in the reset time of the protection zones in the several line terminals.

The receive logic of the DCB scheme is shown in Figure 5.35.

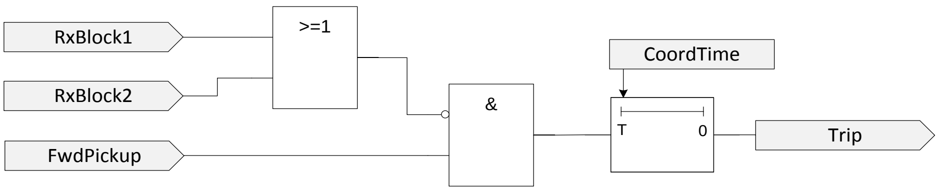

Figure 5.35. Directional Comparison Blocking (DCB) receive logic (three line ends).

Function inputs **RxBlock1** and/or **RxBlock2** should be associated to remote end communication channels or to binary inputs, depending on the number of line ends. The reception of any of these signals blocks the function trip that otherwise is issued due to the pickup of a forward Directional Earth-Fault stage. That pickup should be associated with input **FwdPickup**.

The received signals are also available as function outputs for event log purposes. The three-pole trip is available in function output **Trip**.

The operation should be delayed for a defined amount of time, to allow the reception of the remote block signal. This time delay is constant and can be set by the user in setting **CoordTime**.

Directional Comparison Unblocking (DCUB) Scheme Logic

In a permissive scheme, when the signal is sent directly over the protected line, using a conventional communication channel based on power line carrier (PLC) technology, it may be lost or severely attenuated as the result of a fault in the line. This may prevent the teleprotection scheme of tripping because the permissive signal will not be received by the remote line ends.

To overcome this limitation, specific unblocking logic is usually provided in the receiver so that tripping is possible even if the permissive signal is not received. It may be applied in association with DC scheme.

The DCUB logic requires a guard signal to be keyed in a different transmit frequency from the one that is used for the trip signal. The guard signal is transmitted in permanence during load conditions or when a fault is detected in the reverse direction. When a fault is detected in the forward direction, the transmitter is keyed to the trip frequency. The channel can thus be monitored on a continuous basis.

Up to two guard signals corresponding to two distinct remote line ends can be connected to inputs **RxGuard1** and/or **RxGuard2**, and they may be associated to remote end communication channels or to binary inputs. The DCUB logic is presented in Figure 5.36.

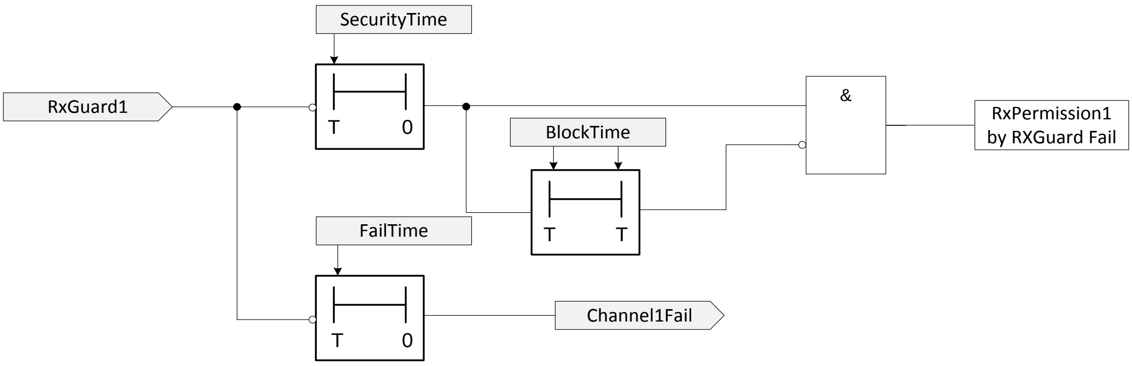

Figure 5.36. Directional Comparison Unblocking logic.

The loss of the guard signal for more than a pre-defined amount of time (setting **SecurityTime**) will lead to a temporary unblocking of the permissive scheme trip. Tripping is released during a short period of time, until a second timer, defined by setting **BlockTime**, elapses. If a fault is detected in the forward direction by the associated overreach Directional Earth-Fault Protection stage, a trip will be initiated, even if the remote signal is not received. After that, the unblocking logic remains inoperative and only after the guard signal is recovered again and remains stable for more than **BlockTime**, the quiescent state is reached again.

It is possible to set an additional time delay (setting **FailTime**), independently from the trip release logic, to signal channel failure due to loss of the guard signal. This indication is available in function outputs **Channel1Fail** and **Channel2Fail**.

Current Reversal Logic

The Current Reversal Logic is used in association with DC scheme to prevent inadvertent tripping of the communication scheme logic in an unfaulted feeder due to the sequential opening of circuit breakers in a parallel line. This failure is caused by the change in current direction when one of the circuit breakers of the faulted line opens before the other end, and depends largely on the fault location and the system impedances.

The Current Reversal Logic can be activated if the pickup of a reverse Directional Earth-Fault stage is connected to the input **RevPickup**. If the protection detects a fault in the reverse direction and that decision is maintained for more than **BlkConfirmTime**, the trip of the permissive scheme is blocked, irrespective of a permissive signal being sent by the relay in the other terminal, which is detecting the fault in the forward direction. Then, if the fault current changes direction, and the forward element picks up, the function remains blocked for an additional time delay, defined in setting **BlkBlockTime**. This timer is used to stabilize the relay decision during this fault current reversal, allowing the remote end to reverse direction and the transmitted permissive signal to reset.

Figure 5.37. Current Reversal logic.

In blocking schemes, such as DCB, an equivalent result can be obtained by prolonging the block signal for a pre-set time, as explained in the respective section.

Open Circuit Breaker Logic

If the circuit breaker is open, an internal fault cannot be detected by the local protection and hence a pickup or trip signal cannot be sent as permissive signal to the remote line ends. To overcome this limitation, specific logic is usually provided in the transmitter so that the permissive signal is sent in permanence when the circuit breaker is open. It may be applied in association with DC scheme. This logic is shown in Figure 5.38.

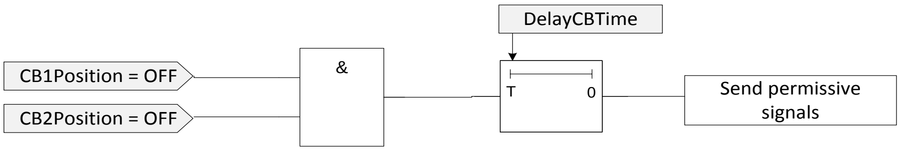

Figure 5.38. Open circuit breaker permissive logic.

This logic can be activated in setting **TxOpenCB**. The circuit breaker position should be associated to the function input **CB1Position**. To enable the application of this scheme logic in multiple breaker topologies, a second circuit breaker may be associated to input **CB2Position**. When the circuit breaker (or both circuit breakers) is (or are) detected open, a continuous permissive signal is sent to the remote line terminals. A confirmation time can be programmed in setting **DelayCBTime**.

Echo Transmission Logic

An instantaneous trip will be issued by DC scheme only if a fault in the forward direction is detected by the protection relays in all line terminals at the same time. In case at least one of the line ends has a weak infeed or no infeed at all, Directional Earth-Fault Protection may not pick up for some internal faults and a permissive signal will not be sent to the other ends, thus preventing the DC scheme to trip even in the line ends with strong infeed. However, if Echo Transmission Logic is activated in association with DC scheme, a permissive signal will be returned as an echo by the weak infeed terminal when the protection is not able to detect the fault, unblocking the trip in the other line ends, as represented in Figure 5.39.

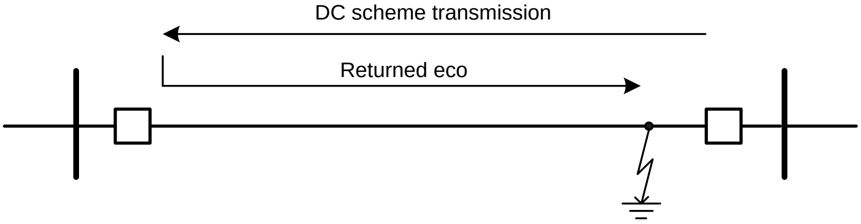

Figure 5.39. Echo transmission logic.

In order to the Echo Transmission Logic to be applied, the pickup signal from a selected reverse Directional Earth-Fault Protection stage should be associated to the function input **GenPickup**, indicating that a fault was not detected in the reverse direction. The general Directional Earth-Fault Protection pickup can be used for that purpose as an alternative, since forward faults that are detected by the weak infeed are already tackled by the DC scheme logic.

The sequence of events for some examples of application of the Echo Transmission Logic is represented in Figure 5.40.

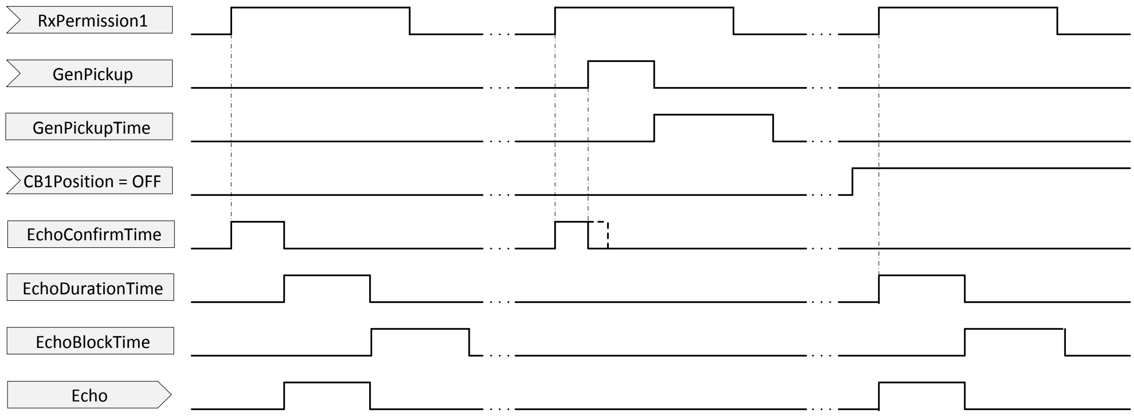

Figure 5.40. Sequence of events for echo signal transmission.

If the permissive signal is received from at least one of the remote ends, but the presence of a backward fault is not indicated by the **GenPickup** input, an echo signal will be transmitted to the other ends. A time delay, defined in setting **EchoConfirmTime**, is necessary before sending the echo signal, to deal with the possibility of a longer fault detection time in the weak infeed terminal due to unfavourable conditions. If the protection does not pick up until this timer elapses, an echo signal will be transmitted and its duration can be defined in setting **EchoDurationTime**. To avoid the repetition of the echo signal after the line is switched off an additional block time can be defined in setting **EchoBlockTime**. After a pulse is sent, a new signal will not be transmitted again until this timer has elapsed.

By the contrary, if **GenPickup** occurs while timer **EchoConfirmTime** is counting, the echo signal will not be transmitted. After the protection resets, the echo signal transmission will remain blocked for an additional time interval defined in setting **GenPickupTime**, to allow for the cancelation of the remote permissive signal and thus avoid a false echo signal.

The echo signal is transmitted without delay after the reception of the remote permissive signal if the circuit breaker is already open (or both circuit breakers in multiple breaker topologies) as indicated by **CB1Position** and **CB2Position**.

The echo signal is transmitted as a normal permissive signal, in output **TxPermission**. Additionally, the function output **Echo** is also signalled.

The echo signal transmission can also be subject to confirmation by a residual overvoltagestage (same as used for Weak Infeed Tripp). If setting **EchoVoltageSup** is set to **ON**, the echo sgnal is only sent if the undervoltage stage picks up.

Weak Infeed (WI) Trip Logic

The Weak Infeed Trip Logic can be activated independently of the Echo Transmission Logic or it can complement it. The WI Trio Logic is necessary to accelerate the trip in the Weak Infeed terminal, in order to avoid a sequential delayed trip only after the remote circuit breakers open. It can be used in association with DC scheme.

The built-in logic is similar to the Echo Transmission Logic: it operates when a permissive signal is received from the remote end and simultaneously Directional Earth-Fault Protection does not pick up, either in the forward or in the reverse direction. Additionally, if a complementary protection element detects the fault, a local trip can be issued by the WI Trip Logic.

A built-in residual overvoltage stage is used as fault detector element. The residual voltage, which corresponds to three times the zero sequence voltage, is monitored. It can be obtained from the internal sum of the three phase-to-earth voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_{res} = \overline{U}_A + \overline{U}_B + \overline{U}_C \tag{5.8}$$

As an alternative to the previous method, the displacement voltage can be directly measured in one analogue input, for instance from an independent open-delta connected voltage transformer winding. In this case, the function input **U** should be associated to a neutral analogue channel.

The stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding setting (**Uop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The pickup threshold is set in values per unit, relative to the rated VT primary phase-to-earth voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \qquad (5.9)$$

The WI Trip Logic is depicted in Figure 5.41.

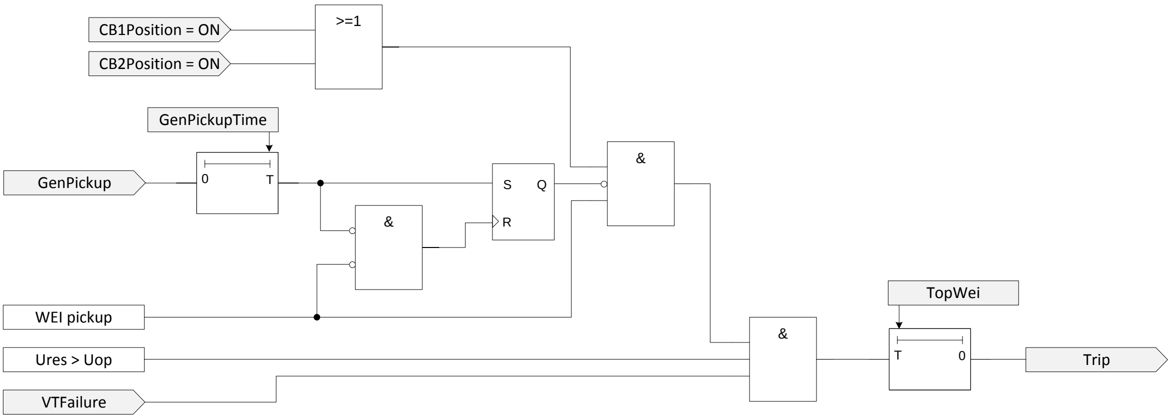

Figure 5.41. Weak Infeed (WI) trip logic.

If the permissive signal is received from the remote end and the presence of a backward fault is not indicated by the **GenPickup** input, a local trip can be issued if at the same time a fault is detected by the residual overvoltage condition. The operation should be delayed for a defined amount of time, to cope with the possibility of a longer fault detection time of the backward protection element in the weak infeed terminal due to unfavourable conditions. This time delay is constant and can be set by the user in setting **TopWei**. The trip due to the WI Trip Logic is signalled in function output **WeiOp**.

If **GenPickup** occurs while timer **TopWei** is counting, the trip will not be initiated. After the protection resets, the trip will remain blocked for an additional time interval defined in setting **GenPickupTime**, to allow for the cancelation of the remote permissive signal.

The trip will not be allowed in case a failure in the voltage measuring circuit is indicated in the **VTFailure** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision) or the trip indication of the MCB that protects the voltage transformer can be directly used.

The circuit breaker (or at least one of the circuit breakers in multiple breaker topologies) should also be closed, as indicated by **CB1Position** and **CB2Position**, so that a trip can be initiated.

Blocking Conditions

The function provides a general function block input (**Block**) and independent block inputs to block only transmission or only tripping (**BlockTx** and **BlockTrip**). It can be freely associated to any user-defined condition. The blocking conditions are signalled in the corresponding outputs (**Blocked, BlockedTx** and **BlockedTrip**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- DC scheme is selected and **FwdPickup** input or **ReleasePickup** input are disconnected;
- DC scheme is selected and both **RxPermission1** and **RxPermission2** inputs are disconnected;
- DCB scheme is selected and **FwdPickup** input is disconnected;
- DCB scheme is selected and **RevPickup** input is disconnected;
- DCB scheme is selected and both **RxBlock1** and **RxBlock2** inputs are disconnected;
- DC scheme is selected, Weak Infeed Trip Logic is enabled and there is no analogue channel connected to function input **U**;
- DC scheme is selected, Weak Infeed Trip Logic is enabled and the analogue channel associated to input **U** does not correspond to a neutral or to a group of three phase-to-earth voltage signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- DC scheme is selected, Open Circuit Breaker Logic is enabled and both **CB1Position** and **CB2Position** inputs are disconnected;
- DC scheme is selected, Echo Transmission Logic and/or Weak Infeed Trip Logic is/are enabled and **GenPickup** input is disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.5.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.19 and Table 5.20, respectively.

Table 5.19. Directional Earth-Fault Teleprotection Schemes function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltage
Block	Block	DIG	4	Block function
BlockTx	Block Tx	DIG	4	Block transmission
BlockTrip	Block Trip	DIG	4	Block trip
VTFailure	VT Failure	DIG	2	Voltage transformer failure
RxPermission1	Rx Permission 1	DIG	1	Receive permission indication from side 1
RxPermission2	Rx Permission 2	DIG	1	Receive permission indication from side 2
RxBlock1	Rx Block 1	DIG	1	Receive block indication from side 1
RxBlock2	Rx Block 2	DIG	1	Receive block indication from side 2
FwdPickup	Fwd Pickup	DIG	1	Forward pickup indication
RevPickup	Rev Pickup	DIG	1	Reverse pickup indication
ReleasePickup	Release Pickup	DIG	1	Release pickup
GenPickup	Gen Pickup	DIG	32	General pickup indication
RxGuard1	Rx Guard 1	DIG	1	Receive guard signal from side 1
RxGuard2	Rx Guard 2	DIG	1	Receive guard signal from side 2
CB1Position	CB 1 Position	DBL DIG	1	Circuit breaker 1 position
CB2Position	CB 2 Position	DBL DIG	1	Circuit breaker 2 position

Table 5.20. Directional Earth-Fault Teleprotection Schemes function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
BlockedTx	Blocked Tx	DIG	-	Transmission blocked
BlockedTrip	Blocked Trip	DIG	-	Trip blocked
TxPermission	Tx Permission	DIG	-	Transmit permission signal

Identifier	Title	Type	NV	Description
TxBlock	Tx Block	DIG	-	Transmit block signal
Trip	Trip	DIG	-	General trip
Echo	Echo	DIG	-	Tx Permission is being sent as echo signal
WeiOp	Wei Op	DIG	-	Indication that Op is the operate from the weak end infeed function
Channel1Fail	Channel 1 Fail	DIG	-	Channel 1 fault alarm
Channel2Fail	Channel 2 Fail	DIG	-	Channel 2 fault alarm
RxPermission1	Rx Permission 1	DIG	-	Permission indication received from side 1
RxPermission2	Rx Permission 2	DIG	-	Permission indication received from side 2
RxBlock1	Rx Block 1	DIG	-	Block indication received from side 1
RxBlock2	Rx Block 2	DIG	-	Block indication received from side 2

5.5.4 Settings

The function settings are listed in Table 5.21.

Table 5.21. Directional Earth-Fault Teleprotection Schemes function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Function operation
EFScheme	Earth Fault Scheme	DC / DCB	DC	Earth fault teleprotection scheme
ProlongTime	Prolong Time	[0..10000] ms	50	Time delay after activation conditions are reset
CoordTime	Coord Time	[0..10000] ms	100	Coordination time for blocking schemes
SecurityTime	Security Time	[20..10000] ms	30	Security time for unblocking scheme
BlockTime	Block Time	[20..10000] ms	100	Block time used in unblocking scheme
FailTime	Fail Time	[50..60000] ms	10000	Delay time for channel fail alarm
BlkConfirmTime	Blk Confirm Time	[20..10000] ms	40	Confirm time for transient coditions block
BlkBlockTime	Blk Block Time	[20..10000] ms	100	Block time for transient conditions block
EchoMode	Echo Mode	OFF / TRIP / ECHO / ECHO+TRIP	OFF	Echo and week end infeed operation mode
EchoConfirmTime	Echo Confirm Time	[20..10000] ms	50	Confirmation time for echo send
EchoDurationTime	Echo Duration Time	[0..10000] ms	50	Echo signal duration time
EchoBlockTime	Echo Block Time	[20..10000] ms	30	Echo signal block time

Identifier	Title	Range	Factory value	Description
GenPickupTime	Gen Pickup Time	[0..10000] ms	0	General pickup signal prolong time
Uop	Uop	[0,05..0,7] × U_r	0,50	Minimum voltage operation threshold
TopWei	Top Wei	[0..10000] ms	50	Week end infeed trip operation time
EchoVoltageSup	Echo Voltage Sup	OFF / ON	OFF	Enable voltage supervision for echo transmit
TxOpenCB	Tx Open CB	OFF / ON	OFF	Transmit permission signal on open circuit breaker
DelayCBTime	Delay CB Time	[0..1000] ms	100	Time delay for circuit breaker open permission signal
RemEnd2Operation	Rem End2 Operation	OFF / ON	OFF	Second remote end operation. If set to **OFF**, inputs **RxPermission2** and **RxBlock2** have no effect.

5.6 Remote Tripping

5.6.1 Introduction

In some applications it might be needed to trip one or more remote circuit breakers when a fault is detected by local protection functions. This is the case, for example, of a power transformer inside a transmission line protection zone, for which low-current internal faults in the transformer can only be detected by its dedicated protection functions but they must be cleared by the remote line end protection relay.

On the other hand, Direct Transfer Trip communication scheme logic can be implemented to provide high-speed tripping irrespective of the location of the fault in the protected line. With this scheme, a fault near the remote line end, outside the protection zone of a local underreach protection element (typically the zone 1 of the Distance Protection function) can be instantaneously cleared if the trip of the corresponding protection relay in the other line terminal is received.

This function can also be used in other user defined schemes, to issue a trip due to any signal received from an external protection or control device.

5.6.2 Operation Method

The Remote Tripping function can be activated by setting change (setting **Operation**). It provides separate modules for transmission and receive logic, so that it can be used only for transmitting a local protection trip to a remote device, only for tripping due to the reception of an external signal, or for both applications.

A Direct Underreach Transfer Trip (DUTT) scheme can thus be implemented (Figure 5.42). For this purpose, the function should be typically associated to an underreach Distance Protection zone, configured for example to cover about 80% of the protected line: the protection relay in each line terminal will send its local trip to the remote line end and will issue an unsupervised trip if the trip signal from the remote line end is received.

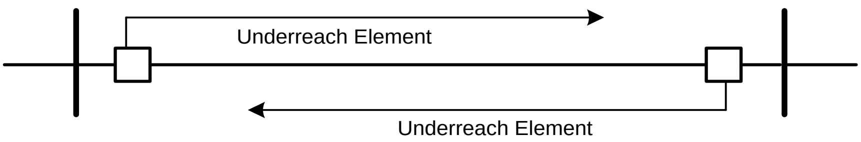

Figure 5.42. Direct Underreach Transfer Trip (DUTT) scheme.

The Remote Tripping function can be used in association with different communication interfaces, according to the several options available in the TPU L500. It can also be associated with binary inputs and outputs.

Transmission Logic

The transmission logic of the Remote Tripping function is shown in Figure 5.43.

In most cases, this module can be activated by associating the **CBTrip** output from the Three-Phase Trip Logic function (or, in option, the trip signal from selected protection functions or stages) to the function input **LocalTrip**. The output signal **TxTrip** should be associated to a remote end communication channel or to a binary output, depending on the communication media being used. In case of three-end lines, **TxTrip** should be transmitted simultaneously to both remote line ends, *i.e.* it should be associated to two distinct remote end communication channels or to two binary outputs. The resulting remote end trip will always be three-pole when using this configuration.

As an alternative, phase-segregated trip signals can be transmitted to the remote end if inputs **LocalTripA**, **LocalTripB** and **LocalTripC** are associated, for example, with the corresponding outputs of a specific protection function or stage. The output signals **TxTripA**, **TxTripB** and **TxTripC** should be configured in the same way as **TxTrip** in the previous example. Since there is no confirmation by the remote end of the information received, this configuration should be used if a remote single-phase tripping is required. **TxTrip** will also be available to send to the remote end, as the logical OR of the three phase input signals.

Whatever the chosen option is, the transmitted signal or signals can be extended for a pre-defined amount of time (setting **ProlongTime**) after dropout of the input trip signal. This guarantees a minimum duration of the pulse sent, enhancing the overall dependability of the logic scheme.

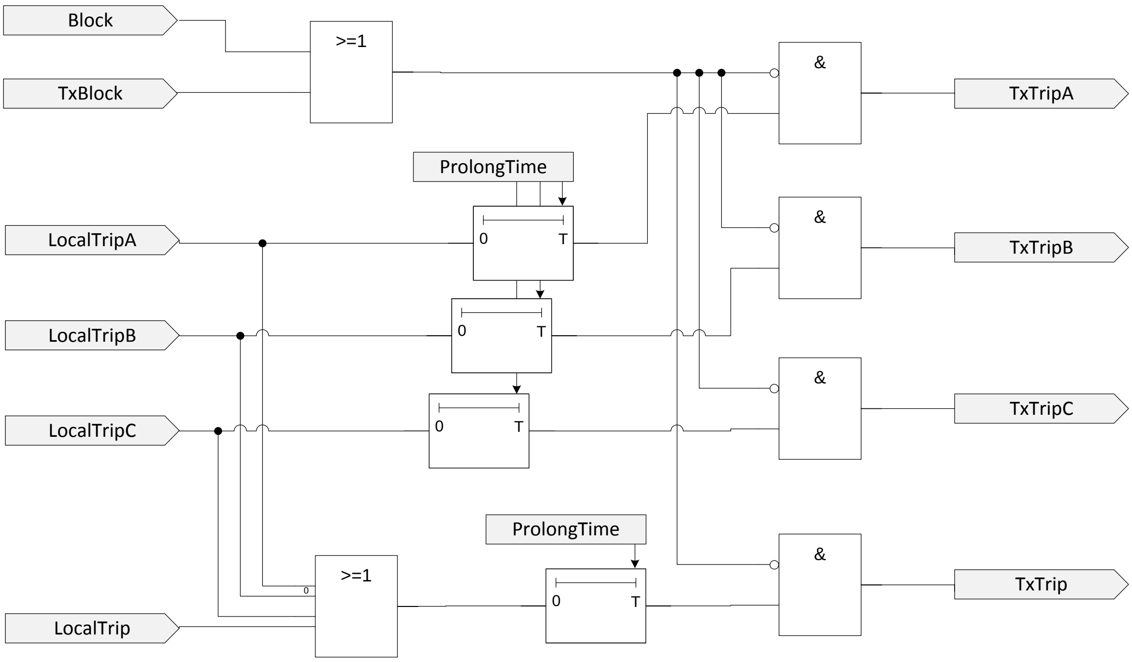

Figure 5.43. Remote Tripping transmission logic.

Receive Logic

The receive logic of the Remote Tripping function is shown in Figure 5.44.

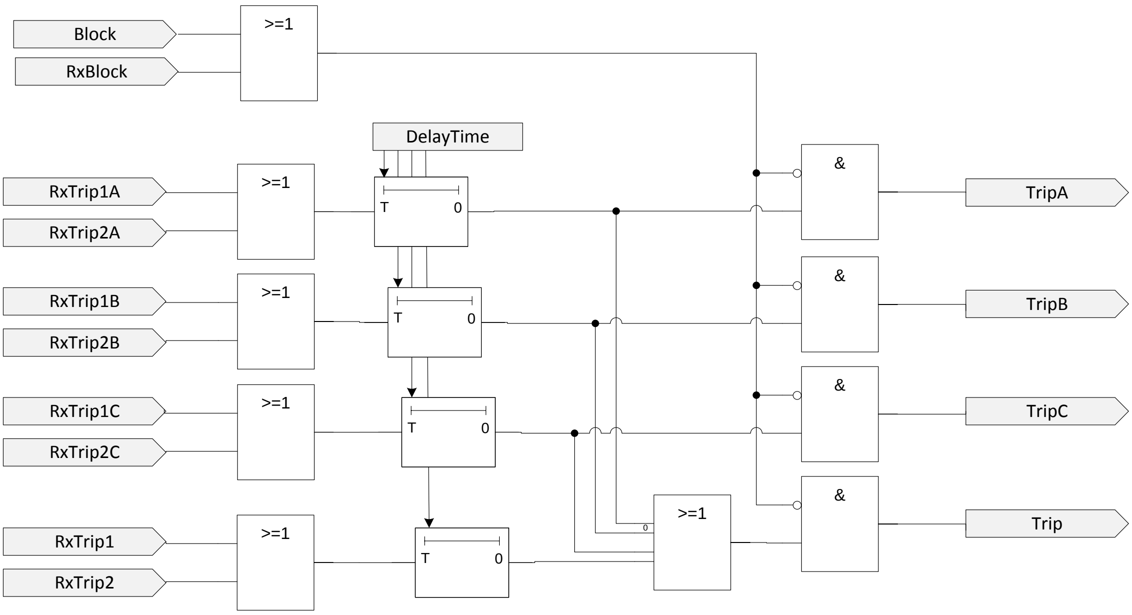

Figure 5.44. Remote Tripping receive logic.

When only three-pole tripping is required, function input **RxTrip1** should be associated to a remote end communication channel or to a binary input. In case of three-end lines, both **RxTrip1** and **RxTrip2** should be used, each one corresponding to a distinct channel. The reception of any of these signals leads to an unsupervised trip, available in output **Trip**.

The reception of phase-segregated trip signals is also possible. For this purpose, **RxTrip1A**, **RxTrip1B** and **RxTrip1C** should be associated to remote end communication channels or binary inputs. In case of three-end lines, **RxTrip2A**, **RxTrip2B** and **RxTrip2C** should also be used. The single-pole trip outputs are available in **TripA**, **TripB** and **TripC**. The reception of any of the phase signals will also issue a general **Trip** signal (logical OR of the individual inputs).

The receive signals are also available as function outputs for event log purposes.

The operation can be delayed for a defined amount of time. This time delay is constant and can be set by the user in setting **DelayTime**. If the operational time is set to zero, the trip will be instantaneous.

Blocking Conditions

The function provides an individual block input for transmission and receive logic (**TxBlock** and **RxBlock**, respectively) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

Each blocking condition is signalled in the corresponding output (**TxBlocked**, **RxBlocked** and **Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **RxTrip1**, **RxTrip1A**, **RxTrip1B**, **RxTrip1C**, **RxTrip2**, **RxTrip2A**, **RxTrip2B** and **RxTrip2C** inputs are all disconnected.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The **RxTrip1** input and any of the **RxTrip1A**, **RxTrip1B** or **RxTrip1C** inputs are connected simultaneously;
- The **RxTrip2** input and any of the **RxTrip2A**, **RxTrip2B** or **RxTrip2C** inputs are connected simultaneously.

The configuration is valid and the function operates accordingly otherwise.

5.6.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.22 and Table 5.23, respectively.

Table 5.22. Remote Tripping function inputs.

Identifier	Title	Type	Mlt	Description
Block	Block	DIG	4	Block function
RxBlock	Rx Block	DIG	4	Block receiving logic
TxBlock	Tx Block	DIG	4	Block transmission logic
RxTrip1A	Rx Trip1 PhA	DIG	1	Receive trip signal from side 1 phase A
RxTrip1B	Rx Trip1 PhB	DIG	1	Receive trip signal from side 1 phase B
RxTrip1C	Rx Trip1 PhC	DIG	1	Receive trip signal from side 1 phase C
RxTrip1	Rx Trip1	DIG	1	Receive general trip signal from side 1
RxTrip2A	Rx Trip2 PhA	DIG	1	Receive trip signal from side 2 phase A
RxTrip2B	Rx Trip2 PhB	DIG	1	Receive trip signal from side 2 phase B
RxTrip2C	Rx Trip2 PhC	DIG	1	Receive trip signal from side 2 phase C
RxTrip2	Rx Trip2	DIG	1	Receive general trip signal from side 2
LocalTripA	Local Trip PhA	DIG	16	Local trip phase A
LocalTripB	Local Trip PhB	DIG	16	Local trip phase B
LocalTripC	Local Trip PhC	DIG	16	Local trip phase C

Identifier	Title	Type	Mlt	Description
LocalTrip	Local Trip	DIG	32	Local general trip

Table 5.23. Remote Tripping function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
RxBlocked	Rx Blocked	DIG	-	Receiving logic blocked
TxBlocked	Tx Blocked	DIG	-	Transmission logic blocked
TxTripA	Tx Trip PhA	DIG	-	Transmit phase A trip signal
TxTripB	Tx Trip PhB	DIG	-	Transmit phase B trip signal
TxTripC	Tx Trip PhC	DIG	-	Transmit phase C trip signal
TxTrip	Tx Trip	DIG	-	Transmit general trip signal
TripA	Trip PhA	DIG	-	Phase A trip
TripB	Trip PhB	DIG	-	Phase B trip
TripC	Trip PhC	DIG	-	Phase C trip
Trip	Trip	DIG	-	General trip
RxTrip1A	Rx Trip1 PhA	DIG	-	Trip signal from side 1 phase A received
RxTrip1B	Rx Trip1 PhB	DIG	-	Trip signal from side 1 phase B received
RxTrip1C	Rx Trip1 PhC	DIG	-	Trip signal from side 1 phase C received
RxTrip1	Rx Trip1	DIG	-	General trip signal from side 1 received
RxTrip2A	Rx Trip2 PhA	DIG	-	Trip signal from side 2 phase A received
RxTrip2B	Rx Trip2 PhB	DIG	-	Trip signal from side 2 phase B received
RxTrip2C	Rx Trip2 PhC	DIG	-	Trip signal from side 2 phase C received
RxTrip2	Rx Trip2	DIG	-	General trip signal from side 2 received

5.6.4 Settings

The function settings are listed in Table 5.24.

Table 5.24. Remote Tripping function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
DelayTime	Delay Time	[0..10000] ms	0	Delay time for receive logic

Identifier	Title	Range	Factory value	Description
ProlongTime	Prolong Time	[0..10000] ms	0	Prolongation time for transmission logic

5.7 STUB

5.7.1 INTRODUCTION

In multiple breaker topologies such as breaker-and-a-half, double breaker / double bus or ring arrangements, which are typical in Transmission and Sub-Transmission substations, the main Distance Protection will remain inoperative for faults between two sets of current transformers when the associated power equipment (line or transformer) is disconnected for maintenance, because the voltage transformers will be in the disconnected section. A fault occurring between the pair of CTs and the disconnecting switch can only be cleared after a pre-defined time delay by the backup protection of the adjacent lines, which can seriously compromise power system stability.

The Stub Protection is an independent protection function that is required to tackle faults in the stub section when the disconnecting switch is open. The corresponding circuit breakers can be tripped without delay since the Stub Protection can operate as a unit protection function according to the differential principle.

5.7.2 OPERATION METHOD

The Stub Protection function provides an independent definite time stage, which supervises the differential current between two sets of current transformers in multiple breaker topologies, while the corresponding disconnecting switch is open. The function can be activated by setting change (setting **Operation**).

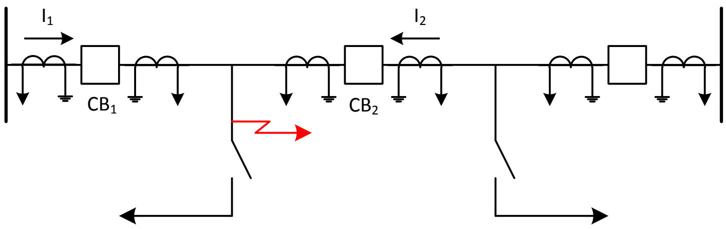

Figure 5.45. Stub fault in a multi-breaker arrangement.

The function is ready to operate only if function input **Enable** is active. This input should correspond to the Normally Closed contact 89b of the circuit switch that isolates the line or transformer.

Measuring Principle

While enabled by input **Enable**, the Stub Protection function continuously monitors the differential current in the corresponding stub section, obtained from the three phase current signals from both current transformer sets, associated in two analogue channels connected to the function inputs **I1** and **I2**, respectively.

$$\bar{I}_{diff} = \bar{I}_1 + \bar{I}_2 \qquad (5.10)$$

The current transformers should be connected towards the protected element so that the differential current calculated according to the equation (5.10) equals zero if the disconnecting switch is open except for power system faults in the stub section.

The CT polarity is directly defined in the analogue channel that is connected to a specific function input. The exact configuration can be consulted in subsection 4.4.3 - Channels. The user can thus define the direction of each analogue signal so that it matches the direction into the power system object.

Two distinct types of measuring elements are available. The first one measures the differential current per phase. The protection function is executed in full-scheme mode, which means that there are three separate protection elements for monitoring the differential current in each phase. The function pickup and trip are independently signalled for each phase if the operating conditions are met.

Additionally, an independent protection element with enhanced sensitivity against earth-faults measures the difference between the residual current in each CT set, which is obtained from the internal sum of the three phase current signals.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \quad (5.11)$$

There are also general pickup and trip outputs. They correspond to the logical OR of the phase and the neutral outputs, that is, they are activated, respectively, if at least one phase or neutral pickup or trip is active.

The function operates according to a stabilization characteristic, as shown in Figure 5.46, to avoid incorrect function trips due to different phase CT errors or, in case of the earth protection element, asymmetrical load conditions. The magnitude of the differential current is the operative quantity while the largest phase current among the two CT sets is used as the restraining quantity, as defined by equation (5.12).

$$I_{rest} = Max\left(\left|\bar{I}_{1A}\right|, \left|\bar{I}_{1B}\right|, \left|\bar{I}_{1C}\right|, \left|\bar{I}_{2A}\right|, \left|\bar{I}_{2B}\right|, \left|\bar{I}_{2C}\right|\right) \quad (5.12)$$

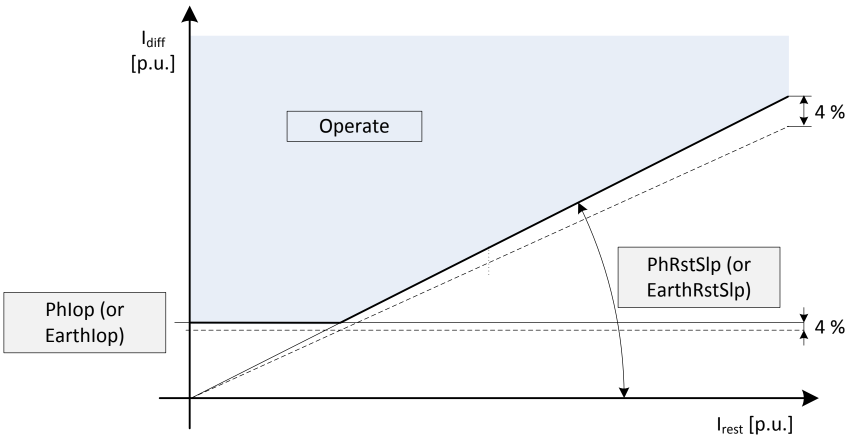

Figure 5.46. Stub operating characteristic.

The minimum differential current threshold is set in values per unit, relative to the rated CT primary current, in setting **PhIop** for the phase characteristic and **EarthIop** for the earth characteristic.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \quad (5.13)$$

The slope of the stabilization characteristic is configured in settings **PhRstSlp** for the phase characteristic and **EarthRstSlp** for the earth characteristic. A built-in hysteresis of 4% between pickup and reset levels guarantees the adequate stability of the function outputs.

A dedicated built-in algorithm ensures additional stabilization of the Stub Protection function against CT saturation caused by large fault currents flowing through the stub (for example, due to close-in external faults).

Definite Time Characteristic

The trip time is constant and can be set by the user in the corresponding function settings: **PhTop** for faults detected by the phase characteristic and **EarthTop** for faults detected by the earth characteristic. If the operational time is set to zero, the trip will be instantaneous. The function instantaneously resets if the differential current magnitude drops below the reset level of the stabilization characteristic.

Time settings may be overridden if function input **InstTrip** is active. This may be used to initiate an instantaneous trip by user-defined conditions.

Blocking Conditions

The function provides a general function block input (**Block**). It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I1** or **I2**;
- The analogue channel associated to input **I1** does not correspond to a group of three phase current signals;
- The analogue channel associated to input **I2** does not correspond to a group of three phase current signals;
- The primary rated value of the analogue channels associated to input **I1** and **I2** do not match;
- The **Enable** input is disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.7.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.25 and Table 5.26, respectively.

Table 5.25. Stub function inputs.

Identifier	Title	Type	Mlt	Description
I1	I1	ANL CH	-	Phase currents 1
I2	I2	ANL CH	-	Phase currents 2
Enable	Enable	DIG	1	Function enable
Block	Block	DIG	4	Function block
InstTrip	Instantaneous Trip	DIG	1	Instantaneous trip

Table 5.26. Stub function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
Enabled	Enabled	DIG	-	Function enabled
PickupA	Pickup A	DIG	-	Function start, phase A
PickupB	Pickup B	DIG	-	Function start, phase B
PickupC	Pickup C	DIG	-	Function start, phase C
PickupN	Pickup N	DIG	-	Function start, neutral
Pickup	Pickup	DIG	-	Function general start
TripA	Trip A	DIG	-	Function trip, phase A
TripB	Trip B	DIG	-	Function trip, phase B

Identifier	Title	Type	NV	Description
TripC	Trip C	DIG	-	Function trip, phase C
TripN	Trip N	DIG	-	Function trip, neutral
Trip	Trip	DIG	-	Function general trip

5.7.4 Settings

The function settings are listed in Table 5.27.

Table 5.27. Stub function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
PhIop	Phase Iop	[0,05..10,0] × I_r	0,2	Phase operation threshold
PhRstSlp	Phase Restraint Slp	[0,1..1,0] I_{diff}/I_{bias}	0,2	Phase restraint slope
PhTop	Phase Top	[0..60000] ms	50	Phase operation delay
EarthIop	Earth Iop	[0,05..10,0] × I_r	0,1	Earth operation threshold
EarthRstSlp	Earth Restraint Slp	[0,1..1,0] I_{diff}/I_{bias}	0,2	Earth restraint slope
EarthTop	Earth Top	[0..60000] ms	100	Earth operation delay

5.8 (Directional) Phase Overcurrent

5.8.1 Introduction

The Phase Overcurrent Protection is able to discriminate fault conditions provided that the current magnitude in one or more phases exceeds the maximum expected load current. Although this principle can be applied for all types of faults, it is particularly effective for phase-to-phase faults, because the fault arc resistance is typically low in this type of short-circuits, and the high current value allows a dependable trip of the protection function.

In some applications, like MV feeders in radial distribution networks, this simple operation principle is enough to provide an effective protection, and the Phase Overcurrent Protection can be used as the main protection function against phase-to-phase faults. In other applications, such as transmission lines or power transformers, where more sophisticated protection criteria are often required, this function may nonetheless be configured for backup or emergency operation, in this last case replacing the main function only when it is not able to operate (for example when the voltage signal is lost due to a failure in the measuring circuit).

Besides ensuring the adequate detection of fault conditions in the protected feeder, the Phase Overcurrent Protection can also provide some backup protection to downstream network elements. The coordination with other protection relays in the same network can be achieved in several ways, whether based on the current threshold or the corresponding time delay. It can also be set to issue an instantaneous trip in the case of high-current short-circuits in the protected feeder.

In meshed networks or when faults can be fed from more than one source (*e.g.* in the presence of distributed generation), the Phase Overcurrent Protection may be complemented with a directional criterion based for instance in the phase angle difference between phase currents and a polarization voltage, which ensures the adequate discrimination of faults in the forward and reverse directions.

5.8.2 Operation Method

Four independent overcurrent stages are available: the first two stages have a definite time characteristic, whereas for the third and fourth stages a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3 or 4). In alternative to its non-directional overcurrent default behaviour, directionality can be independently added to each stage in option.

Measuring Principle

The Phase Overcurrent Protection function continuously monitors one, two or three phase current signals, associated in one analogue channel connected to the function input **I**. In most cases, the three phase currents will be supervised but the function can be used in other scenarios, for example: when there are only CTs in two of the phases, which is still sufficient to detect all phase-to-phase faults; or in single-phase applications.

The protection function is executed in full-scheme mode, which means that there are separate protection elements for monitoring each input current. The function pickup and trip are independently signalled for each phase and stage if the operating conditions are met.

There are also general pickup and trip outputs for each stage. They correspond to the logical OR of the phase outputs, that is, they are activated, respectively, if at least one phase pickup or trip is active.

The stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \quad (5.14)$$

For all the stages, the operation threshold has an extended setting range that allows choosing distinct sensitivity levels for fault detection and enables the implementation of different protection coordination schemes.

Definite Time Characteristic

This is the only possible operating characteristic for stages 1 and 2. It can also be set in option for stages 3 and 4.

If definite time characteristic is selected, the stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous.

A dropout delay can be additionally set to stabilize pickup outputs. It is available in setting **StxDropDelay**. If the dropout delay is zero, the reset of the corresponding stage is always instantaneous if the current magnitude drops below the reset level. On the other hand, if the dropout delay is other than zero, the stage reset will be delayed (please consult subsection 8.1.3 - Definite Time Reset for more details).

After the trip has been issued, the stage always resets immediately after the pickup condition is cancelled.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stages 3 and 4.

If inverse time characteristic is selected, the pickup only occurs if the current magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equations (5.15) and (5.16)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the ratio between the measured current I and the operation threshold I_{op} (setting **StxIop**): the greater the current, the shorter the trip time. Several curves from the ANSI and IEC standards are available, and can be independently selected for each stage (in setting **StxCurve**). ANSI time characteristics follow the general equation (5.15), whereas IEC time characteristics obey to the equation (5.16). The expressions are integrated over time in order to accommodate current variations in the time between pickup and trip. The timer T_{MAX} (setting **StxMaxTime**) determines the starting point of the curve, together with the general current threshold I_{op} (setting **StxIop**). However, the stage pickup is only signalled if the current is higher than a specific setting (**StxIstart**) that must be greater or equal than I_{op}. The time multiplier TM (setting **StxTMS**) allows the user to adjust the trip time. A minimum operating time can also be set (in setting **StxMinTime**), which defines, for large currents, the lower limit of the time characteristic. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on these characteristics.

$$t = \left(\frac{A}{(I/I_{op})^p - 1} + B \right) \cdot TM \tag{5.15}$$

$$t = \frac{A \cdot TM}{(I/I_{op})^p - 1} \tag{5.16}$$

Each stage can reset instantaneously or the reset time can be defined according to a time inverse characteristic, in option selected by the user (in setting **StxDropType**).

If the inverse time reset option is selected, the time to reset depends on the measured current, according to the equation (5.17). This option, defined in the ANSI standard, is extended in the TPU L500 to the IEC curves. It allows emulating the dynamic behaviour of old electromechanical relays, if coordination with this kind of devices is an issue. As for the instantaneous reset, the pickup signal is set inactive as soon as the current drops below the reset level; however, the relay does not resume the reset position immediately. If a new fault occurs before this position is reached, the following trip will be initiated in a shorter time, dependent on the measured current and on the time elapsed between faults. The time multiplier (TM) corresponds to the same setting used in the trip characteristic. The expression is also integrated over time in order to accommodate variations in the current magnitude.

$$t = \frac{t_{reset} \cdot TM}{1 - (I/I_{op})^2} \tag{5.17}$$

Directionality

Each stage can be independently complemented with a directional element, *i.e.* it can be set as non-directional (only overcurrent measurement) or directional (forward or reverse). This is configurable in setting **StxDirection**.

The directional element of the Phase Overcurrent Protection is only available if the TPU L500 has three voltage analogue inputs available.

The forward direction is defined as the direction into the protected object, whereas the reverse direction is the direction out from the protected object. The CT polarity should be conveniently configured according to this convention (please consult the corresponding subsection 4.4.3 - Channels).

There are two different directional characteristics depending on the polarization selected: sequence polarization (setting **Polarization** set to SEQUENCE) and cross voltage polarization (setting **Polarization** set to CROSS-90DEG). For any polarization the directional characteristic is only evaluated when the operating current is greater than the corresponding pickup threshold.

When working with sequence polarization (setting **Polarization** set to SEQUENCE), the polarization of the directional element is done with the positive and negative sequence voltages (equations (5.18) and (5.19), respectively). These quantities can be obtained from the three phase-to-earth voltage signals or from at least two phase-to-phase voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_1 = 1/3 \cdot \left(\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C\right), \quad a = e^{j120^\circ} \tag{5.18}$$

$$\overline{U}_2 = 1/3 \cdot \left(\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C\right), \quad a = e^{j120^\circ} \tag{5.19}$$

With sequence polarization, the relay evaluates the fault direction by taking into account the phase angle difference between the positive sequence current and the positive sequence voltage and the phase angle difference between the negative sequence current and the symmetrical of the negative sequence voltage. The use of both positive and negative sequence components ensures that, irrespective of the fault type, there is always an adequate polarization quantity. Negative sequence component, if available, allows correct direction selectivity for all asymmetrical faults. By the contrary, in case of three-phase symmetrical faults, only positive sequence voltage is evaluated. The corresponding directional characteristic for each one of these components is represented in Figure 5.47.

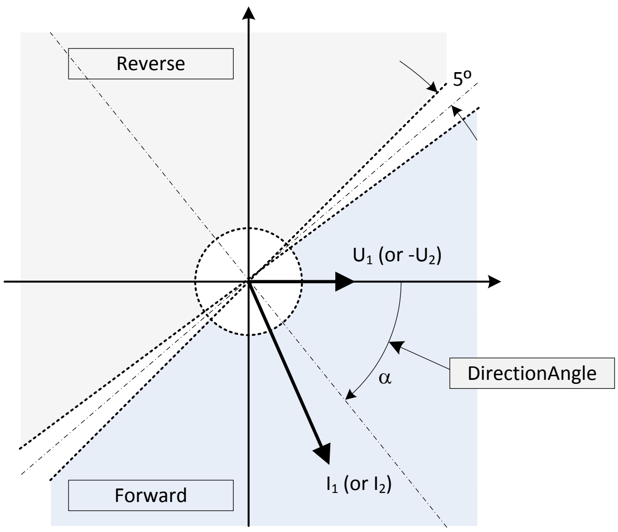

Figure 5.47. Phase Overcurrent sequence polarized directional characteristic.

When working with cross voltage polarization (setting **Polarization** set to CROSS-90DEG), the polarization of the directional element is done with the cross phase-to-phase voltages. These quantities can be calculated from the three phase-to-earth voltage signals or measured directly from at least two phase-to-phase voltage signals, associated in one analogue channel connected to the function input **U**.

With cross voltage polarization the relay evaluates the fault direction by taking into account the phase angle difference between the phase current and the phase-to-phase cross voltage. The use of the phase-to-phase cross voltage as polarization exploits the voltages most likely to be unfaulted and thus maximises the changes of achieving adequate polarization quantity. The corresponding directional characteristic for cross polarization is represented in Figure 5.48.

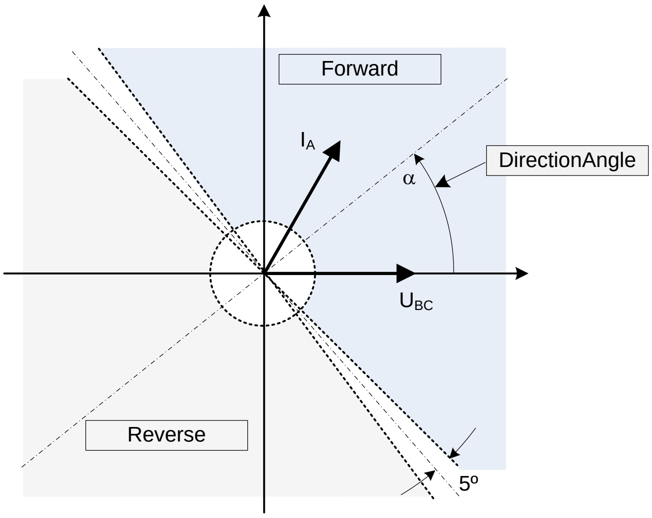

Figure 5.48. Phase Overcurrent cross polarized directional characteristic.

The maximum torque angle, which defines the rotation of the directional characteristic, is configured by the user in setting **DirectionAngle**. It should be set according to the phase angle of the system positive sequence impedance: directly for sequence polarization or with the difference to 90° for cross voltage polarization. A built-in hysteresis of 5° guarantees the adequate stability of the direction decision.

In case of a close-in three-phase fault, if no voltages are available for polarizing the directional element, the TPU L500 relies on the memory of the pre-fault voltage to determine fault direction. Besides that, the pre-fault voltage is always used for polarization immediately after fault inception, regardless of the type of fault, so that the relay decision is not affected by voltage signal transients. Special arrangements are also made to compensate for the phase rotation due to frequency variations during the time the memory is active.

The memory of the pre-fault voltages is kept during approximately one second; in real operating conditions, this is usually enough to guarantee a safe trip decision. If nonetheless the fault condition persists after the memory timeout elapses, the protection maintains the directional decision that was taken before. On the other hand if, at the time of fault inception, there is no longer voltage memory, the directional element cannot operate and a non-directional trip is allowed.

A voltage transformer failure also causes the loss of the polarization quantity. In case the MCB trips, no measuring voltage will be available for relay polarization in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, the polarization voltages cannot be calculated. The VT failure indication should be connected to the function input **VTFail**. It may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision). If this indication is received, the function will operate according to the behaviour defined in setting **VTFailAction**. The user can choose to inhibit the directional criterion, allowing a non-directional trip, or to block the directional stages instead.

The fault direction is signalled in function output **FaultDirection**, which has three possible values: **UNKNOWN**, **FORWARD** and **REVERSE**. If the directional element is not enabled for any stage, **FaultDirection** always indicates **UNKNOWN**. This is also the default entity state while no fault is detected.

Inrush Restraint

An inrush restraint blocking function is provided for all stages. It can be independently activated for each stage, in setting **StxHarmonicOperation**.

This feature allows blocking the Phase Overcurrent Protection trip if the percentage of second harmonic in phase current signals is higher than a pre-defined value. The maximum ratio between the second harmonic and the fundamental frequency component, above which the function is blocked, is set in setting **HarmonicOperationValue**. This blocking threshold is the same for all stages. A built-in hysteresis guarantees the adequate stability of the function outputs.

There are separate block elements monitoring each phase current. They can operate independently or a cross-block between distinct phases can be configured. If setting **HarmonicCrossBlock** has the value **ONE-OF-THREE**, all three phases are blocked if a high second harmonic ratio is detected in at least one of them; if setting **HarmonicCrossBlock** has the value **TWO-OF-THREE**, the cross-block is only activated if the inrush restraint conditions are met in two phases simultaneously.

The inrush restraint is independently signalled for each phase if the conditions described above are met. There is also a general inrush restraint output, if at least one phase indication is active.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St4Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- A neutral current channel is associated to input **I**.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There is no analogue channel associated to input **U**: the directional stages are not enabled in this case;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth or at least two phase-to-phase voltage signals: the directional stages are not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.8.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.28 and Table 5.29, respectively.

Table 5.28. (Directional) Phase Overcurrent function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating currents
U	U	ANL CH	-	Polarizing voltages
Block	Block	DIG	4	Function general block
VTFail	VT Failure	DIG	2	Voltage transformer failure
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
ColdLoadMultiplier	Cold Load Mult	INT	1	Cold load pickup multiplier

Table 5.29. (Directional) Phase Overcurrent function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version

Identifier	Title	Type	NV	Description
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St1PickupA	St1 Pickup A	DIG	-	Stage 1 start, phase A
St1PickupB	St1 Pickup B	DIG	-	Stage 1 start, phase B
St1PickupC	St1 Pickup C	DIG	-	Stage 1 start, phase C
St2PickupA	St2 Pickup A	DIG	-	Stage 2 start, phase A
St2PickupB	St2 Pickup B	DIG	-	Stage 2 start, phase B
St2PickupC	St2 Pickup C	DIG	-	Stage 2 start, phase C
St3PickupA	St3 Pickup A	DIG	-	Stage 3 start, phase A
St3PickupB	St3 Pickup B	DIG	-	Stage 3 start, phase B
St3PickupC	St3 Pickup C	DIG	-	Stage 3 start, phase C
St4PickupA	St4 Pickup A	DIG	-	Stage 4 start, phase A
St4PickupB	St4 Pickup B	DIG	-	Stage 4 start, phase B
St4PickupC	St4 Pickup C	DIG	-	Stage 4 start, phase C
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St1TripA	St1 Trip A	DIG	-	Stage 1 trip, phase A
St1TripB	St1 Trip B	DIG	-	Stage 1 trip, phase B
St1TripC	St1 Trip C	DIG	-	Stage 1 trip, phase C
St2TripA	St2 Trip A	DIG	-	Stage 2 trip, phase A
St2TripB	St2 Trip B	DIG	-	Stage 2 trip, phase B
St2TripC	St2 Trip C	DIG	-	Stage 2 trip, phase C
St3TripA	St3 Trip A	DIG	-	Stage 3 trip, phase A
St3TripB	St3 Trip B	DIG	-	Stage 3 trip, phase B
St3TripC	St3 Trip C	DIG	-	Stage 3 trip, phase C
St4TripA	St4 Trip A	DIG	-	Stage 4 trip, phase A
St4TripB	St4 Trip B	DIG	-	Stage 4 trip, phase B
St4TripC	St4 Trip C	DIG	-	Stage 4 trip, phase C
St1Trip	St1 Trip	DIG	-	Stage 1 general trip

Identifier	Title	Type	NV	Description
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
HarmonicBlockA	Harmonic Block A	DIG	-	Harmonic block start, phase A
HarmonicBlockB	Harmonic Block B	DIG	-	Harmonic block start, phase B
HarmonicBlockC	Harmonic Block C	DIG	-	Harmonic block start, phase C
HarmonicBlock	Harmonic Block	DIG	-	General harmonic block start
FaultDirection	Fault Direction	INT	-	Fault direction indication

5.8.4 Settings

The function settings are listed in Table 5.30.

Table 5.30. (Directional) Phase Overcurrent function settings.

Identifier	Title	Range	Factory value	Description
Polarization	Polarization Type	SEQUENCE / CROSS-90DEG	SEQUENCE	Polarization type
DirectionAngle	Direction Angle	[-90,0..90,0] °	45,0	Characteristic direction angle
VTFailAction	VT Fail Action	TRIP / BLOCK	TRIP	Action on voltage transformer failure
HarmonicOperationValue	Harmonic Op Value	[0,05..1,0] I_{2h}/I_{1h}	0,2	Harmonic operation threshold
HarmonicCrossBlock	Harmonic Cross Blk	OFF / ONE-OF-THREE / TWO-OF-THREE	OFF	Harmonic crossed block
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1HarmonicOperation	St1 Harmonic Op	OFF / ON	OFF	Stage 1 harmonic block operation
St1Direction	St1 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 1 direction
St1DropType	St1 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 1 reset type
St1DropDelay	St1 Drop Delay	[0..60000] ms	0	Stage 1 reset delay time
St1Iop	St1 Iop	[0,05..40,0] × I_r	4,0	Stage 1 operation threshold
St1MaxColdLoadMult	St1 Cold Load Mult	[1,0..20,0] × I_{op}	1,0	Stage 1 maximum cold load pickup multiplier
St1Top	St1 Top	[0..60000] ms	0	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2HarmonicOperation	St2 Harmonic Op	OFF / ON	OFF	Stage 2 harmonic block operation
St2Direction	St2 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 2 direction

Identifier	Title	Range	Factory value	Description
St2DropType	St2 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 2 reset type
St2DropDelay	St2 Drop Delay	[0..60000] ms	0	Stage 2 reset delay time
St2Iop	St2 Iop	[0,05..40,0] × I_r	4,0	Stage 2 operation threshold
St2MaxColdLoadMult	St2 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 2 maximum cold load pickup multiplier
St2Top	St2 Top	[0..60000] ms	0	Stage 2 operation delay time
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3HarmonicOperation	St3 Harmonic Op	OFF / ON	OFF	Stage 3 harmonic block operation
St3Direction	St3 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 3 direction
St3Curve	St3 Curve	See Annex 8.1	ANSI DEF	Stage 3 curve type
St3TMS	St3 TMS	[0,05..15,0]	1,0	Stage 3 time multiplier
St3DropType	St3 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 3 reset type
St3DropDelay	St3 Drop Delay	[0..60000] ms	0	Stage 3 reset delay time
St3Iop	St3 Iop	[0,05..20,0] × I_r	2,0	Stage 3 operation threshold
St3MaxColdLoadMult	St3 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 3 maximum cold load pickup multiplier
St3Top	St3 Top	[0..60000] ms	400	Stage 3 operation delay time
St3TimeAdder	St3 Time Adder	[0..30000] ms	0	Stage 3 constant time adder
St3MaxTime	St3 Max Time	[0..60000] ms	0	Stage 3 maximum operation time
St3MinTime	St3 Min Time	[0..60000] ms	0	Stage 3 minimum operation time
St3Istart	St3 Istart	[1.0..4.0] × I_{op}	1.0	Stage 3 minimum start current
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4HarmonicOperation	St4 Harmonic Op	OFF / ON	OFF	Stage 4 harmonic block operation
St4Direction	St4 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 4 direction
St4Curve	St4 Curve	See Annex 8.1	ANSI DEF	Stage 4 curve type
St4TMS	St4 TMS	[0,05..15,0]	1,0	Stage 4 time multiplier
St4DropType	St4 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 4 reset type
St4DropDelay	St4 Drop Delay	[0..60000] ms	0	Stage 4 reset delay time
St4Iop	St4 Iop	[0,05..20,0] × I_r	2,0	Stage 4 operation threshold
St4MaxColdLoadMult	St4 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 4 maximum cold load pickup multiplier
St4Top	St4 Top	[0..60000] ms	400	Stage 4 operation delay time
St4TimeAdder	St4 Time Adder	[0..30000] ms	0	Stage 4 constant time adder

Identifier	Title	Range	Factory value	Description
St4MaxTime	St4 Max Time	[0..60000] ms	0	Stage 4 maximum operation time
St4MinTime	St4 Min Time	[0..60000] ms	0	Stage 4 minimum operation time
St4Istart	St4 Istart	[1.0..4.0] × I_{op}	1.0	Stage 4 minimum start current

5.9 (Directional) Earth-Fault Overcurrent

5.9.1 Introduction

Because three-phase power systems are operated in almost balanced conditions, the Earth-Fault Overcurrent Protection, based on the measurement of the residual current, provides an effective method of detecting insulation failures of one or more phases to the earth, particularly in solid or low-impedance earthed systems. It may also be applied with some restrictions to isolated or compensated earthed networks, even if more specific protection functions are usually available for this type of applications.

The residual current can be directly measured from the sum of the three phase currents. The function sensitivity can be further enhanced if an independent phase-balance neutral current transformer is used to measure the residual current. If properly dimensioned, the detection of very large fault resistances is possible.

In meshed networks or when faults can be fed from more than one source, the Earth-Fault Overcurrent Protection may be complemented with a directional criterion in order to discriminate between forward and reverse faults. Directional operation must also be configured to distinguish between the current in the faulted feeder and capacitive currents flowing in healthy network components, if very high sensitivity levels are required. The directional characteristic should be carefully configured according to the type of neutral connection.

In some applications, like MV feeders in radial distribution networks, the Earth-Fault Overcurrent Protection is normally used as the main protection function against phase-to-earth faults. Due to its enhanced sensitivity it can also successfully complement other protection functions in more complex protection schemes. For instance, the Earth-Fault Overcurrent Protection is usually needed for tripping large resistance earth-faults that are not detected by the operating characteristic of the Distance Protection.

5.9.2 Operation Method

Four independent overcurrent stages are available: the first two stages have a definite time characteristic, whereas for the third and fourth stages a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3 or 4). In alternative to its non-directional overcurrent default behaviour, directionality can be independently added to each stage in option.

Measuring Principle

The Earth-Fault Overcurrent Protection function continuously monitors the residual current, which corresponds to three times the zero sequence current. It can be obtained from the internal sum of the three phase current signals, associated in one analogue channel connected to the function input **I**.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \qquad (5.20)$$

As an alternative to the previous method, the residual current can be directly measured in one analogue input, for instance from an independent phase-balance neutral current transformer. It can also be obtained from the external sum of the three phase currents (Holmgreen circuit). In these cases, the function input **I** should be associated to a neutral analogue channel.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \qquad (5.21)$$

For all the stages, the operation threshold has an extended setting range that allows choosing distinct sensitivity levels for fault detection and enables the implementation of different protection coordination schemes. The configuration of highly sensitive operation thresholds is possible, namely if input **I** is associated with an extra sensitive analogue input.

The setting range for which the current threshold is valid depends on the specific option of the analogue input that is associated to the function:

- If the function is associated with three phase currents (internal sum option), the minimum threshold that can be set is 0,05 p.u. (5% of the rated value). If the setting is set below that value, the function operates when the current is above 0,05 p.u. only.
- The same applies if the function is associated to a neutral current with normal sensitivity.
- If the function is associated with an extra sensitive current input, the minimum threshold that can be set is 0,005 p.u. (0,5% of the rated value). If the setting is set above 4,0 p.u. the function does not operate.

Additional stabilization can be configured if the residual current is obtained from the internal sum of the three phase currents, to avoid incorrect function trips due to different phase CT errors or asymmetrical load conditions. The largest of the three phase currents is used to restrain the residual current pickup, according to a characteristic like the represented in Figure 5.49. The greater the phase current is, the less sensitive the Earth-Fault Overcurrent function becomes. The slope of the stabilization characteristic can be configured, in setting **PhCurrRestraintSlope**.

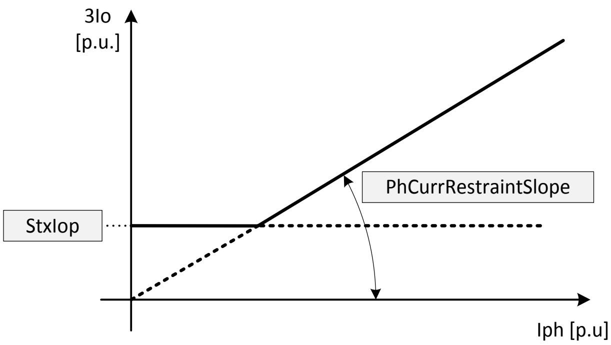

Figure 5.49. Residual current stabilization by phase current.

Definite Time Characteristic

This is the only possible operating characteristic for stages 1 and 2. It can also be set in option for stages 3 and 4.

If definite time characteristic is selected, the stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous.

A dropout delay can be additionally set to stabilize pickup outputs. It is available in setting **StxDropDelay**. If the dropout delay is zero, the reset of the corresponding stage is always instantaneous if the current magnitude drops below the reset level. On the other hand, if the dropout delay is other than zero, the stage reset will be delayed (please consult subsection 8.1.3 - Definite Time Reset for more details).

After the trip has been issued, the stage always resets immediately after the pickup condition is cancelled.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stages 3 and 4.

If inverse time characteristic is selected, the pickup only occurs if the current magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equations (5.22) and (5.23)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the ratio between the measured current I and the operation threshold I_{op} (setting **StxIop**): the greater the current, the shorter the trip time. Several curves from the ANSI and IEC standards are available, and can be independently selected for each stage (in setting **StxCurve**). ANSI time characteristics follow the general equation (5.22), whereas IEC time characteristics obey to the equation (5.23). The expressions are integrated over time in order to accommodate current variations in the time between pickup and trip. The timer T_{MAX} (setting **StxMaxTime**) determines the starting point of the curve, together with the general current threshold I_{op} (setting **StxIop**). However, the stage pickup is only signalled if the current is higher than a specific setting (**StxIstart**) that must be greater or equal than I_{op}. The time multiplier *TM* (setting **StxTMS**) allows the user to adjust the trip time. A minimum operating time can also be set (in setting **StxMinTime**), which defines, for large currents, the lower limit of the time characteristic. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on these characteristics.

$$t = \left(\frac{A}{(I/I_{op})^p - 1} + B \right) \cdot TM \tag{5.22}$$

$$t = \frac{A \cdot TM}{(I/I_{op})^p - 1} \tag{5.23}$$

Each stage can reset instantaneously or the reset time can be defined according to a time inverse characteristic, in option selected by the user (in setting **StxDropType**).

If the inverse time reset option is selected, the time to reset depends on the measured current, according to the equation (5.24). This option, defined in the ANSI standard, is extended in the TPU L500 to the IEC curves. It allows emulating the dynamic behaviour of old electromechanical relays, if coordination with this kind of devices is an issue. As for the instantaneous reset, the pickup signal is set inactive as soon as the current drops below the reset level; however, the relay does not resume the reset position immediately. If a new fault occurs before this position is reached, the following trip will be initiated in a shorter time, dependent on the measured current and on the time elapsed between faults. The time multiplier (*TM*) corresponds to the same setting used in the trip characteristic. The expression is also integrated over time in order to accommodate variations in the current magnitude.

$$t = \frac{t_{reset} \cdot TM}{1 - (I/I_{op})^2} \tag{5.24}$$

The logarithmic curve is an additional time characteristic option available. Its trip time complies with equation (5.25). It has a distinctive property, relevant for earth-fault protection coordination: if, at two distinct locations of the network, the measured fault currents are proportional for different phase-to-earth faults, than the time difference between the trips of the corresponding protection relays is always constant.

$$t = T_{MAX} - TM \cdot \ln\left(\frac{I}{I_{op}} \right) \tag{5.25}$$

When the logarithmic curve is selected, the stage reset is always instantaneous. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for some examples.

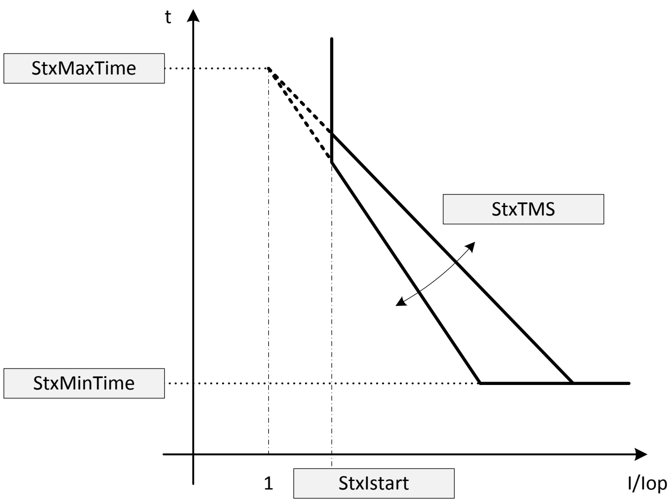

Figure 5.50. Logarithmic curve settings.

Directionality

Each stage can be independently complemented with a directional element, *i.e.* it can be set as non-directional (only overcurrent measurement) or directional (forward or reverse). This is configurable in setting **StxDirection**.

The directional element of the Earth-Fault Overcurrent Protection is only available if the TPU L500 has at least one voltage analogue input available.

The forward direction is defined as the direction into the protected object, whereas the reverse direction is the direction out from the protected object. The CT polarity should be conveniently configured according to this convention (please consult the corresponding subsection 4.4.3 - Channels).

The directional characteristic is evaluated when the operating current is greater than the corresponding pickup threshold.

There are several options available for polarization of the directional element. The most common is the polarization with residual voltage. This quantity can be obtained from the internal sum of the three phase-to-earth voltage signals, associated in one analogue channel connected to the function input **Upol**; or, in alternative, it can be directly measured in one analogue input, for instance from an independent open-delta connected voltage transformer winding, in which case the function input **Upol** should be associated to a neutral analogue channel.

$$\overline{U}_{res} = \overline{U}_A + \overline{U}_B + \overline{U}_C \quad (5.26)$$

The relay evaluates the fault direction by the phase angle difference between the residual current and the symmetrical of the residual voltage. The corresponding directional characteristic is represented in Figure 5.51. The maximum torque angle, which defines the rotation of the characteristic, is configured by the user in setting **DirectionAngle**. It should be set according to the phase angle of the system zero sequence impedance. A built-in hysteresis of 5° guarantees the adequate stability of the direction decision.

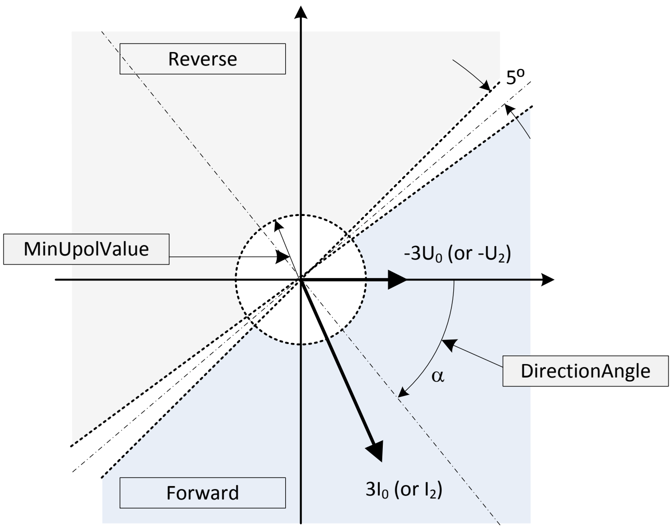

Figure 5.51. Earth-Fault directional characteristic with polarization by voltage.

A minimum polarizing quantity must be available; the direction will only be determined if the residual voltage is greater than the setting **MinUpolValue**. Its setting range provides adequate sensitivity for most fault conditions. Nevertheless, when the residual voltage is not high enough to polarize the relay, the user can choose to inhibit the directional criterion, allowing a non-directional trip, or to block the directional stages instead. These two options are available in setting **VTFailAction**.

A voltage transformer failure also causes the loss of the polarization quantity. In case the MCB trips, no measuring voltage will be available for relay polarization in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, the residual voltage cannot be calculated. The VT failure indication should be connected to the function input **VTFail**. It may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision). If this indication is received, the function will operate according to the behaviour defined in setting **VTFailAction**.

In option, a neutral current connected to input **Ipol** can be chosen as the polarizing quantity. This option is immune to voltage transformer failures but needs an adequate source of current to polarize the relay (example, the connection of the neutral point of a transformer). The direction is determined in this case by the phase angle difference between the operating and the polarizing currents, according to the characteristic shown in Figure 5.52. Once more, a built-in hysteresis of 5° guarantees the adequate stability of the direction decision.

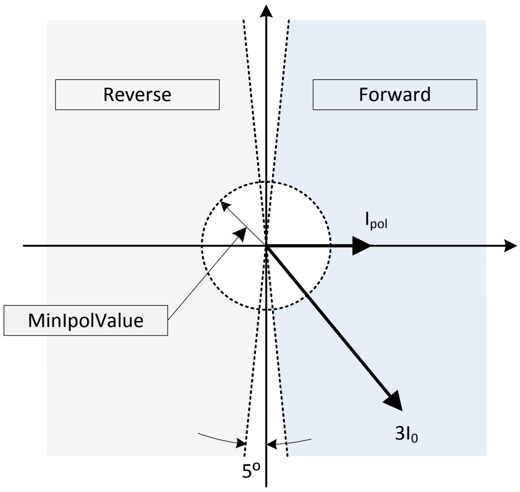

Figure 5.52. Earth-Fault directional characteristic with polarization by current.

A minimum polarizing quantity must also be available in this case; the direction will only be determined if the polarizing current is greater than the setting **MinIpolValue**. Its setting range provides adequate sensitivity for most fault conditions. Nevertheless, when the polarizing current is not high enough to polarize the relay, the user can choose how the function behaves, in setting **VTFailAction**.

If both inputs **Upol** and **Ipol** are connected, the directional element implements a dual polarization mechanism, combining both methods presented. This choice maximizes the availability of a polarizing quantity for the directional element.

In alternative to the previous methods, the user can choose to evaluate the fault direction using negative sequence components. In this case, the fault direction is evaluated by the phase angle difference between the negative sequence current and the symmetrical of the negative sequence voltage, calculated from **I** and **Upol** inputs, respectively. The directional characteristic is the same as for residual voltage polarization (see Figure 5.51) and the maximum torque angle is also selectable in setting **DirectionAngle**. In case of voltage transformer failure, or if the positive sequence voltage is less than the **MinUpolValue** threshold, the function will operate according to the behaviour defined in setting **VTFailAction**.

The fault direction is signalled in function output **FaultDirection**, which has three possible values: **UNKNOWN**, **FORWARD** and **REVERSE**. If the directional element is not enabled for any stage, **FaultDirection** always indicates **UNKNOWN**. This is also the default entity state while no fault is detected.

Inrush Restraint

An inrush restraint blocking function is provided for all stages. It can be independently activated for each stage, in setting **StxHarmonicOperation**.

This feature allows blocking the Earth-Fault Overcurrent Protection trip if the percentage of second harmonic in the residual current signal is higher than a pre-defined value. The maximum ratio between the second harmonic and the fundamental frequency component, above which the function is blocked, is set in setting **HarmonicOperationValue**. This blocking threshold is the same for all stages. A built-in hysteresis guarantees the adequate stability of the function outputs.

The inrush restraint is indicated in a specific output when the conditions described above are met.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St4Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The Earth-Fault Overcurrent Protection should be blocked during an open pole condition, if the circuit breaker is capable of single-pole tripping, because a current asymmetry may exist in this situation. An independent input (**OpenPole**) is available for this purpose; it should be associated with the corresponding output of a separate open pole detector function.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- The analogue channel associated to input **I** does not correspond to a neutral or to a group of three phase current signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There are no analogue channels associated to inputs **Ipol** and **Upol**: the directional stages are not enabled in this case;
- The analogue channel associated to input **Upol** does not correspond to a neutral or to a group of three phase-to-earth voltage signals: the directional stages are not enabled in this case;
- The analogue channel associated to input **Ipol** does not correspond to a neutral or to a group of three phase current signals: the directional stages are not enabled in this case;
- The negative sequence components directional criterion is activated and the analogue channel associated to input **I** does not correspond to a group of three phase current signals or the analogue channel associated to input **Upol** does not correspond to a group of three phase-to-earth voltage signals: the directional stages are not enabled in this case.
- The value of setting **IresOp** does not comply with the measuring range of the current input the function is associated with: the function sensitivity is limited according to the possible measuring range.

The configuration is valid and the function operates accordingly otherwise.

5.9.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.31 and Table 5.32, respectively.

Table 5.31. (Directional) Earth-Fault Overcurrent function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating current
Ipol	Ipol	ANL CH	-	Polarizing current
Upol	Upol	ANL CH	-	Polarizing voltage
Block	Block	DIG	4	Function general block
OpenPole	Open Pole	DIG	2	Open pole
VTFail	VT Failure	DIG	2	Voltage transformer failure
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
ColdLoadMultiplier	Cold Load Mult	INT	1	Cold load pickup multiplier

Table 5.32. (Directional) Earth-Fault Overcurrent function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
HarmonicBlock	Harmonic Block	DIG	-	General harmonic block start
FaultDirection	Fault Direction	INT	-	Fault direction indication

5.9.4 Settings

The function settings are listed in Table 5.33.

Table 5.33. (Directional) Earth-Fault Overcurrent function settings.

Identifier	Title	Range	Factory value	Description
DirectionAngle	Direction Angle	[-90,0..90,0] °	0,0	Characteristic direction angle
MinUpolValue	Min Upol Value	[0,01..1,0] × U_r	0,05	Minimum polarizing voltage
MinIpolValue	Min Ipol Value	[0,05..1,0] × I_r	0,07	Minimum polarizing current
NegSeqDirOperation	Neg Seq Dir Op	OFF / ON	OFF	Negative sequence polarization
VTFailAction	VT Fail Action	TRIP / BLOCK	TRIP	Action on voltage transformer failure
HarmonicOperationValue	Harmonic Op Value	[0,05..1,0] I_{2h}/I_{1h}	0,2	Harmonic operation threshold

Identifier	Title	Range	Factory value	Description
PhCurrRestraintSlope	Ph Curr Rest Slope	[0,0..0,3] I_{res}/I_{ph}	0,1	Phase current restraint slope
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1HarmonicOperation	St1 Harmonic Op	OFF / ON	OFF	Stage 1 harmonic block operation
St1Direction	St1 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 1 direction
St1DropType	St1 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 1 reset type
St1DropDelay	St1 Drop Delay	[0..60000] ms	0	Stage 1 reset delay time
St1Iop	St1 Iop	[0,005..40,0] × I_r	4,0	Stage 1 operation threshold
St1MaxColdLoadMult	St1 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 1 maximum cold load start multiplier
St1Top	St1 Top	[0..60000] ms	0	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2HarmonicOperation	St2 Harmonic Op	OFF / ON	OFF	Stage 2 harmonic block operation
St2Direction	St2 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 2 direction
St2DropType	St2 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 2 reset type
St2DropDelay	St2 Drop Delay	[0..60000] ms	0	Stage 2 reset delay time
St2Iop	St2 Iop	[0,005..40,0] × I_r	4,0	Stage 2 operation threshold
St2MaxColdLoadMult	St2 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 2 maximum cold load start multiplier
St2Top	St2 Top	[0..60000] ms	0	Stage 2 operation delay time
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3HarmonicOperation	St3 Harmonic Op	OFF / ON	OFF	Stage 3 harmonic block operation
St3Direction	St3 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 3 direction
St3Curve	St3 Curve	See Annex 8.1	ANSI DEF	Stage 3 curve type
St3TMS	St3 TMS	[0,05..15,0]	1,0	Stage 3 time multiplier
St3DropType	St3 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 3 reset type
St3DropDelay	St3 Drop Delay	[0..60000] ms	0	Stage 3 reset delay time
St3Iop	St3 Iop	[0,005..20,0] × I_r	2,0	Stage 3 operation threshold
St3MaxColdLoadMult	St3 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 3 maximum cold load start multiplier
St3Top	St3 Top	[0..300000] ms	400	Stage 3 operation delay time
St3TimeAdder	St3 Time Adder	[0..30000] ms	0	Stage 3 constant time adder
St3MaxTime	St3 Max Time	[0..60000] ms	5800	Stage 3 maximum operation time
St3MinTime	St3 Min Time	[0..60000] ms	1200	Stage 3 minimum operation time

Identifier	Title	Range	Factory value	Description
St3Istart	St3 Istart	[1,0..4,0] × I_{op}	1.0	Stage 3 minimum start current
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4HarmonicOperation	St4 Harmonic Op	OFF / ON	OFF	Stage 4 harmonic block operation
St4Direction	St4 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 4 direction
St4Curve	St4 Curve	See Annex 8.1	ANSI DEF	Stage 4 curve type
St4TMS	St4 TMS	[0,05..15,0]	1,0	Stage 3 time multiplier
St4DropType	St4 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 4 reset type
St4DropDelay	St4 Drop Delay	[0..60000] ms	0	Stage 4 reset delay time
St4Iop	St4 Iop	[0,005..20,0] × I_r	2,0	Stage 4 operation threshold
St4MaxColdLoadMult	St4 Cold Load Mult	[1.0..20.0] × I_{op}	1.0	Stage 4 maximum cold load start multiplier
St4Top	St4 Top	[0..300000] ms	400	Stage 4 operation delay time
St4TimeAdder	St4 Time Adder	[0..30000] ms	0	Stage 4 constant time adder
St4MaxTime	St4 Max Time	[0..60000] ms	5800	Stage 4 maximum operation time
St4MinTime	St4 Min Time	[0..60000] ms	1200	Stage 4 minimum operation time
St4Istart	St4 Istart	[1,0..4,0] × I_{op}	1.0	Stage 4 minimum start current

5.10 (DIRECTIONAL) NEGATIVE SEQUENCE OVERCURRENT

5.10.1 INTRODUCTION

The Negative Sequence Overcurrent Protection, or Phase Balance Protection, provides an effective resource against the majority of power system faults. In fact, with the exception of three-phase symmetrical faults, which are usually quite rare, a greater or lesser amount of negative sequence component is present for all other types of short-circuits, whether phase-to-phase or phase-to-earth.

Together with other protection functions, namely Phase and Earth-Fault Overcurrent, Negative Sequence Overcurrent guarantees a complete and reliable protection of power system equipment. In particular, it offers higher sensitivity for phase-to-phase faults than Phase Overcurrent Protection because it is less dependent on load current; and it can replace Earth-Fault Overcurrent Protection for phase-to-earth faults if there is not enough zero sequence current flowing. When complemented with directional options, this function can also be used in meshed networks or when faults can be fed from more than one source (*e.g.* in the presence of distributed generation).

Furthermore, its application can be extended to other types of faults that may not be detected by conventional protection functions, such as broken conductors in overhead lines or current unbalances in rotating machines caused by single-phase operation or heavy load unbalance.

5.10.2 OPERATION METHOD

Four independent overcurrent stages are available: the first two stages have a definite time characteristic, whereas for the third and fourth stages a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3 or 4). In alternative to its non-directional overcurrent default behaviour, directionality can be independently added to each stage in option.

Measuring Principle

The Negative Sequence Overcurrent Protection function continuously monitors the negative sequence current, obtained from the three phase current signals, associated in one analogue channel connected to the function input **I**.

$$\bar{I}_2 = 1/3 \cdot \left(\bar{I}_A + a^2 \cdot \bar{I}_B + a \cdot \bar{I}_C\right), \quad a = e^{j120^\circ} \qquad (5.27)$$

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \qquad (5.28)$$

For all the stages, the operation threshold has an extended setting range that allows choosing distinct sensitivity levels for fault detection and enables the implementation of different protection coordination schemes.

Definite Time Characteristic

This is the only possible operating characteristic for stages 1 and 2. It can also be set in option for stages 3 and 4.

If definite time characteristic is selected, the stage pickup is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**StxIop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous.

A dropout delay can be additionally set to stabilize pickup outputs. It is available in setting **StxDropDelay**. If the dropout delay is zero, the reset of the corresponding stage is always instantaneous if the current magnitude drops below the reset level. On the other hand, if the dropout delay is other than zero, the stage reset will be delayed (please consult subsection 8.1.3 - Definite Time Reset for more details).

After the trip has been issued, the stage always resets immediately after the pickup condition is cancelled.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stages 3 and 4.

If inverse time characteristic is selected, the pickup only occurs if the current magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equations (5.29) and (5.30)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the ratio between the measured current I and the operation threshold I_{op} (setting **StxIop**): the greater the current, the shorter the trip time. Several curves from the ANSI and IEC standards are available, and can be independently selected for each stage (in setting **StxCurve**). ANSI time characteristics follow the general equation (5.29), whereas IEC time characteristics obey to the equation (5.30). The expressions are integrated over time in order to accommodate current variations in the time between pickup and trip. The timer T_{MAX} (setting **StxMaxTime**) determines the starting point of the curve, together with the general current threshold I_{op} (setting **StxIop**). However, the stage pickup is only signalled if the current is higher than a specific setting (**StxIstart**) that must be greater or equal than I_{op}. The time multiplier TM (setting **StxTMS**) allows the user to adjust the trip time. A minimum operating time can also be set (in setting **StxMinTime**), which defines, for large currents, the lower limit of the time characteristic. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on these characteristics.

$$t=\left(\frac{A}{(I/I_{op})^{p}-1}+B\right)\cdot TM \qquad (5.29)$$

$$t=\frac{A\cdot TM}{(I/I_{op})^{p}-1} \qquad (5.30)$$

Each stage can reset instantaneously or the reset time can be defined according to a time inverse characteristic, in option selected by the user (in setting **StxDropType**).

If the inverse time reset option is selected, the time to reset depends on the measured current, according to the equation (5.31). This option, defined in the ANSI standard, is extended in the TPU L500 to the IEC curves. It allows emulating the dynamic behaviour of old electromechanical relays, if coordination with this kind of devices is an issue. As for the instantaneous reset, the pickup signal is set inactive as soon as the current drops below the reset level; however, the relay does not resume the reset position immediately. If a new fault occurs before this position is reached, the following trip will be initiated in a shorter time, dependent on the measured current and on the time elapsed between faults. The time multiplier (*TM*) corresponds to the same setting used in the trip characteristic. The expression is also integrated over time in order to accommodate variations in the current magnitude.

$$t=\frac{t_{reset}\cdot TM}{1-(I/I_{op})^{2}} \qquad (5.31)$$

Directionality

Each stage can be independently complemented with a directional element, *i.e.* it can be set as non-directional (only overcurrent measurement) or directional (forward or reverse). This is configurable in setting **StxDirection**.

The directional element of the Negative Sequence Overcurrent Protection is only available if the TPU L500 has three voltage analogue inputs available.

The forward direction is defined as the direction into the protected object, whereas the reverse direction is the direction out from the protected object. The CT polarity should be conveniently configured according to this convention (please consult the corresponding subsection 4.4.3 - Channels).

The directional characteristic is evaluated when the operating current is greater than the corresponding pickup threshold. The polarization of the directional element is done with the negative sequence voltage. It can be obtained from the three phase-to-earth voltage signals or from at least two phase-to-phase voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_2 = 1/3 \cdot \left(\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C\right), \quad a = e^{j120^\circ} \tag{5.32}$$

The relay evaluates the fault direction by the phase angle difference between the negative sequence current and the symmetrical of the negative sequence voltage. The corresponding directional characteristic is represented in Figure 5.53. The maximum torque angle, which defines the rotation of the characteristic, is configured by the user in setting **DirectionAngle**. It should be set according to the phase angle of the system negative sequence impedance. A built-in hysteresis of 5° guarantees the adequate stability of the direction decision.

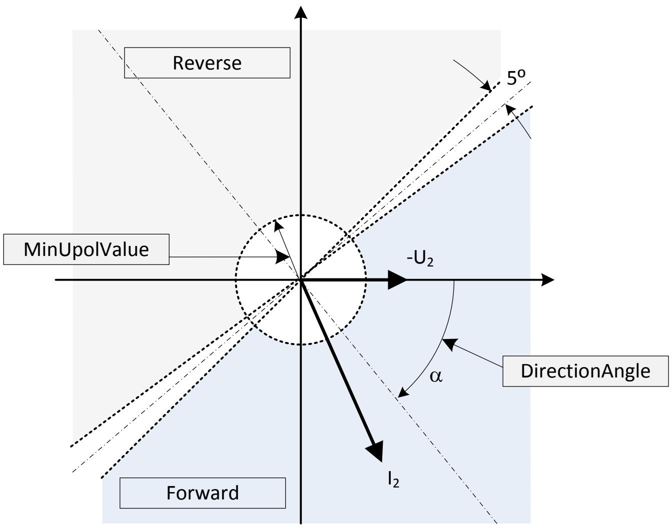

Figure 5.53. Negative sequence directional characteristic with polarization by voltage.

A minimum polarizing quantity must be available; the direction will only be determined if the negative sequence voltage is greater than the setting **MinUpolValue**. Its setting range provides adequate sensitivity for most fault conditions. Nevertheless, when the negative sequence voltage is not high enough to polarize the relay, the user can choose to inhibit the directional criterion, allowing a non-directional trip, or to block the directional stages instead. These two options are available in setting **VTFailAction**.

A voltage transformer failure also causes the loss of the polarization quantity. In case the MCB trips, no measuring voltage will be available for relay polarization in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, the negative sequence voltage cannot be calculated. The VT failure indication should be connected to the function input **VTFail**. It may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision). If this indication is received, the function will operate according to the behaviour defined in setting **VTFailAction**.

The fault direction is signalled in function output **FaultDirection**, which has three possible values: **UNKNOWN**, **FORWARD** and **REVERSE**. If the directional element is not enabled for any stage, **FaultDirection** always indicates **UNKNOWN**. This is also the default entity state while no fault is detected.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St4Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I;**

- The analogue channel associated to input **I** does not correspond to a group of three phase current signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There is no analogue channel associated to input **U**: the directional stages are not enabled in this case;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth or at least two phase-to-phase voltage signals: the directional stages are not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.10.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.34 and Table 5.35, respectively.

Table 5.34. (Directional) Negative Sequence Overcurrent function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating currents
U	U	ANL CH	-	Polarizing voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
VTFail	VT Failure	DIG	2	Voltage transformer failure

Table 5.35. (Directional) Negative Sequence Overcurrent function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start

Identifier	Title	Type	NV	Description
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
FaultDirection	Fault Direction	INT	-	Fault direction indication

5.10.4 Settings

The function settings are listed in Table 5.36.

Table 5.36. (Directional) Negative Sequence Overcurrent function settings.

Identifier	Title	Range	Factory value	Description
DirectionAngle	Direction Angle	[-90,0..90,0] °	45,0	Characteristic direction angle
MinUpolValue	Min Upol Value	[0,01..1,0] × U_r	0,05	Minimum polarizing voltage
VTFailAction	VT Fail Action	TRIP / BLOCK	TRIP	Action on voltage transformer failure
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Direction	St1 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 1 direction
St1DropType	St1 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 1 reset type
St1DropDelay	St1 Drop Delay	[0..60000] ms	0	Stage 1 reset delay time
St1Iop	St1 Iop	[0,05..4,0] × I_r	0,5	Stage 1 operation threshold
St1Top	St1 Top	[0..60000] ms	0	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Direction	St2 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 2 direction
St2DropType	St2 Drop Type	INSTANTANEOUS / DEFINITE TIME	INSTANT.	Stage 2 reset type
St2DropDelay	St2 Drop Delay	[0..60000] ms	0	Stage 2 reset delay time
St2Iop	St2 Iop	[0,05..4,0] × I_r	0,5	Stage 2 operation threshold
St2Top	St2 Top	[0..60000] ms	0	Stage 2 operation delay time
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3Direction	St3 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 3 direction
St3Curve	St3 Curve	See Annex 8.1	ANSI DEF	Stage 3 curve type
St3TMS	St3 TMS	[0,05..15,0]	1,0	Stage 3 time multiplier

Identifier	Title	Range	Factory value	Description
St3DropType	St3 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 3 reset type
St3DropDelay	St3 Drop Delay	[0..60000] ms	0	Stage 3 reset delay time
St3Iop	St3 Iop	[0,05..4,0] × I_r	0,2	Stage 3 operation threshold
St3Top	St3 Top	[0..60000] ms	400	Stage 3 operation delay time
St3TimeAdder	St3 Time Adder	[0..30000] ms	0	Stage 3 constant time adder
St3MaxTime	St3 Max Time	[0..60000] ms	0	Stage 3 maximum operation time
St3MinTime	St3 Min Time	[0..60000] ms	0	Stage 3 minimum operation time
St3Istart	St3 Istart	[1.0..4.0] × I_{op}	1.0	Stage 3 minimum start current
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4Direction	St4 Direction	NON-DIR / FORWARD / REVERSE	NON-DIR	Stage 4 direction
St4Curve	St4 Curve	See Annex 8.1	ANSI DEF	Stage 4 curve type
St4TMS	St4 TMS	[0,05..15,0]	1,0	Stage 4 time multiplier
St4DropType	St4 Drop Type	INSTANTANEOUS / DEFINITE TIME / INVERSE TIME	INSTANT.	Stage 4 reset type
St4DropDelay	St4 Drop Delay	[0..60000] ms	0	Stage 4 reset delay time
St4Iop	St4 Iop	[0,05..4,0] × I_r	0,2	Stage 4 operation threshold
St4Top	St4 Top	[0..60000] ms	400	Stage 4 operation delay time
St4TimeAdder	St4 Time Adder	[0..30000] ms	0	Stage 4 constant time adder
St4MaxTime	St4 Max Time	[0..60000] ms	0	Stage 4 maximum operation time
St4MinTime	St4 Min Time	[0..60000] ms	0	Stage 4 minimum operation time
St4Istart	St4 Istart	[1.0..4.0] × I_{op}	1.0	Stage 4 minimum start current

5.11 THERMAL OVERLOAD

5.11.1 INTRODUCTION

The Thermal Overload Protection is a function which implements a thermal model of the motor, transformer or cable, based in its input currents. This function is based on a differential equation which relates the increase in temperature to the current in the conductor. This temperature rise depends on the dissipation capacity of the material and the conditions surrounding it. This may hinder the application of the protection function to overhead lines due to the uncertainty in the surrounding conditions (moisture, wind...).

Since this function works with temperature quantities, which have a naturally delayed time response, it is not expected that this function be capable of detecting short-circuits. For these fault conditions, protection functions, like the Phase Overcurrent function, should be used. The Thermal Overload function protects the equipment in specific scenarios, such as when there are several occurrences of periodic overcurrent, which are not high enough for the short-circuit protection functions to operate. This condition turns out to overheat the material, possibly leading to its destruction.

This function has the main purpose of preventing the deterioration of insulating and electrical properties of the material when exposed to overheating caused by the currents. Since this function deals with long-term phenomena, it continuously monitors the current value in each phase and calculates its contribution to the increase in temperature.

5.11.2 OPERATION METHOD

The Thermal Overload Protection provides an independent protection stage. The function can be activated by setting change (setting **Operation**).

Measuring Principle

The Thermal Overload function estimates the temperature increase above the environment temperature in the power equipment that is being supervised. The calculation is based on the actual current value and on the maximum permissible current in continuous operation. The estimation of the temperature rise caused by the current is based on the following differential equation:

$$\tau \frac{\partial \Theta}{\partial t} + \Theta = I^2 \qquad (5.33)$$

Θ = Temperature rise.

τ = Thermal time constant.

I^2 = Ratio between the measured RMS current and the maximum continuous RMS current supported $\left(I_{RMS}/I_{Max}\right)^2$.

If we consider that the temperature value has reached a steady state condition, then the value of $\tau \frac{\partial \Theta}{\partial t}$ in the equation is zero. This way we can find the maximum temperature driven by that current:

$$\Theta_{Max} = \left(\frac{I_{RMS}}{I_{Max}}\right)^2 \times T_{Max} \qquad (5.34)$$

Θ_{Max} = Maximum temperature rise due to I_{RMS}.

T_{Max} = Maximum temperature rise due to I_{Max}.

The actual temperature rise of each phase is calculated taking into account the previous value (a time step Δt before) of the same quantity:

$$\Theta_n = \Theta_{n-1} + \left(\Theta_{Max} - \Theta_{n-1}\right)\left(1 - e^{-\frac{\Delta t}{\tau}}\right) \qquad (5.35)$$

The final temperature used for the thermal model (which is available in function output **TempThmModel**) is the highest temperature Θ_n among the three phases, after adding the environment temperature.

Settings

Since immediately after relay startup the previous temperature value is not known, the first parameter that the user must configure is the **InitTempOpt** setting. This allows the user to set whether the function starts from the maximum temperature corresponding to the actual current (**InitTempOpt** = ON), assuming the steady state was already reached, or whether the function starts from the environment temperature (**InitTempOpt** = OFF).

If the **InitTempOpt** parameter is enabled, this can lead to an instantaneous signalization after startup (**Pickup**, **Alarm**, **Trip**, **Reclose**), depending on the current input values.

The thermal time constant τ is related to the temperature rate-of-change and by consequence its rise time. This setting is normally supplied by the manufacturer. Note that τ is usually provided in minutes and the function receives the setting in seconds. If this information is not available, the user can always estimate its value based on the permissible short-circuit rated current (I_{1s}) and the maximum continuous current (setting **IMax**).

$$\tau = \left(\frac{I_{1s}}{I_{Max}} \right)^2 \qquad (5.36)$$

The user must always define the maximum temperature rise above the environment temperature that is supported by the equipment (setting **TempMax**), which corresponds to the maximum continuous current (setting **IMax**). This value is very important to the correct configuration of the thermal model.

The **Pickup** output is signalled when the current in at least one of the phases is such that the corresponding maximum temperature (Θ_{Max}) plus the environment temperature is greater than the operate threshold (setting **TripTemp**). This means that, if that current value is maintained, it will cause after a certain time a function trip.

The **Alarm** condition is reached when **TempThmModel** is higher than setting **AlarmTemp**. The **Trip** and **RecloseTemp** outputs are also related with **TempThmModel** but the associated threshold is defined by setting **TripTemp**. After the **Trip** signal is issued the temperature needs to decrease to a temperature lower than setting **RecloseTemp** to disable the **BlockReclose** output.

The **TempMax** setting is the maximum temperature rise above environment temperature supported by the equipment. On the contrary, the **AlarmTemp**, **TripTemp** and **RecloseTemp** settings are defined in absolute temperature (including the environment temperature).

Operation Modes

The environment temperature can be set by the user or it can be directly read from an external sensor if available.

- Using the external temperature sensor, variations in the environment temperature will cause equivalent variations in the temperature of the thermal model that will directly influence the maximum continuous current supported.
- If there is no external temperature measurement, the function can be configured using a default environment temperature (setting **EnvTemp**).
- The user can always define the **EnvTemp** as zero and define the alarm, trip and reclose temperatures as temperature rise allowed above environment temperature, like **TempMax** is defined.

Blocking Conditions

The function provides a general function block input (**Block**) that can be freely associated to any user-defined condition.

This block can be used to prevent incorrect function operation, by blocking all function digital outputs. Independently of the user-defined block conditions, the function still runs and updates the measurement outputs (like **TempThmModel**). If the goal is to turn off the Thermal Overload function, then the user must change instead the setting **Operation**.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- **AlarmTemp**, **TripTemp** and **RecloseTemp** are defined below environment temperature (**EnvTemp**) and there is no external temperature measurement (**TempSensor** = OFF);
- The user indicates the existence of a temperature sensor (**TempSensor** = ON) but no valid analogue measurement is associated to the input **EnvTempIn**.

The configuration is valid and the function operates accordingly otherwise.

5.11.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.37 and Table 5.38, respectively.

Table 5.37. Thermal Overload function inputs.

Identifier	Title	Type	Mlt	Description
I	Currents	ANL CH	-	Currents used for thermal model
Block	Block	DIG	-	Block the outputs
EnvTempIn	Env Temp Sensor	ANL	-	Environment temperature sensor input

Table 5.38. Thermal Overload function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Pickup	Pickup	DIG	-	Function pickup
Alarm	Alarm	DIG	-	Alarm temperature reached
Trip	Trip	DIG	-	Thermal overload reached
BlockReclose	Block Reclose	DIG	-	Blocks the reclosing
TempA	Phase A Temperature	ANL	-	Phase A Temperature
TempB	Phase B Temperature	ANL	-	Phase B Temperature
TempC	Phase C Temperature	ANL	-	Phase C Temperature
TempThmModel	Temp Thermal Model	ANL	-	Temperature used for thermal model
TempRatio	Ratio Temp/TempMax	ANL	-	Ratio between temperature and maximum temperature

5.11.4 Settings

The function settings are listed in Table 5.39.

Table 5.39. Thermal Overload function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
InitTempOpt	Initial Temp Option	OFF / ON	OFF	Start with the temperature of the actual current in each phase
Tau	Time Constant	[1.. 60000] s	600	Thermal load time constant
Imax	Maximum Current	[0,0..999999,9] A	999999,9	Steady state maximum current
TempMax	Maximum Temperature	[0..250] °C	60	Steady state maximum temperature
TempSensor	Temperature Sensor	OFF / ON	OFF	Operation of the temperature sensor
EnvTemp	Env Temp	[-50..200] °C	0	Manual value for environment temperature
AlarmTemp	Alarm Temperature	[0..250] °C	50	Alarm temperature value
TripTemp	Trip Temperature	[0..250] °C	60	Trip temperature value
RecloseTemp	Reclose Temperature	[0..250] °C	40	Reclose temperature value

5.12 SWITCH-ONTO-FAULT

5.12.1 INTRODUCTION

The Switch-Onto-Fault Protection is an instantaneous protection function providing a very fast trip when a fault is detected immediately after the circuit breaker is closed.

The main goal of the Switch-Onto-Fault Protection is to complement Distance Protection in cases this last function cannot operate, namely close-in three-phase faults following line energization (for example, a fault caused by a ground switch that was left closed at the time the circuit breaker is switched on). These faults may be undetected if voltage transformers are located in the line side of the circuit breaker, because neither instantaneous voltage signals nor pre-fault voltage memory will be available in this situation for polarization of Distance Protection.

The Switch-Onto-Fault Protection is usually based on a non-directional overcurrent element, to ensure dependability in the absence of voltage memory. Optionally, the Switch-Onto-Fault logic can also be used to enable the instantaneous trip of any other protection element (for example, a non-directional Distance Protection stage).

This protection scheme may be used in other applications, independently of Distance Protection. Its operation may be restricted to manual close commands or it may also be applied following automatic reclosing sequences.

5.12.2 OPERATION METHOD

The Switch-Onto-Fault logic can be associated to any protection function stage. Alternatively, a built-in overcurrent stage is available.

Activation

The Switch-Onto-Fault Protection is only allowed to trip when some internal or external conditions are met.

It is activated by an external indication associated to the function input **ExtEnable**. This input can be freely associated to any user-defined condition, but it will be normally associated to a circuit breaker closing command.

As an alternative, the Switch-Onto-Fault Protection can also be activated by internal conditions, depending on the value of the analogue inputs associated to the function. This mechanism (dead line detection) is automatically enabled if a voltage input is connected to the function input **U**. It is described below.

Both methods can be simultaneously enabled, in which case the first activation condition to be met will activate the protection function.

After all activation conditions are cancelled, the function remains active for a determined time interval, defined by setting **SustainTime**. This provides a time window following line energization during which the Switch-Onto-Fault Protection is allowed to trip.

The state of the Switch-Onto-Fault Protection is signalled in its output **Active**. This indication can be associated to other protection stages selected by the user, via external trip logic (please consult section 5.22 - Three-Phase / Single-Phase Trip Logic for more details). The selected stages will trip instantaneously in case the Switch-Onto-Fault indication is active. The trip is always three-pole.

Dead Line Detection

A complementary dead line detection mechanism is integrated in the Switch-Onto-Fault Protection. As referred before, it is used for the activation of the Switch-Onto-Fault Protection; in this case, the function trip is enabled in advance of the circuit breaker close command. The respective dead line indication is available as a function output (**DeadLineDetected**) so it can be used for other purposes.

The dead line detection is automatically activated when a voltage channel is connected to the function input **U**. One or more phase-to-earth or phase-to-phase voltage signals are allowed, provided the corresponding VT is connected to the line side of the circuit breaker.

The base principle for the detection of a switched off line is the simultaneous absence of both currents and voltages. All three phase currents must be lower than setting **ImaxDead** and all voltage signals associated to input **U** must be lower than setting **UmaxDead**. The line is declared as disconnected if these two conditions remain active for more than a determined time interval, set in **DLDConfirmTime**. The indication is cancelled as soon as one of the current or voltage magnitudes is higher than the corresponding setting.

The setting **DLDConfirmTime** can be used to prevent Switch-Onto-Fault trip during Automatic Reclosing sequences. For example, the Switch-Onto-Fault will not be activated after a fast reclosing command if **DLDConfirmTime** is greater than the configured Automatic Reclosing dead time.

Built-in Overcurrent Stage

An independent high-speed tripping overcurrent stage is available. It can be separately activated by setting change (setting **OCOperation**). This overcurrent stage is only enabled as long as the Switch-Onto-Fault function is active.

This stage continuously monitors the three phase current signals, associated in one analogue channel connected to the function input **I**. The overcurrent stage is executed in full-scheme mode, which means that there are separate protection elements for monitoring each input current. The function trip is independently signalled for each phase if the operating conditions are met.

There is also a general trip output. It corresponds to the logical OR of the phase outputs, that is, it is activated if at least one phase trip is active.

The trip is always instantaneous. It is signalled when the measured current magnitude is higher than the threshold defined in the corresponding stage setting (**OCIop**). The stage resets when the magnitude is lower than 96% of that setting. The built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs.

The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \tag{5.37}$$

The operation threshold has an extended setting range that allows enabling the overcurrent stage only for high-current faults.

Blocking Conditions

The function provides a general function block input (**Block**) that can be freely associated to any user-defined condition.

The function provides a block input (**OCBlock**) for blocking the built-in overcurrent stage. It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**OCBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- The current channel associated to input **I** does not include all the three phases.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There is no analogue channel associated to input **U**: the dead line detection is not enabled in this case;
- A neutral voltage channel is associated to input **U**: the dead line detection is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.12.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.40 and Table 5.41, respectively.

Table 5.40. Switch-Onto-Fault function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating currents
U	U	ANL CH	-	Line voltages
Block	Block	DIG	4	Function block
OCBlock	OC Block	DIG	4	Overcurrent stage block
VTFail	VT Failure	DIG	2	Voltage transformer failure
ExtEnable	Ext Enable	DIG	2	External function activation

Table 5.41. Switch-Onto-Fault function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
OCBehavior	OC Behavior	INT	-	Overcurrent stage operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
OCBlocked	OC Blocked	DIG	-	Overcurrent stage blocked
DeadLineDetected	Dead Line Detected	DIG	-	Dead line detection
Active	Active	DIG	-	Switch-Onto-Fault active
OCTripA	OC Trip A	DIG	-	Overcurrent stage trip, phase A
OCTripB	OC Trip B	DIG	-	Overcurrent stage trip, phase B
OCTripC	OC Trip C	DIG	-	Overcurrent stage trip, phase C
OCTrip	OC Trip	DIG	-	Overcurrent stage general trip

5.12.4 Settings

The function settings are listed in Table 5.42.

Table 5.42. Switch-Onto-Fault function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
SustainTime	Sustain Time	[40..60000] ms	500	Extension time of activation conditions
ImaxDead	Imax Dead	[0,05..1,5] × I_r	0,1	Maximum dead current threshold
UmaxDead	Umax Dead	[0,05..0,8] × U_r	0,2	Maximum dead voltage threshold

Identifier	**Title**	**Range**	**Factory value**	**Description**
DLDConfirmTime	DLD Confirm Time	[40..10000] ms	1000	Confirmation time for dead line detection
OCOperation	OC Operation	OFF / ON	OFF	Overcurrent stage operation
OCIop	OC Iop	[0,5..40,0] × I_r	2,0	Overcurrent stage operation threshold

5.13 DIRECTIONAL EARTH-FAULT OVERCURRENT FOR NON-EARTHED SYSTEMS

5.13.1 INTRODUCTION

High impedance earthed systems, whether isolated from earth or earthed through an arc suppression coil (or Petersen coil), are characterized by very low earth-fault currents, as well as by the presence of an extremely high residual voltage, irrespective of the fault location or of its resistance.

Although it can be dependably detected by the sudden increase in residual voltage magnitude, a phase-to-earth fault is typically difficult to locate in high impedance earthed systems. However, such a fault condition can be maintained for some time because it does not significantly affect network operation or endangers the lives of people, allowing for changes in the system before the fault is cleared.

In networks where the neutral is disconnected from earth, the system is still linked to the earth due to capacitances, which causes the fault current to be in quadrature with the residual voltage. On the other hand, where an arc suppression coil is used, the fault current is almost null, and phase-to-earth faults are most frequently located by the temporary insertion of a resistor in parallel with the Petersen coil, which increments the active residual current component.

The small residual currents that are observed during a phase-to-earth fault compromise the effectiveness of conventional Earth-Fault Overcurrent Protection. The Directional Earth-Fault Overcurrent Protection for Non-Earthed Systems, with its specially designed directional characteristic, based on the measurement of residual power, is a suitable alternative against earth-faults in systems which are isolated from earth or earthed through a Petersen coil.

5.13.2 OPERATION METHOD

The Directional Earth-Fault Overcurrent Protection for Non-Earthed Systems provides an independent protection stage, with two different selectable criteria for pickup. The pickup criteria can be based solely on the residual voltage (setting **Mode** configured as **U0**), or based on the residual voltage and the residual current (setting **Mode** configured as **I0 AND U0**). For pickup criteria based on residual voltage and residual current, several operating characteristics can be chosen in option. An additional and independent alarm stage capable of signalling the faulted phase, is also available. The function can be activated by setting change (setting **Operation**).

Voltage Pickup Mode

If setting **Mode** is configured as **U0**, the Directional Earth-Fault Overcurrent Protection for Non-Earthed Systems pickup depends only on the voltage signal. The function continuously monitors the residual voltage, which corresponds to three times the zero sequence voltage. It can be obtained from the internal sum of the three phase-to-earth voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_{res} = \overline{U}_A + \overline{U}_B + \overline{U}_C \tag{5.38}$$

As an alternative to the previous method, the displacement voltage can be directly measured in one analogue input, for instance from an independent open-delta connected voltage transformer winding. In this case, the function input **U** should be associated to a neutral analogue channel.

A timer, corresponding to setting **StrDelay**, starts counting if the measured residual voltage magnitude is higher than the threshold defined in setting **UresStr**. The function pickup is signalled after the timer elapses. This delay can be set to zero and in this case the pickup will be instantaneous. The stage instantaneously resets when the voltage magnitude is lower than 96% of setting **UresStr**. The built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs.

The pickup threshold is set in values per unit, relative to the rated VT primary phase-to-earth voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \tag{5.39}$$

An extended setting range provides the adequate discrimination of distinct asymmetrical fault conditions and the optional configuration of extremely sensitive pickup thresholds.

Voltage and Current Pickup Mode

If setting **Mode** is configured as **I0 AND U0**, the function uses both residual voltage (as defined in **Voltage Pickup Mode**) and residual current quantities for issuing the pickup signal.

The residual current corresponds to three times the zero sequence current. It can be obtained from the internal sum of the three phase current signals, associated in one analogue channel connected to the function input **I**.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \quad (5.40)$$

As an alternative to the previous method, the residual current can be directly measured in one analogue input, for instance from an independent phase-balance neutral current transformer. It can also be obtained from the external sum of the three phase currents (Holmgreen circuit). In these cases, the function input **I** should be associated to a neutral analogue channel.

A timer, corresponding to setting **StrDelay**, starts counting if the measured residual voltage magnitude is higher than the threshold defined in setting **UresStr** and the selected operational characteristic is breach. The function pickup is signalled after the timer elapses. This delay can be set to zero and in this case the pickup will be instantaneous. The stage instantaneously resets when any of the criteria ceases to be met (with the respectives dead bands).

Two distinct measuring principles for the operational characteristic, described below, are available: current magnitude (setting **ChrMode** configured with the option **MOD**) and wattmetric-based (setting **ChrMode** configured with the option **COS**). In both cases the operational characteristic is released by current threshold **IresOp** which is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \quad (5.41)$$

The operation threshold has an extended setting range that allows choosing distinct sensitivity levels for fault detection and enables the implementation of different protection coordination schemes. The configuration of highly sensitive operation thresholds is possible, namely if input **I** is associated with an extra sensitive analogue input.

The setting range for which the current threshold is valid depends on the specific option of the analogue input that is associated to the function:

- If the function is associated with three phase currents (internal sum option), the minimum threshold that can be set is 0,05 p.u. (5% of the rated value). If the setting is set below that value, the function operates when the current is above 0,05 p.u. only.
- The same applies if the function is associated to a neutral current with normal sensitivity.
- If the function is associated with an extra sensitive current input, the minimum threshold that can be set is 0,005 p.u. (0,5% of the rated value).

Current Magnitude

If setting **ChrMode** is configured with the option **MOD**, the function operates when the measured current magnitude is higher than **IresOp**. The trip timer is cancelled when the magnitude is lower than 96% of that setting. The built-in hysteresis guarantees the adequate stability of the trip decision.

Additionally, the overcurrent stage can be complemented with a directional element, *i.e.* it can be set as non-directional (only overcurrent measurement) or directional (forward or reverse). This is configurable in setting **DirMode**.

The forward direction is defined as the direction into the protected object, whereas the reverse direction is the direction out from the protected object. The CT polarity should be conveniently configured according to this convention (please consult the corresponding subsection 4.4.3 - Channels).

In this mode, the relay evaluates the fault direction by the phase angle difference between the residual current and the symmetrical of the residual voltage. Both quantities should be greater than the respective thresholds. The corresponding directional characteristic is represented in Figure 5.54. The maximum torque angle, which defines the rotation of the characteristic, is configured by the user in setting **DirectionAngle**. A built-in hysteresis of 5° guarantees the adequate stability of the direction decision. Furthermore, it is possible to set the opening angle of the characteristic in setting **ChrOpnAngle**, with the aim of restraining the range of operation of the relay and thus prevent its operation due to phase angle errors caused by CT saturation, for example.

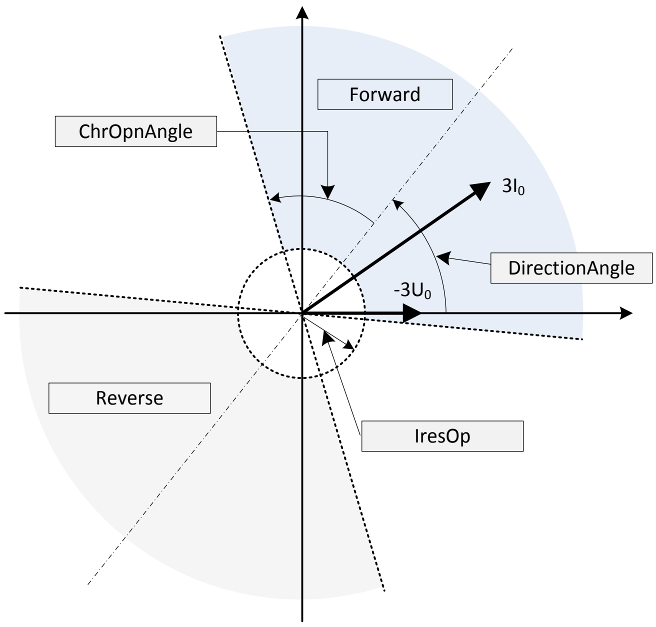

Figure 5.54. Directional Earth-Fault for Non-Earthed systems, with current magnitude operation.

Wattmetric-Based

If setting **ChrMode** is configured with the option **COS**, the function compares the component of the residual current in the direction defined in setting **DirectionAngle** (relative to the symmetrical of the residual voltage) with the threshold **IresOp**, according to the characteristic shown in Figure 5.55.

The stage can be configured to operate in the forward or reverse direction. It may also be set as non-directional, in which case the function trips in both sides of the characteristic, provided that the modulus of the component of the residual current being evaluated is greater than the threshold **IresOp**. This is configurable in setting **DirMode**.

If **DirectionAngle** is set to 0°, in the forward direction, the Directional Earth-Fault Overcurrent Protection for Non-Earthed Systems behaves as a typical directional earth-fault protection relay measuring $3I_0 \cos\varphi$, where φ is the angle between the residual current and the symmetrical of the residual voltage. This configuration is recommended for networks with compensated neutral (Petersen coil) or high impedance earthed networks with a resistor connected to the neutral point, where the faulted feeder is the only one with active current component.

On the other hand, if **DirectionAngle** is set to 90°, also in the forward direction, the function behaves as a directional earth-fault protection measuring $3I_0 \sin\varphi$, which is typically the most adequate characteristic in case of systems with isolated neutral, where the currents are mainly capacitive.

The wide setting range of **DirectionAngle** enables other applications such as in networks that can be operated either with isolated or compensated neutral.

Furthermore, it is possible to set the opening angle of the characteristic in setting **ChrOpnAngle**, with the aim of restraining the range of operation of the relay by increasing the operate level for currents where the angle is larger than that setting. This prevents the operation due to phase angle errors caused by CT saturation, for example. When **ChrOpnAngle** is equal to 90°, the operating characteristic is simply limited by a straight line corresponding to threshold **IresOp**.

A built-in hysteresis, corresponding to 96% of **IresOp** or 5° relatively to **ChrOpnAngle**, guarantees the adequate stability of the trip decision.

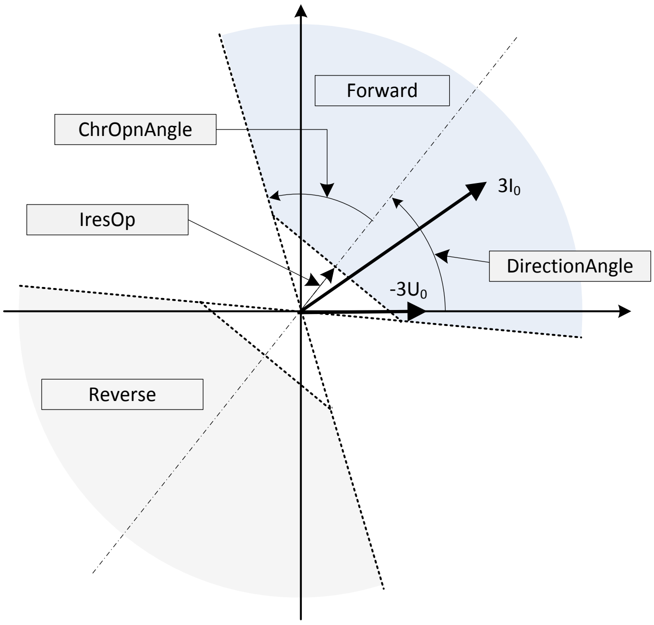

Figure 5.55. Directional Earth-Fault for Non-Earthed systems, with wattmetric-based operation.

Definite Time Trip

The trip condition is the same for every pickup mode and operational characteristic selected; trip is signalled a selectable definite time after the pickup has been signalled, and is reset instantaneously with the pickup reset. The tripping time can be defined in setting **OpDelay**.

Fault Indication and Alarm

Whenever the function trips, irrespective of the specific mode that is activated, a fault indication is signalled in **FltIndRs**. This output is persistent and the information is kept in non-volatile memory, preventing its loss in case of a device restart. It can only be manually cancelled by user control over the entity **FltIndRs**. The control order will only be accepted if the fault condition is no longer active.

The fault direction is signalled in function output **FaultDirection**, which has three possible values: **UNKNOWN**, **FORWARD** and **REVERSE**. If the directional element is not enabled, **FaultDirection** always indicates **UNKNOWN**. This is also the default entity state while no fault is detected.

Besides the trip stage, an independent alarm level is also available, but only if three phase-to-earth voltage signals are associated to the function input **U**. It is based on the supervision of the voltage unbalance between different phases during an earth-fault. When the magnitude of one of the phase-to-earth voltages is less than threshold **PhMinU** and simultaneously the magnitude of the other two is greater than threshold **PhMaxU**, the faulted phase (the one corresponding to **PhMinU**) is immediately signalled in the respective output **AlarmA**, **AlarmB** or **AlarmC**.

Blocking Conditions

The function provides a general function block input (**Block**). It can be freely associated to any user-defined condition.

A voltage transformer failure causes the loss of the pickup and polarization quantity. In case the MCB trips, no measuring voltage will be available for relay polarization in all three phases simultaneously; on the other hand, in case of an unbalanced VT fault, the residual voltage cannot be calculated. The VT failure indication should be connected to the function input **VTFail**. It may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision). If this indication is received, the function will be blocked.

The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- The analogue channel associated to input **U** does not correspond to a neutral or to a group of three phase-to earth voltage signals;
- Setting **Mode** is configured as **I0 AND U0** and there is no analogue channel associated to input **I**;
- Setting **Mode** is configured as **I0 AND U0** and the analogue channel associated to input **I** does not correspond to a neutral or to a group of three phase current signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The value of setting **IresOp** does not comply with the measuring range of the current input the function is associated with: the function sensitivity is limited according to the possible measuring range.

The configuration is valid and the function operates accordingly otherwise.

5.13.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.43 and Table 5.44, respectively.

Table 5.43. Directional Earth-Fault Overcurrent for Non-Earthed Systems function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Polarizing voltages
I	I	ANL CH	-	Operating current
Block	Block	DIG	4	Function block
VTFail	VT Failure	DIG	2	Voltage transformer failure

Table 5.44. Directional Earth-Fault Overcurrent for Non-Earthed Systems function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
Pickup	Pickup	DIG	-	Start
Trip	Trip	DIG	-	Trip
AlarmA	Alarm A	DIG	-	Fault detection in phase A
AlarmB	Alarm B	DIG	-	Fault detection in phase B
AlarmC	Alarm C	DIG	-	Fault detection in phase C
FaultDirection	Fault Direction	INT	-	Fault direction indication
FltIndRs	Fault Ind Rs	DIG CTRL	Yes	Fault persistent indication

5.13.4 Settings

The function settings are listed in Table 5.45.

Table 5.45. Directional Earth-Fault Overcurrent for Non-Earthed Systems function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
UresStr	Ures Str	[0,01..3,0] × U_r	0,2	Residual voltage start threshold
StrDelay	Str Delay	[0..300000] ms	0	Start delay time
OpDelay	Op Delay	[0..300000] ms	1000	Operation delay time
PhMinU	Phase MinU	[0,1..2,0] × U_r	0,5	Faulted phase voltage threshold
PhMaxU	Phase MaxU	[0,1..2,0] × U_r	1,5	Unfaulted phase voltage threshold
Mode	Mode	U0 / I0 AND U0	I0 AND U0	Operation quantity
IresOp	IresOp	[0,005..1,0] × I_r	0,05	Residual current operation threshold
DirMode	Dir Mode	NON-DIR / FORWARD / REVERSE	NON-DIR	Direction
ChrMode	Chr Mode	COS / MOD	MOD	Operation characteristic shape
DirectionAngle	Direction Angle	[0,0..90,0] °	0,0	Characteristic direction angle
ChrOpnAngle	Chr Open Angle	[10,0..90,0] °	90,0	Characteristic opening angle

5.14 Directional Power

5.14.1 Introduction

The Directional Power Protection supervises the three-phase complex power in a certain network element, whether it is a feeder, a generator or other power equipment. It is responsible for operating when the component of the power in a specified direction is higher (overpower protection) or lower (underpower protection) than a pre-defined threshold.

The Directional Power Protection is most used in generator applications, as a reverse active power protection. In this mode, it allows the identification of low mechanical power in the rotating shaft, when this is not sufficient to cover generator losses and the machine starts operating as a synchronous motor, consuming energy from the network it is connected to. Although this is a safe operation mode for the generator, the machine will behave as a load in this state and it may be desirable to disconnect it from the network. The reverse power condition may also indicate a problem in the turbine, and it should be advisable to trip in order to prevent further damage and overheating.

Reverse underpower protection is more dependable because an additional margin is considered in the forward direction; however, an unwanted trip may be issued, if the active power in the forward direction is low, especially during generator startup. By the contrary, overpower protection is more secure but less dependable because a minimum power in the reverse direction is required to operate.

Other applications of the Directional Power Protection may be envisaged. For instance, a forward active power protection can be considered, as well as a protection element supervising the reactive power (forward or reverse). The component of the three-phase power in any other direction can also be evaluated, for specific applications.

5.14.2 Operation Method

Two independent overpower stages and two independent underpower stages, all with definite time characteristic, are available. Each stage can be separately activated by setting change (setting **OPStxOperation** for overpower stages, and setting **UPStxOperation** for underpower stages, x = 1 or 2).

Measuring Principle

The Directional Power Protection function continuously monitors the three-phase power, obtained from the current and voltage signals associated in the analogue channels connected to the function inputs **I** and **U**, respectively.

The three-phase power is available in a wide range of possible configurations. Its specific calculation formula depends on the current and voltage signals that are connected to the function. Table 5.46 lists the possible cases.

Table 5.46. Three-phase power calculation.

Voltage signals (available)	Current signals (required)	Power calculation	Description
U_A, U_B, U_C	I_A, I_B, I_C	$\bar{S} = \bar{U}_A \cdot \bar{I}_A^* + \bar{U}_B \cdot \bar{I}_B^* + \bar{U}_C \cdot \bar{I}_C^*$	If all three phase-to-earth voltages are available
U_{AB}, U_{BC}	I_A, I_C	$\bar{S} = \bar{U}_{AB} \cdot \bar{I}_A^* - \bar{U}_{BC} \cdot \bar{I}_C^*$	If two phase-to-phase voltages are available, according to Aron connection (similar for other pair of voltages)
U_{AB}	I_A, I_B	$\bar{S} = \bar{U}_{AB} \cdot \left(\bar{I}_A^* - \bar{I}_B^*\right)$	If only one phase-to-phase voltage is available (similar for U_{BC} or U_{CA})
U_A	I_A	$\bar{S} = 3 \cdot \bar{U}_A \cdot \bar{I}_A^*$	If only one phase-to-earth voltage is available (similar for U_B or U_C)

Only the first two cases provide the exact three-phase power measurement. The last two only give the exact value if one assumes that the system is operating in perfectly symmetrical conditions.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met. The operating characteristic depends on the type of stage: overpower or underpower.

The pickup thresholds are directly set in MVA. An extended setting range is available, from a power level as low as 1 kVA to a power level as high as 1 GVA, which allows adapting the function sensitivity to generators of distinct rated values.

Overpower Stages

In the case of overpower stages, the pickup is signalled according to the characteristic shown in Figure 5.56, *i.e.* when the component of the three-phase complex power in the direction specified in setting **OPStxDirectionAngle** is greater than the pickup threshold defined in setting **OPStxSop**.

An adjustable hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The function resets when the three-phase complex power component being evaluated is less than the reset threshold. The ratio between reset and pickup thresholds is defined in setting **OPStxDropRatio**. A maximum dropout ratio of 96% is allowed.

The directional overpower stage enables the implementation of a typical reverse power protection scheme if the direction angle is set to 180°. In this case, the power component supervised is the active power. It is also possible to implement a forward active power protection stage if the characteristic angle is set to 0°. If instead the direction angle is configured to 90° or 270°, only the reactive power component is supervised, and a forward or reverse reactive power protection stage is implemented, respectively.

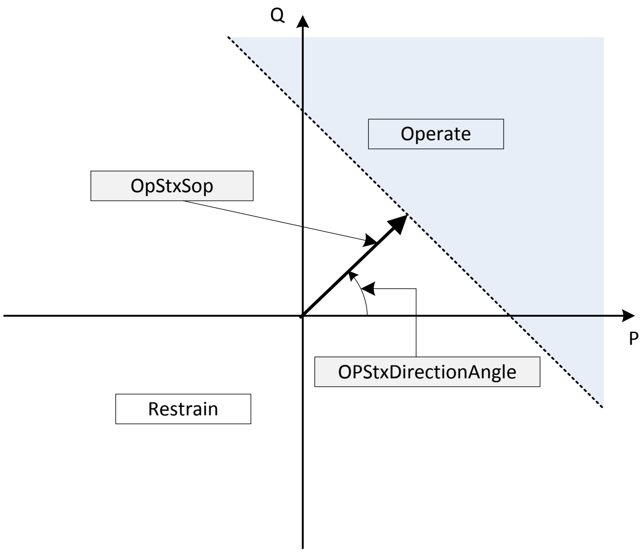

Figure 5.56. Directional overpower stage characteristic.

Underpower Stages

In the case of underpower stages, the pickup is signalled according to the characteristic shown in Figure 5.57, *i.e.* when the component of the three-phase complex power in the direction specified in setting **UPStxDirectionAngle** is less than the pickup threshold defined in setting **UPStxSop**.

An adjustable hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The function resets when the three-phase complex power component being evaluated is greater than the reset threshold. The ratio between reset and pickup thresholds is defined in setting **UPStxDropRatio**. A minimum dropout ratio of 104% is allowed.

The directional underpower stage enables the implementation of a typical reverse power protection scheme if the direction angle is set to 0°. In this case, the power component supervised is the active power. It is also possible to implement a forward active power protection stage if the characteristic angle is set to 180°. If instead the direction angle is configured to 90° or 270°, only the reactive power component is supervised, and a reverse or forward reactive power protection stage is implemented, respectively.

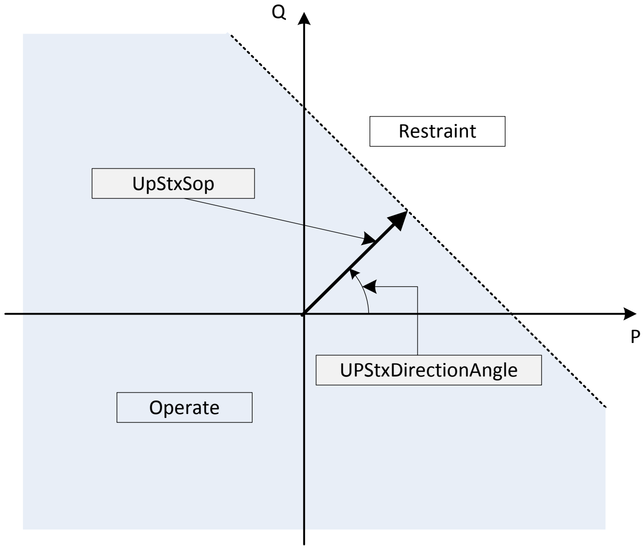

Figure 5.57. Directional underpower stage characteristic.

Definite Time Characteristic

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**OPStxTop** or **UPStxTop**). If the operational time is set to zero, the trip will be instantaneous.

A dropout delay can be additionally set to stabilize pickup outputs. It is available in setting **OPStxDropDelay** for overpower stages and **UPStxDropDelay** for underpower stages. If the dropout delay is zero, the reset of the corresponding stage is always instantaneous when the three-phase complex power component being evaluated meets the reset criterion. On the other hand, if the dropout delay is other than zero, the stage reset will be delayed (please consult subsection 8.1.3 - Definite Time Reset for more details).

After the trip has been issued, the stage always resets immediately after the pickup condition is cancelled.

Blocking Conditions

The function provides an individual block input for each protection stage (**OPSt1Block**, **OPSt2Block**, **UPSt1Block** and **UPSt2Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

Independently of the user-defined block conditions, the function may be optionally blocked due to circuit breaker open, if the circuit breaker status is associated to the **Position** input. In the case some stage is already picked up when the circuit breaker opens, it will be immediately reset. This can be relevant for underpower stages because the zero power condition is located inside the operating characteristic, preventing those stages from resetting after tripping. This option is also applied to the overpower stages. The function may be kept blocked after the circuit breaker closes for a settable amount of time, defined in setting **BlockedTime**. This ensures that the function does not operate while the power is still low during the startup of the generator to which it is applied.

The Directional Power Protection can also operate incorrectly in case of a failure in the voltage measuring circuit because the three-phase power will be miscalculated in this case. All function stages are automatically blocked if a failure in the voltage measuring circuit is indicated in the **VTFail** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision) or the trip indication of the MCB that protects the voltage transformer can be directly used.

The blocking condition is signalled in the corresponding stage output (**OPStxBlocked** or **UPStxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I** or **U**;

- There are analogue channels associated to inputs **I** and **U**, but there is not enough information for three-phase power calculation (*e.g.*, only I_A and U_B are available).

The configuration is valid and the function operates accordingly otherwise.

5.14.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.47 and Table 5.48, respectively.

Table 5.47. Directional Power function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
U	U	ANL CH	-	Phase voltages
Block	Block	DIG	4	Function general block
OPSt1Block	OP St1 Block	DIG	2	Overpower stage 1 block
OPSt2Block	OP St2 Block	DIG	2	Overpower stage 2 block
UPSt1Block	UP St1 Block	DIG	2	Underpower stage 1 block
UPSt2Block	UP St2 Block	DIG	2	Underpower stage 2 block
VTFail	VT Failure	DIG	2	Voltage transformer failure
Position	Position	DB DIG	1	Circuit breaker position

Table 5.48. Directional Power function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
OPSt1Behavior	OP St1 Behavior	INT	-	Overpower stage 1 operation mode
OPSt2Behavior	OP St2 Behavior	INT	-	Overpower stage 2 operation mode
UPSt1Behavior	UP St1 Behavior	INT	-	Underpower stage 1 operation mode
UPSt2Behavior	UP St2 Behavior	INT	-	Underpower stage 2 operation mode
Health	Health	INT	-	Function health
OPSt1Blocked	OP St1 Blocked	DIG	-	Overpower stage 1 blocked
OPSt2Blocked	OP St2 Blocked	DIG	-	Overpower stage 2 blocked
UPSt1Blocked	UP St1 Blocked	DIG	-	Underpower stage 1 blocked
UPSt2Blocked	UP St2 Blocked	DIG	-	Underpower stage 2 blocked
OPSt1Pickup	OP St1 Pickup	DIG	-	Overpower stage 1 general start
OPSt2Pickup	OP St2 Pickup	DIG	-	Overpower stage 2 general start
UPSt1Pickup	UP St1 Pickup	DIG	-	Underpower stage 1 general start
UPSt2Pickup	UP St2 Pickup	DIG	-	Underpower stage 2 general start
OPSt1Trip	OP St1 Trip	DIG	-	Overpower stage 1 general trip
OPSt2Trip	OP St2 Trip	DIG	-	Overpower stage 2 general trip

Identifier	Title	Type	NV	Description
UPSt1Trip	UP St1 Trip	DIG	-	Underpower stage 1 general trip
UPSt2Trip	UP St2 Trip	DIG	-	Underpower stage 2 general trip

5.14.4 Settings

The function settings are listed in Table 5.49.

Table 5.49. Directional Power function settings.

Identifier	Title	Range	Factory value	Description
BlockedTime	Blocked Time	[0..60000] ms	15000	Block time after the breaker switches from open to closed
OPSt1Operation	OP St1 Operation	OFF / ON	OFF	Overpower stage 1 operation
OPSt1DirectionAngle	OP St1 Dir Angle	[0,0..360,0] °	180,0	Overpower stage 1 characteristic direction angle
OPSt1Sop	OP St1 Sop	[0,001..1000,0] MVA	1,0	Overpower stage 1 operation threshold
OPSt1Top	OP St1 Top	[0..60000] ms	1000	Overpower stage 1 operation delay time
OPSt1DropRatio	OP St1 Drop Ratio	[0,80..0,96] × S_{op}	0,96	Overpower stage 1 dropout ratio
OPSt1DropDelay	OP St1 Drop Delay	[0..60000] ms	0	Overpower stage 1 dropout delay time
OPSt2Operation	OP St2 Operation	OFF / ON	OFF	Overpower stage 2 operation
OPSt2DirectionAngle	OP St2 Dir Angle	[0,0..360,0] °	270,0	Overpower stage 2 characteristic direction angle
OPSt2Sop	OP St2 Sop	[0,001..1000,0] MVA	1,0	Overpower stage 2 operation threshold
OPSt2Top	OP St2 Top	[0..60000] ms	1000	Overpower stage 2 operation delay time
OPSt2DropRatio	OP St2 Drop Ratio	[0,80..0,96] × S_{op}	0,96	Overpower stage 2 dropout ratio
OPSt2DropDelay	OP St2 Drop Delay	[0..60000] ms	0	Overpower stage 2 dropout delay time
UPSt1Operation	UP St1 Operation	OFF / ON	OFF	Underpower stage 1 operation
UPSt1DirectionAngle	UP St1 Dir Angle	[0,0..360,0] °	0,0	Underpower stage 1 characteristic direction angle
UPSt1Sop	UP St1 Sop	[0,001..1000,0] MVA	1,0	Underpower stage 1 operation threshold
UPSt1Top	UP St1 Top	[0..60000] ms	1000	Underpower stage 1 operation delay time
UPSt1DropRatio	UP St1 Drop Ratio	[1,04..1,20] × S_{op}	1,04	Underpower stage 1 dropout ratio
UPSt1DropDelay	UP St1 Drop Delay	[0..60000] ms	0	Underpower stage 1 dropout delay time

Identifier	Title	Range	Factory value	Description
UPSt2Operation	UP St2 Operation	OFF / ON	OFF	Underpower stage 2 operation
UPSt2DirectionAngle	UP St2 Dir Angle	[0,0..360,0] °	90,0	Underpower stage 2 characteristic direction angle
UPSt2Sop	UP St2 Sop	[0,001..1000,0] MVA	1,0	Underpower stage 2 operation threshold
UPSt2Top	UP St2 Top	[0..60000] ms	1000	Underpower stage 2 operation delay time
UPSt2DropRatio	UP St2 Drop Ratio	[1,04..1,20] × S_{op}	1,04	Underpower stage 2 dropout ratio
UPSt2DropDelay	UP St2 Drop Delay	[0..60000] ms	0	Underpower stage 2 dropout delay time

5.15 Phase Undervoltage

5.15.1 Introduction

Undervoltage conditions, whether voltage sags or interruptions, correspond to a sustained decrease in the magnitude of the fundamental frequency component of one or more phase-to-earth or phase-to-phase voltage signals. These abnormal conditions may compromise power system stability and must be detected as soon as possible in order to minimize their effect in the overall operating conditions. They can also be responsible for ineffective attempts of the on-load tap changers to increase the voltage value or they can cause permissible torques in electric machines to be exceeded.

Several causes may be associated to voltage sags and interruptions, such as:

- Incorrect operation of the voltage regulator or failure of the on-load tap changer;
- Extreme system overload, possibly in association with the previous factor;
- A short-circuit at some location of the network or a subsequent power outage.

In case of short-circuits, dedicated protection functions provide an effective resource to eliminate the undervoltage source. The Phase Undervoltage Protection can be used in complement of main protection, for circuit breaker tripping, as a backup function with a long operation time. It can also be applied for selective tripping of asynchronous machines when excessive torques can be reached. In alternative, the Phase Undervoltage Protection can be used in specific fault detection or blocking logic or for alarm only. It can also be integrated in a user programmable logic scheme with the aim of issuing voltage control actions.

Most frequently, the Phase Undervoltage Protection is used to initiate load shedding programs, for selective disconnection of network sections in case of major power outages, in order to prepare subsequent system restoration.

5.15.2 Operation Method

Two independent undervoltage stages are available: the first stage has a definite time characteristic, whereas for the second stage a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1 or 2).

Measuring Principle

The Phase Undervoltage Protection function continuously monitors one, two or three voltage signals, associated in one analogue channel connected to the function input **U**. The operating quantities can be either phase-to-earth or phase-to-phase voltages. If all three phase-to-earth voltages are connected to input U, the function can be configured to evaluate the input phase-to-earth voltages or, in option, the calculated phase-to-phase voltages, according to setting VoltageQty. On the other hand, if one or more phase-to-phase voltages are associated to input U, only phase-to-phase voltages can be used as operating quantities.

The protection function is executed in full-scheme mode, which means that there are separate protection elements for monitoring each operating voltage. The function pickup and trip are independently signalled for each phase and stage if the operating conditions are met. If the operating quantities are phase-to-phase voltages, whenever some of the input signals meet the operating conditions, the two corresponding phase outputs are signalled.

There are also general pickup and trip outputs for each stage. They correspond to the logical OR of the phase outputs, that is, they are activated, respectively, if at least one phase pickup or trip is active.

The stage pickup is signalled when the measured voltage magnitude is lower than the threshold defined in the corresponding stage setting (**StxUop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated VT primary voltage: in the case of phase-to-earth operating voltage, equation (5.42) applies; in the case of phase-to-phase operating voltage, equation (5.43) should be used instead.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \qquad (5.42)$$

$$U_{op}[kV]=U_{op}[p.u.]\cdot U_r \quad (5.43)$$

For all the stages, the operation threshold can be set below or above rated voltage. This extended setting range provides additional configuration flexibility, allowing the function to be used for detection of voltage sags, voltage interruptions or voltage recovery conditions.

Definite Time Characteristic

This is the only possible operating characteristic for stage 1. It can also be set in option for stage 2.

If definite time characteristic is selected, the stage pickup is signalled when the measured voltage magnitude is lower than the threshold defined in the corresponding stage setting (**StxUop**). It resets when the magnitude is higher than 104% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the voltage magnitude rises above the reset level.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stage 2.

If inverse time characteristic is selected, the pickup only occurs if the voltage magnitude is lower than 0,96 times the operation threshold, in order to avoid infinite time integration (see equation (5.44)). The reset occurs when the measured value is higher than the threshold setting.

The trip time is not constant and depends on the measured voltage. It is inversely proportional to the difference between the measured voltage U and the operation threshold U_{op} (setting **StxUop**), according to (5.44). The expression is integrated over time in order to accommodate voltage variations in the time between pickup and trip. The time multiplier TM (setting **StxTMS**) allows the user to adjust the trip time. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on this characteristic.

$$t=\frac{TM}{\frac{(U_{op}-U)}{U_{op}}} \quad (5.44)$$

As for the previous option, the stage reset is also instantaneous when the time inverse characteristic is selected.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** and **St2Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The Phase Undervoltage Protection should be blocked when the line that is being supervised is disconnected, if the voltage transformers are in the line side of the circuit breaker. The actual blocking condition may depend on the status of several circuit breakers (especially for topologies with more than one bus or breaker bypass arrangements); it can be programmed by the user and associated to the block inputs mentioned above.

The same applies during an open pole condition, if the circuit breaker is capable of single-pole tripping. Three independent inputs (**OpenPoleA**, **OpenPoleB** and **OpenPoleC**) are available for this purpose; they should be associated with the corresponding outputs of a separate open pole detector function. Only the undervoltage elements that monitor the disconnected phase are blocked in this case.

The Phase Undervoltage Protection can also operate incorrectly in case of a failure in the voltage measuring circuit. Only one phase is typically affected if this is the result of a blown fuse; however, if the associated voltage transformer is protected by a miniature circuit breaker (MCB), no measuring voltage will be available in all three phases simultaneously. All function stages are automatically blocked if a failure in the voltage measuring circuit is indicated in the **VTFail** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision) or the trip indication of the MCB that protects the voltage transformer can be directly used.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- A neutral voltage channel is associated to input **U**;
- One or two phase-to-earth voltages are associated to input **U** and setting **VoltageQty** is equal to **PHASE-PHASE**;
- One or more phase-to-phase voltages are associated to input **U** and setting **VoltageQty** is equal to **PHASE-EARTH**.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- At least one open pole input is connected but not all the three: the open pole block is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.15.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.50 and Table 5.51, respectively.

Table 5.50. Phase Undervoltage function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
VTFail	VT Failure	DIG	2	Voltage transformer failure
OpenPoleA	Open Pole A	DIG	2	Open pole, phase A
OpenPoleB	Open Pole B	DIG	2	Open pole, phase B
OpenPoleC	Open Pole C	DIG	2	Open pole, phase C

Table 5.51. Phase Undervoltage function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St1PickupA	St1 Pickup A	DIG	-	Stage 1 start, phase A
St1PickupB	St1 Pickup B	DIG	-	Stage 1 start, phase B
St1PickupC	St1 Pickup C	DIG	-	Stage 1 start, phase C
St2PickupA	St2 Pickup A	DIG	-	Stage 2 start, phase A
St2PickupB	St2 Pickup B	DIG	-	Stage 2 start, phase B
St2PickupC	St2 Pickup C	DIG	-	Stage 2 start, phase C
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start

Identifier	Title	Type	NV	Description
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St1TripA	St1 Trip A	DIG	-	Stage 1 trip, phase A
St1TripB	St1 Trip B	DIG	-	Stage 1 trip, phase B
St1TripC	St1 Trip C	DIG	-	Stage 1 trip, phase C
St2TripA	St2 Trip A	DIG	-	Stage 2 trip, phase A
St2TripB	St2 Trip B	DIG	-	Stage 2 trip, phase B
St2TripC	St2 Trip C	DIG	-	Stage 2 trip, phase C
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip

5.15.4 Settings

The function settings are listed in Table 5.52.

Table 5.52. Phase Undervoltage function settings.

Identifier	Title	Range	Factory value	Description
VoltageQty	Voltage Quantity	PHASE-EARTH / PHASE-PHASE	PHASE-EARTH	Voltage quantity
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Uop	St1 Uop	[0,01..2,0] × U_r	0,8	Stage 1 operation threshold
St1Top	St1 Top	[0..300000] ms	1000	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Uop	St2 Uop	[0,01..2,0] × U_r	0,8	Stage 2 operation threshold
St2Top	St2 Top	[0..300000] ms	1000	Stage 2 operation delay time
St2Curve	St2 Curve	DEF TIME / INV TIME	DEF TIM.	Stage 2 curve type
St2TMS	St2 TMS	[0,05..15,0]	1,0	Stage 2 time multiplier

5.16 PHASE OVERVOLTAGE

5.16.1 INTRODUCTION

The Phase Overvoltage Protection protects the electric power system against voltage levels that may damage the power equipment, leading to the failure of the insulation or to ineffective attempts of the on-load tap changers to decrease the voltage value.

Overvoltages in a power system can be of a transient or permanent nature. Different causes and protection mechanisms are associated to each one of these types of phenomenon. Transient overvoltages are originated by electric discharges on the vicinity of conductors or by switching operations. They correspond to very fast transients superimposed in the a.c. voltage waveform, and they are tackled by specific equipment as surge arresters.

The Phase Overvoltage Protection is suited to the protection against permanent overvoltages, *i.e.* those that correspond to a sustained condition at the fundamental frequency component. The increment of the voltage magnitude in one or more phases can be associated to several causes, such as:

- Incorrect operation of the voltage regulator or failure of the on-load tap changer;
- Sudden loss of load, voltage recovery after load shedding or inadvertent connection of a capacitor bank;
- Phase-to-earth faults, especially in networks with a non-solid neutral connection to earth.

For the last situation, dedicated earth-fault protection functions provide an effective resource to eliminate the overvoltage source. For the first two causes, the Phase Overvoltage Protection function should be used instead.

The function can be used for circuit breaker tripping or, as an alternative, for alarm only. It can also be integrated in a user programmable logic scheme with the aim of issuing voltage control actions.

5.16.2 OPERATION METHOD

Two independent overvoltage stages are available: the first stage has a definite time characteristic, whereas for the second stage a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1 or 2).

Measuring Principle

The Phase Overvoltage Protection function continuously monitors one, two or three voltage signals, associated in one analogue channel connected to the function input **U**. The operating quantities can be either phase-to-earth or phase-to-phase voltages. If all three phase-to-earth voltages are connected to input **U**, the function can be configured to evaluate the input phase-to-earth voltages or, in option, the calculated phase-to-phase voltages, according to setting **VoltageQty**. On the other hand, if one or more phase-to-phase voltages are associated to input **U**, only phase-to-phase voltages can be used as operating quantities.

The protection function is executed in full-scheme mode, which means that there are separate protection elements for monitoring each operating voltage. The function pickup and trip are independently signalled for each phase and stage if the operating conditions are met. If the operating quantities are phase-to-phase voltages, whenever some of the input signals meet the operating conditions, the two corresponding phase outputs are signalled.

There are also general pickup and trip outputs for each stage. They correspond to the logical OR of the phase outputs, that is, they are activated, respectively, if at least one phase pickup or trip is active.

The stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated VT primary voltage: in the case of phase-to-earth operating voltages, equation (5.45) applies; in the case of phase-to-phase operating voltages, equation (5.46) should be used instead.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \qquad (5.45)$$

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r \qquad (5.46)$$

For all the stages, the operation threshold can be set above or below rated voltage. This extended setting range provides additional configuration flexibility, allowing the function to be used for detection of both overvoltage and voltage recovery conditions.

Definite Time Characteristic

This is the only possible operating characteristic for stage 1. It can also be set in option for stage 2.

If definite time characteristic is selected, the stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the voltage magnitude drops below the reset level.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stage 2.

If inverse time characteristic is selected, the pickup only occurs if the voltage magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equation (5.47)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the measured voltage. It is inversely proportional to the difference between the measured voltage *U* and the operation threshold U_{op} (setting **StxUop**), according to (5.47). The expression is integrated over time in order to accommodate voltage variations in the time between pickup and trip. The time multiplier *TM* (setting **StxTMS**) allows the user to adjust the trip time. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on this characteristic.

$$t = \frac{TM}{\frac{(U - U_{op})}{U_{op}}} \qquad (5.47)$$

As for the previous option, the stage reset is also instantaneous when the time inverse characteristic is selected.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** and **St2Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- A neutral voltage channel is associated to input **U**;
- One or two phase-to-earth voltages are associated to input **U** and setting **VoltageQty** is equal to **PHASE-PHASE**;
- One or more phase-to-phase voltages are associated to input **U** and setting **VoltageQty** is equal to **PHASE-EARTH**.

The configuration is valid and the function operates accordingly otherwise.

5.16.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.53 and Table 5.54, respectively.

Table 5.53. Phase Overvoltage function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block

Table 5.54. Phase Overvoltage function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St1PickupA	St1 Pickup A	DIG	-	Stage 1 start, phase A
St1PickupB	St1 Pickup B	DIG	-	Stage 1 start, phase B
St1PickupC	St1 Pickup C	DIG	-	Stage 1 start, phase C
St2PickupA	St2 Pickup A	DIG	-	Stage 2 start, phase A
St2PickupB	St2 Pickup B	DIG	-	Stage 2 start, phase B
St2PickupC	St2 Pickup C	DIG	-	Stage 2 start, phase C
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St1TripA	St1 Trip A	DIG	-	Stage 1 trip, phase A
St1TripB	St1 Trip B	DIG	-	Stage 1 trip, phase B
St1TripC	St1 Trip C	DIG	-	Stage 1 trip, phase C
St2TripA	St2 Trip A	DIG	-	Stage 2 trip, phase A
St2TripB	St2 Trip B	DIG	-	Stage 2 trip, phase B
St2TripC	St2 Trip C	DIG	-	Stage 2 trip, phase C
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip

5.16.4 Settings

The function settings are listed in Table 5.55.

Table 5.55. Phase Overvoltage function settings.

Identifier	Title	Range	Factory value	Description
VoltageQty	Voltage Quantity	PHASE-EARTH / PHASE-PHASE	PHASE-EARTH	Voltage quantity
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Uop	St1 Uop	[0,01..2,0] × U_r	1,2	Stage 1 operation threshold
St1Top	St1 Top	[0..300000] ms	1000	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Uop	St2 Uop	[0,01..2,0] × U_r	1,2	Stage 2 operation threshold
St2Top	St2 Top	[0..300000] ms	1000	Stage 2 operation delay time
St2Curve	St2 Curve	DEF TIME / INV TIME	DEF TIM.	Stage 2 curve type
St2TMS	St2 TMS	[0,05..15,0]	1,0	Stage 2 time multiplier

5.17 Residual Overvoltage

5.17.1 Introduction

The Residual Overvoltage Protection function can be used as an additional protective element for earth-fault detection, in complement of other protection functions. In fact, the zero sequence voltage is a reliable indicator of the presence of an earth-fault in the network, since this component has a very low magnitude in all other power system conditions such as three-phase balanced load or phase-to-phase faults.

The magnitude of the zero sequence voltage during a phase-to-earth fault is affected by several factors, depending on the system earthing. For instance, in networks which are isolated from earth or earthed through an arc suppression coil, the zero sequence voltage reaches extremely high values for most phase-to-earth faults in the network, enabling their secure detection by the Residual Overvoltage Protection. On the other hand, for low impedance earthed systems, the magnitude of the zero sequence voltage decreases as the fault resistance increases or the fault is further away from the relay location. In these systems, the zero sequence voltage can reach very high values for close-in phase-to-earth faults, whereas high-impedance faults may require extremely sensitive detection thresholds.

The Residual Overvoltage Protection provides an effective way to detect earth-faults, although it is not able to identify the fault location. Nevertheless, it can be used for circuit breaker tripping, for example when configured as a backup function with a long operation time; or in network locations where no zero sequence current flowing is possible, for example, near a delta-connected transformer winding. In alternative, it can be used for alarm only or integrated in an earth-fault detection scheme, combined, for instance, with the Earth-Fault Overcurrent Protection.

5.17.2 Operation Method

Two independent overvoltage stages are available: the first stage has a definite time characteristic, whereas for the second stage a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1 or 2).

Measuring Principle

The Residual Overvoltage Protection function continuously monitors the residual voltage, which corresponds to three times the zero sequence voltage. It can be obtained from the internal sum of the three phase-to-earth voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_{res} = \overline{U}_A + \overline{U}_B + \overline{U}_C \tag{5.48}$$

As an alternative to the previous method, the displacement voltage can be directly measured in one analogue input, for instance from an independent open-delta connected voltage transformer winding. In this case, the function input **U** should be associated to a neutral analogue channel.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated VT primary phase-to-earth voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \tag{5.49}$$

For all the stages, an extended setting range provides the adequate discrimination of distinct asymmetrical fault conditions and the optional configuration of extremely sensitive operation thresholds.

Definite Time Characteristic

This is the only possible operating characteristic for stage 1. It can also be set in option for stage 2.

If definite time characteristic is selected, the stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the voltage magnitude drops below the reset level.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stage 2.

If inverse time characteristic is selected, the pickup only occurs if the voltage magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equation (5.50)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the measured voltage. It is inversely proportional to the difference between the measured voltage *U* and the operation threshold U_{op} (setting **StxUop**), according to (5.50). The expression is integrated over time in order to accommodate voltage variations in the time between pickup and trip. The time multiplier *TM* (setting **StxTMS**) allows the user to adjust the trip time. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on this characteristic.

$$t = \frac{TM}{\frac{(U - U_{op})}{U_{op}}} \qquad (5.50)$$

As for the previous option, the stage reset is also instantaneous when the time inverse characteristic is selected.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** and **St2Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The Residual Overvoltage Protection should be blocked during an open pole condition, if the circuit breaker is capable of single-pole tripping, because a voltage asymmetry may exist in this situation. An independent input (**OpenPole**) is available for this purpose; it should be associated with the corresponding output of a separate open pole detector function.

The function can also operate incorrectly in case of an asymmetrical failure in the voltage measuring circuit due to a blown fuse. All function stages are automatically blocked if a failure in the voltage measuring circuit is indicated in the **VTFail** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision).

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- The analogue channel associated to input **U** does not correspond to a neutral or to a group of three phase-to-earth voltage signals.

The configuration is valid and the function operates accordingly otherwise.

5.17.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.56 and Table 5.57, respectively.

Table 5.56. Residual Overvoltage function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block

Identifier	Title	Type	Mlt	Description
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
VTFail	VT Failure	DIG	2	Voltage transformer failure
OpenPole	Open Pole	DIG	2	Open pole

Table 5.57. Residual Overvoltage function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip

5.17.4 Settings

The function settings are listed in Table 5.58.

Table 5.58. Residual Overvoltage function settings.

Identifier	Title	Range	Factory value	Description
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Uop	St1 Uop	[0,01..3,0] × U_r	0,2	Stage 1 operation threshold
St1Top	St1 Top	[0..300000] ms	1000	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Uop	St2 Uop	[0,01..3,0] × U_r	0,2	Stage 2 operation threshold
St2Top	St2 Top	[0..300000] ms	1000	Stage 2 operation delay time
St2Curve	St2 Curve	DEF TIME / INV TIME	DEF TIM.	Stage 2 curve type
St2TMS	St2 TMS	[0,05..15,0]	1,0	Stage 2 time multiplier

5.18 Negative Sequence Overvoltage

5.18.1 Introduction

Like the zero sequence component, the negative sequence normally indicates the existence of an asymmetry in the power system that can be the result of some fault condition. Unlike the zero sequence, the negative sequence component is not cross-related to the existence of an earth-fault, and may be present in other types of short-circuits or asymmetrical conditions. For example, negative sequence provides a good indicator of phase unbalance.

The principle of the Negative Sequence Overvoltage Protection can be applied for instance to capacitor banks, to detect the voltage unbalance resulting from the failure of a single capacitor element. The function can also be used as a phase reversal protection that trips when the phase rotation of an electric machine is incorrect. The function can be used for circuit breaker tripping or, as an alternative, for alarm only. It can also be integrated in a user programmable logic scheme, combined with other functions.

5.18.2 Operation Method

Two independent overvoltage stages are available: the first stage has a definite time characteristic, whereas for the second stage a definite or inverse time characteristic can be chosen in option. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1 or 2).

Measuring Principle

The Negative Sequence Overvoltage Protection function continuously monitors the negative sequence voltage, obtained from the three phase-to-earth voltage signals (according to equation (5.51)) or from at least two phase-to-phase voltage signals, associated in one analogue channel connected to the function input **U**.

$$\overline{U}_2 = 1/3 \cdot \left(\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C\right), \quad a = e^{j120^\circ} \tag{5.51}$$

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The exact pickup and reset levels depend on the time characteristic selected.

The pickup threshold is set in values per unit, relative to the rated VT primary phase-to-earth voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \tag{5.52}$$

For all the stages, an extended setting range provides the adequate discrimination of distinct asymmetrical fault conditions and the optional configuration of extremely sensitive operation thresholds.

Definite Time Characteristic

This is the only possible operating characteristic for stage 1. It can also be set in option for stage 2.

If definite time characteristic is selected, the stage pickup is signalled when the measured voltage magnitude is higher than the threshold defined in the corresponding stage setting (**StxUop**). It resets when the magnitude is lower than 96% of that setting.

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the voltage magnitude drops below the reset level.

Inverse Time Characteristic

This operating characteristic can be selected in option only for stage 2.

If inverse time characteristic is selected, the pickup only occurs if the voltage magnitude is higher than 1,04 times the operation threshold, in order to avoid infinite time integration (see equation (5.53)). The reset occurs when the measured value is lower than the threshold setting.

The trip time is not constant and depends on the measured voltage. It is inversely proportional to the difference between the measured voltage U and the operation threshold U_{op} (setting **StxUop**), according to (5.53). The expression is integrated over time in order to accommodate voltage variations in the time between pickup and trip. The time multiplier *TM* (setting **StxTMS**) allows the user to adjust the trip time. Please refer to annex 8.1 - Definite and Inverse Time Characteristics for more details on this characteristic.

$$t = \frac{TM}{\frac{(U - U_{op})}{U_{op}}} \tag{5.53}$$

As for the previous option, the stage reset is also instantaneous when the time inverse characteristic is selected.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** and **St2Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

The Negative Sequence Overvoltage Protection should be blocked during an open pole condition, if the circuit breaker is capable of single-pole tripping, because a voltage asymmetry may exist in this situation. An independent input (**OpenPole**) is available for this purpose; it should be associated with the corresponding output of a separate open pole detector function.

The function can also operate incorrectly in case of an asymmetrical failure in the voltage measuring circuit due to a blown fuse. All function stages are automatically blocked if a failure in the voltage measuring circuit is indicated in the **VTFail** input. This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision).

The blocking condition is signalled in the corresponding stage output (**StxBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals or to a group of at least two phase-to-phase voltage signals.

The configuration is valid and the function operates accordingly otherwise.

5.18.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.59 and Table 5.60, respectively.

Table 5.59. Negative Sequence Overvoltage function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
VTFail	VT Failure	DIG	2	Voltage transformer failure
OpenPole	Open Pole	DIG	2	Open pole

Table 5.60. Negative Sequence Overvoltage function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip

5.18.4 Settings

The function settings are listed in Table 5.61.

Table 5.61. Negative Sequence Overvoltage function settings.

Identifier	Title	Range	Factory value	Description
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Uop	St1 Uop	[0,01..3,0] × U_r	0,2	Stage 1 operation threshold
St1Top	St1 Top	[0..300000] ms	1000	Stage 1 operation delay time
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Uop	St2 Uop	[0,01..3,0] × U_r	0,2	Stage 2 operation threshold
St2Top	St2 Top	[0..300000] ms	1000	Stage 2 operation delay time
St2Curve	St2 Curve	DEF TIME / INV TIME	DEF TIM.	Stage 2 curve type
St2TMS	St2 TMS	[0,05..15,0]	1,0	Stage 2 time multiplier

5.19 Underfrequency

5.19.1 Introduction

Power system frequency must be kept in a narrow range around its rated value to guarantee a stable operation of the power network. For this reason, the entire system is supervised and control actions are executed in real-time to ensure a permanent balance between generation and demand.

Underfrequency occurs when demand exceeds generation in an uncontrolled way. This condition can be caused by a sudden increase in load or by the reduction of available generated power, for example due to the loss of some generators or to a malfunction in the power frequency control system. It can also be the result of a cascading series of events leading to a split of a synchronous system in two or more sections.

The Underfrequency Protection reacts to frequency deviations below the allowed range. It is normally used to initiate load shedding programs, which reduce demand in order to re-establish a new stable operating condition. It can also be used in remedial action schemes or to detect islanding, when a generator remains connected to a section of the power system that is separated from the rest of the network.

5.19.2 Operation Method

Five independent underfrequency stages, all with definite time characteristic, are available. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3, 4 or 5).

Measuring Principle

The Underfrequency Protection function continuously monitors the power system frequency. One, two or three voltage signals, associated in one analogue channel connected to the function input **U**, are used for frequency measurement. The operating quantities can be either phase-to-earth or phase-to-phase voltages. A fit-for-purpose set of filters guarantees the adequate rejection of harmonics, transients and phase jumps in frequency evaluation.

The frequency is supervised in all voltage signals available in the input channel, provided that their magnitude is higher than a pre-defined undervoltage block threshold (**StxUmin**). The pickup is signalled only when the frequency operating conditions are simultaneously reached in all voltage inputs for which the magnitude is above the undervoltage block threshold.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured frequency is lower than the threshold defined in the corresponding stage setting (**StxFop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The dropout differential is independent of the operation threshold and equal to 20 mHz.

The pickup threshold is set in values per unit, relative to the frequency rated value (50 Hz or 60 Hz).

$$f_{op}[Hz] = f_{op}[p.u.] \cdot f_r \qquad (5.54)$$

For all the stages, the operation threshold can be set below or above rated frequency. This extended setting range provides additional configuration flexibility, allowing the function to be used for detection of both underfrequency and frequency recovery conditions.

Definite Time Characteristic

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the frequency rises above the reset level.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St5Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

Independently of the user-defined block conditions, the function integrates a built-in undervoltage block. It is used to prevent incorrect function operation due to unstable decaying voltage signals (for example, when that network section is disconnected from the rest of the power system). The voltage threshold can be set independently for each stage (in setting **StxUmin**). The undervoltage block is only effective, and its corresponding output indication signalled, when the magnitude of all available voltage inputs is below the block voltage threshold. In the case some stage is already picked up when the voltage drops, it will be immediately reset.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**). The undervoltage blocking condition is also signalled in its corresponding stage output (**St1UminBlocked** to **St5UminBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- A neutral voltage channel is associated to input **U**.

The configuration is valid and the function operates accordingly otherwise.

5.19.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.62 and Table 5.63, respectively.

Table 5.62. Underfrequency function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
St5Block	St5 Block	DIG	2	Stage 5 block

Table 5.63. Underfrequency function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
St5Behavior	St5 Behavior	INT	-	Stage 5 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked

Identifier	Title	Type	NV	Description
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St5Blocked	St5 Blocked	DIG	-	Stage 5 blocked
St1UminBlocked	St1 Umin Blocked	DIG	-	Stage 1 blocked by low voltage
St2UminBlocked	St2 Umin Blocked	DIG	-	Stage 2 blocked by low voltage
St3UminBlocked	St3 Umin Blocked	DIG	-	Stage 3 blocked by low voltage
St4UminBlocked	St4 Umin Blocked	DIG	-	Stage 4 blocked by low voltage
St5UminBlocked	St5 Umin Blocked	DIG	-	Stage 5 blocked by low voltage
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St5Pickup	St5 Pickup	DIG	-	Stage 5 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
St5Trip	St5 Trip	DIG	-	Stage 5 general trip

5.19.4 Settings

The function settings are listed in Table 5.64.

Table 5.64. Underfrequency function settings.

Identifier	Title	Range	Factory value	Description
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Fop	St1 Fop	[0,8..1,2] × f_r	0,95	Stage 1 operation threshold
St1Top	St1 Top	[0..120000] ms	200	Stage 1 operation delay time
St1Umin	St1 Umin	[0,15..1,0] × U_r	0,8	Stage 1 undervoltage block threshold
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Fop	St2 Fop	[0,8..1,2] × f_r	0,95	Stage 2 operation threshold
St2Top	St2 Top	[0..120000] ms	200	Stage 2 operation delay time
St2Umin	St2 Umin	[0,15..1,0] × U_r	0,8	Stage 2 undervoltage block threshold
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3Fop	St3 Fop	[0,8..1,2] × f_r	0,95	Stage 3 operation threshold
St3Top	St3 Top	[0..120000] ms	200	Stage 3 operation delay time

Identifier	Title	Range	Factory value	Description
St3Umin	St3 Umin	[0,15..1,0] × U_r	0,8	Stage 3 undervoltage block threshold
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4Fop	St4 Fop	[0,8..1,2] × f_r	0,95	Stage 4 operation threshold
St4Top	St4 Top	[0..120000] ms	200	Stage 4 operation delay time
St4Umin	St4 Umin	[0,15..1,0] × U_r	0,8	Stage 4 undervoltage block threshold
St5Operation	St5 Operation	OFF / ON	OFF	Stage 5 operation
St5Fop	St5 Fop	[0,8..1,2] × f_r	0,95	Stage 5 operation threshold
St5Top	St5 Top	[0..120000] ms	200	Stage 5 operation delay time
St5Umin	St5 Umin	[0,15..1,0] × U_r	0,8	Stage 5 undervoltage block threshold

5.20 OVERFREQUENCY

5.20.1 INTRODUCTION

Power system frequency must be kept in a narrow range around its rated value to guarantee a stable operation of the power network. For this reason, the entire system is supervised and control actions are executed in real-time to ensure a permanent balance between generation and demand.

Overfrequency occurs when generation exceeds demand in an uncontrolled way. This condition can be caused by a sudden decrease in load, a three-phase fault or a malfunction in the power frequency control system. It can also be the result of a cascading series of events leading to a split of a synchronous system in two or more sections.

The Overfrequency Protection reacts to frequency deviations above the allowed range. It is normally used in generator shedding programs, which reduce generation in order to re-establish a new stable operating condition, or to detect islanding, when a generator remains connected to a section of the power system that is separated from the rest of the network. It can also be used in remedial action schemes or to initiate load restoration after major load shedding events.

5.20.2 OPERATION METHOD

Five independent overfrequency stages, all with definite time characteristic, are available. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3, 4 or 5).

Measuring Principle

The Overfrequency Protection function continuously monitors the power system frequency. One, two or three voltage signals, associated in one analogue channel connected to the function input **U**, are used for frequency measurement. The operating quantities can be either phase-to-earth or phase-to-phase voltages. A fit-for-purpose set of filters guarantees the adequate rejection of harmonics, transients and phase jumps in frequency evaluation.

The frequency is supervised in all voltage signals available in the input channel, provided that their magnitude is higher than a pre-defined undervoltage block threshold (**StxUmin**). The pickup is signalled only when the frequency operating conditions are simultaneously reached in all voltage inputs for which the magnitude is above the undervoltage block threshold.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the measured frequency is higher than the threshold defined in the corresponding stage setting (**StxFop**). A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The dropout differential is independent of the operation threshold and equal to 20 mHz.

The pickup threshold is set in values per unit, relative to the frequency rated value (50 Hz or 60 Hz).

$$f_{op}[Hz] = f_{op}[p.u.] \cdot f_r \quad (5.55)$$

For all the stages, the operation threshold can be set above or below rated frequency. This extended setting range provides additional configuration flexibility, allowing the function to be used for detection of both overfrequency and frequency recovery conditions.

Definite Time Characteristic

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous. When the definite time characteristic is selected, the stage instantaneously resets if the frequency drops below the reset level.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St5Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

Independently of the user-defined block conditions, the function integrates a built-in undervoltage block. It is used to prevent incorrect function operation due to unstable decaying voltage signals (for example, when that network section is disconnected from the rest of the power system). The voltage threshold can be set independently for each stage (in setting **StxUmin**). The undervoltage block is only effective, and its corresponding output indication signalled, when the magnitude of all available voltage inputs is below the block voltage threshold. In the case some stage is already picked up when the voltage drops, it will be immediately reset.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**). The undervoltage blocking condition is also signalled in its corresponding stage output (**St1UminBlocked** to **St5UminBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- A neutral voltage channel is associated to input **U**.

The configuration is valid and the function operates accordingly otherwise.

5.20.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.65 and Table 5.66, respectively.

Table 5.65. Overfrequency function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
St5Block	St5 Block	DIG	2	Stage 5 block

Table 5.66. Overfrequency function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
St5Behavior	St5 Behavior	INT	-	Stage 5 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked

Identifier	Title	Type	NV	Description
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St5Blocked	St5 Blocked	DIG	-	Stage 5 blocked
St1UminBlocked	St1 Umin Blocked	DIG	-	Stage 1 blocked by low voltage
St2UminBlocked	St2 Umin Blocked	DIG	-	Stage 2 blocked by low voltage
St3UminBlocked	St3 Umin Blocked	DIG	-	Stage 3 blocked by low voltage
St4UminBlocked	St4 Umin Blocked	DIG	-	Stage 4 blocked by low voltage
St5UminBlocked	St5 Umin Blocked	DIG	-	Stage 5 blocked by low voltage
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St5Pickup	St5 Pickup	DIG	-	Stage 5 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
St5Trip	St5 Trip	DIG	-	Stage 5 general trip

5.20.4 Settings

The function settings are listed in Table 5.67.

Table 5.67. Overfrequency function settings.

Identifier	Title	Range	Factory value	Description
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1Fop	St1 Fop	[0,8..1,2] × f_r	1,05	Stage 1 operation threshold
St1Top	St1 Top	[0..120000] ms	200	Stage 1 operation delay time
St1Umin	St1 Umin	[0,15..1,0] × U_r	0,8	Stage 1 undervoltage block threshold
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2Fop	St2 Fop	[0,8..1,2] × f_r	1,05	Stage 2 operation threshold
St2Top	St2 Top	[0..120000] ms	200	Stage 2 operation delay time
St2Umin	St2 Umin	[0,15..1,0] × U_r	0,8	Stage 2 undervoltage block threshold
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3Fop	St3 Fop	[0,8..1,2] × f_r	1,05	Stage 3 operation threshold
St3Top	St3 Top	[0..120000] ms	200	Stage 3 operation delay time

Identifier	Title	Range	Factory value	Description
St3Umin	St3 Umin	[0,15..1,0] × U_r	0,8	Stage 3 undervoltage block threshold
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4Fop	St4 Fop	[0,8..1,2] × f_r	1,05	Stage 4 operation threshold
St4Top	St4 Top	[0..120000] ms	200	Stage 4 operation delay time
St4Umin	St4 Umin	[0,15..1,0] × U_r	0,8	Stage 4 undervoltage block threshold
St5Operation	St5 Operation	OFF / ON	OFF	Stage 5 operation
St5Fop	St5 Fop	[0,8..1,2] × f_r	1,05	Stage 5 operation threshold
St5Top	St5 Top	[0..120000] ms	200	Stage 5 operation delay time
St5Umin	St5 Umin	[0,15..1,0] × U_r	0,8	Stage 5 undervoltage block threshold

5.21 Frequency Rate-of-Change

5.21.1 Introduction

Power system frequency must be kept in a narrow range around its rated value to guarantee a stable operation of the power network. For this reason, the entire system is supervised and control actions are executed in real-time to ensure a permanent balance between generation and demand.

The supervision of the frequency derivative provides an early indication of major disturbances and anticipates excessive frequency deviations below or above the allowed range, caused by unbalances between generation and demand. These can be the result of sudden loss of generation or load, of a malfunction in the power frequency control system or of a cascading series of events leading to a split of a synchronous system in two or more sections.

The Frequency Rate-of-Change Protection usually guarantees a faster reaction to frequency deviations than the Under and Overfrequency functions standalone. It allows a faster initiation of load and generation shedding programs, in order to re-establish as soon as possible the normal system operating conditions. It can also be used in remedial action schemes. When applied to anti-islanding protection, it allows the early disconnection of the generators remaining separated from the rest of the network, which increases the success rate of a subsequent automatic reclosing command.

5.21.2 Operation Method

Five independent frequency rate-of-change stages, all with definite time characteristic, are available. Each stage can be separately activated by setting change (setting **StxOperation**, x = 1, 2, 3, 4 or 5).

Measuring Principle

The Frequency Rate-of-Change Protection function continuously monitors the power system frequency and its rate-of-change. One, two or three voltage signals, associated in one analogue channel connected to the function input **U**, are used for frequency measurement. The operating quantities can be either phase-to-earth or phase-to-phase voltages. A fit-for-purpose set of filters guarantees the adequate rejection of harmonics, transients and phase jumps in frequency evaluation.

The frequency and its rate-of-change are supervised in all voltage signals available in the input channel, provided that their magnitude is higher than a pre-defined undervoltage block threshold (**StxUmin**). The pickup is signalled only when the frequency operating conditions are simultaneously reached in all voltage inputs for which the magnitude is above the undervoltage block threshold.

The function pickup and trip are independently signalled for each stage, if the operating conditions are met.

The stage pickup is signalled when the rate at which the measured frequency changes is higher than the threshold defined in the corresponding stage setting (**StxVarFop**). Each protection stage can be configured, in option, to operate for positive or negative derivatives of the power system frequency. This is defined in setting **StxSignVarFop**.

The pickup threshold is directly set in Hz/s. An extended setting range is available, up to a maximum rate of 10 Hz/s. A built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs. The dropout differential is independent of the operation threshold and less than 0,1 Hz/s.

Besides the rate-of-change monitoring, each stage can be additionally supervised by an underfrequency or overfrequency threshold. The supervision frequency threshold is set in values per unit, relative to the frequency rated value (50 Hz or 60 Hz).

$$f_{op}[Hz] = f_{op}[p.u.] \cdot f_r \qquad (5.56)$$

When the stage is configured to operate for negative frequency rates, the supervision threshold should be less than the frequency rated value (less than 1 p.u.); in this case, the pickup will only be signalled if both operating conditions (frequency rate-of-change threshold and frequency supervision threshold) are met. On the contrary, for positive frequency rate-of-change stages, the supervision threshold should be greater than the frequency rated value (more than 1 p.u.). If the supervision threshold is equal to the rated frequency (1 p.u.), the stage is ready to operate by the rate-of-change criterion, as long as the frequency deviates from the rated value.

In order to achieve further security in function operation, the frequency rate-of-change can be averaged over a number of user defined power network cycles (setting **StxAverageCyc**). Erroneous function decisions during transient system disturbances such as power swings can thus be avoided by monitoring the trend in the change of frequency instead of its instantaneous value. A minimum observation time interval of 10 cycles is always guaranteed.

Definite Time Characteristic

The trip time is constant in this option and can be set by the user in the corresponding stage setting (**StxTop**). If the operational time is set to zero, the trip will be instantaneous, immediately after the pickup is signalled. In any case, the trip time only starts counting after the evaluation time used to calculate the average rate-of-change has expired. When the definite time characteristic is selected, the stage instantaneously resets if any of the configured operating conditions ceases to verify.

Blocking Conditions

The function provides an individual block input for each protection stage (**St1Block** to **St5Block**) and a general function block input (**Block**). Any of them can be freely associated to any user-defined condition.

Independently of the user-defined block conditions, the function integrates a built-in undervoltage block. It is used to prevent incorrect function operation due to unstable decaying voltage signals (for example, when that network section is disconnected from the rest of the power system). The voltage threshold can be set independently for each stage (in setting **StxUmin**). The undervoltage block is only effective, and its corresponding output indication signalled, when the magnitude of all available voltage inputs is below the block voltage threshold. In the case some stage is already picked up when the voltage drops, it will be immediately reset.

The blocking condition is signalled in the corresponding stage output (**StxBlocked**). The undervoltage blocking condition is also signalled in its corresponding stage output (**St1UminBlocked** to **St5UminBlocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- A neutral voltage channel is associated to input **U**.

The configuration is valid and the function operates accordingly otherwise.

5.21.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.68 and Table 5.69, respectively.

Table 5.68. Frequency Rate-of-Change function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Operating voltages
Block	Block	DIG	4	Function general block
St1Block	St1 Block	DIG	2	Stage 1 block
St2Block	St2 Block	DIG	2	Stage 2 block
St3Block	St3 Block	DIG	2	Stage 3 block
St4Block	St4 Block	DIG	2	Stage 4 block
St5Block	St5 Block	DIG	2	Stage 5 block

Table 5.69. Frequency Rate-of-Change function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision

Identifier	Title	Type	NV	Description
Version	Version	TEXT	-	Function configuration version
St1Behavior	St1 Behavior	INT	-	Stage 1 operation mode
St2Behavior	St2 Behavior	INT	-	Stage 2 operation mode
St3Behavior	St3 Behavior	INT	-	Stage 3 operation mode
St4Behavior	St4 Behavior	INT	-	Stage 4 operation mode
St5Behavior	St5 Behavior	INT	-	Stage 5 operation mode
Health	Health	INT	-	Function health
St1Blocked	St1 Blocked	DIG	-	Stage 1 blocked
St2Blocked	St2 Blocked	DIG	-	Stage 2 blocked
St3Blocked	St3 Blocked	DIG	-	Stage 3 blocked
St4Blocked	St4 Blocked	DIG	-	Stage 4 blocked
St5Blocked	St5 Blocked	DIG	-	Stage 5 blocked
St1UminBlocked	St1 Umin Blocked	DIG	-	Stage 1 blocked by low voltage
St2UminBlocked	St2 Umin Blocked	DIG	-	Stage 2 blocked by low voltage
St3UminBlocked	St3 Umin Blocked	DIG	-	Stage 3 blocked by low voltage
St4UminBlocked	St4 Umin Blocked	DIG	-	Stage 4 blocked by low voltage
St5UminBlocked	St5 Umin Blocked	DIG	-	Stage 5 blocked by low voltage
St1Pickup	St1 Pickup	DIG	-	Stage 1 general start
St2Pickup	St2 Pickup	DIG	-	Stage 2 general start
St3Pickup	St3 Pickup	DIG	-	Stage 3 general start
St4Pickup	St4 Pickup	DIG	-	Stage 4 general start
St5Pickup	St5 Pickup	DIG	-	Stage 5 general start
St1Trip	St1 Trip	DIG	-	Stage 1 general trip
St2Trip	St2 Trip	DIG	-	Stage 2 general trip
St3Trip	St3 Trip	DIG	-	Stage 3 general trip
St4Trip	St4 Trip	DIG	-	Stage 4 general trip
St5Trip	St5 Trip	DIG	-	Stage 5 general trip

5.21.4 Settings

The function settings are listed in Table 5.70.

Table 5.70. Frequency Rate-of-Change function settings.

Identifier	Title	Range	Factory value	Description
St1Operation	St1 Operation	OFF / ON	OFF	Stage 1 operation
St1SignVarFop	St1 Sign Var Fop	POSITIVE / NEGATIVE	NEG.	Stage 1 positive/negative frequency rate-of-change

Identifier	Title	Range	Factory value	Description
St1VarFop	St1 Var Fop	[0,1..10,0] Hz/s	0,1	Stage 1 frequency rate-of-change threshold
St1Top	St1 Top	[0..120000] ms	200	Stage 1 operation delay time
St1Umin	St1 Umin	[0,15..1,0] × U_r	0,8	Stage 1 undervoltage block threshold
St1SupFop	St1 Sup Fop	[0,8..1,2] × f_r	1,0	Stage 1 frequency supervision threshold
St1AverageCyc	St1 Average Cycles	[10..50] cycles	10	Stage 1 observation cycles
St2Operation	St2 Operation	OFF / ON	OFF	Stage 2 operation
St2SignVarFop	St2 Sign Var Fop	POSITIVE / NEGATIVE	NEG.	Stage 2 positive/negative frequency rate-of-change
St2VarFop	St2 Var Fop	[0,1..10,0] Hz/s	0,1	Stage 2 frequency rate-of-change threshold
St2Top	St2 Top	[0..120000] ms	200	Stage 2 operation delay time
St2Umin	St2 Umin	[0,15..1,0] × U_r	0,8	Stage 2 undervoltage block threshold
St2SupFop	St2 Sup Fop	[0,8..1,2] × f_r	1,0	Stage 2 frequency supervision threshold
St2AverageCyc	St2 Average Cycles	[10..50] cycles	10	Stage 2 observation cycles
St3Operation	St3 Operation	OFF / ON	OFF	Stage 3 operation
St3SignVarFop	St3 Sign Var Fop	POSITIVE / NEGATIVE	NEG.	Stage 3 positive/negative frequency rate-of-change
St3VarFop	St3 Var Fop	[0,1..10,0] Hz/s	0,1	Stage 3 frequency rate-of-change threshold
St3Top	St3 Top	[0..120000] ms	200	Stage 3 operation delay time
St3Umin	St3 Umin	[0,15..1,0] × U_r	0,8	Stage 3 undervoltage block threshold
St3SupFop	St3 Sup Fop	[0,8..1,2] × f_r	1,0	Stage 3 frequency supervision threshold
St3AverageCyc	St3 Average Cycles	[10..50] cycles	10	Stage 3 observation cycles
St4Operation	St4 Operation	OFF / ON	OFF	Stage 4 operation
St4SignVarFop	St4 Sign Var Fop	POSITIVE / NEGATIVE	NEG.	Stage 4 positive/negative frequency rate-of-change
St4VarFop	St4 Var Fop	[0,1..10,0] Hz/s	0,1	Stage 4 frequency rate-of-change threshold
St4Top	St4 Top	[0..120000] ms	200	Stage 4 operation delay time
St4Umin	St4 Umin	[0,15..1,0] × U_r	0,8	Stage 4 undervoltage block threshold
St4SupFop	St4 Sup Fop	[0,8..1,2] × f_r	1,0	Stage 4 frequency supervision threshold
St4AverageCyc	St4 Average Cycles	[10..50] cycles	10	Stage 4 observation cycles
St5Operation	St5 Operation	OFF / ON	OFF	Stage 5 operation

Identifier	Title	Range	Factory value	Description
St5SignVarFop	St5 Sign Var Fop	POSITIVE / NEGATIVE	NEG.	Stage 5 positive/negative frequency rate-of-change
St5VarFop	St5 Var Fop	[0,1..10,0] Hz/s	0,1	Stage 5 frequency rate-of-change threshold
St5Top	St5 Top	[0..120000] ms	200	Stage 5 operation delay time
St5Umin	St5 Umin	[0,15..1,0] × U_r	0,8	Stage 5 undervoltage block threshold
St5SupFop	St5 Sup Fop	[0,8..1,2] × f_r	1,0	Stage 5 frequency supervision threshold
St5AverageCyc	St5 Average Cycles	[10..50] cycles	10	Stage 5 observation cycles

5.22 Three-Phase / Single-Phase Trip Logic

5.22.1 Introduction

The Three-Phase / Single-Phase Trip Logic function aggregates the pickup and trip information of all protection functions in the TPU L500, together with additional trip conditioning inputs originating from other functions like Switch-Onto-Fault, Automatic Reclosure or from specific blocking conditions. It is responsible for issuing a common protection trip signal to be transmitted to a certain circuit breaker (or pair of circuit breakers) in the event of a fault. The function supports three-phase and single-phase tripping circuit breakers.

5.22.2 Operation Method

The Three-Phase / Single-Phase Trip Logic function allows combining in its inputs the individual pickup and trip indications of the several protection functions. These inputs are the base for the implemented general trip logic, which is executed with the highest priority among other internal functions.

Up to two circuit breakers are supported, allowing the application of the function in breaker-and-a-half or other multiple breaker topologies.

Both three-phase and single-phase tripping is allowed, according to the protection function that has issued the trip order and the type of fault. Function inputs **FuncTripA**, **FuncTripB** and **FuncTripC** must be associated to the phase-discriminated trip indications of all protections functions or stages for which a single-phase trip is allowed. For all other protection functions or stages that should always issue a three-phase trip irrespective of the fault type, their general trip output must be directly associated to the three-pole trip input **FuncTrip**.

A specific protection stage should be only associated to the three-phase trip input (**FuncTrip**) or to the corresponding phase-discriminated inputs (**FuncTripA**, **FuncTripB** and **FuncTripC**), not to both of them at the same time.

A single-pole trip will be issued if the following conditions are simultaneously met:

- At least one and only one of the inputs **FuncTripA**, **FuncTripB** and **FuncTripC** is active;
- The three-phase trip input **FuncTrip** is inactive;
- All other conditions required for single-phase tripping, concerning the interaction with the Automatic Reclosure function, as described next, are fulfilled.

On the other hand, a three-pole trip will be issued if any of the following conditions is met:

- Two or more inputs **FuncTripA**, **FuncTripB** and **FuncTripC** are active;
- The three-phase trip input **FuncTrip** is active;
- By default, when some of the conditions required for single-phase tripping are not fulfilled.

Single-phase tripping additionally requires that the association with at least one external Automatic Reclosure function is configured (please refer to section 5.23 - Automatic Reclosure for more details). In multiple breaker arrangements, the association with two independent Automatic Reclosure functions (one per circuit breaker) is optional.

If two independent Automatic Reclosure functions are associated with the Trip Logic function, each one defines the trip behaviour of the associated circuit breaker. A single-phase trip in CBx (x = 1 or 2) will only be allowed if it is permitted for the actual reclose cycle (function input **RecxSPPermitted** is active).

If only one Automatic Reclosure function is associated with the Trip Logic function, the trip behaviour is the same for both circuit breakers, according to the rule stated above.

The simplified logic scheme of the Trip Logic function is depicted in Figure 5.58, Figure 5.59 and Figure 5.60.

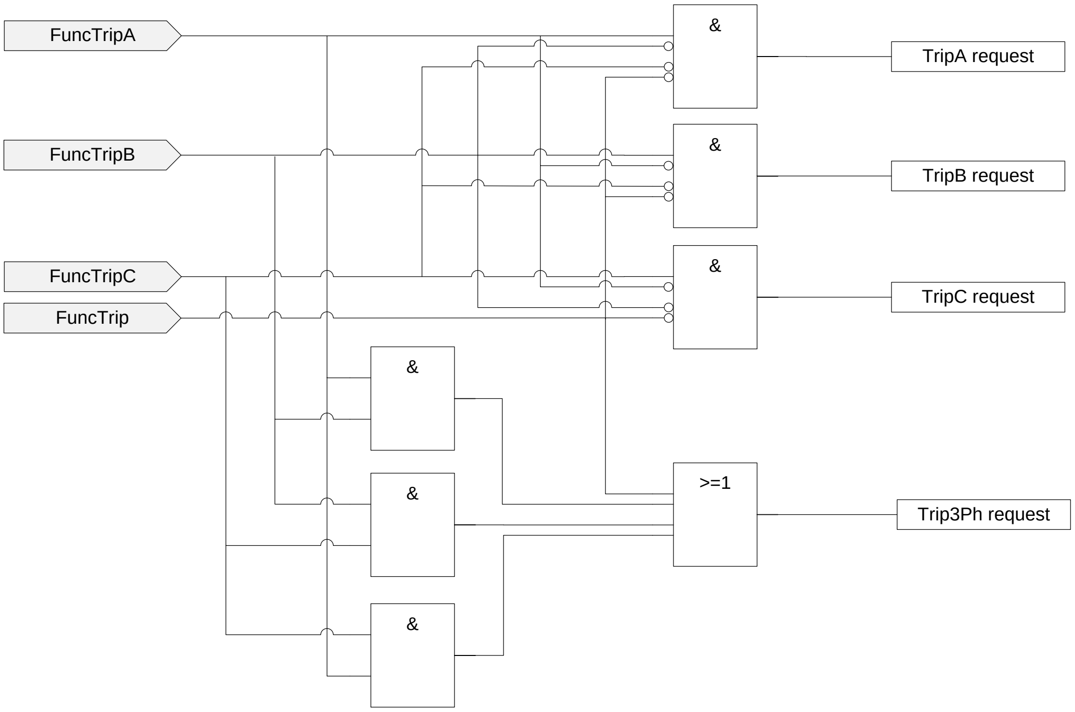

Figure 5.58. Internal requests logic.

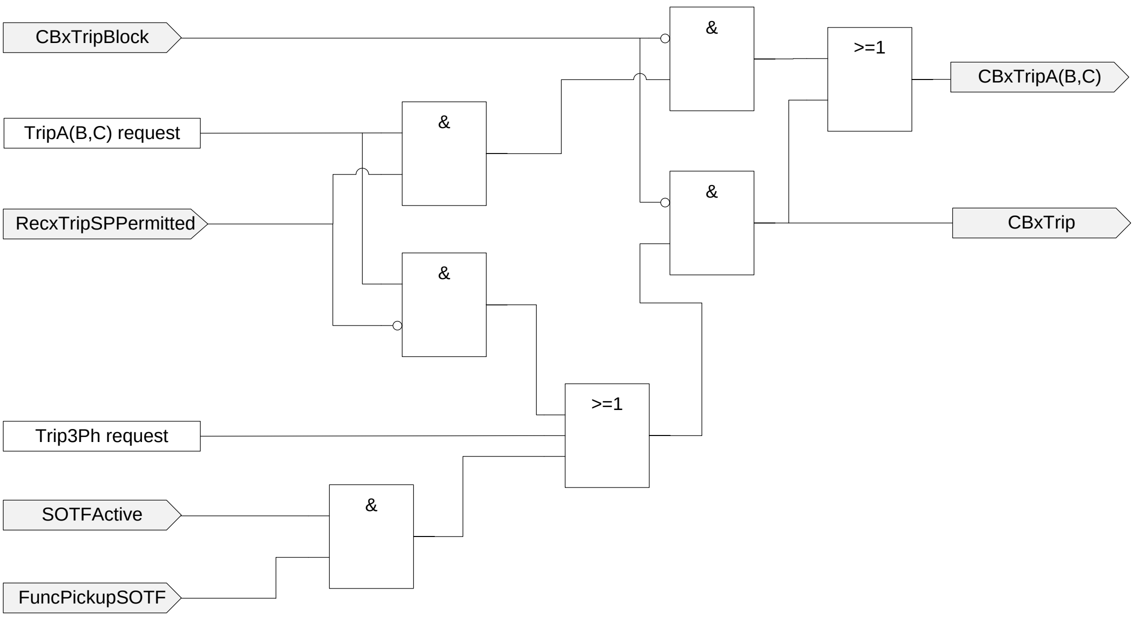

Figure 5.59. Circuit breaker tripping logic.

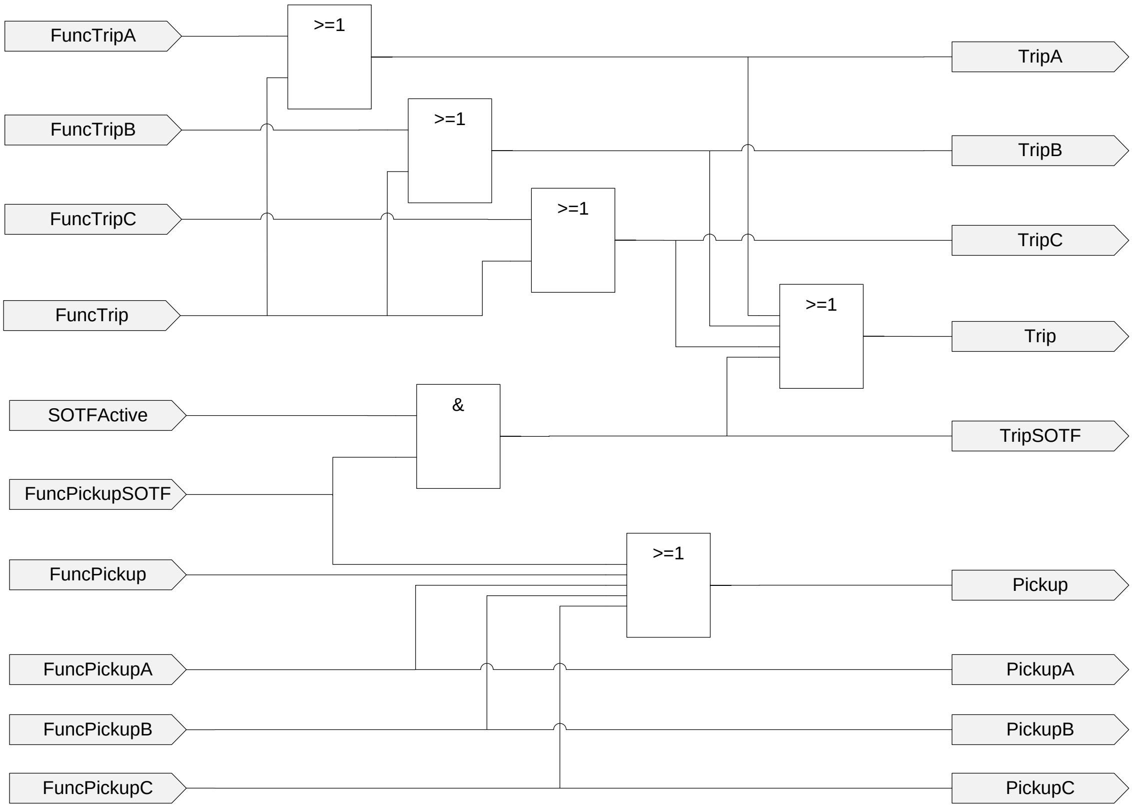

Figure 5.60. Auxiliar information logic.

In case of circuit breakers with single-pole operation, function outputs **CBxTripA**, **CBxTripB** and **CBxTripC** (x = 1 or 2) should be used for circuit breaker tripping. For each circuit breaker, the three outputs will be simultaneously operated in case of a three-phase trip. For circuit breakers with three-pole operation only, **CBxTrip** outputs can be directly used instead, since they are the logical OR of the corresponding three phase outputs.

The trip can also be issued according to an external Switch-Onto-Fault function (please refer to section 5.12 - Switch-Onto-Fault). For this purpose, the pickup signal of one or more user selected protection stages can be associated in option to the input **FuncPickupSOTF**. In the event a fault is detected by the selected stages, the circuit breaker trip will be instantaneously issued after pickup, if the external switch-onto-fault logic indication, connected to the function input **SOTFActive**, is active. The circuit breaker trip generated due to the switch-onto-fault logic is always three-pole and an additional indication is signalled (function output **TripSOTF**), for event log purposes.

The function outputs **CBxTrip** (or **CBxTripA**, **CBxTripB** and **CBxTripC**) can be routed to binary outputs: this should be done connecting them with the corresponding input of the circuit breaker function (please refer to section 5.33 - Circuit Breaker Supervision). In alternative, the trip indication can be issued over a communication channel to other IED directly controlling the circuit breaker.

The function provides a block input for each circuit breaker (**CBxTripBlock**) for blocking the corresponding trip. It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**CBxTripBlocked**).

General pickup (output **Pickup**) and trip (output **Trip**) indications are also available: the **Pickup** output combines the pickup signals of all protection functions, including those selected for instantaneous trip with switch-onto-fault conditions; the **Trip** indication is the logical OR of all protection function trip signals and of the trip due to the switch-onto-fault logic.

Additionally, for event log or other purposes, pickup indications discriminated per phase are provided in function outputs **PickupA**, **PickupB** and **PickupC**, according to the corresponding inputs **FuncPickupA**, **FuncPickupB** and **FuncPickupC**. Phase-discriminated trip indications are provided in outputs **TripA**, **TripB** and **TripC**.

The accumulated number of trips is available as additional information in the entity **TripCounter**. It can be reset by the user at any time.

Function Health

The function operates with possible limitations and its output **Health** is set to Warning status if:

- At least one of the inputs **FuncPickupA**, **FuncPickupB** or **FuncPickupC** is connected but not all the three;
- At least one of the inputs **FuncTripA**, **FuncTripB** or **FuncTripC** is connected but not all the three: single-phase tripping is not allowed in this case;
- At least one of the inputs **FuncPickupSOTF** and **SOTFActive** is connected but not both: the trip due to switch-onto-fault is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.22.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.71 and Table 5.72, respectively.

Table 5.71. Three-Phase / Single-Phase Trip Logic function inputs.

Identifier	Title	Type	Mlt	Description
CB1TripBlock	CB 1 Trip Block	DIG	2	Circuit breaker 1 trip block
CB2TripBlock	CB 2 Trip Block	DIG	2	Circuit breaker 2 trip block
FuncTripA	Function Trip PhA	DIG	16	Protection trip phase A
FuncTripB	Function Trip PhB	DIG	16	Protection trip phase B
FuncTripC	Function Trip PhC	DIG	16	Protection trip phase C
FuncTrip	Function Trip	DIG	100	Protection trip
Rec1TipSPPermitted	Rec1 SP Permitted	DIG	2	Recloser 1 permitting 1 pole reclosing
Rec2TipSPPermitted	Rec2 SP Permitted	DIG	2	Recloser 2 permitting 1 pole reclosing
FuncPickupA	Function Pickup PhA	DIG	64	Protection pickup phase A
FuncPickupB	Function Pickup PhB	DIG	64	Protection pickup phase B
FuncPickupC	Function Pickup PhC	DIG	64	Protection pickup phase C
FuncPickup	Function Pickup	DIG	100	Protection pickup
FuncPickupSOTF	Func Pickup SOTF	DIG	20	Protection pickup for SOTF trip
SOTFActive	SOTF Active	DIG	4	Switch-Onto-Fault active

Table 5.72. Three-Phase / Single-Phase Trip Logic function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
CB1TripBlocked	CB 1 Trip Blocked	DIG	-	Circuit breaker 1 trip blocked
CB2TripBlocked	CB 2 Trip Blocked	DIG	-	Circuit breaker 2 trip blocked
CB1TripA	CB 1 Trip PhA	DIG	-	Circuit breaker 1 trip phase A
CB1TripB	CB 1 Trip PhB	DIG	-	Circuit breaker 1 trip phase B

Identifier	Title	Type	NV	Description
CB1TripC	CB 1 Trip PhC	DIG	-	Circuit breaker 1 trip phase C
CB1Trip	CB 1 Trip	DIG	-	Circuit breaker 1 trip
CB2TripA	CB 2 Trip PhA	DIG	-	Circuit breaker 2 trip phase A
CB2TripB	CB 2 Trip PhB	DIG	-	Circuit breaker 2 trip phase B
CB2TripC	CB 2 Trip PhC	DIG	-	Circuit breaker 2 trip phase C
CB2Trip	CB 2 Trip	DIG	-	Circuit breaker 2 trip
PickupA	Pickup PhA	DIG	-	Start indication for phase A
PickupB	Pickup PhB	DIG	-	Start indication for phase B
PickupC	Pickup PhC	DIG	-	Start indication for phase C
Pickup	Pickup	DIG	-	General start indication
TripA	Trip PhA	DIG	-	Trip indication for phase A
TripB	Trip PhB	DIG	-	Trip indication for phase B
TripC	Trip PhC	DIG	-	Trip indication for phase C
Trip	Trip	DIG	-	General trip indication
TripSOTF	Trip SOTF	DIG	-	Trip due to SOTF
TripCounter	Trip Counter	INT CTRL	Yes	Trip counter

5.22.4 Settings

This function has no associated settings.

5.23 AUTOMATIC RECLOSURE

5.23.1 INTRODUCTION

A high percentage of faults in overhead lines, like those caused by lightning, is temporary in nature and the fault arc is automatically extinguished after the circuit breaker trips. The Automatic Reclosure function is responsible for re-energizing and restoring the faulted section after a pre-defined time interval, thus increasing the availability of power equipment and improving overall power system stability. It cannot be used in other power equipment, like transformers or underground cables, because in these cases insulation failures are always permanent.

Automatic Reclosure can be set as high-speed (no intentional delay, only long enough so that the fault arc becomes extinct) or delayed. In some cases, multiple reclosing attempts can be programmed. It can also be optionally supervised by an external synchronism check function.

5.23.2 OPERATION METHOD

The Automatic Reclosure function operates by temporarily disconnecting a line following a fault detection and attempting to close it again after a configurable waiting period (dead time), hoping the fault has been extinguished.

The TPU L500 is capable of performing up to five reclosing attempts with independently configurable dead times. The **NumCycles** setting designates the number of reclose shots.

The TPU L500 is able to reclose after single-phase or three-phase tripping. Reclosure sequences are triggered by protection function (or protection function stage) trip signals, as long as they are connected to the **FuncTrip3P** input (three-pole reclosures only), and/or **FuncTripA**, **FuncTripB**, and **FuncTripC** inputs (single-pole and three-pole reclosures). The function also provides a dedicated interface for external single-phase trip signals (**ExtTripSP** input). As an option, the corresponding protection function pickup signals can be associated to the **FuncPickup** input for monitoring the time interval between pickup and trip signals.

The type of trip allowed for each reclosure cycle (three-pole only, single-pole only, or both) is configurable by adjusting the **CyclexTripMode** settings (where x identifies the reclosure cycle, x = 1, 2, 3, 4, or 5). The type of trip permitted for the next cycle is indicated by the **TripBehavior** output (Table 5.73). The function also provides an indication of whether or not single-pole tripping is allowed (**TripSPPermitted** output). This signal should be made available to the Trip Logic function (refer to section 5.22 - Three-Phase / Single-Phase Trip Logic) in order to prevent single-pole tripping in situations where the function is only capable of reclosing three-pole (Trip Logic **Recloser1Perm1Pole** and **Recloser2Perm1Pole** inputs are provided specifically for this reason). The single-pole tripping permission is updated according to the logic diagram in Figure 5.61.

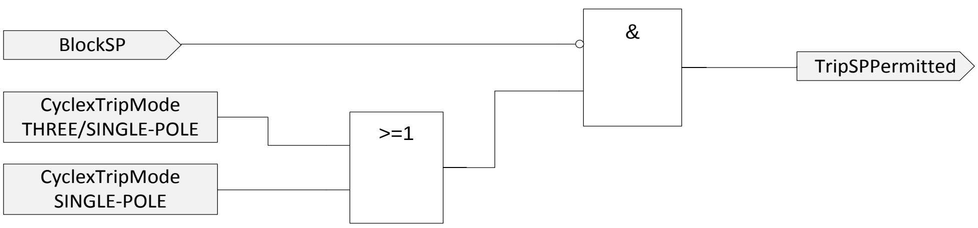

Figure 5.61. Single-pole tripping permitted indication.

Table 5.73. Trip behaviour values.

Title	Value	Description
Single-Pole	1	Single-pole and three-pole tripping allowed or single-pole tripping only
Three-Pole	3	Three-pole tripping only

Single-pole tripping will not be permitted and the function will not perform single-pole reclosing operations unless all single-phase trip inputs (**FuncTripA**, **FuncTripB**, and **FuncTripC**) and/or the external single-phase trip input (**ExtTripSP**) are available.

The Automatic Reclosure function is capable of reclosing during evolving faults (*i.e.*, faults that start-off as single-phase but propagate to at least one of the other phases). This feature can be enabled by setting the parameter **BlockEvolvingFault** to **OFF**. If a fault evolves during a single-pole reclosure with this feature disabled the function does not reclose and locks out. Figure 5.62 depicts the evolving fault reclose blocking logic.

Reclosing operations taking place during evolving faults are signalled by the **EvolvingFault** output.

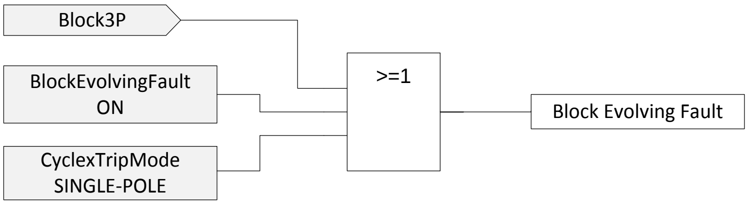

Figure 5.62. Evolving fault reclose blocking logic.

State Machine

The Automatic Reclosure function operates according to the state machine presented in Figure 5.63.

Reclosing sequences can only be initiated when the function is ready to reclose (this status is signalled by the **RecReady** output). This is only possible if the following conditions are met:

- reclosure is not blocked;
- there is no reclosing operation currently in progress;
- the circuit breaker is closed;
- the circuit breaker is ready for an OFO cycle (optional). This condition is only evaluated if the **CBReady** input is connected and the **CBReadyEval** setting is configured as **BEFORE START** or **BEFORE START AND BEFORE CLOSE**, otherwise the circuit breaker will be considered ready.

The action time corresponds to the time interval between the detection of protection function pickup and trip signals. The maximum amount of time the function can wait for a trip signal after a reclosure has been triggered is determined by the **MaxActionTime** setting; the absence of a trip signal during the action time will cause the reclosure to abort.

The use of function pickup signals is optional. If the Automatic Reclosure function does not have access to protection function pickup signals the action time will not be monitored – the action time state will be skipped and the function will advance directly to one of the opening time states upon receiving a trip signal.

The circuit breaker position must be continuously monitored throughout the reclosing sequences. When available, the circuit breaker pole discriminated position indications (**PositionA**, **PositionB**, and **PositionC** inputs) are monitored in addition to the circuit breaker general position (**Position** input). If the pole discriminated positions are not available, the single-pole function trip indications (**FuncTripA**, **FuncTripB**, and **FuncTripC** inputs) will be evaluated instead: a pole will be considered open the moment the corresponding trip indication resets.

The maximum allowed times for the circuit breaker opening and closing manoeuvres are configurable (**MaxCBOpeningTime** and **MaxCBClosingTime** settings). The maximum time configured for monitoring the circuit breaker opening applies both to three-pole and single-pole opening operations.

The dead time corresponds to the interval between the instant the circuit breaker opens and the instant the closing command is issued. This delay should be long enough for most transient faults to be extinguished and, at the same time, as reduced as possible in order to ensure synchronism and system stability.

Dead times can be configured independently for each cycle and it is possible to parameterize different time lengths for single-pole reclosures (**DeadTimeSPCyclex** settings), three-pole reclosures (**DeadTime3PCyclex** settings), and for reclosing operations triggered by evolving faults (**DeadTimeEvFltCyclex** settings).

The Automatic Reclosure function provides a dedicated synchronism verification interface, which can be enabled by connecting the Synchronism and Voltage Check automatic release signal (section 5.24 - Synchronism and Voltage Check) to the **SyncEnableClose** input (if this input is disconnected, this feature is disabled). During three-pole reclosing cycles, if synchronism verification is enabled, the function will wait for the release signal (**SyncEnableClose** input) for a maximum of **MaxSyncTime** after the dead time has elapsed. If the release is not granted during the configured time, the reclosure will lockout.

The maximum dead time, configurable by adjusting the **MaxDeadTimeSP** and **MaxDeadTime3P** settings, indicates the amount of time the function is allowed to remain in this state for single-pole and three-pole reclosures, respectively. The **MaxDeadTime3P** setting is also used for monitoring reclosing operations triggered by evolving faults. The monitored time corresponds to the duration of the dead time plus the wait for the synchronism verification release. If this timer is exceeded, the reclosure will lockout. For the function to operate correctly, the **MaxDeadTimeSP** setting should be higher than each **DeadTimeSPCyclex** value, and the **MaxDeadTime3P** setting should be higher than each **DeadTime3PCyclex**, and **DeadTimeEvFltCyclex** value.

After the dead time has elapsed, the function evaluates whether the system is prepared for an FO cycle – the function locks out if the circuit breaker is not ready for a close-open cycle at this time. This validation is optional, and can be enabled by connecting the appropriate signal to the **CBReady** input and configuring the **CBReadyEval** setting as **BEFORE CLOSE** or **BEFORE START AND BEFORE CLOSE**.

If all conditions are met, a circuit breaker close command will be issued through the **CmdClose** output. After the circuit breaker closed position is reached, the function waits in stand-by for a configurable time (**ReclaimTime**). If a fault is detected within this time interval the function will either lockout (the **Unsuccessful** output signals the transition to this state) or start a new reclose cycle, depending on whether or not this occurs during the last configured reclosing cycle. If no faults are detected during the reclaim time, the reclosure is successful (this will be signalled by the **Successful** output).

After a successful reclosing sequence the function will wait for a configurable time period (setting **ResetTime**) before being able to reclose again. The function will remain locked out until this timer has expired.

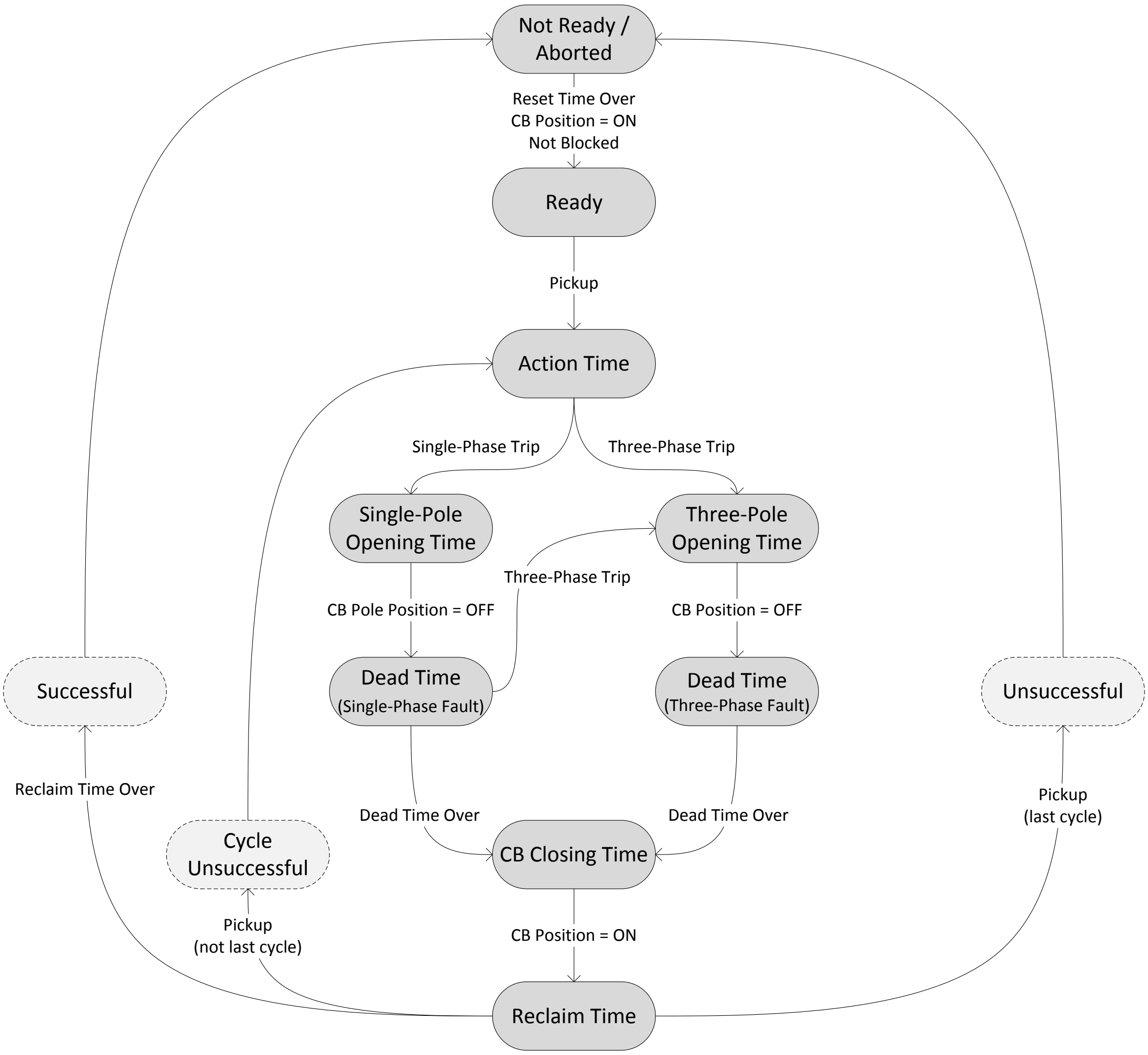

Figure 5.63. Automatic Reclosure state machine.

Current Automatic Reclosure status can be observed at any time by consulting the **RecStatus** output. All possible values are described in Table 5.74.

Table 5.74. Automatic Reclosure status.

Title	Value	Transient	Description
Not Ready	-1	No	Not ready to reclose / Lockout
Ready	1	No	Ready to reclose
Successful	3	Yes	Successful reclosure
Waiting For Trip	4	No	Action time
Trip From Protection	5	No	Circuit breaker opening time
Fault Disappeared	6	No	Dead time
Wait To Complete	7	No	Circuit breaker closing time
CB Closed	8	No	Reclaim time

Title	Value	Transient	Description
Cycle Unsuccessful	9	Yes	Unsuccessful reclosing cycle
Unsuccessful	10	Yes	Unsuccessful reclosure
Aborted	11	No	Aborted

As long as a reclosure sequence is in progress, the **RecInProgress** output remains active. There are similar outputs dedicated to each individual cycle (**CyclexInProgress** ouputs). During a reclosure operation, the output **RecCycle** is always updated accordingly, otherwise it presents the value 0.

If the circuit breaker does not remain closed or if there are active **FuncTrip** or **FuncPickup** inputs at the end of a reclosure sequence, the function will lockout. The function is also likely to lockout if a reclosure sequence is interrupted (*e.g.*, the function is blocked by external conditions or a timer expires). However, in some situations it is not possible to ascertain whether the function should lockout or be ready to attempt another reclosure after an interruption – in these cases the function will abort, and remain aborted, until a decision can be made. This can happen, for instance, if a pickup signal resets before the start of the first cycle (*i.e.*, during the first action time).

If a single-pole reclosing sequence is interrupted while the faulty phase is open, the function will issue a three-pole trip (output **CmdOpen**) before locking out. It is possible to inhibit this three-pole definitive trip by setting **InhibitTrip3P** to **ON**.

The function will remain in a not ready state if blocked (*i.e.*, **Block** input is activated) or while the conditions to start a new reclosure sequence have not been fulfilled. The **RecNotReady** output indicates whether the function is in this state. After a manual circuit breaker close command, if no other blocking conditions are present, the function will transit into the ready state after a configurable delay (**BlockedTime** setting).

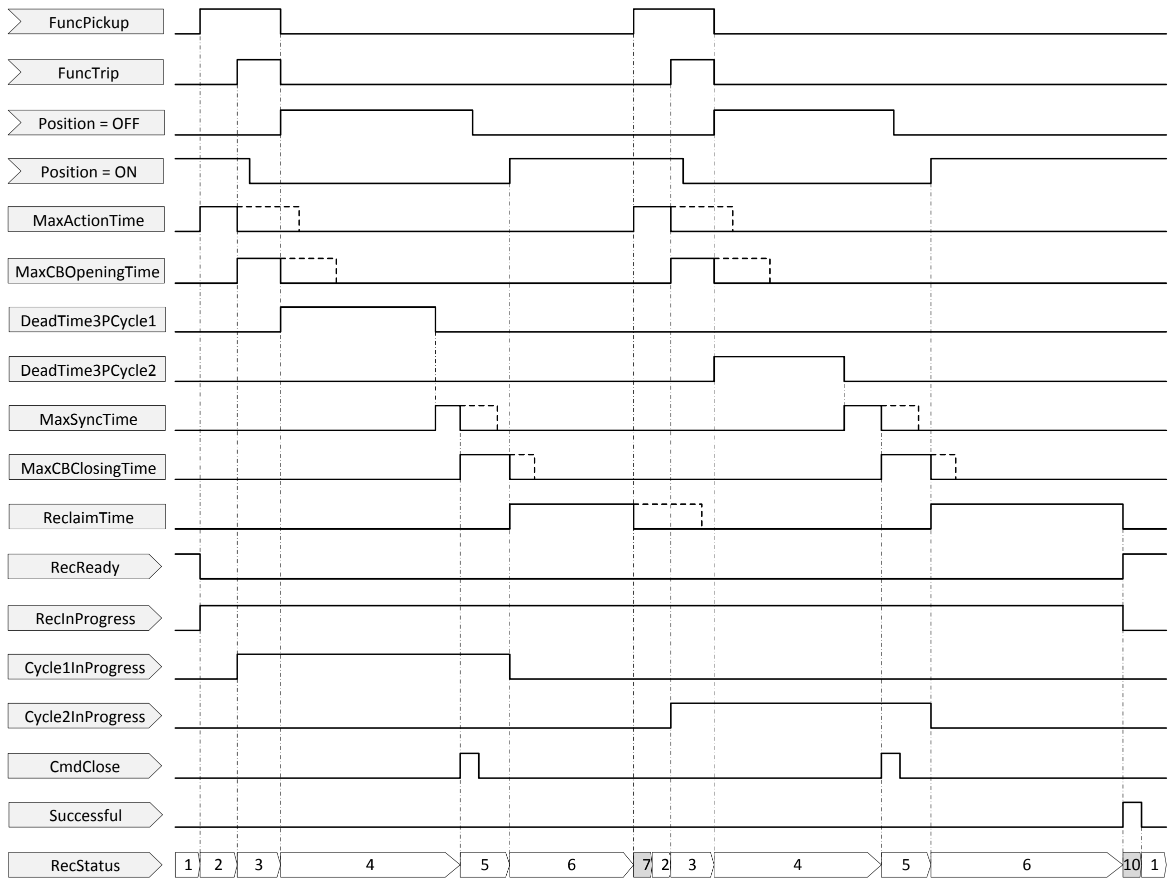

Figure 5.64. Example of a successful two-shot three-phase reclosure sequence.

Operation Modes

Depending on the network topology and on the circuit breaker location in the network, it may be essential that the function behaves differently. Some network schemes require more than one circuit breaker to open in order to eliminate a fault. In these cases the Automatic Reclosure functions associated to all breakers must be coordinated – typically one operates as master and the remaining as slaves (the functions operating as slaves have to wait for the master to eliminate the fault before attempting to reclose).

Four distinct operation modes are provided: defined times, dead line check, live line check, and wait for master. The first two are appropriate for stand-alone operation or to be used as masters in master-slave configurations; the last two have dynamic dead times and are supposed to be used as slaves. The intended operation mode can be selected by adjusting the **OperationMode** setting.

These operation modes mainly affect the dead time duration – the remaining stages behave as described in the previous section. If enabled, synchronism verification is performed as described above, regardless of the selected operation mode.

The dead line check and live line check modes can only operate if the function has access to the line voltage levels (it is necessary to connect a voltage channel to input **U**). The function supports all types of phase voltage channels (three-phase, single-phase, phase-to-phase, phase-to-earth), but single-pole tripping and therefore single-pole reclosing is only allowed if the function has access to a three-phase phase-to-earth voltage channel.

> The correct functioning of the dead line check and live line check operation modes requires that the function has access to the voltage from the VTs that are on the line side of the circuit breaker.

Defined Times

This operation mode can be enabled by setting **OperationMode** to **DEFINED TIMES**.

Dead times have fixed durations that correspond to the values of the settings **DeadTimeSPCyclex**, **DeadTime3PCyclex**, and **DeadTimeEvFltCyclex**.

Dead Line Check

This operation mode can be enabled by setting **OperationMode** to **DEAD LINE CHECK**.

Dead times have fixed durations that correspond to the values of the settings **DeadTimeSPCyclex**, **DeadTime3PCyclex**, and **DeadTimeEvFltCyclex**. When this mode is enabled, the function will only reclose if the line voltage disappears during the dead time. If, at the end of the dead time, the voltage has failed to remain below the configured threshold (setting **UmaxDead**) for at least the amount of time indicated by setting **UminCheckTime**, the function will lock out.

Live Line Check

This operation mode can be enabled by setting **OperationMode** to **LIVE LINE CHECK**.

This operation mode can be used for coordinating with a remote Automatic Reclosure function located on the far end of the line. When this mode is enabled the function will wait for the return of line voltage (i.e., for the remote function to reclose) before attempting to reclose.

With this operation mode enabled the extent of the dead time is dynamic – all **DeadTimeSPCyclex**, **DeadTime3PCyclex**, and **DeadTimeEvFltCyclex** settings are ignored, and the function will only perform one reclosing cycle. The dead time is sustained until the line voltage levels rise above a configured threshold (setting **UminLive**) and remain above that threshold for at least the amount of time indicated by setting **UminCheckTime**. If the maximum dead time (setting **MaxDeadTimeSP** for single-pole reclosures or setting **MaxDeadTime3P** for three-pole reclosures) expires before the voltage has returned, the function will lock out.

For the live line check mode to work properly the following conditions should be met:

- The maximum dead time for three-pole reclosures (setting **MaxDeadTime3P**) should be large enough to encompass a complete three-pole reclosure sequence performed by the remote function (*i.e.*, should be prepared for a successful reclosure that uses the maximum number of configured shots).

- The maximum dead time for single-pole reclosures (setting **MaxDeadTimeSP**) should be large enough to encompass a complete single-pole reclosure sequence performed by the remote function (*i.e.*, should be prepared for a successful reclosure that uses the maximum number of configured shots).
- The voltage monitoring time (setting **UminCheckTime**) should be greater than the remote function reclaim time, thus ensuring that the local function will not reclose before the remote function succeeds at eliminating the fault (*i.e.*, the complete remote sequence is over).

Wait For Master

This operation mode can be enabled by setting **OperationMode** to **WAIT FOR MASTER**.

This operation mode is suitable for multi-breaker schemes that require more than one circuit breaker to open in order to eliminate the fault (*e.g.*, breaker-and-a-half or double breaker - double bus).

With this operation mode enabled the extent of the dead time is dynamic – all **DeadTimeSPCyclex**, **DeadTime3PCyclex**, and **DeadTimeEvFltCyclex** settings are ignored, and the function will only perform one reclosing cycle. The dead time is sustained while the wait indication from the remote Automatic Reclosure function persists (*i.e.*, while the **WaitForMaster** input remains active). If the maximum dead time (setting **MaxDeadTimeSP** for single-pole reclosures or setting **MaxDeadTime3P** for three-pole reclosures) expires before the wait indication disappears, the function will lock out. The correct functioning of this feature relies on the master's waiting indication remaining active throughout its reclosing sequences.

For the wait for master mode to work properly the following conditions should be met:

- The maximum dead time for three-pole reclosures (setting **MaxDeadTime3P**) should be large enough to encompass a complete three-pole reclosure sequence performed by the remote function (*i.e.*, should be prepared for a successful reclosure that uses the maximum number of configured shots).
- The maximum dead time for single-pole reclosures (setting **MaxDeadTimeSP**) should be large enough to encompass a complete single-pole reclosure sequence performed by the remote function (*i.e.*, should be prepared for a successful reclosure that uses the maximum number of configured shots).
- The remote function's waiting indication must be connected to the **WaitForMaster** input.

There is no dedicated wait signal for functions operating as master – the waiting conditions must be designated by the user according to their specific needs. This can be achieved by resorting to user-programmable logic (refer to section 4.5 - User Programmable Automation), or by using one of the available status indications (e.g., the **RecInProgress** output or the negated **RecReady** output).

Counters

The Automatic Reclosure function provides two counters that exhibit the number of successful and unsuccessful reclosure sequences (**RecSuccessfulCounter** and **RecUnsuccessfulCounter**, respectively), and five additional counters indicating the number of reclosure sequences successful after each cycle (**CyclexSuccessfulCounter**).

All counters may be initialized by the user by executing a command with the desired value on the corresponding entity (**RecSuccessfulCounter**, **RecUnsuccessfulCounter** or **CyclexSuccessfulCounter**).

Blocking Conditions

The function provides a block input (**Block**) that can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

The function also provides dedicated inputs for blocking single-pole reclosing operations (**BlockSP** input) and three-pole reclosing operations (**Block3P** input).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **Position** input is disconnected.
- All function trip signals are disconnected (**FuncTrip3P**, **FuncTripA**, **FuncTripB**, **FuncTripC**, and **ExtTripSP** are disconnected).
- The function is operating in "wait for master" mode (**OperationMode** = **WAIT FOR MASTER**) and the **WaitForMaster** input is disconnected.

- The function is operating in "live line check" mode (**OperationMode** = **LIVE LINE CHECK**) and there is no analogue voltage channel connected to input **U**.
- The function is operating in "dead line check" mode (**OperationMode** = **DEAD LINE CHECK**) and there is no analogue voltage channel connected to input **U**.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- Dynamic dead times are configured (**OperationMode** is set to **WAIT FOR MASTER** or **LIVE LINE CHECK**) and **NumCycles** is higher than 1. In this case, the function does not perform more than one reclosing cycle.
- Only one or two single-phase function trip signals (inputs **FuncTripA**, **FuncTripB**, and **FuncTripC**) are connected.
- There is at least one cycle configured for single-phase reclosing and the external single-phase trip input and one or more of the remaining single-phase trip inputs are disconnected.
- The function is operating in "live line check" mode, there is at least one cycle configured for single-phase reclosing, and the function does not have access to a three-phase phase-to-earth voltage channel.
- The function is operating in "dead line check" mode, there is at least one cycle configured for single-phase reclosing, and the function does not have access to a three-phase phase-to-earth voltage channel.
- The **CBReady** input is disconnected and the **CBReadyEval** setting is not set to OFF; in this case the function will turn off CB ready evaluation.

The configuration is valid and the function operates accordingly otherwise.

5.23.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.75 and Table 5.76, respectively.

Table 5.75. Automatic Reclosure function inputs.

Identifier	Title	Type	Mlt	Description
U	U	ANL CH	-	Line voltages
Block	Block	DIG	16	Function general block
BlockSP	Single Ph Block	DIG	2	Single phase reclosure block
Block3P	Three Ph Block	DIG	2	Three phase reclosure block
Position	Position	DB DIG	1	Circuit breaker position
PositionA	PhA Position	DB DIG	1	Phase A circuit breaker position
PositionB	PhB Position	DB DIG	1	Phase B circuit breaker position
PositionC	PhC Position	DB DIG	1	Phase C circuit breaker position
FuncPickup	Function Pickup	DIG	16	Function pickup
FuncTripA	PhA Function Trip	DIG	16	Function trip, phase A
FuncTripB	PhB Function Trip	DIG	16	Function trip, phase B
FuncTripC	PhC Function Trip	DIG	16	Function trip, phase C
FuncTrip	Function Trip	DIG	16	Protection trip
CBReady	CB Ready	DIG	1	Circuit breaker ready for FO cycle
SyncEnableClose	Sync Enable Close	DIG	1	Synchrocheck automatic release
WaitForMaster	Wait For Master	DIG	1	Wait for master

Table 5.76. Automatic Reclosure function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
RecStatus	Rec Status	INT	-	Automatic reclosure status
RecCycle	Rec Cycle	INT	-	Actual reclose cycle
RecReady	Rec Ready	DIG	-	Ready to reclose
RecNotReady	Rec Not Ready	DIG	-	Not ready to reclose
RecInProgress	Rec In Progress	DIG	-	Automatic reclosure in progress
Cycle1InProgress	Cycle 1 In Progress	DIG	-	Automatic reclosure cycle 1 in progress
Cycle2InProgress	Cycle 2 In Progress	DIG	-	Automatic reclosure cycle 2 in progress
Cycle3InProgress	Cycle 3 In Progress	DIG	-	Automatic reclosure cycle 3 in progress
Cycle4InProgress	Cycle 4 In Progress	DIG	-	Automatic reclosure cycle 4 in progress
Cycle5InProgress	Cycle 5 In Progress	DIG	-	Automatic reclosure cycle 5 in progress
CycleSPInProgress	Cycle SP In Progress	DIG	-	Automatic reclosure single phase cycle in progress
Cycle3PInProgress	Cycle 3P In Progress	DIG	-	Automatic reclosure three phase cycle in progress
EvolvingFault	Evolving Fault	DIG	-	Evolving fault detection
Successful	Successful	DIG	-	Reclosure successful
Unsuccessful	Unsuccessful	DIG	-	Reclosure unsuccessful
TripBehavior	Trip Behavior	DIG	-	Trip type for next trip
TripSPPermitted	SP Trip Permitted	DIG	-	Single phase trips permission for next trip
CmdOpen	Cmd Open	DIG	-	Open command
CmdClose	Cmd Close	DIG	-	Close command
RecSuccessfulCounter	Rec Suc Counter	INT CTRL	Yes	Successful reclosure counter
RecUnsuccessfulCounter	Rec Unsuc Counter	INT CTRL	Yes	Unsuccessful reclosure counter
Cycle1SuccessfulCounter	Cyc 1 Rec Suc Count	INT CTRL	Yes	Successful one cycle reclosure counter
Cycle2SuccessfulCounter	Cyc 2 Rec Suc Count	INT CTRL	Yes	Successful two cycle reclosure counter
Cycle3SuccessfulCounter	Cyc 3 Rec Suc Count	INT CTRL	Yes	Successful three cycle reclosure counter
Cycle4SuccessfulCounter	Cyc 4 Rec Suc Count	INT CTRL	Yes	Successful four cycle reclosure counter
Cycle5SuccessfulCounter	Cyc 5 Rec Suc Count	INT CTRL	Yes	Successful five cycle reclosure counter

5.23.4 Settings

The function settings are listed in Table 5.77.

Table 5.77. Automatic Reclosure function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
OperationMode	Operation Mode	DEFINED TIMES / DEAD LINE CHECK / LIVE LINE CHECK / WAIT FOR MASTER	DEFINED TIMES	Reclosure mode of operation
NumCycles	Num Cycles	[1..5]	1	Maximum number of reclose cycles
Cycle1TripMode	Cycle 1 Trip Mode	THREE-POLE / THREE/SINGLE-POLE / SINGLE-POLE	THREE-POLE	Cycle 1, reclosure trip type
Cycle2TripMode	Cycle 2 Trip Mode	THREE-POLE / THREE/SINGLE-POLE / SINGLE-POLE	THREE-POLE	Cycle 2, reclosure trip type
Cycle3TripMode	Cycle 3 Trip Mode	THREE-POLE / THREE/SINGLE-POLE / SINGLE-POLE	THREE-POLE	Cycle 3, reclosure trip type
Cycle4TripMode	Cycle 4 Trip Mode	THREE-POLE / THREE/SINGLE-POLE / SINGLE-POLE	THREE-POLE	Cycle 4, reclosure trip type
Cycle5TripMode	Cycle 5 Trip Mode	THREE-POLE / THREE/SINGLE-POLE / SINGLE-POLE	THREE-POLE	Cycle 5, reclosure trip type
InhibitTrip3P	3P Trip Inhibit	OFF / ON	OFF	Three phase trip inhibition
MaxDeadTimeSP	Max Dead Time SP	[500..3000000] ms	5000	Maximum reclose time for a single phase reclosure
MaxDeadTime3P	Max Dead Time 3P	[500..3000000] ms	60000	Maximum reclose time for a three phase reclosure
DeadTimeSPCycle1	SPCycle1 Dead Time	[100.. 180000] ms	900	Cycle 1 reclose time for a single phase reclosure
DeadTimeSPCycle2	SPCycle2 Dead Time	[100.. 180000] ms	900	Cycle 2 reclose time for a single phase reclosure
DeadTimeSPCycle3	SPCycle3 Dead Time	[100.. 180000] ms	900	Cycle 3 reclose time for a single phase reclosure
DeadTimeSPCycle4	SPCycle4 Dead Time	[100.. 180000] ms	900	Cycle 4 reclose time for a single phase reclosure
DeadTimeSPCycle5	SPCycle5 Dead Time	[100.. 180000] ms	900	Cycle 5 reclose time for a single phase reclosure
DeadTime3PCycle1	3PCycle1 Dead Time	[100.. 180000] ms	300	Cycle 1 reclose time for a three phase reclosure
DeadTime3PCycle2	3PCycle2 Dead Time	[100.. 180000] ms	300	Cycle 2 reclose time for a three phase reclosure

Identifier	Title	Range	Factory value	Description
DeadTime3PCycle3	3PCycle3 Dead Time	[100.. 180000] ms	300	Cycle 3 reclose time for a three phase reclosure
DeadTime3PCycle4	3PCycle4 Dead Time	[100.. 180000] ms	300	Cycle 4 reclose time for a three phase reclosure
DeadTime3PCycle5	3PCycle5 Dead Time	[100.. 180000] ms	300	Cycle 5 reclose time for a three phase reclosure
DeadTimeEvFltCycle1	Cy1EvFlt Dead Time	[100.. 360000] ms	1200	Cycle 1 reclose time after an evolving fault detection
DeadTimeEvFltCycle2	Cy2EvFlt Dead Time	[100.. 360000] ms	1200	Cycle 2 reclose time after an evolving fault detection
DeadTimeEvFltCycle3	Cy3EvFlt Dead Time	[100.. 360000] ms	1200	Cycle 3 reclose time after an evolving fault detection
DeadTimeEvFltCycle4	Cy4EvFlt Dead Time	[100.. 360000] ms	1200	Cycle 4 reclose time after an evolving fault detection
DeadTimeEvFltCycle5	Cy5EvFlt Dead Time	[100.. 360000] ms	1200	Cycle 5 reclose time after an evolving fault detection
ReclaimTime	Reclaim Time	[100..300000] ms	500	Reclaim time
MaxCBOpeningTime	Max CB Opening Time	[10..1000] ms	300	Maximum allowed time for circuit breaker to open
MaxCBClosingTime	Max CB Closing Time	[10..1000] ms	300	Maximum allowed time for circuit breaker to close
MaxActionTime	Max Action Time	[10..300000] ms	200	Maximum time after fault detection during which auto-reclosing is permitted
MaxSyncTime	Max Sync Time	[0..60000] ms	500	Maximum allowed time for waiting for synchrocheck release
ResetTime	Reset Time	[0..300000] ms	500	Time between successful reclosure and ready to reclose
BlockedTime	Blocked Time	[0..300000] ms	1000	Minimum block time after a manual circuit breaker close command
UminCheckTime	U Min Chk Time	[100..60000] ms	500	Minimum time for voltage threshold evaluation
UmaxDead	Max Dead U	[0.05..0.80] × U_r	0.20	Maximum dead line voltage threshold
UminLive	Min Live U	[0.20..1.20] × U_r	0.80	Minimum live line voltage threshold
CBReadyEval	CB Ready Eval	OFF / BEFORE START / BEFORE CLOSE / BEFORE START AND BEFORE CLOSE	OFF	CB Ready indication evaluation
BlockEvolvingFault	Block Evol Fault	OFF / ON	ON	Evolving fault reclosure block

5.24 Synchronism and Voltage Check

5.24.1 Introduction

Before closing a circuit breaker, it must be first verified if the two network sections that are going to be reconnected are in synchronism conditions, meaning that the difference between the two voltage signals in terms of magnitude, phase angle and frequency is within pre-defined tolerances. The lack of synchronism between both sides of the circuit breaker, typically a busbar and a line (or transformer), or two different busbars, may seriously compromise power system stability when the circuit breaker is closed.

The Synchronism and Voltage Check function is responsible for ensuring that the two network sections are synchronous at the time the circuit breaker closes. If the systems are asynchronous, *i.e.* if the slip frequency between them is greater than the maximum frequency difference allowed but nevertheless it remains within a limited value, a close command can still be issued, provided that measures are taken to close the circuit breaker poles when the voltage across them is near zero. In some applications or operating conditions, the function can also be used to check if the line (or the busbar) is de-energized before reconnecting it.

Although it is more often applied to manual close commands, including remote controls, the Synchronism and Voltage Check function can also be used in interaction with the Automatic Reclosure function.

5.24.2 Operation Method

The Synchronism and Voltage Check function has two completely independent stages, with different sets of settings, one dedicated to manual close commands and one dedicated to automatic close commands (including those corresponding to automatic reclosing sequences). These stages can be independently activated by setting change (**ManOperation** and **AutoOperation**, respectively).

Distinct operation modes, described below, can be separately enabled by the user:

- Voltage Check mode;
- Synchronism Check mode;
- Asynchronous mode;
- Unconditional Release mode.

The Synchronism and Voltage Check function continuously performs a dead / live check to verify which operation mode should be applied. The particular conditions defined by the user for the current operation mode are then checked for both stages. If the adequate conditions are met, the **ManRelease** or **AutoRelease** indications are signalled, enabling manual or automatic circuit breaker close commands, respectively.

The **ManRelease** and **AutoRelease** signals should be used together with the built-in function that manages circuit breaker controls (please refer to section 5.32 - Circuit Breaker Control). The same applies to automatic reclosing commands (please refer to section 5.23 - Automatic Reclosure).

Since the release signals continuously indicate the existence or absence of synchronism conditions, they can also be used in interaction with an external reclosing device or they can assist manual synchronization.

Dead / Live Check

The Synchronism and Voltage Check function continuously monitors two voltage signals, corresponding to two distinct analogue channels, one connected to the function input **U1** and one connected to the function input **U2**. The analogue channels can either associate phase-to-earth or phase-to-phase voltages, single or three-phase. It is only required that there is at least one common phase between both analogue channels. The function automatically chooses the most adequate voltage signal for the subsequent calculations. All possible combinations are listed in Table 5.78.

Table 5.78. Voltage signals for Synchronism and Voltage Check function.

Voltage signals available in U1 (or U2)	Voltage signals available in U2 (or U1)	Voltage signal used for calculation	Description
U_A, U_B, U_C	U_A, U_B, U_C	U_A	If all three phase-to-earth voltages are available
U_{AB}, U_{BC}, U_{CA}	U_{AB}, U_{BC}, U_{CA}	U_{AB}	If all three phase-to-phase voltages are available
U_X	U_A, U_B, U_C (or U_X only)	U_X	If only one phase-to-earth voltage is available in one of circuit breaker sides
U_{XY}	U_A, U_B, U_C (or U_X, U_Y only)	U_{XY}	If only one phase-to-phase voltage is available in one of circuit breaker sides
U_{XY}	U_{AB}, U_{BC}, U_{CA} (or U_{XY} only)	U_{XY}	

Both voltages are continuously checked against two pre-defined thresholds, to determine is the respective circuit breaker side is energized (live) or not (dead).

The voltage **U1** (or **U2**) is signalled as live, in function output **U1Live** (or **U2Live**), when:

- the measured voltage magnitude is higher than the threshold defined in the corresponding setting **U1minLive** (or **U2minLive**);
- the measured voltage magnitude is lower than the maximum voltage threshold defined in setting **Umax**;
- the frequency of the voltage signal is in a range of $\pm$ 3 Hz around the rated frequency value.

The voltage **U1** (or **U2**) is signalled as dead, in function output **U1Dead** (or **U2Dead**), when:

- the measured voltage magnitude is lower than the threshold defined in the corresponding setting **U1maxDead** (or **U2maxDead**);
- there is no identified failure in the associated voltage transformer measuring circuit, *i.e.* the corresponding input **VT1Fail** (or **VT2Fail**) is not active.

In order to distinguish between a de-energized section of the power system and a voltage transformer failure, the VT failure signal should be associated to the corresponding function input (**VT1Fail** or **VT2Fail**). This information may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision) or the trip indication of the MCB that protects the voltage transformer can be directly used.

The dead and live thresholds are set in values per unit, relative to the rated VT primary voltage: in the case of phase-to-earth voltage inputs, equation (5.57) applies; in the case of phase-to-phase voltage inputs, equation (5.58) should be used instead.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \quad (5.57)$$

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r \quad (5.58)$$

A built-in hysteresis below **U1minLive** (or **U2minLive**) and above **U1maxDead** (or **U2maxDead**) guarantees the adequate stability of the function outputs.

Voltage Check Modes

If at least one of the circuit breaker sides is de-energized, the function operates in Voltage Check mode. The circuit breaker close commands can be released in three different conditions. Each of them can be independently activated by the user.

- **Dead U1 / Dead U2**: the release of manual (or automatic) close commands is signalled when both sides are de-energized (**U1Dead** and **U2Dead** are active), if setting **ManDeadDeadMode** (or **AutoDeadDeadMode**) is enabled.
- **Dead U1 / Live U2**: the release of manual (or automatic) close commands is signalled when side 1 is de-energized and side 2 is energized (**U1Dead** and **U2Live** are active), if setting **ManDeadLiveMode** (or **AutoDeadLiveMode**) is enabled.

- **Live U1 / Dead U2**: the release of manual (or automatic) close commands is signalled when side 2 is de-energized and side 1 is energized (**U1Live** and **U2Dead** are active), if setting **ManLiveDeadMode** (or **AutoLiveDeadMode**) is enabled.

The function signals the release indication for any of the three operation modes described if the corresponding conditions are stable for more than a pre-defined time. This confirmation time can also be independently set for manual (setting **ManConfirmTime**) and automatic (setting **AutoConfirmTime**) close commands.

Synchronism Check Mode

If both sides of the circuit breaker are energized and synchronous (*i.e.* the frequency difference between voltages **U1** and **U2** is very small) the function operates in Synchronism Check mode. Besides the live voltage check, the function supervises the difference in magnitude, phase angle and frequency between the two voltage signals. This mode can be independently enabled for manual (setting **ManLiveLiveMode**) or automatic (setting **AutoLiveLiveMode**) close commands. In this mode, the release is signalled when:

- both sides are energized (**U1Live** and **U2Live** are active);
- the magnitude difference between voltages **U1** and **U2** is less than setting **ManMaxMagDiff** (manual commands) or **AutoMaxMagDiff** (automatic commands);
- the phase angle difference between voltages **U1** and **U2** is less than setting **ManMaxAngleDiff** (manual commands) or **AutoMaxAngleDiff** (automatic commands);
- the frequency difference between voltages **U1** and **U2** is less than setting **ManMaxSyncFreqDiff** (manual commands) or **AutoMaxSyncFreqDiff** (automatic commands).

The function signals the release indication if the above conditions are stable for more than a pre-defined time. This confirmation time is the same as for Voltage Check mode and can be independently set for manual (setting **ManConfirmTime**) and automatic (setting **AutoConfirmTime**) close commands.

The function additionally signals which thresholds were exceeded, allowing a continuous supervision of voltage conditions across the circuit breaker and providing a detailed reason for blocking circuit breaker closing.

- **ManMagDiffInd** (or **AutoMagDiffInd**) is signalled if the magnitude difference between **U1** and **U2** is exceeded for manual (or automatic) commands;
- **ManMagAngleDiffInd** (or **AutoAngleDiffInd**) is signalled if the phase angle difference between **U1** and **U2** is exceeded for manual (or automatic) commands;
- **ManFreqDiffInd** (or **AutoFreqDiffInd**) is signalled if the frequency difference between **U1** and **U2** is exceeded for manual (or automatic) commands.

Asynchronous Mode

If the two disconnected networks cannot be considered as synchronous, *i.e.* if the frequency difference is greater than **ManMaxSyncFreqDiff** (manual commands) or **AutoMaxSyncFreqDiff** (automatic commands), the previous operation mode cannot be applied, because there will be a fast phase angle variation between the two voltages signals.

A special operation mode can be enabled to deal with these particular conditions. In the Asynchronous mode, the close command is issued in anticipation of the time instant the synchronism conditions are reached, taking into consideration the circuit breaker close time.

This mode can be enabled for manual (setting **ManAsyncOperation**) or automatic (setting **AutoAsyncOperation**) close commands. The Synchronism Check mode should also be enabled. In this mode, the release is signalled when:

- both sides are energized (**U1Live** and **U2Live** are active);
- the magnitude difference between voltages **U1** and **U2** is less than setting **ManMaxMagDiff** (manual commands) or **AutoMaxMagDiff** (automatic commands);
- the frequency difference between voltages **U1** and **U2** is greater than setting **ManMaxSyncFreqDiff** (manual commands) or **AutoMaxSyncFreqDiff** (automatic commands).
- the frequency difference between voltages **U1** and **U2** is less than setting **ManMaxAsyncFreqDiff** (manual commands) or **AutoMaxAsyncFreqDiff** (automatic commands);
- the phase angle difference between voltages **U1** and **U2** at the time the circuit breaker poles close is less than setting **ManMaxAngleDiff** (manual commands) or **AutoMaxAngleDiff** (automatic commands). The function determines the adequate time interval to release the close command based on the circuit breaker close time and on the phase angle rate-of-change calculated from the slip frequency and its corresponding rate-of-change (as shown in Figure 5.65).

The function is able to operate correctly at frequency differences up to 2 Hz.

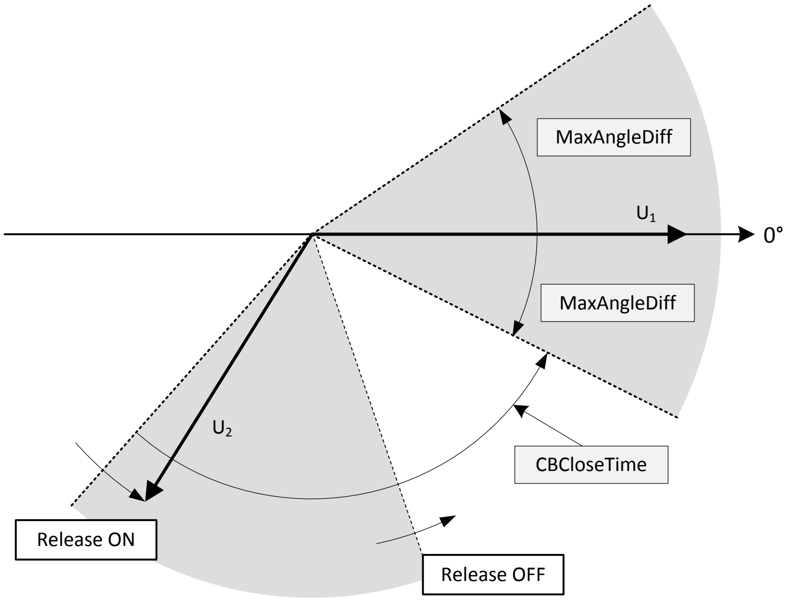

Figure 5.65. Asynchronous mode.

The circuit breaker closing time is defined in setting **ManCBCloseTime** (manual commands) and **ManCBCloseTime** (automatic commands).

Unconditional Release Mode

Complementing the previous modes, there is an additional option for unconditionally releasing all manual or automatic close commands. The function provides two separate inputs for this purpose, one for manual (**ManUncRelease**) and one for automatic close commands (**AutoUncRelease**). These inputs can be associated to any user-defined condition.

While the **ManUncRelease** input is active, the synchronism and voltage check conditions for manual close commands are not evaluated and the corresponding release indication is permanently signalled. The same happens for automatic close commands if the **AutoUncRelease** input is active. The operation of the respective function stage must be enabled.

The unconditional release mode of the Synchronism and Voltage Check function can be used, for instance, to automatically release all close commands when the circuit breaker is in test and isolated from the rest of the power system. In this case, **ManUncRelease** and **AutoUncRelease** should be obtained from a logic condition combining the state of the associated circuit switches.

Measurements

The Synchronism and Voltage Check function additionally calculates the measurements of magnitude, phase angle and frequency difference between voltages **U1** and **U2**. These measurements correspond to the function outputs **MagDiff**, **AngleDiff** and **FreqDiff**, respectively.

They are available in the Local HMI, in the embedded Webserver, or via communication protocol, and so they can be used for manual check of synchronism conditions, instead of the release signals automatically generated by the function.

Blocking Conditions

The function provides an individual block input for each one of the synchronism and voltage check stages (**BlockMan** and **BlockAuto**, for manual and automatic close commands, respectively). Any of them can be freely associated to any user-defined condition.

The blocking condition is signalled in the corresponding stage output (**ManBlocked** and **AutoBlocked**). While blocked, the respective release indication is not signalled, irrespective of the voltage conditions being met. The blocking mode also overrides the unconditional release mode.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There are no analogue channels associated to inputs **U1** or **U2**;
- There are no common phases between the analogue channels associated to inputs **U1** and **U2** (*e.g.*, **U1** is a phase A to earth voltage signal and **U2** is a phase B to phase C voltage signal);
- The primary rated values of input voltages **U1** and **U2** are different.

The configuration is valid and the function operates accordingly otherwise.

5.24.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.79 and Table 5.80, respectively.

Table 5.79. Synchronism and Voltage Check function inputs.

Identifier	Title	Type	Mlt	Description
U1	U1	ANL CH	-	Side 1 voltage
U2	U2	ANL CH	-	Side 2 voltage
BlockMan	Block Man	DIG	2	Function block for manual commands
BlockAuto	Block Aut	DIG	2	Function block for automatic commands
VT1Fail	VT1 Failure	DIG	2	Side 1 voltage transformer failure
VT2Fail	VT2 Failure	DIG	2	Side 2 voltage transformer failure
ManUncRelease	Man Unc Release	DIG	2	Unconditional release for manual commands
AutUncRelease	Aut Unc Release	DIG	2	Unconditional release for automatic commands

Table 5.80. Synchronism and Voltage Check function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
ManBehavior	Man Behavior	INT	-	Operation mode for manual commands
AutoBehavior	Aut Behavior	INT	-	Operation mode for automatic commands
Health	Health	INT	-	Function health
ManBlocked	Man Blocked	DIG	-	Function blocked for manual commands
AutoBlocked	Aut Blocked	DIG	-	Function blocked for automatic commands
ManRelease	Man Release	DIG	-	Manual close commands released
AutoRelease	Aut Release	DIG	-	Automatic close commands released

Identifier	Title	Type	NV	Description
ManMagDiffInd	Man Mag Diff Ind	DIG	-	Maximum magnitude difference exceeded for manual commands
ManAngleDiffInd	Man Angle Diff Ind	DIG	-	Phase angle difference exceeded for manual commands
ManFreqDiffInd	Man Freq Diff Ind	DIG	-	Frequency difference exceeded for manual commands
AutoMagDiffInd	Aut Mag Diff Ind	DIG	-	Magnitude difference exceeded for automatic commands
AutoAngleDiffInd	Aut Angle Diff Ind	DIG	-	Phase angle difference exceeded for automatic commands
AutoFreqDiffInd	Aut Freq Diff Ind	DIG	-	Frequency difference exceeded for automatic commands
U1Live	U1 Live	DIG	-	Side 1 live
U1Dead	U1 Dead	DIG	-	Side 1 dead
U2Live	U2 Live	DIG	-	Side 2 live
U2Dead	U2 Dead	DIG	-	Side 2 dead
MagDiff	Mag Diff	ANL	-	Magnitude difference
FreqDiff	Freq Diff	ANL	-	Frequency difference
AngleDiff	Angle Diff	ANL	-	Phase angle difference

5.24.4 Settings

The function settings are listed in Table 5.81.

Table 5.81. Synchronism and Voltage Check function settings.

Identifier	Title	Range	Factory value	Description
U1maxDead	U1max Dead	[0,05..0,8] × U_r	0,2	Maximum side 1 dead voltage threshold
U1minLive	U1min Live	[0,2..1,2] × U_r	0,8	Minimum side 1 live voltage threshold
U2maxDead	U2max Dead	[0,05..0,8] × U_r	0,2	Maximum side 2 dead voltage threshold
U2minLive	U2min Live	[0,2..1,2] × U_r	0,8	Minimum side 2 live voltage threshold
Umax	Umax	[0,5..1,5] × U_r	1,1	Maximum voltage threshold
ManOperation	Man Operation	OFF / ON	OFF	Operation for manual commands
ManAsyncOperation	Man Async Operation	OFF / ON	OFF	Operation for manual commands in asynchronous networks
ManMaxMagDiff	Man Max Mag Diff	[0,01..0,5] × U_r	0,05	Maximum magnitude difference for manual commands

Identifier	Title	Range	Factory value	Description
ManMaxSyncFreqDiff	Man Sync Freq Diff	[0,01..1,0] Hz	0,02	Maximum frequency difference for manual commands in synchronous networks
ManMaxAsyncFreqDiff	Man Async Freq Diff	[0,02..2,0] Hz	0,2	Maximum frequency difference for manual commands in asynchronous networks
ManMaxAngleDiff	Man Max Angle Diff	[2,0..80,0] °	20,0	Maximum phase angle difference for manual commands
ManDeadDeadMode	Man Dead Dead Mode	OFF / ON	OFF	Side 1 dead, side 2 dead operation for manual commands
ManDeadLiveMode	Man Dead Live Mode	OFF / ON	OFF	Side 1 dead, side 2 live operation for manual commands
ManLiveDeadMode	Man Live Dead Mode	OFF / ON	OFF	Side 1 live, side 2 dead operation for manual commands
ManLiveLiveMode	Man Live Live Mode	OFF / ON	OFF	Side 1 live, side 2 live operation for manual commands
ManConfirmTime	Man Confirm Time	[0..60000] ms	100	Confirmation time for manual commands
ManCBCloseTime	Man CB Close Time	[10..500] ms	100	Circuit breaker close time for manual commands
AutoOperation	Aut Operation	OFF / ON	OFF	Operation for automatic commands
AutoAsyncOperation	Aut Async Operation	OFF / ON	OFF	Operation for automatic commands in asynchronous networks
AutoMaxMagDiff	Aut Max Mag Diff	[0,01..0,5] × U_r	0,05	Maximum magnitude difference for automatic commands
AutoMaxSyncFreqDiff	Aut Sync Freq Diff	[0,01..1,0] Hz	0,02	Maximum frequency difference for automatic commands in synchronous networks
AutoMaxAsyncFreqDiff	Aut Async Freq Diff	[0,02..2,0] Hz	0,2	Maximum frequency difference for automatic commands in asynchronous networks
AutoMaxAngleDiff	Aut Max Angle Diff	[2,0..80,0] °	20,0	Maximum phase angle difference for automatic commands
AutoDeadDeadMode	Aut Dead Dead Mode	OFF / ON	OFF	Side 1 dead, side 2 dead operation for automatic commands
AutoDeadLiveMode	Aut Dead Live Mode	OFF / ON	OFF	Side 1 dead, side 2 live operation for automatic commands
AutoLiveDeadMode	Aut Live Dead Mode	OFF / ON	OFF	Side 1 live, side 2 dead operation for automatic commands
AutoLiveLiveMode	Aut Live Live Mode	OFF / ON	OFF	Side 1 live, side 2 live operation for automatic commands
AutoConfirmTime	Aut Confirm Time	[0..60000] ms	100	Confirmation time for automatic commands

Identifier	Title	Range	Factory value	Description
AutoCBCloseTime	Aut CB Close Time	[10..500] ms	100	Circuit breaker close time for automatic commands

5.25 Circuit Breaker Failure

5.25.1 Introduction

The dependability of power system protection depends on the correct operation of circuit breakers which, like other power system components, are subject to failures during their service life. Special measures must be taken in case a circuit breaker fails to execute a protection trip command, in order to clear the fault. Backup protection already ensures this task but it usually provides a slow response because it must be time-coordinated with other protection relays.

A faster backup protection can be achieved by the Circuit Breaker Failure function, which operates locally in the substation, issuing a trip order to all other circuit breakers connected to the same bus.

As an additional feature, for instance when the circuit breaker is provided with a separate backup coil, the Circuit Breaker Failure function may be configured to re-trip the same circuit breaker, before issuing an external order and disconnecting the entire bus. If successful, that action prevents the disconnection of several other lines or transformers, considerably reducing the consequences of the failure on power system stability.

5.25.2 Operation Method

There are two independent definite time stages associated to Circuit Breaker Failure function: the first one tries to re-trip the same circuit breaker; the second issues an external trip to all circuit breakers in the same bus. The external trip is always three-pole. The first stage is activated depending on setting **St1TripEnable**; when active, it can be configured for three-pole tripping only (**St1TripEnable** = **THREE-POLE**) or for single-pole and three-pole tripping (**St1TripEnable** = **SINGLE-POLE**). The second stage is always activated if the function is activated (setting **Operation**).

The Circuit Breaker Function independently checks that the circuit breaker has tripped based on the monitoring of the currents in the circuit breaker, on the monitoring of its position, or on a combination of both criteria. The function does not depend on the reset of any protection function.

Single-Stage Operation

If setting **St1TripEnable** is set to **OFF**, stage 1 is disabled and only the second stage of the Circuit Breaker Failure function is enabled. This operation mode should be used when there is no local backup trip coil available or when only an external trip is intended in case the circuit breaker fails.

The Circuit Breaker Failure stage picks up immediately after a protection trip is issued. The **CBxTrip**, **CBxTripA**, **CBxTripB**, and **CBxTripC** outputs from the Trip Logic (where x represents one particular circuit breaker), combining all independent protection function trip signals should be associated to inputs **FuncTrip3P, FuncTripA**, **FuncTripB**, and **FuncTripC**, respectively. As an alternative, the trip signals from selected protection functions or stages can be used. The pickup of the Circuit Breaker Failure function is indicated in the respective output **Pickup**.

When the function picks up, a timer starts running. If the circuit breaker opens while the timer is running the stage instantaneously resets, as expected. On the other hand, if the function does not detect circuit breaker opening, the external trip (function output **St2Trip**) is initiated when the stage 2 operation time elapses. It is possible to configure different delays for single-phase and three-phase circuit breaker operation (settings **St2SPTripDelay** and **St2TPTripDelay**). Figure 5.66 and Figure 5.67 depict the single-stage operation.

Figure 5.66. Single-stage circuit breaker operation originated by three-phase tripping.

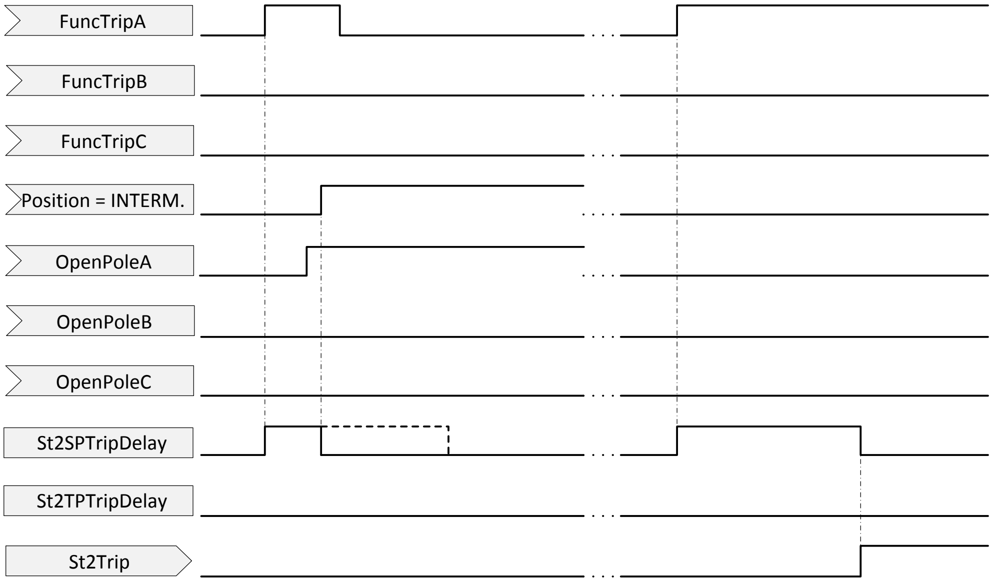

Figure 5.67. Single-stage circuit breaker operation originated by single-phase tripping.

Two-Stage Operation

If setting **St1TripEnable** is set to **THREE-POLE** or **SINGLE-POLE**, both function stages are enabled. In these cases, both re-trip and external trip operations are allowed. Both Circuit Breaker Failure stages pick up after a protection trip is issued, in the same manner as for single-stage operation. Configuring **St1TripEnable** as **SINGLE-POLE** allows single-pole re-tripping. If **St1TripEnable** is set to **THREE-POLE** all re-trip operations will be three-pole, regardless of the original trip signal.

Two independent timers, one for the re-trip stage and the other for the external trip stage, start counting after pickup. It is possible to configure different delays for single-phase and three-phase circuit breaker operation for both stages (settings **St1SPTripDelay** and **St1TPTripDelay** for stage 1 and settings **St2SPTripDelay** and **St2TPTripDelay** for stage 2). In order to ensure the correct function behaviour setting **St1SPTripDelay** should be less than **St2SPTripDelay** and setting **St1TPTripDelay** should be less than **St2TPTripDelay**.

If the circuit breaker opens while the stage 1 timer is running (**St1SPTripDelay** or **St1TPTripDelay)**, as expected, both stages instantaneously reset. On the other hand, if the function does not detect circuit breaker (or circuit breaker pole) opening, the re-trip is issued when the stage 1 operation time elapses (output **St1Trip**, **St1TripA**, **St1TripB**, or **St1TripC**). If the re-trip is successful and the circuit breaker (or circuit breaker pole) opens, the stage 2 timer is immediately cancelled. However, if this is not the case, and the stage 2 operation time also elapses before the circuit breaker has opened, the external trip order is initiated (function output **St2Trip**). Figure 5.68 and Figure 5.69 depict the two-stage operation.

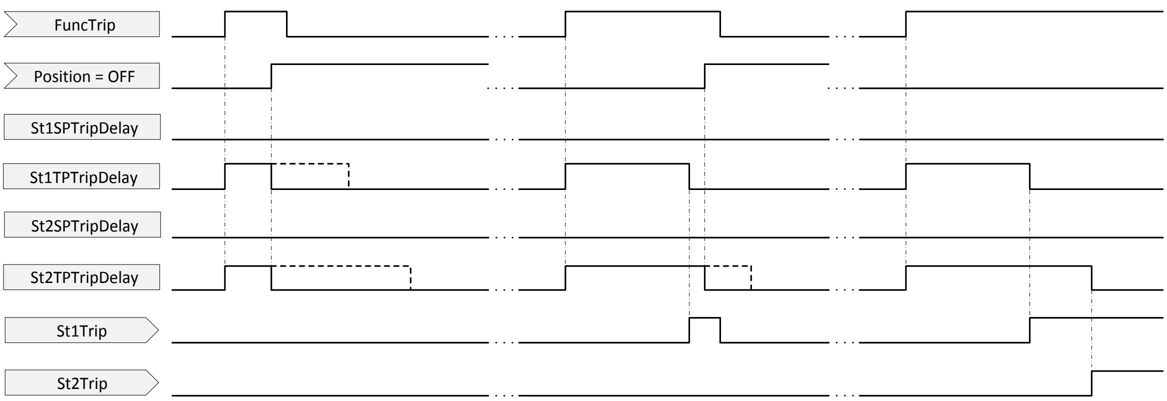

Figure 5.68. Two-stage circuit breaker operation originated by three-phase tripping.

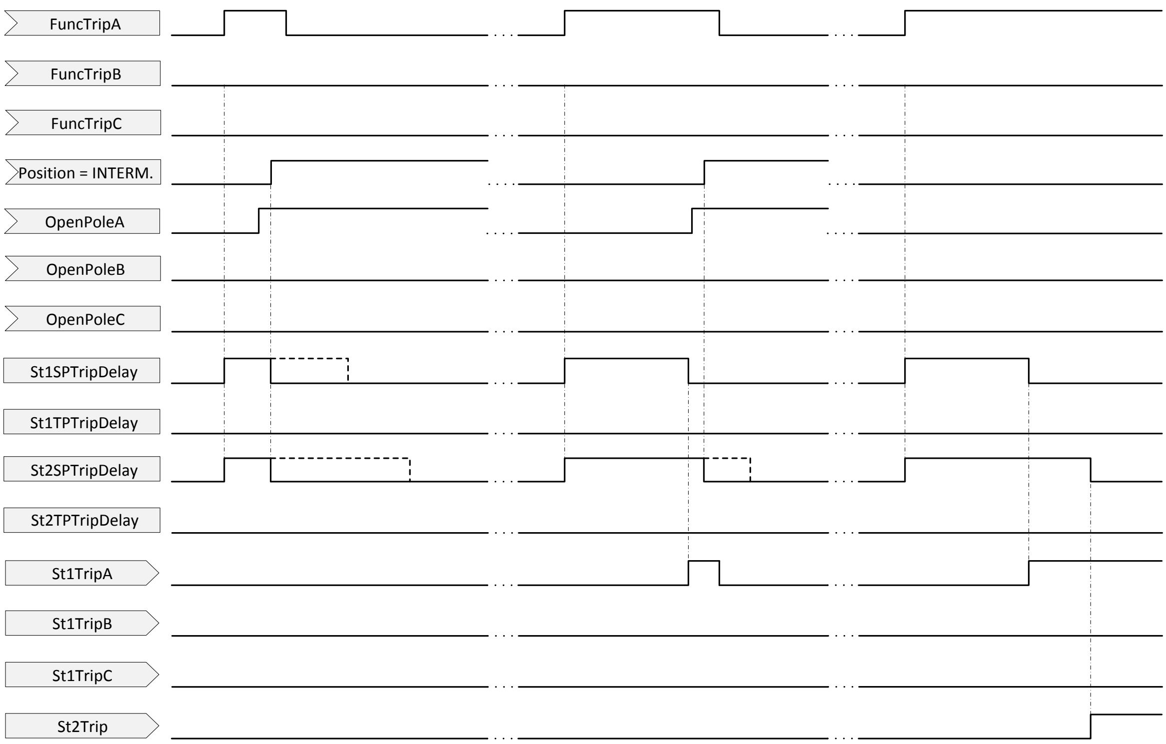

Figure 5.69. Two-stage circuit breaker operation originated by single-phase tripping.

Current Flow Monitoring

The Circuit Breaker Failure function should preferentially use the method based on current flow monitoring to detect when the circuit breaker has opened. This ensures most of the times a faster reset time of the function; it also guarantees a more secure fail trip decision.

This criterion is automatically enabled if three phase current signals, associated in one analogue channel, are connected to the function input **I**. The protection function is executed in full-scheme mode, which means that there are separate protection elements for continuously monitoring each input current.

The Circuit Breaker Failure function only picks up in consequence of a protection trip if the magnitude of at least one phase current is higher than the threshold defined in setting **IopStart**. The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op,start}\left[A\right]=I_{op,start}\left[p.u.\right]\cdot I_r \tag{5.59}$$

The operation threshold has an extended setting range that allows choosing the most adequate sensitivity level for fault detection. This adds a plausibility check to the protection function trip, ensuring a secure decision of the Circuit Breaker Failure function.

For additional security in the Circuit Breaker Failure trip decision, the pickup of additional protection stages and functions can be monitored in input **FuncPickup**. In this case, the Circuit Breaker Failure stages will only start if the protection pickup input is active at the time the protection trips. This feature can be used, for instance, in cooperation with Negative Sequence or Residual protective elements, for extra verification of the presence of a fault.

With current flow monitoring option, the circuit breaker pole opening is detected when the magnitude of the corresponding phase currentis less than a pre-defined reset threshold (setting **Iop**). The implemented algorithm ensures a very fast detection of current interruption, so that a very short reset time is achieved.

CB Position Monitoring

As an alternative to the previous method, the function can monitor the circuit breaker position to detect circuit breaker opening. This method must be used if the protection function trip that is being supervised does not depend on the current flow, like for example in case of a Bucholz relay.

This criterion is automatically enabled if the circuit breaker status is associated to the function input **Position**. In this case, the auxiliary contacts indicating the circuit breaker status are supervised by the function. The Circuit Breaker Failure function only picks up if the circuit breaker is closed prior to the protection trip. The circuit breaker opening is detected and the function immediately resets when **Position** reaches the final position, indicating that the circuit breaker is open.

When this method is used for monitoring single-pole operations, it is advisable to connect the Open Pole Detection function open pole indications to the **OpenPoleA**, **OpenPoleB**, and **OpenPoleC** inputs. Otherwise, the decision of whether or not a single-pole operation has been successful will be solely based on the circuit breaker reaching the intermediate position.

For additional security in the Circuit Breaker Failure trip decision, the pickup of protection stages and functions can also be monitored by connecting the intended signals to the **FuncPickup** input. If this is the case, the Circuit Breaker Failure stages will only start if the protection pickup input is active at the time the protection trips.

Both methods (current flow and position monitoring) can be configured simultaneously, if inputs **I** and **Position** are both connected. Precedence is given to the current flow monitoring method, if the respective pickup conditions are verified. Only if the current magnitude does not exceed the start threshold in any of the phases, the function uses the CB position monitoring method as an alternative to the previous criterion.

Defective CB

The circuit breaker will certainly fail to trip if there is a discontinuity in the trip circuit. If this fault condition has already been detected prior to the protection function pickup, the circuit breaker failure trip can be immediately issued after the protection trip.

The circuit breaker trip is instantaneous if a trip circuit failure is indicated by the **CBFaulty** input. This information may be the result of a dedicated supervision function (please refer to section 5.26 - Trip Circuit Supervision). If there is no data entity associated with **CBFaulty**, this feature will not be activated.

If the circuit breaker failure trip is generated due to the **CBFaulty** input, an additional indication is signalled (function output **TripCBFaulty**), for event log purposes.

Blocking Conditions

The function provides a block input (**Block**) for blocking both stages. It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **FuncTrip3P** input and one or more **FuncTripx** inputs are disconnected.
- The **Position** input is disconnected and there is no three-phase analogue channel associated to input **I**.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- Retrip is enabled (**St1TripEnable** is set to **THREE-POLE** or **SINGLE-POLE**) and at least one of the following conditions is verified (re-trip will not be permitted in any of these cases):
  - **St1SPTripDelay** is greater or equal than **St2SPTripDelay** and there is at least one **FuncTripx** input connected;
  - **St1TPTripDelay** is greater or equal than **St2TPTripDelay**.
- Single-pole re-trip is enabled (**St1TripEnable** is set to **SINGLE-POLE**) and at least one of the **FuncTripx** inputs is disconnected.
- The configuration is valid and the function operates accordingly otherwise.

5.25.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.82 and Table 5.83, respectively.

Table 5.82. Circuit Breaker Failure function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating currents
Block	Block	DIG	4	Function block
Position	Position	DB DIG	1	Circuit breaker position
OpenPoleA	PhA Open Pole	DIG	2	Phase A open pole
OpenPoleB	PhB Open Pole	DIG	2	Phase B open pole
OpenPoleC	PhC Open Pole	DIG	2	Phase C open pole
FuncPickup	Function Pickup	DIG	100	Protection pickup
FuncTripA	PhA Function Trip	DIG	32	Phase A protection trip
FuncTripB	PhB Function Trip	DIG	32	Phase B protection trip
FuncTripC	PhC Function Trip	DIG	32	Phase C protection trip
FuncTrip3P	Function Trip 3P	DIG	100	Protection trip, three-pole
CBFaulty	CB Faulty	DIG	4	Faulty circuit breaker circuit indication

Table 5.83. Circuit Breaker Failure function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
Pickup	Pickup	DIG	-	General pickup
St1TripA	Phase A Retrip	DIG	-	Phase A retrip
St1TripB	Phase B Retrip	DIG	-	Phase B retrip
St1TripC	Phase C Retrip	DIG	-	Phase C retrip
St1Trip	Retrip	DIG	-	Retrip
St2Trip	External Trip	DIG	-	External trip
TripCBFaulty	Trip CB Faulty	DIG	-	Trip due to faulty circuit breaker circuit

5.25.4 Settings

The function settings are listed in Table 5.84.

Table 5.84. Circuit Breaker Failure function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation

Identifier	Title	Range	Factory value	Description
St1TripEnable	Enable Retrip	OFF / THREE-POLE / SINGLE-POLE	OFF	Enable retrip
St1SPTripDelay	1Ph Retrip Delay	[0..30000] ms	0	One phase retrip delay
St1TPTripDelay	3Ph Retrip Delay	[0..30000] ms	0	Three phase retrip delay
St2SPTripDelay	Ext 1Ph Trip Delay	[50..30000] ms	150	One phase external trip delay
St2TPTripDelay	Ext 3Ph Trip Delay	[50..30000] ms	150	Three phase external trip delay
IopStart	Iop Start	[0,05..20,0] × I_r	1,0	Pickup current detector threshold
Iop	Iop	[0,05..1,5] × I_r	0,1	Reset current detector threshold

5.26 Trip Circuit Supervision

5.26.1 Introduction

The circuit connecting the output of the protection relay to the corresponding circuit breaker is one of the key components of the protection system. The Trip Circuit Supervision function is responsible for monitoring the status of the trip circuit of a specific circuit breaker, allowing the identification of discontinuities in the circuit that may compromise the operation of protection functions. This way, the Trip Circuit Supervision may be used to issue an alarm that, when acknowledged in advance, can be used to prevent a major failure.

In some cases, for backup reasons, there are two independent trip circuits for the same circuit breaker, which increases the security of the overall protection system. The backup circuit should be supervised in a similar manner as the main one.

5.26.2 Operation Method

The Trip Circuit Supervision can be independently activated by setting change (setting **Operation**).

The supervision of the circuit continuity is performed through the monitoring of the state of a binary input, configured to this end. This input should be associated to the function input **MonitorTripCircuit**. If this input is suitably connected, it will indicate the status of the trip circuit: while there is circuit continuity, the binary input will remain active; when the protection relays operates, the binary input will be temporarily turned off.

However, if the binary input remains turned off for more than a pre-defined time, which can be set in setting **AlarmDelay**, the trip circuit failure is signalled in the function output **TripCircuitFail**. An additional time interval between consecutive function pickups can be defined in setting **ResetTime**. After the function drops out it will not evaluate the pickup conditions again until this timer has elapsed.

Optionally, the function can resort to the circuit breaker status position indication (available in function input **Position**) in order to supervise the integrity of the trip circuit only when the circuit breaker is closed. This may be required depending on the particular connection available for circuit supervision.

Three possible connection schemes are presented next.

The first option is the simplest and is shown in Figure 5.70. With this connection scheme, only the normally open auxiliary contact is available, therefore the trip circuit supervision can only be performed if the circuit breaker is closed (contact 52a closed). For this scheme to work properly the function must have access to the circuit breaker position (**Position** input), otherwise the trip circuit failure alarm will be issued whenever the breaker is open (even if the circuit is healthy).

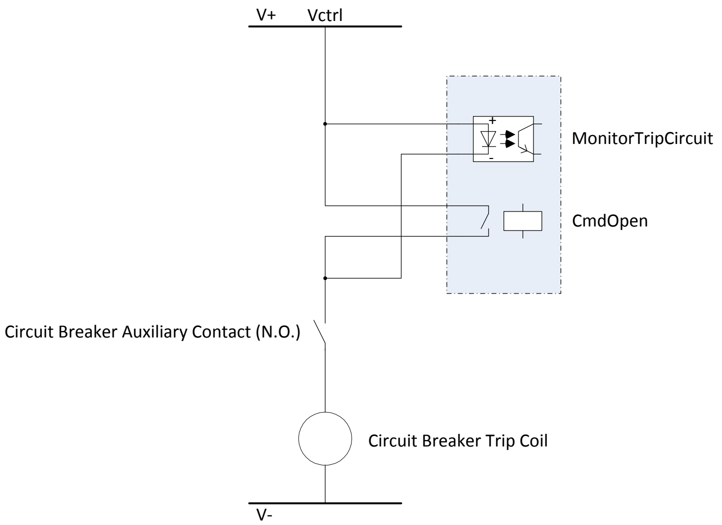

Figure 5.70. Trip circuit supervision (1st connection scheme).

In the second possible connection scheme, shown in Figure 5.71, the supervision of the trip circuit can be done, irrespective of the circuit breaker status. However, the trip coil is only supervised if the circuit breaker is closed (contact 52a closed and contact 52b open).

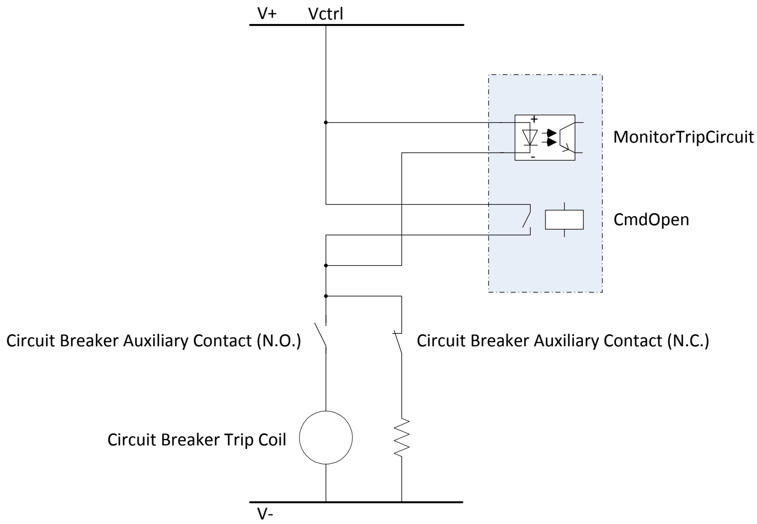

Figure 5.71. Trip circuit supervision (2nd connection scheme).

The last scheme (according to Figure 5.72) allows the full supervision of the trip circuit, irrespective of the circuit breaker status.

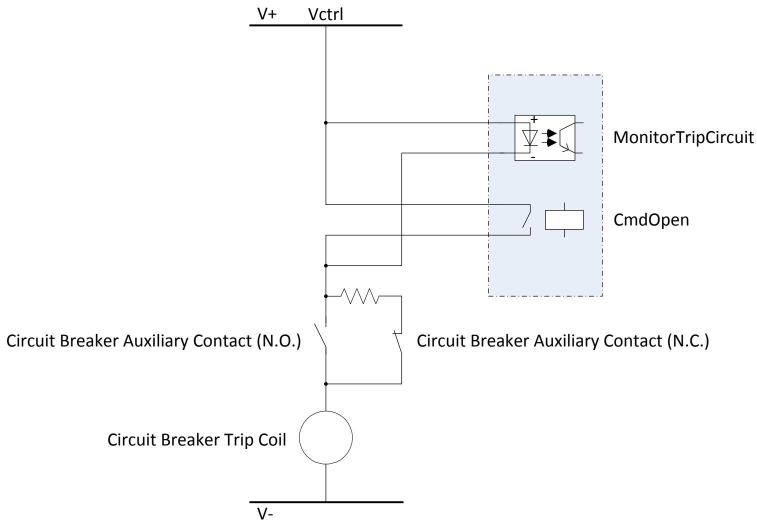

Figure 5.72. Trip circuit supervision (3rd connection scheme).

In option, the trip circuit associated to the backup coil of the circuit breaker can also be monitored. The supervision method is similar to the one provided for the main coil. The function input **MonitorBackupCircuit** must be used for this purpose, together with the optional information concerning the circuit breaker state. The corresponding failure indication is signalled in the function output **BackupCircuitFail**.

Blocking Conditions

The function provides a block input (**Block**) for blocking its operation. It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The **MonitorTripCircuit** and **MonitorBackupCircuit** inputs are both disconnected.
- The **BackupCircuitOper** setting is **ON** and the **MonitorBackupCircuit** input is disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.26.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.85 and Table 5.86, respectively.

Table 5.85. Trip Circuit Supervision function inputs.

Identifier	Title	Type	Mlt	Description
Block	Block	DIG	4	Function block
Position	Position	DB DIG	1	Circuit breaker position
MonitorTripCircuit	Monitor Trip Circ	DIG	1	Trip circuit monitoring input
MonitorBackupCircuit	Monitor Backup Circ	DIG	1	Backup trip circuit monitoring input

Table 5.86. Trip Circuit Supervision function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
TripCircuitFail	Trip Circuit Fail	DIG	-	Trip circuit failure alarm
BackupCircuitFail	Backup Circuit Fail	DIG	-	Backup trip circuit failure alarm

5.26.4 Settings

The function settings are listed in Table 5.87.

Table 5.87. Trip Circuit Supervision function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation

Identifier	Title	Range	Factory value	Description
AlarmDelay	Alarm Delay	[500..60000] ms	2000	Trip circuit failure alarm delay
ResetTime	Reset Time	[500..60000] ms	1000	Reset time
BackupCircuitOper	Backup Circuit Oper	OFF / ON	OFF	Operation of the backup circuit monitoring
IgnorePosition	Ignore Position	OFF / ON	OFF	Ignore circuit breaker open position monitoring

5.27 Lockout

5.27.1 Introduction

There are several operating conditions for which circuit breaker closing should not be allowed and must be locked.

Some power equipment, like power transformers or underground cables, should not be reconnected after an internal fault, because this is caused by an insulation failure and the equipment must be repaired before being put in service again. A permanent close lock is usually required in these cases. It should only be manually cancelled after confirming the fault was cleared.

In other circumstances, however, the circuit breaker lock can last only for the time interval the fault condition is present and it can be automatically removed after that. That is the case, for instance, of excessive overload operating conditions: after disconnecting the equipment, it can be switched on again as soon as the temperature drops below a certain reset level.

Finally, it may be fundamental to lock the circuit breaker close operation for a specific time interval after it opens. This is typical for capacitor banks, which must be disconnected from the power system for a certain amount of time, in order to ensure its complete discharge before reconnecting them.

The use of additional control switches and pushbuttons in the switchgear cubicle with the purpose of implementing the circuit breaker close lock logic can be avoided with the integration of a full-featured Lockout function in the TPU L500.

5.27.2 Operation Method

Three distinct mechanisms for automatically locking circuit breaker close operations are supported: a latched lock; an unlatched lock; and a timed lock. Each of them can be associated to different internal or external conditions. The three mechanisms can be used in conjunction. The resulting lock indication (function output **Locked**) is the logical OR of the three distinct block conditions.

The output **Locked** should be associated to the input **BlockClose** of the functions that manage the respective circuit breakers (please refer to sections 5.32 - Circuit Breaker Control and 5.33 - Circuit Breaker Supervision), so that any close command can be immediately rejected and the cause of rejection is reported accordingly.

For added security the logical negation of the function output **Locked** can be associated to a normally closed binary output. Besides allowing a mechanical lock of the circuit breaker operation, this ensures that the lock is active even when the TPU L500 is disconnected.

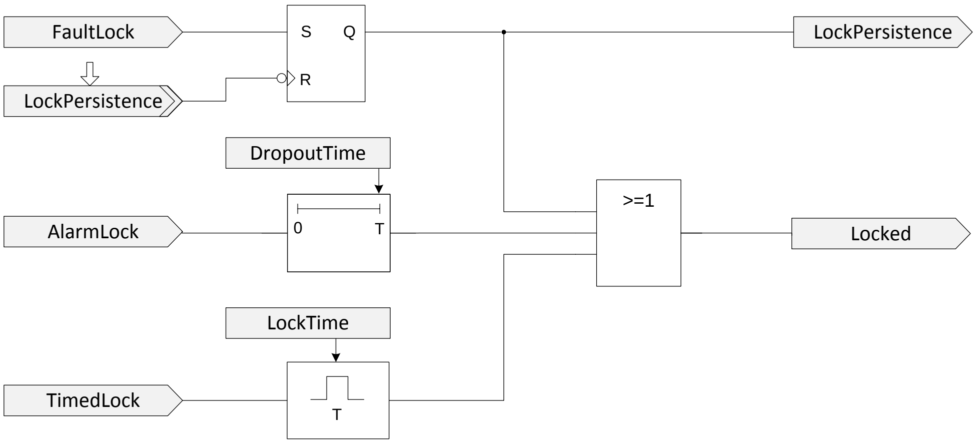

Figure 5.73. Lockout logic scheme.

Latched Lock

The latched lock is a persistent block of circuit breaker close operations which, once triggered, can only be cancelled by user command. It is normally associated with a permanent fault condition that requires user intervention.

The corresponding activation conditions should be associated to the function input **FaultLock**. When this lock is active, this is also indicated in the status of the function output **LockPersistence**. The information is kept in non-volatile memory, preventing its loss in case of a device restart.

The blocking condition can only be manually reset by user control over the entity **LockPersistence**. The control order will only be accepted if the fault condition is no longer active.

Unlatched Lock

Unlike the previous mechanism, the unlatched lock is a transient block of circuit breaker close operations, which remains active only as long as the fault condition that triggered it persists. The corresponding activation conditions should be associated to the function input **AlarmLock**. An additional extension time can be adjusted by the user in the setting **DropoutTime**, delaying the dropout of the lock condition after the fault is eliminated. This dropout time can be set to zero in option, in which case the reset will be instantaneous.

Timed Lock

This option provides a close lock that, once triggered, remains active for a pre-determined time interval, independently of the condition that originated it. This pulse time can be set by the user (function setting **LockTime**). The corresponding activation conditions should be associated to the function input **TimedLock**.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **FaultLock**, **AlarmLock** and **TimedLock** inputs are all disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.27.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.88 and Table 5.89, respectively.

Table 5.88. Lockout function inputs.

Identifier	Title	Type	Mlt	Description
FaultLock	Fault Lock	DIG	32	Persistent lock
AlarmLock	Alarm Lock	DIG	32	Transient lock
TimedLock	Timed Lock	DIG	32	Timed lock

Table 5.89. Lockout function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Locked	Locked	DIG	-	Lock indication
LockPersistence	Lock Persistence	DIG CTRL	Yes	Persistent lock indication

5.27.4 Settings

The function settings are listed in Table 5.90.

Table 5.90. Lockout function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
LockTime	Lock Time	[1..3600] s	10	Timed lock duration
DropoutTime	Dropout Time	[0..3600] s	0	Transient lock dropout time

5.28 VT SUPERVISION

5.28.1 INTRODUCTION

Voltage transformers are subject to internal faults as any other component in power systems. They must be disconnected if this happens, so they are usually protected by some device, either a miniature circuit breaker (MCB) or a set of three fuses, one per phase.

The internal fault and subsequent opening of the corresponding protective device causes a sudden loss of potential in one or more phases in all measuring devices and protective relays connected to the VT secondary. This condition can lead to an incorrect trip of several protection functions, namely Distance and Undervoltage Protection or those functions that detect some asymmetry in the power system, like Residual or Negative Sequence Overvoltage.

The VT Supervision function is responsible for monitoring the voltage signals and for checking their plausibility, in order to identify possible failures and instantaneously block the trip of selected protection elements. Depending on the kind of protective device applied to the voltage transformers, different methods may be necessary to guarantee the detection of all possible faults.

5.28.2 OPERATION METHOD

The VT Supervision function executes two distinct algorithms in parallel: one high-speed VT fault detector used for blocking protection functions and one additional and independent monitoring function, with the main purpose of checking voltage measurements and connections. The function can be activated by setting change (setting **Operation**).

The high-speed VT supervision function is executed with high priority, so that it is able to block high-speed tripping protection stages. Distinct methods are available for detection of failures in the voltage measuring circuits almost instantaneously. They are all executed in parallel by the TPU L500. Function output **VTFail** is signalled whenever any of the criteria detects a VT fault. If there is no three-phase current signals associated to input **I**, the only criteria evaluated for high-speed VT supervision is the MCB trip status supervision.

MCB Trip Status Supervision

The status of the miniature circuit breaker (MCB) associated to the voltage transformers should be supervised by the VT Supervision function if possible. For this purpose, the auxiliary contact corresponding to the MCB open status must be associated to the function input **MCBOpen**. If the MCB is detected open, the function immediately signals a VT failure.

All VT faults are covered by this method; however, it is not applicable if the VT is protected by fuses. It must also be taken into account the delay associated to the auxiliary contact.

In order to block high-speed tripping protection functions, the binary input associated to the MCB status should have a very low debounce time configured.

Asymmetrical VT Failure Detection

Asymmetrical faults are closely related to the loss of potential in only one or two phases, when measuring transformers are protected with fuses. These faults lead to an asymmetry in the three-phase voltage system, which however does not correspond to an equivalent asymmetry in the three-phase current system, because they are not associated to a power system fault but only to a failure in the voltage measuring transformers.

This method continuously monitors both negative and zero sequence components obtained from the three voltage and three current signals, associated in two analogue channels connected to function inputs **U** and **I**, respectively.

A failure will be signalled if at least one of the two following conditions is met (the first of them can only be evaluated if three phase-to-earth voltage signals are associated to input **U**):

- the magnitude of the zero sequence voltage is greater than the threshold defined in setting **UresOp** and at the same time the magnitude of the zero sequence current is less than the corresponding level **IresOp**;

- the magnitude of the negative sequence voltage is greater than the threshold defined in setting **U2Op** and at the same time the magnitude of the negative sequence current is less than the corresponding level **I2Op**.

The pickup thresholds are set in values per unit, relative to the rated VT (or CT) primary voltage (or current).

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \tag{5.60}$$

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \tag{5.61}$$

In order to evaluate the absence of asymmetry in the phase currents, this method can only be applied if the magnitude of at least one phase current is higher than the minimum threshold defined in setting **Imin**.

After the VT failure is signalled, and while the timer defined in setting **LatchTime** is running, the blocking condition can be automatically reset if an asymmetry in current signals is detected meanwhile (according to levels **IresOp** and **I2Op**). After this timer elapses, the blocking condition is latched and it can only be reset when the asymmetry in the three voltage signals is cleared.

Symmetrical VT Failure Detection

In case of symmetrical voltage transformer faults, when all three phase-to-earth voltages drop simultaneously, which is the general rule if the VT is protected by a MCB, the previous criterion is no longer applicable. In alternative, the VT Supervision function provides an additional method especially fitted for symmetrical faults.

In case of a close-in three-phase fault, all three phase-to-earth voltage signals will be very low; however the short-circuit current is expected to be very high in all three phases, and consequently a great variation in current magnitude is expected at the same time the voltages drop. This fact allows discriminating three-phase faults from actual voltage transformer faults, where no simultaneous variation in current magnitude is expected. Most of the times, this method provides a faster response than the MCB trip supervision because it only depends on analogue signals.

For this purpose, the VT Supervision function continuously checks if all three phase-to-earth voltage magnitudes are below the threshold defined in setting **Umin**. If this condition is met and simultaneously the variation in current magnitude is less than setting **Ivar**, the VT is declared faulty and the **VTFail** output is signalled. If, by the contrary, the current variation is higher than **Ivar** at the same time the voltage drops, a power system fault is declared and the VT Supervision function does not operate.

The current variation threshold (setting **Ivar**) is compared with: the variation in current magnitude for the last power system cycle, for stable conditions; or the variation between the current magnitude between last stable state and the new stable state, for very abrupt systems transitions.

Like the previous criterion, this method can only be applied if the magnitude of at least one phase current is higher than the minimum threshold defined in setting **Imin**.

Voltage Measurements Monitoring

An additional monitoring function is available for low priority checking of VT connections and voltage measurements. It can be activated in setting **MeasEvaluation**.

The three voltage signals are continuously checked for polarity or phase sequence errors. If a polarity reversal is detected in any of the voltages, the output **PolarityFail** will be issued. If a phase sequence error is detected instead, for example if two voltages are swapped, the output **SequenceFail** is issued. These indications are always signalled after a settable timeout, defined in setting **EvaluationTime**.

Additionally, a loss of voltage check is performed, so that an alarm is signalled if a power line is connected and no voltage measurements are available. This is particularly relevant if voltage transformers are connected in the line side of the circuit breaker. If the current magnitude is greater than **Imin** in at least one of the phases and the magnitude of all three phase-to-earth voltages is less than setting **Umin**, the function output **VoltAbsence** is signalled after a confirmation time defined in setting **EvaluationTime**.

The monitoring is blocked during a fault condition, *i.e.* if there is a protection function pickup, because the implemented rules are only valid for balanced load conditions. For this purpose, the pickup of independent protection functions or stages should be associated to input **FuncPickup**.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **U**;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth or at least two phase-to-phase voltage signals;

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The analogue channel associated to input **I** does not correspond to a group of three-phase current signals, in this case, both the symmetrical and the asymmetrical VT failure detection criteria are not evaluated.

The configuration is valid and the function operates accordingly otherwise.

5.28.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.91 and Table 5.92, respectively.

Table 5.91. VT Supervision function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Reference currents
U	U	ANL CH	-	Supervised voltages
OpenPole	Open Pole	DIG	2	Open pole
MCBOpen	MCB Open	DIG	2	VT circuit breaker open
FuncPickup	Function Pickup	DIG	32	Protection pickup

Table 5.92. VT Supervision function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
VTFail	VT Failure	DIG	-	Voltage transformer failure
VoltAbsence	Voltage Absence	DIG	-	Voltage absence indication
PolarityFail	Polarity Fail	DIG	-	Polarity failure indication
SequenceFail	Sequence Fail	DIG	-	Sequence failure indication

5.28.4 Settings

The function settings are listed in Table 5.93.

Table 5.93. VT Supervision function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
UresOp	UresOp	[0,01..1,0] × U_r	0,2	Residual voltage threshold
IresOp	IresOp	[0,05..1,0] × I_r	0,2	Residual current threshold
U2op	U2op	[0,01..1,0] × U_r	0,2	Negative sequence voltage threshold
I2op	I2op	[0,05..1,0] × I_r	0,2	Negative sequence current threshold
LatchTime	Latch Time	[1000..20000] ms	2000	Latch time for asymmetrical detection
Umin	Umin	[0,01..1,0] × U_r	0,05	Minimum three-phase voltage
Ivar	Ivar	[0,03..1,0] × I_r	0,1	Maximum phase current variation
MeasEvaluation	Meas Evaluation	OFF / ON	OFF	Measurement evaluation enabled
EvaluationTime	Evaluation Time	[1000..60000] ms	3000	Evaluation time
Imin	Imin	[0,05..1,0] × I_r	0,2	Minimum current of at least one phase

5.29 CT Supervision

5.29.1 Introduction

A malfunction in the current signal acquisition circuits, for instance an open or short-circuited current transformer, can lead to an incorrect trip of several protection functions, namely Differential Protection functions and those that detect some asymmetry in the power system, like Earth-Fault or Negative Sequence Overcurrent. The CT Supervision function is responsible for monitoring the current signals and for checking their plausibility, in order to identify possible failures and instantaneously block the trip of selected protection elements.

On the other hand, an open circuit in one of the current measuring transformers will cause extremely high voltages in the secondary circuit. Bearing this in mind, and since protection functions will be blocked, it may be preferable to disconnect the CT from the rest of the power system after a certain time, in order to prevent further damage.

5.29.2 Operation Method

The CT Supervision function executes two distinct algorithms in parallel: one high-speed CT fault detector used for blocking protection functions and one additional and independent monitoring function, with the main purpose of checking current measurements and connections. The function can be activated by setting change (setting **Operation**).

CT Failure Detection

The CT Supervision function implements several criteria that enable the detection of failures in the current measuring circuits almost instantaneously. The function is executed with high priority, so that it is able to block high-speed tripping protection stages. The function is based on the detection of asymmetries in the supervised currents and in the difference between these and a reference signal.

For this purpose, the CT Supervision function continuously monitors the residual current, which corresponds to three times the zero sequence current. It can be obtained from the internal sum of the three phase current signals that are being supervised, associated in one analogue channel connected to the function input **I**.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \quad (5.62)$$

The residual current is then compared with a reference current signal. An independent neutral current, connected to input **Iref**, provides an adequate signal for comparison with the supervised currents. Optionally, an independent set of three phase current signals, associated in one analogue channel connected to input **Iref** can be used, in which case the corresponding residual current will be used as reference signal.

A failure will be signalled if the magnitude of the supervised residual current is greater than the threshold defined in setting **IresOp** and the magnitude of the reference current is less than the corresponding level **IresRef**. The ratio between the supervised residual current and the positive sequence current should also be greater than 0,8, according to Figure 5.74, in order to stabilize function operation against the errors caused by CT saturation in case of large fault currents.

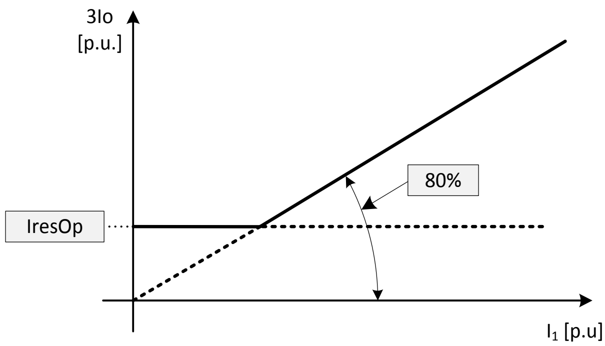

Figure 5.74. CT failure detection operational characteristic.

The pickup threshold is set in values per unit, relative to the rated CT primary current.

$$I_{op}[A]=I_{op}[p.u.]\cdot I_r \quad (5.63)$$

Alternatively the supervised currents can be checked for consistency against a residual voltage signal, obtained from the internal sum of three phase-to-earth voltage signals, or from an independent open-delta connected voltage transformer winding, connected to the function input **Uref**. In this case, the CT failure will be signalled if the magnitude of the supervised residual current meets the conditions defined by the characteristic in Figure 5.74 and the magnitude of the reference voltage is less than the corresponding level **UresRef**.

The CT Supervision function will perform both methods (comparison with reference current and voltage signals) if both **Iref** and **Uref** inputs are associated with some analogue channel.

If the failure is identified by the reference current criterion, **CurrentRefFail** will be signalled; on the other hand, if the failure is identified by the voltage criterion, **VoltageRefFail** will be signalled. In both cases, the **CTFail** output will indicate a CT failure and must be used to block selected protection stages. In addition, if **CTFail** is still active after a settable timeout (defined in setting **SupTime**), the function output **CTFailAlarm** will also be signalled. This alarm can be used, for instance, for tripping in case of a dangerous CT fault condition.

CT Failure Detection Using Remote Signals

An additional method for detecting failures in the current measuring circuits can be selected when the three phase current signals from the remote line ends are available through dedicated communication channels for Differential Protection application. Up to four remote analogue channels are supported (function inputs **I_R1** to **I_R4**). It can also be used with a second set of local current transformers in multiple breaker arrangements, in which case a second set of three phase current signals may be associated to the function input **I_L2**.

This criterion is based on the ratio between the negative and positive sequence currents in each line end.

$$r_{op}=\frac{|\bar{I}_2|}{|\bar{I}_1|} \quad (5.64)$$

$$\bar{I}_2=1/3\cdot\left(\bar{I}_A+a^2\cdot\bar{I}_B+a\cdot\bar{I}_C\right),\quad a=e^{j120^\circ} \quad (5.65)$$

$$\bar{I}_1=1/3\cdot\left(\bar{I}_A+a\cdot\bar{I}_B+a^2\cdot\bar{I}_C\right),\quad a=e^{j120^\circ} \quad (5.66)$$

If the ratio in the local supervised currents is greater than the threshold defined in setting **I2I1**, a fault or a CT failure may exist. The CT failure condition can be confirmed if at the same time no asymmetry is detected neither in any of the configured remote channels nor in the second local analogue channel. For this purpose, the ratio between the negative and positive sequence currents for each remote channel should be less than the corresponding setting **I2I1remx** (x = 1 to 4). In the case of the second set of local currents, it is compared with setting **I2I1loc2**.

Only the remote channels where the positive sequence current is greater than the associated setting **I1remx** will be considered. The same condition is applied to the second set of local currents (setting **I1loc2**). These minimum current thresholds are set in values per unit, relative to the rated CT primary current. Additionally, a remote channel will not be considered too in case of communications failure.

CT Failure Detection For Symetric Failure

If all fases are lost at the same time, asymmetries won't be detected impeding the previous criterea from working. A symmetric failure algorithm can also be enabled in setting **Fail3PhOp** to detect this situation. This is rare, however, since even if all cables end up being severed it is likely that asymmetries are detected temporarily making the asymmetric criterias pickup. The **Fail3PhOp** should be **OFF** unless it is specifically required.

For this algorithm it is necessary that at least one of the references is connected and it will use all references available to detect the failure.

The algorithm is based in the sudden disapearence of all three currents after a stable load current as been in place without any change in the reference measurements.

Current Measurements Monitoring

An additional monitoring function is available for low priority checking of CT connections and current measurements. The three phase current signals are continuously checked for polarity or phase sequence errors. If a polarity reversal is detected in any of the phase currents, the output **PolarityFail** will be issued. If a phase sequence error is detected instead, for example if two phase currents are swapped, the output **SequenceFail** is issued. These indications are always signalled after a settable timeout, defined in setting **MonitorTime**.

The polarity and phase sequence monitoring is active whenever all phase currents are greater than a minimum threshold defined in setting **Imin**. The monitoring is also blocked during a fault condition, *i.e.* if there is a protection function pickup, because the implemented rules are only valid for balanced load conditions. For this purpose, the pickup of independent protection functions or stages should be associated to input **FuncPickup**.

Blocking Conditions

The function provides a block input (**Block**) for blocking its operation. It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- The analogue channel associated to input **I** does not correspond to a group of three phase current signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There are no analogue channels associated to inputs **Iref** and **Uref**: the CT failure detection is not enabled in this case;
- The analogue channel associated to input **Iref** does not correspond to a neutral or to a group of three phase current signals: the CT failure detection is not enabled in this case;
- The analogue channel associated to input **Uref** does not correspond to a neutral or to a group of three phase-to-earth voltage signals: the CT failure detection is not enabled in this case.
- At least one of the analogue channels associated to the inputs **I_L2**, **I_R1**, **I_R2**, **I_R3** or **I_R4** does not correspond to a group of three phase current signals: the CT failure detection by remote signals is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.29.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.94 and Table 5.95, respectively.

Table 5.94. CT Supervision function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Supervised currents
Iref	Iref	ANL CH	-	Reference current
Uref	Uref	ANL CH	-	Reference voltage
I_L2	I_L2	ANL CH	-	Local current2
I_R1	I_R1	ANL CH	-	Remote current1
I_R2	I_R2	ANL CH	-	Remote current2
I_R3	I_R3	ANL CH	-	Remote current3
I_R4	I_R4	ANL CH	-	Remote current4
Block	Block	DIG	4	Block function
FuncPickup	Function Pickup	DIG	64	Function pickup indication

Table 5.95. CT Supervision function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
PolarityFail	Polarity Fail	DIG	-	Polarity failure indication
SequenceFail	Sequence Fail	DIG	-	Sequence failure indication
CurrentRefFail	Current Ref Fail	DIG	-	CT failure by current reference
VoltageRefFail	Voltage Ref Fail	DIG	-	CT failure by voltage reference
RemoteRefFail	Remote Ref Fail	DIG	-	CT failure by remote current comparison
CTFail	CT Fail	DIG	-	CT failure indication
CTFailAlarm	CT Fail Alarm	DIG	-	CT failure after delay
CTFailPersistence	CT Fail Persist	DIG CTRL	Yes	CT failure persistence
CT3PhFail	CT 3Ph Fail	DIG	-	CT three phase failure

5.29.4 Settings

The function settings are listed in Table 5.96.

Table 5.96. CT Supervision function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
LachedOp	Latched Op	OFF / ON	OFF	Latched operation
Fail3PhOp	Three phase Op	OFF / ON	OFF	Three phase fail detection operation
IresOp	IresOp	[0,05..4,0] × I_r	0,1	Residual current operation threshold
IresRef	IresRef	[0,05..4,0] × I_r	0,1	Residual reference current threshold
UresRef	UresRef	[0,01..1,0] × U_r	0,1	Residual reference voltage threshold
Iload	I load	[0,1..1,0] × I_r	0,5	Load current
I2I1	I2/I1	[0,05..1,0] I_2/I_1	0,4	Operational unbalance current
I2I1loc2	I2/I1 loc2	[0,05..1,0] I_2/I_1	0,05	Local current2 unbalance
I1loc2	I1 loc2	[0,05..4,0] × I_r	0,1	Local current2 load current

Identifier	Title	Range	Factory value	Description
I2I1rem1	I2/I1 rem1	[0,05..1,0] I_2/I_1	0,05	Remote current1 unbalance
I1rem1	I1 rem1	[0,05..4,0] × I_r	0,1	Remote current1 load current
I2I1rem2	I2/I1 rem2	[0,05..1,0] I_2/I_1	0,05	Remote current2 unbalance
I1rem2	I1 rem2	[0,05..4,0] × I_r	0,1	Remote current2 load current
I2I1rem3	I2/I1 rem3	[0,05..1,0] I_2/I_1	0,05	Remote current3 unbalance
I1rem3	I1 rem3	[0,05..4,0] × I_r	0,1	Remote current3 load current
I2I1rem4	I2/I1 rem4	[0,05..1,0] I_2/I_1	0,05	Remote current4 unbalance
I1rem4	I1 rem4	[0,05..4,0] × I_r	0,1	Remote current4 load current
SupTime	Sup Time	[0..60000] ms	0	Supervision time delay
Imin	Imin	[0,05..1,0] × I_r	0,2	Minimum monitoring current
MonitorTime	Monitor Time	[1000..60000] ms	3000	Monitoring time

5.30 Open Pole Detection

5.30.1 Introduction

Single-phase tripping is a common practice used to clear phase-to-earth faults in transmission and sub-transmission power networks above certain voltage level because it enables some power transfer in the faulted line during the dead time before reclosing, thus improving power system stability for a significant number of power system disturbances. However, protection functions are required to deal with the asymmetry that arises from the temporary operation of the system with one of the poles open.

The Open Pole Detector is an auxiliary function that detects an open pole condition following the clearance of a phase-to-earth fault. It may be used to block or to restrain the operation of specific protection functions during the dead time of a single-phase automatic reclosing cycle. It is also useful to supervise the correct operation of the circuit breaker during open pole operations, and the outputs of the function can be applied in other user-defined logic schemes.

5.30.2 Operation Method

The Open Pole Detector function is based on three distinct algorithms that can be independently activated according to the logic configuration of the function:

- Loss of phase current and presence of residual current;
- Loss of phase current and of phase voltage;
- Loss of phase current and circuit breaker pole open.

Any of the three algorithms includes several built-in checks to guarantee a secure operation and to deal with the non-simultaneity of the events processed by the function. The Open Pole Detector function is executed with high priority, so that it is able to block high-speed tripping protection stages.

The function is prepared for single or multiple breaker topologies.

Irrespective of the algorithm or algorithms selected, at least three phase current signals, corresponding to the currents flowing in one circuit breaker, should be associated in one analogue channel connected to one of the function inputs **I1** or **I2**. Both analogue channels **I1** and **I2** are required if the function is to be applied in multiple breaker topologies and the information should be discriminated by circuit breaker.

The open pole condition for each one of the circuit breakers is always signalled in function outputs **CB1OpenPole** and **CB2OpenPole**, respectively. If only one circuit breaker is associated with the function, the open pole condition of the line, signalled in **LineOpenPole**, matches the one relative to the corresponding circuit breaker; if two distinct circuit breakers are being monitored, **LineOpenPole** corresponds to the logical OR or AND of the two outputs **CB1OpenPole** and **CB2OpenPole**, according to setting **LineOpenPoleLogic**.

The corresponding phase-segregated information is also available for circuit breaker 1 (in function outputs **CB1OpenPoleA**, **CB1OpenPoleB** and **CB1OpenPoleC**) and for circuit breaker 2 (in function outputs **CB2OpenPoleA**, **CB2OpenPoleB** and **CB2OpenPoleC**). The phase-segregated information concerning the line is available in function outputs **LineOpenPoleA**, **LineOpenPoleB** and **LineOpenPoleC**. These outputs enable the identification of the phase that is open.

Loss of Phase Current and Presence of Residual Current

An open pole condition is identified by the low magnitude of one (and only one) of the phase currents. It is signalled when the measured current magnitude in one of the phases is less than the threshold defined in setting **Imin**, while in the other two phases the magnitude is higher than the same setting.

As a further check, the magnitude of the residual current, corresponding to three times the zero sequence current and obtained from the internal sum of the three phase current signals, should also be higher than setting **Imin**.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \tag{5.67}$$

Both phase and residual thresholds are set in values per unit, relative to the rated CT primary current.

$$I_{op}[A] = I_{op}[p.u.] \cdot I_r \tag{5.68}$$

A single-pole trip indication is also required in order to enable this criterion. This information should preferably be phase-discriminated. Normally, the **CBTripA**, **CBTripB**, and **CBTripC** outputs from the Trip Logic function should be associated to inputs **CBTripA, CBTripB** and **CBTripC**, respectively. As an alternative, if the single-pole trip is issued by an external protection, and the phase-segregated trip is not available, it should be associated with function input **ExtTripSP**.

The open pole condition is only signalled if a single-pole trip is detected immediately before the phase and residual current conditions are checked. If the trip indication per phase is available, the phase that has tripped must match the one with a low current magnitude.

Optionally the pickup information per phase can also be associated to the function inputs **FuncPickupA**, **FuncPickupB** and **FuncPickupC**. If these inputs are available, the Open Pole Detector will also signal open pole conditions that correspond to phase-to-earth faults cleared by other protection relays.

Loss of Phase Current and of Phase Voltage

This criterion may be used if the information concerning the voltages in the line side of the circuit breaker is accessible to the function. It is activated only if three phase-to-earth voltage signals, associated in one analogue channel, are connected to the function input **U**.

An open pole condition is identified by the low magnitude of one (and only one) of the phase currents, as in the previous criterion, and the simultaneous low magnitude of the corresponding phase-to-earth voltage (and only that one), *i.e.* the measured voltage magnitude in the phase that is open should be less than the threshold defined in setting **Umin**, while in the other two phases the magnitude should be higher than the same setting.

The voltage threshold is set in values per unit, relative to the rated VT primary voltage.

$$U_{op}[kV] = U_{op}[p.u.] \cdot U_r / \sqrt{3} \tag{5.69}$$

The protection trip signals are required and should be connected as in the previous algorithm. The protection pickup signals per phase can also be optionally used.

Loss of Phase Current and Circuit Breaker Pole Open

This criterion may be used if the information concerning the circuit breaker position is discriminated by pole and accessible to the function. It requires that the normally closed auxiliary contacts 52b per phase of the circuit breaker are associated with function inputs **CB1OpenA**, **CB1OpenB** and **CB1OpenC**, or **CB2OpenA**, **CB2OpenB** and **CB2OpenC**, depending on the analogue channel **I1** or **I2** that is connected. In case of multiple breaker topologies, both sets of inputs are required.

In this algorithm, an open pole condition is identified if the magnitude of one (and only one) of the phase currents is low, as in the previous criteria, and simultaneously the circuit breaker contact 52b for the corresponding phase (and only for this one) is active.

In this criterion, the protection trip and/or pickup signals are not required.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- Both inputs **I1** and **I2** are disconnected;
- The analogue channel associated to input **I1** or **I2** does not correspond to a group of three phase current signals;
- There are no conditions to enable any open pole detection criteria.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals;
- At least one of the inputs **FuncTripA**, **FuncTripB** or **FuncTripC** is connected but not all the three;
- The analogue channel **I1** (or **I2**) is connected and at least one of the inputs **CB1OpenA**, **CB1OpenB** or **CB1OpenC** (or **CB2OpenA**, **CB2OpenB** or **CB2OpenC**) is connected but not all the three.

The configuration is valid and the function operates accordingly otherwise.

5.30.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.97 and Table 5.98, respectively.

Table 5.97. Open Pole Detector function inputs.

Identifier	Title	Type	Mlt	Description
I1	I CB1	ANL CH	-	Circuit breaker 1 currents
I2	I CB2	ANL CH	-	Circuit breaker 2 currents
U	U	ANL CH	-	Phase voltages
CB1OpenA	CB 1 Open A	DIG	1	Circuit breaker 1 open pole, phase A
CB1OpenB	CB 1 Open B	DIG	1	Circuit breaker 1 open pole, phase B
CB1OpenC	CB 1 Open C	DIG	1	Circuit breaker 1 open pole, phase C
CB2OpenA	CB 2 Open A	DIG	1	Circuit breaker 2 open pole, phase A
CB2OpenB	CB 2 Open B	DIG	1	Circuit breaker 2 open pole, phase B
CB2OpenC	CB 2 Open C	DIG	1	Circuit breaker 2 open pole, phase C
CB1TripA	CB1 Trip A	DIG	1	Circuit breaker 1 trip, phase A
CB1TripB	CB1 Trip B	DIG	1	Circuit breaker 1 trip, phase B
CB1TripC	CB1 Trip C	DIG	1	Circuit breaker 1 trip, phase C
CB2TripA	CB2 Trip A	DIG	1	Circuit breaker 2 trip, phase A
CB2TripB	CB2 Trip B	DIG	1	Circuit breaker 2 trip, phase B
CB2TripC	CB2 Trip C	DIG	1	Circuit breaker 2 trip, phase C
FuncPickupA	Function Pickup A	DIG	16	Protection pickup, phase A
FuncPickupB	Function Pickup B	DIG	16	Protection pickup, phase B
FuncPickupC	Function Pickup C	DIG	16	Protection pickup, phase C
ExtTripSP	External Trip SP	DIG	16	External trip, single-pole

Table 5.98. Open Pole Detector function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
CB1OpenPoleA	CB1 Open Pole A	DIG	-	Circuit breaker 1 open pole, phase A
CB1OpenPoleB	CB1 Open Pole B	DIG	-	Circuit breaker 1 open pole, phase B
CB1OpenPoleC	CB1 Open Pole C	DIG	-	Circuit breaker 1 open pole, phase C
CB2OpenPoleA	CB2 Open Pole A	DIG	-	Circuit breaker 2 open pole, phase A
CB2OpenPoleB	CB2 Open Pole B	DIG	-	Circuit breaker 2 open pole, phase B
CB2OpenPoleC	CB2 Open Pole C	DIG	-	Circuit breaker 2 open pole, phase C
LineOpenPoleA	Line Open Pole A	DIG	-	Line open pole, phase A

Identifier	Title	Type	NV	Description
LineOpenPoleB	Line Open Pole B	DIG	-	Line open pole, phase B
LineOpenPoleC	Line Open Pole C	DIG	-	Line open pole, phase C
CB1OpenPole	CB1 Open Pole	DIG	-	Circuit breaker 1 open pole
CB2OpenPole	CB2 Open Pole	DIG	-	Circuit breaker 2 open pole
LineOpenPole	Line Open Pole	DIG	-	Line open pole

5.30.4 Settings

The function settings are listed in Table 5.99.

Table 5.99. Open Pole Detector function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
Imin	Open Pole Current	[0,05..1,0] × I_r	0,1	Minimum current for open pole detection
Umin	Open Pole Voltage	[0,05..1,0] × U_r	0,5	Minimum voltage for open pole detection
LineOpenPoleLogic	Line OpenPole Logic	CB1 AND CB2 / CB1 OR CB2	CB1 AND CB2	Logic used for line information

5.31 Broken Conductor Check

5.31.1 Introduction

Continuous or severe overload conditions remaining undetected by the protection system can lead to the deterioration and subsequent rupture of phase conductors. This breakdown may also be originated by some kind of mechanical stress over the conductors.

Broken conductors, as short-circuits, are power system fault conditions that must be handled by the protection system. Detection of broken conductors is often troublesome, because the asymmetry that is observed is dependent on load and it may be below the operation threshold of conventional protection functions, which are not usually prepared to deal with all broken conductor conditions.

Negative sequence components are usually associated to some kind of unbalance in the power system, and they can be successfully used in the detection of broken conductors and phase discontinuities. However, a simple Negative Sequence Overcurrent stage must be desensitized to allow measurement errors caused by large phase currents and hence will not be able to operate under weak load conditions. The consideration of a characteristic based on the ratio between negative and positive sequence currents stabilizes function operation against the errors caused by CT saturation in case of large fault currents while providing enhanced sensitivity for low load currents.

Although the Broken Conductor Check function can be used to trip the associated circuit breaker, it is more often used for issuing an alarm.

5.31.2 Operation Method

The Broken Conductor Check function provides an independent definite time stage, which supervises the ratio between negative and positive sequence currents. The function can be activated by setting change (setting **Operation**).

Measuring Principle

The Broken Conductor Check function continuously monitors the ratio between the negative and positive sequence currents, obtained from the three phase current signals, associated in one analogue channel connected to the function input **I**.

$$r_{op} = \frac{\left|\bar{I}_2\right|}{\left|\bar{I}_1\right|} \tag{5.70}$$

$$\bar{I}_2 = 1/3 \cdot \left(\bar{I}_A + a^2 \cdot \bar{I}_B + a \cdot \bar{I}_C\right), \quad a = e^{j120^\circ} \tag{5.71}$$

$$\bar{I}_1 = 1/3 \cdot \left(\bar{I}_A + a \cdot \bar{I}_B + a^2 \cdot \bar{I}_C\right), \quad a = e^{j120^\circ} \tag{5.72}$$

The ratio between negative and positive sequence currents is only calculated if the current magnitude of at least one of the phases is greater than the threshold defined in setting **MinPhaseCurrent**. The minimum current threshold is set in values per unit, relative to the rated CT primary current.

$$I_{\min}[A] = I_{\min}[p.u.] \cdot I_r \tag{5.73}$$

The function pickup is signalled when the measured ratio is higher than the setting **MinStartValue**. The extended setting range of **MinStartValue** allows configuring highly sensitive operation thresholds. To ensure the stability of function decision for very low phase currents, a minimum negative sequence current threshold of 2,5% of the rated CT primary current is built-in. The operational characteristic is shown in Figure 5.75.

For large positive sequence currents, the function resets with a dropout ratio of 97% of the corresponding operate level; for low currents, if the operate level corresponds to a negative sequence current less than 5% of the rated CT primary current, a larger margin (6%) is considered between pickup and reset levels. This can also be seen in Figure 5.75. The built-in hysteresis between pickup and reset levels guarantees the adequate stability of the function outputs.

If the pickup condition persists for more than a pre-set time delay (setting **AlarmTime**), an alarm is signalled in function output **Alarm**.

An additional time interval between consecutive function pickups can be defined in setting **ResetDelay**. After the function drops out it will not evaluate the pickup conditions again until this timer has elapsed.

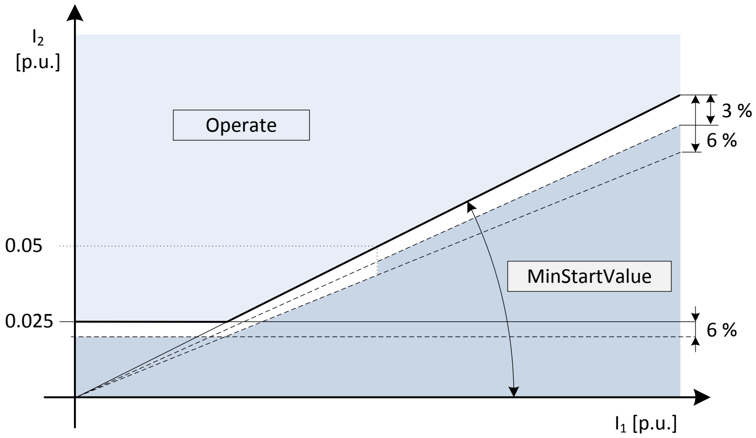

Figure 5.75. Broken Conductor Check operational characteristic.

Blocking Conditions

The function provides a general function block input (**Block**). It can be freely associated to any user-defined condition. The blocking condition is signalled in the corresponding output (**Blocked**).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I**;
- The analogue channel associated to input **I** does not correspond to a group of three phase current signals.

The configuration is valid and the function operates accordingly otherwise.

5.31.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.100 and Table 5.101, respectively.

Table 5.100. Broken Conductor Check function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Operating currents
Block	Block	DIG	4	Function block

Table 5.101. Broken Conductor Check function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision

Identifier	Title	Type	NV	Description
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Blocked	Blocked	DIG	-	Function blocked
Pickup	Pickup	DIG	-	Start
Alarm	Alarm	DIG	-	Broken conductor alarm

5.31.4 Settings

The function settings are listed in Table 5.102.

Table 5.102. Broken Conductor Check function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
AlarmDelay	Alarm Delay	[100..60000] ms	2000	Broken conductor alarm delay
ResetDelay	Reset Delay	[0..60000] ms	50	Function reset delay
MinStartValue	Min Start Value	[0,2..1,0] I_2/I_1	0,5	Minimum I2/I1 ratio
MinPhaseCurrent	Min Phase Current	[0,05..0,3] × I_r	0,2	Minimum current of at least one phase

5.32 CIRCUIT BREAKER CONTROL

5.32.1 INTRODUCTION

The Circuit Breaker Control function is responsible for the management of both manual and automatic open and close commands issued over a specific circuit breaker, centralizing all the necessary information required to block or release them. This includes optionally interacting with an external synchronism-check function, accessing interlocking status, and supervising distinct blocking conditions, according to the type and origin of the command.

Protection function trip signals are directly managed by a distinct built-in function, with high priority (please see section 5.22 - Three-Phase / Single-Phase Trip Logic). The same happens with the open and close commands issued by the Automatic Reclosure. For user manual commands, both local and remote, as well as other automatic function controls, including those originating from user programmable functions, the Circuit Breaker Control function should be used instead.

5.32.2 OPERATION METHOD

Circuit Breaker Status

The circuit breaker status is permanently available in function output **Position**. It is represented as a double status entity. In case of three-phase controllable circuit breakers, its value directly mirrors the function input **Position**.

The **Position** input can be associated, for instance, to the corresponding output of the Circuit Breaker Supervision function (please refer to section 5.33 - Circuit Breaker Supervision). All value and quality changes in circuit breaker position are correctly time tagged, according to the time tag of the input entity. The originator of the last command issued over the circuit breaker is also available in the corresponding field of output **Position**.

Command Processing

Circuit breaker open and close commands should be executed over the double status controllable output **Position**. Several conditions are then evaluated in order to release or reject the command:

- The command is rejected if the circuit breaker is already in the intended position.
- The switching hierarchy is managed according to the rules presented in subsection 5.1.4 - Control Authority Management.
- Open and close command blocking conditions are evaluated, according to the status of the corresponding function inputs that are described below.
- Specific interlocking release conditions can be programmed in user-defined functions and associated to the respective inputs. Independent interlocking conditions can be defined for open (function input **InterlockEnableOpen**) and close (function input **InterlockEnableClose**) operations.
- Close commands can be optionally supervised by an external synchronism check function (please refer to section 5.24 - Synchronism and Voltage Check). Independent inputs are provided for manual (function input **ManSyncEnableClose**) and automatic (function input **AutSyncEnableClose**) close commands.

If the synchronism check release is already active when a close command is executed, the command is immediately released, provided all other conditions are verified. If, by the contrary, there are no synchronism conditions when the order is received, the command execution is allowed to wait a maximum time for the synchronism check release. This timer is independently defined for manual (setting **ManSyncTime**) and automatic (setting **AutSyncTime**) close commands.

The function output **SyncInProgress** is signalled while the Circuit Breaker Control function is waiting for the external synchronism check release. If this indication is received while the timer is running, the command is immediately released, provided all other conditions are still verified. If the timer expires without the reception of the synchronism check release, the close command is rejected and the **SyncFail** indication is signalled.

After evaluating all the previous conditions, if the command is finally released by the Circuit Breaker Control function, a pulse is issued in one of **CmdOpen** or **CmdClose** outputs, for open or close commands respectively. Otherwise, a cause of rejection is indicated (see Table 5.103).

Table 5.103. Causes of rejection of circuit breaker commands.

Identifier	Value	Description
UNKNOWN	0	Unknown cause
BLOCKED BY SWITCHING HIERARCHY	2	At least one level with lower switching hierarchy in local mode
POSITION REACHED	5	Switch already in the intended position
BLOCKED BY MODE	8	Blocked by actual operation mode
BLOCKED BY PROCESS	9	Blocked due to some external event at process level
BLOCKED BY INTERLOCKING	10	Blocked due to interlocking of switching devices
BLOCKED BY SYNCHRO-CHECK	11	Blocked by synchronism check function
COMMAND ALREADY IN EXECUTION	12	Control action already in execution
BLOCKED BY HEALTH	13	Blocked due to some internal event that prevents a successful operation
NONE	25	No cause of rejection; control executed

The number of open commands executed is available in function output **OpCounter**. This counter can be reset by the user at any time, by executing a control order over that entity. Its initial value can be freely defined.

Blocking Conditions

The function provides distinct open and close command blocking conditions, for distinct command origins. Any of them can be freely associated to any user-defined condition.

The blocking conditions can be independently defined according to the origin of the command: local manual commands (**BlockManLocOpen** and **BlockManLocClose**), remote manual commands (**BlockRemLocOpen** and **BlockRemLocClose**) and automatic commands (**BlockAutOpen** and **BlockAutClose**). There are also general blocking conditions (**BlockOpen** and **BlockClose**) that block all commands, irrespective of its origin.

Two additional block inputs (**BlockProcessOpen** and **BlockProcessClose**) are available, and allow the association of specific blocking conditions related to the process, for example insulation gas level alarm or loose spring. Although the blocking conditions related to the process should be directly associated at the process level (to see how, please consult section 5.33 - Circuit Breaker Supervision), they should also be associated to these inputs of the Circuit Breaker Control function, so that the control can be immediately rejected and the cause of rejection is reported accordingly if those conditions are active.

Function Health

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The three-phase (**Position**) status input is not connected: the function will not have access to the circuit breaker position, therefore the **Position** output will present an invalid status (**VALUE** = **BAD STATE**; **QUALITY** = **INVALID**; **ORIGIN** = **NOT SUPPORTED**).

The configuration is valid and the function operates accordingly otherwise.

5.32.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.104 and Table 5.105, respectively.

Table 5.104. Circuit Breaker Control function inputs.

Identifier	Title	Type	Mlt	Description
BlockOpen	Block Open	DIG	4	Block opening
BlockClose	Block Close	DIG	4	Block closing

Identifier	Title	Type	Mlt	Description
BlockManLocOpen	Block Man Loc Open	DIG	2	Block manual local open commands
BlockManLocClose	Block Man Loc Close	DIG	2	Block manual local close commands
BlockManRemOpen	Block Man Rem Open	DIG	2	Block manual remote open commands
BlockManRemClose	Block Man Rem Close	DIG	2	Block manual remote close commands
BlockAutOpen	Block Aut Open	DIG	2	Block automatic open commands
BlockAutClose	Block Aut Close	DIG	2	Block automatic close commands
BlockProcessOpen	Block Process Open	DIG	2	Block opening due to external event at process level
BlockProcessClose	Block Process Close	DIG	2	Block closing due to external event at process level
Position	Position	DB DIG	1	Circuit breaker position
PositionA	Position A	DB DIG	1	Circuit breaker position, phase A
PositionB	Position B	DB DIG	1	Circuit breaker position, phase B
PositionC	Position C	DB DIG	1	Circuit breaker position, phase C
InterlockEnableOpen	Interlock Ena Open	DIG	1	Open command allowed by interlock conditions
InterlockEnableClose	Interlock Ena Close	DIG	1	Close command allowed by interlock conditions
ManSyncEnableClose	Man Sync Ena Close	DIG	1	Manual close command released by synchrocheck
AutSyncEnableClose	Aut Sync Ena Close	DIG	1	Automatic close command released by synchrocheck

Table 5.105. Circuit Breaker Control function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Position	Position	DB CTRL	-	Circuit breaker position
Bypass	Bypass	CTRL	-	Bypass blocking conditions
CmdOpen	Cmd Open	DIG	-	Circuit breaker open command
CmdClose	Cmd Close	DIG	-	Circuit breaker close command
CmdDelays	Cmd Delay (s)	INT	-	Countdown for delayed command execution, in seconds
SyncInProgress	Sync In Progress	DIG	-	Synchronism check in progress
SyncFailure	Sync Failure	DIG	-	Synchronism failure
OpCounter	Op Counter	INT CTRL	Yes	Operation counter

5.32.4 Settings

The function settings are listed in Table 5.106.

Table 5.106. Circuit Breaker Control function settings.

Identifier	Title	Range	Factory value	Description
OpenCmdDelay	Open Cmd Delay	[0..300] s	0	Delay for open command
CloseCmdDelay	Close Cmd Delay	[0..300] s	0	Delay for close command
BypassTime	Bypass Time	[0..3600] s	180	Bypass timeout
ManSyncTime	Man Sync Time	[0..600000] ms	1000	Maximum allowed synchronism check time for manual close operation
AutSyncTime	Aut Sync Time	[0..600000] ms	1000	Maximum allowed synchronism check time for automatic close operation

5.33 Circuit Breaker Supervision

5.33.1 Introduction

The Circuit Breaker Supervision function is responsible for controlling and monitoring a certain circuit breaker. Namely, it is responsible for:

- Acquiring the circuit breaker state from the process level and providing it to other functions;
- Processing protection function trips, as well as manual and automatic commands, and operating the circuit breaker according to them;
- Supervising the correct operation of the circuit breaker;
- Monitoring the circuit breaker wear by assessing the sum of squared currents and the number of operations.

The function supports three-phase and single-phase tripping circuit breakers.

5.33.2 Operation Method

Circuit Breaker Status

The discriminated status of each circuit breaker pole is permanently available in outputs **PositionA**, **PositionB**, and **PositionC**. These status are represented as double status entities. The pole-discriminated output values are calculated from the state of the circuit breaker (or circuit breaker pole) auxiliary contacts. Since the function is prepared to work either with circuit breakers capable only of three-pole tripping or circuit breakers capable of single-pole tripping, independent interfaces are provided for both cases. Inputs **CBOpen** and **CBClosed**, which should be connected to the Normally Closed contact 52b and to the Normally Open contact 52a, respectively, are intended for the former; **CBOpenA**, **CBClosedA**, **CBOpenB**, **CBClosedB**, **CBOpenC**, and **CBClosedC** for the latter (these inputs should be connected to the 52a and 52b auxiliary contacts of each pole). These contacts are usually acquired directly from the process via binary inputs but they can also be received through a communication link (for instance, using GOOSE messages).

The circuit breaker general status is also provided and is available in function output **Position**. The general status value is computed as a combination of the three pole-discriminated values according to the rules described in Table 5.108.

Typically both contacts are accessible for all circuit breaker poles and they complement each other. When one of the poles is in movement, from open to closed position (or vice-versa), both contacts are temporarily zero, which is called the intermediate state. The user can choose to display this state always or, in option, hide it for a maximum amount of time defined in setting **FilterTime**, which should be configured with a value long enough for the circuit breaker to reach the final position. This option can be set in setting **IntermediateState**. If the intermediate state filter is active and one of the circuit breaker poles does not reach the final position in less than **FilterTime**, the corresponding intermediate state is reported when the timer expires.

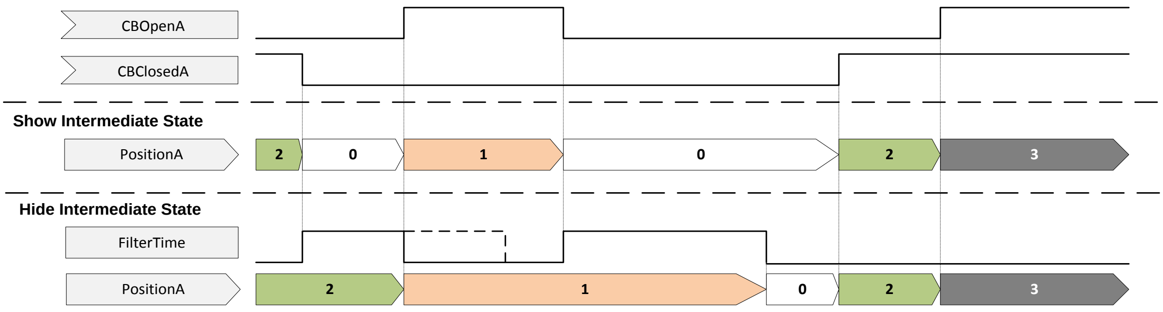

Figure 5.76. Intermediate filter.

The function is also prepared to work if only one of the auxiliary contacts is available (for each pole). In this last case, the **Positionx** outputs are directly calculated from the available contact (negated if the contact that is available is **CBOpenx**).

The intermediate states are not available in this case. Table 5.111 shows how **PositionA, PositionB, and PositionC** are calculated in all possible cases.

The quality attribute associated to each **Positionx** output is updated according to the quality attribute of the corresponding input contacts. All value and quality changes in circuit breaker pole positions are correctly time tagged, according to the time tag of the input entities. The originator of the last command issued over each circuit breaker pole is also available in the corresponding field of output **Positionx**.

Table 5.107. Circuit breaker pole position (outputs PositionA, PositionB, and PositionC).

	CBOpen = 1 CBClosed = 0	CBOpen = 0 CBClosed = 0	CBOpen = 0 CBClosed = 1	CBOpen = 1 CBClosed = 1
CBOpen and CBClosed	OFF	INTERMEDIATE	ON	BAD STATE
Only CBOpen	OFF	ON	ON	OFF
Only CBClosed	OFF	OFF	ON	ON

Table 5.108. Circuit breaker general position (output Position).

Position	PositionA, PositionB, and PositionC
BAD STATE	One or more poles indicating BAD STATE
OFF	All poles OFF
ON	All poles ON
INTERMEDIATE	All poles in INTERMEDIATE position or differing pole positions.

Command Processing

Circuit breaker open and close commands are received for processing by the function in inputs **CmdOpenA**, **CmdOpenB**, **CmdOpenC**, **CmdOpen,** and **CmdClose**. They correspond to pulses originating from protection trips (see section 5.22 - Three-Phase / Single-Phase Trip Logic), reclosing operations (see section 5.23 - Automatic Reclosure), or manual and automatic commands (see section 5.32 - Circuit Breaker Control). The open and close commands can also be issued directly over the double status controllable output **Position**, namely for test purposes.

Only process related conditions are evaluated at the level of the Circuit Breaker Supervision function; other checks should have been performed by the function that has issued the command pulse.

- The command is rejected if a previous command is already in execution.
- The command is rejected if manual control is selected at the circuit breaker (process level), and if this indication is associated to the function input **Local**.
- The command is rejected if it is blocked by some specific condition.

The function provides individual inputs for open and close command blocking conditions (**BlockOpen** and **BlockClose**). Any of them can be freely associated to any user-defined condition. They should be typically used for specific blocking conditions related to the process, for example insulation gas level alarm (in the case of open commands) or loose spring (in the case of close commands). The close commands should also be rejected if the circuit breaker operation is locked (please refer to section 5.27 - Lockout). If the open or close operations are blocked, this is signalled in the corresponding outputs (**BlockedOpenA**, **BlockedOpenB**, and **BlockedOpenC** or **BlockedCloseA**, **BlockedCloseB**, and **BlockedCloseC**).

Open/Close Signals

After evaluating all the previous conditions, if the command is finally released by the Circuit Breaker Supervision function, a pulse is issued in **CmdOpenA**, **CmdOpenB**, and/or **CmdOpenC** outputs for open commands or in the **CmdClose** output, for close commands.

The pulse duration can be set by the user, for open commands in setting **MinOpenCmdTime**, for close commands in setting **MinCloseCmdTime**. The pulse duration defined by the previous settings can be fixed (equal to the value defined) or adaptive, if setting **AdaptivePulse** is **ON**. With this option selected the command pulse will be extended until the circuit breaker reaches the final position, as depicted in Figure 5.77.

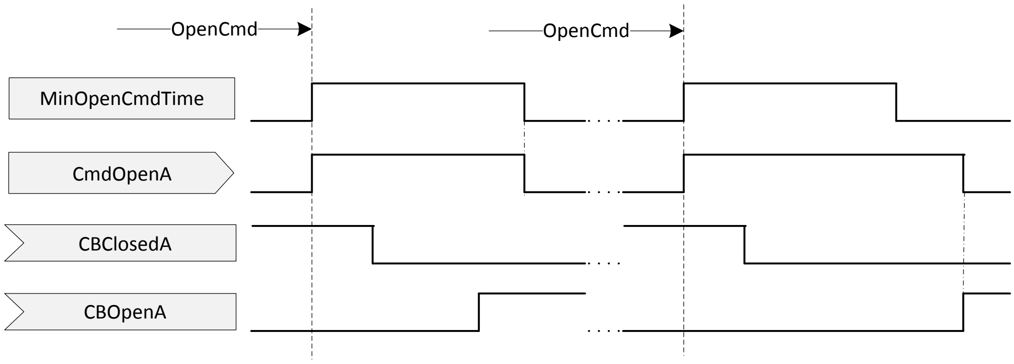

Figure 5.77. Circuit breaker command with adaptive pulse.

The adaptive pulse option should only be used if the indication of manual control selected at circuit breaker is associated to the input **Local** and if the function has access to all conditions that may block circuit breaker operation at process level, namely mechanical locks.

The open and close pulse durations should be long enough to guarantee that the auxiliary contacts of the circuit breaker interrupt the current in the coil circuit before the output relay tries to open.

The failure to comply with these recommendations may endanger the correct operation of the TPU L500 and cause personnel injuries and/or equipment damage.

Operation Monitoring

The success of circuit breaker pole operations is supervised by the function. Three distinct checks are performed:

- The time between the command release and the time instant the intermediate position is reached must not exceed the maximum allowed time for movement to start, defined in settings **MaxOpenStartTime** for opening operations and **MaxCloseStartTime** for closing operations;
- The time between reaching the intermediate position and reaching the final position must not exceed the maximum allowed time for the breaker pole to remain in the intermediate state, defined in setting **FilteringTime**.
- The time between the command release and the time instant the final position is reached must not exceed the maximum allowed time for operation to complete, defined in settings **MaxOpenOpTime** for opening operations and **MaxCloseOpTime** for closing operations.

If any of the previous conditions is not met, a fail indication is signaled, in function output **OpenFailure** (in case of open commands) or **CloseFailure** (for close commands). Figure 5.78 depicts the monitoring of circuit breaker operation.

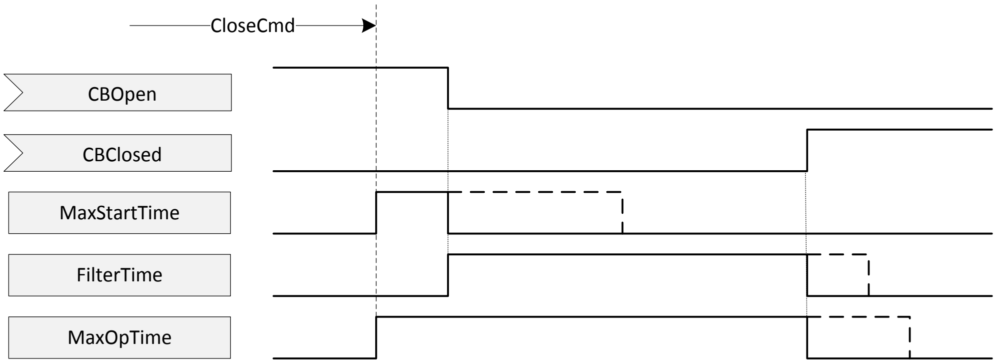

Figure 5.78. Circuit breaker operation monitoring.

The total number of open operations performed by the circuit breaker is available in the function output **OpCounter**. Its value is kept in non-volatile memory. If this counter exceeds a maximum number of open operations set by the user in setting **MaxOpCounter**, the alarm indication **OpCounterAlarm** is issued.

Switch Currents Monitoring

The switched currents are also monitored if one analogue channel, associating three phase current signals, is connected to the function input **I**.

The last current switched by each pole of the circuit breaker is available in outputs **SwitchCurrA**, **SwitchCurrB** and **SwitchCurrC**, in kA. For each pole, the total sum of the switched currents raised to a power configurable by the user (setting **SwitchCurrExponent**)is also updated after each open operation and made available in outputs **SwitchCurrSumA**, **SwitchCurrSumB** and **SwitchCurrSumC**. By default, these outputs will display the total sum of the squared switched currents (*i.e.*, the default value for setting **SwitchCurrExponent** is 2). Their values are represented as 64-bit counters, in kA^2. All these values are persistent and kept in non-volatile memory.

If at least one of the counters relative to the sum of squared currents exceeds the maximum threshold defined in setting **MaxSwitchCurrSum**, the alarm indication **SwitchCurrAlarm** is issued.

All statistics (number of open operations, switched currents, and sum of the squared switched currents) can be simultaneously reset by issuing a control order over entity **ResetStatistics**.

Open Pole Monitoring

The Circuit Breaker Supervision function monitors discordant pole situations – if one (only one) of the poles remains open longer than a configurable time interval (setting **MaxOpenPoleTime**), the **OpenPoleAlarm** indication is signalled.

The pole discrepancy indication provided by the circuit breaker is also monitored by the function in the input **OpenPole**. If a pole discrepancy condition is detected this way, the **OpenPoleAlarm** indication is signalled instantly.

Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **CBOpen** and **CBClosed** inputs are both disconnected and neither all **CBOpenx** nor all **CBClosedx** are connected.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The **CBOpen** input and any **CBOpenx** inputs are connected simultaneously;
- The **CBClosed** input and any **CBClosedx** inputs are connected simultaneously;
- Only one or two **CBOpenx** inputs are connected;
- Only one or two **CBClosedx** inputs are connected.

The configuration is valid and the function operates accordingly otherwise.

5.33.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.109 and Table 5.110, respectively.

Table 5.109. Circuit Breaker Supervision function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
Local	Local	DIG	1	Local control
BlockOpen	Block Open	DIG	12	Block opening
BlockClose	Block Close	DIG	12	Block closing
CBOpenA	CB PhA Open	DIG	1	Circuit breaker phase A open
CBOpenB	CB PhB Open	DIG	1	Circuit breaker phase B open
CBOpenC	CB PhC Open	DIG	1	Circuit breaker phase C open
CBOpen	CB Open	DIG	1	Circuit breaker open
CBClosedA	CB PhA Closed	DIG	1	Circuit breaker phase A closed
CBClosedB	CB PhB Closed	DIG	1	Circuit breaker phase B closed
CBClosedC	CB PhC Closed	DIG	1	Circuit breaker phase C closed
CBClosed	CB Closed	DIG	1	Circuit breaker closed
CmdOpenA	PhA Open Cmd	DIG	6	Phase A open command
CmdOpenB	PhB Open Cmd	DIG	6	Phase B open command
CmdOpenC	PhC Open Cmd	DIG	6	Phase C open command
CmdOpen	Cmd Open	DIG	6	Open command
CmdClose	Cmd Close	DIG	4	Close command
OpenPole	Open Pole	DIG	2	Open pole

Table 5.110. Circuit Breaker Supervision function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Local	Local	DIG	-	Local control behavior
BlockedOpenA	PhA Open Blocked	DIG CTRL	-	Phase A open command blocked
BlockedOpenB	PhB Open Blocked	DIG CTRL	-	Phase B open command blocked
BlockedOpenC	PhC Open Blocked	DIG CTRL	-	Phase B open command blocked
BlockedCloseA	PhA Close Blocked	DIG CTRL	-	Phase A Close command blocked
BlockedCloseB	PhB Close Blocked	DIG CTRL	-	Phase B Close command blocked
BlockedCloseC	PhC Close Blocked	DIG CTRL	-	Phase C Close command blocked
PositionA	PhA Position	DB CTRL	-	Phase A circuit breaker position
PositionB	PhB Position	DB CTRL	-	Phase B circuit breaker position

Identifier	Title	Type	NV	Description
PositionC	PhC Position	DB CTRL	-	Phase C circuit breaker position
Position	Position	DB CTRL	-	Circuit breaker position
CmdOpenA	PhA Open Cmd	DIG	-	Phase A open command
CmdOpenB	PhB Open Cmd	DIG	-	Phase B open command
CmdOpenC	PhC Open Cmd	DIG	-	Phase C open command
CmdClose	Cmd Close	DIG	-	Close command
OpenFailure	Open Failure	DIG	-	Opening operation failure
CloseFailure	Close Failure	DIG	-	Closing operation failure
OpenOpTimeAms	Open Op Time A (ms)	INT	Yes	Time of last open operation in ms, phase A
OpenOpTimeBms	Open Op Time B (ms)	INT	Yes	Time of last open operation in ms, phase B
OpenOpTimeCms	Open Op Time C (ms)	INT	Yes	Time of last open operation in ms, phase C
CloseOpTimeAms	Close Op Time A (ms)	INT	Yes	Time of last close operation in ms, phase A
CloseOpTimeBms	Close Op Time B (ms)	INT	Yes	Time of last close operation in ms, phase B
CloseOpTimeCms	Close Op Time C (ms)	INT	Yes	Time of last close operation in ms, phase C
OpCounterA	PhA Op Counter	INT CTRL	Yes	Phase A operation counter
OpCounterB	PhB Op Counter	INT CTRL	Yes	Phase B operation counter
OpCounterC	PhC Op Counter	INT CTRL	Yes	Phase C operation counter
SwitchCurrA	Switch IA	ANL	Yes	Current interrupted during last open operation, phase A
SwitchCurrB	Switch IB	ANL	Yes	Current interrupted during last open operation, phase B
SwitchCurrC	Switch IC	ANL	Yes	Current interrupted during last open operation, phase C
SwitchCurrSumA	Switch I2A Sum	CNT	Yes	Sum of squared switched currents, phase A
SwitchCurrSumB	Switch I2B Sum	CNT	Yes	Sum of squared switched currents, phase B
SwitchCurrSumC	Switch I2C Sum	CNT	Yes	Sum of squared switched currents, phase C
RemainingOpA	Remaining Op A	INT CTRL	Yes	Number of remaining opening operations, phase A
RemainingOpB	Remaining Op B	INT CTRL	Yes	Number of remaining opening operations, phase B
RemainingOpC	Remaining Op C	INT CTRL	Yes	Number of remaining opening operations, phase C
ContactWearA	Contact Wear A (%)	ANL	-	Percentage of contact wear, phase A
ContactWearB	Contact Wear B (%)	ANL	-	Percentage of contact wear, phase B
ContactWearC	Contact Wear C (%)	ANL	-	Percentage of contact wear, phase C
OpTimeh	Op Time (h)	INT CTRL	Yes	Time since installation or last maintenance in hours
OpenPoleAlarm	Open Pole Alarm	DIG	-	Open pole alarm
OpCounterAlarm	Op Counter Alarm	DIG	-	Maximum allowed opening operations exceeded
SwitchCurrAlarm	Switch Curr Alarm	DIG	-	Maximum allowed squared switched currents sum exceeded

Identifier	Title	Type	NV	Description
ContactWearWarning	Contact Wear Warn	DIG	-	Contact wear warning level reached
ContactWearAlarm	Contact Wear Alarm	DIG	-	Contact wear alarm level reached
PauseStatistics	Pause Statistics	DIG CTRL	Yes	Pause/Resume statistics
ResetStatistics	Reset Statistics	DIG CTRL	-	Reset statistics

5.33.4 Settings

The function settings are listed in Table 5.111.

Table 5.111. Circuit Breaker Supervision function settings.

Identifier	Title	Range	Factory value	Description
AdaptivePulse	Adaptive Pulse	OFF / ON	OFF	Adaptive pulse
MinOpenCmdTime	Min Open Cmd Time	[10..60000] ms	200	Minimum open command pulse time
MinCloseCmdTime	Min Close Cmd Time	[10..60000] ms	200	Minimum close command pulse time
NumCloseRetries	Num Close Retries	[1..500]	1	Number of close retries for automatic commands
CloseRetryInterval	Close Retry Interv	[1..60] s	15	Time interval between reclose retries
IntermediateState	Intermediate State	HIDE / SHOW	HIDE	Show intermediate position
FilterTime	Filter Time	[0..60000] ms	1000	Intermediate position filtering time
MaxOpenStartTime	Max Open Str Time	[0..60000] ms	100	Maximum allowed time for movement to start in an opening operation
MaxCloseStartTime	Max Close Str Time	[0..60000] ms	100	Maximum allowed time for movement to start in a closing operation
MaxOpenOpTime	Max Open Op Time	[0..60000] ms	1000	Maximum allowed time for opening operation
MaxCloseOpTime	Max Close Op Time	[0..60000] ms	1000	Maximum allowed time for closing operation
OpenOpTimeCorrA	Open Op Time Corr A	[0..500] ms	0	Opening operation time correction, phase A
OpenOpTimeCorrB	Open Op Time Corr B	[0..500] ms	0	Opening operation time correction, phase B
OpenOpTimeCorrC	Open Op Time Corr C	[0..500] ms	0	Opening operation time correction, phase C
CloseOpTimeCorrA	Close Op Time Corr A	[0..500] ms	0	Closing operation time correction, phase A
CloseOpTimeCorrB	Close Op Time Corr B	[0..500] ms	0	Closing operation time correction, phase B

Identifier	Title	Range	Factory value	Description
CloseOpTimeCorrC	Close Op Time Corr C	[0..500] ms	0	Closing operation time correction, phase C
MaxOpenPoleTime	Max Open Pole Time	[0..60000] ms	1000	Maximum allowed time for the open pole state
MaxOpCounter	Max Op Counter	[1..100000]	5000	Maximum allowed opening operations
SwitchCurrExponent	Switch Curr Exp	[1.0..3.0]	2.0	Exponent for switched currents sum
MaxSwitchCurrSum	Max Switch Curr Sum	[1,0..99999] kA^2	100,0	Maximum allowed squared switched currents sum
RatedOpCurr	Rated Op Curr	[0.05..25] kA	1.0	Rated operational current
MaxOpRated	Max Op Rated	[10..100000]	10000	Number of supported opening operations at rated current
MaxFaultCurr	Max Fault Curr	[0.1..100] kA	10.0	Maximum interruptable fault current
MaxOpFault	Max Op Fault	[1..10000]	100	Number of supported opening operations at maximum fault current
RefCurrMult	Ref Curr Mult	[0.1..100]	0.1	Rated operational current multiplier used as reference for contact wear monitoring
WearMonitCriterion	Wear Monit Criteria	NONE / REMAINING OPERATIONS ALARM / REMAINING OPERATIONS WARNING / CONTACT WEAR ALARM / CONTACT WEAR WARNING	NONE	Contact wear monitoring criterion
WearWarningLevel	Wear Warning Level	[1..10000]	5	Contact wear warning level
WearAlarmLevel	Wear Alarm Level	[1..10000]	1	Contact wear alarm level

5.34 Circuit Switch Control

5.34.1 Introduction

The Circuit Switch Control function is responsible for the management of both manual and automatic open and close commands issued over a specific circuit switch, centralizing all the necessary information required to block or release them. This includes accessing interlocking status, and supervising distinct blocking conditions, according to the type and origin of the command.

5.34.2 Operation Method

Circuit Switch Status

The circuit switch status is permanently available in function output **Position**. It is represented as a double status entity. In case of three-phase controllable circuit switches, its value directly mirrors the function input **Position**.

The **Position** input can be associated, for instance, to the corresponding output of the Circuit Switch Supervision function (please refer to section 5.35 - Circuit Switch Supervision). All value and quality changes in circuit switch position are correctly time tagged, according to the time tag of the input entity. The originator of the last command issued over the circuit switch is also available in the corresponding field of output **Position**.

Command Processing

Circuit switch open and close commands should be executed over the double status controllable output **Position**. Several conditions are then evaluated in order to release or reject the command:

- The command is rejected if the circuit switch is already in the intended position.
- The switching hierarchy is managed according to the rules presented in subsection 5.1.4 - Control Authority Management.
- Open and close command blocking conditions are evaluated, according to the status of the corresponding function inputs that are described below.
- Specific interlocking release conditions can be programmed in user-defined functions and associated to the respective inputs. Independent interlocking conditions can be defined for open (function input **InterlockEnableOpen**) and close (function input **InterlockEnableClose**) operations.

After evaluating all the previous conditions, if the command is finally released by the Circuit Switch Control function, a pulse is issued in one of **CmdOpen** or **CmdClose** outputs, for open or close commands respectively. Otherwise, a cause of rejection is indicated (see Table 5.103).

Table 5.112. Causes of rejection of circuit switch commands.

Identifier	Value	Description
UNKNOWN	0	Unknown cause
BLOCKED BY SWITCHING HIERARCHY	2	At least one level with lower switching hierarchy in local mode
POSITION REACHED	5	Switch already in the intended position
BLOCKED BY MODE	8	Blocked by actual operation mode
BLOCKED BY PROCESS	9	Blocked due to some external event at process level
BLOCKED BY INTERLOCKING	10	Blocked due to interlocking of switching devices
COMMAND ALREADY IN EXECUTION	12	Control action already in execution
BLOCKED BY HEALTH	13	Blocked due to some internal event that prevents a successful operation

Identifier	Value	Description
NONE	25	No cause of rejection; control executed

The number of open commands executed is available in function output **OpCounter**. This counter can be reset by the user at any time, by executing a control order over that entity. Its initial value can be freely defined.

Blocking Conditions

The function provides distinct open and close command blocking conditions, for distinct command origins. Any of them can be freely associated to any user-defined condition.

The blocking conditions can be independently defined according to the origin of the command: local manual commands (**BlockManLocOpen** and **BlockManLocClose**), remote manual commands (**BlockRemLocOpen** and **BlockRemLocClose**) and automatic commands (**BlockAutOpen** and **BlockAutClose**). There are also general blocking conditions (**BlockOpen** and **BlockClose**) that block all commands, irrespective of its origin.

Two additional block inputs (**BlockProcessOpen** and **BlockProcessClose**) are available, and allow the association of specific blocking conditions related to the process. Although the blocking conditions related to the process should be directly associated at the process level (to see how, please consult section 5.35 - Circuit Switch Supervision), they should also be associated to these inputs of the Circuit Switch Control function, so that the control can be immediately rejected and the cause of rejection is reported accordingly if those conditions are active.

Function Health

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The three-phase (**Position**) status input is not connected: the function will not have access to the circuit switch position, therefore the **Position** output will present an invalid status (**VALUE** = **BAD STATE**; **QUALITY** = **INVALID**; **ORIGIN** = **NOT SUPPORTED**).

The configuration is valid and the function operates accordingly otherwise.

5.34.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.104 and Table 5.105, respectively.

Table 5.113. Circuit Switch Control function inputs.

Identifier	Title	Type	Mlt	Description
BlockOpen	Block Open	DIG	4	Block opening
BlockClose	Block Close	DIG	4	Block closing
BlockManLocOpen	Block Man Loc Open	DIG	2	Block manual local open commands
BlockManLocClose	Block Man Loc Close	DIG	2	Block manual local close commands
BlockManRemOpen	Block Man Rem Open	DIG	2	Block manual remote open commands
BlockManRemClose	Block Man Rem Close	DIG	2	Block manual remote close commands
BlockAutOpen	Block Aut Open	DIG	2	Block automatic open commands
BlockAutClose	Block Aut Close	DIG	2	Block automatic close commands
BlockProcessOpen	Block Process Open	DIG	2	Block opening due to external event at process level
BlockProcessClose	Block Process Close	DIG	2	Block closing due to external event at process level
Position	Position	DB DIG	1	Circuit switch position

Identifier	Title	Type	Mlt	Description
InterlockEnableOpen	Interlock Ena Open	DIG	1	Open command allowed by interlock conditions
InterlockEnableClose	Interlock Ena Close	DIG	1	Close command allowed by interlock conditions

Table 5.114. Circuit Switch Control function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Position	Position	DB CTRL	-	Circuit switch position
CmdOpen	Cmd Open	DIG	-	Circuit switch open command
CmdClose	Cmd Close	DIG	-	Circuit switch close command
OpCounter	Op Counter	INT CTRL	Yes	Operation counter

5.34.4 Settings

This function has no associated settings.

5.35 Circuit Switch Supervision

5.35.1 Introduction

The Circuit Switch Supervision function is responsible for controlling and monitoring a certain circuit switch. Namely, it is responsible for:

- Acquiring the circuit switch state from the process level and providing it to other functions;
- Processing manual and automatic commands, and operating the circuit switch according to them;
- Supervising the correct operation of the circuit switch;
- Monitoring the circuit switch wear by assessing the number of operations.

5.35.2 Operation Method

Circuit Switch Status

The circuit switch status is permanently available in function output **Position**. It is represented as a double status entity, whose value is calculated from the state of the circuit switch auxiliary contacts (function inputs **SWOpen**, which should be connected to the Normally Closed contact 89b, and **SWClosed**, which should be connected to the Normally Open contact 89a). These contacts are usually acquired directly from the process via binary inputs but they can also be received through a communication link (for instance, using GOOSE messages).

Typically both contacts are accessible and they complement each other. When the circuit switch is in movement, from open to closed position (or vice-versa), both contacts are temporarily zero, which is called the intermediate state. The user can choose to display this state always or, in option, hide it for a maximum amount of time defined in setting **FilterTime**, which should be configured with a value long enough for the circuit switch to reach the final position. This option can be set in setting **IntermediateState**. If the intermediate state filter is active and the circuit switch does not reach the final position in less than **FilterTime**, the intermediate state is reported when the timer expires.

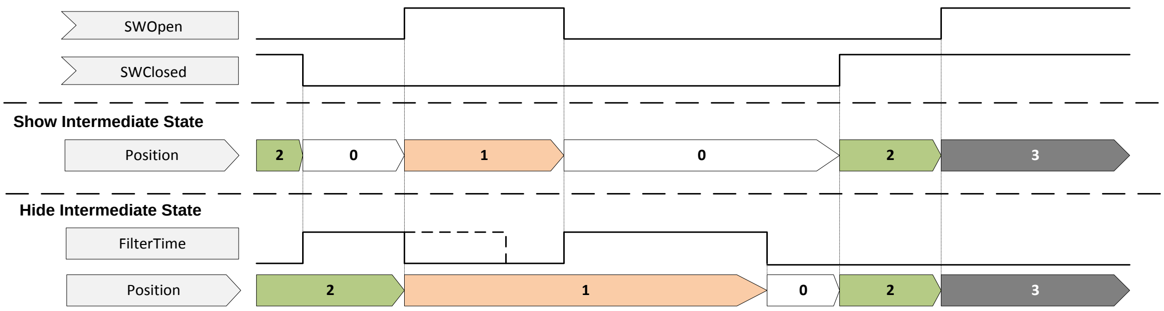

Figure 5.79. Intermediate filter.

The function is also prepared to work if only one of the auxiliary contacts is available. In this last case, the **Position** output is directly calculated from the available contact (negated if the contact that is available is **SWOpen**). The intermediate state is not available in this case. Table 5.111 shows how **Position** is calculated in all possible cases.

The quality attribute associated to **Position** is updated according to the quality attribute of the corresponding input contacts. All value and quality changes in circuit switch position are correctly time tagged, according to the time tag of the input entities. The originator of the last command issued over the circuit switch is also available in the corresponding field of output **Position**.

Table 5.115. Circuit switch position.

	SWOpen = 1 SWClosed = 0	SWOpen = 0 SWClosed = 0	SWOpen = 0 SWClosed = 1	SWOpen = 1 SWClosed = 1
SWOpen and SWClosed	OFF	INTERMEDIATE	ON	BAD STATE
Only SWOpen	OFF	ON	ON	OFF
Only SWClosed	OFF	OFF	ON	ON

Command Processing

Circuit switch open and close commands are received for processing by the function in inputs **CmdOpen** and **CmdClose**, respectively. They correspond to pulses originating from manual and automatic commands (see section 5.34 - Circuit Switch Control). The open and close commands can also be issued directly over the double status controllable output **Position**, namely for test purposes.

Only process related conditions are evaluated at the level of the Circuit Switch Supervision function; other checks should have been performed by the function that has issued the command pulse.

- The command is rejected if a previous command is already in execution.
- The command is rejected if manual control is selected at the circuit switch (process level), and if this indication is associated to the function input **Local**.
- The command is rejected if it is blocked by some specific condition.

The function provides individual inputs for open and close command blocking conditions (**BlockOpen** and **BlockClose**). Any of them can be freely associated to any user-defined condition. They should be typically used for specific blocking conditions related to the process. If the open or close operations are blocked, this is signalled in the corresponding output (**BlockedOpen** or **BlockedClose**).

Open/Close Signals

After evaluating all the previous conditions, if the command is finally released by the Circuit Switch Supervision function, a pulse is issued in one of **CmdOpen** or **CmdClose** outputs, for open or close commands respectively.

The pulse duration can be set by the user, for open commands in setting **MinOpenCmdTime**, for close commands in setting **MinCloseCmdTime**. The pulse duration defined by the previous settings can be fixed (equal to the value defined) or adaptive, if setting **AdaptivePulse** is **ON**. With this option selected the command pulse will be extended until the circuit switch reaches the final position, as depicted in Figure 5.77.

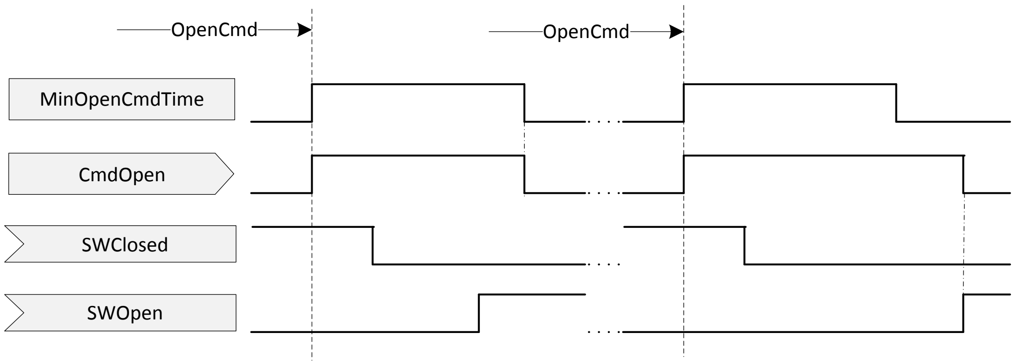

Figure 5.80. Circuit switch command with adaptive pulse.

> The adaptive pulse option should only be used if the indication of manual control selected at circuit switch is associated to the input **Local** and if the function has access to all conditions that may block circuit switch operation at process level, namely mechanical locks.

Operation Monitoring

The success of the circuit switch operation is supervised by the function. Three distinct checks are performed:

- The time between the command release and the time instant the intermediate position is reached must not exceed the maximum allowed time for movement to start, defined in setting **MaxStartTime**;
- The time between reaching the intermediate position and reaching the final position must not exceed the maximum allowed time for the switch to remain in the intermediate state, defined in setting **FilteringTime**.
- The time between the command release and the time instant the final position is reached must not exceed the maximum allowed time for operation to complete, defined in setting **MaxOpTime**.

If any of the previous conditions is not met, a fail indication is signaled, in function output **OpenFailure** (in case of open commands) or **CloseFailure** (for close commands). Figure 5.78 depicts the monitoring of circuit switch operation.

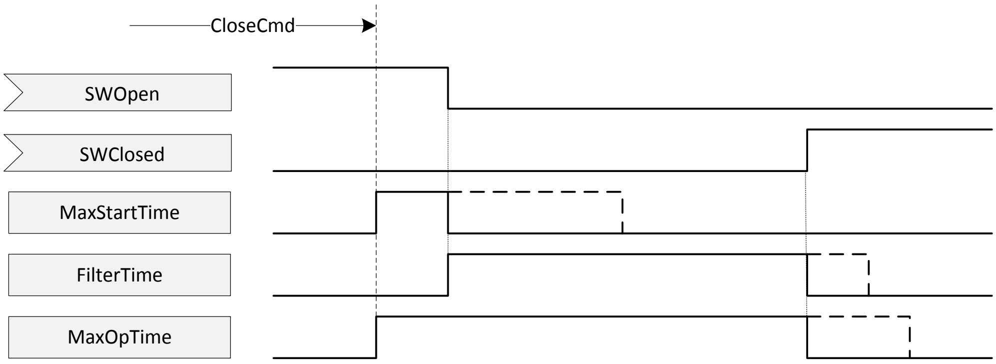

Figure 5.81. Circuit switch operation monitoring.

The total number of open operations performed by the circuit switch is available in the function output **OpCounter**. Its value is kept in non-volatile memory. If this counter exceeds a maximum number of open operations set by the user in setting **MaxOpCounter**, the alarm indication **OpCounterAlarm** is issued.

Health

The function does not operate and its output **Health** is set to Alarm status if:

- The **SWOpen** and **SWClosed** inputs are both disconnected.

The configuration is valid and the function operates accordingly otherwise.

5.35.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.109 and Table 5.110, respectively.

Table 5.116. Circuit Switch Supervision function inputs.

Identifier	Title	Type	Mlt	Description
Local	Local	DIG	1	Local control
BlockOpen	Block Open	DIG	4	Block opening
BlockClose	Block Close	DIG	4	Block closing
SWOpen	SW Open	DIG	1	Circuit switch open
SWClosed	SW Closed	DIG	1	Circuit switch closed
CmdOpen	Cmd Open	DIG	4	Open command

Identifier	Title	Type	Mlt	Description
CmdClose	Cmd Close	DIG	4	Close command

Table 5.117. Circuit Switch Supervision function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Local	Local	DIG	-	Local control behavior
BlockedOpen	Blocked Open	DIG CTRL	-	Open command blocked
BlockedClose	Blocked Close	DIG CTRL	-	Close command blocked
Position	Position	DB CTRL	-	Circuit switch position
CmdOpen	Cmd Open	DIG	-	Open command
CmdClose	Cmd Close	DIG	-	Close command
OpenFailure	Open Failure	DIG	-	Opening operation failure
CloseFailure	Close Failure	DIG	-	Closing operation failure
OpCounter	Op Counter	INT CTRL	Yes	Opening operation counter
OpCounterAlarm	Op Counter Alarm	DIG	-	Maximum allowed opening operations exceeded

5.35.4 Settings

The function settings are listed in Table 5.111.

Table 5.118. Circuit Switch Supervision function settings.

Identifier	Title	Range	Factory value	Description
AdaptivePulse	Adaptive Pulse	OFF / ON	OFF	Adaptive pulse
MinOpenCmdTime	Min Open Cmd Time	[10..60000] ms	10000	Minimum open command pulse time
MinCloseCmdTime	Min Close Cmd Time	[10..60000] ms	10000	Minimum close command pulse time
IntermediateState	Intermediate State	HIDE / SHOW	HIDE	Show intermediate position
FilterTime	Filter Time	[0..60000] ms	10000	Intermediate position filtering time
MaxStartTime	Max Start Time	[0..60000] ms	1000	Maximum allowed time for movement to start
MaxOpTime	Max Op Time	[0..60000] ms	0	Maximum allowed time for operation

Identifier	Title	Range	Factory value	Description
MaxOpCounter	Max Op Counter	[1..100000]	5000	Maximum allowed opening operations

5.36 THREE-PHASE MEASUREMENTS

5.36.1 INTRODUCTION

The Three-Phase Measurements function is responsible for the continuous update of all measured values relative to a three-phase power system.

The function outputs are derived from the a.c. current and voltage inputs of the TPU L500 and are calculated with very high accuracy, which allows avoiding a set of separate measuring instruments. The measured values can be accessed in the Local HMI or the embedded webserver and can be configured to be reported to the station and remote control levels through a communication protocol. They can also be the inputs of user-defined logic schemes implemented locally in the device or distributed by a set of different devices in the same LAN.

The function outputs can also be used as effective diagnostic information, enabling the identification of eventual CT and VT connection errors during commissioning as well as the validation of the adequate CT orientation for other protection and control functions. The function can also be used to access the power system present status and to detect some abnormal condition of the analogue measuring circuits of the TPU L500 during normal system operation.

5.36.2 OPERATION METHOD

The Three-Phase Measurements function accepts a maximum of three phase currents (function input **I**) and three phase-to-earth or phase-to-phase voltages (function input **U**) but other configuration scenarios with less analogue signals are also possible, enabling its flexible application in any CT or VT connection scheme.

Additionally, it is possible to connect a fourth neutral current input (**I0**) and a fourth neutral voltage input (**U0**) if available. The neutral current input will be typically obtained from an independent phase-balance neutral current transformer or from an external Holmgreen connection. The typical application for the neutral voltage input is an independent open-delta connected winding for residual voltage measurement.

In order to preserve coherence among the several function outputs, the neutral inputs should only be connected if they are closely related to the three-phase power system channels connected to the main inputs, *i.e.* if they were acquired in the same power system location.

Otherwise, an extra Single-Phase Measurements function (see section 5.37 - Single-Phase Measurements) should be preferably used to calculate their measured values.

The number of calculated measured values depends on the specific input configuration. Some output values may not be available if they require an input that is not present in the configuration.

Measuring Process

The function periodically evaluates the configured analogue channels and updates all measured value outputs that are possible to calculate. The measuring process is executed according to the following sequence:

- The analogue channels are first compensated for deterministic magnitude and phase angle errors in the TPU L500 measuring circuit, using the factors resultant from the calibration process executed in factory.
- The several quantities are calculated based on the calibrated inputs.
- For each output an average of the measured values for several consecutive time instants is obtained, in order to eliminate non-deterministic errors. The outputs are provided in a one second time basis.
- If configured for that, some measurements can be monitored and additional magnitude range information provided (please refer to subsection 4.1.2 - Measurement Entities for details).

Magnitude and Phase Angle Information

All measured values correspond to the RMS fundamental (phasor information). The magnitude of all quantities is provided in primary values, taking into account the corresponding CT or VT ratio that should be configured in the appropriate analogue channel (see subsection 4.4.3 - Channels).

For some quantities the phase angle is calculated besides the corresponding magnitude. The phasor information from this function can be directly compared with the measured values from other functions because one specific analogue input is used as a common phase angle reference for all built-in functions in the device (please refer to subsection 4.4.1 - Physical Configuration).

Analogue Input Orientation

The CT or VT polarity is directly defined in the channel that is connected to a specific function input. The exact configuration can be consulted in subsection 4.4.3 - Channels. The user can thus define the direction of each analogue signal so that it matches the direction into the power system object.

For further flexibility, the directional convention used by the Three-Phase Measurements function for active and reactive power values can be reversed relatively to the convention (into the power system object) used by all other functions. This can be done by changing setting **InvertOrientation** to **ON**; it can be useful for example in the case of the secondary winding of power transformers, when the intended direction for protection functions is into the transformer but for power measurement purposes is out of the transformer (into the bus, *i.e.* in the load direction). This is depicted in Figure 5.82.

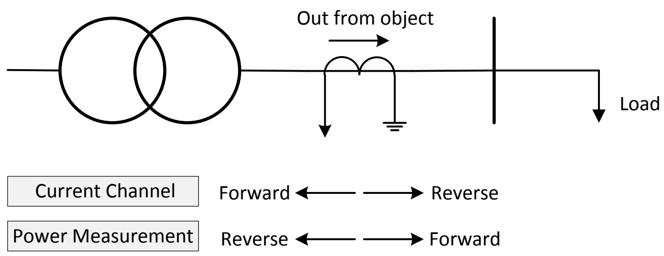

Figure 5.82. Direction reversal for power measurement function.

Current Measurements

Both magnitude and phase angle information is provided for all the phase current signals contained in the corresponding analogue channel.

The maximum, minimum and the arithmetic average of the three phase current magnitudes is also provided.

$$I_{\max} = Max\left(\left|\bar{I}_A\right|, \left|\bar{I}_B\right|, \left|\bar{I}_C\right|\right) \quad (5.74)$$

$$I_{\min} = Min\left(\left|\bar{I}_A\right|, \left|\bar{I}_B\right|, \left|\bar{I}_C\right|\right) \quad (5.75)$$

$$I_{avg} = Avg\left(\left|\bar{I}_A\right|, \left|\bar{I}_B\right|, \left|\bar{I}_C\right|\right) \quad (5.76)$$

Additionally, the residual current is calculated if all the three phase currents are available.

$$\bar{I}_{res} = \bar{I}_A + \bar{I}_B + \bar{I}_C \quad (5.77)$$

Voltage Measurements

Both magnitude and phase angle information is provided for all the phase-to-earth or phase-to-phase voltage signals contained in the corresponding analogue channel. The phase-to-phase measured values are also calculated in the case of phase-to-earth voltage input signals.

The maximum, minimum and the arithmetic average of the three phase-to-earth and of the three phase-to-phase voltage magnitudes is also provided.

$$U_{ph,\max} = Max\left(\left|\overline{U}_A\right|, \left|\overline{U}_B\right|, \left|\overline{U}_C\right|\right) \quad (5.78)$$

$$U_{ph,\min} = Min\left(\left|\overline{U}_A\right|, \left|\overline{U}_B\right|, \left|\overline{U}_C\right|\right) \quad (5.79)$$

$$U_{ph,avg} = Avg\left(\left|\overline{U}_A\right|, \left|\overline{U}_B\right|, \left|\overline{U}_C\right|\right) \quad (5.80)$$

$$U_{ph-ph,\max} = Max\left(\left|\overline{U}_{AB}\right|, \left|\overline{U}_{BC}\right|, \left|\overline{U}_{CA}\right|\right) \quad (5.81)$$

$$U_{ph-ph,\min} = Min\left(\left|\overline{U}_{AB}\right|, \left|\overline{U}_{BC}\right|, \left|\overline{U}_{CA}\right|\right) \quad (5.82)$$

$$U_{ph-ph,avg} = Avg\left(\left|\overline{U}_{AB}\right|, \left|\overline{U}_{BC}\right|, \left|\overline{U}_{CA}\right|\right) \quad (5.83)$$

Additionally, the residual voltage is calculated if all the three phase-to-earth voltages are available.

$$\overline{U}_{res} = \overline{U}_A + \overline{U}_B + \overline{U}_C \quad (5.84)$$

Power Measurements

When both current and voltage inputs are available, the total and per phase power measured values are calculated. The power per phase is only evaluated if the corresponding phase current and phase-to-earth voltage signals are available.

The total three-phase power is available in a wider range of possible configurations. Its specific calculation formula depends on the current and voltage signals that are connected to the function. Table 5.119 lists the possible cases.

Table 5.119. Three-phase power calculation.

Voltage signals (available)	Current signals (required)	Power calculation	Description
U_A, U_B, U_C	I_A, I_B, I_C	$\overline{S} = \overline{U}_A \cdot \overline{I}_A^* + \overline{U}_B \cdot \overline{I}_B^* + \overline{U}_C \cdot \overline{I}_C^*$	If all three phase-to-earth voltages are available
U_{AB}, U_{BC}	I_A, I_C	$\overline{S} = \overline{U}_{AB} \cdot \overline{I}_A^* - \overline{U}_{BC} \cdot \overline{I}_C^*$	If two phase-to-phase voltages are available, according to Aron connection (similar for other pair of voltages)
U_{AB}	I_A, I_B	$\overline{S} = \overline{U}_{AB} \cdot \left(\overline{I}_A^* - \overline{I}_B^*\right)$	If only one phase-to-phase voltage is available (similar for U_{BC} or U_{CA})
U_A	I_A	$\overline{S} = 3 \cdot \overline{U}_A \cdot \overline{I}_A^*$	If only one phase-to-earth voltage is available (similar for U_B or U_C)

Only the first two cases provide the exact three-phase power measurement. The last two only give the exact value if one assumes that the system is operating in perfectly symmetrical conditions.

Besides the apparent power, also real and reactive power and power factor measurements are available, both per phase and three-phase.

$$P = \mathrm{Re}\left\{\overline{S}\right\} \quad (5.85)$$

$$Q = \mathrm{Im}\left\{\overline{S}\right\} \quad (5.86)$$

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2} \quad (5.87)$$

$$\cos\varphi = P/S \quad (5.88)$$

The sign of the power factor measurements is attributed according to one of two possible conventions: if setting **PowerFactorSign** has the value **ACTIVE POWER**, the power factor sign is the sign of the corresponding active power measurement (IEC convention); if setting **PowerFactorSign** has the value **LEAD/LAG**, the power factor sign is positive when the corresponding active and reactive power measurements have opposite signs (IEEE convention).

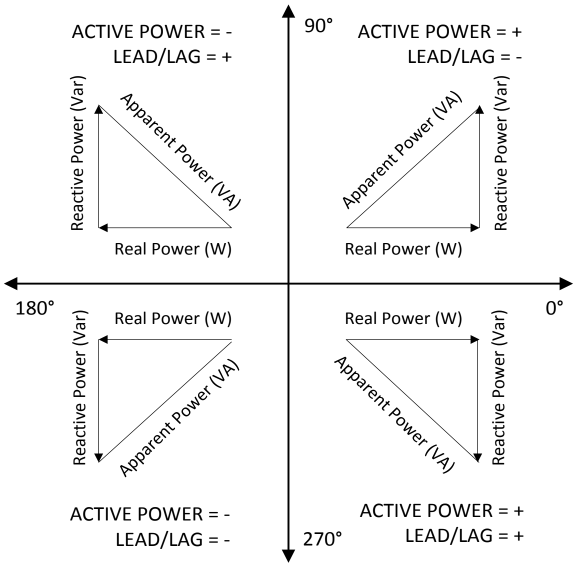

Figure 5.83. Power factor sign conventions.

Impedance Measurements

The impedance is calculated per phase, from the corresponding current and phase-to-earth voltage signals, if available.

$$\bar{Z}_i = \bar{U}_i / \bar{I}_i \qquad (5.89)$$

Frequency Measurement

The frequency is calculated by an independent method during the analogue signal estimation process. It is calculated for each analogue channel (current or voltage) independently. When updating the corresponding function output, one of the input channels is chosen automatically by the function. If both current and voltage inputs are connected, the frequency is always obtained from the voltage channel due to the higher stability of voltage signals.

Symmetrical Components Measurements

If all the three phase current inputs are available, the corresponding symmetrical components can be calculated. The positive sequence, negative sequence and zero sequence components are provided. The same feature applies in the case of voltage inputs, if all three phase-to-earth signals are available. Negative and positive sequence values are also calculated if three phase-to-phase voltages are available.

The symmetrical components give an image of the symmetry of the three-phase power system, together with the residual and neutral quantities, and provide significant diagnostic information concerning the CT or VT connections.

Neutral Measurements

If additional neutral current and/or neutral voltage inputs are connected to the function, their value (both magnitude and phase angle information) is also calculated and available in specific outputs.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- All inputs are disconnected (there are no analogue channels associated to **I**, **U**, **I0**and **U0**).

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There are analogue channels associated to inputs **I** and **U**, but there is not enough information for three-phase power calculation (*e.g.*, only I_A and U_B are available).

The configuration is valid and the function operates accordingly otherwise.

5.36.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.120 and Table 5.121, respectively.

Table 5.120. Three-Phase Measurements function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
I0	I0	ANL CH	-	Neutral current
U	U	ANL CH	-	Phase voltages
U0	U0	ANL CH	-	Neutral voltage

Table 5.121. Three-Phase Measurements function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
CurrentA	IA	CPX ANL	-	Phase A current
CurrentB	IB	CPX ANL	-	Phase B current
CurrentC	IC	CPX ANL	-	Phase C current
ResidualCurrent	Ires	CPX ANL	-	Residual current
NeutralCurrent	Ineut	CPX ANL	-	Neutral current
VoltageA	UA	CPX ANL	-	Phase A voltage
VoltageB	UB	CPX ANL	-	Phase B voltage
VoltageC	UC	CPX ANL	-	Phase C voltage
ResidualVoltage	Ures	CPX ANL	-	Residual voltage
NeutralVoltage	Uneut	CPX ANL	-	Neutral voltage
VoltageAB	UAB	CPX ANL	-	AB phase-to-phase voltage
VoltageBC	UBC	CPX ANL	-	BC phase-to-phase voltage
VoltageCA	UCA	CPX ANL	-	CA phase-to-phase voltage
RealPower	P	ANL	-	Three phase real power
RealPowerA	PA	ANL	-	Phase A real power
RealPowerB	PB	ANL	-	Phase B real power
RealPowerC	PC	ANL	-	Phase C real power
ReactivePower	Q	ANL	-	Three phase reactive power
ReactivePowerA	QA	ANL	-	Phase A reactive power

Identifier	Title	Type	NV	Description
ReactivePowerB	QB	ANL	-	Phase B reactive power
ReactivePowerC	QC	ANL	-	Phase C reactive power
ApparentPower	S	ANL	-	Three phase apparent power
ApparentPowerA	SA	ANL	-	Phase A apparent power
ApparentPowerB	SB	ANL	-	Phase B apparent power
ApparentPowerC	SC	ANL	-	Phase C apparent power
PowerFactor	PF	ANL	-	Three phase power factor
PowerFactorA	PFA	ANL	-	Phase A power factor
PowerFactorB	PFB	ANL	-	Phase B power factor
PowerFactorC	PFC	ANL	-	Phase C power factor
ImpedanceA	ZA	CPX ANL	-	Phase A impedance
ImpedanceB	ZB	CPX ANL	-	Phase B impedance
ImpedanceC	ZC	CPX ANL	-	Phase C impedance
Frequency	Frequency	ANL	-	Frequency
PositiveSeqCurrent	I1	CPX ANL	-	Positive sequence current
NegativeSeqCurrent	I2	CPX ANL	-	Negative sequence current
ZeroSeqCurrent	I0	CPX ANL	-	Zero sequence current
PositiveSeqVoltage	U1	CPX ANL	-	Positive sequence voltage
NegativeSeqVoltage	U2	CPX ANL	-	Negative sequence voltage
ZeroSeqVoltage	U0	CPX ANL	-	Zero sequence voltage
MaxCurrent	Max(IA,IB,IC)	ANL	-	Maximum of the three phase current magnitudes
MinCurrent	Min(IA,IB,IC)	ANL	-	Minimum of the three phase current magnitudes
AvgCurrent	Avg(IA,IB,IC)	ANL	-	Arithmetic average of the three phase current magnitudes
MaxVoltagePE	Max(UA,UB,UC)	ANL	-	Maximum of the three phase-to-earth voltage magnitudes
MinVoltagePE	Min(UA,UB,UC)	ANL	-	Minimum of the three phase-to-earth voltage magnitudes
AvgVoltagePE	Avg(UA,UB,UC)	ANL	-	Arithmetic average of the three phase-to-earth voltage magnitudes
MaxVoltagePP	Max(UAB,UBC,UCA)	ANL	-	Maximum of the three phase-to-phase voltage magnitudes
MinVoltagePP	Min(UAB,UBC,UCA)	ANL	-	Minimum of the three phase-to-phase voltage magnitudes
AvgVoltagePP	Avg(UAB,UBC,UCA)	ANL	-	Arithmetic average of the three phase-to-phase voltage magnitudes

5.36.4 Settings

The function settings are listed in Table 5.122.

Table 5.122. Three-Phase Measurements function settings.

Identifier	Title	Range	Factory value	Description
InvertOrientation	Invert Orientation	OFF / ON	OFF	Invert power orientation
PowerFactorSign	Power Factor Sign	ACTIVE POWER / LEAD/LAG	ACTIVE POWER	Power factor sign

5.37 Single-Phase Measurements

5.37.1 Introduction

The Single-Phase Measurements function is responsible for the continuous update of all measured values relative to a non-phase related current and/or voltage signal. Typical applications are: an a.c. single-phase transmission system; an independent neutral current for earth-fault directional polarization; a neutral voltage obtained from an open-delta connected winding; a separate phase-to-earth or phase-to-phase voltage for synchronism check purposes. The function versatility allows other cases to be configured.

The function outputs are derived from the a.c. current and voltage inputs of the TPU L500 and are calculated with very high accuracy, which allows avoiding a set of separate measuring instruments. The measured values can be accessed in the Local HMI or the embedded webserver and can be configured to be reported to the station and remote control levels through a communication protocol. They can also be the inputs of user-defined logic schemes implemented locally in the device or distributed by a set of different devices in the same LAN.

The function outputs can also be used as effective diagnostic information, enabling the identification of eventual CT and VT connection errors during commissioning as well as the validation of the adequate CT orientation for other protection and control functions. The function can also be used to access the power system present status and to detect some abnormal condition of the analogue measuring circuits of the TPU L500 during normal system operation.

5.37.2 Operation Method

The Single-Phase Measurements function only accepts one single input current channel (function input **I**) and/or one single input voltage channel (function input **U**). Any phase current (or neutral current in option) is allowed, as well as any phase-to-earth or phase-to-phase voltage (or neutral voltage in option).

If the neutral inputs are closely related to other three-phase power system channels, *i.e.* if they were acquired in the same power system location, then they should be preferably connected to the corresponding neutral inputs of a Three-Phase Measurements function (see section 5.36 - Three-Phase Measurements).

The number of calculated measured values depends on the specific input configuration. Some output values may not be available if they require an input that is not present in the configuration.

Measuring Process

The function periodically evaluates the configured analogue channels and updates all measured value outputs that are possible to calculate. The measuring process is executed according to the following sequence:

- The analogue channels are first compensated for deterministic magnitude and phase angle errors in the TPU L500 measuring circuit, using the factors resultant from the calibration process executed in factory.
- The several quantities are calculated based on the calibrated inputs.
- For each output an average of the measured values for several consecutive time instants is obtained, in order to eliminate non-deterministic errors. The outputs are provided in a one second time basis.
- If configured for that, some measurements can be monitored and additional magnitude range information provided (please refer to subsection 4.1.2 - Measurement Entities for details).

Magnitude and Phase Angle Information

All measured values correspond to the RMS fundamental (phasor information). The magnitude of all quantities is provided in primary values, taking into account the corresponding CT or VT ratio that should be configured in the appropriate analogue channel (see subsection 4.4.3 - Channels).

For some quantities the phase angle is calculated besides the corresponding magnitude. The phasor information from this function can be directly compared with the measured values from other functions because one specific analogue input is used as a common phase angle reference for all built-in functions in the device (please refer to subsection 4.4.1 - Physical Configuration).

Analogue Input Orientation

The CT or VT polarity is directly defined in the channel that is connected to a specific function input. The exact configuration can be consulted in subsection 4.4.3 - Channels. The user can thus define the direction of each analogue signal so that it matches the direction into the power system object.

For further flexibility, the directional convention used by the Single-Phase Measurements function for active and reactive power values can be reversed relatively to the convention (into the power system object) used by all other functions. This can be done by changing setting **InvertOrientation** to **ON**.

Current Measurements

Both magnitude and phase angle information is provided for the current signal contained in the corresponding analogue channel.

Voltage Measurements

Both magnitude and phase angle information is provided for the voltage signal contained in the corresponding analogue channel.

Power Measurements

When both current and voltage inputs are available, the power is calculated in two cases: if it is a phase-to-earth voltage and it corresponds to the same phase as the current signal; if both are neutral quantities. In this last case, the following formula corresponds to the residual power.

$$\bar{S} = \bar{U} \cdot \bar{I}^* \tag{5.90}$$

Besides the apparent power, also real and reactive power and power factor measurements are available.

$$P = \mathrm{Re}\{\bar{S}\} \tag{5.91}$$

$$Q = \mathrm{Im}\{\bar{S}\} \tag{5.92}$$

$$S = |\bar{S}| = \sqrt{P^2 + Q^2} \tag{5.93}$$

$$\cos\varphi = P/S \tag{5.94}$$

The sign of the power factor measurement is attributed according to one of two possible conventions: if setting **PowerFactorSign** has the value **ACTIVE POWER**, the power factor sign is the sign of the active power measurement (IEC convention); if setting **PowerFactorSign** has the value **LEAD/LAG**, the power factor sign is positive when the active and reactive power measurements have opposite signs (IEEE convention).

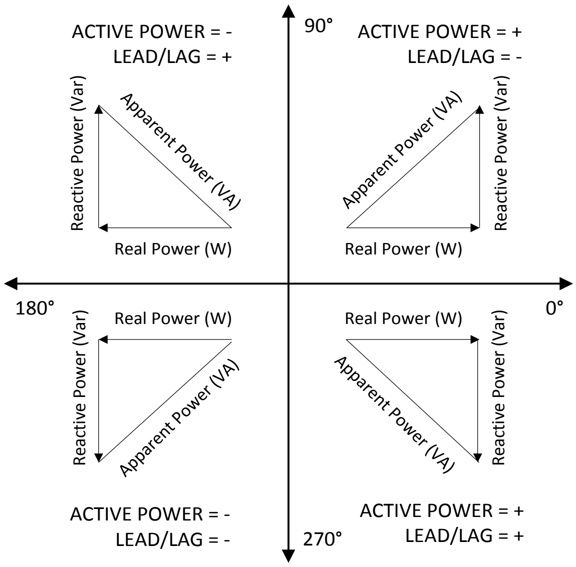

Figure 5.84. Power factor sign conventions.

Impedance Measurements

The impedance is calculated from the current and voltage signals, if both available, in two cases: if it is a phase-to-earth voltage and it corresponds to the same phase as the current signal; if both are neutral quantities.

$$\bar{Z} = \bar{U} / \bar{I} \tag{5.95}$$

Frequency Measurement

The frequency is calculated by an independent method during the analogue signal estimation process. It is calculated for each analogue channel (current or voltage) independently. When updating the corresponding function output, one of the input channels is chosen automatically by the function. If both current and voltage inputs are connected, the frequency is always obtained from the voltage channel due to the higher stability of voltage signals.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- All inputs are disconnected (there are no analogue channels associated to **I** and **U**).

The function operates with possible limitations and its output **Health** is set to Warning status if:

- There are analogue channels associated to inputs **I** and **U**, but there is not enough information for power calculation (*e.g.*, the current and voltage signals correspond to different phases).

The configuration is valid and the function operates accordingly otherwise.

5.37.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.123 and Table 5.124, respectively.

Table 5.123. Single-Phase Measurements function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Current
U	U	ANL CH	-	Voltage

Table 5.124. Single-Phase Measurements function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
Current	I	CPX ANL	-	Current
Voltage	U	CPX ANL	-	Voltage
RealPower	P	ANL	-	Real power
ReactivePower	Q	ANL	-	Reactive power
ApparentPower	S	ANL	-	Apparent power
PowerFactor	PF	ANL	-	Power factor
Impedance	Z	CPX ANL	-	Impedance
Frequency	Frequency	ANL	-	Frequency

5.37.4 Settings

The function settings are listed in Table 5.125.

Table 5.125. Single-Phase Measurements function settings.

Identifier	Title	Range	Factory value	Description
InvertOrientation	Invert Orientation	OFF / ON	OFF	Invert power orientation
PowerFactorSign	Power Factor Sign	ACTIVE POWER / LEAD/LAG	ACTIVE POWER	Power factor sign

5.38 Three-Phase Metering

5.38.1 Introduction

The Three-Phase Metering function calculates the energy in a three-phase power system, from the a.c. current and voltage inputs of the TPU L500. The available metered values have very high accuracy. However, it is not recommended its use for billing purposes because the external CT cores which are connected to the TPU L500 inputs are usually not the adequate ones for this kind of application. A set of separate dedicated meters is usually required.

The energy counters provided by the TPU L500 are mainly for validation of the metered values calculated by dedicated devices and to complement other power system information available. They can be accessed in the Local HMI or the embedded webserver. They can also be configured to be reported to the station and remote control levels through a communication protocol or be the inputs of user-defined logic schemes.

5.38.2 Operation Method

The Three-Phase Metering function accepts a maximum of three phase currents (function input **I**) and three phase-to-earth or phase-to-phase voltages (function input **U**) but other configuration scenarios with less analogue signals are also possible, enabling its flexible application in any CT or VT connection scheme.

Only analogue channel combinations from which the three-phase power can be derived are accepted as valid configurations. The list of possible cases can be found in Table 5.126.

The exact three-phase energy is only available in the two first cases listed; the last two cases only give the exact value if one assumes that the system is operating in perfectly symmetrical conditions.

Table 5.126. Three-phase power for energy calculation.

Voltage signals (available)	Current signals (required)	Power calculation	Description
U_A, U_B, U_C	I_A, I_B, I_C	$p = u_A \cdot i_A + u_B \cdot i_B + u_C \cdot i_C$	If all three phase-to-earth voltages are available
U_{AB}, U_{BC}	I_A, I_C	$p = u_{AB} \cdot i_A - u_{BC} \cdot i_C$	If two phase-to-phase voltages are available, according to Aron connection (similar for other pair of voltages)
U_{AB}	I_A, I_B	$p = u_{AB} \cdot (i_A - i_B)$	If only one phase-to-phase voltage is available (similar for U_{BC} or U_{CA})
U_A	I_A	$p = 3 \cdot u_A \cdot i_A$	If only one phase-to-earth voltage is available (similar for U_B or U_C)

Energy Counters

The energy counters are calculated by integration of the three-phase power over time. Both real and reactive energy values are available, for forward (*i.e.* demand) as well reverse (*i.e.* supply) direction. The energy in the demand direction is incremented whenever the corresponding power value is positive; the energy in the supply direction whenever the corresponding power value is negative. The total real and reactive energy values are also provided, according to (5.96) and (5.97), as well as the total apparent energy, obtained by integration of the instantaneous apparent power.

$$\text{TotalRealEnergy} = \text{FwdRealEnergy} + \text{RvRealEnergy} \tag{5.96}$$

$$\text{TotalReactiveEnergy} = \text{FwdReactiveEnergy} + \text{RvReactiveEnergy} \tag{5.97}$$

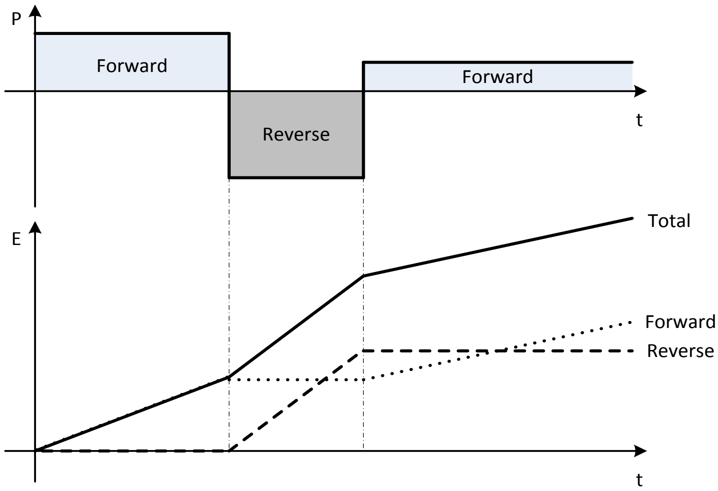

Figure 5.85. Total, forward and reverse energy values.

With the conventions described above, all energy counters are always positive. The instantaneous values are available in 64-bit counters, which enables the representation of very large numbers (please refer to subsection 4.1.2 - Measurement Entities for more details).

The calibrated inputs are used in the metering process which allows for the compensation of deterministic magnitude and phase angle errors in the TPU L500 measuring circuit.

Analogue Input Orientation

The CT or VT polarity is directly defined in the channel that is connected to a specific function input. The exact configuration can be consulted in subsection 4.4.3 - Channels. The user can thus define the direction of each analogue signal so that it matches the direction into the power system object.

For further flexibility, the directional convention used by the Three-Phase Metering function for real and reactive energy (or power) values can be reversed relatively to the convention (into the power system object) used by all other functions. This can be done by changing setting **InvertOrientation** to **ON**; it can be useful for example in the case of the secondary winding of power transformers, when the intended direction for protection functions is into the transformer but for metering purposes is out of the transformer (into the bus, *i.e.* in the load direction). This is depicted in Figure 5.86.

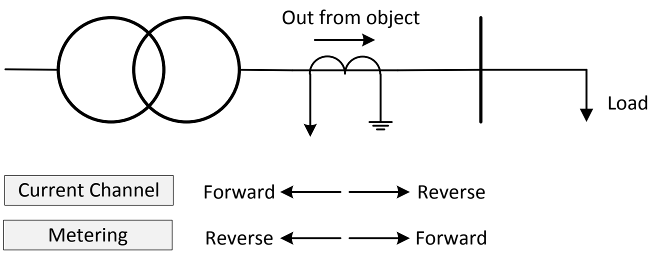

Figure 5.86. Direction reversal for metering function.

Control Over Metering

The metering process can be stopped and restarted again by issuing control orders over the entity **StartMeter**. It is also possible to reset all energy values executing a control over **ResetMeter**.

These two entities give additional control over the metering function, enabling the user to clear all energy values after the device commissioning and to disable the metering process during testing and maintenance procedures.

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I** or **U**;
- The three-phase power cannot be calculated from the analogue channels associated to inputs **I** and **U** (*e.g.*, I_A and U_B).

The configuration is valid and the function operates accordingly otherwise.

5.38.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.127 and Table 5.128, respectively.

Table 5.127. Three-Phase Metering function inputs.

Identifier	Title	Type	Mlt	Description
I	I	ANL CH	-	Phase currents
U	U	ANL CH	-	Phase voltages

Table 5.128. Three-Phase Metering function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Health	Health	INT	-	Function health
TotalApparentEnergy	Tot Apparent Energy	CNT	Yes	Total apparent energy counter
TotalRealEnergy	Tot Real Energy	CNT	Yes	Total real energy counter
TotalReactiveEnergy	Tot Reactive Energy	CNT	Yes	Total reactive energy counter
FwdRealEnergy	Fwd Real Energy	CNT	Yes	Forward real energy counter
FwdReactiveEnergy	Fwd Reactive Energy	CNT	Yes	Forward reactive energy counter
RvRealEnergy	Rv Real Energy	CNT	Yes	Reverse real energy counter
RvReactiveEnergy	Rv Reactive Energy	CNT	Yes	Reverse reactive energy counter
ResetMeter	Reset Meter	DIG CTRL	-	Reset energy counters
StartMeter	Start Meter	DIG CTRL	Yes	Start/stop metering

5.38.4 Settings

The function settings are listed in Table 5.129.

Table 5.129. Three-Phase Metering function settings.

Identifier	Title	Range	Factory value	Description
InvertOrientation	Invert Orientation	OFF / ON	OFF	CT polarity inversion

5.39 Fault Locator

5.39.1 Introduction

The Fault Locator complements the protection functions by providing an accurate measurement of the distance to the fault in ohm, km, miles and percentage of the total line length. It enables the faster location and clearance of persistent faults in the system, thus helping to increase the availability of power system lines. It is also useful in the identification of weak spots whose insulation may fail in the future, following the occurrence of transient or automatically cleared faults.

The function algorithm is based on impedance measurement, and can be applied both to overhead lines and underground cables. It is most suitable for locating phase-to-phase faults in any kind of networks, as well as phase-to-earth faults in solid or low-impedance earthed systems.

The function results can be accessed in the Local HMI or the embedded webserver, and they can also be configured to be reported to the station and remote control levels through a communication protocol. The results can also be provided to external applications with the aim of cross-relating fault information from distinct network locations.

5.39.2 Operation Method

The Fault Locator can be activated by setting change (setting **Operation**). The calculations are performed whenever a new fault condition is detected, according to the trigger condition corresponding to **FuncPickup** input. All relevant protection function or function stage pickup signals should be connected to this input. This ensures that fault location will be triggered even in the case the fault is cleared by another protection relay. The trigger conditions can be extended to external protection functions, whose pickup is being monitored by the TPU L500.

Measuring Principle

Except for the trigger condition, the Fault Locator is completely independent from all protection functions in the device. This means that all necessary calculations are performed by the function, directly from voltage and current signal samples. Three phase current signals and three phase-to-earth voltage signals should be associated in two analogue channels, connected to the function inputs **ILocal** and **ULocal**, respectively.

If suitable communication channels are available, the Fault Locator can use additional information from the remote line ends to enhance the accuracy of its estimates. In this case, the three phase current signals measured in the remote end should be associated to input **IRemote1**; for multiple breaker topologies, a second set of remote phase currents should be associated to **IRemote2**.

The calculation of the distance to the fault is based on an impedance measuring algorithm. A dedicated phase and loop selector is built-in in the function, integrating multiple criteria to allow discriminating the type of fault and selecting the most adequate measuring loop for performing subsequent calculations. The selected loop is always the one from the list in Table 5.130 that best fits the actual fault condition. If, despite all measures taken, the function is not able to select any valid loop, an indication of **Unknown** is signalled.

Table 5.130. Fault loop options.

Identifier	Value	Description
Unknown	0	Impossible to select a measuring loop
A0	1	Phase A to earth measuring loop
B0	2	Phase B to earth measuring loop
C0	3	Phase C to earth measuring loop
AB	4	Phase A to phase B measuring loop
BC	5	Phase B to phase C measuring loop
CA	6	Phase C to phase A measuring loop

The Fault Locator algorithm provides the best possible accuracy by compensating for the effect of load currents, in the presence of fault resistance and eventual double end in-feed. When available, the pre-fault phasors are directly used to eliminate the error in the impedance calculation due to the load current. If these pre-fault values cannot be discriminated (for example, in case of high resistance earth-faults), special polarization techniques are employed to achieve the same goal. Due to this compensation, the exact loop reactance and fault resistance values can be estimated with very high accuracy.

For two-end lines, the effect of the load current in the presence of fault resistance can be better compensated if the current value is known in the remote end. In the event of communication channel failure, the algorithm uses only local quantities, as described above.

The algorithm can also take into account the mutual inductive coupling between the protected line and one parallel line, which may influence distance measurement for phase-to-earth faults. To enable the compensation of the zero sequence mutual coupling, the residual current measured in the parallel line should be associated to the input **IParallel**. For a phase-to-earth fault in phase x, the algorithm compensates for the effect of the residual current in the protected line ($3I_0$) and in the parallel line ($3I_{0,parallel}$) according to equation (5.98), where Z_1 and Z_0 are respectively the positive and zero sequence impedances of the protected line and Z_{0M} is the zero sequence mutual impedance.

$$V_x = n \cdot Z_1 \cdot \left(I_x + \frac{Z_0 - Z_1}{3Z_1} \cdot 3I_o + \frac{Z_{0M}}{3Z_1} \cdot 3I_{o,parallel} \right) \tag{5.98}$$

The voltage and current fault signals are stored in a separate data window when the function is triggered, together with the pre-fault phasors whenever the internal fault detector is able to discriminate the pre-fault and fault conditions. Several impedance measurements, corresponding to distinct time instants, are performed over the recorded data values. The function adjusts the time window so that inaccurate values due to the transients that occur immediately after fault inception or after the opening of the circuit breaker are not considered, even in the case of high speed tripping. In order to achieve the highest accuracy, additional filtering is performed, and results that deviate from the mean value are eliminated.

The Fault Locator algorithm is prepared for lines with up to three distinct sections in sequence. The second and third line sections can be separately activated in settings **Sect2Operation** and **Sect3Operation**, respectively.

For each line section, the positive sequence and zero sequence line impedance values, corresponding to settings **SectxR1**, **SectxX1**, **SectxR0** and **SectxX0** (x = 1, 2 or 3) are required in order to perform impedance calculations. If a parallel line is to be considered, the corresponding mutual resistance **SectxRm** and reactance **SectxXm** should be adequately set for each section. The total line section length should also be introduced in setting **SectxLength**, so that it is possible to convert the information from Ω to length units. The setting **DistanceUnit** enables the user to choose how to introduce the line length: in km or mile.

The accuracy of the Fault Locator results depends largely on the accuracy of line impedance values introduced by the user. It is therefore required that these values are obtained from experimental measurements when accurate values are not directly available from theoretical calculations. This is particularly relevant in the case of zero sequence impedances, where the influence of earth is usually difficult to estimate.

Outputs

Each time a fault is detected, the Fault Locator updates the value of several entities, namely:

- **FaultType**: the type of fault detected, from one of the listed in Table 5.131;
- **FaultLoop**: the measuring loop selected for distance calculation;
- **FaultImpedance**: the total impedance, in Ω, of the selected loop, represented in polar coordinates (magnitude and phase angle);
- **FaultLoopReactance**: the total fault loop reactance, in Ω;
- **FaultLoopResistance**: the total fault loop resistance, in Ω;
- **FaultDistanceKm**: the distance to the fault in km;
- **FaultDistanceMile**: the distance to the fault in miles;

- **FaultDistance**: the distance to the fault in p.u. of the total line length (1 p.u. corresponds to a fault at the extreme end of the line);
- **FaultResistance**: the fault resistance, in Ω.

Table 5.131. Fault type options.

Value	Description
0	Unknown
1	Three-phase
2	Phase-earth
3	Phase-phase
4	Phase-phase-earth

All values in Ω are relative to the primary side of voltage and current transformers.

In the unlikely event the function is unable to select a valid measuring loop (for instance, if the function could not determine a sufficient number of impedance results), both **FaultType** and **FaultLoop** are set as **Unknown**; in this case, all other results are not calculated and their quality is marked as **INVALID**.

The number of times the function was triggered is available in **OpCounter**, which can be manually reset by the user.

The information regarding fault location is also part of the Fault Report, which stores relevant information concerning the last faults detected by the protection relay (for more details on this, please consult section 4.8 - Fault Report).

Blocking Conditions

A voltage transformer failure prevents the fault location from being correctly calculated so, in case a VT failure indication is received, the fault location algorithm is blocked. The VT failure indication should be connected to the function input **VTFail**. It may be the result of a dedicated supervision function (please refer to section 5.28 - VT Supervision).

Function Health

The function does not operate and its output **Health** is set to Alarm status if:

- There is no analogue channel associated to input **I** or input **U**;
- The analogue channel associated to input **I** does not correspond to a group of three phase current signals;
- The analogue channel associated to input **U** does not correspond to a group of three phase-to-earth voltage signals;
- The analogue channel associated to one of the inputs **Iremote1** to **Iremote4** does not correspond to a group of three phase current signals.

The function operates with possible limitations and its output **Health** is set to Warning status if:

- The analogue channel associated to one of the inputs **Iremote1** to **Iremote4** does not correspond to a group received through a remote end communication channel: the function works as expected, but only for test purposes;
- The analogue channel associated to input **Iparallel** does not correspond to a neutral or to a group of three phase current signals: the compensation of the zero sequence mutual coupling with the parallel line is not enabled in this case.

The configuration is valid and the function operates accordingly otherwise.

5.39.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.132 and Table 5.133, respectively.

Table 5.132. Fault Locator function inputs.

Identifier	Title	Type	Mlt	Description
ULocal	U	ANL CH	-	Local voltages
ILocal	I	ANL CH	-	Local currents
IRemote1	I Remote 1	ANL CH	-	Remote currents 1
IRemote2	I Remote 2	ANL CH	-	Remote currents 2
IRemote3	I Remote 3	ANL CH	-	Remote currents 3
IRemote4	I Remote 4	ANL CH	-	Remote currents 4
IParallel	I Parallel	ANL CH	-	Parallel line currents
VTFail	VT Failure	DIG	2	Voltage transformer failure
FuncPickup	Function Pickup	DIG	16	Protection pickup

Table 5.133. Fault Locator function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Sect1Behavior	Sect 1 Behavior	INT	-	Line section 1 operation mode
Sect2Behavior	Sect 2 Behavior	INT	-	Line section 2 operation mode
Sect3Behavior	Sect 3 Behavior	INT	-	Line section 3 operation mode
Health	Health	INT	-	Function health
FaultImpedance	Fault Impedance	CPX ANL	-	Fault impedance
FaultLoopReactance	Fault Loop X	ANL	-	Fault loop reactance
FaultLoopResistance	Fault Loop R	ANL	-	Fault loop resistance
FaultDistanceKm	Fault Distance km	ANL	-	Fault distance in km
FaultDistanceMile	Fault Distance mile	ANL	-	Fault distance in mile
FaultDistance	Fault Distance	ANL	-	Fault distance in pu
FaultResistance	Fault Resistance	ANL	-	Fault resistance estimation
FaultType	Fault Type	INT	-	Fault type
FaultLoop	Fault Loop	INT	-	Fault loop
OpCounter	Op Counter	INT CTRL	Yes	Operation resettable counter

5.39.4 Settings

The function settings are listed in Table 5.134.

Table 5.134. Fault Locator function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
DistanceUnit	Distance Unit	km / mile	km	Distance unit
Sect1R1	Sect 1 R Pos	[0,01..500,0] Ω	1,0	Line section 1 total positive-sequence resistance
Sect1X1	Sect 1 X Pos	[0,01..500,0] Ω	20,0	Line section 1 total positive-sequence reactance
Sect1R0	Sect 1 R Zero	[0,01..500,0] Ω	20,0	Line section 1 total zero-sequence resistance
Sect1X0	Sect 1 X Zero	[0,01..500,0] Ω	80,0	Line section 1 total zero-sequence reactance
Sect1Rm	Sect 1 R Mut	[0,01..500,0] Ω	0,01	Line section 1 total mutual resistance
Sect1Xm	Sect 1 X Mut	[0,01..500,0] Ω	0,01	Line section 1 total mutual reactance
Sect1Length	Sect 1 Length	[0,1..1000] km (or mile)	100,0	Line section 1 total length
Sect2Oper	Sect 2 Operation	OFF / ON	OFF	Line section 2 operation
Sect2R1	Sect 2 R Pos	[0,01..500,0] Ω	1,0	Line section 2 total positive-sequence resistance
Sect2X1	Sect 2 X Pos	[0,01..500,0] Ω	20,0	Line section 2 total positive-sequence reactance
Sect2R0	Sect 2 R Zero	[0,01..500,0] Ω	20,0	Line section 2 total zero-sequence resistance
Sect2X0	Sect 2 X Zero	[0,01..500,0] Ω	80,0	Line section 2 total zero-sequence reactance
Sect2Rm	Sect 2 R Mut	[0,01..500,0] Ω	0,01	Line section 2 total mutual resistance
Sect2Xm	Sect 2 X Mut	[0,01..500,0] Ω	0,01	Line section 2 total mutual reactance
Sect2Length	Sect 2 Length	[0,1..1000] km (or mile)	100,0	Line section 2 total length
Sect3Oper	Sect 3 Operation	OFF / ON	OFF	Line section 3 operation
Sect3R1	Sect 3 R Pos	[0,01..500,0] Ω	1,0	Line section 3 total positive-sequence resistance
Sect3X1	Sect 3 X Pos	[0,01..500,0] Ω	20,0	Line section 3 total positive-sequence reactance
Sect3R0	Sect 3 R Zero	[0,01..500,0] Ω	20,0	Line section 3 total zero-sequence resistance
Sect3X0	Sect 3 X Zero	[0,01..500,0] Ω	80,0	Line section 3 total zero-sequence reactance

Identifier	Title	Range	Factory value	Description
Sect3Rm	Sect 3 R Mut	[0,01..500,0] Ω	0,01	Line section 3 total mutual resistance
Sect3Xm	Sect 3 X Mut	[0,01..500,0] Ω	0,01	Line section 3 total mutual reactance
Sect3Length	Sect 3 Length	[0,1..1000] km (or mile)	100,0	Line section 3 total length

5.40 Disturbance Recorder

5.40.1 Introduction

The Disturbance Recorder is responsible for recording voltage and current waveforms, as well as related binary signal state transitions, whenever a fault occurs in a power system, so that they are available for post-fault analysis. A record can also be triggered by other events that give rise to power system transients, like circuit breaker close commands.

A detailed record of a disturbance is very useful during post-fault analysis. It may be required to distinguish between cause and effect and it is a valuable resource to help identify the type of fault and potential failures or misbehaviours of the protection system. If the effects of a fault are spread over a wide area, records of the disturbance from a number of different locations can also assist in determining the location of the fault.

The Disturbance Recorder can also be manually triggered, enabling its use for checking CT and VT connections and the adequate CT orientation for other protection and control functions. The function can also be used to access the power system status at any time and to detect some abnormal condition of the analogue measuring circuits during normal system operation.

5.40.2 Operation Method

The Disturbance Recorder can be activated by setting change (setting **Operation**). This function has the capability to register up to 96 binary signals and all a.c. analogue inputs supported by the device. These records are stored using the IEEE Standard Common Format for Transient Data Exchange (COMTRADE) for Power Systems.

Inputs and Triggers

The settings to be configured in the function are related to the trigger source and recording times. The **TriggerSource** can be defined as **INTERNAL** (if a new record is triggered according to the state transitions or magnitude variations of its binary and analogue inputs, respectively), **EXTERNAL** (if a new record is triggered as a result of an external order, for instance, a manual trigger) or **BOTH**.

The manual trigger can be set via HMI or communication protocol (like for instance IEC 61850). It can also be issued from the embedded Web Server and from the Automation Studio toolset. In alternative, the external trigger can have automatic origin, if issued from a user-defined logic scheme.

The user can disable all the internal triggers without disabling the entire function; this may be useful during simulation or other tests.

The IED is able to register up to 96 binary signals configured by the user (in function inputs **Binaryx**, x = 1 to 96). The initial status and the corresponding state transitions of all binary inputs configured are recorded when a disturbance occurs in the network. The user can also define any binary input as a trigger source; it just have to be chosen the adequate trigger level (in the corresponding setting **TriggerValuex**), from the two possible options: **POSITIVE** (trigger in the rising edge) and **NEGATIVE** (trigger in the falling edge).

The function is also able to register all a.c. analogue inputs of the IED, which should correspond to analogue channels associated to inputs **Analoguex**, x = 1 to 24. For each three-phase voltage or current channel, the calculated residual voltage or current is also registered. The user can also define any analogue input as a trigger source by setting its high or low trigger levels (in the corresponding settings **HighTrgLevx** and **LowTrgLevelx**) to a value other than zero. The levels are defined in RMS value, and depend on the input type (Table 5.135).

Table 5.135. Trigger levels for a.c. analogue inputs types.

HighTrgLev / LowTrgLev	Range	Unit
Currents	0,0 - 999999,9	A
Voltages	0,0 - 999999,9	kV

The analogue trigger is determined based on the peak-to-peak value of the signal during one period of the fundamental frequency. This method has a greater immunity to the d.c. offset in the input signal and allows a quicker response by the function.

Recording Time and Memory

The Disturbance Recorder function has the following characteristics (Table 5.136):

Table 5.136. Disturbance Recorder characteristics.

Network Frequency	50 Hz	60 Hz
Sample Rate	4000 S/s	4800 S/s
Samples/Cycle	80	
Max. Records	250	
Max. **PreFaultTime**	500 ms	
Max. **PostFaultTime**	2 s	
Max. **MaxTime**	10 s	

The recording times (**PreFaultTime**, **PostFaultTime** and **MaxTime**) are adjustable by the user in the Disturbance Recorder settings (Figure 5.87). These parameters are already defined by default but they can be redefined based on the connected signals and the types of disturbances to be recorded. The maximum record duration corresponds to **PreFaultTime** plus **MaxTime**.

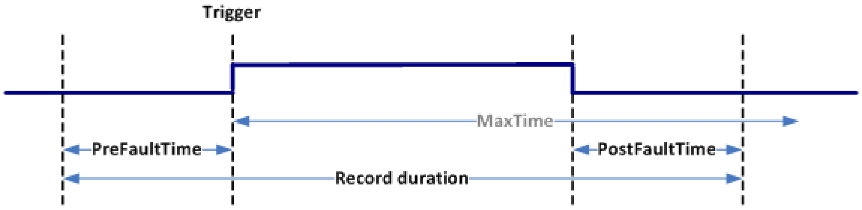

Figure 5.87. Recording times.

The function has an extra setting (**Retrigger**) used to ignore the post-fault timer when a new trigger occurs before this timer has elapsed, storing this way all successive events in a single file (Figure 5.88).

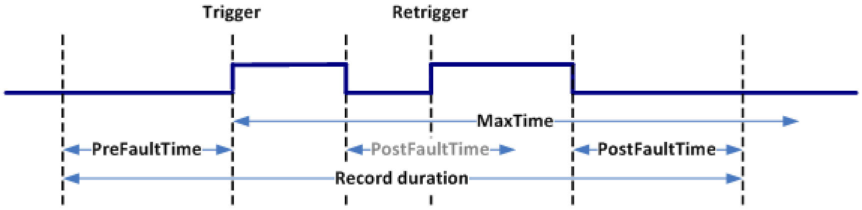

Figure 5.88. Recording times with retrigger condition.

The above behaviour applies to the logical OR of all internal trigger conditions configured. In case of an external trigger, the record duration can be independently set by the user in setting **ManualTrgTime**.

The IED has a maximum storage capacity of 250 records. The actual number of stored records depends on the duration of each one (according to Figure 5.89) and, in the worst case the device is capable of storing at least 50 records without erasing older files.

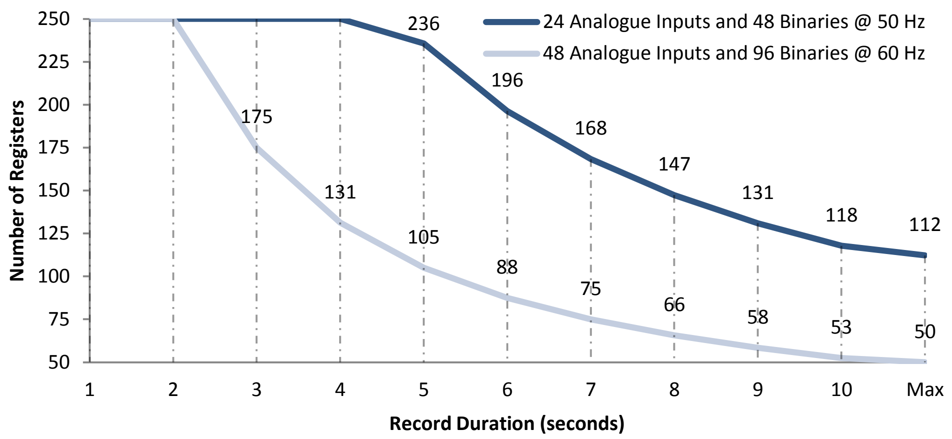

Figure 5.89. Disturbance Recorder memory capacity.

Outputs and Controls

Each time it is triggered, the Disturbance Recorder updates the value of several entities, namely:

- **Trigger**: This control is used to issue a manual trigger; its status is **TRUE** when a new binary, analogue or manual trigger is detected.
- **ChannelTriggered**: This output indicates that one or more inputs are in trigger condition.
- **RecordStarted**: This output indicates that the recording has started and is in progress.
- **RecordEnd**: This output indicates that the function has just generated a new Disturbance Record file that is already available for reading.
- **MemoryClear**: This control is used to erase all Disturbance Record files; its status is **TRUE** when the memory is empty.
- **MemoryUsed**: Information of the percentage of used memory.
- **RecordNumber**: Number of the last Disturbance Record file saved in memory.

5.40.3 Interface

The inputs and outputs corresponding to the function interface are listed in Table 5.137 and Table 5.138, respectively.

Table 5.137. Disturbance Recorder function inputs.

Identifier	Title	Type	Mlt	Description
Analogue1	Analogue 1	ANL CH	-	Analogue channel 1
…	…	ANL CH	-	…
Analogue24	Analogue 24	ANL CH	-	Analogue channel 24
Binary1	Binary 1	DIG	1	Digital channel 1
…	…	DIG	1	…
Binary96	Binary 96	DIG	1	Digital channel 96

Table 5.138. Disturbance Recorder function outputs.

Identifier	Title	Type	NV	Description
Description	Description	TEXT	-	Function description

Identifier	Title	Type	NV	Description
SWRevision	SW Revision	TEXT	-	Function software revision
Version	Version	TEXT	-	Function configuration version
Behavior	Behavior	INT	-	Function operation mode
Health	Health	INT	-	Function health
Trigger	Trigger	DIG CTRL	-	Manual trigger
ChannelTriggered	Channel Triggered	DIG	-	Trigger status
RecordEnd	Record End	DIG	-	Record end indication
RecordStarted	Record Started	DIG	-	Record started indication
MemoryClear	Memory Clear	DIG CTRL	-	Clear memory control
MemoryUsed	Memory Used	INT	-	Percentage of memory used
RecordNumber	Record Number	INT	Yes	Last record number

5.40.4 Settings

The function settings are listed in Table 5.139.

Table 5.139. Disturbance Recorder function settings.

Identifier	Title	Range	Factory value	Description
Operation	Operation	OFF / ON	OFF	Operation
TriggerSource	Trigger Source	INTERNAL / EXTERNAL / BOTH	BOTH	Trigger source
Retrigger	Retrigger	OFF / ON	OFF	Retrigger enable
PreFaultTime	Pre-Fault Time	[50..500] ms	100	Record pre-fault time
PostFaultTime	Post-Fault Time	[50..2000] ms	200	Record post-fault time
MaxTime	Max Time	[200..10000] ms	3000	Record max time
ManualTrgTime	Manual Trg Time	[200..10000] ms	3000	Record max time for manual trigger
HighTrgLev1	High Trg Lev 1	[0,0..999999,9]	999999,9	Analogue channel 1 high trigger value
…	…	[0,0..999999,9]	999999,9	…
HighTrgLev24	High Trg Lev 24	[0,0..999999,9]	999999,9	Analogue channel 24 high trigger value
LowTrgLev1	Low Trg Lev 1	[0,0..999999,9]	0,0	Analogue channel 1 low trigger value
…	…	[0,0..999999,9]	0,0	…
LowTrgLev24	Low Trg Lev 24	[0,0..999999,9]	999999,9	Analogue channel 24 low trigger value

Identifier	Title	Range	Factory value	Description
TriggerValue1	Trigger Value 1	POSITIVE / NEGATIVE / NONE	NONE	Digital channel 1 trigger option
…	…	POSITIVE / NEGATIVE / NONE	NONE	…
TriggerValue96	Trigger Value 96	POSITIVE / NEGATIVE / NONE	NONE	Digital channel 96 trigger option

Chapter

6

COMMUNICATIONS

This chapter describes the several alternative communication protocols supported by the TPU L500. The device includes an IEC 61850 server and supports GOOSE publish/subscribe messaging, along with several other protocol options, either serial or over Ethernet. The main features and the base configuration are explained for each of them. The information contained in this chapter is complemented by specific protocol documentation. The different communication interfaces available in the TPU L500 are also succinctly described in an introductory section.

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6.1 COMMUNICATION INTERFACES

The TPU L500 supports up to four communication protocols simultaneously, according to the defined product ordering code. Any communication protocol available in the TPU L500 can be freely associated by the user to any communication port, provided they are taken into account the specific restrictions of each protocol.

In this section, the different communication interfaces and physical media options available are succinctly described.

6.1.1 SERIAL PORTS

The TPU L500 supports up to three independent serial ports, accessible in its rear panel.

The ports (COM1, COM2 and COM3) have four configuration options: RS-232 or RS-485 (both for copper interface), glass fibre optics or plastic fibre optics. The option for each port is chosen in the product ordering code. Please refer to subsection 2.4.10 - Serial Ports for more details.

All typical serial port settings can be configured for each port independently. Table 6.1 lists these settings and its configuration ranges.

Table 6.1. Serial port configuration settings.

Identifier	Title	Range	Factory value	Description
Type	Type	RS-232 / RS-485	RS-232	Interface type
Baudrate	Baud Rate	600 / 1200 / 2400 / 3600 / 4800 / 9600 / 19200 / 38400 / 57600	9600	Baud rate
DataBits	Data Bits	7 DATA BITS / 8 DATA BITS	8 DATA BITS	Number of data bits
StopBits	Stop Bits	1 STOP BIT / 2 STOP BITS	1 STOP BIT	Number of stop bits
Parity	Parity	NONE / EVEN / ODD	NONE	Parity
RTSCTS	RTS CTS	OFF / ON	OFF	Flow control

The management of the serial interface is dependent on the value of the setting **Type**. When **RS-232** is selected, additional flow control option can be activated by configuring the setting **RTSCTS**. This setting has no effect when **RS-485** is selected.

The change of the setting **Type** is not enough to define the interface type of the serial port. A specific hardware configuration, as described in subsection 2.4.10 - Serial Ports, must also be changed.

The setting value must match the hardware configuration, as defined in the ordering code of the device.

When a fibre optics interface is available, the option **RS-232** should be set in the setting **Type**.

The settings described above are also available as specific entities that can be accessed through any diagnostic interface, as in Table 6.2.

Table 6.2. Serial port information.

Identifier	Title	Type	NV	Description
Type	Type	INT	-	Interface type
Baudrate	Baud Rate	INT	-	Baud rate
DataBits	Data Bits	INT	-	Number of data bits
StopBits	Stop Bits	INT	-	Number of stop bits
Parity	Parity	INT	-	Parity
RTSCTS	RTS CTS	DIG	-	Flow control
Link	Link	DIG	-	Serial port link status

The entity **Link** indicates the current status of the communications through the interface. It is active whenever there are messages sent and received through the serial port.

6.1.2 IRIG-B PORT

The last port, COM4, available in the rear of the IED is reserved for the IRIG-B dedicated synchronism network. This port can be galvanic or optical fibre as chosen in the product ordering code.

6.1.3 LOCAL ACCESS INTERFACE

The TPU L500 provides one Ethernet port, at the front panel, for diagnostic, maintenance and configuration purposes. This port cannot be used for remote communication with a Control Centre. This port has a 10/100BASE-TX copper interface. Please refer to subsection 2.4.9 - Front Service Interface for more details.

The front panel Ethernet port has a fixed network configuration:

- IP Address: 192.168.0.100
- Subnet Mask: 255.255.255.0

This port is intended for local access to the device, for example, for connection to a laptop.

The front panel Ethernet port should be completely independent from the two rear Ethernet interfaces. For this to be possible, the IP addresses and subnet masks of the two rear ports must be conveniently set so that these two interfaces are in completely separated sub-networks from the front panel interface.

The fixed configuration described above is also available in specific entities that can be accessed through any diagnostic interface, as in Table 6.3.

Table 6.3. Service interface information.

Identifier	Title	Type	NV	Description
IPAddress	IP Address	TEXT	-	IP address
SubnetMask	Subnet Mask	TEXT	-	Subnet mask

6.1.4 Ethernet Port

The TPU L500 provides three rear Ethernet ports that can be used for remote communication with a Control Centre or for other purposes (for example, device configuration or disturbance data retrieval). These ports have two configuration options: 10/100BASE-TX copper interface or 100BASE-FX fibre optics interface. Please refer to subsection 2.4.8 - Local Area Network Connections for more details.

Table 6.4. Ethernet port information.

Identifier	Title	Type	NV	Description
MACAddress	MAC Address	TEXT	-	MAC address
Links > Optical	Links > Optical	DIG	-	Optical interface link status
Links > Copper	Links > Copper	DIG	-	Copper interface link status

The entity **MACAddress** indicates the value of the MAC address of the Ethernet interface. This unique identifier is recorded in the device at the factory and cannot be changed later.

The entities **Links > Optical** and **Links > Copper** indicate the current status of the communications through the port. Only one of the outputs is valid at each time instant, depending on the interface that is connected. That entity is active whenever there is link activity in the Ethernet interface.

6.1.5 Ethernet Networks

In the IED the logical networks must be associated to the physical Ethernet ports when they are defined an enabled. There are two types of networks: the idependent and the redundant. The Table 6.5, Table 6.6, Table 6.7, Table 6.8, Table 6.9, Table 6.10 and the Table 6.11 show all the settings and information related with the logical networks.

The three rear Ethernet ports can be operated as two completely independent network interfaces, one has redundancy and the other has not. The redundant network must be associated to the ETH1 and ETH2 ports and the not redundant one (independent network) must be associated to the ETH3 port. For this to be possible, the corresponding IP addresses and subnet masks must be conveniently set so that the two networks are in completely separated sub-networks.

Table 6.5. Independent network configuration settings.

Identifier	Title	Range	Factory value	Description
Ethernet	Ethernet	ETH3	-	Ethernet port associated to the network
DHCP	DHCP	OFF / ON	OFF	DHCP active

Table 6.6. Redundant network configuration settings.

Identifier	Title	Range	Factory value	Description
EthernetSlave1	Ethernet slave1	ETH1/ETH2	-	First ethernet port slave associated to the network
EthernetSlave2	Ethernet slave2	ETH1/ETH2	-	Second ethernet port slave associated to the network

Identifier	Title	Range	Factory value	Description
DHCP	DHCP	OFF / ON	OFF	DHCP active

Table 6.7. Networks VLAN configuration settings.

Identifier	Title	Range	Factory value	Description
Identifier	Identifier	[1…4095]	1	Virtual local area network identification
Priority	Priority	[0…7]	0	Virtual local area network priority
DHCP	DHCP	OFF / ON	OFF	DHCP active

The **DHCP** option is not available for runtime operation and is not recommended in general. A fixed network configuration should be used instead, by defining the settings **IPAddress**, **SubnetMask** and **DefaultGateway**.

Table 6.8. Network/Vlan information.

Identifier	Title	Type	NV	Description
RxBytes	Rx Bytes	INT	-	Number of received bytes
TxBytes	Tx Bytes	INT	-	Number of transmitted bytes

Table 6.9. IP configuration settings.

Identifier	Title	Range	Factory value	Description
IPAddress	IP Address	Max 16 Char.	0.0.0.0	First ethernet port slave associated to the network
SubnetMask	Subnet Mask	Max 16 Char.	255.255. 255.255	Second ethernet port slave associated to the network

Table 6.10. IP information.

Identifier	Title	Type	NV	Description
IPAddress	IP Address	TEXT	-	IP Address
SubnetMask	Subnet Mask	TEXT	-	Subnet Mask

Table 6.11. Route configuration settings.

Identifier	Title	Range	Factory value	Description
Destination	Destination	Max 16 Char.	0.0.0.0	Packets route destination for a specific host (e.g. 192.168.1.3) or a specific subnet (192.168.1.0) or by defaut (e.g. 0.0.0.0)

Identifier	Title	Range	Factory value	Description
SubnetMask	Subnet Mask	Max 16 Char.	255.255.255.255	Allows to restrict the range of the destination setting for a specific host (e.g. 255.255.255.255), a specific subnet (e.g. 255.255.255.0) or for any (e.g. 0.0.0.0).
Gateway	Gateway	Max 16 Char.	0.0.0.0	Forwards the packets to the defined gateway IP address (e.g. 192.168.1.254) or by default (e.g. 0.0.0.0).

Only one default Gateway can be defined in the IED. To define it just choose the network were it should be and set the route Gateway IP with both Destination and Subnet Mask IP's set to 0.0.0.0.

If the device never had a user configuration, the factory configuration is loaded by default and the networks interfaces must be configured by the Automation Studio accessing thru the local access port (frontal Ethernet port) that has the fixed IP address of 192.168.0.100 .

While loading a user configuration, if this is rejected, the factory configuration is again restored. If the network interface was already configured, its settings are kept. This allows continued access to the device, in order to re-establish user configuration.

The information described above is available on specific entities that can be accessed through any diagnostic interface (e. g. Webserver).

6.2 Remote End Communication

Remote communication is based on IEEE C37.94 state-of-the-art standard, and communication channels can be optionally redundant. Sample synchronization can be achieved by GPS or by an alternative echo method, and includes compensation for route switching.

The TPU L500 supports up to four remote end communication interfaces for analogue and digital data transfer with devices located in other substations. This data transfer is mainly used by the line differential protection, but it can also be used for teleprotection schemes and improved fault locator algorithms.

The four interfaces allow redundant communication in T line protection (three line ends) or alternatively multi-terminal topologies.

6.2.1 Analogue Data Transmission

For the remote analogue information to be compared with the local one, it has to refer to the same time instant. Sample synchronization can be achieved by GPS or by an alternative echo method (Ping Pong).

With GPS synchronization the sampling itself is synchronized. Timestamps in the transmitted message are used to correctly coordinate samples with local ones and to calculate correct transmission delay and asymmetry.

If Ping Pong mode is in place, the timestamp of the remote samples is calculated in local reference using a Ping-Pong algorithm to calculate transmission delay. In this case the samples are then interpolated.

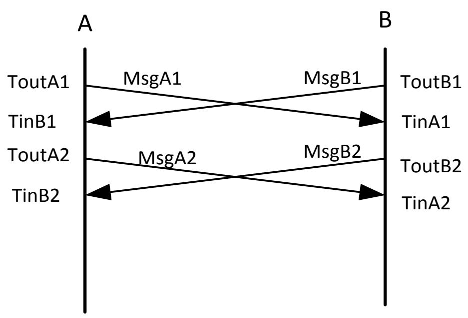

Figure 6.1. Communication messages flow.

MsgA1: Message flowing from line end A to Line end B.

MsgA2: Next message flowing from line end A to Line end B. It carries a reference to message **MsgB1** and times **TinA1** and **ToutB2**.

MsgB1: Message flowing from line end B to line end A.

MsgB2: Next message flowing from line end B to line end A. It carries a reference to message **MsgA1** and times **TinB1** and **ToutA2**.

ToutA1: Time message MsgA1 left node A.

ToutA2: Time message MsgA2 left node A.

TinA1: Time message MsgA1 arrived to node B.

TinA2: Time message MsgA2 arrived to node B.

ToutB1: Time message MsgB1 left node B.

ToutB2: Time message MsgB2 left node B.

TinB1: Time message MsgB1 arrived to node A.

TinB2: Time message MsgB2 arrived to node A.

Time delay in both directions (**TxDelay** and **RxDelay**) as well as transmission asymmetry (**TxRxDelayDifference**) can be calculated from messages timestamps and from setting **AverageAsymmetryTime** depending on current sample synchronization mode.

In node A calculations would be:

- GPS Mode:

$$TxDelay = TinA1 - ToutA1 \tag{6.1}$$

$$RxDelay = TinB2 - ToutB2 \tag{6.2}$$

$$TxRxDelayDifference = TxDelay - RxDelay \tag{6.3}$$

- Ping Pong Mode:

$$TxRxDelayDifference = AverageAsymmetryTime \tag{6.4}$$

$$TxDelay = ((TinB2 - ToutA1) - (ToutB2 - TinA1)) + \frac{AverageAsymmetryTime}{2} \tag{6.5}$$

$$RxDelay = ((TinB2 - ToutA1) - (ToutB2 - TinA1)) - \frac{AverageAsymmetryTime}{2} \tag{6.6}$$

In Ping Pong mode, the actual asymmetry isn't known, and a phase error is expected in the analogue values being transmitted. This error depends on the difference between the real asymmetry and de **AverageAsymmetryTime**. The setting **MaximumAsymmetryVariation** is used to calculate the maximum expected error.

Functions that use remote end communications, like the Line Differential protection function, take measures to accommodate such errors.

6.2.2 Interface

Each communication interface produces status information and failure alarms.

Table 6.12. Remote end communication channel outputs.

Identifier	Title	Type	NV	Description
CfgError	CfgError	DIG	-	Configuration error detected.
SWRevisionMismatch	SWRevisionMismatch	DIG	-	Software revision mismatch detected.
DataReflection	DataReflection	DIG	-	Data reflection detected.
BackupChannel	BackupChannel	DIG	-	Communication is using backup channel.
CommunicationFail	CommunicationFail	DIG	-	Communication failure.
MaxDelayAlarm	MaxDelayAlarm	DIG	-	Maximum transmission delay reached.
RemoteGPS	RemoteGPS	DIG	-	Remote end has GPS connected.
LocalGPS	LocalGPS	DIG	-	Local GPS connected.
AddressError	AddressError	DIG	-	Message received with unexpected address.
CRCError	CRCError	DIG	-	Message received with CRC error.
RemoteEndAlarm	RemoteEndAlarm	DIG	-	Peer alarm in IEEE C37.94 connection.
OutOfSync	OutOfSync	DIG	-	IEEE C37.94 connection lost synchronism.
LossOfSignal	LossOfSignal	DIG	-	IEEE C37.94 connection does not detect a signal.

Identifier	Title	Type	NV	Description
BitErrorRate	BitErrorRate	ANL	-	BitErrorRate.
TxDelay	TxDelay	INT	-	Transmission delay.
RxDelay	RxDelay	INT	-	Receiving delay
TxRxDelayDifference	TxRxDelayDifference	INT	-	Difference between transmit and receive (asymmetry).

6.2.3 Configuration

Configuration of the remote end communication interfaces has several aspects. One is the configuration of the communication channel itself. The other is the transmitted information.

The communication interfaces make full use of the IEEE C37.94 standard having a configurable number of valid bytes per timeslot. The number of valid bytes per timeslot – N – determine communications baud rate (setting **BaudRate**). Minimum baud rate is 64kbps (N==1) and the maximum is 768kbps (N==12). A configuration of 64kbps can be used to connect to a G.703 64kbps link through a converter, while a configuration of 768kbps can be used to connect to a G. 703 E1 multiplexer or in peer to peer fibber optic link, taking advantage of the higher speed communication link.

The IEEE C37.94 standard was designed for communications between a remote end and a multiplexer, but in peer to peer communication, the same message format is also used. The only difference is that one of the devices must be clock master to the connection (**ClockMode**).

Device addressing is included in the messages for verification of received messages. There is a common address (**CommonAddressCode**) to be configured in all line ends (backup channels are considered to be in a separate network and should have a different common address). And a line end index (**LocalTerminalIndex** and **RemoteTerminalIndex**) that should be different for each line end.

The transmitted information is configured as remote IO in the same way as the local IO (4.4 - Process Interface). Depending on configuration, the available IO is:

- 32 Digital Input + 32 Digital Output or
- 3 Analogue Input + 3 Analogue Output + 15 Digital Input + 15 Digital Output or
- 6 Analogue Input + 6 Analogue Output + 15 Digital Input + 15 Digital Output.

The communication channel configuration is in the following table.

Table 6.13. Remote end communication channel configuration settings.

Identifier	Title	Range	Factory value	Description
Active	Active	FALSE / TRUE	True	Interface is active
ChannelConfiguration	Channel Configuration	See above list	32 Digital Input + 32 Digital Output	Available remote IO
CommonAddressCode	Common Address Code	[0…255]	0	Address code to be configured in all line ends.
LocalTerminalIndex	Local Terminal Index	[1…5]	1	Local line end index.
RemoteTerminalIndex	Remote Terminal Index	[1…5]	2	Remote line end index.
BackupChannel	Backup Channel	None or any other channel	None	If this channel has a backup channel it identifies it.

Identifier	Title	Range	Factory value	Description
BackupChannelReturn Time	Backup Channel Return Time	[5…500]ms	100ms	Time after the main channel has gain communication before returning to it.
BackupChannelSwitch Time	Backup Channel Switch Time	[5…500]ms	5ms	Time without receiving new valid messages before switching to backup channel.
MainChannel	Main Channel	None or any other channel	None	If this is a backup channel, it identifies the main channel.
AverageAsymmetryTime	Average Asymmetry Time	[-20000… 20000]µs	0µs	Used in delay calculation in eco mode.
BaudRate	Baud Rate	64 /128 / 192 / 256 / 320 / 384 / 448 / 512 / 576 / 640 / 704 / 768	768	Communication speed.
ClockMode	Clock Mode	Slave /Master	Slave	IEEE C37.94 clock synchronization.
CommunicationFailTime	Communication Fail Time	[5…500] ms	100 ms	Time without receiving new valid messages before indicating communication fail.
GPSFailMode	GPS Fail Mode	Block / Change to Ping Pong	Change to Ping Pong	Communication behaviour if **Sync Mode** is set to GPS and GPS fails.
MaximumAsymmetry Variation	Maximum Asymmetry Variation	[0…3000] µs	0 µs	Maximum expected asymmetry variation.
MaximumTransmission Time	Maximum Transmission Time	[0…40] ms	20 ms	Maximum calculated transmission delay allowed.
SyncMode	Sync Mode	Ping Pong / GPS	GPS	Sample synchronization mode.

Chapter

7

OPERATION

This chapter gives a detailed description of the operations available in the TPU L500 and the procedure that should be followed to bring them to a positive conclusion. The intent is to provide a reference guide where it is possible to quickly find how a task is performed thus, while reading the chapter from top to bottom is advised, each topic is structured in a way that can be read as standalone. Most of the operations have the option of being performed by different interface media, be it the Local HMI, the Webserver or the Automation Studio tool. Note that throughout this chapter the examples given for the menus in the Local HMI are of an alphanumeric display option and not of a graphic one, nevertheless, the information displayed is the same for both.

Due to the continuous development of the TPU L500, the organization and the information currently available in this chapter may not reflect the newest firmware versions. Inconsistences that might arise will be resolved with each new revision of the manual.

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7.1 User Management

7.1.1 HMI

Menu **Security**, seen in Figure 7.1, can be accessed by scrolling down in **Main Menu** until reaching it. Here, it is possible to start and end a security session as well as change an ID access password.

Figure 7.1. Security menu.

For a correct authentication you have to enter the correct ID and the respective password. ID is a number from 0 to 9 while password is composed of 6 numbers from 0 to 9 that have to be edited one by one. Table 7.1 shows what the permissions for each ID access are, while the factory accesses are shown in Figure 7.2 and Figure 7.3.

Table 7.1. Access permissions for each ID.

Operation	ID Access 0	ID Access 1	ID Access 2
Change Display Options	Yes	Yes	Yes
Language Configuration	Yes	Yes	Yes
Date and Time Configuration	Visualization only	Yes	Yes
IO Information	Yes	Yes	Yes
Network Configuration	Visualization only	Yes	Yes
Built-in Function Controls	No	Yes	Yes
Operational Settings Configuration	Visualization only	Yes	Yes
Active Setting Group Configuration	Visualization only	Yes	Yes
Logical Device Mode Configuration	Visualization only	Yes	Yes
Delete Records	No	No	Yes
Restore Factory Configuration	No	No	Yes
Restore Factory Operational Settings	No	No	Yes
Event Log Actions	Visualization only	Yes	Yes
Fault Report Actions	Visualization only	Yes	Yes

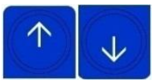
Operation	ID Access 0	ID Access 1	ID Access 2
Restart Device	No	No	Yes
Restart Local HMI	Yes	Yes	Yes
Local HMI tests	No	Yes	Yes
Digital IO tests	No	No	Yes

Start Session

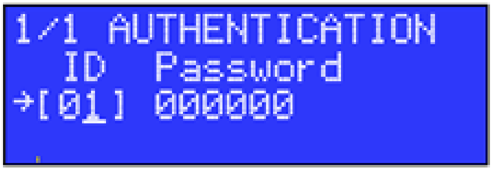
To start a security session, select option **Authentication** and perform the following steps:

1. 

Start editing

2. 

Change element



3. 

Jump to next element

4. Repeat steps 2 and 3 until reaching last editable element

5. 

End edition

If authentication was successfully performed for an ID access, you will jump back to **Security** menu, however, if an invalid ID/password combination was inserted, a menu will appear giving this information and containing the option to press C to try again. At any time, you can press C to cancel authentication. Authentication can also be trigger when trying to perform an action that requires another ID access. In this case, after a correct authentication you will be redirected to the menu you were before authentication was needed.

It is important to note that after an authentication is performed, it won't be necessary to perform it again in the same session.

Figure 7.2. ID Access 1.

Figure 7.3. ID Access 2.

Change Password

To change the password of an ID access, select option **Change Password** and follow the steps to perform an authentication on the ID that will be changed. A correct authentication will bring you to the menu in Figure 7.4, where you can enter the new password.

Figure 7.4. New Password menu.

End Session

After starting a security session, option **Quit** will become available. To end the session, just select it.

Figure 7.5. Option Quit.

If this isn't done, access will reset when screensaver activates.

7.1.2 Webserver

At the moment, the Webserver only supports default users. These are:

- **User**: efacec; **Password**: efacec
- **User**: admin; **Password**: admin

After having accessed the login page, as described in subsection 3.2.1 - Access, just insert the correct credentials. If the login is unsuccessful, message “Wrong user or password!” will be displayed, otherwise, you will be redirected to the main page where you can access information and functionalities, provided you have permission to use them.

If multiple access attempts fail in a row and the credentials used are correct and the TPU L500 is running, try clearing your browser history and restarting it before trying again.

7.2 LANGUAGE CONFIGURATION

7.2.1 HMI

Local HMI supports the English, Portuguese, Spanish, French and Russian languages as long as they were added in the configuration. To change from one language to the other, scroll down in the **Main Menu** until reaching menu **Display**, seen in Figure 7.6. Here, select option **Language** to see a list of the languages present in the TPU L500 (Figure 7.7) and then select the desired one by pressing the navigation key E.

Figure 7.6. Display menu.

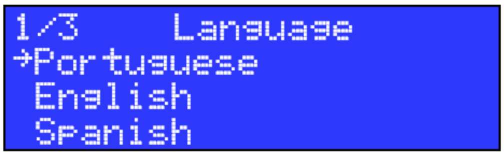


Figure 7.7. Language configuration menu.

7.2.2 WEBSERVER

Webserver supports English, Portuguese, Spanish, French and Russian languages and its selection depends on browser configuration.

7.3 Device Information

In this section it is shown where you can access important information regarding the TPU L500 such as firmware versions and the type and version of the configuration loaded.

Boot-time and runtime system information is registered in the system log and application log files. These records are accessible from the web-based HMI (see section 7.3.2 - Webserver) and can be retrieved from the device using the Automation Studio toolset.

It is advised to check this information when a new configuration is deployed or after a firmware update to make sure they were performed correctly. For a new configuration, checking the type and version of the configuration present in the TPU L500 is the easiest way to verify that the configuration was accepted. When a configuration is rejected, the factory configuration is loaded.

After a firmware update, checking the current versions validates that the process was successful.

7.3.1 HMI

In the Local HMI, this information is available in menu **Informations** that is accessible by scrolling down in **Main Menu** until you reach it. By pressing navigation key E and entering the menu you have the following information available:

- **Configuration**: - configuration type (Factory or User);
- **Config Version:** - configuration version.
- **Ordering Code**: - TPU L500 ordering code;
- **Serial Number:** - TPU L500 serial number;
- **Firmware Version:** - firmware package version;
- **Detailed Information:**
    - **CPU Version:** - firmware version of the CPU;
    - **CPU OS Version:** - firmware version of the CPU's Operating System;
    - **HMI Version:** - firmware version of the Local HMI;
    - **DSP Version:** - firmware version of the DSP;
    - **FPGA Version: -** hardware programming and firmware of the FPGA;
    - **ARM Version:** - firmware version if the ARM;
    - **ARM OS Version:** - firmware version of the ARM CPU's Operating System.

7.3.2 Webserver

In the webserver this information is available in menu **About**, under menu **Device**.

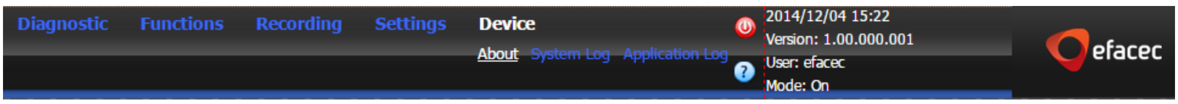


Figure 7.8. Select About menu.

Figure 7.9 shows the information available in this menu. Note that owner, location, power system name and role depend on the configuration. The values shown here are the ones used by default.

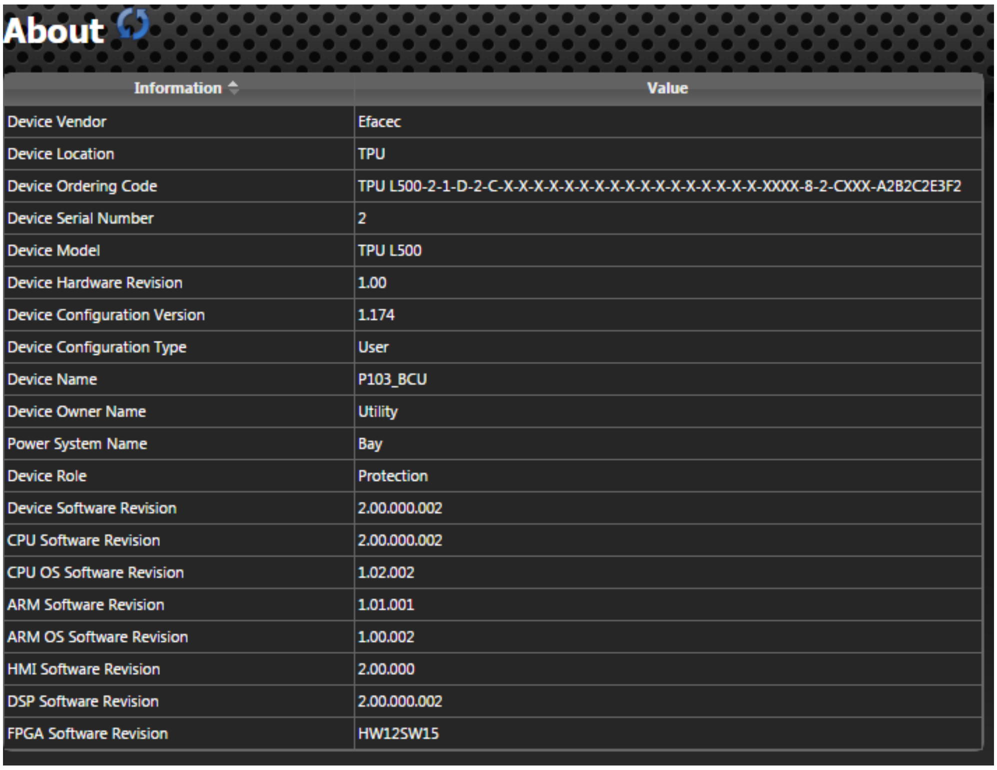


Figure 7.9. About menu.

The **System Log** section shows information of all the operations done in the device. If there are critical failures on some of the device operations the messages are showed in the system log with the level **CRITICAL** and with the color **red**. **ERROR** level messages are showed in **orange** and **WARNING** messages are displayed in **yellow**. In case of misoperation of the IED, consulting this log is an indispensable toll for the correct diagnostic. An example of a healthy operation **System Log** is given on the Figure 7.10.

Figure 7.10. Healthy device startup system log example.

The **Application Log** section shows information of all the operations done in the device active application functions. If there are critical failures on some of the device application functions, the messages generated are showed with the level **ERROR** and with the color **red**. Function configuration or parameterization errors are registered as **WARNING** level messages and displayed in **yellow**. In case of misoperation of the IED, consulting this log is an indispensable toll for the correct diagnostic. An example of a healthy operation **Application Log** is given on the Figure 7.11.

Figure 7.11. Healthy device startup application log example.

7.4 NETWORK CONFIGURATION

7.4.1 HMI

In **Main Menu** scroll down until you reach **Communications** menu and then press navigation key E to access the menu shown in Figure 7.12.

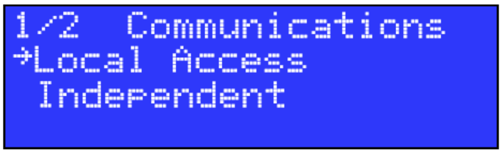


Figure 7.12. Communications menu.

Here, it is possible to select **Local Access** menu to access the front Ethernet port information or the network that was configured in the rear Ethernet port(s). In this example, we show that the network can be configured has **Independent** (no redundancy) in port ETH3 or with the **RSTP, PRP, HSR** or **Active Backup** redundancy protocols in ports ETH1 and ETH2. If a network was not configured, only **Local Access** menu will be available.

Local Access

Local Access has a fixed configuration so, by selecting this menu, you can see a non-editable menu with the interface's MAC address and settings. IP Address and Subnet Mask will always be the ones seen in Figure 7.13.

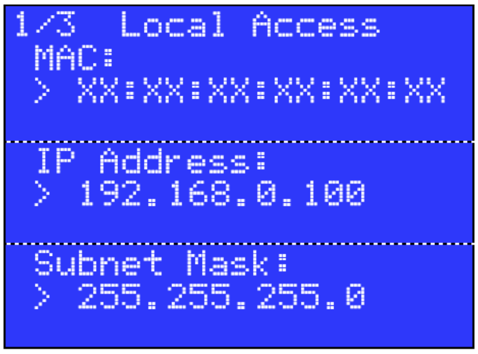


Figure 7.13. Local Access menu.

Independent

The information of the rear Ethernet port used by the network is available in this menu. The network configuration is available in submenus **IPs/Routes** and **Vlans**.

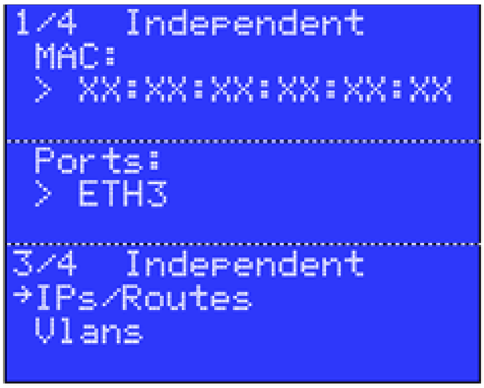


Figure 7.14. Independent menu.

RSTP, PRP and HSR

The information of the rear Ethernet ports used by the network is available on this menus. The network configuration is available in submenus **IPs/Routes** and **Vlans**.

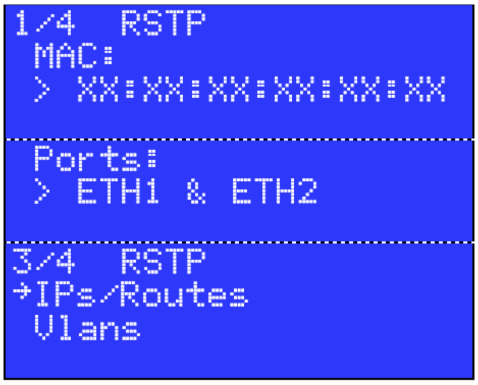


Figure 7.15. Rapid Spanning Tree Protocol menu.

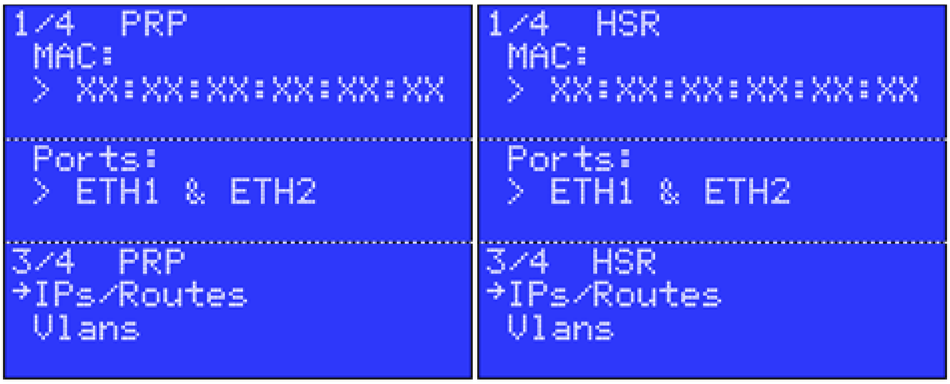


Figure 7.16. Parallel Redundancy and High Availability Seamless Redundancy protocols menus.

IPs/Routes

The rear Ethernet ports can be reconfigured in runtime by a user with ID access 1 or greater. The current values for each setting are displayed in this menu (configuration bellow is not a valid one and is only used to illustrate the menu's layout).

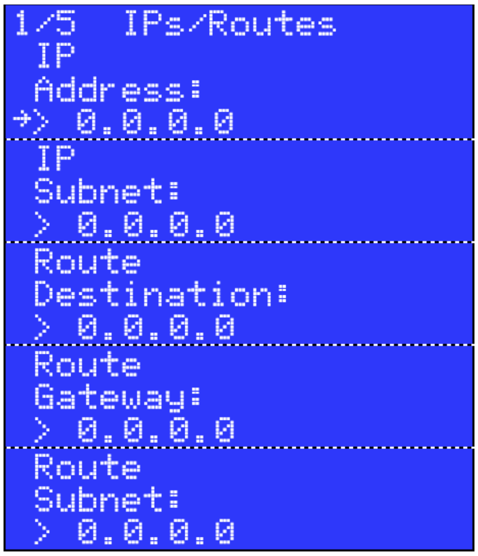


Figure 7.17. IPs and Routes menu.

To configure the network perform the procedure to edit parameters in the local HMI, described in subsection Menu Edition of section 3.1 - Local HMI.

ID access 1 or greater is needed to change these settings. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you start the edition process.

It is important, while configuring the Ethernet interface, not to change and confirm changes one setting at a time. Make sure everything is correctly configured for both interfaces before accepting the changes for the entire menu.

7.5 Date and Time Configuration

7.5.1 HMI

In **Main Menu** scroll down until you reach **Date Time Setup** menu. By selecting it you will be redirected to the menu shown in Figure 7.18.

Figure 7.18. Date Time Setup menu.

Here you can consult the current time and date as well as configure their value. For that, follow the procedure to edit parameters in the local HMI, described in subsection Menu Edition of section 3.1 - Local HMI.

ID access 1 or greater is needed to change these settings. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you start the edition process.

7.5.2 Webserver

Webserver only allows visualization of time and date at this point.

Figure 7.19. Date Time in webserver.

7.6 I/O DIAGNOSTIC AND INFORMATION

7.6.1 HMI

In **Main Menu** scroll down until you reach **IO** menu and then press navigation key E to access menu shown in Figure 7.20.

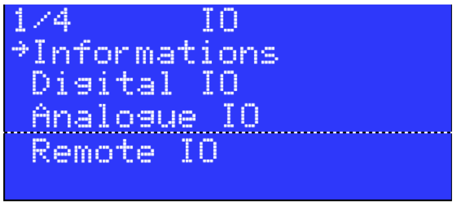


Figure 7.20. IO menu.

Here it is possible to access menu **Informations** that has general information related to all IO boards, such as:

- Board name;
- Serial number;
- Firmware version;
- Board option;
- Board edition;
- Hardware version;
- Number of voltages and currents;
- Number of digital inputs and digital outputs;
- Number of communication channels.

Digital IO

Accessing **Digital IO** menu without a security access will only allow information visualization, so by selecting this menu you will enter the menu shown in Figure 7.21. Selecting **Boards** menu will give you access to a list of the digital boards present in the TPU L500 and, from there, the state of the digital outputs and inputs of the board.

Figure 7.21. Digital IO menu.

However, if you perform the authentication for ID level 2 in the **Security** menu you will have the option to activate the IO test mode by following the sequence described in Figure 7.22. If the TPU L500 enters test mode, the option will change from "**Enter Test Mode**" to "**Exit Test Mode**".

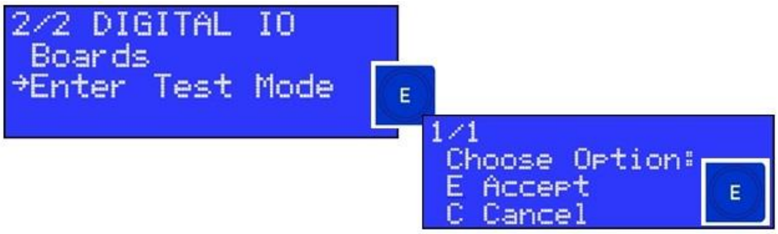


Figure 7.22. Enter digital IO test mode.

Having activated the digital IO test mode, by entering **Boards** menu and then selecting a board you will not only be able to see the state of the digital inputs and outputs but you will also be able to force the value of any digital output. This follows the procedure described in subsection Menu Edition of section 3.1 - Local HMI. After accepting changes, if the digital outputs state changes to the new ones, the board is operating correctly.

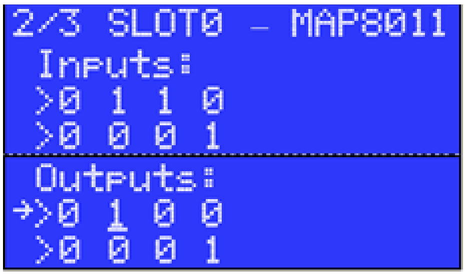


Figure 7.23. Change outputs state of board MAP8011.

Digital IO test can also be accessed through menu **Diagnostic** present in **Main Menu**. The procedure for testing is the same as described above.

ID access 2 is needed to force the digital output state. If you access from **IO** menu you will need to go to **Security** menu to perform authentication, however, if you access it through the **Diagnostic** menu you will be redirected automatically to **Authentication** menu, when you start the process.

If you are forcing the digital outputs state and they don't change after accepting changes, make sure you entered test mode.

When testing digital IO outputs you should not have anything connected to the board other than test equipment to ascertain output status.

After finishing the digital IO diagnostic you have to select option "**Exit Test Mode**" to resume normal operation. **This will reboot the unit**.

Analogue IO

By selecting **Analogue IO** menu, you will be redirected to menu shown in Figure 7.24 where you can select **Boards** menu and see all analogue boards present in the unit, their slot and name or select menu **Calibration**.

Figure 7.24. Analogue IO menu.

By selecting **Calibration** menu you will obtain calibration status for each analogue board present in the TPU L500. In Figure 7.25 and Figure 7.26 you can see that a calibrated board will display the **OK** information while a board that is not calibrated will display the **NOK** information.

Figure 7.25. Calibration OK.

Figure 7.26. Calibration NOK.

By selecting a board with the indication **OK** you will be redirected to a menu that displays the rated values for which the board was calibrated, as seen in Figure 7.27. On the other hand, selecting a **NOK** board will redirect you to a menu where the cause for the board not being calibrated is given. In Table 7.2 you can consult the various reasons for this.

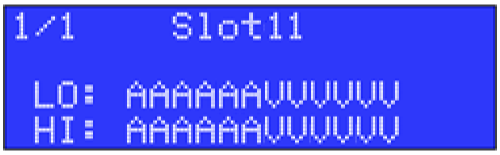


Figure 7.27. Calibration sub-menu.

Table 7.2. Causes for a not calibrated board.

NOK	Description
Not Calibrated	Device was never calibrated
Bad File	Error in the calibration file
Invalid Version	Calibration file version is not supported by the device

Remote IO

By selecting **Remote IO** menu, you will be redirected to menu shown in Figure 7.28 that lists the Remote IO boards present in the TPU L500 and their state.

Figure 7.28. Remote IO sub-menu.

For each board it is possible to view all status information, including specific information for each communication channel as shown in Figure 7.29.

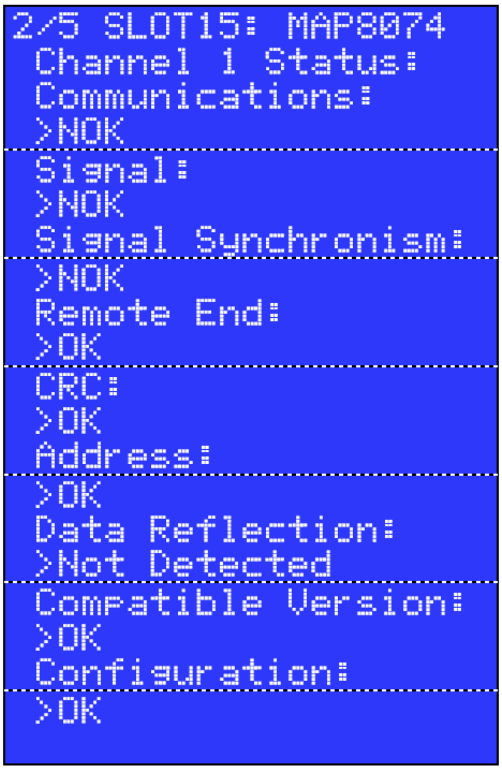


Figure 7.29. Communications channel information.

7.6.2 Webserver

The webserver only supports visualization of information regarding IO boards.

To access this information, select menu **IO** which is a submenu of menu **Diagnostic**, as displayed in Figure 7.30.

Figure 7.30. IO menu.

Here you can check all information related with IO, be it digital IO or analogue IO. To refresh data it is necessary to select the refresh button that appears in the content area.

In the case of Digital IO, for each digital IO board present in the TPU L500 there are three possible tables, with distinct information, that can be visible in this menu. As seen in Figure 7.31, the first table has relevant information on the board itself while the second and third table have information on the current state of the digital inputs and the digital outputs, respectively. The last two tables are only present if the board has digital inputs and or digital outputs.

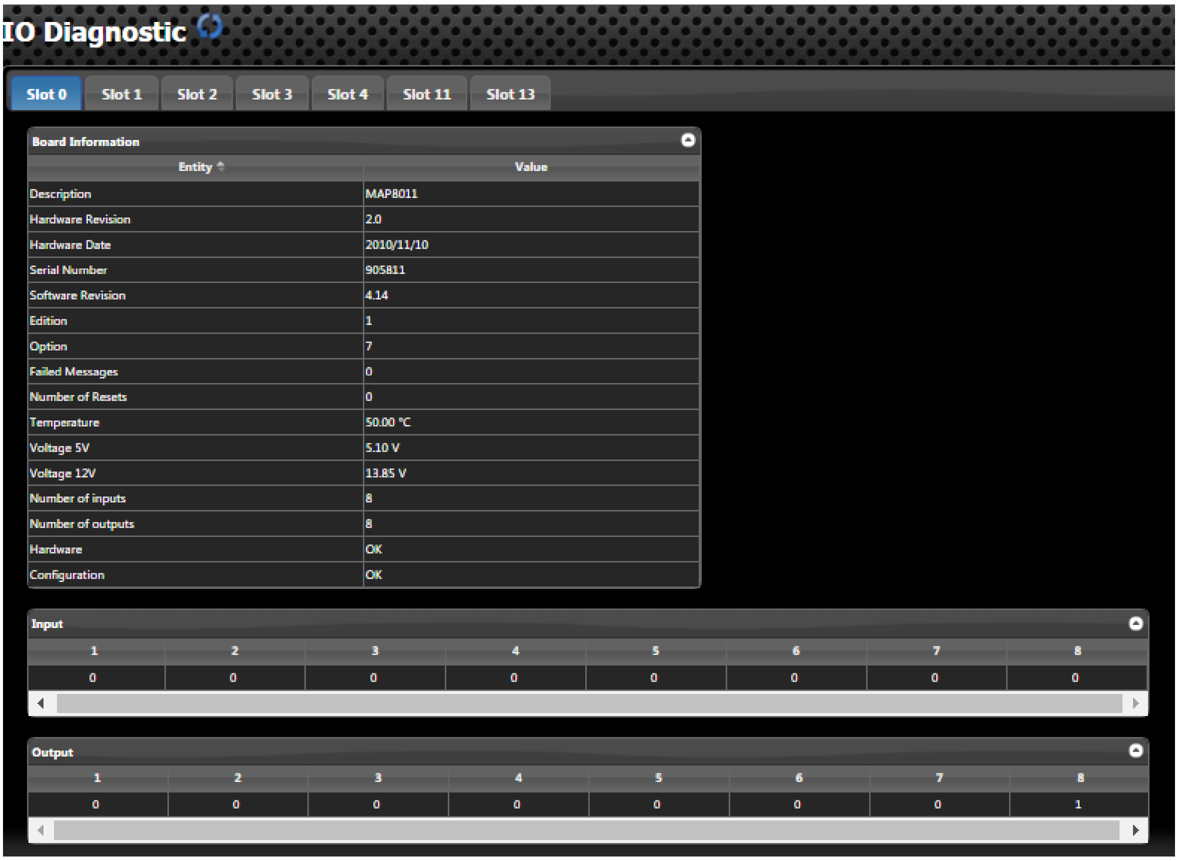
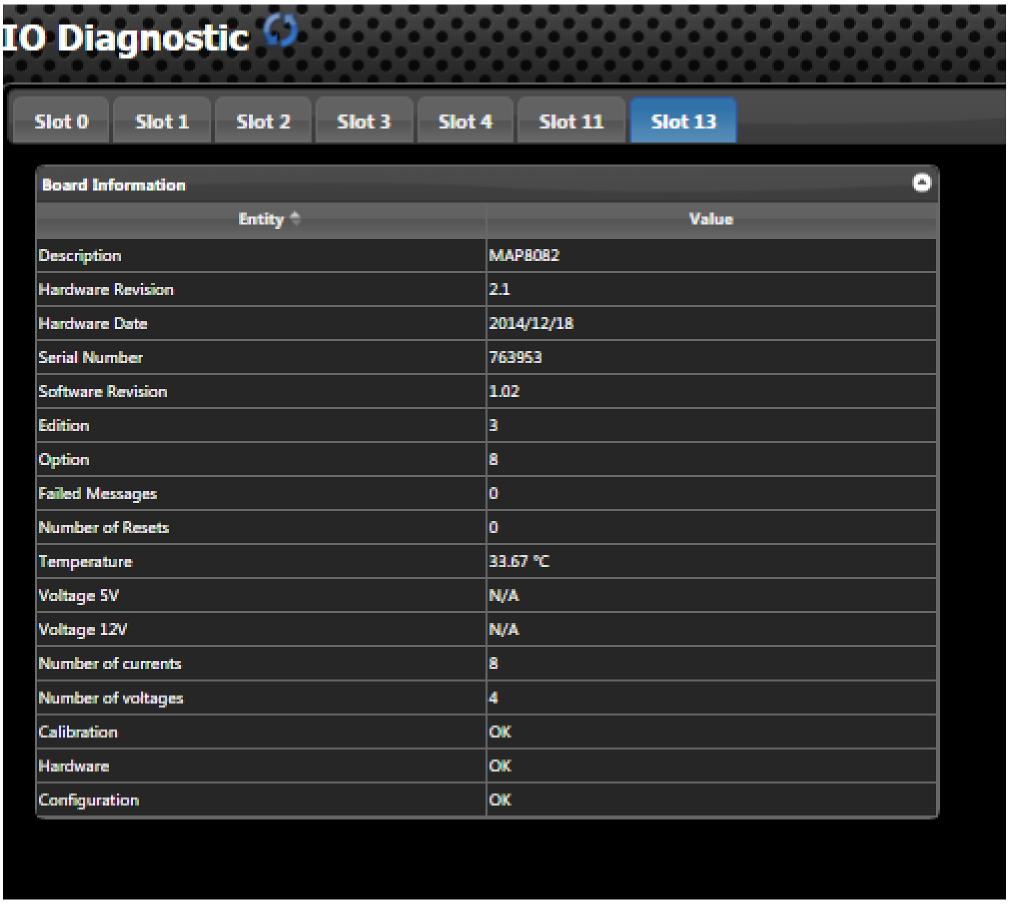


Figure 7.31. Digital IO.

For analogue IO, there is only one table, for each analogue IO board present in the TPU L500, with information on the board itself, as seen in Figure 7.32. In addition, it is also possible to consult the state of the calibration.



IO Diagnostic

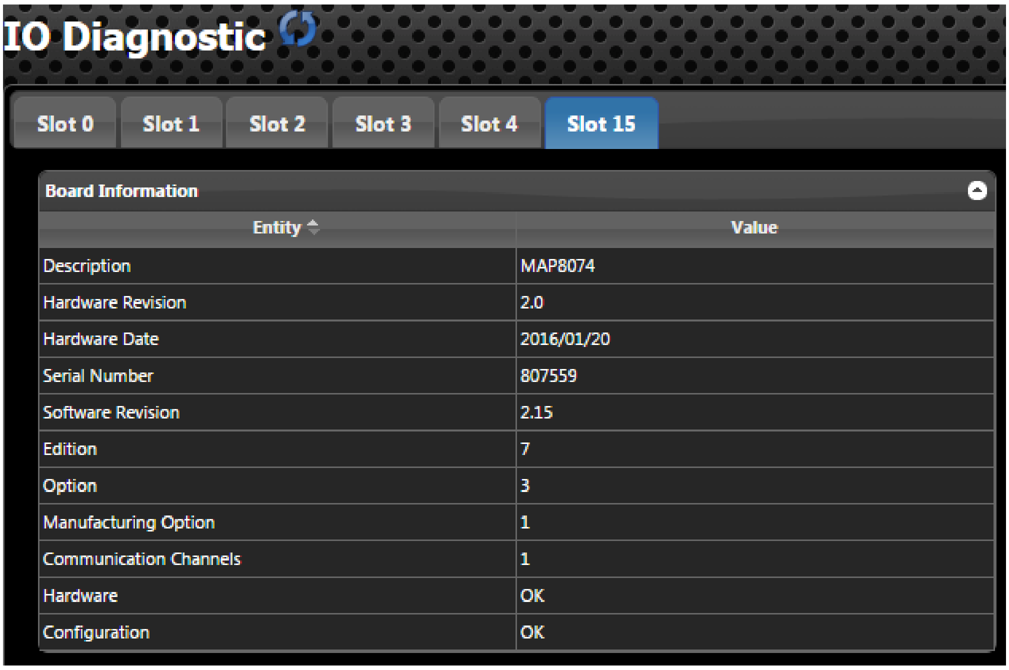
Slot 0 | Slot 1 | Slot 2 | Slot 3 | Slot 4 | Slot 11 | Slot 13

Board Information

Entity	Value
Description	MAP8082
Hardware Revision	2.1
Hardware Date	2014/12/18
Serial Number	763953
Software Revision	1.02
Edition	3
Option	8
Failed Messages	0
Number of Resets	0
Temperature	33.67 °C
Voltage 5V	N/A
Voltage 12V	N/A
Number of currents	8
Number of voltages	4
Calibration	OK
Hardware	OK
Configuration	OK

Figure 7.32. Analogue IO.

In the case of Remote IO, there are two possible tables, with distinct information, that can be visible in this menu. As seen in Figure 7.33, the first table has relevant information on the board itself while the second table has information about each communication channel (Figure 7.34).



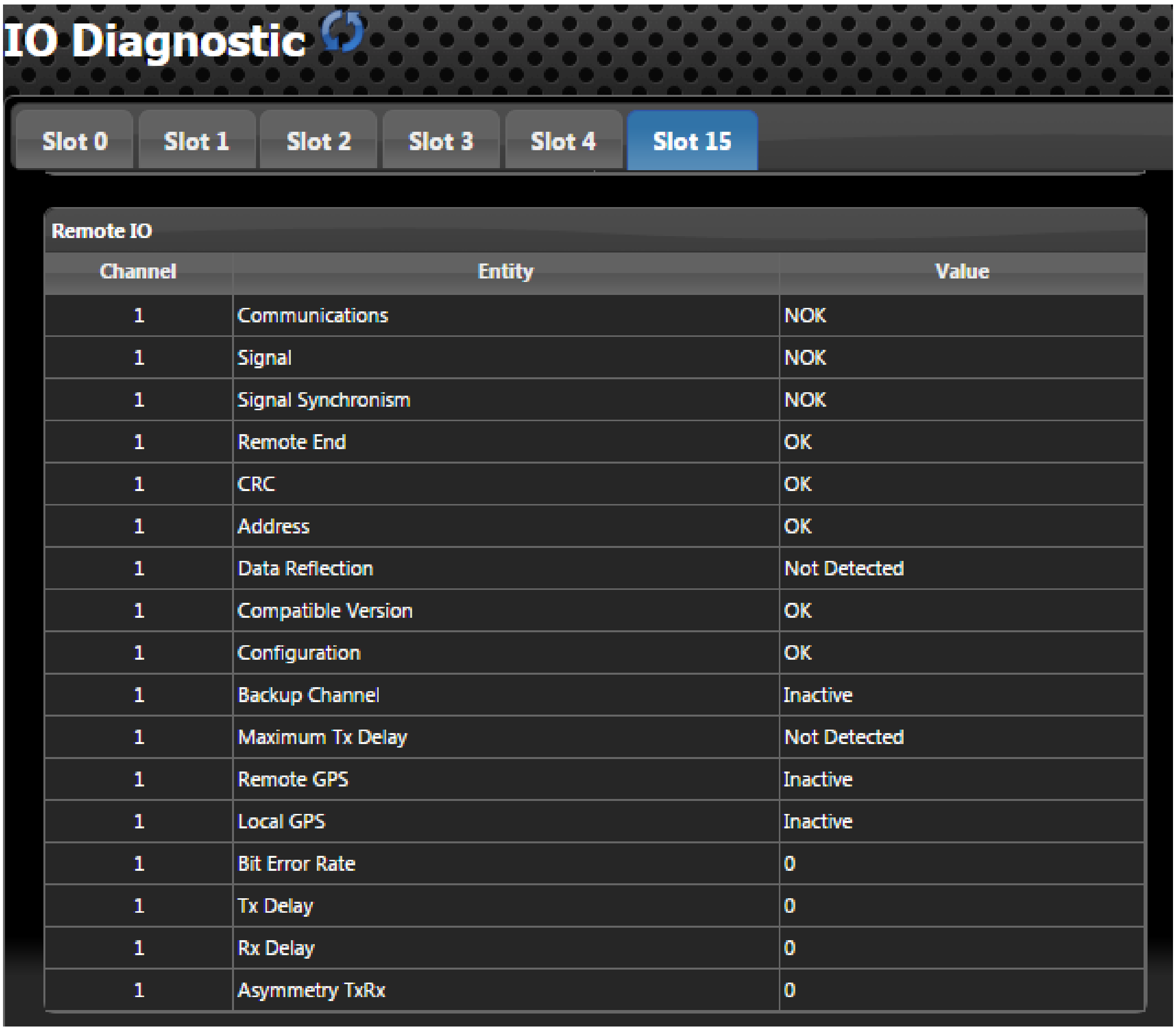
IO Diagnostic

Slot 0 | Slot 1 | Slot 2 | Slot 3 | Slot 4 | Slot 15

Board Information

Entity	Value
Description	MAP8074
Hardware Revision	2.0
Hardware Date	2016/01/20
Serial Number	807559
Software Revision	2.15
Edition	7
Option	3
Manufacturing Option	1
Communication Channels	1
Hardware	OK
Configuration	OK

Figure 7.33. Remote IO board information.



Channel	Entity	Value
1	Communications	NOK
1	Signal	NOK
1	Signal Synchronism	NOK
1	Remote End	OK
1	CRC	OK
1	Address	OK
1	Data Reflection	Not Detected
1	Compatible Version	OK
1	Configuration	OK
1	Backup Channel	Inactive
1	Maximum Tx Delay	Not Detected
1	Remote GPS	Inactive
1	Local GPS	Inactive
1	Bit Error Rate	0
1	Tx Delay	0
1	Rx Delay	0
1	Asymmetry TxRx	0

Figure 7.34. Remote IO channel information

7.7 BUILT-IN FUNCTIONS - VISUALIZATION

For built-in functions, information exists that, for its relevance and importance, must be easily accessible by the user. With this in mind, this information was divided by function in five groups:

- **Measurements**

  Single-Phase Measurements

  Three-Phase Measurements

- **Metering**

  Three-Phase Metering

- **Recording**

  Disturbance Recorder

  Fault Locator

- **Supervision**

  Broken Conductor Check

  Circuit Breaker Failure

  Circuit Breaker Supervision

  Circuit Switch Supervision

  CT Supervision

  VT Supervision

  Thermal Overload

  Trip Circuit Supervision

- **Control**

  Automatic Reclosure

  Circuit Breaker Control

  Circuit Switch Control

  Directional Earth-Fault Overcurrent for Non-Earthed Systems

  Lockout

  Synchronism and Voltage Check

  Three-Phase / Single Phase Trip Logic

It is important to note that this division is used for the Local HMI as well as for the webserver. In both cases each built-in function is a navigable menu.

7.7.1 HMI

From Figure 7.35 is possible to see that the first five menus, in the **Main Menu**, correspond to each category.

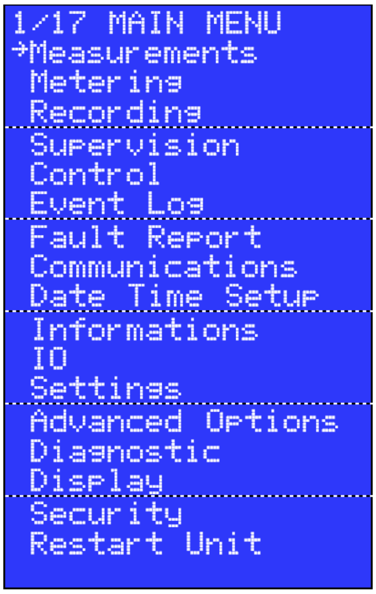


Figure 7.35. Main menu.

By selecting one of these menus you can be confronted with different layouts since the menu format will depend on the configuration and, therefore, the number of functions present in the TPU L500.

As a result, we can have the following situations, depending on the number of functions present:

- **No Built-In function present:**

  Menu "Not Configured".

- **One or more than one Built-In function present:**

  List of functions: - selecting a function will give access to all the relevant data from that function.

7.7.2 WEBSERVER

In the webserver, it is possible to access the built-in function's information through menu **Functions**.

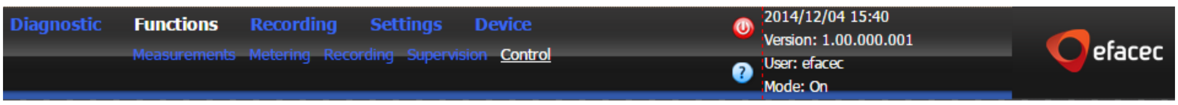


Figure 7.36. Select Built-in function's category.

After selecting a category, you will have a table for each function. To refresh information it is necessary to select the refresh button, present next to the title of each function. In Figure 7.37 you can see an example of the information displayed when the category **Control** is selected.

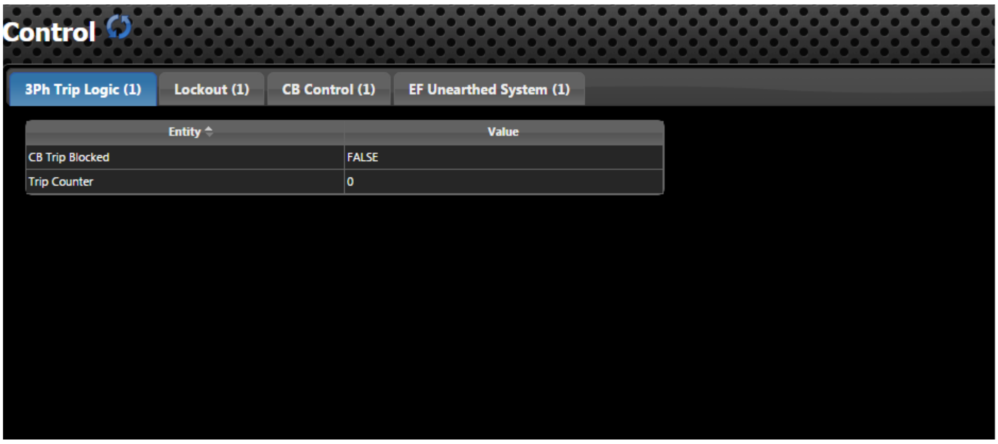


Figure 7.37. Control menu.

7.8 Built-in Functions - Controls

7.8.1 HMI

While navigating in menu **Measurements**, **Metering**, **Recording**, **Supervision** or **Control**, it is possible to find several outputs, identified by the selection bar, in which is possible for the user to execute a control.

Giving a control follows the procedure described in subsection Menu Edition of section 3.1 - Local HMI but, by starting the edition process, you won't be able to edit the value of the output itself but rather the control you want to give. This way, you will be redirected to the menu shown in Figure 7.38.

Figure 7.38. Select Control menu.

After pressing navigation key E to end edition of the desired control, a menu will appear prompting the confirmation or cancelation of that control and, in case of confirmation, you will be able to see if the control was executed or blocked and why it was blocked.

Figure 7.39. Confirmation menu.

In Figure 7.40 it is possible to see a situation where the control was accepted while in Figure 7.41 the control was rejected by "Switching hierarchy". Table 4.19 has all the possible causes for rejection.

Figure 7.40. Control executed.

Figure 7.41. Control blocked.

At any time you can press navigation key C to return to the menu you were before starting this process.

ID access 1 or greater is needed to give a control. If current ID level is insufficient you will be redirected automatically to **Authentication** menu when you start this process.

7.9 Operational Settings

7.9.1 HMI

In **Main Menu**, scroll down until you reach **Settings** menu and then press navigation key E to gain access to the menu displayed in Figure 7.42.

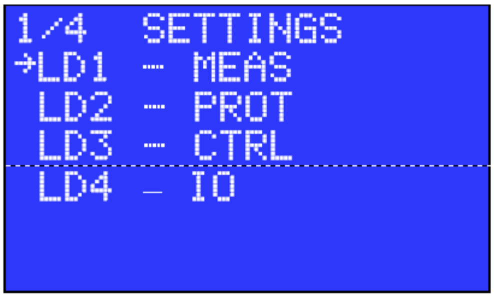


Figure 7.42. Settings menu.

Here, a list is given of all the Logical devices present in the configuration and their name. By following the sequence of instructions in Figure 7.43 you will be able to reach the settings of a built-in function. Note that, for user defined functions, only their list will be available so it won't be possible to see or edit their settings.

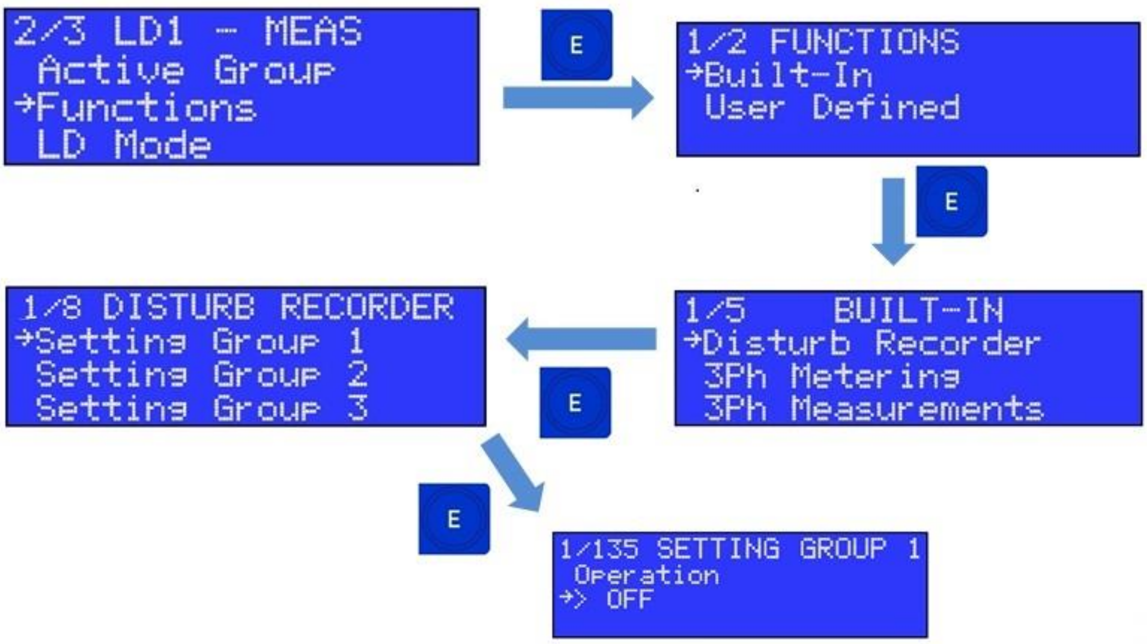


Figure 7.43. Accessing Built-In function's settings.

Built-in functions can have their settings edited by following the procedure described in subsection Menu Edition of section 3.1 - Local HMI. Note that every time changes are accepted, all settings present in the menu will be deployed, therefore, it is advised to make sure all changes have been made before accepting them.

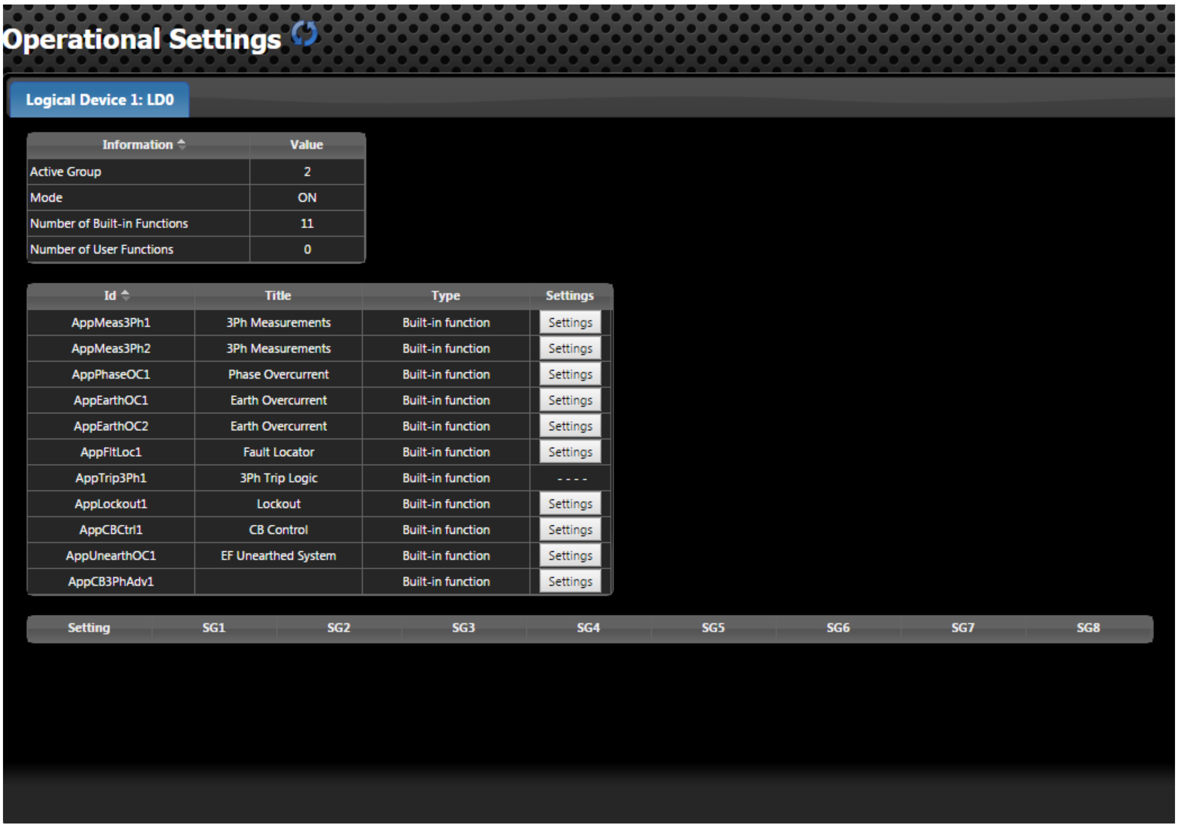
ID access 1 or greater is needed to edit built-in function's settings. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you start the edition process.

7.9.2 WEBSERVER

Operational settings can be accessed in the webserver through menu **Settings** and then submenu **Operational Settings**.

Figure 7.44. Accessing function's settings.

Here you have access to a list of functions present in each logical device, as seen in Figure 7.45.



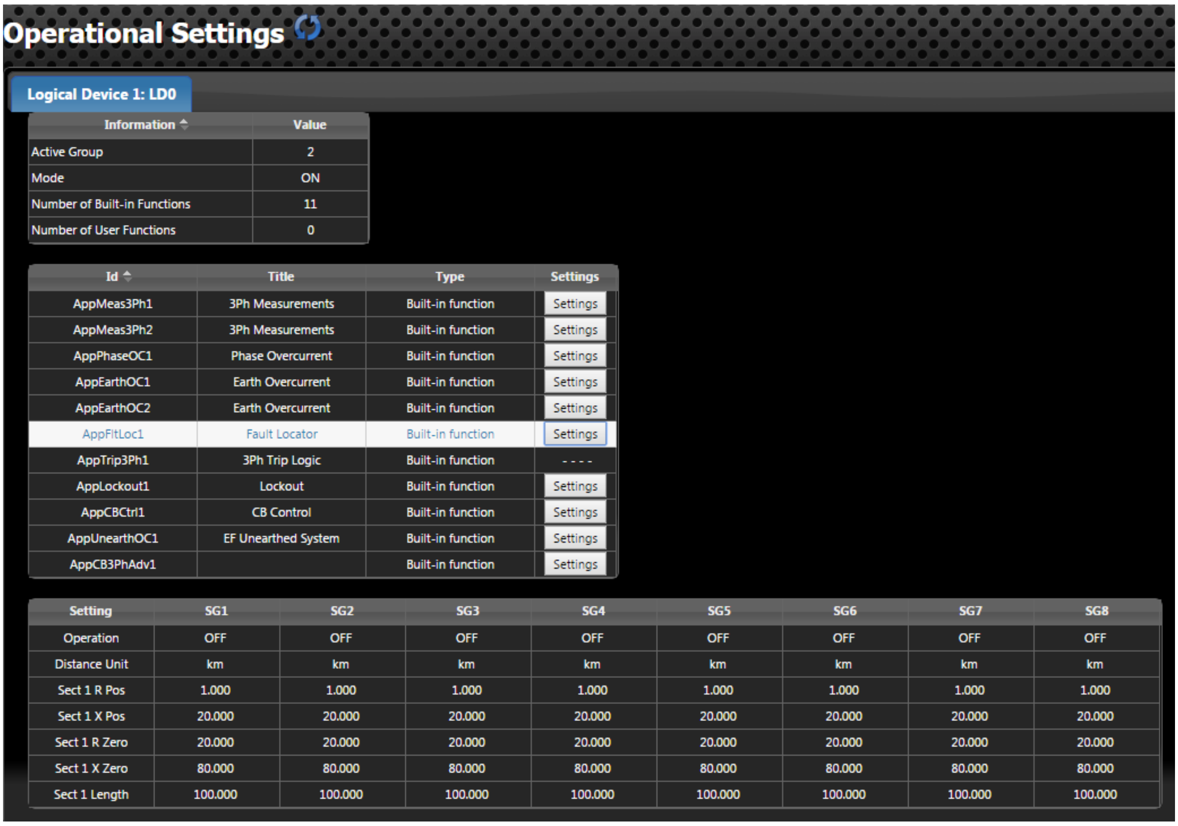
Information	Value
Active Group	2
Mode	ON
Number of Built-in Functions	11
Number of User Functions	0

Id	Title	Type	Settings
AppMeas3Ph1	3Ph Measurements	Built-in function	Settings
AppMeas3Ph2	3Ph Measurements	Built-in function	Settings
AppPhaseOC1	Phase Overcurrent	Built-in function	Settings
AppEarthOC1	Earth Overcurrent	Built-in function	Settings
AppEarthOC2	Earth Overcurrent	Built-in function	Settings
AppFltLoc1	Fault Locator	Built-in function	Settings
AppTrip3Ph1	3Ph Trip Logic	Built-in function	- - - -
AppLockout1	Lockout	Built-in function	Settings
AppCBCtrl1	CB Control	Built-in function	Settings
AppUnearthOC1	EF Unearthed System	Built-in function	Settings
AppCB3PhAdv1		Built-in function	Settings

Setting	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8

Figure 7.45. Settings menu.

By selecting a function, you will be redirected to a table where all settings, from that function, are shown as well as their value for each setting group. At the moment, it is not possible to edit these settings through the webserver.



Operational Settings

Logical Device 1: LD0

Information	Value
Active Group	2
Mode	ON
Number of Built-in Functions	11
Number of User Functions	0

Id	Title	Type	Settings
AppMeas3Ph1	3Ph Measurements	Built-in function	Settings
AppMeas3Ph2	3Ph Measurements	Built-in function	Settings
AppPhaseOC1	Phase Overcurrent	Built-in function	Settings
AppEarthOC1	Earth Overcurrent	Built-in function	Settings
AppEarthOC2	Earth Overcurrent	Built-in function	Settings
AppFltLoc1	Fault Locator	Built-in function	Settings
AppTrip3Ph1	3Ph Trip Logic	Built-in function	- - - -
AppLockout1	Lockout	Built-in function	Settings
AppCBCtrl1	CB Control	Built-in function	Settings
AppUnearthOC1	EF Unearthed System	Built-in function	Settings
AppCB3PhAdv1		Built-in function	Settings

Setting	SG1	SG2	SG3	SG4	SG5	SG6	SG7	SG8
Operation	OFF	OFF	OFF	OFF	OFF	OFF	OFF	OFF
Distance Unit	km	km	km	km	km	km	km	km
Sect 1 R Pos	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Sect 1 X Pos	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000
Sect 1 R Zero	20.000	20.000	20.000	20.000	20.000	20.000	20.000	20.000
Sect 1 X Zero	80.000	80.000	80.000	80.000	80.000	80.000	80.000	80.000
Sect 1 Length	100.000	100.000	100.000	100.000	100.000	100.000	100.000	100.000

Figure 7.46. Fault Locator settings table.

7.9.3 Automation Studio

Operational settings can be configured and deployed by accessing the option **Operational Settings** in the Solution Explorer, seen in Figure 7.47. For a more detailed explanation on how to use this feature, please refer to the Automation Studio's manuals, present in each version, by going to menu **Help** and selecting **User Manuals**.

Figure 7.47. Automation Studio's Solution Explorer.

7.10 Active Setting Group

7.10.1 HMI

In **Main Menu**, scroll down until reaching **Settings** menu and then press navigation key E to gain access to it. By following the sequence in Figure 7.48 it is possible to reach the active group of a logical device.

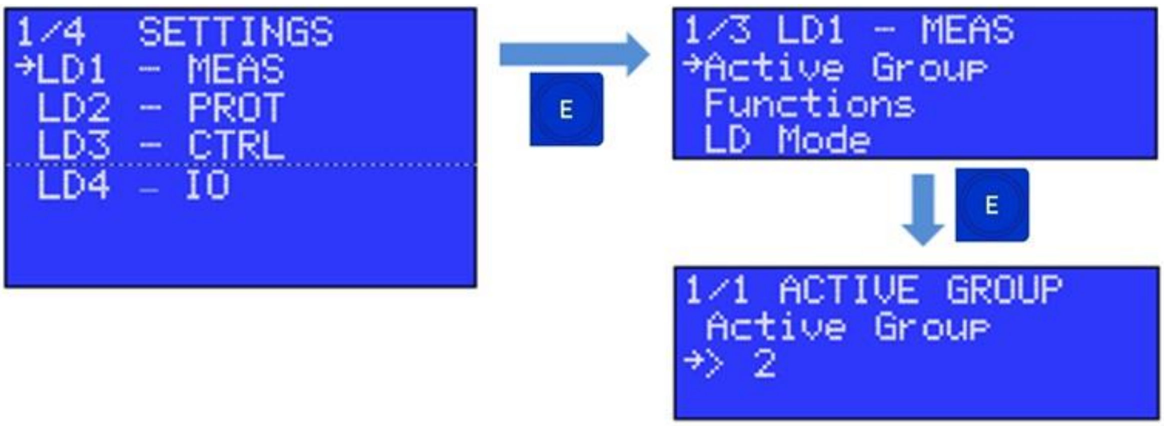


Figure 7.48. Sequence to reach the Active Group of a Logical Device.

To edit the active group, please follow the procedure described in subsection Menu Edition of section 3.1 - Local HMI.

ID access 1 or greater is needed to change the active group of a logical device. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you start the process.

7.10.2 Webserver

In the webserver it is possible to access the active group of a logical device by selecting menu **Settings** and then submenu **Operational Settings**, as seen in Figure 7.49.

Figure 7.49. Accessing Logical Device Active Group.

Here you have access to the active setting group of each logical device, as seen in Figure 7.50. This information is only available for consultation, not being possible to change it via webserver.

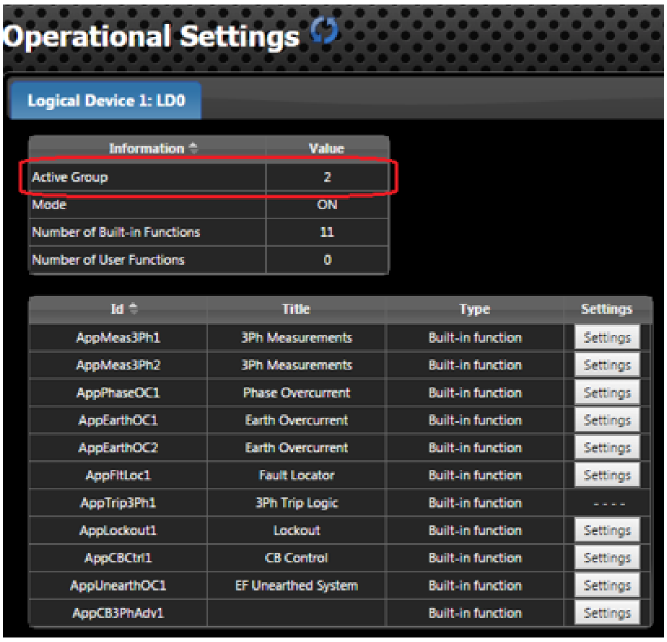


Figure 7.50. Logical Device Active Group.

7.10.3 AUTOMATION STUDIO

Active Setting Group can be configured through the Automation Studio by expanding the option **Operational Settings** in the Solution Explorer, seen in Figure 7.51, and selecting the **current** tag to access the operational settings, where you have the option of selecting the active group of each logical device. For a more detailed explanation on how to use this feature, please refer to the Automation Studio's manuals, present in each version, by going to menu **Help** and selecting **User Manuals**.

Figure 7.51. Automation Studio's Solution Explorer.

7.11 Logical Device Mode

Logical device mode can have the value:

- Off
- Test
- On

7.11.1 HMI

In **Main Menu**, scroll down until reaching **Settings** menu and then press navigation key E to gain access to it. By following the sequence in Figure 7.52 it is possible to reach the mode of a logical device.

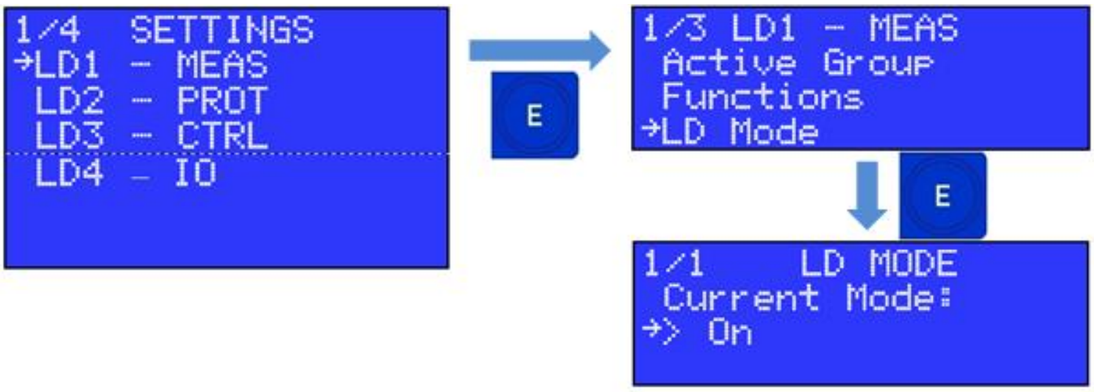


Figure 7.52. Sequence to reach Logical Device Mode.

To edit the logical device mode, please follow the procedure described in subsection Menu Edition of section 3.1 - Local HMI.

ID access 1 or greater is needed to change the mode of a logical device. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you start this process.

7.11.2 Webserver

In the webserver it is possible to access the logical device mode through menu **Settings** and then submenu **Operational Settings**, as seen in Figure 7.53.

Figure 7.53. Accessing Logical Device Mode.

Figure 7.54. Logical Device Mode.

7.12 RESTORE FACTORY CONFIGURATION

7.12.1 HMI

Through the Local HMI it is possible to delete the user configuration and reload the factory one. To access this option, scroll down in the **Main Menu** until you reach **Advanced Options** menu and then press navigation key E to have access to the menu shown in Figure 7.55.

Figure 7.55. Advanced Options menu.

Here, just select option **Delete Conf.** and when propped, accept the command. **This action will reboot the TPU L500**.

ID access 2 is needed to perform this action. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select this option.

7.12.2 WEBSERVER

To be able to delete the user configuration and reload the factory one through the webserver just follow the steps shown in Figure 7.56:

- (1) Press button  to obtain the option list in (2)
- Select option "**Reset Configuration**" (3).

This will reboot the TPU L500.

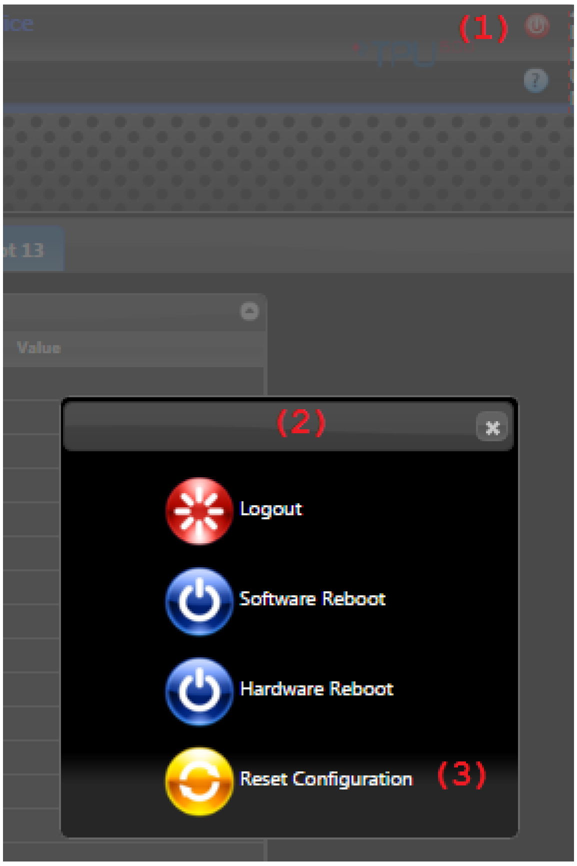


Figure 7.56. Restore factory configuration.

To gain access to this option you have to login as administrator.

7.13 RESTORE FACTORY OPERATIONAL SETTINGS

7.13.1 HMI

Through the Local HMI it is possible to delete the user configured operational settings and reload the factory ones. To access this option, scroll down, in the **Main Menu**, until you reach **Advanced Options** menu and then press navigation key E to gain access to the menu in Figure 7.57.

Figure 7.57. Advanced Options menu.

Here just select option **Delete Settings** and when propped, accept the command. **This action will reboot the TPU L500**.

ID access 2 is needed to perform this action. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select this option.

7.14 EVENT LOG

7.14.1 HMI

To have access to the event log through the local HMI, scroll down in **Main Menu** until you reach **Event Log** menu. Pressing navigation key E will give you access to the menu shown in Figure 7.58.

Figure 7.58. Event Log menu.

Here you can access an **Options** menu with the following items:

- **Events Order:**

  By accessing this submenu it is possible to change the order in which the events are displayed in the local HMI (ascending or descending).

- **Number of Events:**

  By accessing this submenu it is possible to change the number of events that are displayed in the local HMI.

- **Clear Log:**

  It allows clearing all events stored in the TPU L500.

All of these options are for the visualization of the event log in the Local HMI with the exception of the option to clear the event log in the unit which deletes the records from the TPU L500, therefore, also preventing their visualization in the local HMI.

Editing the order and number of events follows the procedure described in subsection Menu Edition of section 3.1 - Local HMI. To clear the event log, one must only select the desired option with navigation key E.

ID access 1 or greater is needed to change event log settings and to give the instruction to clear the event log. If current ID level is insufficient you will be automatically redirected to **Authentication** menu.

Selecting submenu **Log** will give you access to the latest events in the order and number configured in the options menu. Figure 7.59 is a snapshot of one event. The first line of the page gives the number of the event and the information of the total number of events present in the menu. Each event contains the following information:

- **Event Occurrence:**

  Date and time with 1 ms resolution;

- **Entity:**

  Description of the entity that originated the event;

- **Event trigger:**

  Trigger that originated the event. It is indicated which field originated the event as well as its new value.

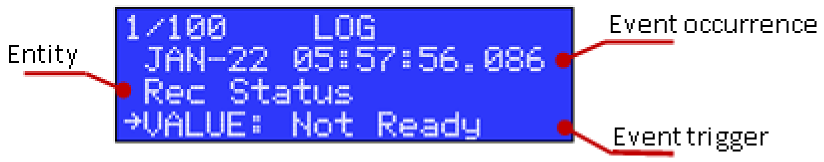


Figure 7.59. Event.

The Selection Arrow, in the event trigger line, indicates that it is possible to press the navigation key E to enter a submenu. Here you can consult, in more detail, all the information recorded when the event occurred.

Note that if more than one trigger originated the event, there will be one page for each trigger, each with the same information with the exception of the trigger information. In those events, the information displayed by navigating inside the submenu will be the same because they are, in fact, the same event.

7.14.2 Webserver

In the webserver is possible to access the Event Log through the Log menu, as seen in Figure 7.60.

Figure 7.60. Webserver Event Log.

In Figure 7.61 it is possible to observe that the event log table is composed of:

- **Identification:**

  Entity identification

- **Date / Time:**

  Insertion date and time of the event in log

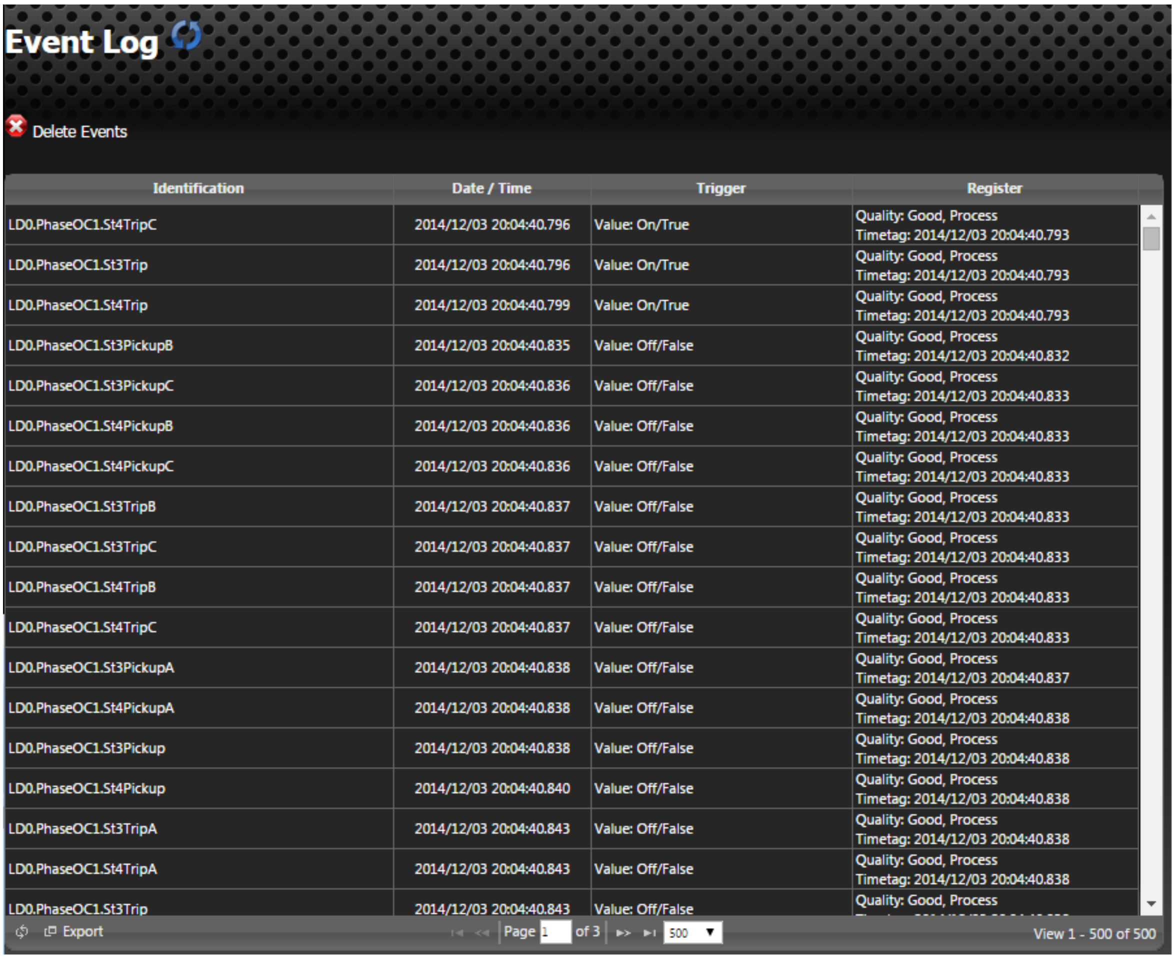
- **Trigger:**

  Trigger or triggers that originated the event

- **Register:**

  Fields of the element that have to be registered when an event occurs

As seen in Figure 7.61, there is also the possibility of clearing the event log by selecting the “Delete Events” option which will delete all records from the TPU L500.



Event Log

Delete Events

Identification	Date / Time	Trigger	Register
LD0.PhaseOC1.St4TripC	2014/12/03 20:04:40.796	Value: On/True	Quality: Good, Process Timetag: 2014/12/03 20:04:40.793
LD0.PhaseOC1.St3Trip	2014/12/03 20:04:40.796	Value: On/True	Quality: Good, Process Timetag: 2014/12/03 20:04:40.793
LD0.PhaseOC1.St4Trip	2014/12/03 20:04:40.799	Value: On/True	Quality: Good, Process Timetag: 2014/12/03 20:04:40.793
LD0.PhaseOC1.St3PickupB	2014/12/03 20:04:40.835	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.832
LD0.PhaseOC1.St3PickupC	2014/12/03 20:04:40.836	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St4PickupB	2014/12/03 20:04:40.836	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St4PickupC	2014/12/03 20:04:40.836	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St3TripB	2014/12/03 20:04:40.837	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St3TripC	2014/12/03 20:04:40.837	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St4TripB	2014/12/03 20:04:40.837	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St4TripC	2014/12/03 20:04:40.837	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.833
LD0.PhaseOC1.St3PickupA	2014/12/03 20:04:40.838	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.837
LD0.PhaseOC1.St4PickupA	2014/12/03 20:04:40.838	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.838
LD0.PhaseOC1.St3Pickup	2014/12/03 20:04:40.838	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.838
LD0.PhaseOC1.St4Pickup	2014/12/03 20:04:40.840	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.838
LD0.PhaseOC1.St3TripA	2014/12/03 20:04:40.843	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.838
LD0.PhaseOC1.St4TripA	2014/12/03 20:04:40.843	Value: Off/False	Quality: Good, Process Timetag: 2014/12/03 20:04:40.838
LD0.PhaseOC1.St3Trip	2014/12/03 20:04:40.843	Value: Off/False	Quality: Good, Process

Export Page 1 of 3 500 View 1 - 500 of 500

Figure 7.61. Event Log table.

7.14.3 Automation Studio

Event Log can be visualized and deleted in Automation Studio through the option **Event Records** in the Solution Explorer, seen in Figure 7.62. For a more detailed explanation on how to use this feature, please refer to the Automation Studio's manuals, present in each version, by going to menu **Help** and selecting **User Manuals**.

Figure 7.62. Automation Studio's Solution Explorer.

7.15 FAULT REPORT

7.15.1 HMI

In the local HMI it is possible to access the information block "**Summary**" of the last Fault Report stored in the TPU L500 as well as access options and relevant information of the Fault Report module.

To access the **Fault Report** menu just scroll down in **Main Menu** until reaching it and then press navigation key E to enter the menu shown in Figure 7.63.

Figure 7.63. Fault Report menu.

Here you have several submenus available.

- **Options:**

  Contains option to delete all Fault Reports created and restart Fault Report counters.

- **Informations**:

  In Progress: - indicates if a report is in progress;

  Number of Reports: - indicates the number of reports created with current configuration;

  Reports Lost: - indicates the number of reports lost with current configuration.

- **Report:**

  Summary component of the last report created. Figure 7.64 displays a possible report.

Figure 7.64. Report menu.

7.15.2 Webserver

In the webserver it is possible to access the **Fault Report** menu through the **Recording** menu, as seen in Figure 7.65.

Figure 7.65. Access Fault Report menu.

After selecting the Fault Report menu you will see a list of Fault Reports present in the TPU L500 that can be refreshed by pressing the refresh button. Here, you also have the option of deleting all of the stored information related with the Fault Report, by selecting option "**Delete Fault Reports**".

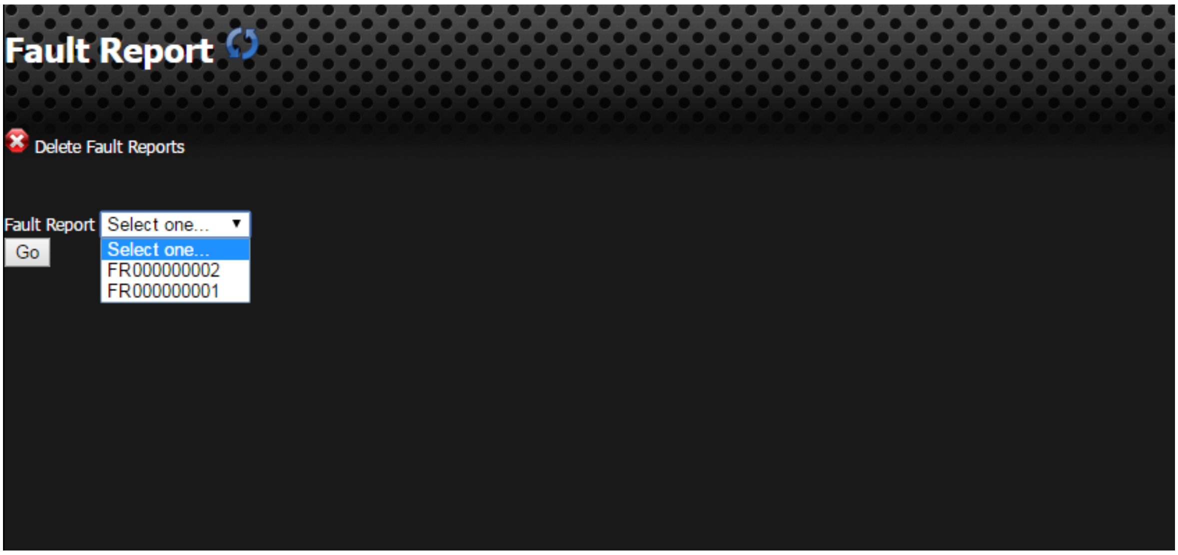
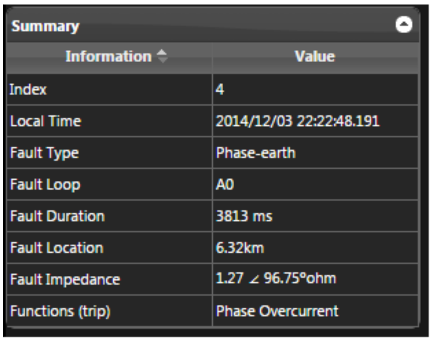


Figure 7.66. Fault Report menu.

By selecting a Fault Report file you can see the information recorder for that report. Figure 7.67 shows the **Summary** component of a possible Fault Report, where the most relevant data is present, Figure 7.68 shows the **Timeline** component, where the most relevant events are ordered chronologically and Figure 7.69 and Figure 7.70 display the pre-fault measurements and fault measurements, respectively.

For a more in-depth description on each block of information please refer to section 4.8 - Fault Report.



Summary

Information	Value
Index	4
Local Time	2014/12/03 22:22:48.191
Fault Type	Phase-earth
Fault Loop	A0
Fault Duration	3813 ms
Fault Location	6.32km
Fault Impedance	1.27 ∠ 96.75ºohm
Functions (trip)	Phase Overcurrent

Figure 7.67. Fault Report - Summary.

Timeline

Date / Time	Information
-------------------	Phase Overcurrent pickup stage(s) 3, 4 phase(s) A
-------------------	Phase Overcurrent trip stage(s) 3, 4 phase(s) A
2014/12/03 22:22:51.996	AppCB3PhAdv1: LD0.CB3PhAdv1.Position OFF

Figure 7.68. Fault Report - Timeline.

Pre-Fault Measurements

Function	Entity	Value
3Ph Measurements	IA	120.06 ∠ 0.00°A
3Ph Measurements	IB	120.23 ∠ -120.14°A
3Ph Measurements	IC	120.23 ∠ 119.93°A
3Ph Measurements	Ires	0.00 ∠ 0.00°A
3Ph Measurements	Ineut	0.00 ∠ 0.00°A
3Ph Measurements	UA	17.32 ∠ 0.00°kV
3Ph Measurements	UB	17.32 ∠ -119.99°kV
3Ph Measurements	UC	17.32 ∠ 120.05°kV
3Ph Measurements	Ures	0.00 ∠ 0.00°kV
3Ph Measurements	Uneut	0.00 ∠ 0.00°kV
3Ph Measurements	UAB	29.99 ∠ 30.00°kV
3Ph Measurements	UBC	29.99 ∠ -89.96°kV
3Ph Measurements	UCA	30.01 ∠ 150.01°kV
3Ph Measurements	I1	120.18 ∠ -120.07°A
3Ph Measurements	I2	0.00 ∠ 0.00°A
3Ph Measurements	I0	0.00 ∠ 0.00°A
3Ph Measurements	U1	17.32 ∠ -119.98°kV
3Ph Measurements	U2	0.00 ∠ 0.00°kV
3Ph Measurements	U0	0.00 ∠ 0.00°kV
3Ph Measurements	IA	120.06 ∠ 0.00°A

Figure 7.69. Fault Report – Pre-fault measurements.

Fault Measurements

Function	Entity	Value
CB 3Ph	Switch IA	0.00
CB 3Ph	Switch IB	0.00
CB 3Ph	Switch IC	0.00

Figure 7.70. Fault Report – Fault measurements.

7.15.3 Automation Studio

Fault Reports can be visualized and deleted in Automation Studio through the option **Fault Reports** in the Solution Explorer, seen in Figure 7.71. For a more detailed explanation on how to use this feature, please refer to the Automation Studio's manuals, present in each version, by going to menu **Help** and selecting **User Manuals**.

Figure 7.71. Automation Studio's Solution Explorer.

7.16 Disturbance Recorder

7.16.1 HMI

In menu **Recording**, accessible in **Main Menu**, you can access information related with the Disturbance Recorded as well as perform actions, such as:

- force the manual start of a disturbance record (**Trigger**);
- Clear memory (**Memory Clear**);
- See information on the number of records made and the size of memory used.

To start a record or to clear the memory used, you have to give a control with value **1** by following the procedure described in section 7.8 - Built-in Functions - Controls, in the outputs indicated above.

7.16.2 Automation Studio

Disturbance Records can be visualized and deleted in Automation Studio through the option **Disturbance Records** in the Solution Explorer, seen in Figure 7.72. For a more detailed explanation on how to use this feature, please refer to the Automation Studio's manuals, present in each version, by going to menu **Help** and selecting **User Manuals**.

Figure 7.72. Automation Studio's Solution Explorer.

7.17 DELETE RECORDS

7.17.1 HMI

Through the Local HMI it is possible to delete all the records of the unit. This includes Event Logs, Fault Reports, Disturbance Records and all the records that might have been done by the built-in functions, such as counters.

To access this option, scroll down in the **Main Menu** until you reach **Advanced Options** menu and then press navigation key E to gain access to the menu shown in Figure 7.73.

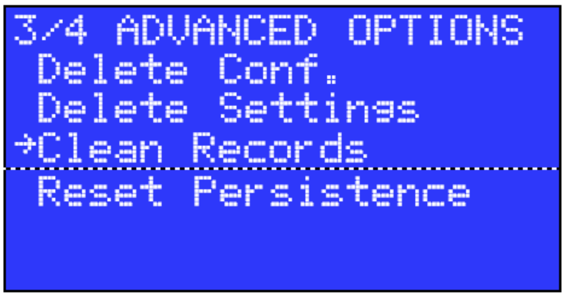


Figure 7.73. Advanced Options menu.

Here, just select option **Clean Records** and when propped, accept the command.

ID access 2 is needed to perform this action. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select this option.

Local mode must be active or else the built-in functions won't accept the command to delete their records.

7.18 Reset Persistence

It is possible to delete all the persistent data in the device. This is advised to do each time we are building up a complete new configuration. This operation can be done from the local HMI (see section 7.18.1 - HMI) or with the Automation Studio engineering tool.

7.18.1 HMI

To access this option, scroll down in the **Main Menu** until you reach **Advanced Options** menu and then press navigation key E to gain access to the menu shown in Figure 7.74.

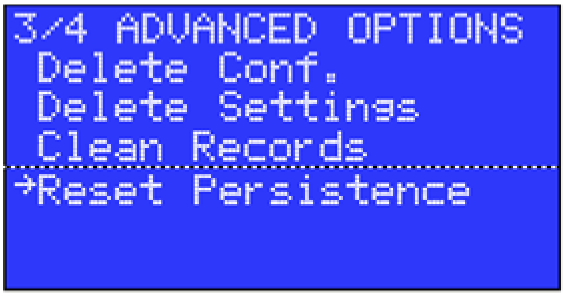


Figure 7.74. Advanced Options menu.

Here just select option **Reset Persistence** and when prompted, accept the command. **This action will reboot the TPU L500**.

ID access 2 is needed to perform this action. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select this option.

7.19 RESTART DEVICE

7.19.1 HMI

To restart the TPU L500 just scroll down in **Main Menu** until you reach option **Restart Unit** (this operation will cause a software reboot). Here, just press navigation key E to give the command and then again when asked for confirmation.

Figure 7.75. Restart Unit menu.

ID access 2 is needed to perform this action. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select this option.

7.19.2 WEB SERVER

To be able to restart the TPU L500, through the webserver, just follow the steps shown in Figure 7.76.

- (1) Press button to obtain the option list in (2)
- Select option "Software Reboot" (3) or Hardware Reboot (4).

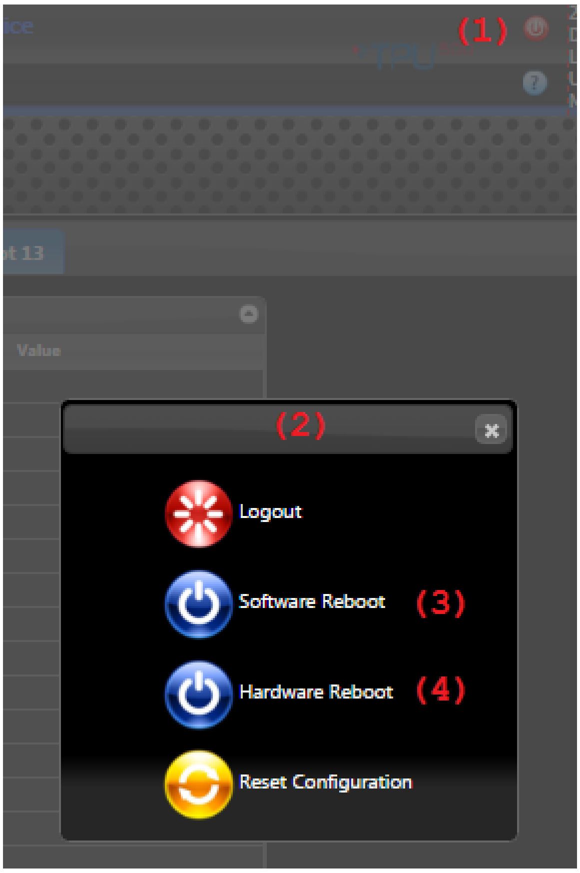


Figure 7.76. Restart unit.

To gain access to this option you have to login as administrator.

7.20 RESTART LOCAL HMI

To restart the Local HMI just press simultaneously navigation key **E** and navigation key **C.**

7.21 DIAGNOSTIC AND TESTS

7.21.1 HMI

Menu **Diagnostics** was created to encompass all available diagnostics and tests for the TPU L500 and it can be accessed by scrolling down in **Main Menu**.

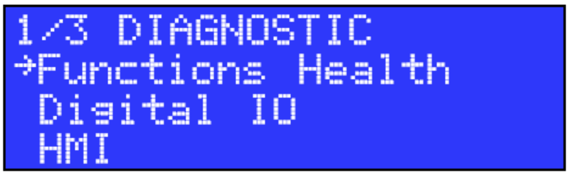


Figure 7.77 Diagnostic menu.

Option **Functions Health** can be accessed without having to enter an ID access while option **HMI** requires ID access 1 or higher and **Digital IO** requires ID access 2. If current ID level is insufficient you will be automatically redirected to **Authentication** menu when you select an option.

Function's Health

By selecting this option you will enter a menu with a list of all the built-in functions present in the configuration. Selecting a function will show the current state of its health.

Digital IO

By selecting this option you will be able to enter IO test mode and test the digital IO outputs, as described in section 7.6 - I/O Diagnostic and Information.

HMI

By selection this option you will enter the menu in Figure 7.78, where you can select **Informations**, **Display Options** and **Diagnostic**.

Figure 7.78. HMI menu.

Menu **Informations** contains:

- **Software Info:** software version;
- **Board info:** name; serial number; HW revision; HW revision date; Edition; Option; Temperature; Voltages;
- **Memory:** Volatile and non-volatile memory size, usage and state (OK or NOK).

Menu **Display Options** contains:

- **Brightness;**

Menu **Diagnostic** contains tests for the display, LEDs and keys. In each, instructions are given on how to perform them.

7.21.2 WEB SERVER

Diagnostic options can be accessed via webserver in menu **Diagnostic.**

Figure 7.79 Diagnostic menu.

System Monitor

By selecting this menu you will have access to system information such as memory usage and CPU information.

IO

By selecting this menu you will have access to all the information regarding digital and analogue IO. IO menu was already described in subsection 7.6 - I/O Diagnostic and Information.

RTDB

By selecting this menu you will be able to see the state of any RTDB entity. To help find the desired element, you have available a group of filters, as seen in Figure 7.80, that allows you to select the desired type and a keyword, in the text box, that will have to be present in the entity's name. It is important to note that while selecting the type is mandatory, writing a keyword is not.

Figure 7.80 RTDB Filter menu.

By submitting the search parameters in Figure 7.80 (type digital) we would have obtained the results shown in Figure 7.81.

Element	Title	Fields
LD0.EarthOC2.St4Trip	St4 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC2.St3Trip	St3 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC2.HarmonicBlock	Harmonic Block	Value: (0) Off/False Quality: Good, Process Timetag: 2014/12/03 21:26:02,740 Origin: Automatic bay
LD0.EarthOC2.St4Pickup	St4 Pickup	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC2.St3Pickup	St3 Pickup	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC2.St2Trip	St2 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC2.St1Trip	St1 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,676 Origin: Automatic bay
LD0.EarthOC1.St4Trip	St4 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,675 Origin: Automatic bay
LD0.EarthOC1.St3Trip	St3 Trip	Value: (0) Off/False Quality: Invalid, Process Timetag: 2014/12/03 21:26:02,675 Origin: Automatic bay
LD0.EarthOC1.HarmonicBlock	Harmonic Block	Value: (0) Off/False Quality: Good, Process

Figure 7.81. Search result.

To gain access to the **RTDB** menu you have to login as administrator.

RTDB search should always be performed with filters as specific as possible to avoid dumping too much information which would have an impact on the TPU L500’s performance while the search was underway.

Chapter

8

ANNEXES

The following annexes provide additional information about the setting options and factory configuration of the TPU L500 that complements the previous chapters.

TABLE OF CONTENTS

Total of pages of the chapter: 12

8.1 Definite and Inverse Time Characteristics

In this annex, the several definite and inverse time characteristics implemented in the TPU L500 are described.

8.1.1 Current Protection Standard Curves

For ANSI and IEC time inverse curves, the trip time depends on the ratio between the measured current I and the setting I_{op}, according to (8.1) and (8.2), respectively.

$$t = \left(\frac{A}{(I/I_{op})^p - 1} + B \right) \cdot TM \tag{8.1}$$

$$t = \frac{A \cdot TM}{(I/I_{op})^p - 1} \tag{8.2}$$

If the inverse time reset option is selected, the time to reset also depends on the measured current, according to the equation (8.3). This option, defined in the ANSI standard, is extended in the TPU L500 to the IEC curves.

$$t = \frac{t_{reset} \cdot TM}{1 - (I/I_{op})^2} \tag{8.3}$$

The time multiplier (*TM*) can be set in order to coordinate the trip and reset time characteristics with other protective devices in the same network. The several standard characteristics available are listed in Table 8.1, together with the constants A, B, p and t_{reset} that define each curve shape.

Table 8.1. Current protection time characteristics.

Curve	A	B	p	t_{reset}
ANSI Extremely Inverse	28,2	0.1217	2,0	29,1
ANSI Very Inverse	19,61	0,491	2,0	21,6
ANSI Normal Inverse	0,0086	0,0185	0,02	0,46
ANSI Moderately Inverse	0,0515	0,1140	0,02	4,85
ANSI Definite Time	Not applicable			
ANSI Long Time Extremely Inverse	64,07	0,250	2,0	30
ANSI Long Time Very Inverse	28,55	0,712	2,0	13,46
ANSI Long Time Inverse	5,6143	2,18592	1,0	12,9
IEC Normal Inverse	0,14	-	0,02	16,86
IEC Very Inverse	13,5	-	1,0	29,7
IEC Inverse	0,14	-	0,02	16,86
IEC Extremely Inverse	80,0	-	2,0	80,0
IEC Short-Time Inverse	0,05	-	0,04	3,006
IEC Long-Time Inverse	120	-	1,0	264,0
IEC Definite Time	Not applicable			
Logarithmic	Not applicable			

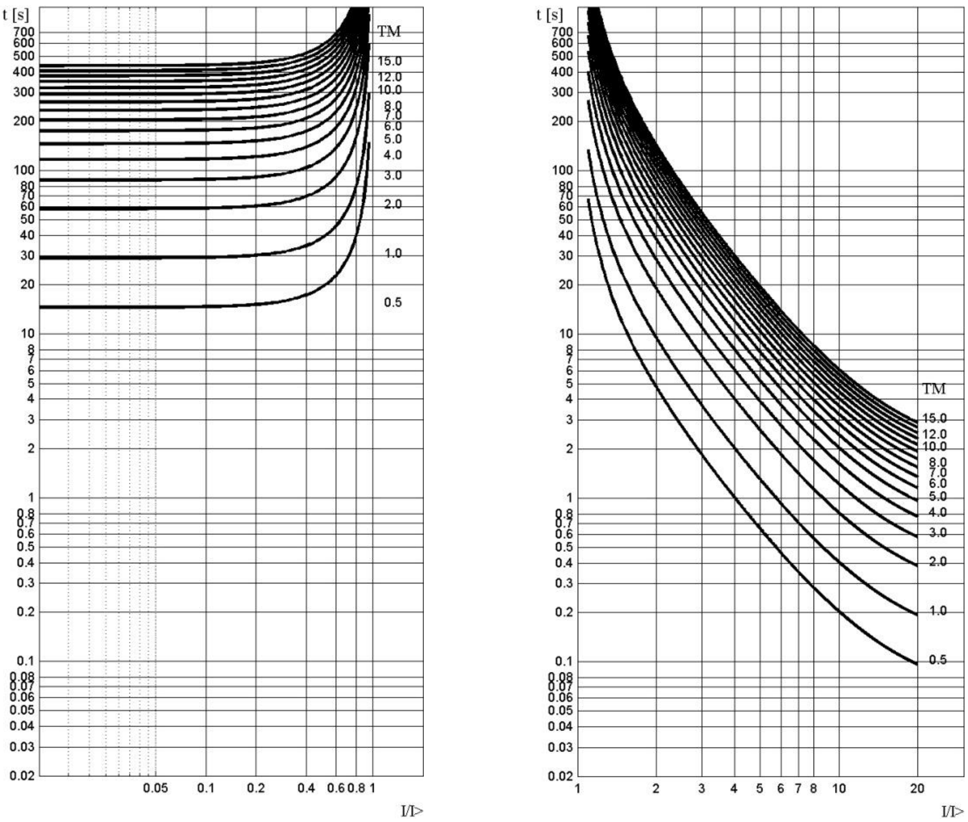


Figure 8.1. Reset and trip curves for ANSI Extremely Inverse characteristic.

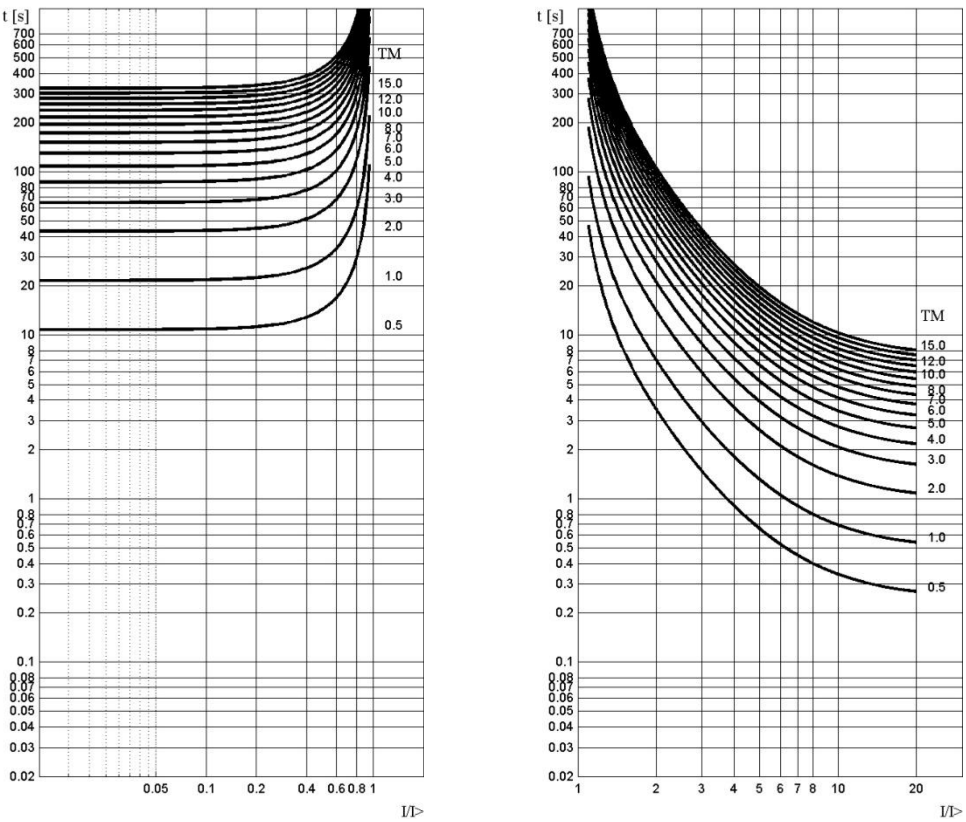


Figure 8.2. Reset and trip curves for ANSI Very Inverse characteristic.

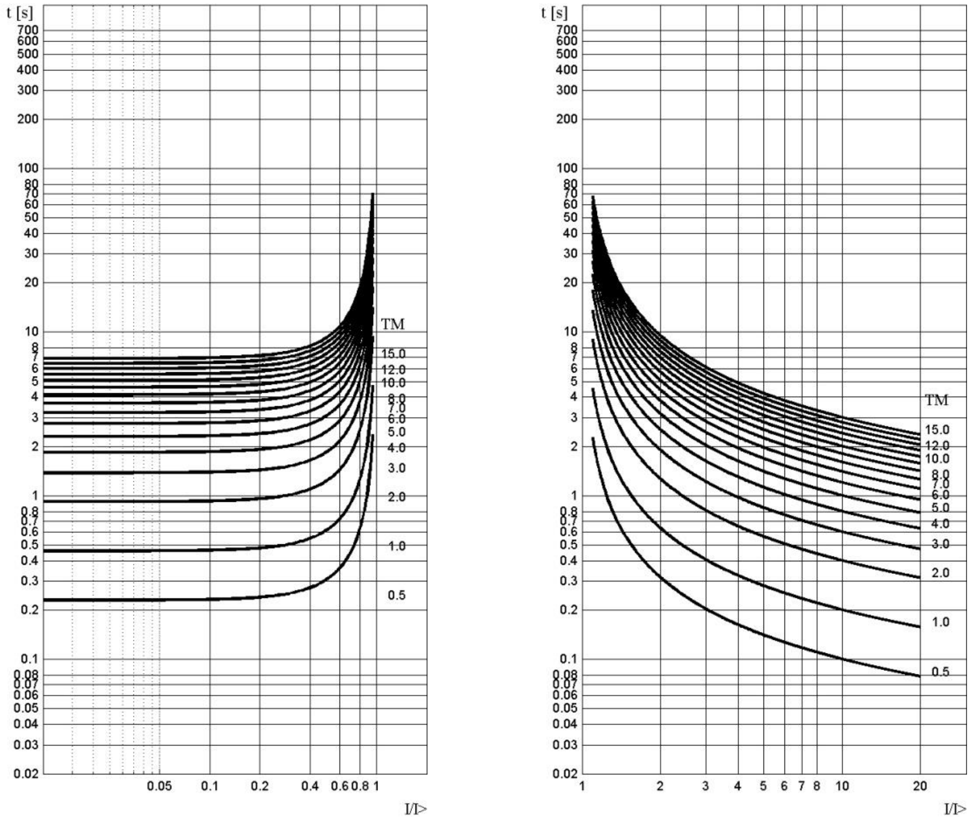


Figure 8.3. Reset and trip curves for ANSI Normal Inverse characteristic.

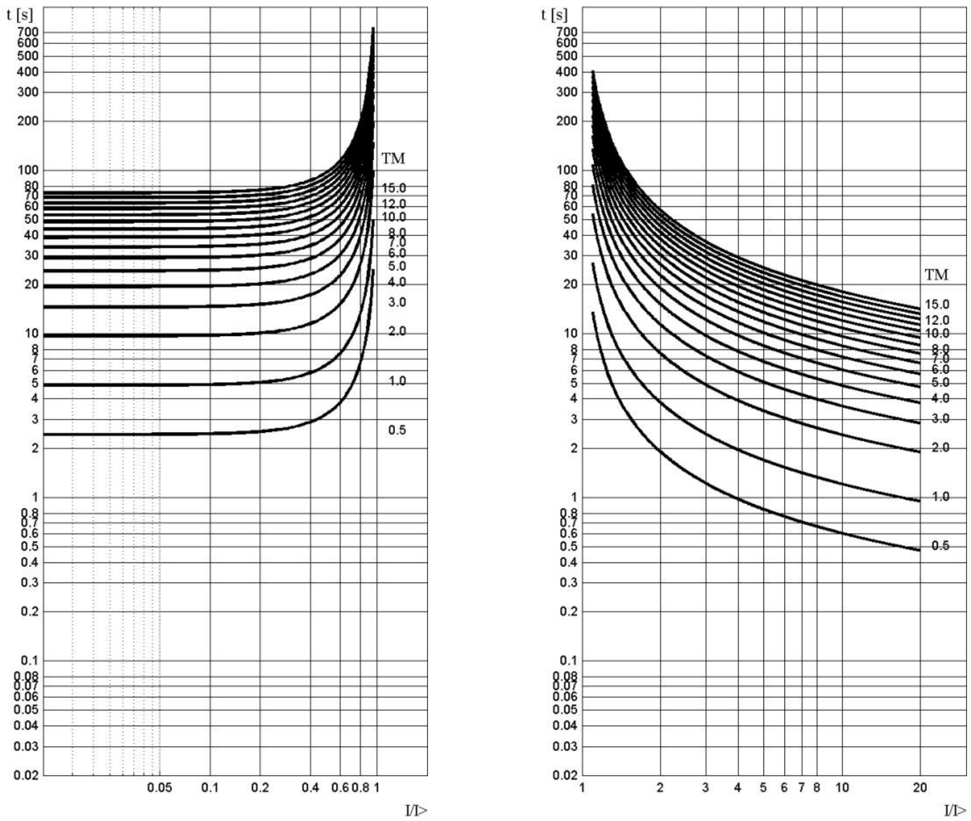


Figure 8.4. Reset and trip curves for ANSI Moderately Inverse characteristic.

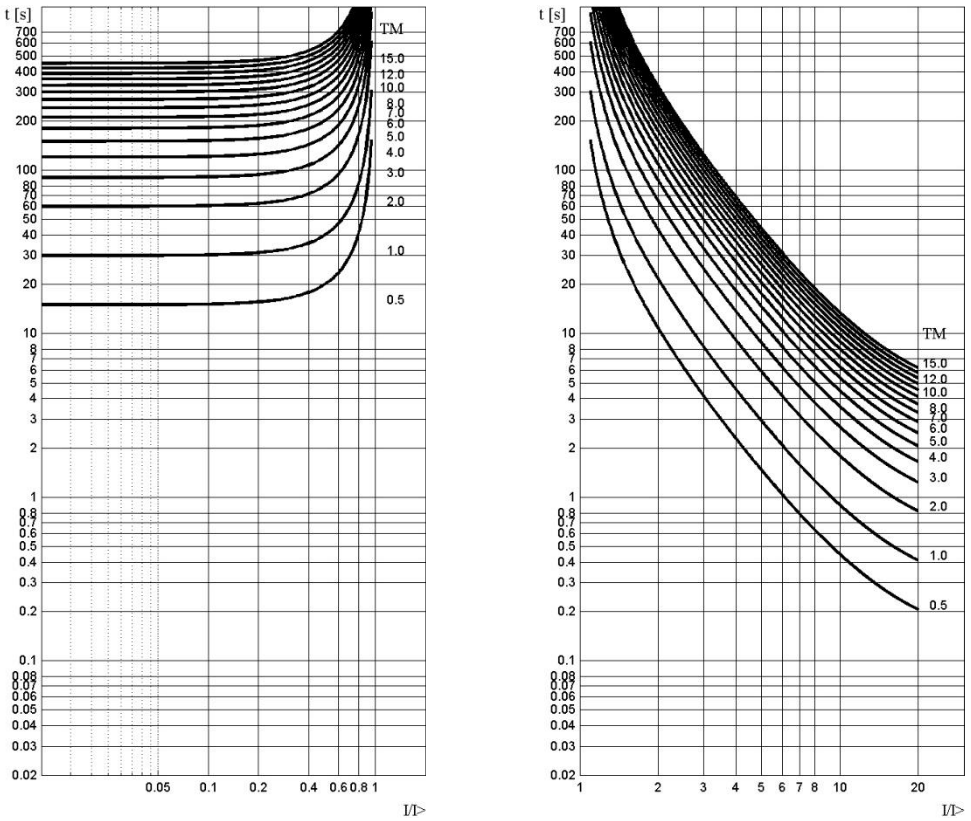


Figure 8.5. Reset and trip curves for ANSI Long Time Extremely Inverse characteristic.

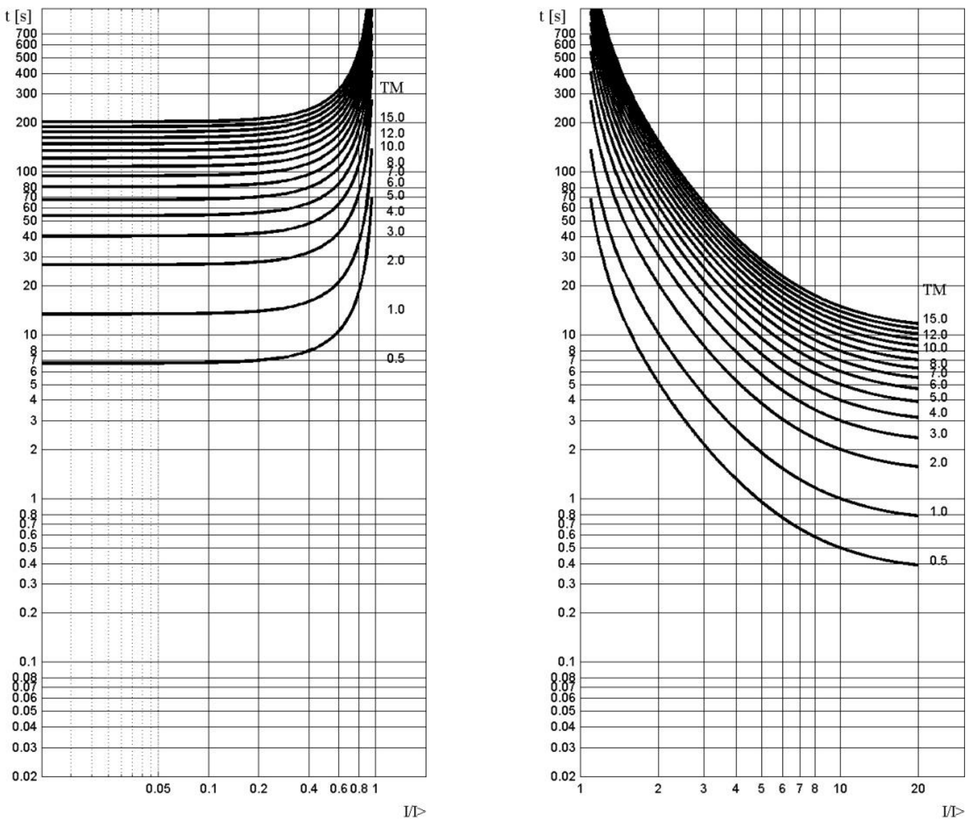


Figure 8.6. Reset and trip curves for ANSI Long Time Very Inverse characteristic.

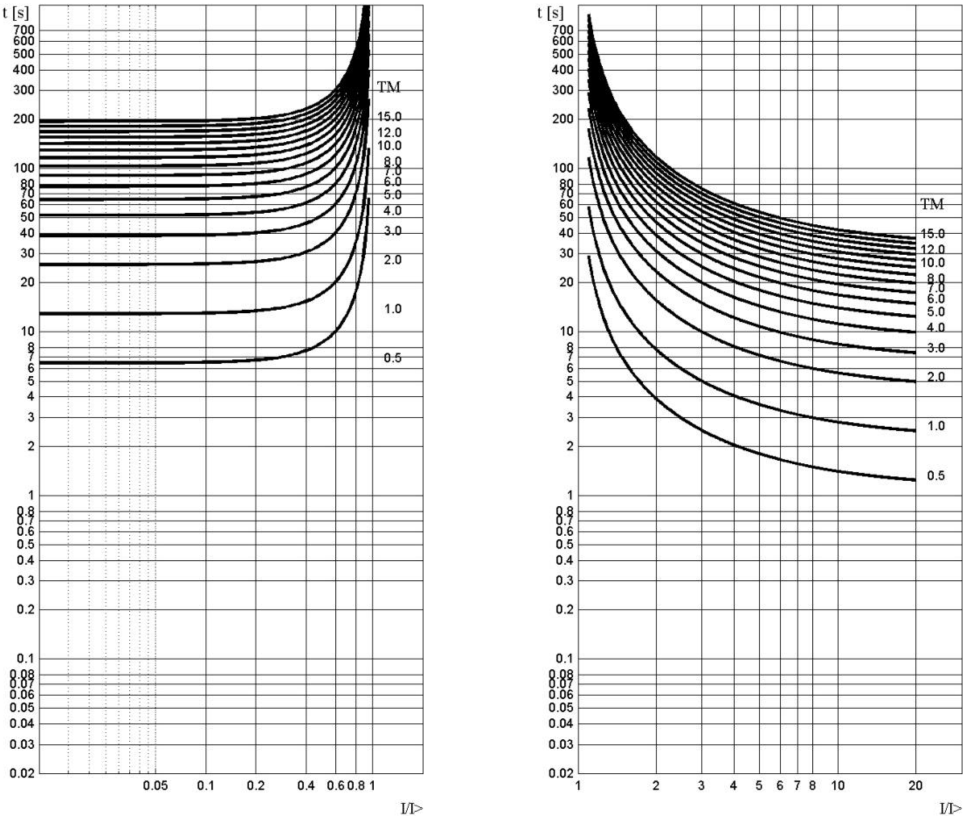


Figure 8.7. Reset and trip curves for ANSI Long Time Inverse characteristic.

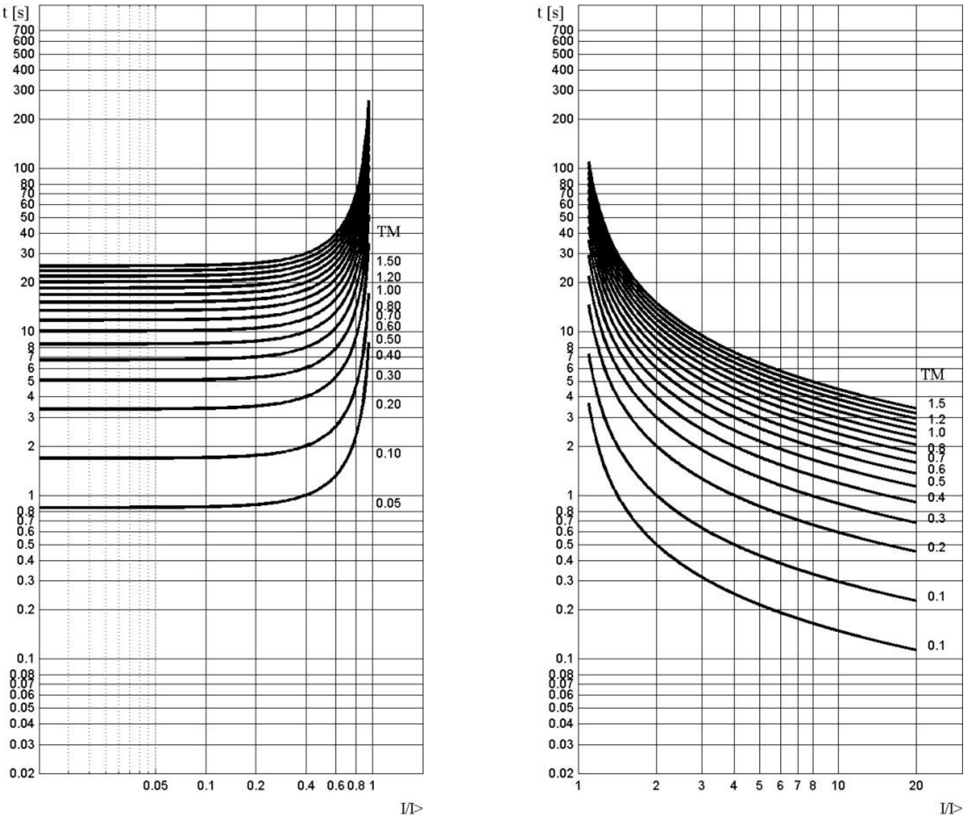


Figure 8.8. Reset and trip curves for IEC Normal Inverse characteristic.

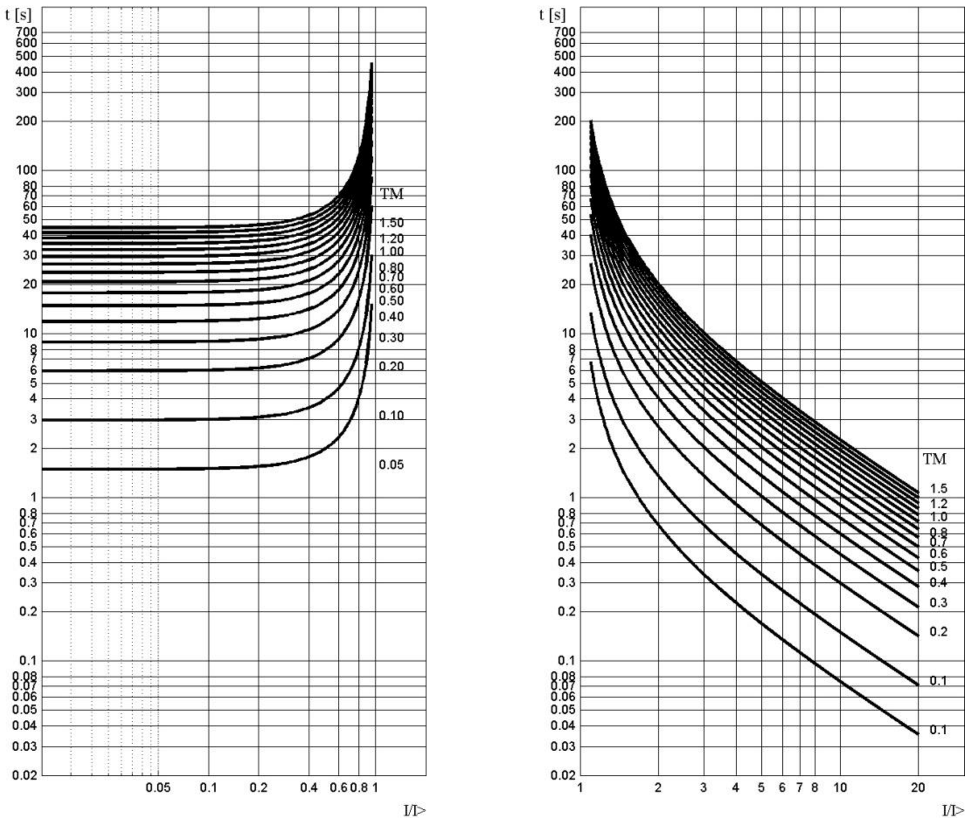


Figure 8.9. Reset and trip curves for IEC Very Inverse characteristic.

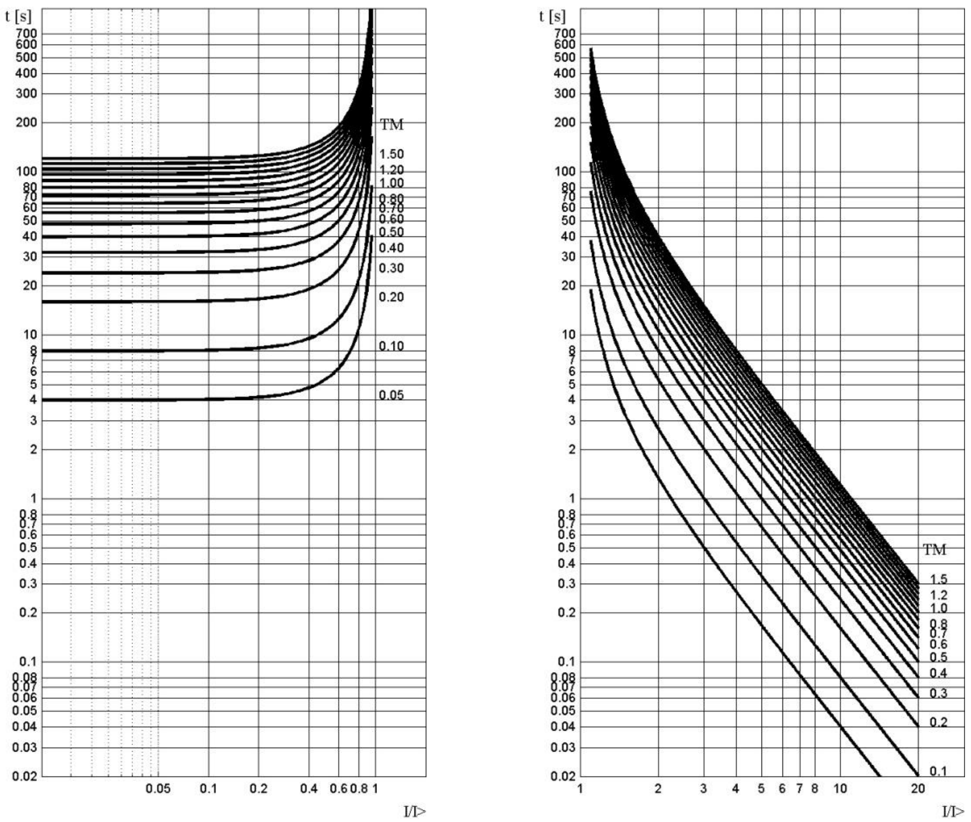


Figure 8.10. Reset and trip curves for IEC Extremely Inverse characteristic.

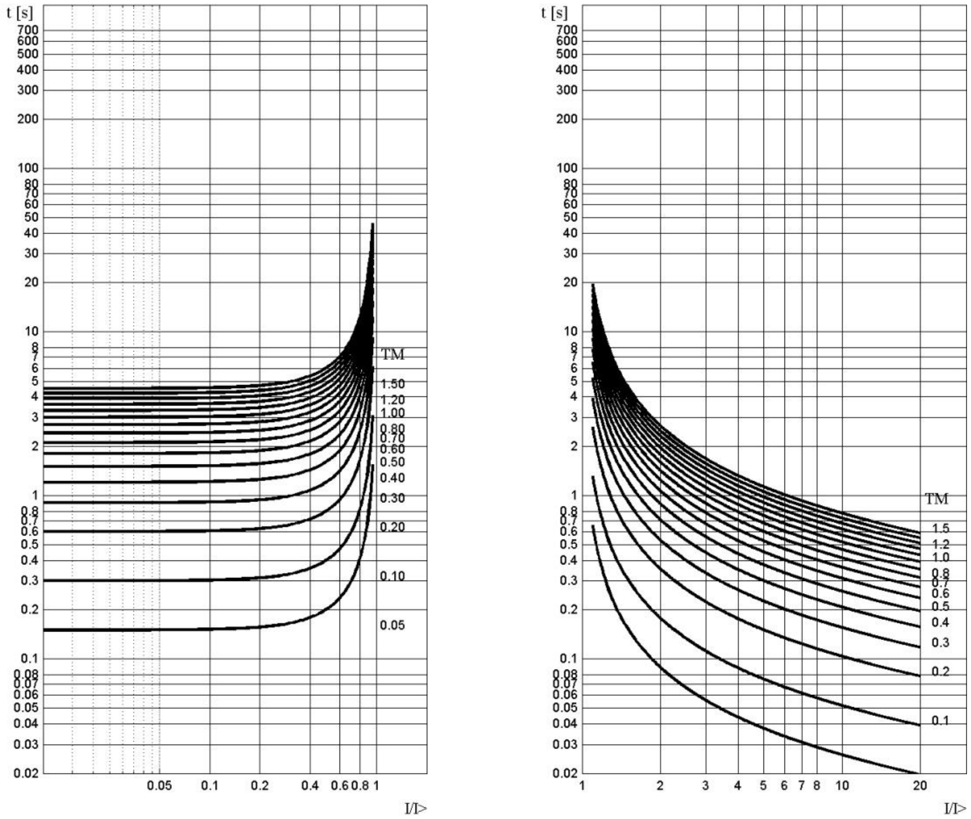


Figure 8.11. Reset and trip curves for IEC Short-Time Inverse characteristic.

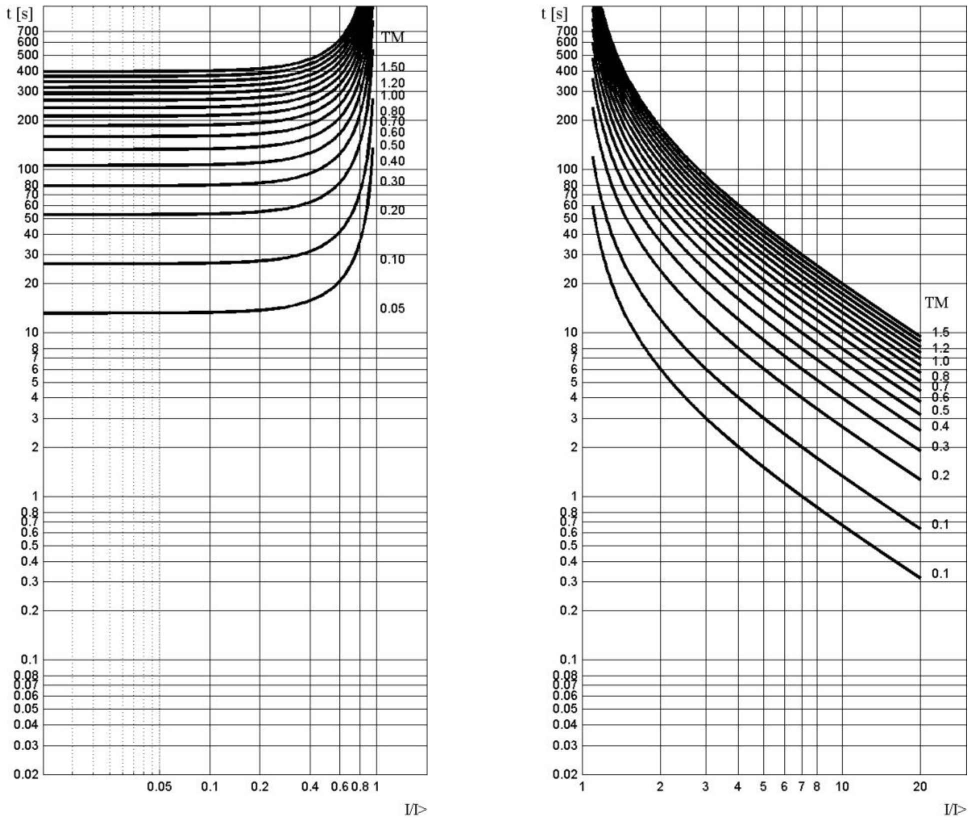


Figure 8.12. Reset and trip curves for IEC Long-Time Inverse characteristic.

The logarithmic curve is a special time inverse characteristic that is only available as an option for earth-fault protection. Its trip time also depends on the ratio between the measured current *I* and the setting I_{op} and complies with equation (8.4). The settings T_{MAX} and *TM* can be configured to define the curve shape. The reset is always instantaneous. More details about its specific configuration can be found in the corresponding section 5.9 - (Directional) Earth-Fault Overcurrent.

$$t = T_{MAX} - TM \cdot \ln\left(\frac{I}{I_{op}}\right) \tag{8.4}$$

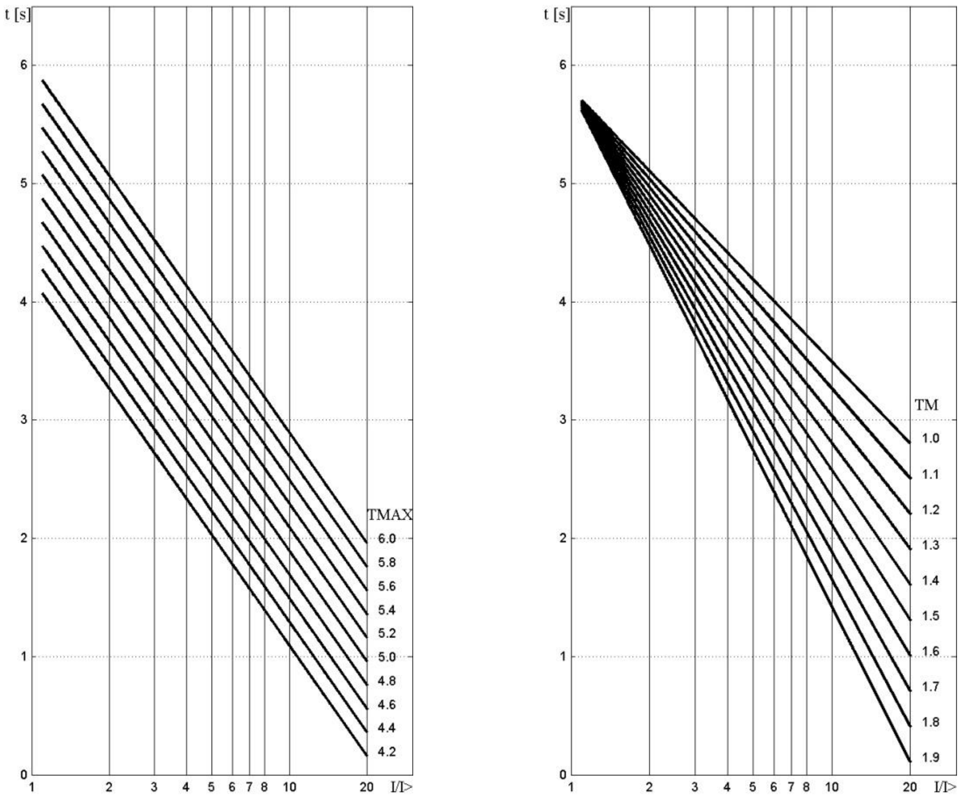


Figure 8.13. Trip curves for logarithmic characteristic (different TMAX with TM=1.35 and different TM with TMAX=5.8).

The ANSI and IEC definite time options can also be chosen, in which case the trip time is constant and set in T_{op}. The reset is always instantaneous. Both options are equivalent.

$$t = T_{op} \tag{8.5}$$

8.1.2 Voltage Protection Standard Curves

For voltage protection functions, there is also an inverse time standard curve. The trip time is inversely proportional to the difference between the measured voltage *U* and the setting U_{op}, according to (8.6) for overvoltage functions and to (8.7) for undervoltage functions.

$$t = \frac{TM}{\frac{(U - U_{op})}{U_{op}}} \tag{8.6}$$

$$t = \frac{TM}{\frac{(U_{op} - U)}{U_{op}}} \tag{8.7}$$

The time multiplier (*TM*) allows the user to adjust the trip time.

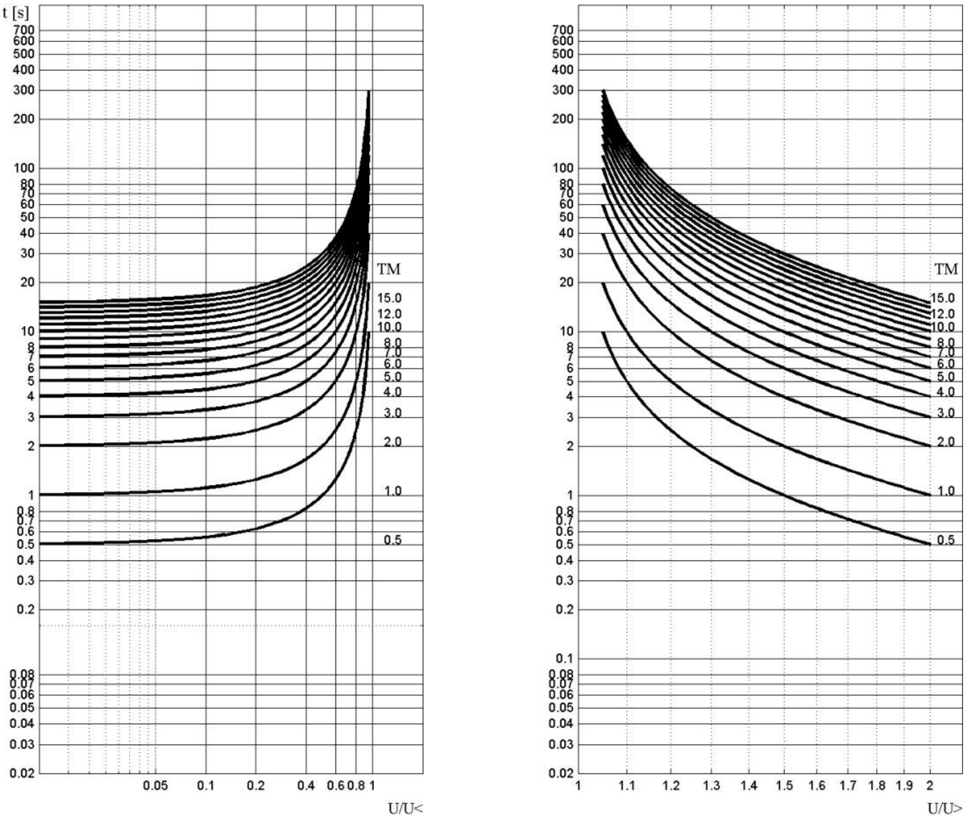


Figure 8.14. Trip curves for undervoltage and overvoltage functions.

8.1.3 Definite Time Reset

This option, when available, enables the definition of a dropout delay T_{reset} used to stabilize pickup outputs during the time interval between stage pickup and trip. If the dropout delay is other than zero, the stage does not reset immediately if the pickup condition is cancelled while the trip delay T_{op} is running. Instead, the stage only resets if the reset condition is maintained until the dropout delay timeout elapses. In the meantime, the trip delay continues running in parallel with the dropout delay but, after the trip time has elapsed, the trip is only issued if the pickup condition is simultaneously active. The behaviour of the definite time reset is illustrated in Figure 8.15.

If the stage trip has already been issued, the stage always resets immediately after the pickup condition is cancelled, *i.e.* the dropout delay is not taken into account.

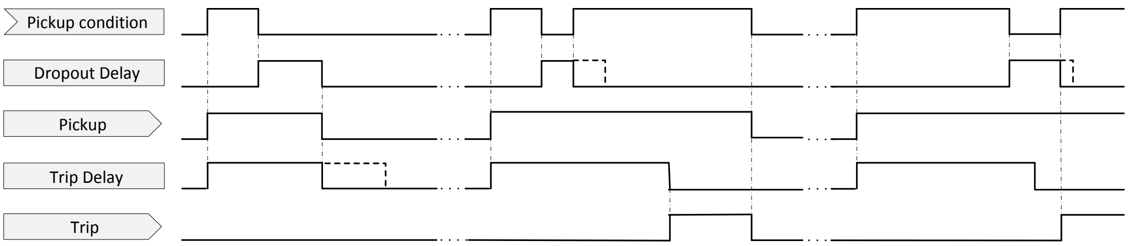


Figure 8.15. Definite time reset.

8.1.4 USER-DEFINED CURVES

The TPU L500 supports user-defined time-current curves that can be designed using the Automation Studio engineering tool. The curve editor allows the user to define between 6 and 25 time-current points in order to trace each curve.