INSTRUCTION MANUAL

AQ T3xx

Transformer Protection IED

Revision	1.00
Date	November 2010
Changes	- The first revision.
Revision	**1.01**
Date	January 2011
Changes	- HW construction and application drawings revised
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Revision	**1.07**
Date	17.12.2019
Changes	- Updated construction and installation chapter

Read these instructions carefully and inspect the equipment to become familiar with it before trying to install, operate, service or maintain it.

Electrical equipment should be installed, operated, serviced, and maintained only by qualified personnel. Local safety regulations should be followed. No responsibility is assumed by Arcteq for any consequences arising out of the use of this material.

We reserve right to changes without further notice.

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1 ABBREVIATIONS

CB – Circuit breaker

CBFP – Circuit breaker failure protection

CT – Current transformer

CPU – Central processing unit

EMC – Electromagnetic compatibility

HMI – Human machine interface

HW – Hardware

IED – Intelligent electronic device

IO – Input output

LED – Light emitting diode

LV – Low voltage

MV – Medium voltage

NC – Normally closed

NO – Normally open

RMS – Root mean square

SF – System failure

TMS – Time multiplier setting

TRMS – True root mean square

VAC – Voltage alternating current

VDC – Voltage direct current

SW – Software

uP - Microprocessor

2 GENERAL

The AQ-T3xx transformer protection IEDs are members of the AQ-300 product line. The AQ-300 protection product line in respect of hardware and software is a modular device. The hardware modules are assembled and configured according to the application IO requirements and the software determines the available functions. This manual describes the specific application of the AQ-T3xx transformer protection IEDs.

Arcteq protection IED can be ordered in two mechanical sizes. The AQ-T35x comes in half of 19 inch rack arrangement and the AQ-T39x comes in full 19 inch rack arrangement allowing for larger quantity of IO cards. The functionality is the same in both units.

3 SOFTWARE SETUP OF THE IED

In this chapter are presented the protection and control functions as well as the monitoring functions.

The implemented protection functions are listed in Table 3-1. The function blocks are described in details in following chapters.

Table 3-1 Available protection functions

Function Name	IEC	ANSI	Description
DIF87	$3I_dT>$	87T	Transformer differential protection
DIF87N	REF	87N	Restricted earth fault protection (low impedance)
IOC50	I >>>	50	Three-phase instantaneous overcurrent protection
TOC50_low TOC50_high	I> I>>	51	Three-phase time overcurrent protection
IOC50N	I0 >>>	50N	Residual instantaneous overcurrent protection
TOC51N_low TOC51N_high	I0> I0>>	51N	Residual time overcurrent protection
INR2	I_{2h} >	68	Inrush detection and blocking
VCB60	I_{ub} >	60	Current unbalance protection
TTR49L	T >	49T	Line thermal protection
TOV59_low TOV59_high	U > U >>	59	Definite time overvoltage protection
TUV27_low TUV27_high	U < U <<	27	Definite time undervoltage protection
TOV59N_low TOV59N_high	U0> U0>>	59N	Residual voltage protection
TOF81_high TOF81_low	f > f >>	81O	Overfrequency protection
TUF81_high TUF81_low	f < f <<	81U	Underfrequency protection
FRC81_high FRC81_low	df/dt	81R	Rate of change of frequency protection
VPH24	V/Hz	24	Overexcitation protection (V/Hz)
BRF50MV	CBFP	50BF	Breaker failure protection

Table 3-2 Available control and monitoring functions

Name	IEC	ANSI	Description
TRC94	-	94	Trip logic
VTS	-	60	Voltage transformer supervision
SYN25	SYNC	25	Synchro-check function Δf, ΔU, Δφ
AVR	-	-	Integrated voltage regulator (option)
DREC	-	-	Disturbance recorder

3.1 MEASUREMENTS

3.1.1 CURRENT MEASUREMENT AND SCALING

If the factory configuration includes a current transformer hardware module, the current input function block is automatically configured among the software function blocks. Separate current input function blocks are assigned to each current transformer hardware module.

A current transformer hardware module is equipped with four special intermediate current transformers. As usual, the first three current inputs receive the three phase currents (IL1, IL2, IL3), the fourth input is reserved for zero sequence current, for the zero sequence current of the parallel line or for any additional current. Accordingly, the first three inputs have common parameters while the fourth current input needs individual setting.

The role of the current input function block is to

- set the required parameters associated to the current inputs,
- deliver the sampled current values for disturbance recording,
- perform the basic calculations
  - Fourier basic harmonic magnitude and angle,
  - True RMS value;
- provide the pre-calculated current values to the subsequent software function blocks,
- deliver the calculated Fourier basic component values for on-line displaying.

The current input function block receives the sampled current values from the internal operating system. The scaling (even hardware scaling) depends on parameter setting, see parameters **Rated Secondary I1-3** and **Rated Secondary I4**. The options to choose from are 1A or 5A (in special applications, 0.2A or 1A). This parameter influences the internal number format and, naturally, accuracy. A small current is processed with finer resolution if 1A is selected.

If needed, the phase currents can be inverted by setting the parameter **Starpoint I1-3**. This selection applies to each of the channels IL1, IL2 and IL3. The fourth current channel can be inverted by setting the parameter **Direction I4**. This inversion may be needed in protection functions such as distance protection, differential protection or for any functions with directional decision.

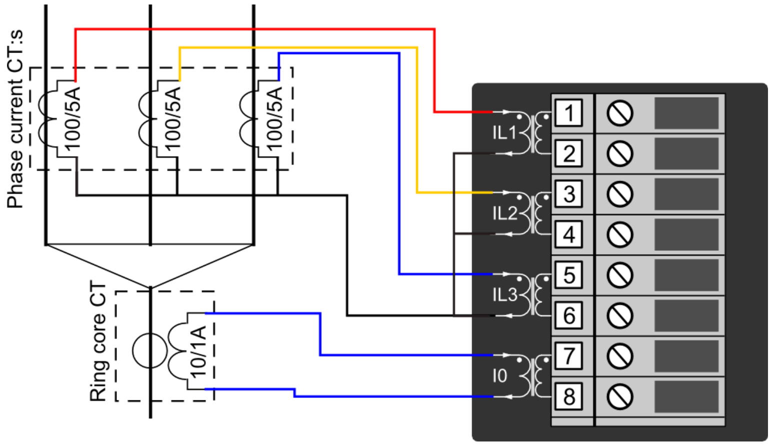


Figure 3-1 Example connection

Phase current CT: CT primary 100A CT secondary 5A	Ring core CT in Input I0: I0CT primary 10A I0CT secondary 1A
Phase current CT secondary currents starpoint is towards the line.	

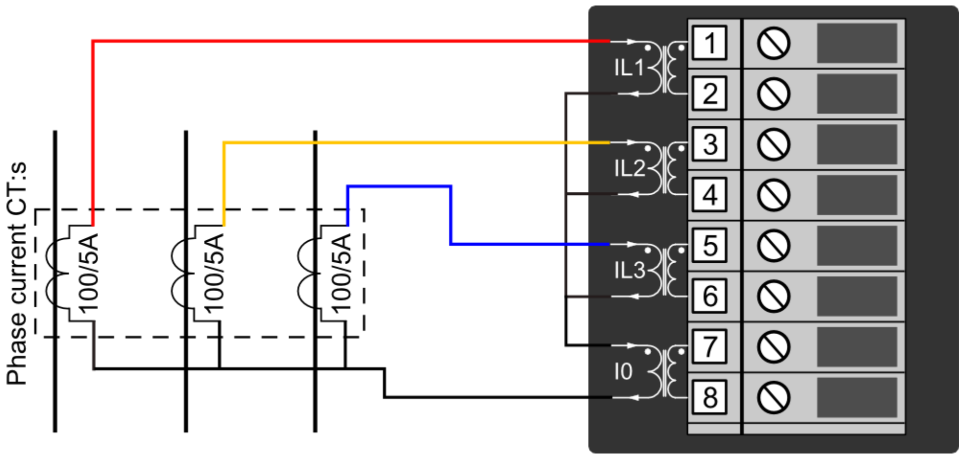


Figure 3-2 Example connection with phase currents connected into summing "Holmgren" connection into the I0 residual input.

Phase current CT: CT primary 100A	Ring core CT in Input I0: I0CT primary 100A

CT secondary 5A	I0CT secondary 5A
Phase currents are connected to summing “Holmgren” connection into the I0 residual input.	

The sampled values are available for further processing and for disturbance recording.

The performed basic calculation results the Fourier basic harmonic magnitude and angle and the true RMS value. These results are processed by subsequent protection function blocks and they are available for on-line displaying as well.

The function block also provides parameters for setting the primary rated currents of the main current transformer (Rated Primary I1-3 and Rated Primary I4). This function block does not need that parameter settings. These values are passed on to function blocks such as displaying primary measured values, primary power calculation, etc.

Table 3-3 Enumerated parameters of the current input function

Parameter name	**Title**	**Selection range**	**Default**
Rated secondary current of the first three input channels. 1A or 5A is selected by parameter setting, no hardware modification is needed.			
CT4_Ch13Nom_EPar_	Rated Secondary I1-3	1A,5A	1A
Rated secondary current of the fourth input channel. 1A or 5A (0.2A, 1A) is selected by parameter setting, no hardware modification is needed.			
CT4_Ch4Nom_EPar_	Rated Secondary I4	1A,5A (0.2A, 1A)	1A
Definition of the positive direction of the first three currents, given by location of the secondary star connection point			
CT4_Ch13Dir_EPar_	Starpoint I1-3	Line,Bus	Line
Definition of the positive direction of the fourth current, given as normal or inverted			
CT4_Ch4Dir_EPar_	Direction I4	Normal,Inverted	Normal

Table 3-4 Floating point parameters of the current input function

Parameter name	**Title**	**Dim.**	**Min**	**Max**	**Default**
Rated primary current of channel1-3					
CT4_PriI13_FPar_	Rated Primary I1-3	A	100	4000	1000
Rated primary current of channel4					
CT4_PriI4_FPar_	Rated Primary I4	A	100	4000	1000

Table 3-5 Online measurements of the current input function

Measured value	Dim.	Explanation
Current Ch - I1	A(secondary)	Fourier basic component of the current in channel IL1
Angle Ch - I1	degree	Vector position of the current in channel IL1
Current Ch – I2	A(secondary)	Fourier basic component of the current in channel IL2
Angle Ch – I2	degree	Vector position of the current in channel IL2
Current Ch – I3	A(secondary)	Fourier basic component of the current in channel IL3
Angle Ch – I3	degree	Vector position of the current in channel IL3
Current Ch – I4	A(secondary)	Fourier basic component of the current in channel I4
Angle Ch – I4	degree	Vector position of the current in channel I4

NOTE1: The scaling of the Fourier basic component is such that if pure sinusoid 1A RMS of the rated frequency is injected, the displayed value is 1A. The displayed value does not depend on the parameter setting values “Rated Secondary”.

NOTE2: The reference of the vector position depends on the device configuration. If a voltage input module is included, then the reference vector (vector with angle 0 degree) is the vector calculated for the first voltage input channel of the first applied voltage input module. If no voltage input module is configured, then the reference vector (vector with angle 0 degree) is the vector calculated for the first current input channel of the first applied current input module. (The first input module is the one, configured closer to the CPU module.)

3.1.2 Voltage measurement and scaling

If the factory configuration includes a voltage transformer hardware module, the voltage input function block is automatically configured among the software function blocks. Separate voltage input function blocks are assigned to each voltage transformer hardware module.

A voltage transformer hardware module is equipped with four special intermediate voltage transformers. As usual, the first three voltage inputs receive the three phase voltages (UL1, UL2, UL3), the fourth input is reserved for zero sequence voltage or for a voltage from the other side of the circuit breaker for synchro switching.

The role of the voltage input function block is to

- set the required parameters associated to the voltage inputs,
- deliver the sampled voltage values for disturbance recording,
- perform the basic calculations
    - Fourier basic harmonic magnitude and angle,

  - True RMS value;
- provide the pre-calculated voltage values to the subsequent software modules,
- deliver the calculated basic Fourier component values for on-line displaying.

The voltage input function block receives the sampled voltage values from the internal operating system. The scaling (even hardware scaling) depends on a common parameter “Range” for type selection. The options to choose from are 100V or 200V, no hardware modification is needed. A small voltage is processed with finer resolution if 100V is selected. This parameter influences the internal number format and, naturally, accuracy.

There is a correction factor available if the rated secondary voltage of the main voltage transformer (e.g. 110V) does not match the rated input of the device. The related parameter is “VT correction“. As an example: if the rated secondary voltage of the main voltage transformer is 110V, then select Type 100 for the parameter “Range” and the required value to set here is 110%.

The connection of the first three VT secondary windings must be set to reflect actual physical connection of the main VTs. The associated parameter is “Connection U1-3“. The selection can be: Ph-N, Ph-Ph or Ph-N-Isolated.

The Ph-N option is applied in solidly grounded networks, where the measured phase voltage is never above 1.5-Un. In this case the primary rated voltage of the VT must be the value of the rated PHASE-TO-NEUTRAL voltage.

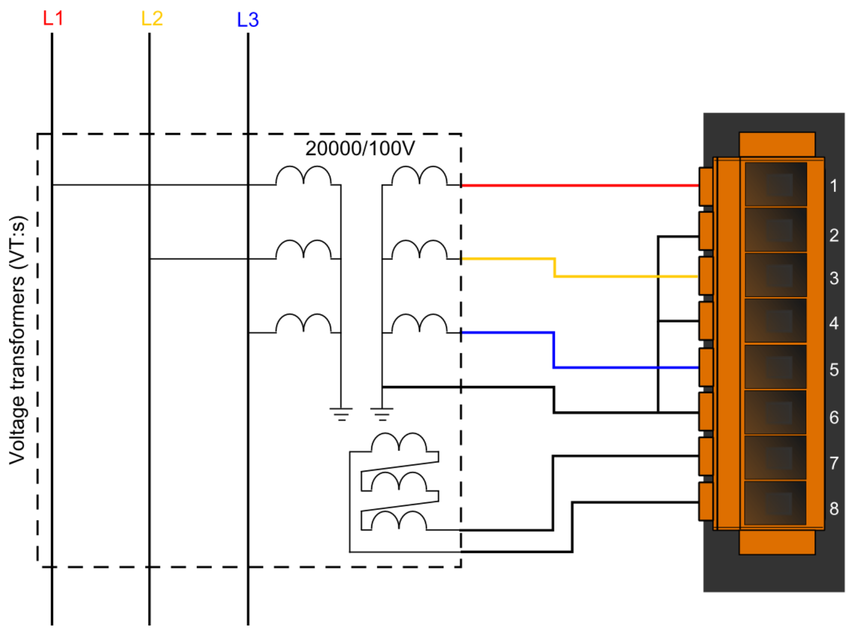


Figure 3-3 Phase to neutral connection. Connection U1-3

Ph-N Voltage: Rated Primary U1-3: 11.55kV (=20kv/√3) Range: Type 100	Residual voltage: Rated Primary U4: 11.54A

If phase-to-phase voltage is connected to the VT input of the device, then the Ph-Ph option is to be selected. Here, the primary rated voltage of the VT must be the value of the rated PHASE-TO-PHASE voltage. This option must not be selected if the distance protection function is supplied from the VT input.

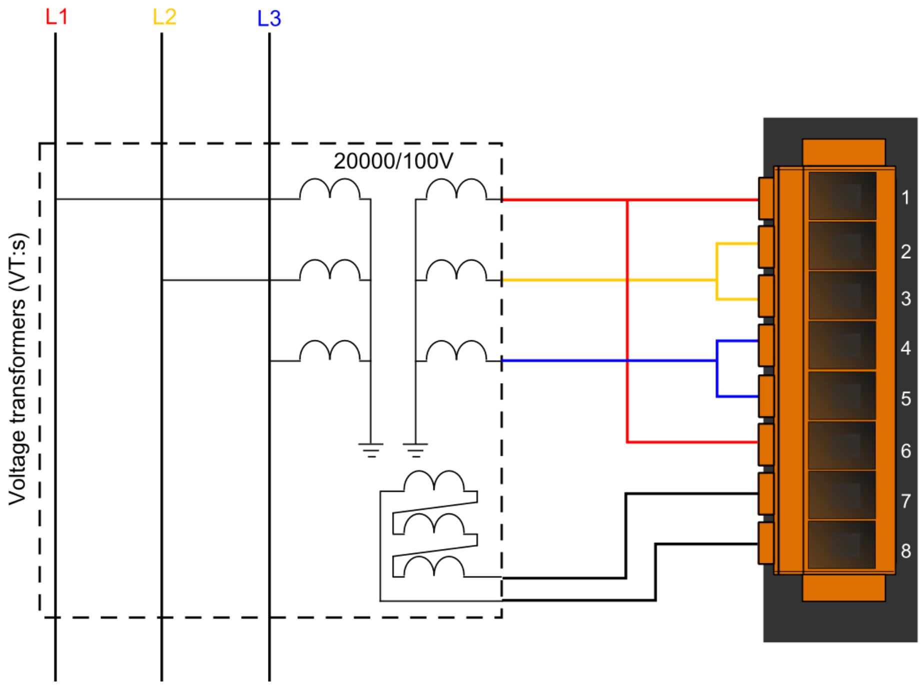


Figure 3-4 Phase-to-phase connection.

Ph-N Voltage: Rated Primary U1-3: 20kV Range: Type 100	Residual voltage: Rated Primary U4: 11.54kV (=20kv/√3)

The fourth input is reserved for zero sequence voltage or for a voltage from the other side of the circuit breaker for synchron switching. Accordingly, the connected voltage must be identified with parameter setting “Connection U4“. Here, phase-to-neutral or phase-to-phase voltage can be selected: Ph-N, Ph-Ph.

If needed, the phase voltages can be inverted by setting the parameter “Direction U1-3“. This selection applies to each of the channels UL1, UL2 and UL3. The fourth voltage channel can be inverted by setting the parameter “Direction U4“. This inversion may be needed in protection functions such as distance protection or for any functions with directional decision, or for checking the voltage vector positions.

These modified sampled values are available for further processing and for disturbance recording.

The function block also provides parameters for setting the primary rated voltages of the main voltage transformers. This function block does not need that parameter setting but these values are passed on to function blocks such as displaying primary measured values, primary power calculation, etc.

Table 3-6 Enumerated parameters of the voltage input function

Parameter name	**Title**	**Selection range**	**Default**
Rated secondary voltage of the input channels. 100 V or 200V type is selected by parameter setting, no hardware modification is needed.			
VT4_Type_EPar_	Range	Type 100,Type 200	Type 100
Connection of the first three voltage inputs (main VT secondary)			
VT4_Ch13Nom_EPar_	Connection U1-3	Ph-N, Ph-Ph, Ph-N-Isolated	Ph-N
Selection of the fourth channel input: phase-to-neutral or phase-to-phase voltage			
VT4_Ch4Nom_EPar_	Connection U4	Ph-N,Ph-Ph	Ph-Ph
Definition of the positive direction of the first three input channels, given as normal or inverted			
VT4_Ch13Dir_EPar_	Direction U1-3	Normal,Inverted	Normal
Definition of the positive direction of the fourth voltage, given as normal or inverted			
VT4_Ch4Dir_EPar_	Direction U4	Normal,Inverted	Normal

Table 3-7 Integer parameters of the voltage input function

Parameter name	**Title**	**Unit**	**Min**	**Max**	**Step**	**Default**
Voltage correction						
VT4_CorrFact_IPar_	VT correction	%	100	115	1	100

Table 3-8 Float point parameters of the voltage input function

Parameter name	**Title**	**Dim.**	**Min**	**Max**	**Default**
Rated primary voltage of channel1					
VT4_PriU1_FPar	Rated Primary U1	kV	1	1000	100
Rated primary voltage of channel2					
VT4_PriU2_FPar	Rated Primary U2	kV	1	1000	100
Rated primary voltage of channel3					
VT4_PriU3_FPar	Rated Primary U3	kV	1	1000	100
Rated primary voltage of channel4					
VT4_PriU4_FPar	Rated Primary U4	kV	1	1000	100

NOTE: The rated primary voltage of the channels is not needed for the voltage input function block itself. These values are passed on to the subsequent function blocks.

Table 3-9 On-line measured analogue values of the voltage input function

Measured value	Dim.	Explanation
Voltage Ch - U1	V(secondary)	Fourier basic component of the voltage in channel UL1
Angle Ch - U1	degree	Vector position of the voltage in channel UL1
Voltage Ch – U2	V(secondary)	Fourier basic component of the voltage in channel UL2
Angle Ch – U2	degree	Vector position of the voltage in channel UL2
Voltage Ch – U3	V(secondary)	Fourier basic component of the voltage in channel UL3
Angle Ch – U3	degree	Vector position of the voltage in channel UL3
Voltage Ch – U4	V(secondary)	Fourier basic component of the voltage in channel U4
Angle Ch – U4	degree	Vector position of the voltage in channel U4

NOTE1: The scaling of the Fourier basic component is such if pure sinusoid 57V RMS of the rated frequency is injected, the displayed value is 57V. The displayed value does not depend on the parameter setting values “Rated Secondary”.

NOTE2: The reference vector (vector with angle 0 degree) is the vector calculated for the first voltage input channel of the first applied voltage input module. The first voltage input module is the one, configured closer to the CPU module.

3.1.3 Connection example

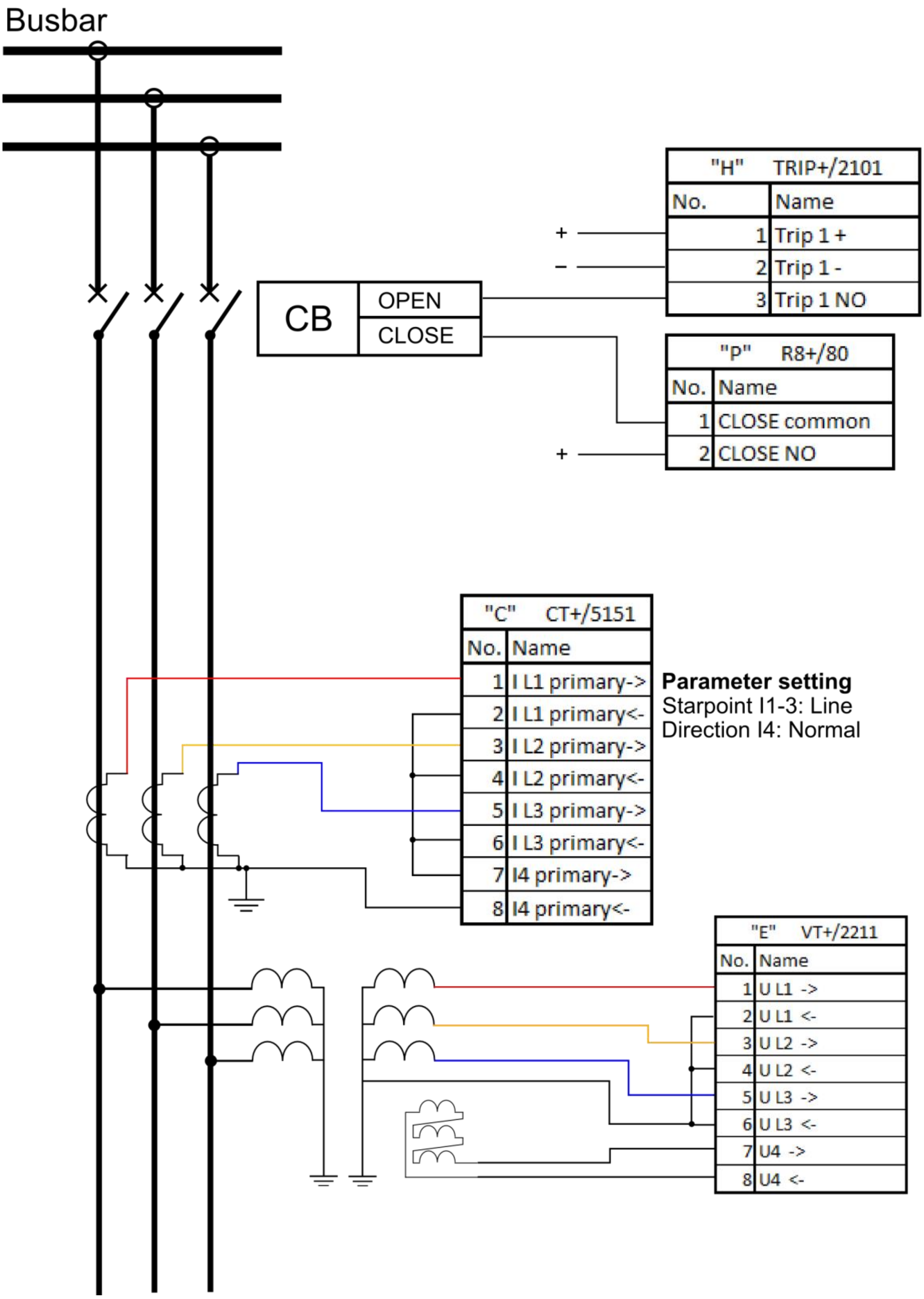


Figure 3-5 Connection example with current breaker open and close connection, CT and VT connection.

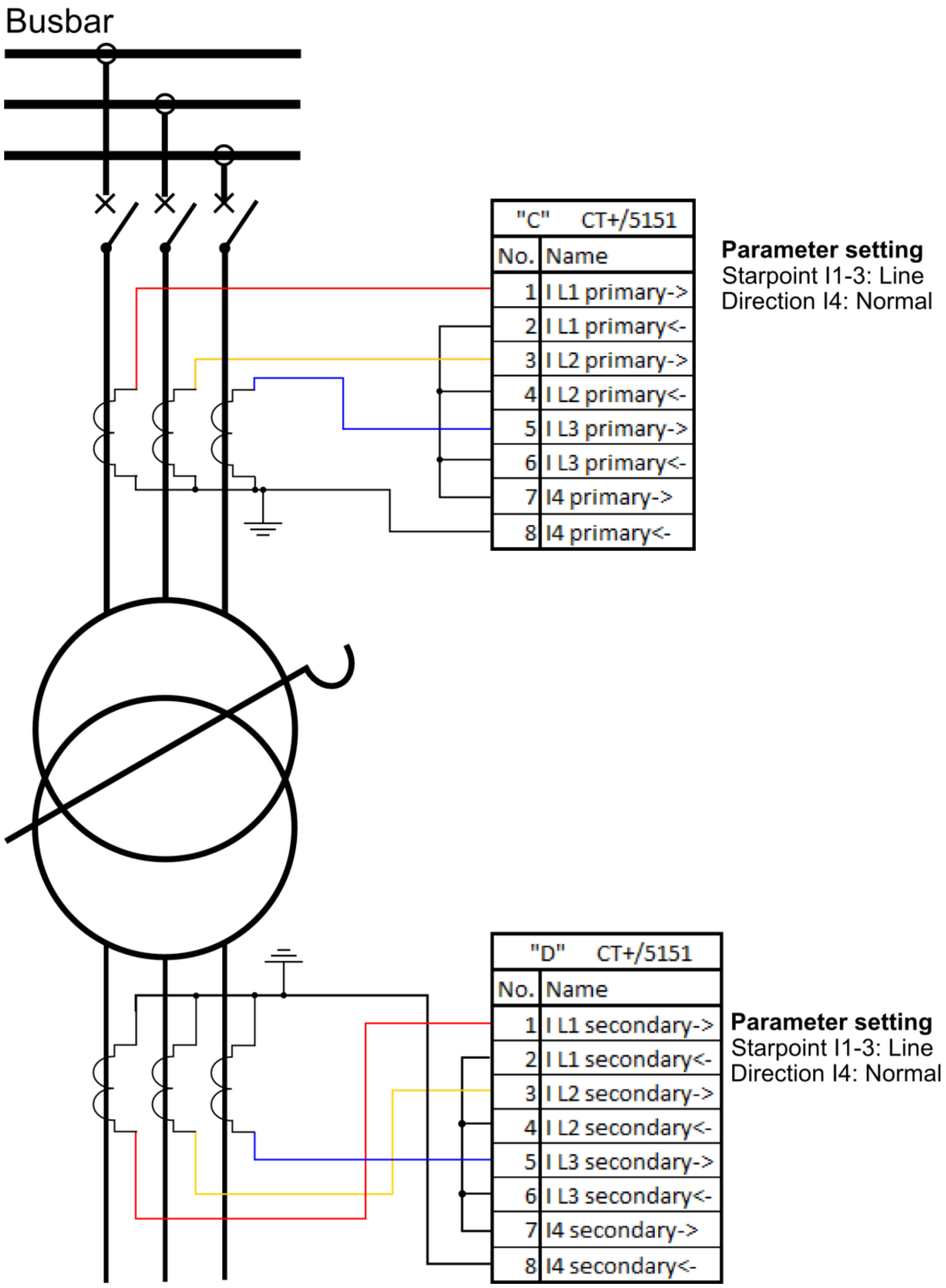


Figure 3-6 Example connection with two CT:s facing each other. Starpoint directions are both set to "Line".

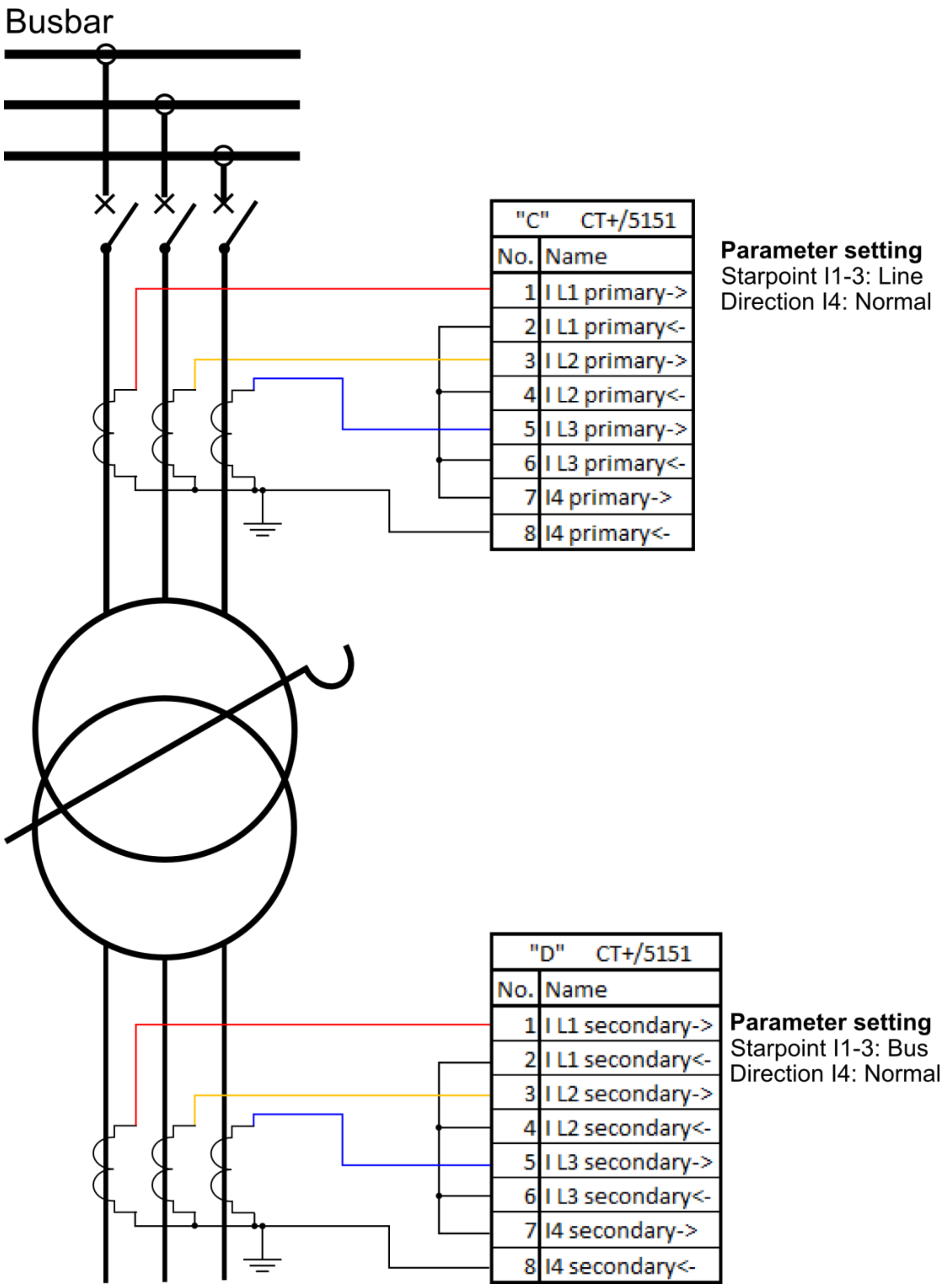


Figure 3-7 Connection example where the direction of the secondary sides starpoint direction has been inverted. Notice the inverted parameter Starpoint I1-3: "Bus".

3.1.4 Line measurement

The input values of the AQ300 devices are the secondary signals of the voltage transformers and those of the current transformers.

These signals are pre-processed by the “Voltage transformer input” function block and by the “Current transformer input” function block. The pre-processed values include the Fourier basic harmonic phasors of the voltages and currents and the true RMS values. Additionally, it is in these function blocks that parameters are set concerning the voltage ratio of the primary voltage transformers and current ratio of the current transformers.

Based on the pre-processed values and the measured transformer parameters, the “Line measurement” function block calculates - depending on the hardware and software configuration - the primary RMS values of the voltages and currents and some additional values such as active and reactive power, symmetrical components of voltages and currents. These values are available as primary quantities and they can be displayed on the on-line screen of the device or on the remote user interface of the computers connected to the communication network and they are available for the SCADA system using the configured communication system.

3.1.4.1 Reporting the measured values and the changes

It is usual for the SCADA systems that they sample the measured and calculated values in regular time periods and additionally they receive the changed values as reports at the moment when any significant change is detected in the primary system. The “Line measurement” function block is able to perform such reporting for the SCADA system.

3.1.4.2 Operation of the line measurement function block

The inputs of the line measurement function are

- the Fourier components and true RMS values of the measured voltages and currents
- frequency measurement
- parameters.

The outputs of the line measurement function are

- displayed measured values
- reports to the SCADA system.

NOTE: the scaling values are entered as parameter setting for the “Voltage transformer input” function block and for the “Current transformer input” function block.

3.1.4.3 Measured values

The measured values of the line measurement function depend on the hardware configuration. As an example, table shows the list of the measured values available in a configuration for solidly grounded networks.

Table 3-10 Example: Measured values in a configuration for solidly grounded networks

Measured value	Explanation
MXU_P_OLM_	Active Power – P (Fourier base harmonic value)
MXU_Q_OLM_	Reactive Power – Q (Fourier base harmonic value)
MXU_S_OLM_	Apparent Power – S (Fourier base harmonic value)
MXU_I1_OLM_	Current L1
MXU_I2_OLM_	Current L2
MXU_I3_OLM_	Current L3
MXU_U1_OLM_	Voltage L1
MXU_U2_OLM_	Voltage L2
MXU_U3_OLM_	Voltage L3
MXU_U12_OLM_	Voltage L12
MXU_U23_OLM_	Voltage L23
MXU_U31_OLM_	Voltage L31
MXU_f_OLM_	Frequency

Another example is in figure, where the measured values available are shown as on-line information in a configuration for compensated networks.

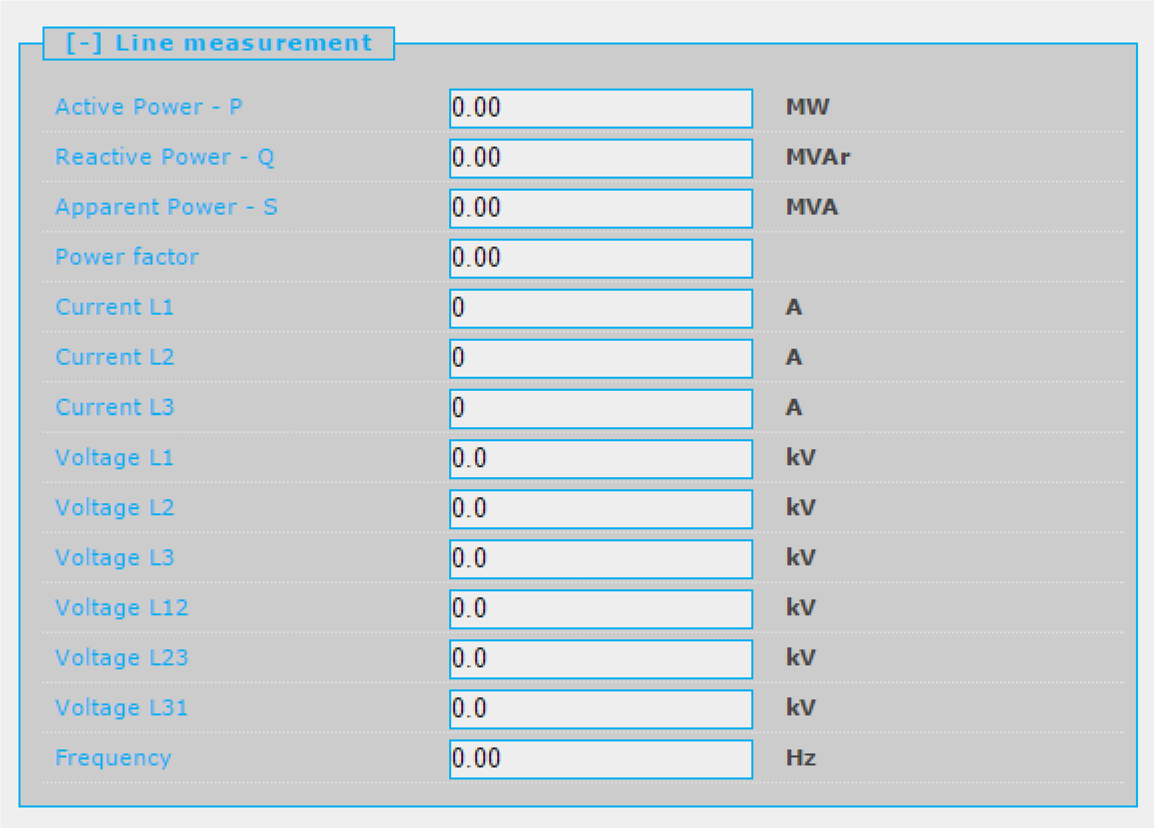


Figure 3-8 Measured values in a configuration for compensated networks

The available quantities are described in the configuration description documents.

3.1.4.4 Reporting the measured values and the changes

For reporting, additional information is needed, which is defined in parameter setting. As an example, in a configuration for solidly grounded networks the following parameters are available:

Table 3-11 The enumerated parameters of the line measurement function.

Parameter name	Title	Selection range	Default
Selection of the reporting mode for active power measurement			
MXU_PRepMode_EPar_	Operation ActivePower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for reactive power measurement			
MXU_QRepMode_EPar_	Operation ActivePower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for apparent power measurement			
MXU_SRepMode_EPar_	Operation ApparPower	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for current measurement			
MXU_IRepMode_EPar_	Operation Current	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for voltage measurement			
MXU_URepMode_EPar_	Operation Voltage	Off, Amplitude, Integrated	Amplitude
Selection of the reporting mode for frequency measurement			
MXU_fRepMode_EPar_	Operation Frequency	Off, Amplitude, Integrated	Amplitude

The selection of the reporting mode items is explained in next chapters.

3.1.4.5 "Amplitude" mode of reporting

If the "Amplitude" mode is selected for reporting, a report is generated if the measured value leaves the deadband around the previously reported value. As an example, Figure 1-2 shows that the current becomes higher than the value reported in "report1" PLUS the Deadband value, this results "report2", etc.

For this mode of operation, the Deadband parameters are explained in table below.

The "Range" parameters in the table are needed to evaluate a measurement as "out-of-range".

Table 3-12 The floating-point parameters of the line measurement function

Parameter name	Title	Dim.	Min	Max	Step	Default
Deadband value for the active power						
MXU_PDeadB_FPar_	Deadband value - P	MW	0.1	100000	0.01	10
Range value for the active power						
MXU_PRange_FPar_	Range value - P	MW	1	100000	0.01	500
Deadband value for the reactive power						
MXU_QDeadB_FPar_	Deadband value - Q	MVAr	0.1	100000	0.01	10
Range value for the reactive power						
MXU_QRange_FPar_	Range value - Q	MVAr	1	100000	0.01	500
Deadband value for the apparent power						
MXU_SDeadB_FPar_	Deadband value - S	MVA	0.1	100000	0.01	10
Range value for the apparent power						
MXU_SRange_FPar_	Range value - S	MVA	1	100000	0.01	500
Deadband value for the current						
MXU_IDeadB_FPar_	Deadband value - I	A	1	2000	1	10
Range value for the current						
MXU_IRange_FPar_	Range value - I	A	1	5000	1	500
Deadband value for the phase-to-neutral voltage						
MXU_UPhDeadB_ FPar_	Deadband value – U ph-N	kV	0.1	100	0.01	1
Range value for the phase-to-neutral voltage						
MXU_UPhRange_ FPar_	Range value – U ph-N	kV	1	1000	0.1	231
Deadband value for the phase-to-phase voltage						
MXU_UPPDeadB_ FPar_	Deadband value – U ph-ph	kV	0.1	100	0.01	1
Range value for the phase-to-phase voltage						
MXU_UPPRange_ FPar_	Range value – U ph-ph	kV	1	1000	0.1	400
Deadband value for the current						
MXU_fDeadB_FPar_	Deadband value - f	Hz	0.01	1	0.01	0.02
Range value for the current						
MXU_fRange_FPar_	Range value - f	Hz	0.05	10	0.01	5

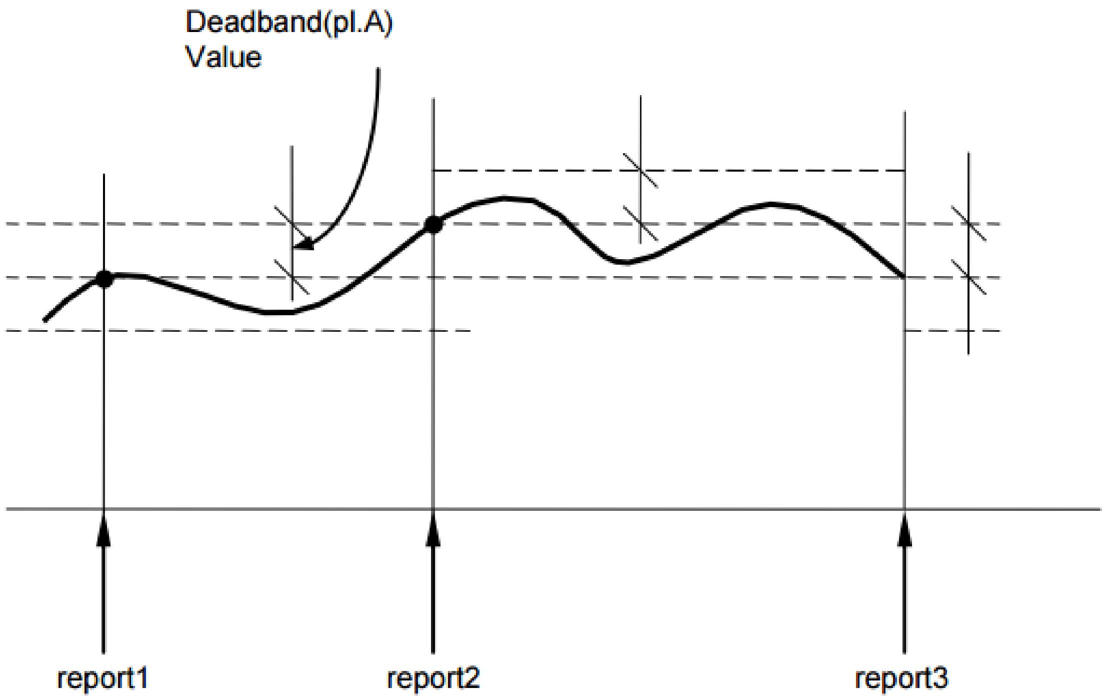


Figure 3-9 Reporting if "Amplitude" mode is selected

3.1.4.6 "Integral" mode of reporting

If the "Integrated" mode is selected for reporting, a report is generated if the time integral of the measured value since the last report gets becomes larger, in the positive or negative direction, then the (deadband*1sec) area. As an example, Figure 1-3 shows that the integral of the current in time becomes higher than the Deadband value multiplied by 1sec, this results "report2", etc.

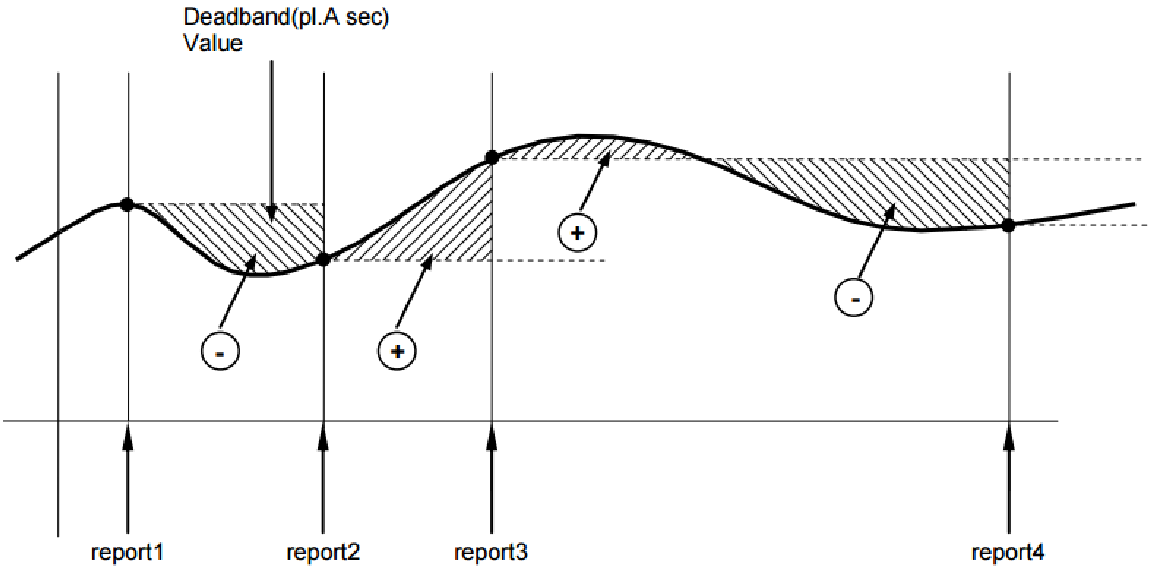


Figure 3-10 Reporting if "Integrated" mode is selected

3.1.4.7 Periodic reporting

Periodic reporting is generated independently of the changes of the measured values when the defined time period elapses.

Table 3-13 The integer parameters of the line measurement function

Parameter name	Title	Unit	Min	Max	Step	Default
Reporting time period for the active power						
MXU_PIntPer_IPar_	Report period P	sec	0	3600	1	0
Reporting time period for the reactive power						
MXU_QIntPer_IPar_	Report period Q	sec	0	3600	1	0
Reporting time period for the apparent power						
MXU_SIntPer_IPar_	Report period S	sec	0	3600	1	0
Reporting time period for the voltage						
MXU_UIntPer_IPar_	Report period U	sec	0	3600	1	0
Reporting time period for the current						
MXU_IIntPer_IPar_	Report period I	sec	0	3600	1	0
Reporting time period for the frequency						
MXU_fIntPer_IPar_	Report period f	sec	0	3600	1	0

If the reporting time period is set to 0, then no periodic reporting is performed for this quantity. All reports can be disabled for a quantity if the reporting mode is set to "Off". See Table 3-11.

3.2 PROTECTION FUNCTIONS

3.2.1 TRANSFORMER DIFFERENTIAL $3I_D$> (87T)

The differential protection function provides main protection for transformers, generators or large motors, but it can also be applied for overhead lines and cables of solidly grounded networks or for the protection of any combination of the aforementioned protected objects. Version DIF87_3w can be applied to protect three-winding transformers. The simpler version DIF87_2w does not process analogue inputs from the tertiary side. This chapter describes the three-winding transformer version but it also refers to necessary changes in application with transformers of two sides only.

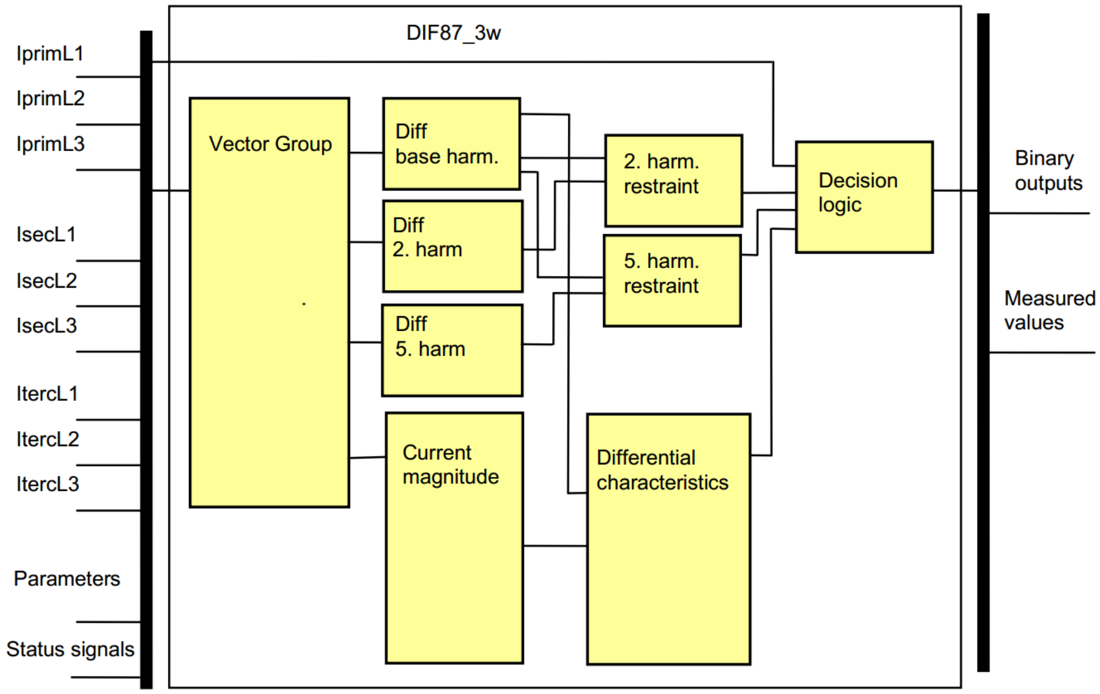


Figure 3-1 Structure of the differential protection algorithm.

The inputs of the function are:

Sampled values of three primary side phase currents,

Sampled values of three secondary side phase currents,

Sampled values of three tertiary side phase currents (in DIF87_3w version only AQ-T393)

Setting parameters

Status signals

The outputs of the function are:

Binary output status signals

Measured values for displaying

The software modules of the differential protection function:

Vector group: This module compensates the phase shift and turns ratio of the transformer. The results of this calculation are the “sampled values” of the phase-shifted phase currents for all three (two) sides of the transformer and those of the three differential currents.

Diff base harm: This module calculates the basic Fourier components of the three differential currents. These results are needed for the high-speed differential current decision and for the second and fifth harmonic restraint calculation.

Diff 2. harm: This module calculates the second harmonic Fourier components of the three differential currents. These results are needed for the second harmonic restraint decision.

Diff 5. harm: This module calculates the fifth harmonic Fourier components of the three differential currents. These results are needed for the fifth harmonic restraint decision.

2. harm. restraint: The differential current can be high during the transients of transformer energizing, due to the current distortion caused by the transformer iron core asymmetric saturation. In this case, the second harmonic content of the differential current is applied in this module to disable the operation of the differential protection function. The result of this calculation is needed for the decision logic.

5. harm. restraint: The differential current can be high if the transformer is over-excited by a connected generator, due to the current distortion caused by the transformer iron core symmetric saturation. In this case, the fifth harmonic content of the differential current is applied in this module to disable the operation of the differential protection function. The result of this calculation is needed for the decision logic.

Current magnitude: This module calculates the magnitude of the phase-shifted phase currents and that of the differential currents. The result of this calculation is needed for the evaluation of differential characteristics.

Differential characteristics: This module performs the necessary calculations for the evaluation of the "percentage differential characteristics". The result of this calculation is needed for the decision logic.

Decision logic: The decision logic module decides if the differential current of the individual phases is above the characteristic curve of the differential protection function. This curve is the function of the restraint current, which is calculated based on the magnitude of the phase-shifted phase currents. This module calculates the second and fifth harmonic ratios of the differential current relative to the basic harmonic content. The result can restrain the operation of the differential protection function. The high-speed overcurrent protection function based on the differential currents is also performed in this module.

Vector shift compensation

The three-phase power transformers transform the primary current to the secondary side according to the turns ratio and the vector group of the transformers. The Y (star), D (delta) or Z (zig-zag) connection of the three phase coils on the primary and secondary sides causes the vector shift of the currents.

The conventional electromechanical or static electronic devices of the differential protection compensate the vector shift with the appropriate connection of the current transformer coils. The numerical differential protection function applies matrix transformation of the directly measured currents of one side of the transformer to match them with the currents of the other side. In AQ-T300 series transformer differential protection the „Vector_group" software module calculates the matrix transformation and turns ratio matching. In this case, the target of the matrix transformation is the delta (D) side.

The Y-connected current transformers on the delta side of the transformer do not shift the currents flowing out of the transformer. The delta-connected current transformers on the Y side of the transformer, however, result in a phase shift. This means that the Y-side currents are shifted according to the vector group of the transformer to match the delta-side currents.

Additionally, the delta connection of the current transformers eliminates the zero sequence current component flowing on the grounded Y side of the transformer. As no zero sequence current can be detected on the delta side, this compensation is essential for the correct operation of the differential protection. If a phase-to-ground fault occurs on the Y side of the transformer, then zero sequence current flows on the grounded Y side while no out-flowing zero sequence current can be detected on the delta side. Without the elimination of the zero sequence current component, the differential protection generates a trip command in case of an external ground fault. If, however, the connection group of the current transformers on the Y side is delta, no zero sequence current flows out of the group. Thus the problem of zero sequence current elimination in case of an external ground fault is solved.

The numerical differential protection function applies numerical matrix transformation for modeling the delta connection of the current transformers. In practice, it means cyclical subtraction of the phase currents. In the vector shift compensation the sampled rst currents of the primary side (I1r, I1s, I1t) and those of the secondary side ((I2r, I2s, I2t)) are transformed to (RSTshift) values of both sides respectively, using matrix transformation. The method of transformation is defined by the „Code" parameter identifying the transformer vector group connection.

The table below summarizes the method of transformation, broken down by the connection group of the transformers with two voltage levels. The tertiary side, if any – related to the primary – is processed similarly:

Table 3-14 Vector shift compensation with transformation to the delta side.

Table 3-15 Vector shift compensation with transformation to the delta side

Tr. Conn. Group.	Code	Transformation of the primary side currents	Transformation of the secondary side currents
Dy1	00	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dy5	01	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dy7	02	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 1 & 0 \\ 0 & -1 & 1 \\ 1 & 0 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dy11	03	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dd0	04	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dd6	05	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dz0	06	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dz2	07	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & -2 & 1 \\ 1 & 1 & -2 \\ -2 & 1 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dz4	08	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -1 & -1 & 2 \\ 2 & -1 & -1 \\ -1 & 2 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dz6	09	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$

Dz8	10	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshif \\ I2Tshif \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -1 & 2 & -1 \\ -1 & -1 & 2 \\ 2 & -1 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Dz10	11	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshif \\ I2Tshif \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & -2 \\ -2 & 1 & 1 \\ 1 & -2 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yy0	12	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yy6	13	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} -1 & 0 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yd1	14	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yd5	15	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshitft \\ I2Sshitft \\ I2Tshitft \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yd7	16	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & -1 & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yd11	17	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yz1	18	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yz5	19	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yz7	20	$\begin{bmatrix} I1Rshitft \\ I1Sshitft \\ I1Tshitft \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} -2 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$
Yz11	21	$\begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} = \frac{1}{\sqrt{3}} \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1r \\ I1s \\ I1t \end{bmatrix}$	$\begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} I2r \\ I2s \\ I2t \end{bmatrix}$

The differential currents are calculated using the (RSTshift) values and the (TR primary) and (TR secondary) parameters, defined by the turns ratio of the transformer and that of the current transformers, resulting in the currents marked with an apostrophe ('). The tertiary side is processed similarly. (The positive direction of the currents is flowing IN on both sides.)

$$\begin{bmatrix} IdR \\ IdS \\ IdT \end{bmatrix} = \begin{bmatrix} I1Rshift' \\ I1Sshift' \\ I1Tshift' \end{bmatrix} + \begin{bmatrix} I2Rshift' \\ I2Sshift' \\ I2Tshift' \end{bmatrix} = \frac{100}{TR\_primary} \begin{bmatrix} I1Rshift \\ I1Sshift \\ I1Tshift \end{bmatrix} + \frac{100}{TR\_secondary} \begin{bmatrix} I2Rshift \\ I2Sshift \\ I2Tshift \end{bmatrix}$$

The current measuring software modules process these momentary values of the differential currents and calculate values that are proportional to the RMS values.

Operation with the zero sequence current in case of a phase-to-ground fault on the delta side

On the secondary side of a high voltage /medium voltage transformer which is connected in delta on the medium voltage side, an additional neutral grounding transformer is applied. Between the neutral point of this grounding transformer and the ground either a grounding resistor is connected to limit the single phase-to-ground fault currents below 100 A – 200 A or with a Petersen coil, which limits the single-phase fault currents to a few Amps. In these cases, there are two locations for the current transformers on the delta side to supply the differential protection.

In one case, the neutral grounding transformer is located inside the protected zone of the differential, in the other case the neutral grounding transformer is outside the protected zone. If the neutral grounding transformer is in the protected zone, then the current distribution depends on the location of the supplying generator. In these cases, for the correct operation of the differential protection (if the operating characteristic lines are set to be sensitive) the subtraction of the zero sequence current is needed. This additional transformation „moves" the measuring location to the point („Y") where no zero sequence current can flow, so these transformed currents do not include the zero sequence current of the neutral grounding transformer.

Harmonic analysis of the differential currents (Diff basic harm.), (Diff 2. harm.), (Diff 5. harm.)

The differential current can be high during the transients of transformer energizing due to the current distortion caused by the transformer iron core asymmetrical saturation. In this case, the second harmonic content of the differential current is applied to disable the operation of the differential protection function.

The differential current can be high in case of the over-excitation of the transformer due to the current distortion caused by the transformer iron core symmetrical saturation. In this case, the fifth harmonic content of the differential current is applied to disable the operation of the differential protection function.

The harmonic analysis block of modules consists of three individual software modules.

Diff base harm: This module calculates the basic Fourier components of the three differential currents. These results are needed for the high-speed differential current decision and for the second and fifth harmonic restraint calculation.

Diff 2. harm: This module calculates the second harmonic Fourier components of the three differential currents. These results are needed for the second harmonic restraint decision.

Diff 5. harm: This module calculates the fifth harmonic Fourier components of the three differential currents. These results are needed for the fifth harmonic restraint decision.

The harmonic restraint decision (2. harmonic restraint) and (5. harmonic restraint)

The differential current can be high during transformer energizing due to the current distortion caused by the transformer iron core asymmetrical saturation. In this case, the second harmonic content of the differential current is applied to disable the operation of the differential protection function.

The differential current can be high in case of the over-excitation of the transformer due to the current distortion caused by the transformer iron core symmetrical saturation. In this case, the fifth harmonic content of the differential current is applied to disable the operation of the differential protection function.

The harmonic analysis block of modules consists of two sub-blocks, one for the second harmonic decision and one for the fifth harmonic decision. Each sub-block includes three individual software modules for the phases.

The software modules evaluate the harmonic content relative to the basic harmonic component of the differential currents and compare the result with the parameter values set for the second and fifth harmonic. If the content is high, then the assigned status signal is set to "true" value. If the duration of the active status is at least 25 ms, then the resetting of the status signal is delayed by an additional 15 ms.

The evaluation of the differential characteristics

This module evaluates the differential characteristics. It compares the magnitudes of the differential currents and those of the restraint currents. The restraint currents are calculated using the following formulas:

$$M\_IbiasR = \frac{M\_I1Rshift' + M\_I2Rshift' + M\_I3Rshift''}{2}$$

$$M\_IbiasS = \frac{M\_I1Sshift' + M\_I2Sshift' + M\_I3Sshift''}{2}$$

$$M\_IbiasT = \frac{M\_I1Tshift' + M\_I2Tshift' + M\_I3Tshift''}{2}$$

Based on these values (generally denoted as "Ires") and the values of the differential current magnitudes (generally denoted as "Id"), the differential protection characteristics is shown in following figure.

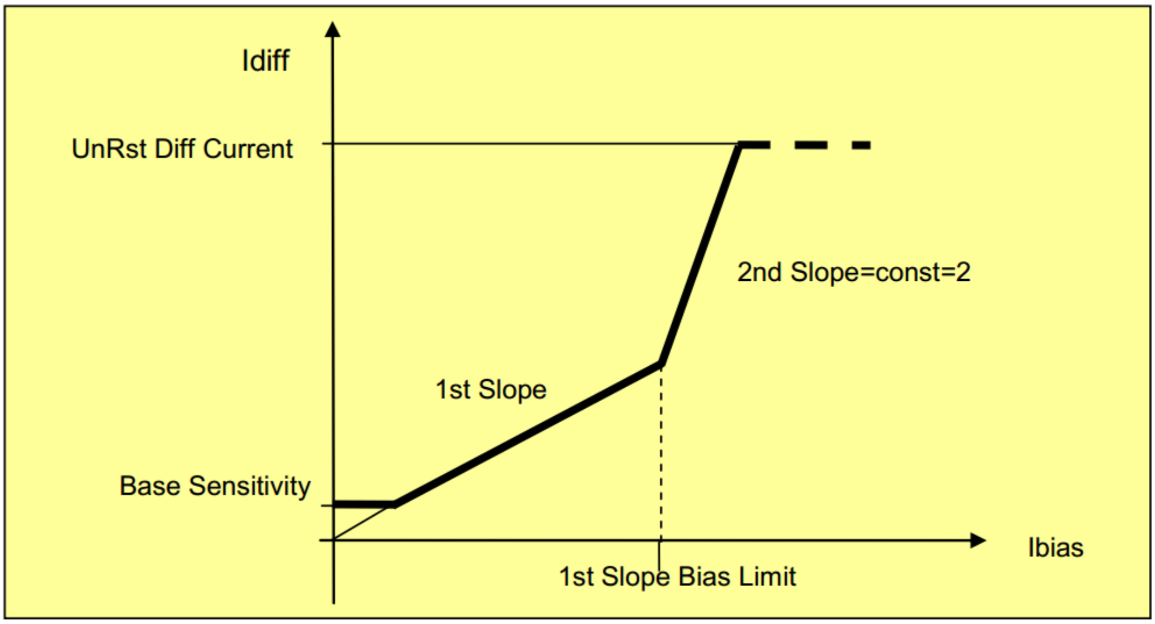


Figure 3-2. Differential characteristics.

Additionally, separate status signals are set to "true" value if the differential currents in the individual phases are above the limit set by the dedicated parameter (see "Unrestricted differential function").

The unrestricted differential function

If the calculated differential current is very high, then the differential characteristic is not considered anymore because the separate status signals for the phases are set to “true” value if the differential currents in the individual phases are above the limit defined by parameter setting. The decisions of the phases are connected in an OR gate to result in the general start status signal.

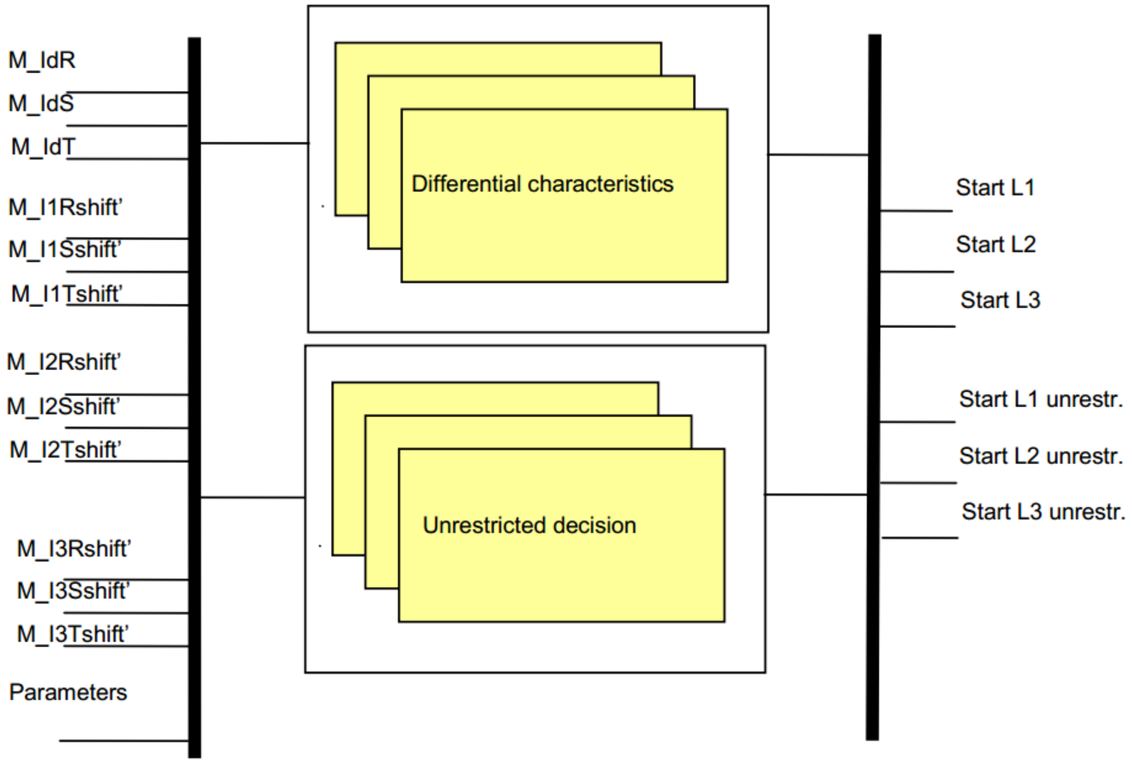


Figure 3-3. Operating principle of the current restraint and non restraint characteristics.

Table 3-16 Setting parameters of the differential protection function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection of the differential function. Default setting is On.
Pri-Sec VGroup*	Dy1,Dy5,Dy7, Dy11,Dd0,Dd6, Dz0,Dz2,Dz4, Dz6,Dz8,Dz10, Yy0,Yy6,Yd1, Yd5,Yd7,Yd11, Yz1,Yz5,Yz7, Yz11	Vector group selection of the transformer coils in primary-secondary relation. Default setting is Dd0.
Pri-Ter VGroup*	Dy1,Dy5,Dy7, Dy11,Dd0,Dd6, Dz0,Dz2,Dz4, Dz6,Dz8,Dz10,	Vector group selection of the transformer coils in primary-tertiary relation. Default setting is Dd0.

	Yy0,Yy6,Yd1, Yd5,Yd7,Yd11, Yz1,Yz5,Yz7, Yz11	
ZeroSequ.Elimination	True False	Selection of the zero sequence current elimination. Default setting is True.
TR Primary comp. TR Secondary comp. TR Tertiary comp.	20…500 % by step of 1 %	Parameters for the current magnitude compensation. Default setting is 100 %.
2nd Harm. Ratio	5…50 % by step of 1 %	Parameter of the second harmonic restraint. Default setting is 15 %.
5th Harm. Ratio	5…50 % by step of 1 %	Parameter of the second harmonic restraint. Default setting is 25 %.
Base sensitivity	10…50 % by step of 1 %	Basic pick up setting for the current restraint differential characteristics. Default setting is 20 %.
1st Slope	10…50 % by step of 1 %	First slope setting. Default setting is 20 %.
1st Slope Bias Limit	200…2000 % by step of 1 %	Second slope setting. Default setting is 200 %.
Unrestrained I-Diff	800…2500 % by step of 1 %	Non-restraint characteristics pick-up setting. Default setting is 800 %.

* If the connection of the primary winding in the primary-secondary and primary-tertiary relations is selected in contradiction, then the protection function is automatically disabled and the function generates a warning signal.

Function	
Operating characteristic	2 breakpoint
Reset ratio	0,95
Characteristic accuracy	<2%
Operate time, unrestrained	Typically 20 ms
Reset time, unrestrained	Typically 25 ms
Operate time, restrained	< 35 ms
Reset time, restrained	< 25 ms

1.1.1.1 Example setting calculation for AQ-300 IED differential protection

As an example the transformer data: Sn = 125 MVA U1/U2 = 132/11.5 kV/kV Yd11 Current transformer:

- CT1 600/1 A/A
- CT2 6000/1 A/A

Rated currents of the transformer:

- I1np = 546 A On the secondary side of the CT I1n = 0.91 A
- I2np = 6275 A On the secondary side of the CT I2n = 1.05 A

The setting parameters

TR Primary Comp = 91 %

(This is a free choice, giving the currents of the primary side current transformer's current, related to the rated current of the CT.)

TR Secondary Comp = 105 %

(This is a direct consequence of selecting TR primary; this is the current of the secondary side current transformer related to the rated current of the CT.)

The code value of the transformer's connection group (Yd11):

Pri-Sec VGroup = Yd11

1.1.1.2 Fixed trip assignment into trip logic

To ensure fast tripping required from differential functions the trip signal always has a factory fixed connection to the TRC94 trip logic blocks. See the picture of logic mentioning this.

DIF87, REF, IOC50, IOC50N have fix connection to TRC94 input (Fast EQU) !

GenTr outputs of TRC94 have fix connection to Trip contacts (TripAssign) !

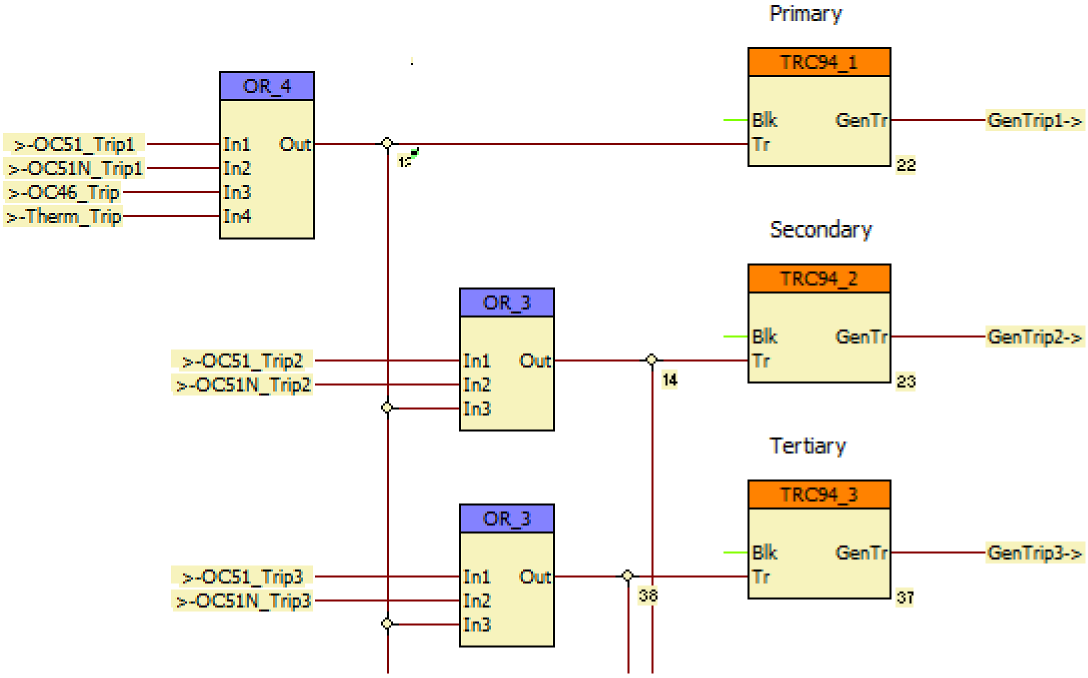


Figure 3-4. Logic where the factory fixed connection of DIF87, REF, IOC50, IOC50N have fix connection to TRC94 blocks seen in the picture.

The tripping contacts for these TRC94 function blocks are defined in *Software configuration → Trip signals → Trip assignment*.

3.2.2 RESTRICTED EARTH FAULT REF (87N)

The restricted earth-fault protection function is basically a low-impedance differential protection function based on zero sequence current components. It can be applied to transformers with grounded neutral. The function compares the measured neutral current and the calculated zero sequence current component of the phase currents and generates a trip command if the difference of these currents is above the characteristics. Restricted earth fault can be applied to both HV and LV side with 2 stages of the function.

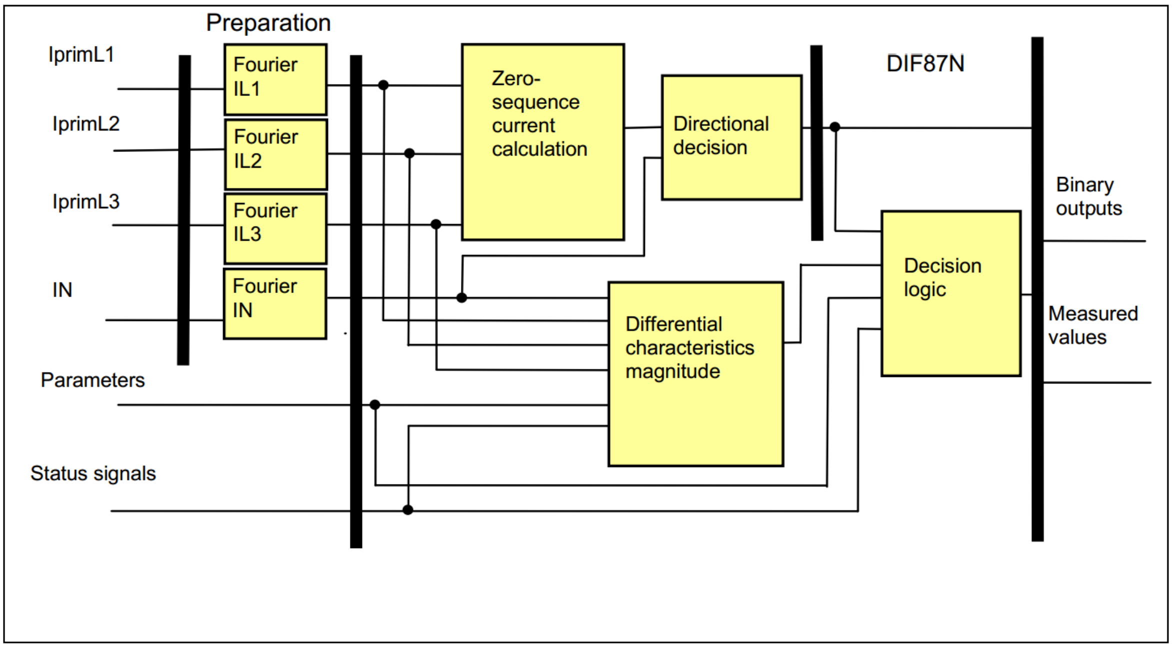


Figure 3-5 Structure of the restricted earth fault protection algorithm.

The inputs for the preparation are the sampled values of three primary phase currents, the sampled value of the neutral current.

The outputs of the preparation are the RMS values of the fundamental Fourier components of the phase currents and that of the neutral current.

The inputs for the DIF87N function are: the RMS values of the fundamental Fourier components of the phase currents and that of the neutral current, parameters, status signal.

The outputs of the DIF87N function are: the binary output status signal, the measured values for displaying.

The software modules of the differential protection function:

Fourier calculations: These modules calculate the basic Fourier current components of the phase currents and that of the neutral current individually. These modules belong to the preparatory phase.

Zero sequence current calculation: This module calculates the zero sequence current components based on the Fourier components of the phase currents. These modules belong to the preparatory phase.

Directional decision: This module compares the direction of the neutral current and that of the calculated zero sequence current. In case of small zero sequence components of the high fault currents in the phases, this decision improves the stability of the function.

Differential characteristics: This module performs the necessary calculations for the evaluation of the "percentage differential characteristics" and decides if the differential current is above the characteristic curve of the differential protection function. This curve is the function of the restraint current, which is the maximum of the phase currents and the current of the neutral point. The result of this calculation is needed for the decision logic.

Decision logic: The decision logic module combines the status signals, binary and enumerated parameters to generate the trip command of the function. The following description explains the details of the individual components.

Directional decision (Directional decision)

This module compares the direction of the neutral current and that of the calculated zero sequence current. In case of small zero sequence component of the high fault currents in the phases, this decision improves the stability of the function.

For the directional decision, the positive directions are drawn in following figure. In this system, if the angle between the calculated zero sequence current 3Io and the measured neutral current IN is out of the range of ±90 degrees, then the restricted earth fault protection can be blocked, the status signal (Dir.element Start) is set to TRUE value. The blocking is decided in the decision logic of the function, using the binary parameter.

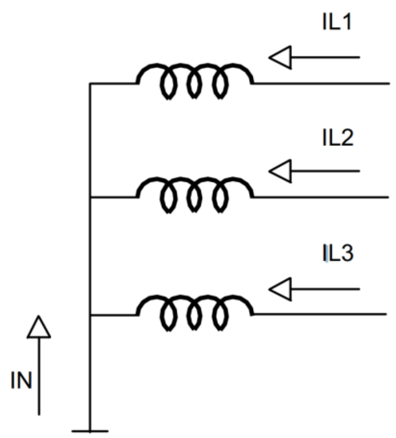


Figure 3-6 Currents positive directions.

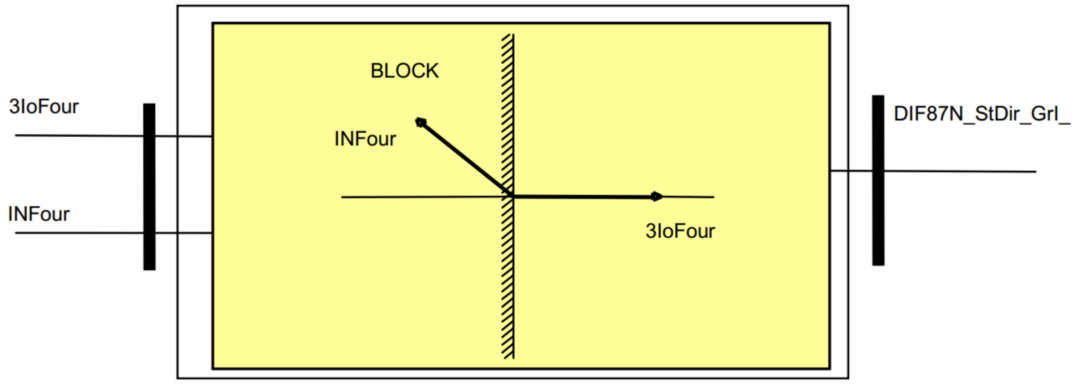


Figure 3-7 Principal scheme of directional decision.

The zero sequence differential characteristics

This module performs the necessary calculations for the evaluation of the "percentage differential characteristics", and decides if the differential current is above the characteristic curve of the zero sequence differential protection function. This curve is the function of the restraint current, which is the maximum of the phase currents and the current of the neutral point. The result of this calculation is processed in the decision logic.

The differential current is calculated using the following formula:

Diff Current = IL1Four + IL2Four + IL3Four + INFour

The restraint current is calculated using the following formula:

Bias Current = MAX(IL1Four, IL2Four, IL3Four, INFour)

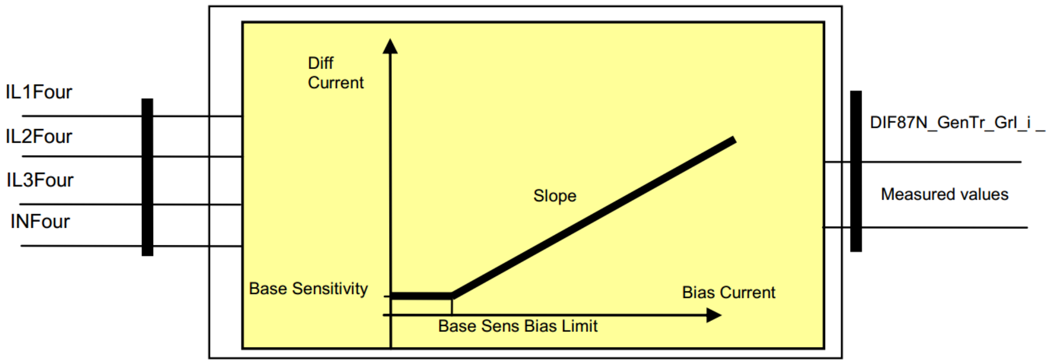


Figure 3-8. Zero sequence differential protection characteristics.

The restricted earth-fault protection function generates a trip signal if the differential current as the function of the bias current is above the differential characteristic lines and the function is not blocked and the operation of the function is enabled by parameter setting. Blocking can be caused by the directional decision if it is enabled by parameter setting and the angle of the currents is in the blocking area or the user has composed a blocking graphic equation, and the conditions result a TRUE value for the blocking.

Table 3-17 Setting parameters of the restricted earth fault protection function

Parameter	**Setting value, range and step**	**Description**
Operation	Off On	Operating mode selection of the restricted earth fault function. Default setting is On.
Directional check	Off On	Enabling the directional checking of the measured and calculated zero sequence currents. Default setting is On.
TR Primary	20...500 % by step of 1 %	Phase current CT compensation. Default setting is 100 %
TR neutral	100…1000 % by step of 1 %	Neutral current CT compensation. Default setting is 500 %
Base sensitivity	10…50 % by step of 1 %	Basic pick-up setting of the restricted earth fault function. Default setting is 30 %
Second part	50…100 % by step of 1 %	Slope of the second section of the characteristics. Default setting is 70 %
Break point	100…200 % by step of 1 %	Break point of the characteristic line. Default setting is 125 %

3.2.3 Three-phase instantaneous overcurrent I>>> (50)

The instantaneous overcurrent protection function operates according to instantaneous characteristics, using the three sampled phase currents. The setting value is a parameter, and it can be doubled with dedicated input binary signal. The basic calculation can be based on peak value selection or on Fourier basic harmonic calculation, according to the parameter setting.

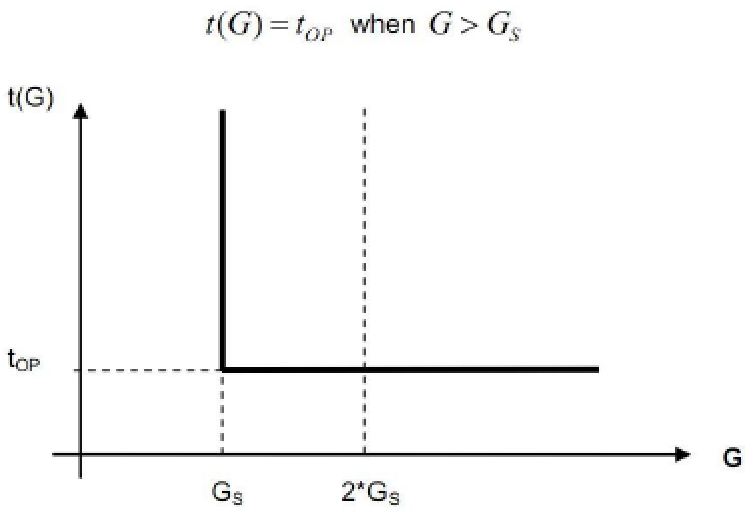


Figure 11: Operating characteristics of the instantaneous overcurrent protection function, where

tOP (seconds) Theoretical operating time if G> GS (without additional time delay),

G Measured peak value or Fourier base harmonic of the phase currents

GS Pick-up setting value

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Peak selection module is an alternative for the Fourier calculation module and the peak selection module selects the peak values of the phase currents individually. Instantaneous decision module compares the peak- or Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

In the figure below. is presented the structure of the instantaneous overcurrent algorithm.

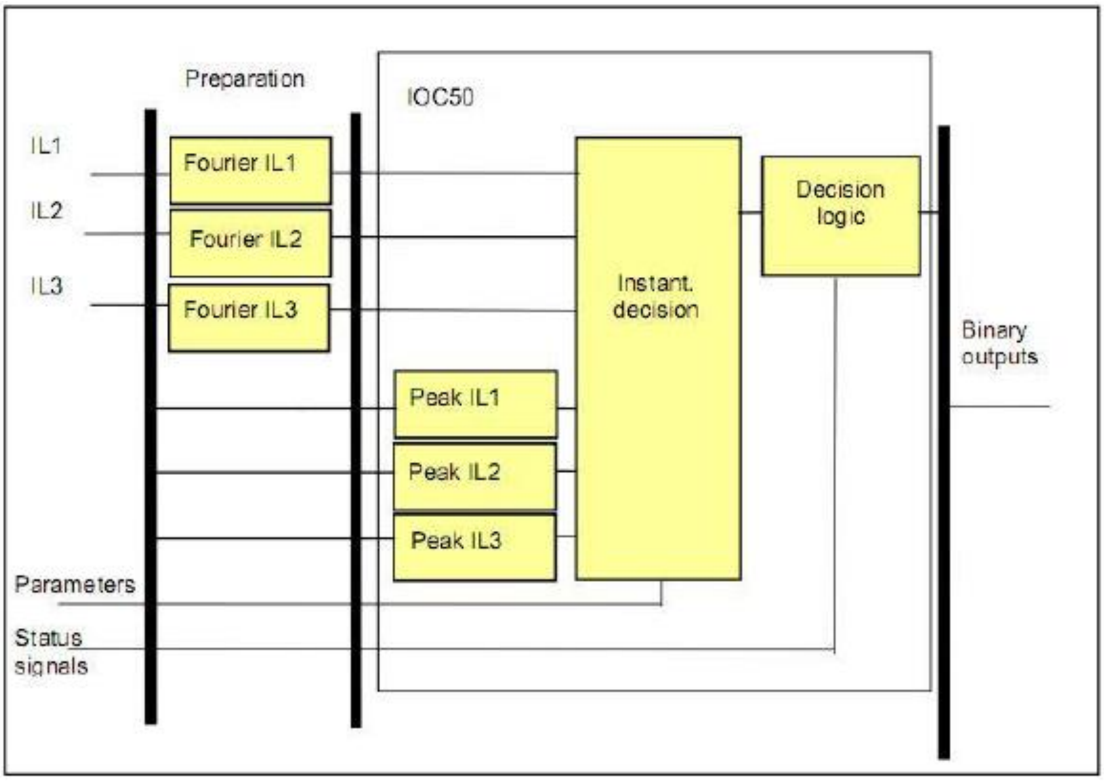


Figure 12: Structure of the instantaneous overcurrent algorithm.

The algorithm generates a trip command without additional time delay based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Table 3-18 Setting parameters of the instantaneous overcurrent protection function

Parameter	Setting value, range and step	Description
Operation	Off Peak value Fundamental value	Operating mode selection of the function. Can be disabled, operating based into measured current peak values or operating based into calculated current fundamental frequency RMS values. Default setting is “Peak value”
Start current	20…3000 %, by step of 1%	Pick-up setting of the function. Setting range is from 20% to 3000% of the configured nominal secondary current. Setting step is 1 %. Default setting is 200 %

3.2.4 RESIDUAL INSTANTANEOUS OVERCURRENT I0>>> (50N)

The residual instantaneous overcurrent protection function operates according to instantaneous characteristics, using the residual current (IN=3Io). The setting value is a parameter, and it can be doubled with dedicated input binary signal. The basic calculation can be based on peak value selection or on Fourier basic harmonic calculation, according to the parameter setting.

$$t(G) = t_{OP} \text{ when } G > G_S$$

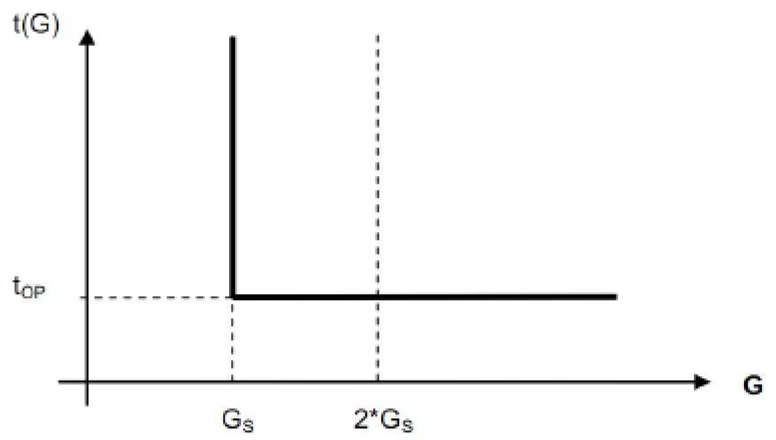


Figure 13: Operating characteristics of the residual instantaneous overcurrent protection function.

tOP (seconds) Theoretical operating time if G> GS (without additional time delay),

G Measured peak value or Fourier base harmonic of the residual current

GS Pick-up setting value

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Peak selection module is an alternative for the Fourier calculation module and the peak selection module selects the peak values of the residual currents individually. Instantaneous decision module compares the peak- or Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

Below is presented the structure of the instantaneous residual overcurrent algorithm.

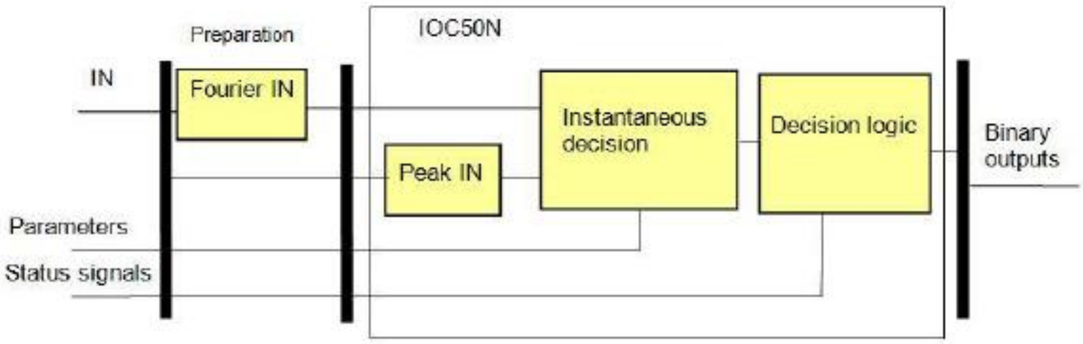


Figure 14: Structure of the instantaneous residual overcurrent algorithm.

The algorithm generates a trip command without additional time delay based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Table 3-19 Setting parameters of the residual instantaneous overcurrent function

Parameter	Setting value, range and step	Description
Operation	Off Peak value Fundamental value	Operating mode selection of the function. Can be disabled, operating based into measured current peak values or operating based into calculated current fundamental frequency RMS values. Default setting is “Peak value”.
Start current	10…400 %, by step of 1%	Pick-up setting of the function. Setting range is from 10 % to 400 % of the configured nominal secondary current. Setting step is 1 %. Default setting is 200 %.

3.2.5 THREE-PHASE TIME OVERCURRENT I>, I>> (50/51)

Three phase time overcurrent function includes the definite time and IDMT characteristics according to the IEC and IEEE standards. The function measures the fundamental Fourier components of the measured three phase currents.

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the 3-phase currents. Characteristics module compares the Fourier basic harmonic components of the phase currents into the setting value. Decision logic module generates the trip signal of the function.

In the figure below is presented the structure of the time overcurrent algorithm.

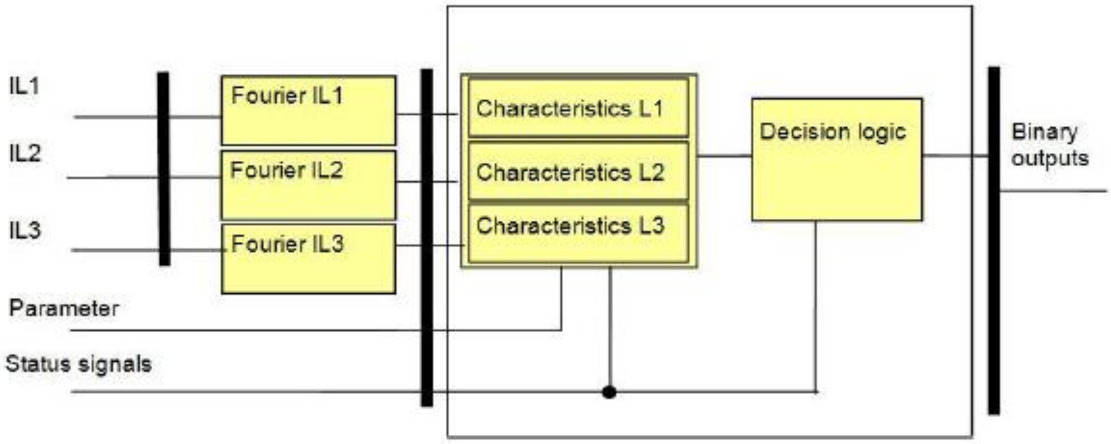


Figure 3-15 Structure of the time overcurrent algorithm.

The algorithm generates a start signal based on the Fourier components of the phase currents or peak values of the phase currents in case if the user set pick-up value is exceeded. Trip signal is generated based into the selected definite time- or IDMT additional time delay is passed from the start conditions. The operation of the function is phase wise and it allows each phase to be tripped separately. Standard operation is three poles.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Operating characteristics of the definite time is presented in the figure below.

$$t(G) = t_{OP} \text{ when } G > G_S$$

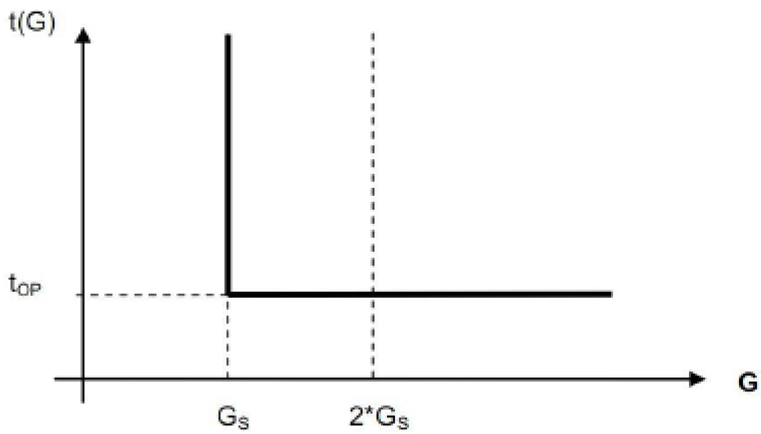


Figure 3-16 Operating characteristics of the definite time overcurrent protection function.

tOP (seconds) Theoretical operating time if G> GS (without additional time delay),

G Measured peak value or Fourier base harmonic of the phase currents

GS Pick-up setting value

IDMT operating characteristics depend on the selected curve family and curve type. All of the available IDMT characteristics follow

Equation 3-1 IDMT characteristics equation.

$$t(G) = TMS\left[\frac{k}{\left(\frac{G}{G_S}\right)^{\alpha} - 1} + c\right] \text{ when } G > G_S$$

t(G)(seconds) Theoretical operate time with constant value of G

k, c constants characterizing the selected curve

α constant characterizing the selected curve

G measured value of the Fourier base harmonic of the phase currents

GS pick-up setting

TMS time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the table below.

Table 3-20 Parameters and operating curve types for the IDMT characteristics.

Curve family	Characteristics	k_r	c	α
IEC	NI (normally inverse)	0,14	0	0,02
IEC	VI (very inverse)	13,5	0	1
IEC	EI (extremely inverse)	80	0	2
IEC	LTI (long time inverse)	120	0	1
IEEE/ANSI	NI (normally inverse)	0,0086	0,0185	0,02
IEEE/ANSI	MI (moderately inverse)	0,0515	0,1140	0,02
IEEE/ANSI	VI (very inverse)	19,61	0,491	2
IEEE/ANSI	EI (extremely inverse)	28,2	0,1217	2
IEEE/ANSI	LTI (long time inverse)	0,086	0,185	0,02
IEEE/ANSI	LTVI (long time very inverse)	28,55	0,712	2
IEEE/ANSI	LTEI (long time extremely inverse)	64,07	0,250	2

In following figures the characteristics of IDMT curves are presented with minimum and maximum pick-up settings in respect of the IED measuring range.

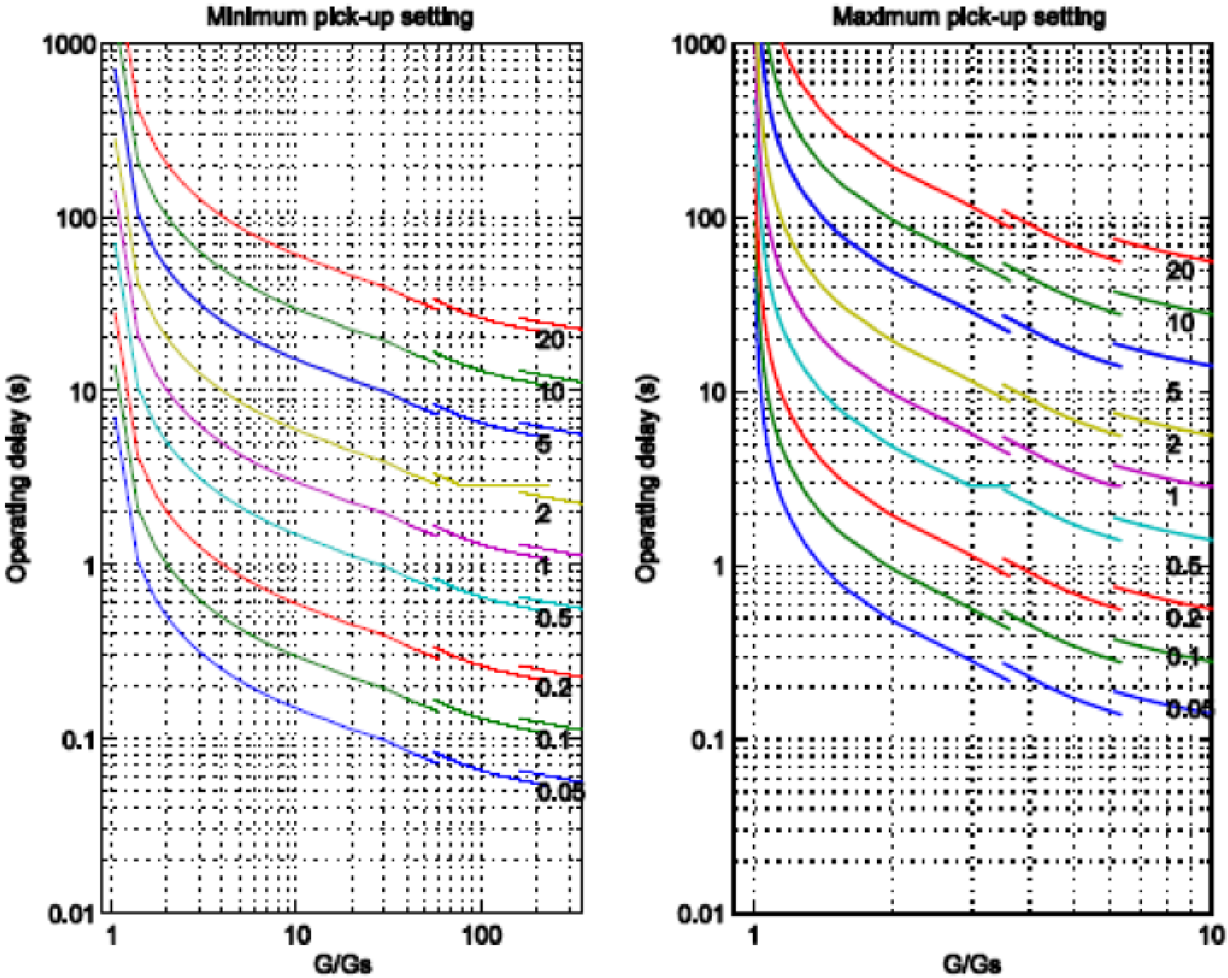


Figure 3-17: IEC Normally Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

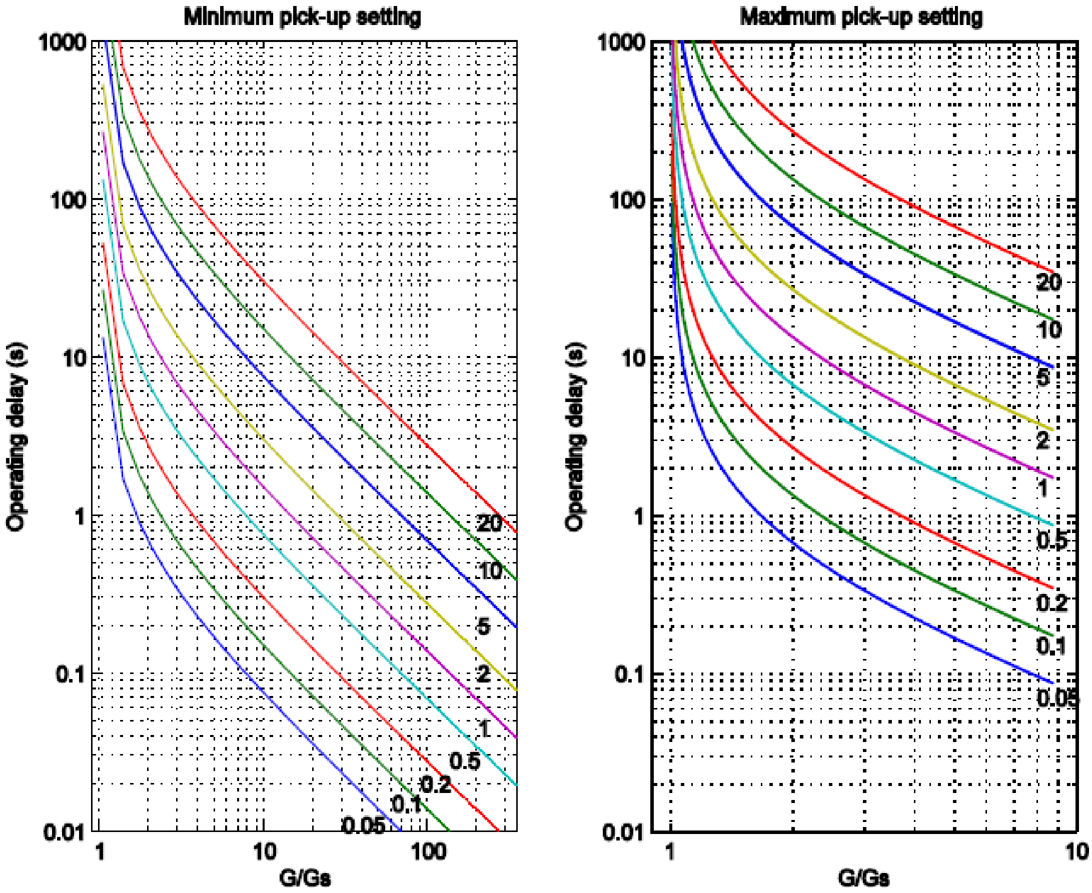


Figure 3-18: IEC Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

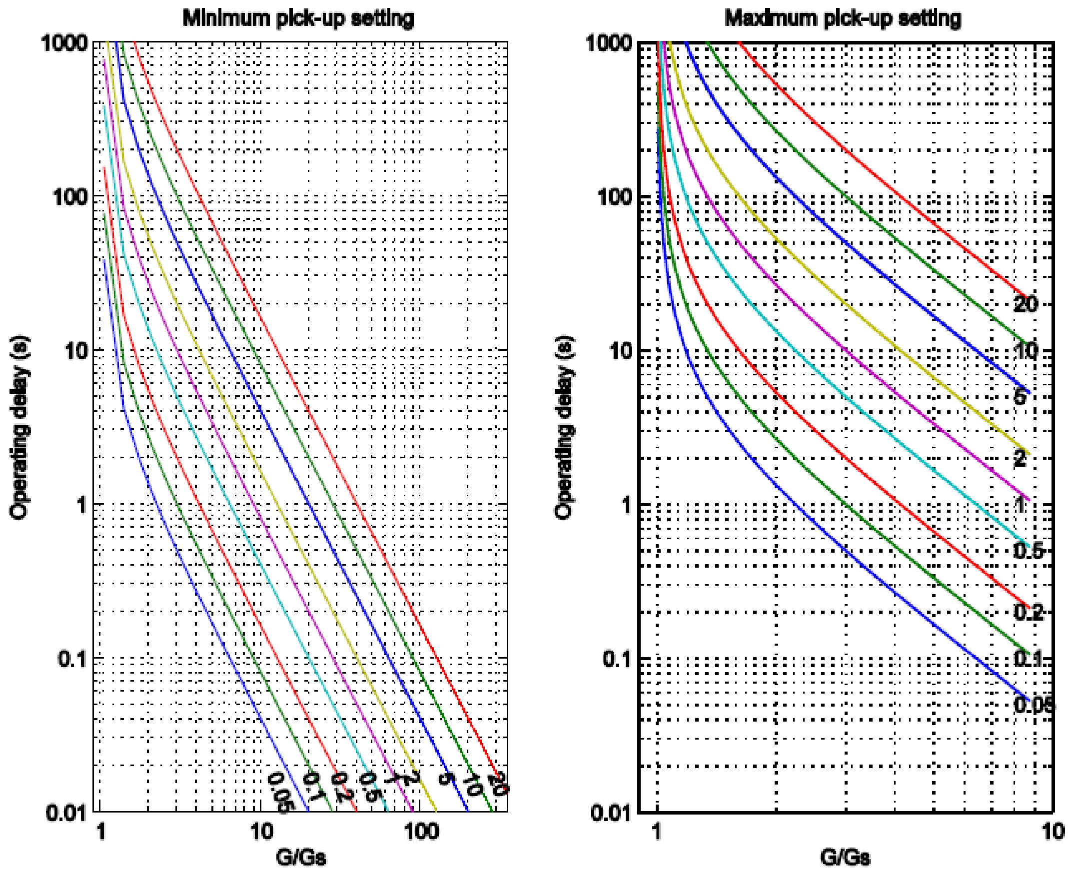


Figure 3-19: IEC Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

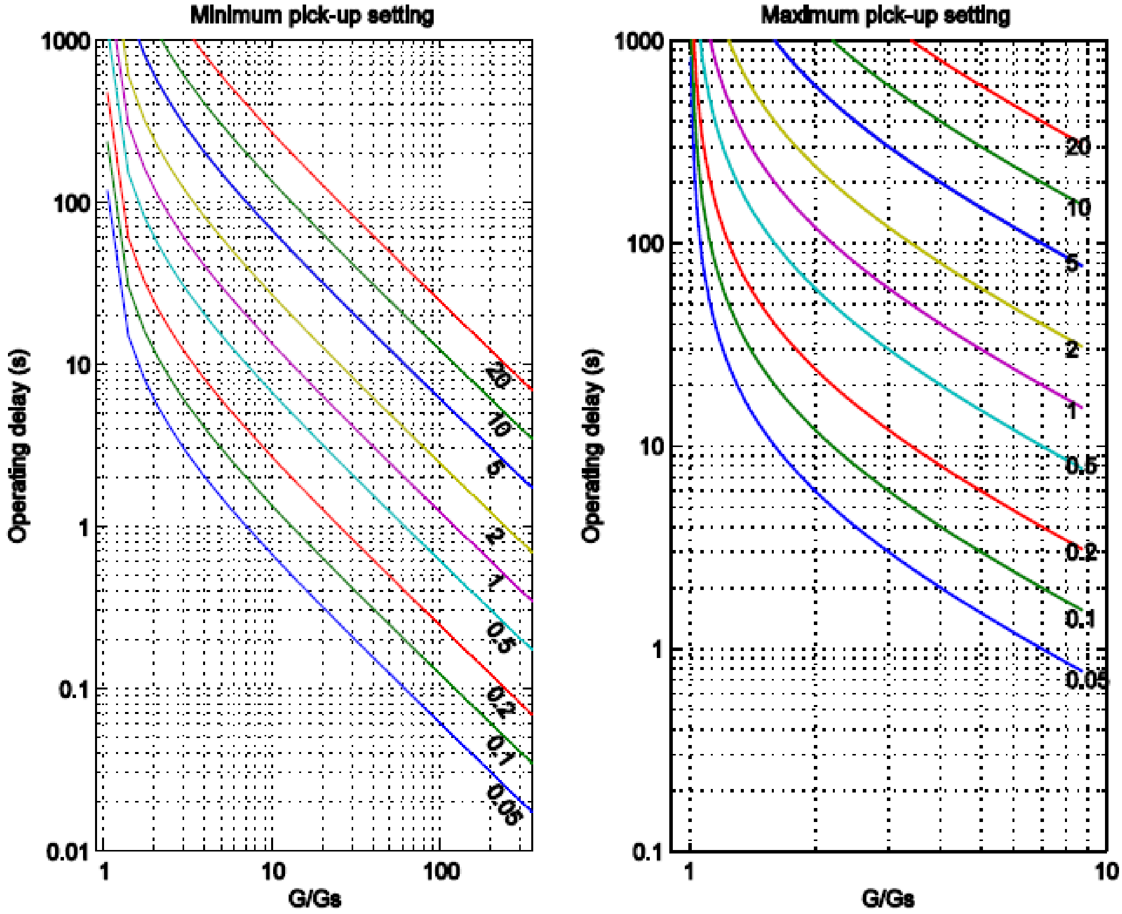


Figure 3-20: IEC Long Time Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

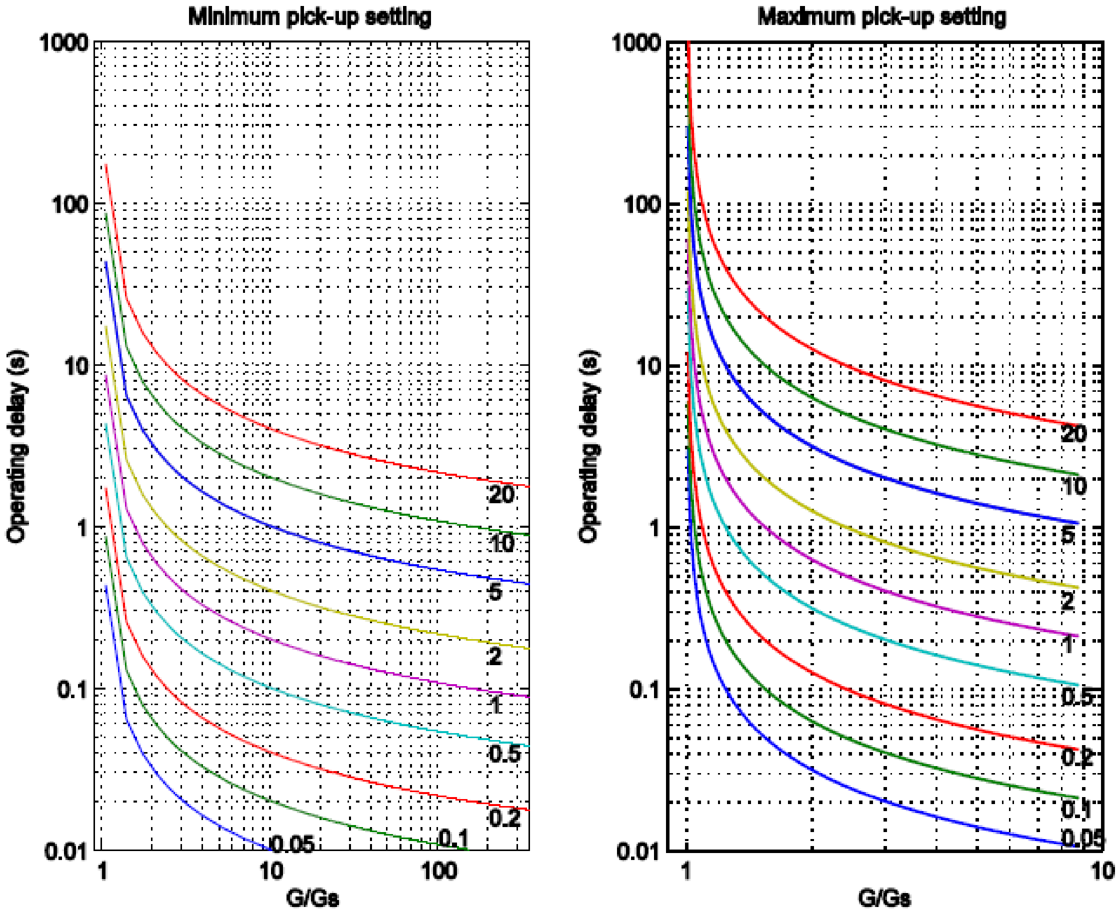


Figure 3-21: ANSI/IEEE Normally Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

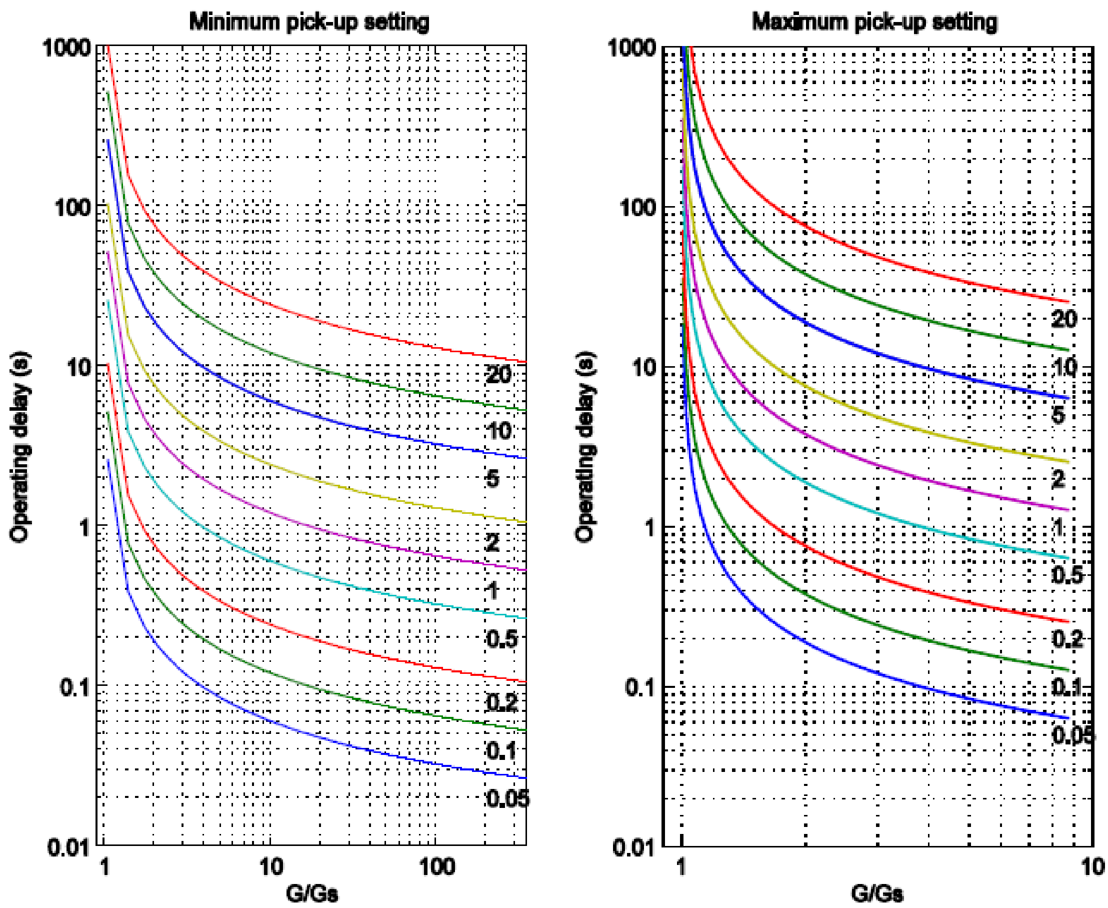


Figure 3-22: ANSI/IEEE Moderately Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

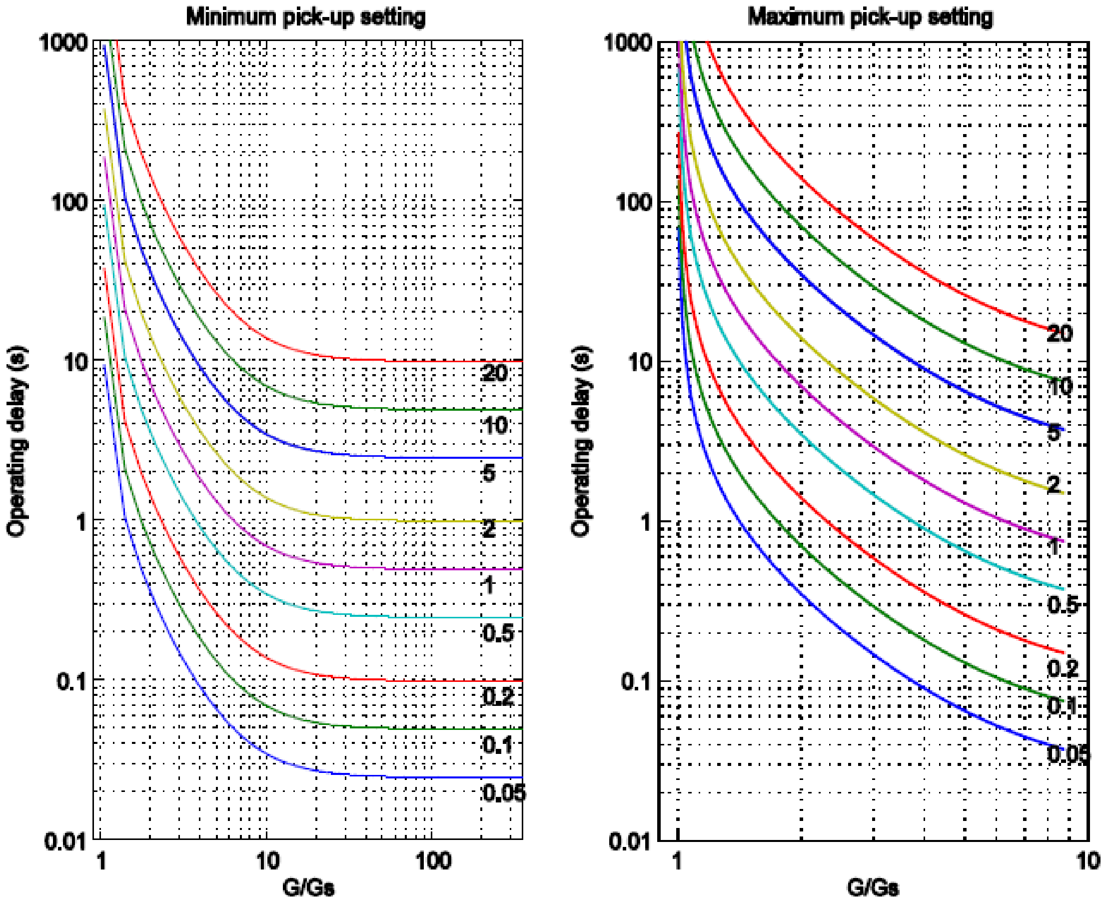


Figure 3-23: ANSI/IEEE Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

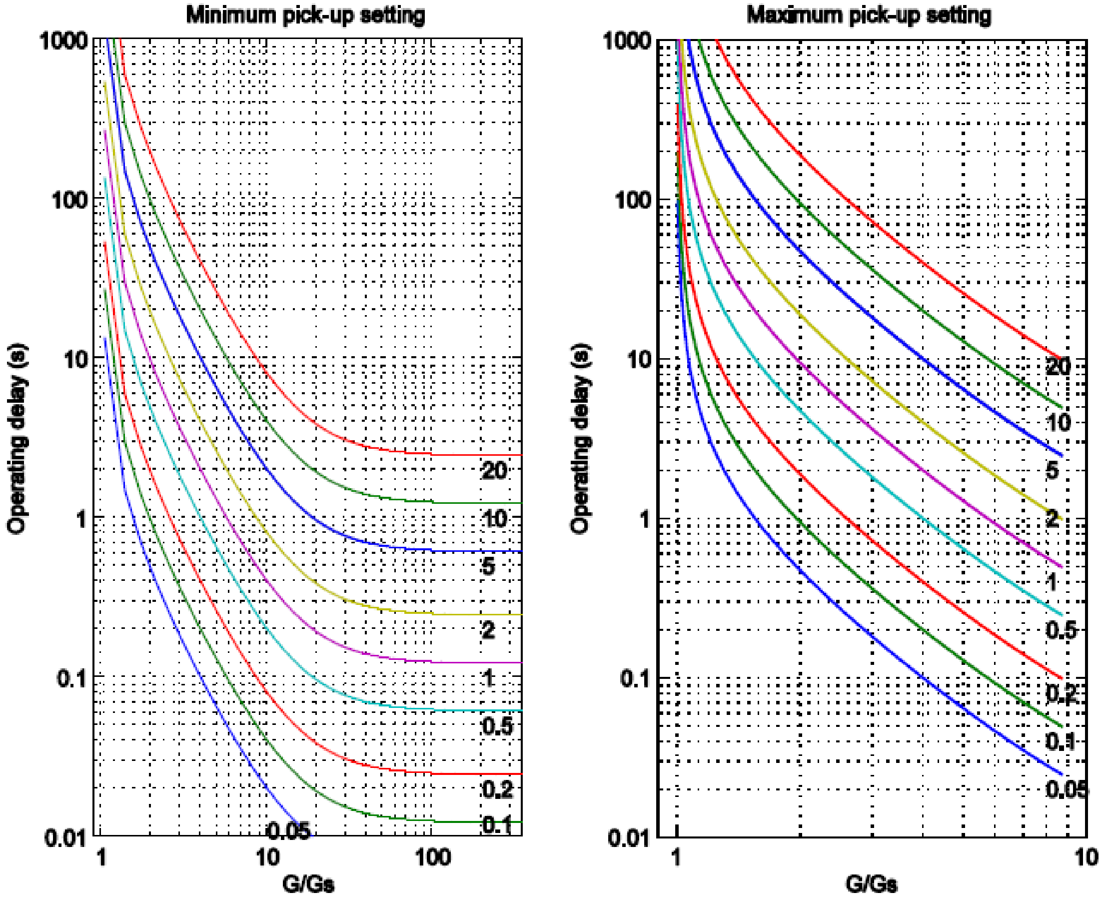


Figure 3-24: ANSI/IEEE Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

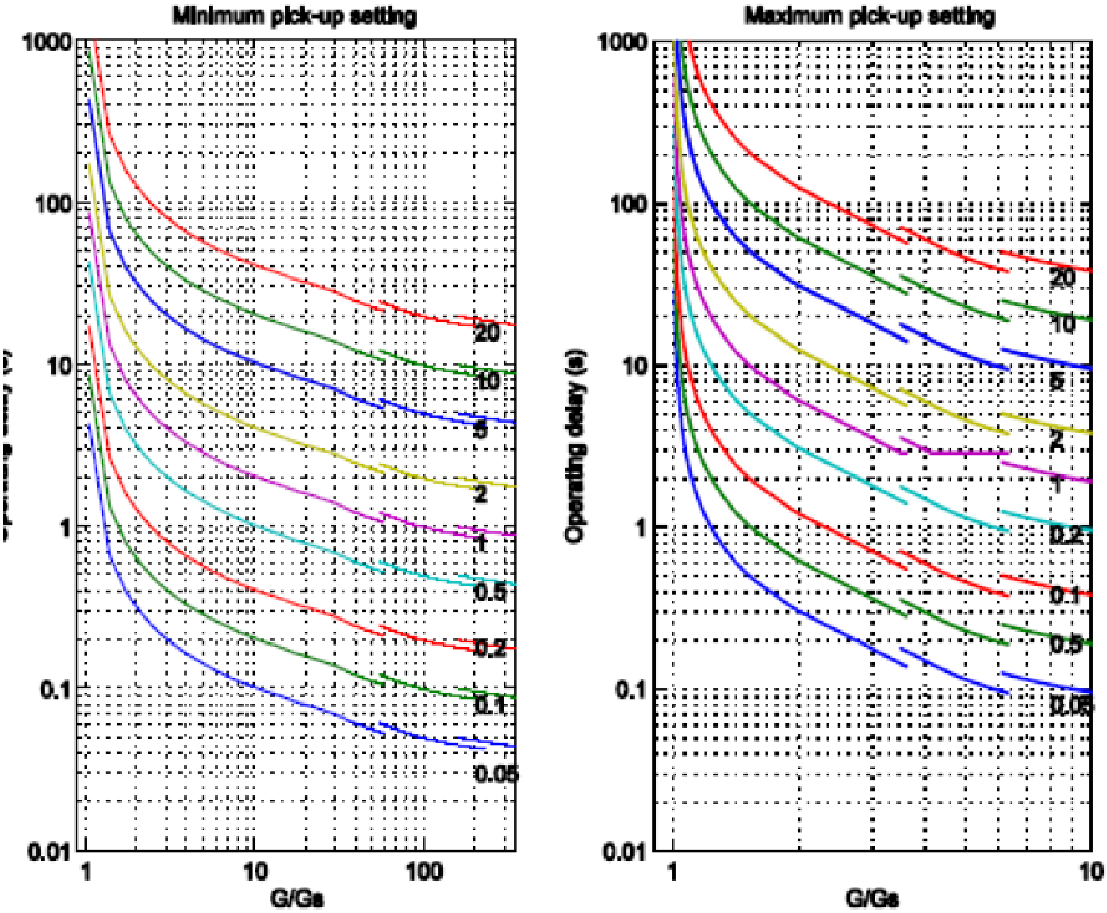


Figure 3-25: ANSI/IEEE Long Time Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

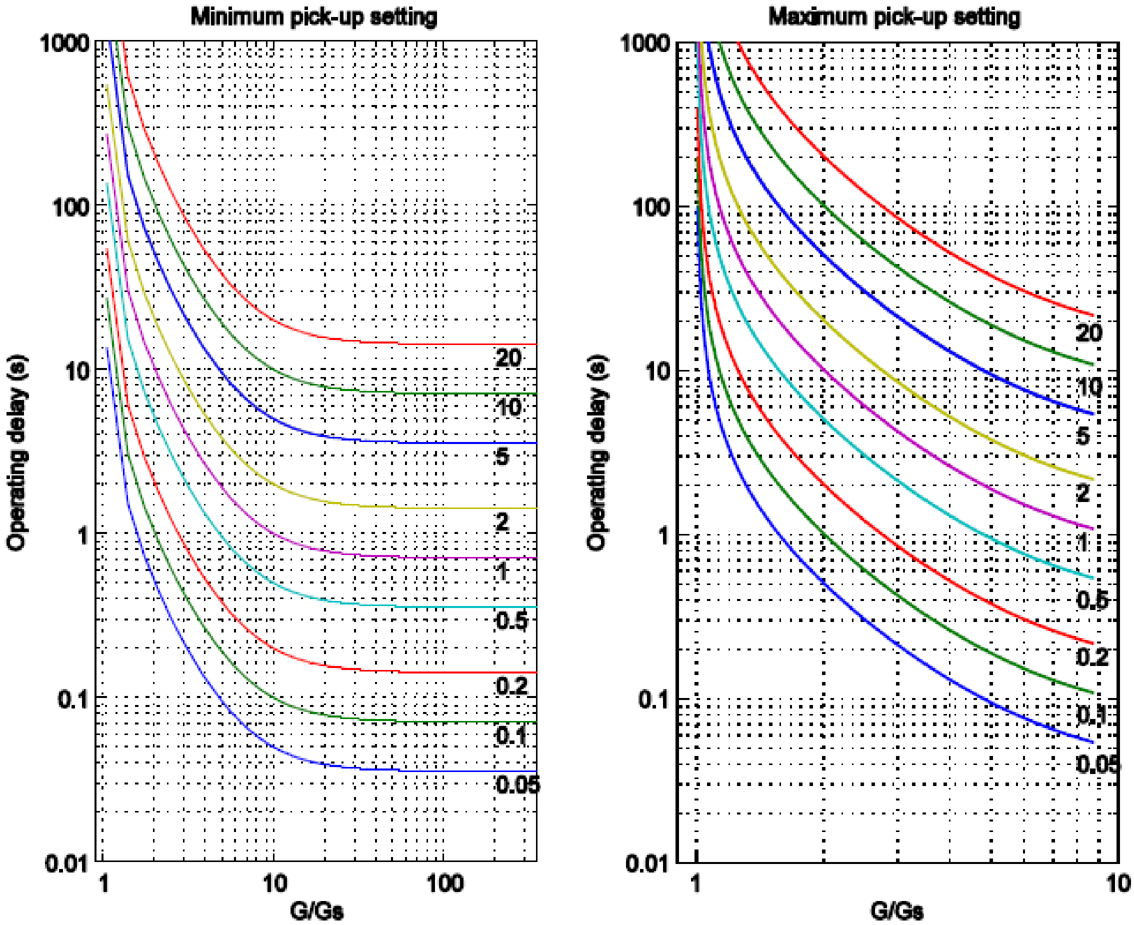


Figure 3-26: ANSI/IEEE Long Time Very Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

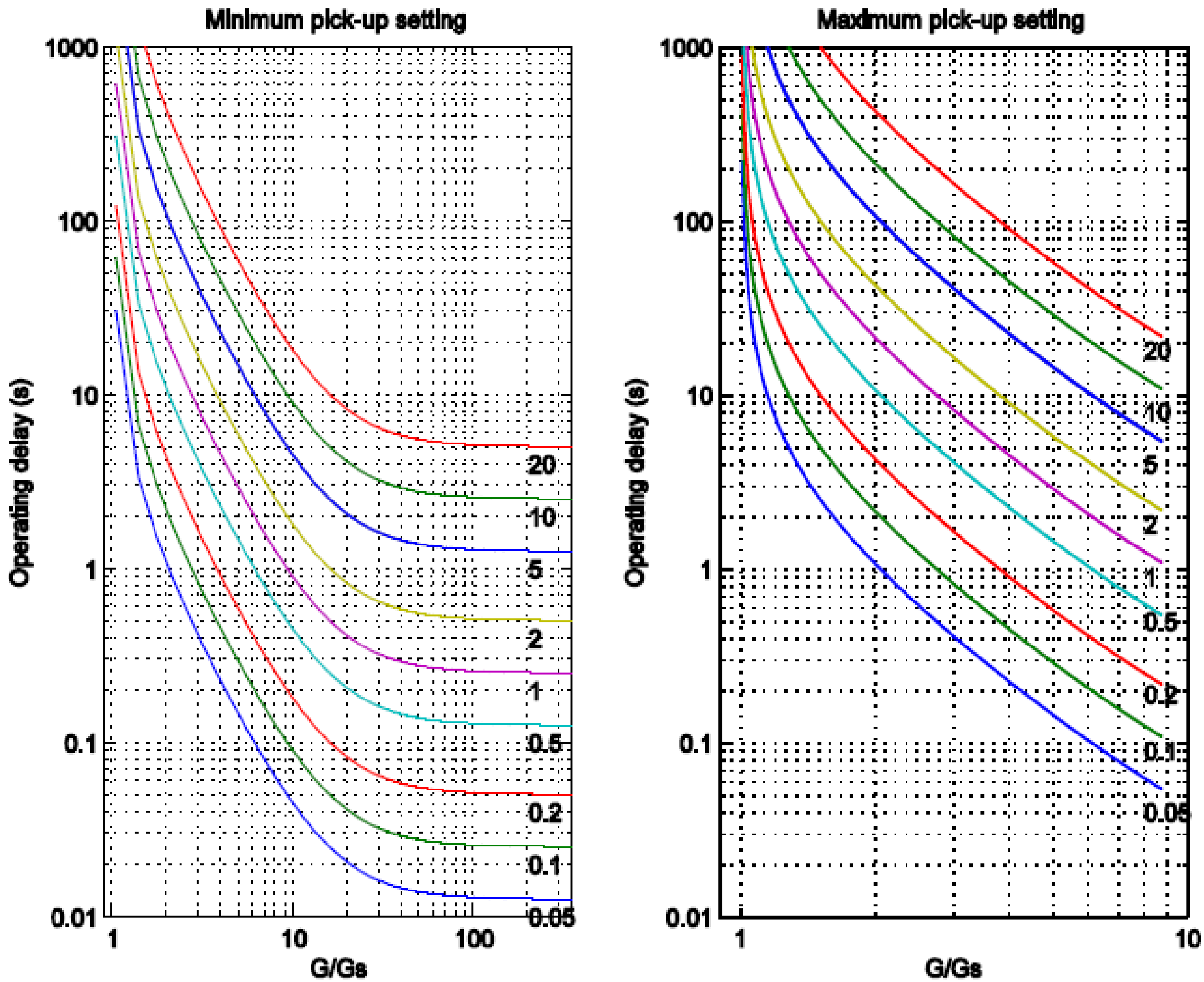


Figure 3-27: ANSI/IEEE Long Time Extremely Inverse operating curves with minimum and maximum pick up settings and TMS settings from 0.05 to 20.

Resetting characteristics for the function depends on the selected operating time characteristics. For the IEC type IDMT characteristics the reset time is user settable and for the ANSI/IEEE type characteristics the resetting time follows equation below.

Equation 3-2: Resetting characteristics for ANSI/IEEE IDMT

$$t_r(G) = TMS\left[\frac{k_r}{1-\left(\frac{G}{G_S}\right)^{\alpha}}\right] \text{ when } G < G_S$$

tr(G)(seconds) Theoretical reset time with constant value of G

kr constants characterizing the selected curve

α constants characterizing the selected curve

G measured value of the Fourier base harmonic of the phase currents

GS pick-up setting

TMS Time dial setting / preset time multiplier

The parameters and operating curve types follow corresponding standards presented in the table below.

Table 3-21: Parameters and operating curve types for the IDMT characteristics reset times.

<table>
<tr><th>Curve family</th><th>Characteristics</th><th>k_r</th><th>α</th></tr>
<tr><td>IEC</td><td>NI (normally inverse)</td><td colspan="2" rowspan="4">User settable fixed reset time</td></tr>
<tr><td>IEC</td><td>VI (very inverse)</td></tr>
<tr><td>IEC</td><td>EI (extremely inverse)</td></tr>
<tr><td>IEC</td><td>LTI (long time inverse)</td></tr>
<tr><td>IEEE/ANSI</td><td>NI (normally inverse)</td><td>0,46</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>MI (moderately inverse)</td><td>4,85</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>VI (very inverse)</td><td>21,6</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>EI (extremely inverse)</td><td>29,6</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>LTI (long time inverse)</td><td>4,6</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>LTVI (long time very inverse)</td><td>13,46</td><td>2</td></tr>
<tr><td>IEEE/ANSI</td><td>LTEI (long time extremely inverse)</td><td>30</td><td>2</td></tr>
</table>

Table 3-22: Setting parameters of the time overcurrent function

Parameter	Setting value, range and step	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards. Default setting is “DefinitTime”
Start current	5…400 %, by step of 1%. Default 200 %.	Pick-up current setting of the function. Setting range is from 5% of nominal current to 400% with step of 1 %. Default setting is 200 % of nominal current.
Min Delay	0…60000 ms, by step of 1 ms. Default 100 ms.	Minimum operating delay setting for the IDMT characteristics. Additional delay setting is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms.
Definite delay time	0…60000 ms by step of 1 ms. Default 100 ms.	Definite time operating delay setting. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset delay	0…60000 ms by step of 1 ms. Default 100 ms.	Settable reset delay for definite time function and IEC IDMT operating characteristics. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is in use with definite time and IEC IDMT chartacteristics-
Time Mult	0.05…999.00 by step of 0.01. Default 1.00.	Time multiplier / time dial setting of the IDMT operating characteristics. Setting range is from 0.05 to 999.00 with step of 0.01. This parameter is not in use with definite time characteristics.

3.2.6 Residual time overcurrent I0>, I0>> (51N)

The residual definite time overcurrent protection function operates with definite time characteristics, using the RMS values of the fundamental Fourier component of the neutral or residual current (IN=3Io). In the figure below is presented the operating characteristics of the function.

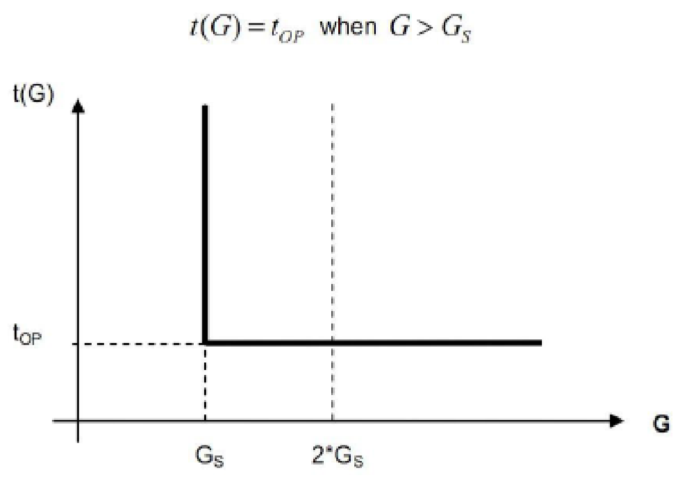


Figure 3-28: Operating characteristics of the residual time overcurrent protection function.

tOP (seconds)	Theoretical operating time if G> GS (without additional time delay),
G	Measured value of the Fourier base harmonic of the residual current
GS	Pick-up setting

The structure of the algorithm consists of following modules. Fourier calculation module calculates the RMS values of the Fourier components of the residual current. Characteristics module compares the Fourier basic harmonic components of the residual current into the setting value. Decision logic module generates the trip signal of the function.

In the figure below is presented the structure of the residual time overcurrent algorithm.

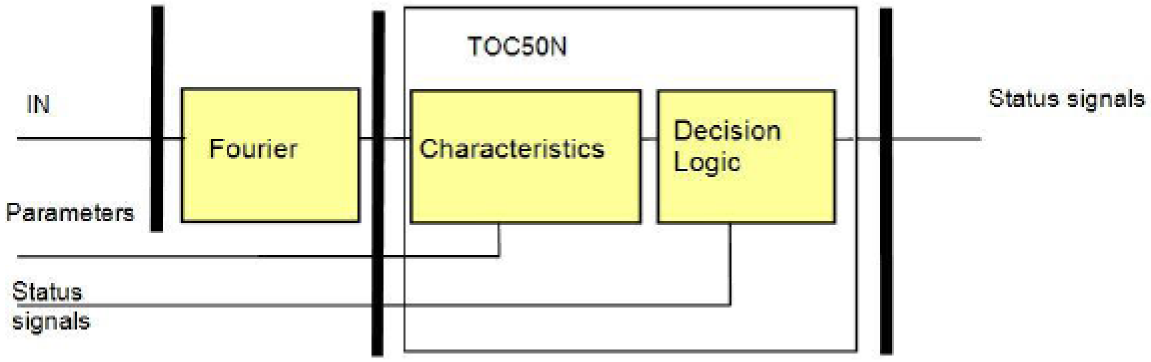


Figure 3-29: Structure of the residual time overcurrent algorithm.

The algorithm generates a start signal based on the Fourier components of the residual current in case if the user set pick-up value is exceeded. Trip signal is generated after the set definite time delay.

The function includes a blocking signal input which can be configured by user from either IED internal binary signals or IED binary inputs through the programmable logic.

Table 3-23: Setting parameters of the residual time overcurrent function

Parameter	Setting value, range and step	Description
Operation	Off DefinitTime IEC Inv IEC VeryInv IEC ExtInv IEC LongInv ANSI Inv ANSI ModInv ANSI VeryInv ANSI ExtInv ANSI LongInv ANSI LongVeryInv ANSI LongExtInv	Operating mode selection of the function. Can be disabled, Definite time or IDMT operation based into IEC or ANSI/IEEE standards. Default setting is “DefinitTime”
Start current	1…200 %, by step of 1%. Default 50 %.	Pick-up current setting of the function. Setting range is from 1% of nominal current to 200% with step of 1 %. Default setting is 50 % of nominal current.
Min Delay	0…60000 ms, by step of 1 ms. Default 100 ms.	Minimum operating delay setting for the IDMT characteristics. Additional delay setting is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms.
Definite delay time	0…60000 ms by step of 1 ms. Default 100 ms.	Definite time operating delay setting. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is not in use when IDMT characteristics is selected for the operation.
Reset time	0…60000 ms by step of 1 ms. Default 100 ms.	Settable reset delay for definite time function and IEC IDMT operating characteristics. Setting range is from 0 ms to 60000 ms with step of 1 ms. Default setting is 100 ms. This parameter is in use with definite time and IEC IDMT chartacteristics-
Time Mult	0.05…999.00 by step of 0.01. Default 1.00.	Time multiplier / time dial setting of the IDMT operating characteristics. Setting range is from 0.05 to 999.00 with step of 0.01. This parameter is not in use with definite time characteristics.

3.2.7 CURRENT UNBALANCE (60)

The current unbalance protection function can be applied to detect unexpected asymmetry in current measurement.

The applied method selects maximum and minimum phase currents (fundamental Fourier components). If the difference between them is above the setting limit, the function generates a start signal.

Structure of the current unbalance protection function is presented in the figure below

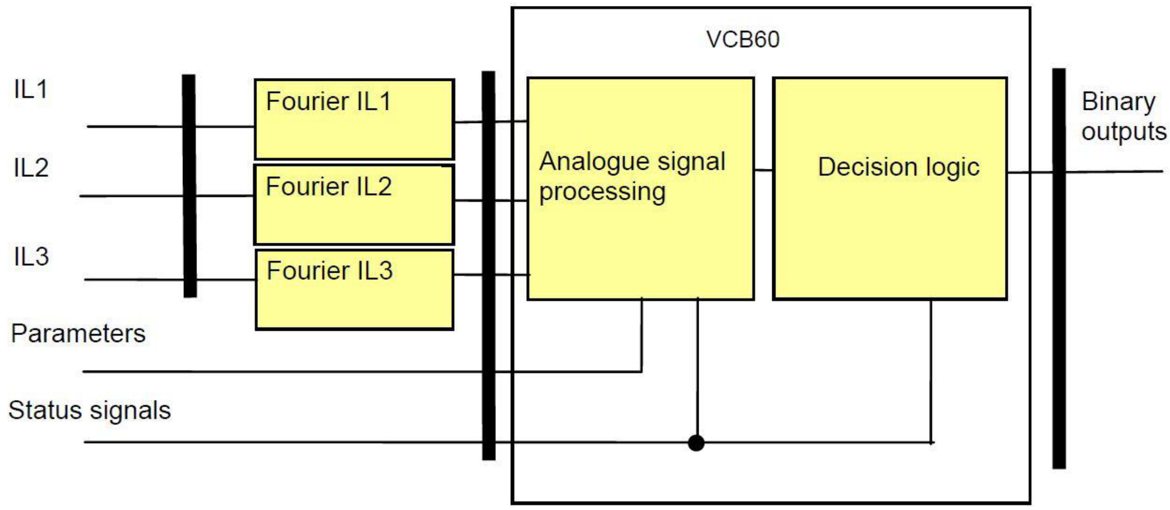


Figure 3-30: Structure of the current unbalance protection algorithm.

The analogue signal processing principal scheme is presented in the figure below.

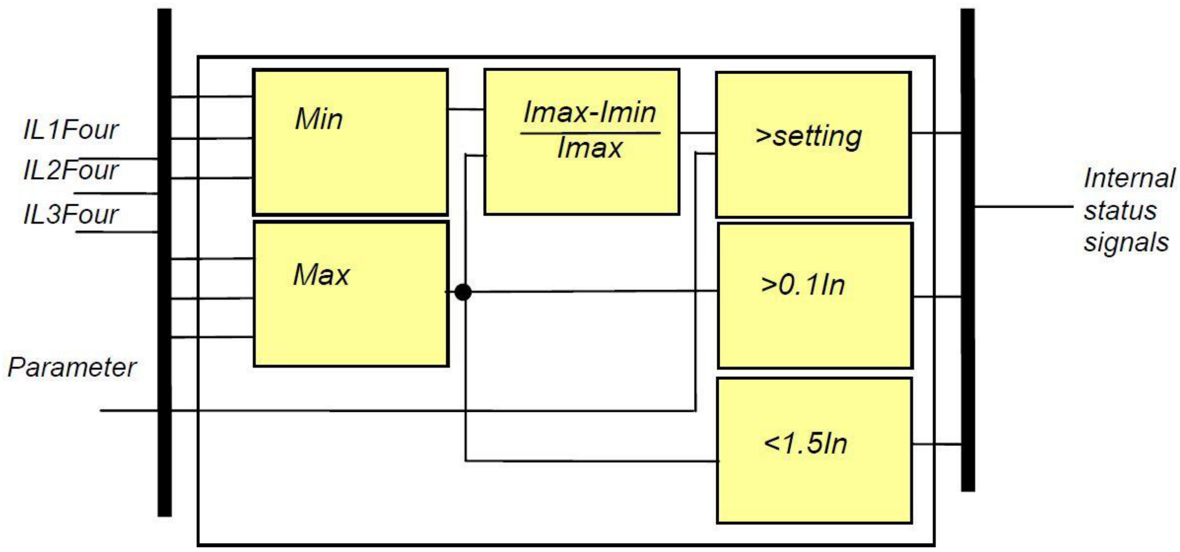


Figure 3-31: Analogue signal processing for the current unbalance function.

The signal processing compares the difference between measured current magnitudes. If the measured relative difference between the minimum and maximum current is higher than the setting value the function generates a trip command. For stage to be operational the measured current level has to be in range of 10 % to 150 % of the nominal current. This precondition prevents the stage from operating in case of very low load and during other faults like short circuit or earth faults.

The function can be disabled by parameter setting, and by an input signal programmed by the user.

The trip command is generated after the set defined time delay.

Table 3-24: Setting parameters of the current unbalance function

Parameter	Setting value, range and step	Description
Operation	On Off	Selection for the function enabled or disabled. Default setting is “On” which means function is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start current	10…90 % by step of 1 %	Pick up setting of the current unbalance. Setting is the maximum allowed difference in between of the min and max phase currents. Default setting is 50 %.
Time delay	0…60000 ms by step of 100 ms	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 1000 ms.

3.2.8 THERMAL OVERLOAD T>, (49L)

The line thermal protection measures basically the three sampled phase currents. TRMS values of each phase currents are calculated including harmonic components up to 10^{th} harmonic, and the temperature calculation is based on the highest TRMS value of the compared three phase currents.

The basis of the temperature calculation is the step-by-step solution of the thermal differential equation. This method provides “overtemperature”, i.e. the temperature above the ambient temperature. Accordingly the final temperature of the protected object is the sum of the calculated “overtemperature” and the ambient temperature.

The ambient temperature can be set manually. If the calculated temperature (calculated “overtemperature”+ambient temperature) is above the threshold values, status signals are generated: Alarm temperature, Trip temperature and Unlock/restart inhibit temperature.

Figure 3-9. The principal structure of the thermal overload function.

In the Figure 3-9 is presented the principal structure of the thermal overload function. The inputs of the function are the maximum of TRMS values of the phase currents, ambient temperature setting, binary input status signals and setting parameters. Function outputs binary signals for Alarm, Trip pulse and Trip with restart inhibit.

The thermal replica of the function follows Equation 3-3.

Equation 3-3. Thermal replica equation of the thermal overload protection.

,where

H(t)	Is the thermal level of the heated object. This is the temperature as a percentage of θ_n reference temperature.
Θ_n	Is the reference temperature above the ambient temperature, which can be measured in steady state in case of a continuous I_n reference current.
I_n	Is the reference current (can be considered as the nominal current of the heated object). If the current flows continuously then the reference temperature can be measured in steady state.
I	Measured current.
Θ_o	Starting temperature
T	Heating time constant

In the table below are presented the setting parameters for the thermal overload function. Temperature degrees in the table are presented in Celsius temperature scale.

Table 3-25: Setting parameters of the thermal overload function

Parameter	Setting value, range and step	Description
Operation	Off Pulsed Locked	Operating mode selection. Pulsed operation means that the function gives tripping pulse when the calculated thermal load exceeds the set thermal load. Locked means that the trip signal releases when the calculated thermal load is cooled under the set Unlock temperature limit after the tripping. Default setting is “Pulsed”.
Alarm temperature	60…200 deg by step of 1 deg	Temperature setting for the alarming of the overloading. When the calculated temperature exceeds the set alarm limit function issues an alarm signal. Default setting is 80 deg.
Trip temperature	60…200 deg by step of 1 deg	Temperature setting for the tripping of the overloading. When the calculated temperature exceeds the set alarm limit function issues a trip signal. Default setting is 100 deg.
Rated temperature	60…200 deg by step of 1 deg	Rated temperature of the protected object. Default setting is 100 deg.
Base temperature	0…40 deg by step of 1 deg	Rated ambient temperature of the device related to allowed temperature rise. Default setting is 40 deg.
Unlock temperature	20…200 deg by step of 1 deg	Releasing of the function generated trip signal when the calculated thermal load is cooled under this setting. Restart inhibit release limit. Default setting is 60 deg.
Ambient temperature	0…40 deg by step of 1 deg	Setting of the ambient temperature of the protected device. Default setting is 25 deg.
Startup Term	0…60 % by step of 1 %	On device restart starting used thermal load setting. When the device is restarted the thermal protection function will start calculating the thermal replica from this starting value. Default setting is 0 %.
Rated LoadCurrent	20…150 % by step of 1%	The rated nominal load of the protected device. Default setting is 100 %
Time constant	1…999 min by step of 1 min	Heating time constant of the protected device. Default setting is 10 min.

3.2.9 Over voltage U>, U>> (59)

The overvoltage protection function measures three phase to ground voltages. If any of the measured voltages is above the pick-up setting, a start signal is generated for the phases individually.

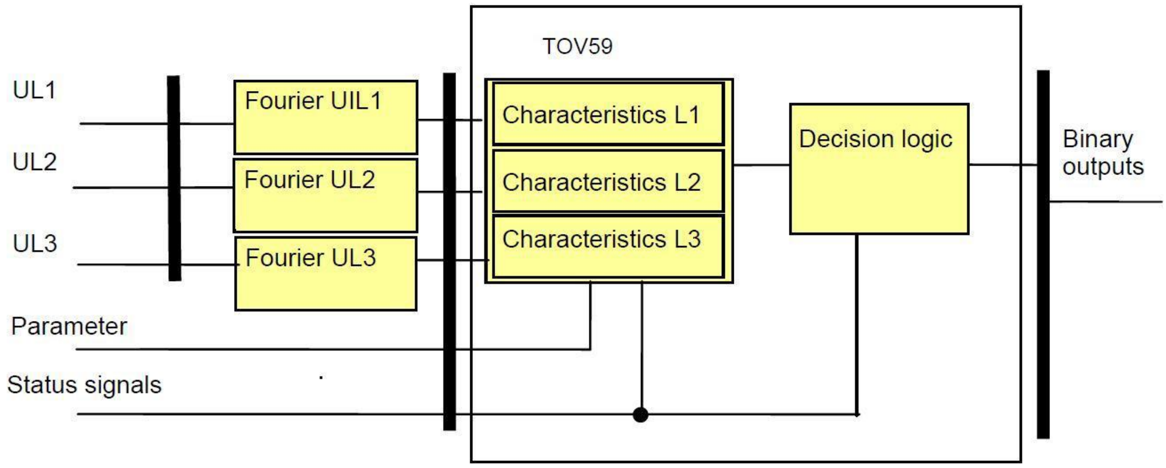


Figure 3-32: The principal structure of the overvoltage function.

The general start signal is set active if the voltage in any of the three measured voltages is above the level defined by pick-up setting value. The function generates a trip command after the definite time delay has elapsed.

Table 3-26: Setting parameters of the overvoltage function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either enabled “On” or disabled “Off”. Default setting is “On”.
Start voltage	30…130 % by step of 1%	Voltage pick-up setting. Default setting 63 %.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Overvoltage protection reset ratio, default setting is 5%
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 100 ms.

3.2.10 UNDER VOLTAGE U<, U<< (27)

The undervoltage protection function measures three voltages. If any of them is below the set pick-up value and above the defined minimum level, then a start signal is generated for the phases individually.

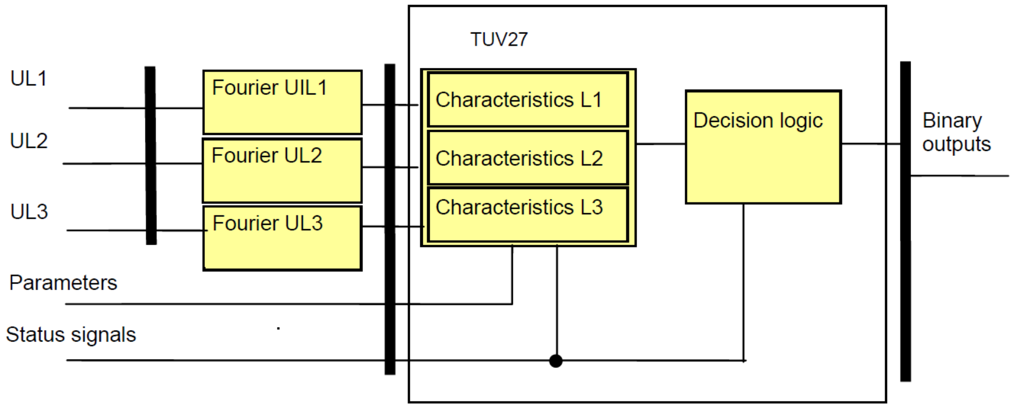


Figure 3-33: The principal structure of the undervoltage function.

The general start signal is set active if the voltage of any of the three measured voltages is below the level defined by pick-up setting value. The function generates a trip command after the definite time delay has elapsed.

Table 3-27: Setting parameters of the undervoltage function

Parameter	**Setting value, range and step**	**Description**
Operation	Off 1 out of 3 2 out of 3 All	Operating mode selection for the function. Operation can be either disabled "Off" or the operating mode can be selected to monitor single phase undervoltage, two phases undervoltage or all phases undervoltage condition. Default setting is "1 out of 3" which means that any phase under the setting limit will cause operation.
Start voltage	30…130 % by step of 1 %	Voltage pick-up setting. Default setting is 90 %.
Block voltage	0…20 % by step of 1 %	Undervoltage blocking setting. This setting prevents the function from starting in undervoltage condition which is caused for example from opened breaker. Default setting is 10 %.
Start signal only	Activated Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Undervoltage protection reset ratio, default setting is 5%
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the "Trip" signal from the "Start" signal. Default setting is 100 ms.

3.2.11 RESIDUAL OVER VOLTAGE U0>, U0>> (59N)

The residual definite time overvoltage protection function operates according to definite time characteristics, using the RMS values of the fundamental Fourier component of the zero sequence voltage (UN=3Uo).

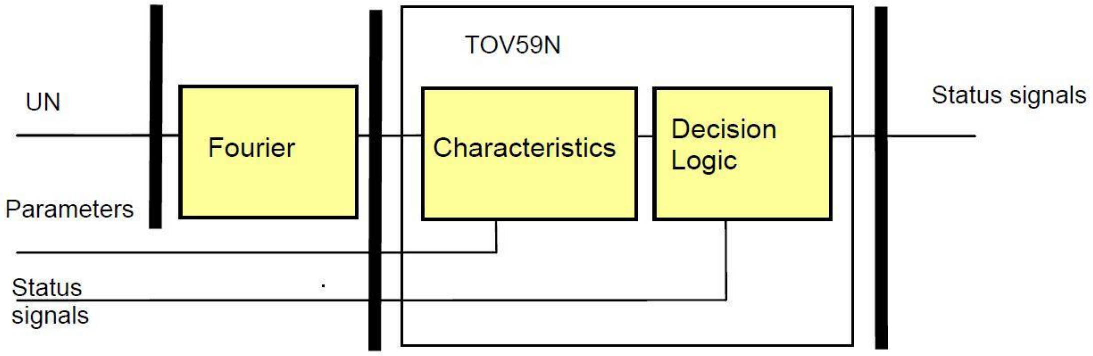


Figure 3-34: The principal structure of the residual overvoltage function.

The general start signal is set active if the measured residual voltage is above the level defined by pick-up setting value. The function generates a trip command after the set definite time delay has elapsed.

Table 3-28: Setting parameters of the residual overvoltage function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either enabled "On" or disabled "Off". Default setting is "On".
Start voltage	2…60 % by step of 1 %	Voltage pick-up setting. Default setting 30 %.
Start signal only	Activated Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal. Default is that both signals are generated (=deactivated).
Reset ratio	1…10% by step of 1%	Residual voltage protection reset ratio, default setting is 5%
Time delay	0…60000 ms by step of 1 ms.	Operating time delay setting for the "Trip" signal from the "Start" signal. Default setting is 100 ms.

3.2.12 OVER FREQUENCY F>, F>>, (81O)

The deviation of the frequency from the rated system frequency indicates unbalance between the generated power and the load demand. If the available generation is large compared to the consumption by the load connected to the power system, then the system frequency is above the rated value.

The over-frequency protection function is usually applied to decrease generation to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of high frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-check and synchro-switch functions.

The frequency measurement is based on channel No. 1 (line voltage) or channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above 30% of the rated voltage value. The over-frequency protection function generates a start signal if at least five measured frequency values are above the preset level.

Table 3-29 Setting parameters of the over frequency protection function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled "Off" or enabled "On". Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either "Start" signal alone or both "Start" and after set time delay "Trip" signal. Default is that both signals are generated (=deactivated).
Start frequency	40.00…60.00 Hz by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates "Start" signal. Default setting is 51 Hz
Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the "Trip" signal from the "Start" signal. Default setting is 200 ms.

3.2.13 UNDER FREQUENCY F<, F<<, (81U)

The deviation of the frequency from the rated system frequency indicates unbalance between the generated power and the load demand. If the available generation is small compared to the consumption by the load connected to the power system, then the system frequency is below the rated value.

The under-frequency protection function is usually applied to increase generation or for load shedding to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of low frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-check and synchro-switch functions.

The frequency measurement is based on channel No. 1 (line voltage) or channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above 30% of the rated voltage value. The under-frequency protection function generates a start signal if at least five measured frequency values are below the setting value.

Table 3-30: Setting parameters of the under-frequency function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start frequency	40.00…60.00 Hz by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 49 Hz
Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.14 Rate of change of frequency df/dt>, df/dt>> (81R)

The deviation of the frequency from the rated system frequency indicates unbalance between the generated power and the load demand. If the available generation is small compared to the consumption by the load connected to the power system, then the system frequency is below the rated value. If the unbalance is large, then the frequency changes rapidly. The rate of change of frequency protection function is usually applied to reset the balance between generation and consumption to control the system frequency. Another possible application is the detection of unintended island operation of distributed generation and some consumers. In the island, there is low probability that the power generated is the same as consumption; accordingly, the detection of a high rate of change of frequency can be an indication of island operation. Accurate frequency measurement is also the criterion for the synchro-switch function.

The source for the rate of change of frequency calculation is an accurate frequency measurement. The frequency measurement is based on channel No. 1 (line voltage) or channel No. 4 (busbar voltage) of the voltage input module. In some applications, the frequency is measured based on the weighted sum of the phase voltages. The accurate frequency measurement is performed by measuring the time period between two rising edges at zero crossing of a voltage signal.

For the confirmation of the measured frequency, at least four subsequent identical measurements are needed. Similarly, four invalid measurements are needed to reset the measured frequency to zero. The basic criterion is that the evaluated voltage should be above

30% of the rated voltage value. The rate of change of frequency protection function generates a start signal if the df/dt value is above the setting vale. The rate of change of frequency is calculated as the difference of the frequency at the present sampling and at three cycles earlier.

Table 3-31: Setting parameters of the df/dt function

Parameter	**Setting value, range and step**	**Description**
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start df/dt	-5…5 Hz/s by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 0.5 Hz
Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.15 Over excitation V/Hz (24)

The overexcitation protection function is applied to protect generators and unit transformers against high flux values causing saturation of the iron cores and consequently high magnetizing currents.

The problem to be solved is as follows: The flux is the integrated value of the voltage:

$$\Phi(t) = \Phi_0 + \int_0^t u(t)dt$$

In steady state, this integral can be high if the area under the sinusoidal voltage-time function is large. Mathematically this means that in steady state the flux, as the integral of the sinusoidal voltage function, can be expressed as

$$\Phi(t) = k\frac{U}{f}\cos\omega t$$

The peak value of the flux increases if the magnitude of the voltage increases, and/or the flux can be high if the duration of a period increases; this means that the frequency of the voltage decreases. That is, the flux is proportional to the peak value (or to the RMS value) of the voltage and inversely proportional to the frequency.

Note: the overexcitation protection function is intended to be applied near the generator, where the voltage is expected to be pure sinusoidal, without any distortion. Therefore, a continuous integration of the voltage and a simple peak detection algorithm can be applied.

The effect of high flux values is the symmetrical saturation of the iron core of the generator or that of the unit transformer. During saturation, the magnetizing current is high and distorted; high current peaks can be detected. The odd harmonic components of the current are of high magnitude and the RMS value of the current also increases. The high peak values of the currents generate high dynamic forces, the high RMS value causes overheating. During saturation, the flux leaves the iron core and high eddy currents are generated in the metallic part of the generator or transformer in which normally no current flows, and which is not designed to withstand overheating.

The frequency can deviate from the rated network frequency during start-up of the generator or at an unwanted disconnection of the load. In this case the generator is not connected to the network and the frequency is not kept at a “constant” value. If the generator is excited in this state and the frequency is below the rated value, then the flux may increase above the tolerated value. Similar problems may occur in distributed generating stations in case of island operation.

The overexcitation protection is designed to prevent this long-term overexcited state.
The flux is calculated continuously as the integral of the voltage. In case of the supposed sinusoidal voltage, the shape of the integrated flux will be sinusoidal too, the frequency of which is identical with that of the voltage. The magnitude of the flux can be found by searching for the maximum and the minimum values of the sinusoid.

The magnitude can be calculated if at least one positive and one negative peak value have been found, and the function starts if the calculated flux magnitude is above the setting value. Accordingly, the starting delay of the function depends on the frequency: if the frequency is low, more time is needed to reach the opposite peak value. In case of energizing, the time to find the first peak depends on the starting phase angle of the sinusoidal flux. If the voltage is increased continuously by increasing the excitation of the generator, this time delay cannot be measured.

3.2.15.1 Operating characteristics

The most harmful effect of the overexcited state is unwanted overheating. As the heating effect of the distorted current is not directly proportional to the flux value, the applied

characteristic is of inverse type (so called IEEE type): If the overexcitation increases, the operating time decreases. To meet the requirements of application, a definite-time characteristic is also offered in this protection function as an alternative.
The supervised quantity is the calculated U/f value as a percentage of the nominal values (index N):

$$G = \frac{\frac{U}{f}}{\frac{U_N}{f_N}} 100[\%] = \frac{\frac{U}{U_N}}{\frac{f}{f_N}} 100[\%]$$

The over-dimensioning of generators in this respect is usually about 5%, that of the transformer about 10%, but for unit transformers this factor can be even higher.
At start-up of the function, the protection generates a warning signal aimed to inform the controller to decrease the excitation. If the time delay determined by the parameter values of the selected characteristics expires, the function generates a trip command to decrease or to switch off the excitation and the generator.

Definite time characteristics

Operate time

$$t(G) = t_{OP} \quad \text{when} \quad G > G_S$$

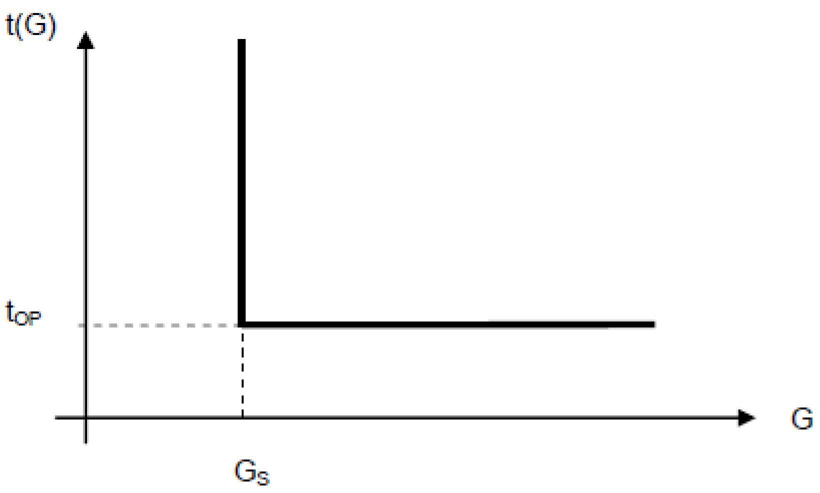


Figure 3-35 Overexcitation independent time characteristic

t_{OP} (seconds) theoretical operating time if G> G_S, fix, according to the parameter setting (VPH24_MinDel_TPar_, Min. Time Delay).

G measured value of the characteristic quantity; this is the $\frac{U}{f}$ peak value as a percentage of the rated $\frac{U_N}{f_N}$ value.

G_S setting value of the characteristic quantity (VPH24_EmaxCont_IPar, Start U/f LowSet). This is the $\frac{U_{set}}{f_{set}}$ peak value as a percentage of the rated $\frac{U_N}{f_N}$ value.

Reset time

$$t(G) = t_{Drop-off} \quad \text{when } G < 0.95 * G_S$$

where

$t_{Drop-off}$ (seconds) drop-off time if G< 0.95*G_S, fix value.

IEEE standard dependent time characteristics

Operating time

- "IEEE square law"

$$t = \frac{0.18 * TMS}{\left(\frac{U/f}{U_N/f_N} - \frac{U_{set}/f_{set}}{U_N/f_N}\right)^2} = \frac{0.18 * TMS}{(G - G_S)^2}$$

where

TMS = 1… 60, time multiplier setting,

U/f flux value calculated at the measured voltage and frequency,

U_N/f_N flux at rated voltage and rated frequency,

U_{set}/f_{set} flux setting value.

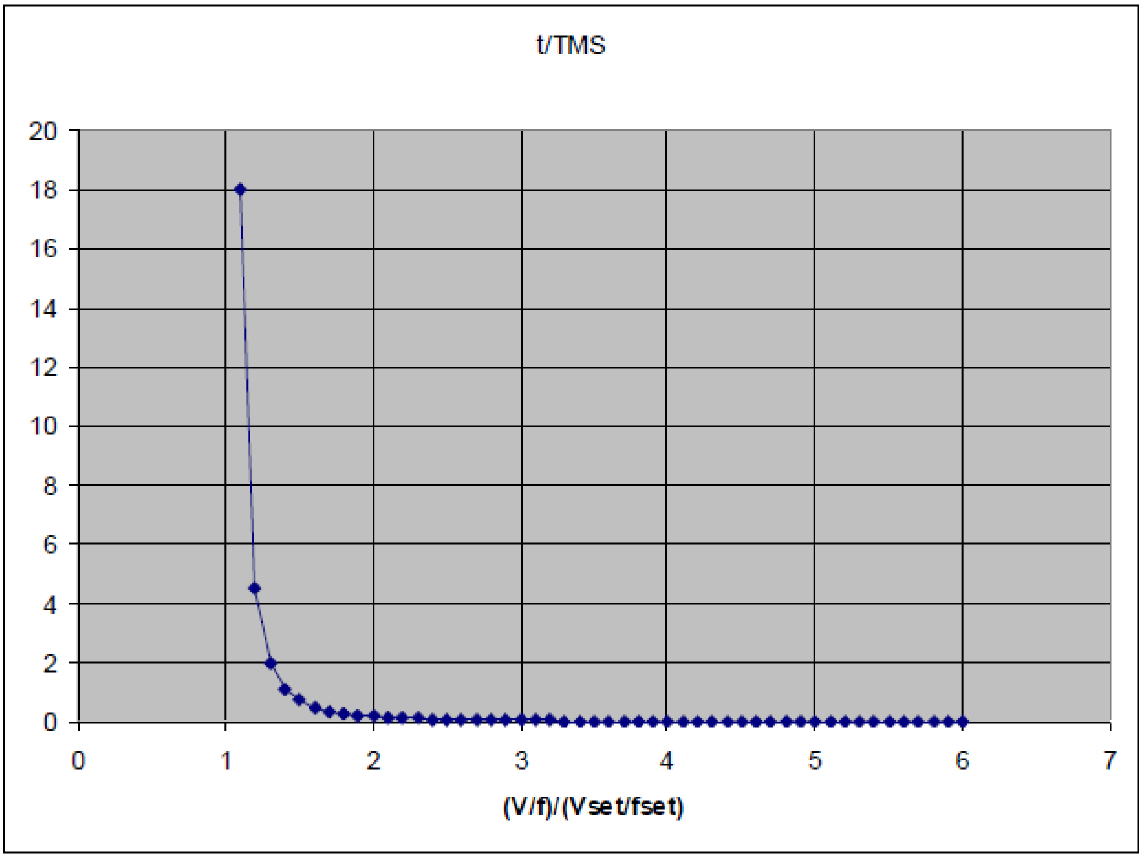


Figure 3-36: IEEE standard dependent time characteristics

The maximum delay time is limited by the parameter VPH24_MaxDel_TPar_ (Max.Time Delay). This time delay is valid if the flux is above the preset value VPH24_EmaxCont_IPar_ (Start U/f LowSet).

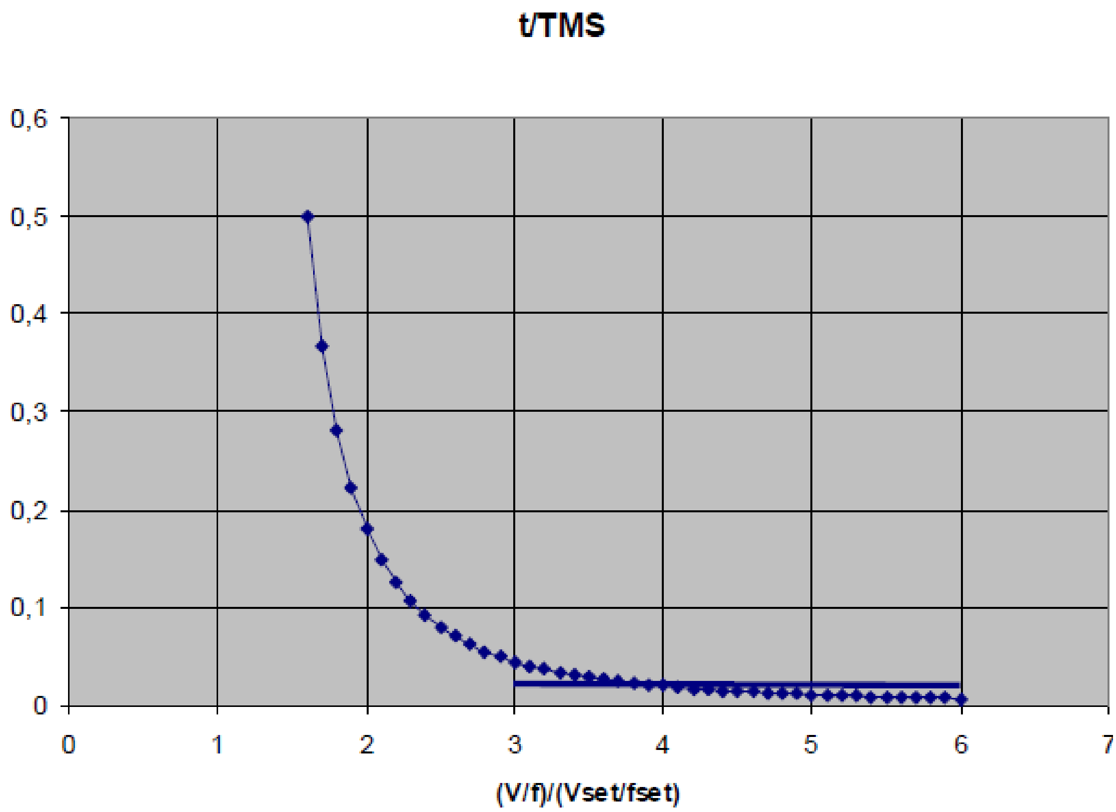


Figure 3-37: IEEE standard dependent time characteristics (enlarged)

This inverse type characteristic is also combined with a minimum time delay, the value of which is set by user parameter VPH24_MinDel_TPar_ (Min. Time Delay). This time delay is valid if the flux is above the setting value VPH24_Emax_IPar_ (Start U/f HighSet).

Reset time

If the calculated flux is below the drop-off flux value (when $sG < 0.95*G$), then the calculated flux value decreases linearly to zero. The time to reach zero is defined by the parameter VPH24_CoolDel_TPar_ (Cooling Time).

3.2.15.2 Analogue input of the function

Overexcitation is a typically symmetrical phenomenon. There are other dedicated protection functions against asymmetry. Accordingly, the processing of a single voltage is sufficient. In a network with isolated neutral, the phase voltage is not exactly defined due to the uncertain zero sequence voltage component. Therefore, line-to-line voltages are calculated based on the measured phase voltages, and one of them is assigned to overfluxing protection.

As overexcitation is a phenomenon which is typical if the generator or the generator transformer unit is not connected to the network, the voltage drop does not need any compensation. If the voltage is measured at the supply side of the unit transformer, then the voltage is higher then the voltage of the magnetization branch of the transformer's equivalent circuit. Thus the calculated flux cannot be less then the real flux value. The protection operates with increased security.

3.2.15.3 Structure of the overexcitation protection function

Figure below shows the structure of the overexcitation protection (VPH24) algorithm.

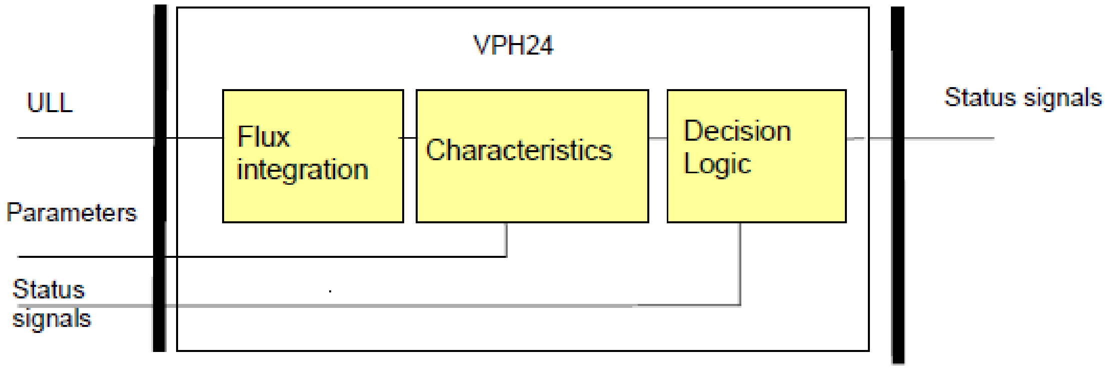


Figure 3-38: Structure of overexcitation protection function.

The inputs are

- The sampled values of a line-to-line voltage (ULL),
- Parameters,
- Status signals.

The outputs are

- The binary output status signals.

The software modules of the overexcitation protection function:

Flux saturation

This module integrates the voltage to obtain the flux time-function and determines the magnitude of the flux.

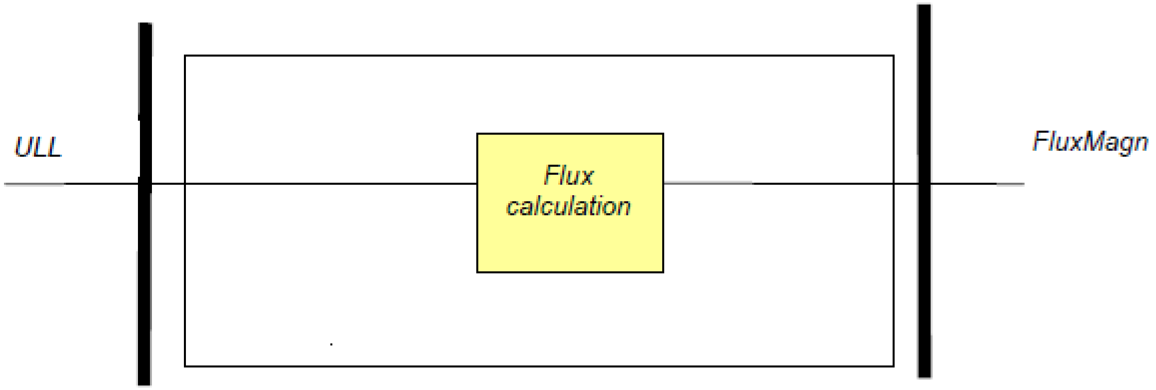


Figure 3-39: Principal scheme of the flux calculation

The inputs are the sampled values of a line-to-line voltage (ULL).
The output is the magnitude of the flux (FluxMagn), internal signal.

Characteristics

This module calculates the required time delay based on the magnitude of the flux and the parameter settings.

Decision logic

The decision logic module combines the status signals to generate the trip command of the function.

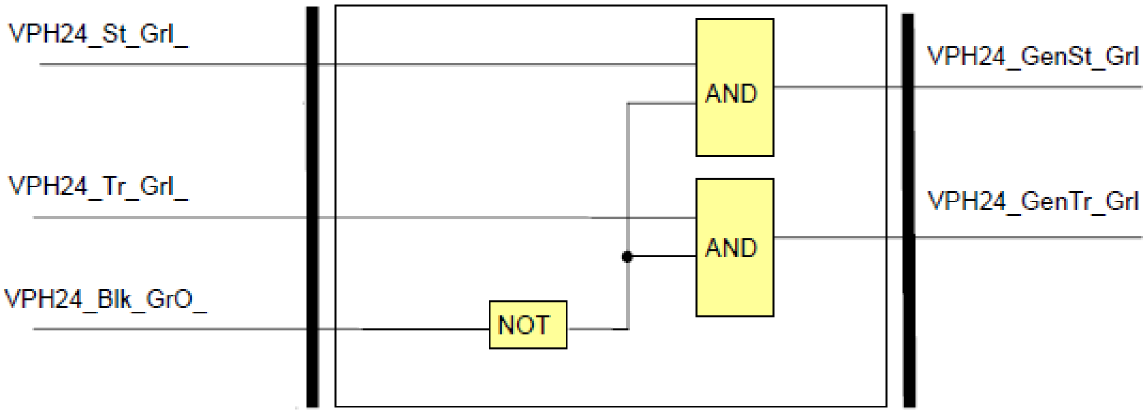


Figure 3-40: Logic scheme of volts per herz function.

Binary status signals

Binary output signals	Signal title	Explanation
VPH24_GenSt_Grl_	General Start	General starting of the function
VPH24_GenTr_Grl_	General Trip	General trip command of the function

Binary status signal	Explanation
VPH24_Blk_GrO_	Output status defined by the user to disable the overexcitation protection function.
VPH24_St_Grl_	Starting of the function
VPH24_Tr_Grl_	Trip command of the function

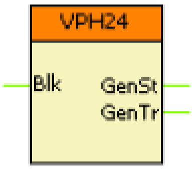


Figure 3-41: The function block of the overexcitation protection function

Table 3-32: Setting parameters of the df/dt function

Parameter	Setting value, range and step	Description
Operation	Off On	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Start signal only	Activated Deactivated	Selection if the function issues either “Start” signal alone or both “Start” and after set time delay “Trip” signal. Default is that both signals are generated (=deactivated).
Start df/dt	-5…5 Hz/s by step of 0.01 Hz	Pick up setting of the function. When the measured frequency value exceeds the setting value function initiates “Start” signal. Default setting is 0.5 Hz
Time delay	100…60000 ms by step of 1 ms.	Operating time delay setting for the “Trip” signal from the “Start” signal. Default setting is 200 ms.

3.2.16 Breaker failure protection function CBFP, (50BF)

After a protection function generates a trip command, it is expected that the circuit breaker opens and/or the fault current drops below the pre-defined normal level. If not, then an additional trip command must be generated for all backup circuit breakers to clear the fault. At the same time, if required, a repeated trip command can be generated to the circuit breaker(s) which are expected to open. The breaker failure protection function can be applied to perform this task.

The starting signal of the breaker failure protection function is usually the trip command of any other protection function defined by the user. Dedicated timers start at the rising edge of the start signals, one for the backup trip command and one for the repeated trip command, separately for operation in the individual phases.

During the running time of the timers the function optionally monitors the currents, the closed state of the circuit breakers or both, according to the user's choice. When operation is based on current the set binary inputs indicating the status of the circuit breaker poles have no effect. If the operation is based on circuit breaker status the current limit values "Start current Ph" and "Start current N" have no effect on operation.

The breaker failure protection function resets only if all conditions for faultless state are fulfilled. If at the end of the running time of the backup timer the currents do not drop below the pre-defined level, and/or the monitored circuit breaker is still in closed position, then a backup trip command is generated in the phase(s) where the timer(s) run off.

The time delay is defined using the parameter "Backup Time Delay". If repeated trip command is to be generated for the circuit breakers that are expected to open, then the enumerated parameter "Retrip" must be set to "On". In this case, at the end of the timer(s) the delay of which is set by the timer parameter "Retrip Time Delay", a repeated trip command is also generated. The pulse duration of the trip command is shall the time defined by setting the parameter "Pulse length". The breaker failure protection function can be enabled or disabled by setting the parameter "Operation" to "Off".

Dynamic blocking is possible using the binary input "Block". The conditions can be programmed by the user.

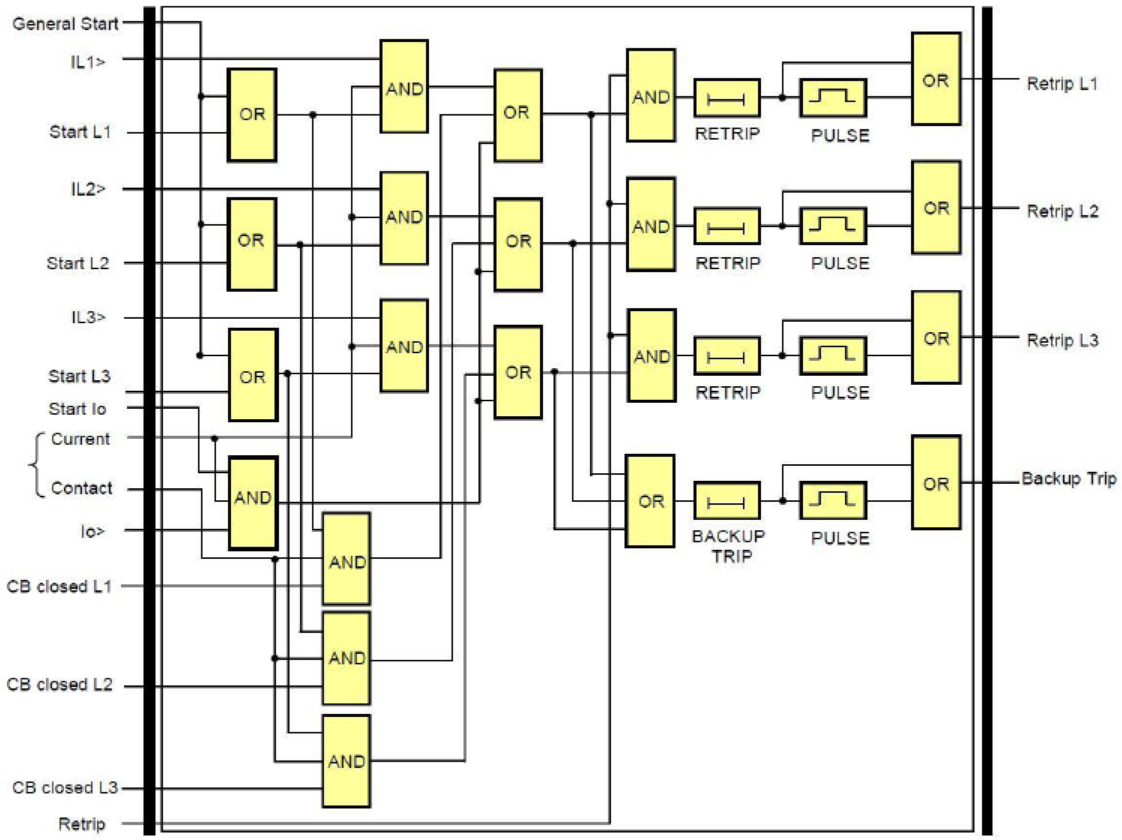


Figure 3-42: Operation logic of the CBFP function

Table 3-33: Setting parameters of the CBFP function

Parameter	Setting value, range and step	Description
Operation	Off Current Contact Current/Contact	Operating mode selection for the function. Operation can be either disabled “Off” or monitoring either measured current or contact status or both current and contact status. Default setting is “Current”.
Start current Ph	20…200 % by step of 1 %	Pick-up current for the phase current monitoring. Default setting is 30 %.
Start current N	10…200 % by step of 1 %	Pick-up current for the residual current monitoring. Default setting is 30 %
Backup Time Delay	60…1000 ms by step of 1 ms	Time delay for CBFP tripping command for the back-up breakers from the pick-up of the CBFP function monitoring. Default setting is 200 ms.
Pulse length	0…60000 ms by step of 1 ms	CBFP pulse length setting. Default setting is 100 ms.

3.2.17 INRUSH CURRENT DETECTION (INR2), (68)

The current can be high during transformer energizing due to the current distortion caused by the transformer iron core asymmetrical saturation. In this case, the second harmonic content of the current is applied to disable the operation of the desired protection function(s).
The inrush current detection function block analyses the second harmonic content of the current, related to the fundamental harmonic. If the content is high, then the assigned status signal is set to “true” value. If the duration of the active status is at least 25 ms, then the resetting of the status signal is delayed by an additional 15 ms. Inrush current detection is applied to residual current measurement also with dedicated separate function.

Table 3-34: Setting parameters of the inrush function

Parameter	Setting value, range and step	Description
Operation	Off Current Contact Current/Contact	Operating mode selection for the function. Operation can be either disabled “Off” or monitoring either measured current or contact status or both current and contact status. Default setting is “Current”.
Start current Ph	20…200 % by step of 1 %	Pick-up current for the phase current monitoring. Default setting is 30 %.
Start current N	10…200 % by step of 1 %	Pick-up current for the residual current monitoring. Default setting is 30 %
Backup Time Delay	60…1000 ms by step of 1 ms	Time delay for CBFP tripping command for the back-up breakers from the pick-up of the CBFP function monitoring. Default setting is 200 ms.
Pulse length	0…60000 ms by step of 1 ms	CBFP pulse length setting. Default setting is 100 ms.

3.3 CONTROL AND MONITORING FUNCTIONS

3.3.1 COMMON-FUNCTION

The AQ300 series devices – independently of the configured protection functions – have some common functionality. The Common function block enables certain kind of extension this common functionality:

1. **The WARNING signal of the device**

   The AQ300 series devices have several LED-s on the front panel. The upper left LED indicates the state of the device:

   - Green means normal operation
   - Yellow means WARNING state

    - The device is booting while the protection functions are operable
    - No time synchron signal is received
    - There are some setting errors such as the rated frequency setting does not correspond to the measured frequency, mismatch in vector group setting in case of transformer with three voltage levels, etc.
    - Wrong phase-voltage v.s. line-to-line voltage assignment
    - No frequency source is assigned for frequency related functions
    - The device is switched off from normal mode to Blocked or Test or Off mode, • the device is in simulation mode
    - There is some mismatch in setting the rated values of the analog inputs.
- Red means ERROR state. (This state is indicated also by the dedicated binary output of the power supply module.)

The list of the sources of the WARNING state can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

2. **The latched LED signals**

   The latched LED signals can be reset:

   - By the dedicated push button below the LED-s on the front panel of the device
   - Using the computer connection and generating a LED reset command
   - Via SCADA system, if it is configured
       - The list of the sources of the LED reset commands can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

The list of the sources of the LED reset commands can be extended using the Common function block. This additional signal is programmed by the user with the help of the graphic logic editor.

3. **The Local/Remote state for generating command to or via the device**

   The Local/Remote state of the device can be toggled:

   - From the local front-panel touch-screen of the device

The Local/Remote selection can be extended using the Common function block. There is possibility to apply up to 4 groups, the Local/Remote states of which can be set separately. These additional signals are programmed by the user with the help of the graphic logic editor

4. AckButton output of the common function block generates a signal whenever the “X” button in the front panel of the relay has been pressed.

5. FixFalse/True can be used to write continuous 0 or 1 into an input of a function block or a logic gate.

The Common function block has binary input signals. **The conditions are defined by the user applying the graphic logic editor.**

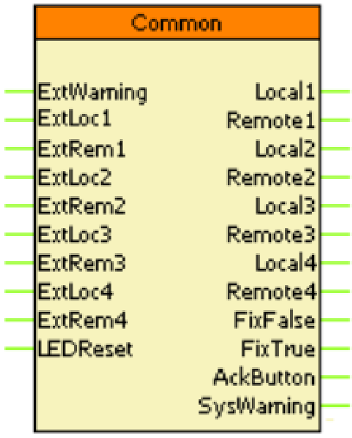


Figure 3-43: The function block of the Common function block

Table 3-35: The binary input status of the common function block

Binary status signal	Title	Explanation
Common_ExtWarning_GrO_	ExtWarning	Input to generate a Warning state of the device.
Common_ExtLoc1_GrO_	ExtLoc1	Input1 to set the state of group 1 to Local
Common_ExtRem1_GrO_	ExtRem1	Input1 to set the state of group 1 to Remote
Common_ExtLoc2_GrO_	ExtLoc2	Input2 to set the state of group 2 to Local
Common_ExtRem2_GrO_	ExtRem2	Input2 to set the state of group 2 to Remote
Common_ExtLoc3_GrO_	ExtLoc3	Input3 to set the state of group 3 to Local
Common_ExtRem3_GrO_	ExtRem3	Input3 to set the state of group 3 to Remote
Common_ExtLoc4_GrO_	ExtLoc4	Input4 to set the state of group 4 to Local
Common_ExtRem4_GrO_	ExtRem4	Input4 to set the state of group 1 to Remote
Common_LEDReset_GrO_	LED reset	Input to reset the LED-s on the front panel of the device

Table 3-36: The binary input status of the common function block

Binary status signal	Title	Explanation
Common_Local1_Grl_	Local 1	Output1 to indicate the state of group 1 as Local
Common_Remote1_Grl_	Remote 1	Output1 to indicate the state of group 1 as Remote
Common_Local2_Grl_	Local 2	Output2 to indicate the state of group 2 as Local
Common_Remote2_Grl_	Remote 2	Output2 to indicate the state of group 2 as Remote
Common_Local3_Grl_	Local 3	Output3 to indicate the state of group 3 as Local
Common_Remote3_Grl_	Remote 3	Output3 to indicate the state of group 3 as Remote
Common_Local4_Grl_	Local 4	Output4 to indicate the state of group 4 as Local
Common_Remote4_Grl_	Remote 4	Output4 to indicate the state of group 4 as Remote
Common_FixFalse_Grl_	False	Fix signal FALSE to be applied in the graphic logic editor, if needed
Common_FixTrue_Grl_	True	Fix signal TRUE to be applied in the graphic logic editor, if needed
Common_AckButton_Grl_	AckButton	This is the composed signal which resets the LED-s, for further processing
Common_SysWarning_Grl_	SystemWarning	This is the composed signal with the meaning "WARNING state", for further processing

The Common function block has a single Boolean parameter. The role of this parameter is to enable or disable the external setting of the Local/Remote state.

Table 3-37: Setting parameters of the Common function

Parameter	Setting value, range and step	Description
Ext LR Source	0	0 means no external local/remote setting is enabled, the local LCD touch-screen is the only source of toggling.

3.3.2 Trip logic (94)

The simple trip logic function operates according to the functionality required by the IEC 61850 standard for the "Trip logic logical node". This simplified software module can be applied if only three-phase trip commands are required, that is, phase selectivity is not applied. The function receives the trip requirements of the protective functions implemented in the device and combines the binary signals and parameters to the outputs of the device.

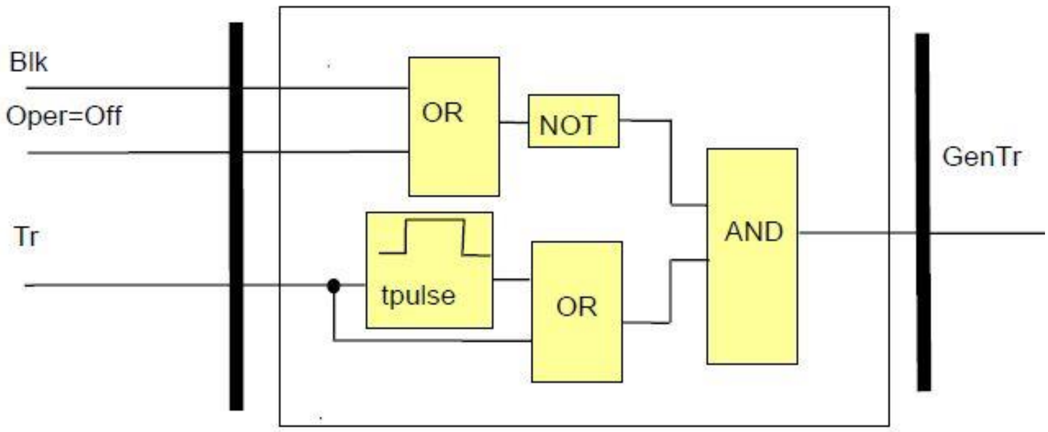


Figure 3-10 Operation logic of the trip logic function.

The trip requirements can be programmed by the user. The aim of the decision logic is to define a minimal impulse duration even if the protection functions detect a very short-time fault.

3.3.2.1 Application example

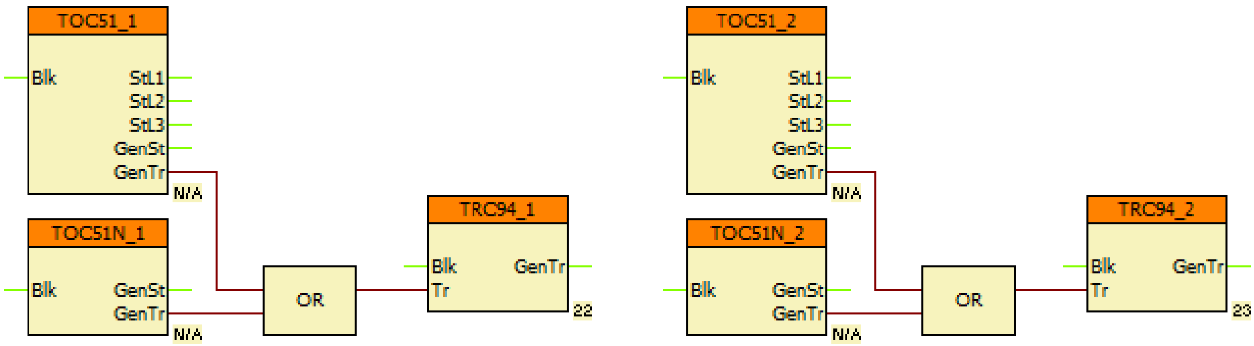


Figure 3-11 Example picture where two I> TOC51 and I0> TOC51N trip signals are connected to two trip logic function blocks.

In this example we have a transformer protection supervising phase and residual currents on both sides of the transformer. So in this case the protection function trips have been connected to their individual trip logic blocks (for high voltage side and low voltage side). After connecting the trip signals into trip logic block the activation of trip contacts have to be assigned. The trip assignment is done in Software configuration → Trip signals → Trip assignment.

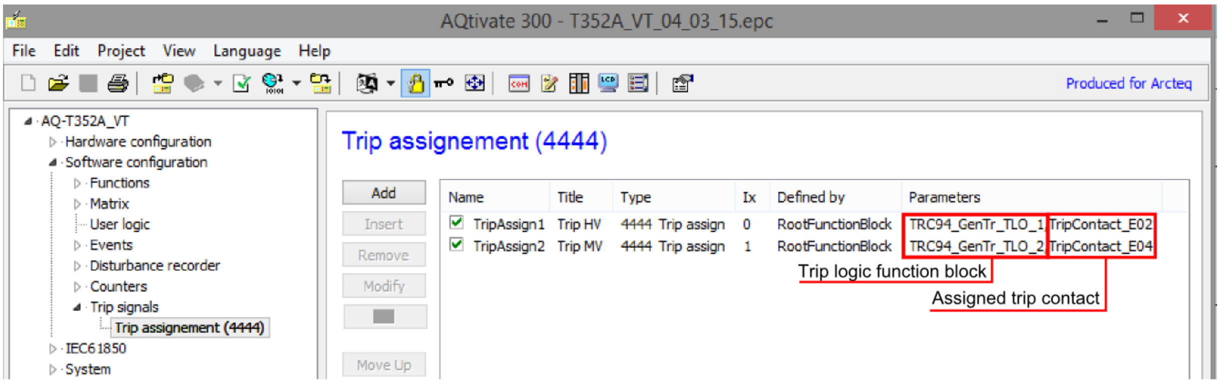


Figure 3-12 Trip logic block #1 has been assigned as HV side trip to activate trip contact E02. Trip logic block #2 has been assigned as MV side trip to activate trip contact E04.

The trip contact assignments can be modified or the same trip logic can activate multiple contacts by adding a new trip assignment.

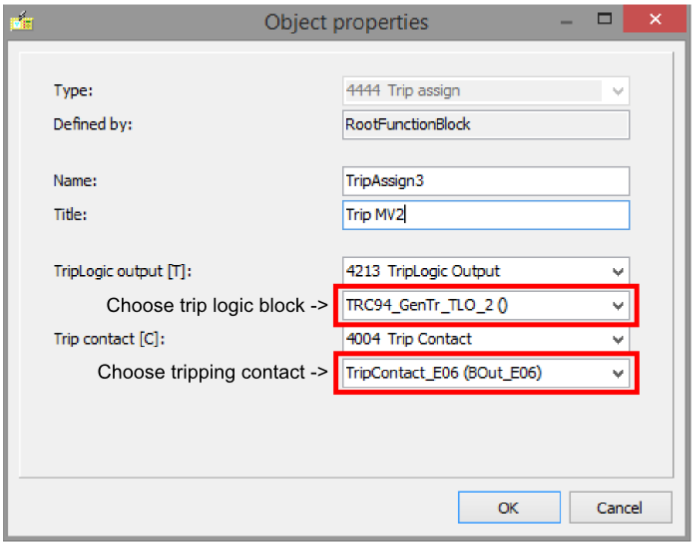


Figure 3-13 Instructions on adding/modifying trip assignment.

Trip contact connections for wirings can be found in Hardware configuration under Rack designer → Preview or in Connection allocations.

During the parameter setting phase it should be taken care that the trip logic blocks are activated. The parameters are described in the following table.

Table 3-38 Setting parameters of the trip logic function

Parameter	Setting value, range and step	Description
Operation	On Off	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “On”. Default setting is enabled.
Min pulse length	50…60000 ms by step of 1 ms	Minimum duration of the generated tripping impulse. Default setting is 150 ms.

3.3.3 VOLTAGE TRANSFORMER SUPERVISION VTS (60)

The voltage transformer supervision function generates a signal to indicate an error in the voltage transformer secondary circuit. This signal can serve, for example, a warning, indicating disturbances in the measurement, or it can disable the operation of the distance protection function if appropriate measured voltage signals are not available for a distance decision.

The voltage transformer supervision function is designed to detect faulty asymmetrical states of the voltage transformer circuit caused, for example, by a broken conductor in the secondary circuit. The voltage transformer supervision function can be used for either tripping or alarming purposes.

The voltage transformer supervision function can be used in three different modes of application:

Zero sequence detection (for typical applications in systems with grounded neutral): “VT failure” signal is generated if the residual voltage (3Uo) is above the preset voltage value AND the residual current (3Io) is below the preset current value

Negative sequence detection (for typical applications in systems with isolated or resonant grounded (Petersen) neutral): “VT failure” signal is generated if the negative sequence voltage component (U2) is above the preset voltage value AND the negative sequence current component (I2) is below the preset current value.

Special application: “VT failure” signal is generated if the residual voltage (3Uo) is above the preset voltage value AND the residual current (3Io) AND the negative sequence current component (I2) are below the preset current values.

The voltage transformer supervision function can be triggered if “Live line” status is detected for at least 200 ms. The purpose of this delay is to avoid mal-operation at line energizing if the poles of the circuit breaker make contact with a time delay. The function is set to be inactive if “Dead line” status is detected. If the conditions specified by the selected mode of operation are fulfilled then the voltage transformer supervision function is triggered and the operation signal is generated. When the conditions for operation are no longer fulfilled, the resetting of the function depends on the mode of operation of the primary circuit:

- If the “Live line” state is valid, then the function resets after approx. 200 ms of time delay.
- If the “Dead line” state is started and the “VTS Failure” signal has been continuous for at least 100 ms, then the “VTS failure” signal does not reset; it is generated continuously even when the line is in a disconnected state. Thus, the “VTS Failure” signal remains active at reclosing.
- If the “Dead line” state is started and the “VTS Failure” signal has not been continuous for at least 100 ms, then the “VTS failure” signal resets.

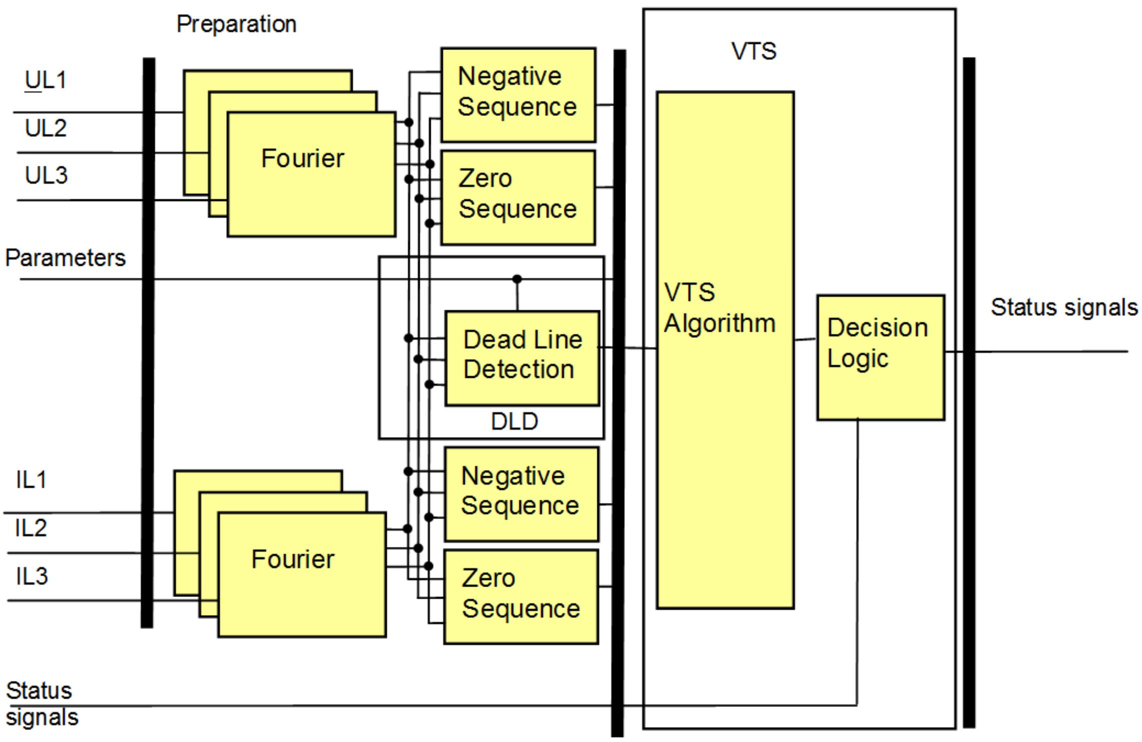


Figure 3-44: Operation logic of the voltage transformer supervision and dead line detection.

The voltage transformer supervision logic operates through decision logic presented in the following figure.

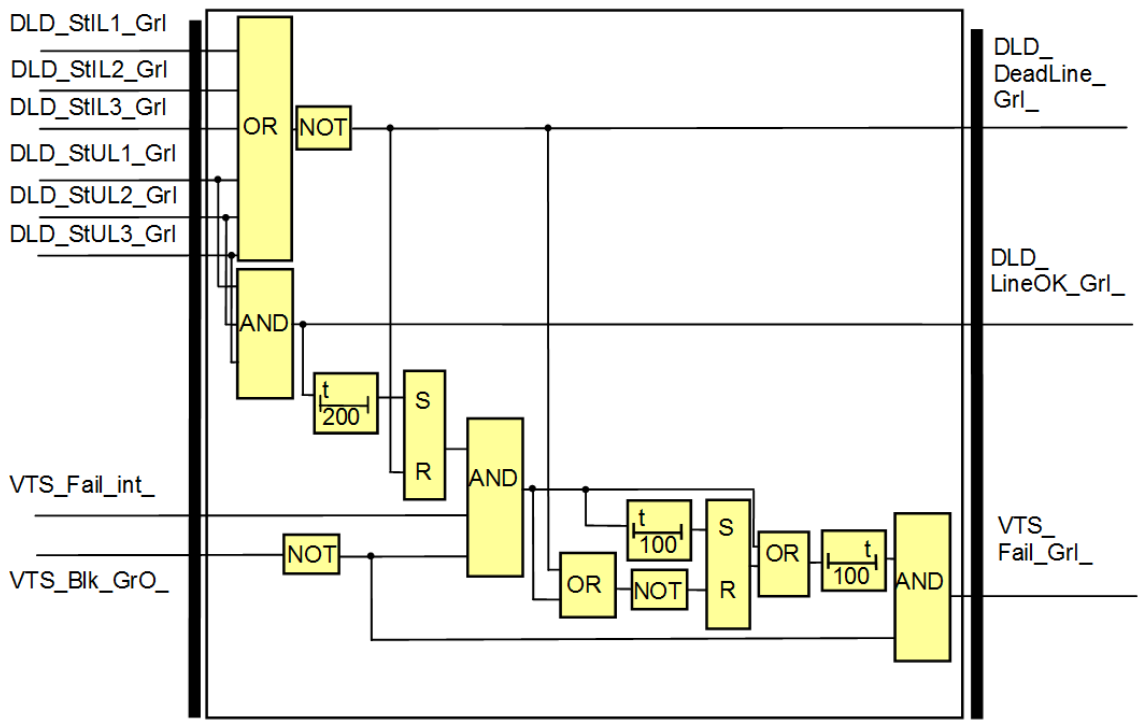


Figure 3-45: Decision logic of the voltage transformer supervision function.

NOTE: For the operation of the voltage transformer supervision function the “ Dead line detection function” must be operable as well: it must be enabled by binary parameter

The symbol of the function block in the AQtivate 300 software

The function block of voltage transformer supervision function is shown in figure below. This block shows all binary input and output status signals that are applicable in the graphic equation editor.

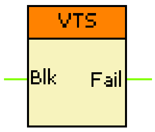


Figure 3-46: The function block of the voltage transformer supervision function

The binary input and output status signals of voltage transformer supervision function are listed in tables below.

Table 3-39 The binary input signal of the voltage transformer supervision function

Binary status signal	Explanation
VTS_Blk_GrO_	Output status defined by the user to disable the voltage transformer supervision function

Table 3-40The binary output signal of the voltage transformer supervision function

Binary status signal	Title	Explanation
VTS_Blk_GrO_	VT Failure	Failure status signal of the VTS function

Table 3-41Setting parameters of the voltage transformer supervision function

Parameter	Setting value, range and step	Description
Operation	Off Neg. Sequence Zero sequence Special	Operating mode selection for the function. Operation can be either disabled “Off” or enabled with criterions “Neg.Sequence”, “Zero sequence” or “Special”. Default setting is enabled with negative sequence criterion.
Start URes	5…50 % by step of 1 %	Residual voltage setting limit. Default setting is 30 %.
Start IRes	10…50 % by step of 1 %	Residual current setting limit. Default setting is 10 %.
Start UNeg	5…50 % by step of 1 %	Negative sequence voltage setting limit. Default setting is 10 %.
Start INeg	10…50 % by step of 1 %	Negative sequence current setting limit. Default setting is 10 %.

3.3.4 CURRENT TRANSFORMER SUPERVISION (CTS)

The current transformer supervision function can be applied to detect unexpected asymmetry in current measurement.

The function block selects maximum and minimum phase currents (fundamental Fourier components). If the difference between them is above the setting limit, the function generates a start signal. For function to be operational the highest measured phase current shall be above 10 % of the rated current and below 150% of the rated current.

The function can be disabled by parameter setting, and by an input signal programmed by the user.

The failure signal is generated after the defined time delay.

The function block of the current transformer supervision function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

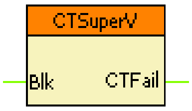


Figure 3-47: The function block of the current transformer supervision function

The binary input and output status signals of the dead line detection function are listed in tables below.

Table 3-42 The binary input signal of the current transformer supervision function

Binary status signal	Title	Explanation
CTSuperV_Blk_GrO_	Block	Blocking of the function

Table 3-43 The binary output status signals of the current transformer supervision function

Binary status signal	Title	Explanation
CTSuperV_Fail_GrI_	CtFail	CT failure signal

Table 3-44 Setting parameters of the current transformer supervision function

Parameter	Setting value, range and step	Description
Operation	On Off	Operating mode selection for the function. Operation can be either disabled “Off” or enabled “ON”. Default setting is enabled.
IPhase Diff	50…90 % by step of 1 %	Phase current difference setting. Default setting is 80 %.
Time delay	100…60000ms	CT supervision time delay. Default setting is 1000ms.

3.3.5 SYNCHROCHECK DU/DF (25)

Several problems can occur in the power system if the circuit breaker closes and connects two systems operating asynchronously. The high current surge can cause damage in the interconnecting elements, the accelerating forces can overstress the shafts of rotating machines or the actions taken by the protective system can result in the eventual isolation of parts of the power system.

To prevent such problems, this function checks if the systems to be interconnected are operating synchronously. If yes, then the close command is transmitted to the circuit breaker. In case of asynchronous operation, the close command is delayed to wait for the appropriate vector position of the voltage vectors on both sides of the circuit breaker. If the conditions for safe closing cannot be fulfilled within an expected time, then closing is declined.

NOTE: For capacitive reference voltage measurement, the voltage measurement card can be ordered with <50 mVA burden special input.

The conditions for safe closing are as follows:

- The difference of the voltage magnitudes is below the set limit
- The difference of the frequencies is below the set limit
- The angle difference between the voltages on both sides of the circuit breaker is within the set limit.

The function processes both automatic reclosing and manual close commands.

The limits for automatic reclosing and manual close commands can be set independently of each other.

The function compares the voltage of the line and the voltage of one of the busbar sections (Bus1 or Bus2). The bus selection is made automatically based on a binary input signal defined by the user.

For the reference of the synchrocheck any phase-to-ground or phase-to-phase voltage can be selected.

The function processes the signals of the voltage transformer supervision function and enables the close command only in case of plausible voltages.

The synchrocheck function monitors three modes of conditions:

- Energizing check:
    - Dead bus, live line,
    - Live bus, dead line,
    - Any Energizing case (including Dead bus, dead line).
- Synchro check (Live line, live bus)
- Synchro switch (Live line, live bus)

If the conditions for “Energizing check” and “Synchro check” are fulfilled, then the function generates the release command, and in case of a manual or automatic close request, the close command is generated.

If the conditions for energizing and synchronous operation are not met when the close request is received, then synchronous switching is attempted within the set time-out. In this case, the rotating vectors must fulfill the conditions for safe switching within the set waiting time: at the moment the contacts of the circuit breaker are closed, the voltage vectors must match each other with appropriate accuracy. For this mode of operation, the expected operating time of the circuit breaker must be set as a parameter value, to generate the close command in advance taking the relative vector rotation into consideration.

Started closing procedure can be interrupted by a cancel command defined by the user.

In “bypass” operation mode, the function generates the release signals and simply transmits the close command.

In the following figure is presented the operating logic of the synchrocheck function.

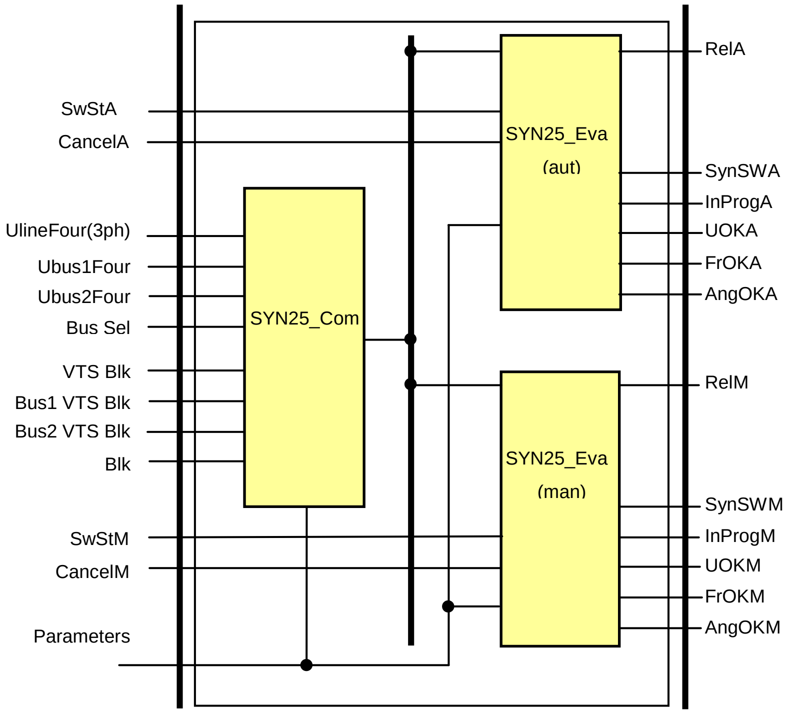


Figure 3-48: Operation logic of the synchrocheck function.

The synchro check/synchro switch function contains two kinds of software blocks:

- SYN25_Com is a common block for manual switching and automatic switching
- SYN25_EVA is an evaluation block, duplicated for manual switching and for automatic switching

The SYN25_Com block selects the appropriate voltages for processing and calculates the voltage difference, the frequency difference and the phase angle difference between the selected voltages. The magnitude of the selected voltages is passed for further evaluation.

These values are further processed by the evaluation software blocks. The function is disabled if the binary input (Block) signal is TRUE. The activation of voltage transformer supervision function of the line voltage blocks the operation (VTS Block). The activation of voltage transformer supervision function of the selected bus section blocks the operation (VTS Bus1 Block or VTS Bus2 Block).

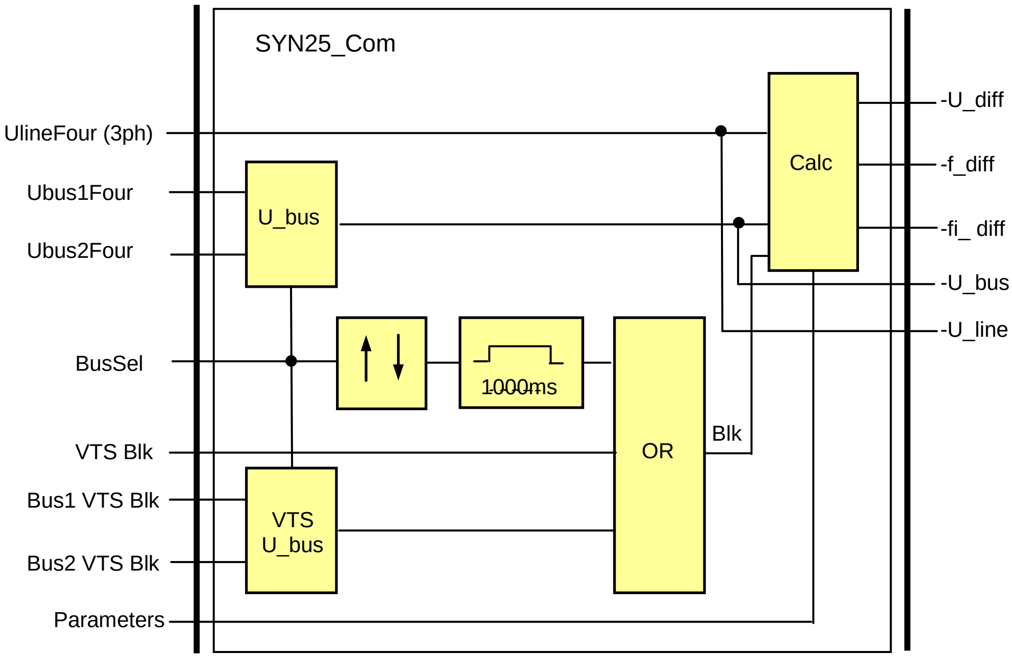


Figure 3-49: Synchrocheck common difference calculation function structure.

If the active bus section changes the function is dynamically blocked for 1000ms and no release signal or switching command is generated. The processed line voltage is selected based on the preset parameter (Voltage select). The choice is: L1-N, L2-N, L3-N, L1-L2, L2-L3 or L3-L1. The parameter value must match the input voltages received from the bus sections. The active bus section is selected by the input signal (Bus select). If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation.

The software block SYN25_Eva is applied separately for automatic and manual commands. This separation allows the application to use different parameter values for the two modes of operation.

The structure of the evaluation software block is shown in the following figure.

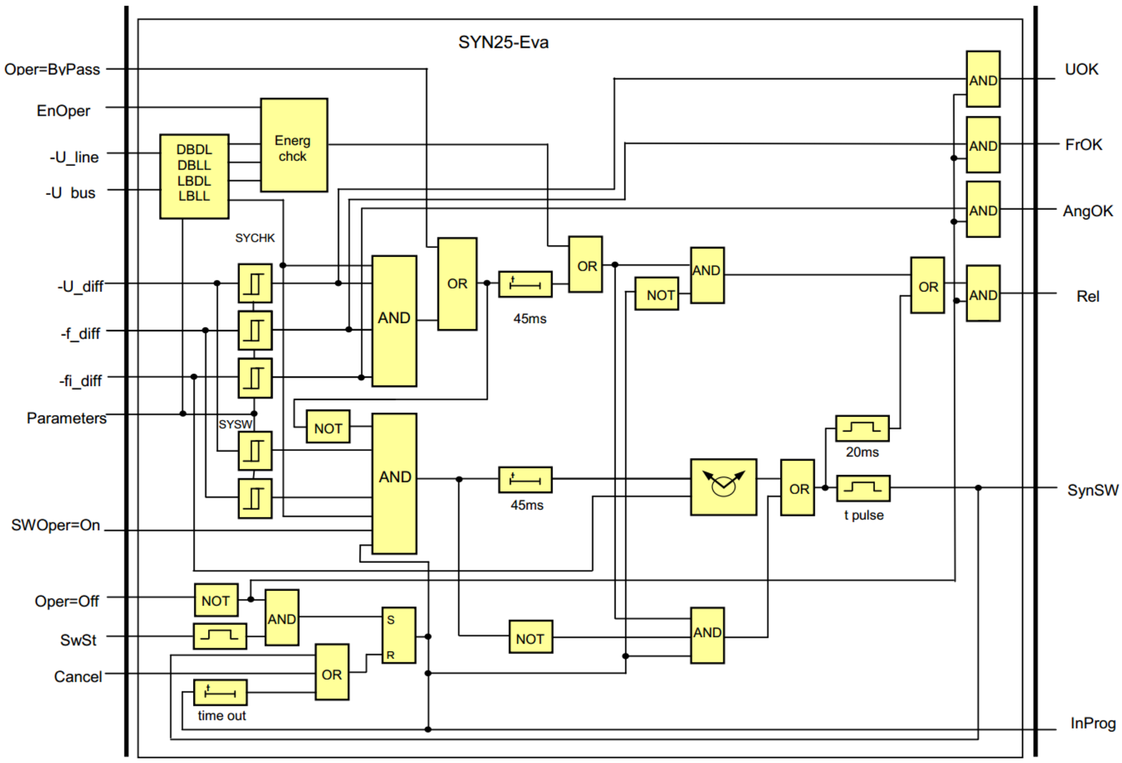


Figure 3-50: Synchrocheck evaluation function structure.

This evaluation software block is used for two purposes: for the automatic reclosing command (the signal names have the suffix “A”) and for the manual close request (the signal names have the suffix “M”). As the first step, based on the selected line voltage and bus voltage, the state of the required switching is decided (Dead bus-Dead line, Dead bus-Live line, Live bus-Dead line or Live bus- Live line). The parameters for decision are (U Live) and (U Dead). The parameters (Energizing Auto/Manual) enable the operation individually. The choice is: (Off, DeadBus LiveLine, LiveBus DeadLine, Any energ case). In simple energizing modes, no further checking is needed. This mode selection is bypassed if the parameter (Operation Auto/Manual) is set to “ByPass”. In this case the command is transmitted without any further checking.

First, the function tries switching with synchro check. This is possible if: the voltage difference is within the defined limits (Udiff SynChk Auto/Manual)) the frequency difference is within the defined limits (FrDiff SynChk Auto) and the phase angle difference is within the defined limits (MaxPhaseDiff Auto/Manual)).

If the conditions are fulfilled for at least 45 ms, then the function generates a release output signal (Release Auto/Manual).

If the conditions for synchro check operation are not fulfilled and a close request is received as the input signal (SySwitch Auto/Manual), then synchro switching is attempted. This is possible if: the voltage difference is within the defined limits (Udiff SynSW Auto /Manual)) the frequency difference is within the defined limits (FrDiff SynSW Auto).

These parameters are independent of those for the synchro check function. If the conditions for synchro check are not fulfilled and the conditions for synchro switch are OK, then the relative rotation of the voltage vectors is monitored. The command is generated before the synchronous position, taking the breaker closing time into consideration (Breaker Time). The pulse duration is defined by the parameter (Close Pulse). In case of slow rotation and if the vectors are for long time near-opposite vector positions, no switching is possible, therefore the waiting time is limited by the preset parameter (Max.Switch Time).

The progress is indicated by the output status signal (SynInProgr Auto/Manual). The started command can be canceled using the input signal (Cancel Auto/Manual).

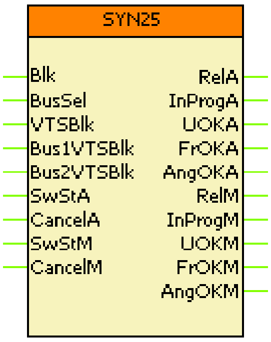


Figure 3-51 The function block of the synchro check / synchro switch function

The binary input and output status signals of the dead line detection function are listed in tables below.

Table 3-45 The binary input signal of the synchro check / synchro switch function

Binary status signal	Title	Explanation
SYN25_BusSel_GrO_	Bus Select	If this signal is logic TRUE, then the voltage of Bus2 is selected for evaluation
SYN25_VTSBlk_GrO_	VTS Block	Blocking signal of the voltage transformer supervision function evaluating the line voltage
SYN25_Bus1VTSBlk_GrO_	VTS Bus1 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus1 voltage
SYN25_Bus2VTSBlk_GrO_	VTS Bus2 Block	Blocking signal of the voltage transformer supervision function evaluating the Bus2 voltage
SYN25_SwStA_GrO_	SySwitch Auto	Switching request signal initiated by the automatic reclosing function
SYN25_CancelA_GrO_	Cancel Auto	Signal to interrupt (cancel) the automatic switching procedure
SYN25_Blk_GrO_	Block	Blocking signal of the function
SYN25_SwStM_GrO_	SySwitch Manual	Switching request signal initiated by manual closing
SYN25_CancelIM_GrO_	Cancel Manual	Signal to interrupt (cancel) the manual switching procedure

Table 3-46 The binary output status signals of the synchro check / synchro switch function

Binary status signal	Title	Explanation
SYN25_RelA_GrI_	Release Auto	Releasing the close command initiated by the automatic reclosing function
SYN25_InProgA_GrI_	SynInProgr Auto	Switching procedure is in progress, initiated by the automatic reclosing function
SYN25_UOKA_GrI_	Udiff OK Auto	The Voltage difference is appropriate for automatic closing command
SYN25_FrOKA_GrI_	FreqDiff OK Auto	The frequency difference is appropriate for automatic closing command, evaluated for synchro-check
SYN25_AngOKA_GrI_	Angle OK Auto	The angle difference is appropriatefor automatic closing command
SYN25_RelM_GrI_	Release Man	Releasing the close command initiated by manual closing request
SYN25_InProgM_GrI_	SynInProgr Man	Switching procedure is in progress, initiated by the manual closing command
SYN25_UOKM_GrI_	Udiff OK Man	The Voltage difference is appropriate for automatic closing command
SYN25_FrOKM_GrI_	FreqDiff OK Man	The frequency difference is appropriate for manual closing command, evaluated for synchro-check
SYN25_AngOKM_GrI_	Angle OK Man	The angle difference is appropriatefor manual closing command

Table 3-47 Setting parameters of the synchro check / synchro switch function

Parameter	Setting value, range and step	Description
Voltage select	L1-N L2-N L3-N L1-L2 L2-L3 L3-L1	Reference voltage selection. The function will monitor the selected voltage for magnitude, frequency and angle differences. Default setting is L1-N
U Live	60…110 % by step of 1 %	Voltage setting limit for “Live Line” detection. When measured voltage is above the setting value the line is considered “Live”. Default setting is 70 %.
U Dead	10…60 % by step of 1%	Voltage setting limit for “Dead Line” detection. When measured voltage is below the setting value the line is considered “dead”. Default setting is 30 %.
Breaker Time	0…500 ms by step of 1 ms	Breaker operating time at closing. This parameter is used for the synchro switch closing command compensation and it describes the breaker travel time from open position to closed position from the close command. Default setting is 80 ms.
Close Pulse	10…60000 ms by step of 1 ms	Close command pulse length. This setting defines the duration of close command from the IED to the circuit breaker. Default setting is 1000 ms.
Max Switch Time	100…60000 ms by step of 1 ms	Maximum allowed switching time. In case synchro check conditions are not fulfilled and the rotation of the networks is slow this parameter defines the maximum waiting time after which the close command is failed. Default setting is 2000ms.
Operation Auto	On Off ByPass	Operation mode for automatic switching. Selection can be automatic switching off, on or bypassed. If the Operation Auto is set to “Off” automatic switch checking is disabled. If selection is “ByPass” Automatic switching is enabled with bypassing the bus and line energization status checking. When the selection is “On” also the energization status of bus and line are checked before processing the command. Default setting is “On”
SynSW Auto	On Off	Automatic synchroswitching selection. Selection may be enabled “On” or disabled “Off”. Default setting is Enabled “On”.
Energizing Auto	Off DeadBus LiveLine LiveBus DeadLine Any energ case	Energizing mode of automatic synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine the selection is “Any energ case”. Default setting is DeadBus LiveLine.
Udiff SynChk Auto	5…30 % by step of 1 %	Voltage difference checking of the automatic synchrocheck mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
Udiff SynSW Auto	5…30 % by step of 1 %	Voltage difference checking of the automatic synchroswitch mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
MaxPhasediff Auto	5…80 deg by step of 1 deg	Phase difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 20 deg.
FrDiff SynChk Auto	0.02…0.50 Hz by step of 0.01 Hz	Frequency difference checking of the automatic synchrocheck mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.02 Hz.

FrDiff SynSW Auto	0.10…1.00 Hz by step of 0.01 Hz	Frequency difference checking of the automatic synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.2 Hz.
Operation Man	On Off ByPass	Operation mode for manual switching. Selection can be manual switching off, on or bypassed. If the Operation Man is set to " Off" manual switch checking is disabled. If selection is "ByPass " manual switching is enabled with bypassing the bus and line energization status checking. When the selection is "On" also the energization status of bus and line are checked before processing the command. Default setting is "On"
SynSW Man	On Off	Manual synchroswitching selection. Selection may be enabled "On" or disabled "Off". Default setting is Enabled "On".
Energizing Man	Off DeadBus LiveLine LiveBus DeadLine Any energ case	Energizing mode of manual synchroswitching. Selections consist of the monitoring of the energization status of the bus and line. If the operation is wanted to be LiveBus LiveLine or DeadBus DeadLine the selection is "Any energ case". Default setting is DeadBus LiveLine.
Udiff SynChk Man	5…30 % by step of 1 %	Voltage difference checking of the manual synchrocheck mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
Udiff SynSW Man	5…30 % by step of 1 %	Voltage difference checking of the manual synchroswitch mode. If the measured voltage difference is below this setting the condition applies. Default setting is 10 %.
MaxPhaseDiff Man	5…80 deg by step of 1 deg	Phase difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 20 deg.
FrDiff SynChk Man	0.02…0.50 Hz by step of 0.01 Hz	Frequency difference checking of the manual synchrocheck mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.02 Hz.
FrDiff SynSW Man	0.10…1.00 Hz by step of 0.01 Hz	Frequency difference checking of the manual synchroswitch mode. If the measured phase difference is below this setting the condition applies. Default setting is 0.2 Hz.

3.3.6 INTEGRATED AUTOMATIC VOLTAGE REGULATOR (AVR)

One of the most important criteria for power quality is to keep the voltage of selected points of the network within the prescribed limits. The most common mode of voltage regulation is the application of transformers with on-load tap changers. When the transformer is connected to different taps, its turns ratio changes and supposing constant primary voltage, the secondary voltage can be increased or decreased as required.

Voltage control can take the actual load state of the transformer and the network into consideration. As a result, the voltage of a defined remote point of the network is controlled assuring that neither consumers near the busbar nor consumers at the far ends of the network get voltages out of the required range.

The voltage control function can be performed automatically or, in manual mode of operation, the personnel of the substation can set the network voltage according to special requirements.

Depending on the selected mode of operation this version of the controller can be applied to regulate a single transformer or to control parallel transformers.

When transformers are connected parallel, i.e. they are connected to the same busbar section on the primary side and also on the secondary side of the transformer, then these transformers must be regulated together to avoid circulating current among the transformers.

This circulating current causes additional losses, and the generated additional heat could overstress the transformers.

The “Operation” parameter for selection of the operating mode has several choices:

- Off, for disabling the control function;
- Single, for regulation a single transformer only;
- CircCurrMin, for operating the controllers of the parallel connected transformers to minimize the circulating current;
- Master, for selection one of the controllers of the parallel connected transformers to be the master, to transmit commands to the slave controllers;
- SlaveCmd, for selection the controller to operate in slave mode, and follow the UP and DOWN commands;
- SlaveTap for selection the controller to operate in slave mode, and drive the tap changer to the same position as the transformer assigned to the master controller.

In any of the active modes of operation the controllers can be set to the “Manual” or to “Automatic” control command generation.

3.3.6.1 Mode of operation to control a single transformer

This mode of operation is selected if the “Operation” parameter is set to “Single”.

3.3.6.2 The scheme of the function block

Figure below shows the scheme of the function block, simplified for single mode of operation.

3.3.6.3 Analog inputs of the controller function

The automatic tap changer controller function receives the following analog inputs:

UL1L2	Line-to-line voltage of the controlled secondary side of the transformer
IL1L2	Difference of the selected line currents of the secondary side of the transformer for voltage drop compensation
IHV	Maximum of the phase currents of the primary side of the transformer for limitation purposes

The parameter “U Correction” permits fine tuning of the measured voltage.

3.3.6.4 Internal checks before control operation

In Figure below the block “U-I BLOCK” performs the following checks before control operation:

- If the voltage of the controlled side UL1L2 is above the value set by the parameter
- “U High Limit”, then control command to increase the voltage is disabled.
- If the voltage of the controlled side UL1L2 is below the value set by the parameter
- “U Low Limit”, then control command to decrease the voltage is disabled.
- If the voltage of the controlled side UL1L2 is below the value set by the parameter
- “U Low Block”, then the transformer is considered to be de-energized and the automatic control is completely disabled.
- If the current of the supply side IHV is above the limit set by the parameter “I_overload”, then both automatic and manual controls are completely disabled. This is to protect the switches inside the tap changer.

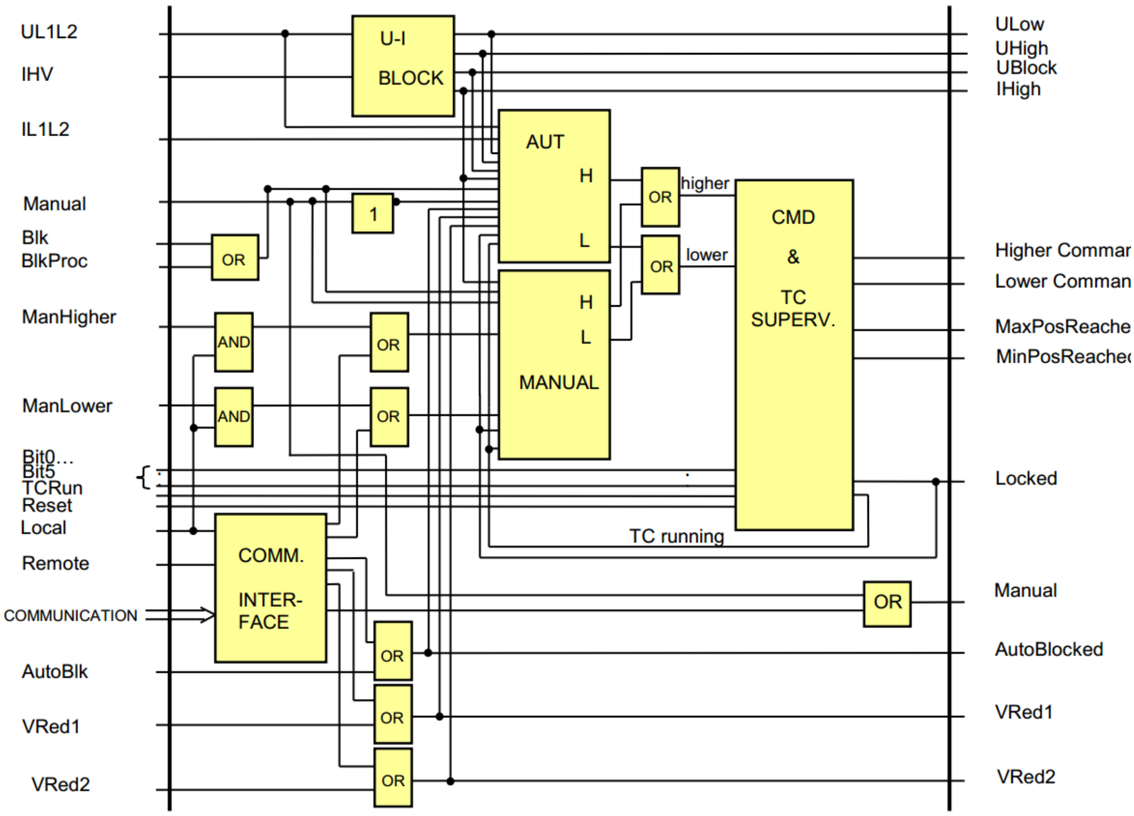


Figure 3-52 The logic schema of the automatic tap changer controller

3.3.6.5 Automatic control mode

Voltage compensation in automatic control mode

The module “AUT” in Figure 3-52 gets the Fourier components of the busbar voltage and those of the current:

- $UL1L2_{Re}$ and $UL1L2_{Im}$
- $IL1L2_{Re}$ and $IL1L2_{Im}$

In automatic control mode the voltage of the controlled side UL1L2 is compensated by the current of the controlled side IL1L2. This means that the voltage of the “load center” of the network is controlled to be constant, in fact within a narrow range. This assures that neither the voltage near to the busbar is too high, nor the voltage at far-away points of the network is too low. The voltage of the “load center”, i.e. the controlled voltage is calculated as:

$$|Ucontrol|=|Ubus-Udrop|$$

There are two compensation modes to be selected by setting the “Compensation” parameter: “AbsoluteComp” and “ComplexComp”.

- If the parameter “Compensation” is set to “AbsoluteComp”, the calculation method is as follows:

In this simplified method the vector positions are not considered correctly, the formula above is approximated with the magnitudes only:

|Ucontrol|=|Ubus-Udrop|≈|Ubus|-|Udrop|≈|Ubus|-|I|*(R)CompoundFactor

, where (R) Compound Factor is a parameter value.

If the “|I|” current is above the value defined by the parameter “I Comp Limit”, then in the formulas above this preset value is considered instead of the higher values measured.

The method is based on the experiences of the network operator. Information is needed: how much is the voltage drop between the busbar and the “load center” if the load of the network is the rated load. The parameter “(R) Compound Factor” means in this case the voltage drop in percent.

NOTE: if the active power flows from the network to be controlled to the busbar then in “AbsoluteComp” mode no compounding is performed.

- If the parameter “Compensation” is set to “ComplexComp”, the calculation method is as follows:

In this method the vector positions are partly considered. In the formula above the voltage drop is approximated with the component of the voltage drop, the direction of which is the same as the direction of the bus voltage vector. (This is “length component” of the voltage drop; the “perpendicular component” of the voltage drop is neglected.)

$$|Ucontrol| = |Ubus - [(IL1L2_{Re} + jIL1L2_{Im}) * ((R)CompoundFactor + jXCompoundFactor)]|$$

Where

(R) Compound Factor	is a parameter value
X Compound Factor	is a parameter value

The voltage of the “load center” of the network is controlled to be within a narrow range. This assures that neither the voltage near to the busbar is too high, nor the voltage at far-away points of the network is too low.

The method is based on the estimated complex impedance between the busbar and the “load center”. The parameter “(R) Compound Factor” means in this case the voltage drop in percent, caused by the real component of the rated current.

The parameter “X Compound Factor” means in this case the voltage drop in percent, caused by the imaginary component of the rated current.

Voltage checking in automatic control mode

In automatic control mode the calculated | Ucontrol | voltage is checked to see if it is outside the limits. The limits are defined by parameter values:

U Set	the setting value defining the centre of the permitted range
U deadband	the width of the permitted range in both + and – directions
Deadband Hysteresis	the hysteresis decreasing the permitted range after the generation of the control command

If the calculated | Ucontrol | voltage is outside the limits, then timers are started.

In an emergency state of the network, when the network elements are overloaded, the “Uset” value can be driven to two lower values defined by the parameters “Voltage Reduction 1” and “Voltage Reduction 2”. “U Set” is decreased by the parameter values if the binary inputs “Voltage Reduction 1” or “Voltage Reduction 2” enter into active state. These inputs must be programmed graphically by the user.

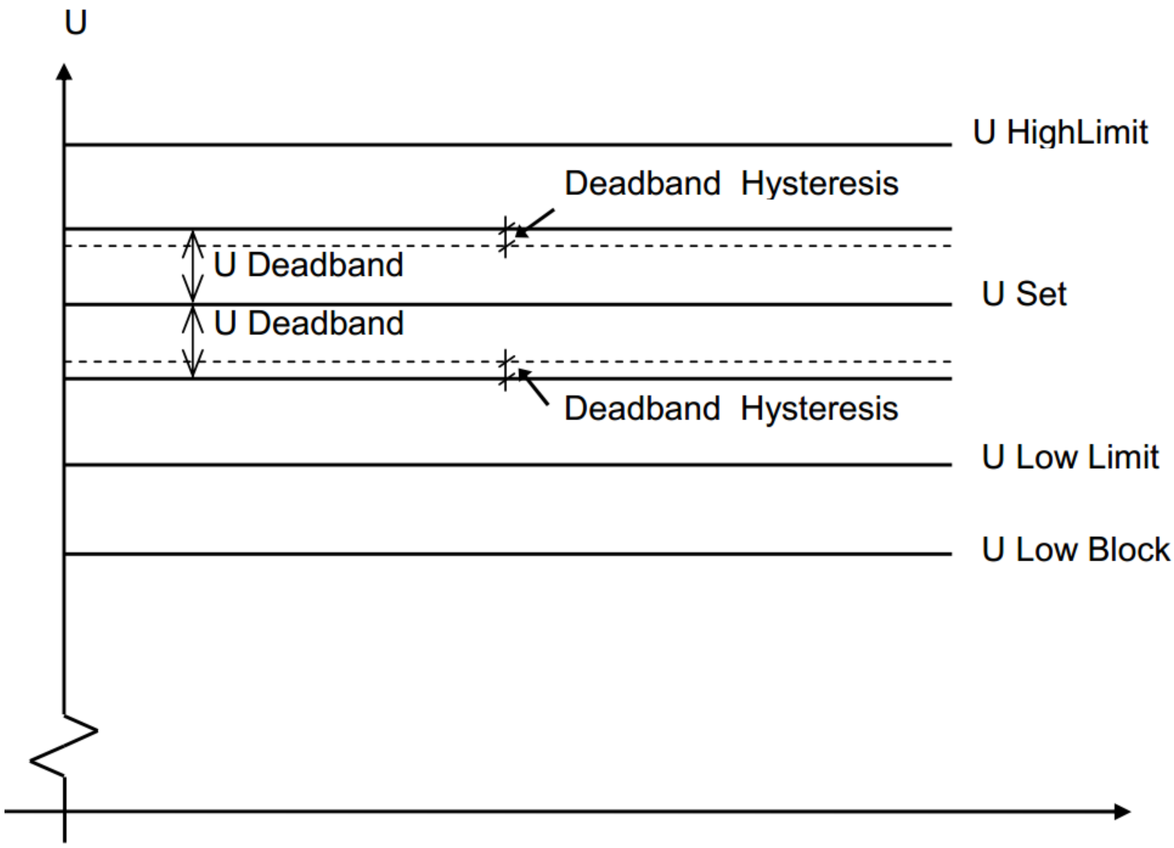


Figure 3-53 Voltage level settings

Time delay in automatic control mode

In automatic control mode the first and every subsequent control command is processed separately.

For the first control command:

The voltage difference is calculated:

$$Udiff = |Ucontrol - Uset|$$

If this difference is above the "U Deadband" value, then depending on the setting of parameter "T1 Delay Type", three different timing modes can be selected:

- "Definite" this definite time delay is defined by parameter T1
- "Inverse" standard IDMT characteristic defined by the parameters:
    - T1 maximum delay defined by the parameter
    - U Deadband is the width of the permitted range in both + and – directions

- Min Delay minimum time delay

$$Tdelay = \frac{T1}{\left(\frac{Udiff}{Udeadband}\right)}, but\ minimum\ MinDelay$$

- "2powerN"

$$Tdelay = T1 * 2^{\left(1-\frac{Udiff}{Udeadband}\right)}$$

The binary parameters "Fast Lower Enable" and/or "Fast Higher Enable" enable fast command generation if the voltage is above the parameter value "U High Limit" or below the "U Low Limit". In this case, the time delay is a definite time delay defined by parameter "T2".

For subsequent control commands:

In this case, the time delay is always a definite time delay defined by parameter "T2" if the subsequent need for regulation with the same direction is detected within the "Reclaim time" defined by parameter.

The automatic control mode can be blocked by a binary signal received via binary input "AutoBlk" and generates a binary output signal "AutoBlocked (ext)"

3.3.6.6 Manual control mode

In manual mode, the automatic control is blocked. The manual mode can be "Local" or "Remote". For this mode, the input "Manual" needs to be in active state (as programmed by the user).

In the local mode, the input "Local" needs to be in active state. The binary inputs "ManHigher" or "ManLower" must be programmed graphically by the user.

In the remote mode, the input "Remote" needs to be in active state as programmed by the user. In this case manual commands are received via the communication interface.

3.3.6.7 Command generation and tap changer supervision

The software module "CMD&TC SUPERV" is responsible for the generation of the "HigherCmd" and "LowerCmd" command pulses, the duration of which is defined by the parameter "Pulse Duration". This is valid both for manual and automatic operation.

The tap changer supervision function receives the information about the tap changer position in six bits of the binary inputs "Bit0 to Bit5". The value is decoded according to the enumerated parameter "CodeType", the values of which can be: Binary, BCD or Gray. During switchover, for the transient time defined by the parameter "Position Filter", the position is not evaluated.

The parameters "Min Position" and "Max Position" define the upper and lower limits. In the upper position, no further increasing command is generated and the output "Max Pos Reached" becomes active. Similarly, in the lower position, no further decreasing command is generated and the output "Min Pos Reached" becomes active.

The function also supervises the operation of the tap changer. Depending on the setting of parameter "TC Supervision", three different modes can be selected:

- TCDrive the supervision is based on the input "TCRun". In this case, after command generation the drive is expected to start operation within one quarter of the value defined by the parameter "Max Operating Time" and it is expected to perform the command within "Max Operating Time"
- Position the supervision is based on the tap changer position in six bits of the binary inputs "Bit0 to Bit5". It is checked if the tap position is incremented in case of a voltage increase, or the tap position is decremented in case of a voltage decrease, within the "Max Operating Time".
- Both in this mode the previous two modes are combined.

In case of an error detected in the operation of the tap changer, the "Locked" input becomes active and no further commands are performed. To enable further operation, the input "Reset" must be programmed for an active state by the user.

3.3.6.8 Error codes

The On-line information includes a variable "ErrorCode" (ATCC_ErrCode_ISt_), indicating different error states. These states are binary coded; any of them causes "Locked" state of the controller function. The explanation of the individual bits in the code value is explained in the Table below.

Bit	Value	Explanation
0	1	Drive started without control command
1	2	Drive did not start after control command
2	4	Drive did not stop in due time
3	8	Invalid position signal
4	16	Position signal did not change value

In case of multiple error states the values are added in the "Error Code"

3.3.6.9 Symbol of the function in AQtivate300 software

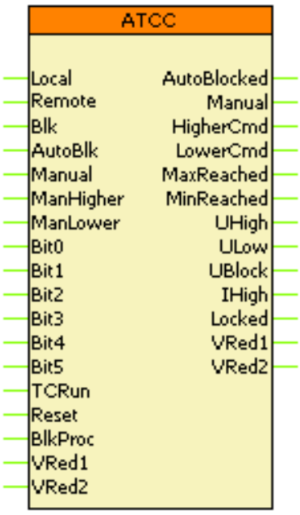


Figure 3-54 Function block of the automatic tap-changer controller

Table 3-48 Outputs of the ATCC function block

Title	Explanation
AutoBlocked	Automatic control blocked
Manual	Signaling the manual mode of operation
Higher Command	Command for increasing the voltage
Lower Command	Command for decreasing the voltage
Max Pos Reached	Signaling the maximal position
Min Pos Reached	Signaling the minimal position
U High	Voltage is high
U Low	Voltage is low
U Block	Blocked state for too low voltage
I High	Blocked because of current limits
Locked	The supervision detected tap changer error, the blocking can be released exclusively by the Reset impulse
Voltage reduction 1	Controlling the reduced voltage 1
Voltage reduction 2	Controlling to reduced voltage 2

Table 3-49 Inputs of the ATCC function block

Title	Explanation
Local	Local state of the manual operation
Remote	Remote state of the manual operation
Blk	Blocking of the function
AutoBlk	Blocking of the automatic function
Manual	Manual mode of operation
ManHigher	Manual command for increasing the voltage
ManLower	Manual command for decrasing the voltage
Bit0	Bit0 of the position indicator
Bit1	Bit1 of the position indicator
Bit2	Bit2 of the position indicator
Bit3	Bit3 of the position indicator
Bit4	Bit4 of the position indicator
Bit5	Bit5 of the position indicator
TCRun	Running state of the tap changer
Reset	Reset to release from blocked state
BlkProc	Blocking signal from the tap changer
VRed1	Reduced voltage 1 is required
VRed2	Reduced voltage 2 is required

Table 3-50: Setting parameters of the automatic tap-changer controller function

Enumerated parameter name	Selection range	Enumerated parameter description
ControlModel	Direct normal, Direct enhanced, SBO enchanced	Control model, according to IEC61850
sboClass	Operate-once, Operate many	Select before operate class, according to IEC61850
Operation	Off, On	Parameter for general blocking of the function
T1 Delay type	Definite, Inverse, 2powerN	Parameter for time delay mode selection
Compensation	Off, AbsoluteComp, ComplexComp	Selection for compensation mode
TC Supervision	Off, TCDrive, Position, Both	Tap changed supervision mode selection
CodeType	Binary, BCD, Gray	Decoding of the position indicator bits

Boolean parameter name	Default	Boolean parameter description
Fast Higher Enable	0	Enabling fast higher control command
Fast Lower Enable	0	Enabling fast lower control command

Integer parameter name	Min	Max	Step	Default	Integer parameter description
Min Position	1	32	1	1	Code value of the minimum position
Max position	1	32	1	32	Code value of the maximum position

Timer parameter name	Unit	Min	Max	Step	Default	Timer parameter description
Max operating time	msec	1000	30000	1	5000	Time limit for tap-change operation
Pulse duration	msec	100	10000	1	1000	Command impulse duration
Position Filter	msec	1000	30000	1	3000	Time overbridging the transient state of the tap changer status signals
SBO Timeout	msec	1000	20000	1	5000	Select before operate timeout, according to IEC 61850

Float parameter name	Unit	Min	Max	Digits	Default	Float parameter description
U Correction	-	0.950	1.050	3	1.000	Factor for fine tuning the measured voltage
U Set	%	80.0	115.0	1	100.0	Set-point for voltage regulation, related to the rated voltage (Valid at I=0)
U Deadband	%	0.5	9.0	1	3.0	Dead band for voltage regulation, related to the rated voltage
Deadband Hysteresis	%	60	90	0	85	Hysteresis value for the dead band, related to the dead band
(R) Compound Factor	%	0.0	15.0	1	5.0	Parameter for the current compensation
X Compound factor	%	0.0	15.0	1	5.0	Parameter for the current compensation
Voltage reduction 1	%	0.0	10.0	1	5.0	Reduced set-point 1 for voltage regulation (priority), related to the rated voltage.
Voltage reduction 2	%	0.0	10.0	1	5.0	Reduced set-point 2 for voltage regulation, related to the rated voltage.
I Comp Limit	%	0.0	150	0	1	Maximum current value to be considered in current compensation formulas.
I Overload	%	50	150	0	100	Current upper limit to disable all operation.
U High Limit	%	90.0	120.0	1	110.0	Voltage upper limit to disable all operation
U Low Limit	%	70.0	110.0	1	90.0	Voltage lower limit to disable step down
U Low Block	%	50.0	100.0	1	70.0	Voltage lower limit to disable all operation
T1	Sec	1.0	600.0	1	10.0	Time delay for the first control command generation
T2	Sec	1.0	100.0	1	10.0	Definite time delay for control command generation or fast operation (if it is enabled)
Min Delay	Sec	1.0	100.0	1	10.0	In case of dependent time characteristics, this is the minimum time delay
Reclaim Time	Sec	1.0	100.0	1	10.0	After a control command, if the voltage is out of the range within reclaim time, then the command is generated after T2 time delay

3.3.7 Switch on to fault logic

Some protection functions, e.g. distance protection, directional overcurrent protection, etc. need to decide the direction of the fault. This decision is based on the angle between the voltage and the current. In case of close-in faults, however, the voltage of the faulty loop is near zero: it is not sufficient for a directional decision. If there are no healthy phases, then the voltage samples stored in the memory are applied to decide if the fault is forward or reverse.

If the protected object is energized, the close command for the circuit breaker is received in “dead” condition. This means that the voltage samples stored in the memory have zero values. In this case the decision on the trip command is based on the programming of the protection function for the “switch-onto-fault” condition.

This “switch-onto-fault” (SOTF) detection function prepares the conditions for the subsequent decision. The function can handle both automatic and manual close commands.

The function receives the “Dead line” status signal from the DLD (dead line detection) function block. After dead line detection, the binary output signal AutoSOTF is delayed by a timer with a constant 200 ms time delay. After voltage detection (resetting of the dead line detection input signal), the drop-off of this output signal is delayed by a timer (SOTF Drop Delay) set by the user. The automatic close command is not used it is not an input for this function.

The manual close command is a binary input signal. The drop-off of the binary output signal ManSOTF is delayed by a timer (SOTF Drop Delay) set by the user. The timer parameter is common for both the automatic and manual close command.

The operation of the “switch-onto-fault” detection function is shown in Figure below.

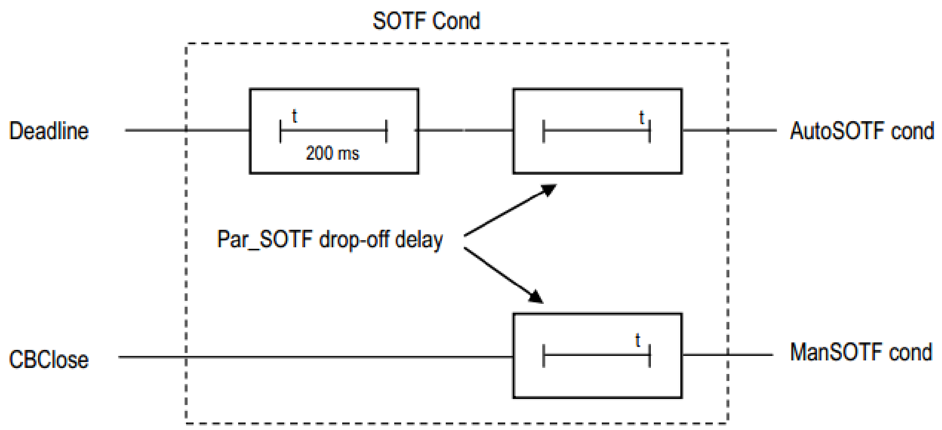


Figure 3.3.7-1 The scheme of the “switch-onto-fault” preparation

The binary input signals of the “switch-onto-fault” detection function are:

- CBClose Manual close command to the circuit breaker,
- DeadLine Dead line condition detected. This is usually the output signal of the DLD (dead line detection) function block.

The binary output signals of the “switch-onto-fault” detection function are:

- AutoSOTF cond Signal enabling switch-onto-fault detection as a consequence of an automatic close command,
- ManSOTF cond Signal enabling switch-onto-fault detection as a consequence of a manual close command.

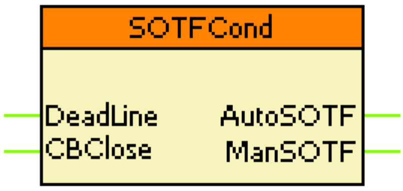


Figure 3.3.7-2 The function block of the switch onto fault function.

Table 3-51 The timer parameter of the switch-onto-fault detection function

Parameter name	Title	Unit	Min	Max	Step	Default
Drop-off time delay for the output signals						
SOTF_SOTFDel_TPar_	SOTF Drop Delay	msec	100	10000	1	1000

Table 3-52 The binary output status signals of the switch-onto-fault detection function

Binary output signals	Signal title	Explanation
Signal enabling switch-onto-fault detection as a consequence of automatic close command		
SOTF_AutoSOTF_GrI_	AutoSOTF cond	Signal enabling switch-onto-fault detection as a consequence of automatic close command
Signal enabling switch-onto-fault detection as a consequence of manual close command		
SOTF_ManSOTF_GrI_	ManSOTF cond	Signal enabling switch-onto-fault detection as a consequence of manual close command

Table 3-53 The binary input signals of the switch-onto-fault detection function

Binary input signal	Signal title	Explanation
Manual close command to the circuit breaker		
SOTF_CBClose_GrO_	CBClose	Manual close command to the circuit breaker
Dead line condition detected		
SOTF_DeadLine_GrO_	DeadLine	Dead line condition detected

3.3.8 DISTURBANCE RECORDER

The disturbance recorder function can record analog signals and binary status signals. These signals are user configurable. The disturbance recorder function has a binary input signal, which serves the purpose of starting the function. The conditions of starting are defined by the user. The disturbance recorder function keeps on recording during the active state of this signal but the total recording time is limited by the timer parameter setting. The pre-fault time, max-fault time and post-fault time can be defined by parameters.

If the conditions defined by the user - using the graphic equation editor – are satisfied, then the disturbance recorder starts recording the sampled values of configured analog signals and binary signals. The analog signals can be sampled values (voltages and currents) received via input modules or they can be calculated analog values (such as negative sequence components, etc.) The number of the configured binary signals for recording is limited to 64. During the operation of the function, the pre-fault signals are preserved for the time duration as defined by the parameter "PreFault". The fault duration is limited by the parameter "MaxFault" but if the triggering signal resets earlier, this section is shorter. The post-fault signals are preserved for the time duration as defined by the parameter "PostFault ". During or after the running of the recording, the triggering condition must be reset for a new recording procedure to start.

The records are stored in standard COMTRADE format.

- The configuration is defined by the file .cfg,
- The data are stored in the file .dat,
- Plain text comments can be written in the file .inf.

The procedure for downloading the records includes a downloading of a single compressed .zip-file. Downloading can be initiated from a web browser tool or from the software tools. This procedure assures that the three component files (.cfg, .dat and .inf) are stored in the same location. The evaluation can be performed using any COMTRADE evaluator software, e.g. Arcteq's AQview software. Consult your nearest Arcteq representative for availability.

The symbol of the function block in the AQtivate 300 software

The function block of the disturbance recorder function is shown in figure bellow. This block shows all binary input and output status signals that are applicable in the AQtivate 300 software.

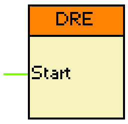


Figure 3-3: The function block of the disturbance recorder function

The binary input and output status signals of the dead line detection function are listed in tables below.

Table 3-54 The binary input signal of the disturbance recorder function

Binary status signal	Explanation
DRE_Start_GrO_	Output status of a graphic equation defined by the user to start the disturbance recorder function.

Table 3-55Setting parameters of the disturbance recorder function

Parameter	Setting value, range and step	Description
Operation	On, Off	Function enabling / disabling. Default setting is On
PreFault	100...500 ms by step of 1 ms	Pre triggering time included in the recording. Default setting is 200 ms.
PostFault	100...1000 ms by step of 1 ms	Post fault time included in the recording. Default setting is 200 ms.
MaxFault	500...10000 ms by step of 1 ms	Overall maximum time limit in the recording. Default setting is 1000 ms.

3.3.9 Event recorder

The events of the device and those of the protection functions are recorded with a time stamp of 1 ms time resolution. This information with indication of the generating function can be checked on the touch-screen of the device in the “Events” page, or using an Internet browser of a connected computer.

Table 3-56 List of events.

Event	Explanation
Voltage transformer supervision function (VTS)	
VT Failure	Error signal of the voltage transformer supervision function
Common	
Mode of device	Mode of device

Health of device	Health of device
Three-phase instantaneous overcurrent protection function (IOC50)	
Trip L1	Trip command in phase L1
Trip L2	Trip command in phase L2
Trip L3	Trip command in phase L3
General Trip	General trip command
Residual instantaneous overcurrent protection function (IOC50N)	
General Trip	General trip command
Directional overcurrent protection function (TOC67) low setting stage	
Start L1	Start signal in phase L1
Start L2	Start signal in phase L2
Start L3	Start signal in phase L3
Start	Start signal
Trip	Trip command
Directional overcurrent protection function (TOC67) high setting stage	
Start L1	Start signal in phase L1
Start L2	Start signal in phase L2
Start L3	Start signal in phase L3
Start	Start signal
Trip	Trip command
Residual directional overcurrent protection function (TOC67N) low setting stage	
Start	Start signal
Trip	Trip command
Residual directional overcurrent protection function (TOC67N) high setting stage	
Start	Start signal
Trip	Trip command
Line thermal protection function (TTR49L)	
Alarm	Line thermal protection alarm signal
General Trip	Line thermal protection trip command
Current unbalance protection function	
General Start	General Start
General Trip	General Trip
Current unbalance protection function	
2.Harm Restraint	Second harmonic restraint
Definite time overvoltage protection function (TOV59)	
Low Start L1	Low setting stage start signal in phase L1
Low Start L2	Low setting stage start signal in phase L2
Low Start L3	Low setting stage start signal in phase L3
Low General Start	Low setting stage general start signal

Low General Trip	Low setting stage general trip command
High Start L1	High setting stage start signal in phase L1
High Start L2	High setting stage start signal in phase L2
High Start L3	High setting stage start signal in phase L3
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Definite time undervoltage protection function (TUV27)	
Low Start L1	Low setting stage start signal in phase L1
Low Start L2	Low setting stage start signal in phase L2
Low Start L3	Low setting stage start signal in phase L3
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High Start L1	High setting stage start signal in phase L1
High Start L2	High setting stage start signal in phase L2
High Start L3	High setting stage start signal in phase L3
High General Start	High setting stage general start signal
High =General Trip	High setting stage general trip command
Overfrequency protection function (TOF81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Underfrequency protection function (TUF81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Rate of change of frequency protection function (FRC81)	
Low General Start	Low setting stage general start signal
Low General Trip	Low setting stage general trip command
High General Start	High setting stage general start signal
High General Trip	High setting stage general trip command
Breaker failure protection function (BRF50)	
Backup Trip	Repeated trip command
Trip logic function (TRC94)	
General Trip	General Trip
Synchro check function (SYN25)	
Released Auto	The function releases automatic close command
In progress Auto	The automatic close command is in progress

Close_Auto	Close command in automatic mode of operation
Released Man	The function releases manual close command
In progress Man	The manual close command is in progress
Close_ Man	Close command in manual mode of operation
Automatic reclosing function (REC79)	
Blocked	Blocked state of the automatic reclosing function
Close Command	Close command of the automatic reclosing function
Status	State of the automatic reclosing function
Actual cycle	Running cycle of the automatic reclosing function
Final Trip	Definite trip command at the end of the automatic reclosing cycles
Measurement function (MXU)	
Current L1	Current violation in phase L1
Current L2	Current violation in phase L2
Current L3	Current violation in phase L3
Voltage L12	Voltage violation in loop L1-L2
Voltage L23	Voltage violation in loop L2-L3
Voltage L31	Voltage violation in loop L3-L1
Active Power – P	Active Power – P violation
Reactive Power – Q	Reactive Power – Q violation
Apparent Power – S	Apparent Power – S violation
Frequency	Frequency violation
CB1Pol	
Status value	Status of the circuit breaker
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
CB OPCap	
Disconnector Line	
Status value	Status of the circuit breaker
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	
Disconnector Earth	
Status value	Status of the Earthing switch
Enable Close	Close command is enabled

Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	
Disconnector Bus	
Status value	Status of the bus disconnector
Enable Close	Close command is enabled
Enable Open	Open command is enabled
Local	Local mode of operation
Operation counter	Operation counter
DC OPCap	

3.3.10 MEASURED VALUES

The measured values can be checked on the touch-screen of the device in the "On-line functions" page, or using an Internet browser of a connected computer. The displayed values are secondary voltages and currents, except the block "Line measurement". This specific block displays the measured values in primary units, using the VT and CT primary value settings.

Table 3-57 Analogue value measurements

Analog value	Explanation
VT4 module	
Voltage Ch - U1	RMS value of the Fourier fundamental harmonic voltage component in phase L1
Angle Ch - U1	Phase angle of the Fourier fundamental harmonic voltage component in phase L1*
Voltage Ch - U2	RMS value of the Fourier fundamental harmonic voltage component in phase L2
Angle Ch - U2	Phase angle of the Fourier fundamental harmonic voltage component in phase L2*
Voltage Ch - U3	RMS value of the Fourier fundamental harmonic voltage component in phase L3
Angle Ch - U3	Phase angle of the Fourier fundamental harmonic voltage component in phase L3*
Voltage Ch - U4	RMS value of the Fourier fundamental harmonic voltage component in Channel U4
Angle Ch - U4	Phase angle of the Fourier fundamental harmonic voltage component in Channel U4*
CT4 module	
Current Ch - I1	RMS value of the Fourier fundamental harmonic current component in phase L1
Angle Ch - I1	Phase angle of the Fourier fundamental harmonic current component in phase L1*

Current Ch - I2	RMS value of the Fourier fundamental harmonic current component in phase L2
Angle Ch - I2	Phase angle of the Fourier fundamental harmonic current component in phase L2*
Current Ch - I3	RMS value of the Fourier fundamental harmonic current component in phase L3
Angle Ch - I3	Phase angle of the Fourier fundamental harmonic current component in phase L3*
Current Ch - I4	RMS value of the Fourier fundamental harmonic current component in Channel I4
Angle Ch - I4	Phase angle of the Fourier fundamental harmonic current component in Channel I4*
Values for the directional measurement	
L12 loop R	Resistance of loop L1L2
L12 loop X	Reactance of loop L1L2
L23 loop R	Resistance of loop L2L3
L23 loop X	Reactance of loop L2L3
L31 loop R	Resistance of loop L3L1
L31 loop X	Reactance of loop L3L1
Line thermal protection	
Calc. Temperature	Calculated line temperature
Synchro check	
Voltage Diff	Voltage magnitude difference
Frequency Diff	Frequency difference
Angle Diff	Angle difference
Line measurement (information displayed here means primary value)	
Active Power – P	Three-phase active power
Reactive Power – Q	Three-phase reactive power
Apparent Power – S	Three-phase power based on true RMS voltage and current measurement
Current L1	True RMS value of the current in phase L1
Current L2	True RMS value of the current in phase L2
Current L3	True RMS value of the current in phase L3
Voltage L1	True RMS value of the voltage in phase L1
Voltage L2	True RMS value of the voltage in phase L2
Voltage L3	True RMS value of the voltage in phase L3
Voltage L12	True RMS value of the voltage between phases L1 L2
Voltage L23	True RMS value of the voltage between phases L2 L3
Voltage L31	True RMS value of the voltage between phases L3 L1
Frequency	Frequency

3.3.11 STATUS MONITORING THE SWITCHING DEVICES

The status of circuit breakers and the disconnectors (line disconnector, bus disconnector, earthing switch) are monitored continuously. This function also enables operation of these devices using the screen of the local LCD. To do this the user can define the user screen and the active scheme.

3.3.12 TRIP CIRCUIT SUPERVISION

All four fast acting trip contacts contain build-in trip circuit supervision function. The output voltage of the circuit is 5V(+-1V). The pickup resistance is 2.5kohm(+-1kohm).

Note: Pay attention to the polarity of the auxiliary voltage supply as outputs are polarity dependent.

3.3.13 LED ASSIGNMENT

On the front panel of the device there is “User LED”-s with the “Changeable LED description label”. Some LED-s are factory assigned, some are free to be defined by the user. Table below shows the LED assignment of the AQ-F350 factory configuration.

Table 3-58 The LED assignment

LED	Explanation
Gen. Trip	Trip command generated by the TRC94 function
OC trip	Trip command generated by the phase overcurrent protection functions
OCN trip	Trip command generated by the residual overcurrent protection functions
Therm. Trip	Trip command of the line thermal protection function
Unbal. Trip	Trip command of the current unbalance protection function
Inrush	Inrush current detected
Voltage trip	Trip command generated by the voltage-related functions
Frequ trip	Trip command generated by the frequency-related functions
REC blocked	Blocked state of the automatic reclosing function
Reclose	Reclose command of the automatic reclosing function
Final trip	Final trip command at the end of the automatic reclosing cycles
LED 312	Free LED
LED 313	Free LED
LED 314	Free LED
LED 315	Free LED
LED 316	Free LED

4 SYSTEM INTEGRATION

The AQ T3xx contains two ports for communicating to upper level supervisory system and one for process bus communication. The physical media or the ports can be either serial fiber optic or RJ 45 or Ethernet fiber optic.

The AQ T3xx Transformer protection IED communicates using IEC 61850, IEC 101, IEC 103, IEC 104, Modbus RTU, DNP3.0 and SPA protocols. For details of each protocol refer to respective interoperability lists.

5 CONNECTIONS

5.1 BLOCK DIAGRAM AQ-T352 MINIMUM OPTIONS

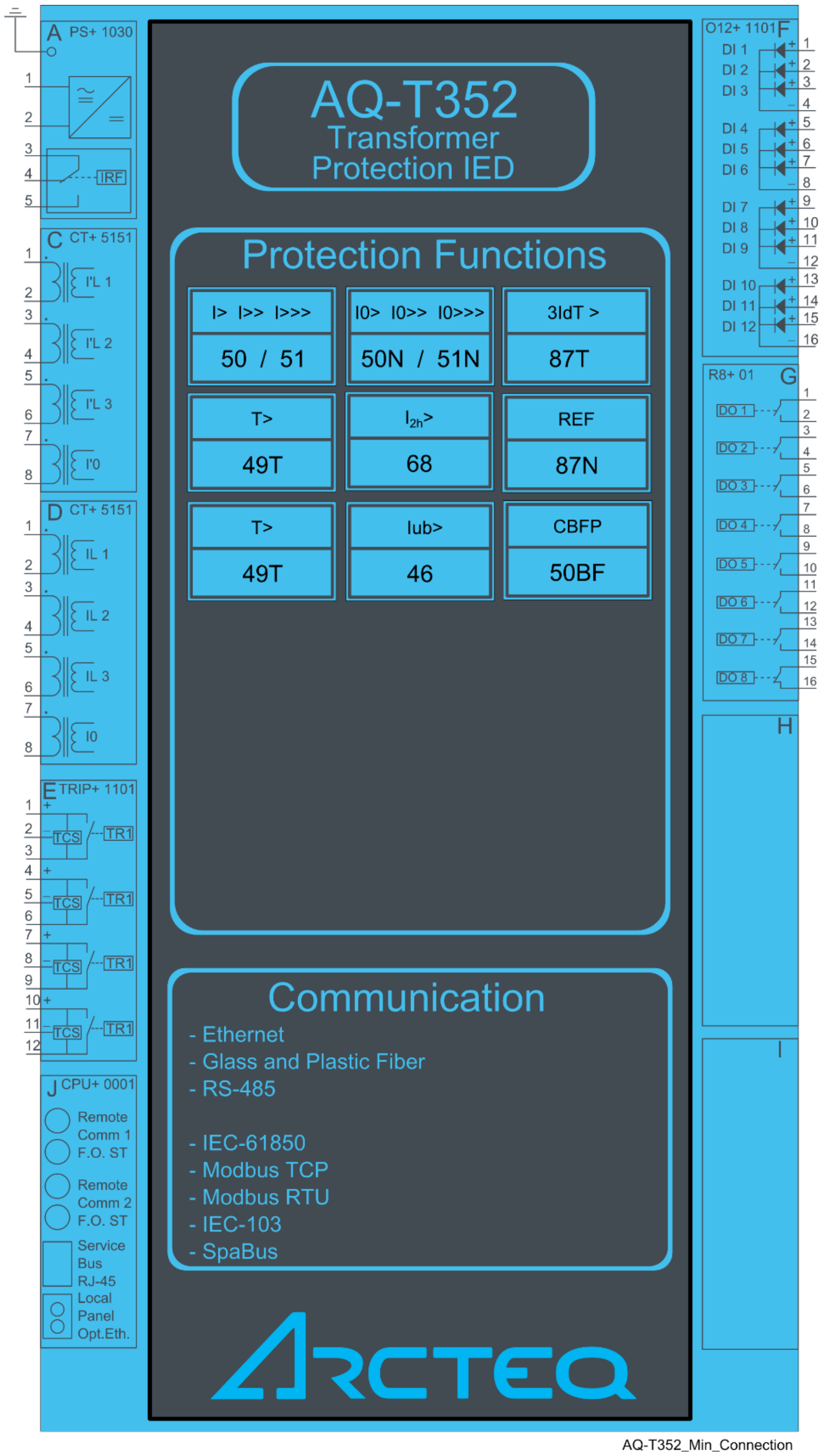


Figure 5-1 Block diagram of AQ-T352 with minimum options installed.

5.2 BLOCK DIAGRAM AQ-T352 ALL OPTIONS

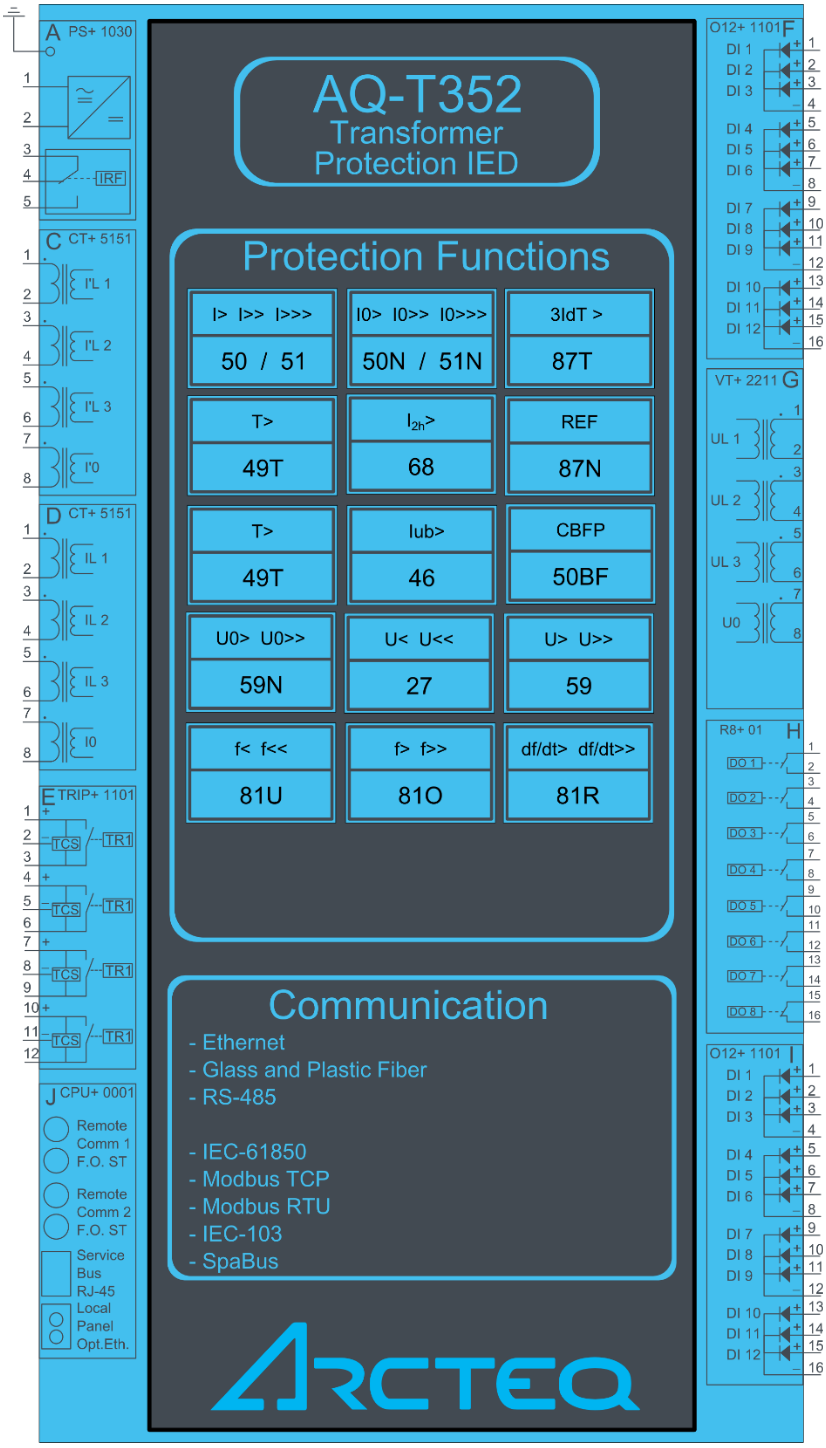


Figure 5-2 Block diagram of AQ-T352 with all options installed.

If voltage measurement option is installed into the IED, voltage based protection functions are available. For the E and F slots can be installed either DI or DO options.

5.3 CONNECTION EXAMPLE OF AQ-T352

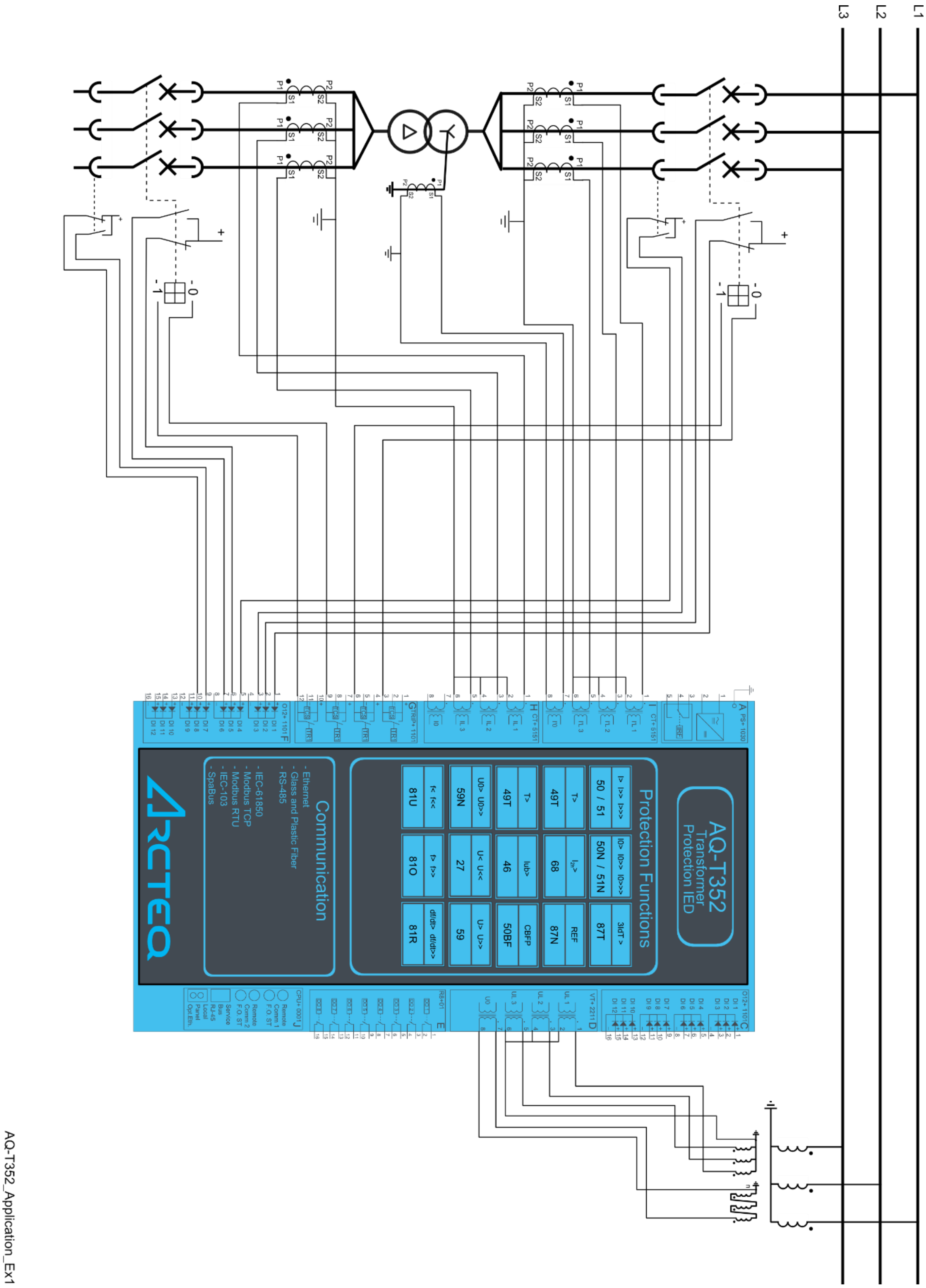
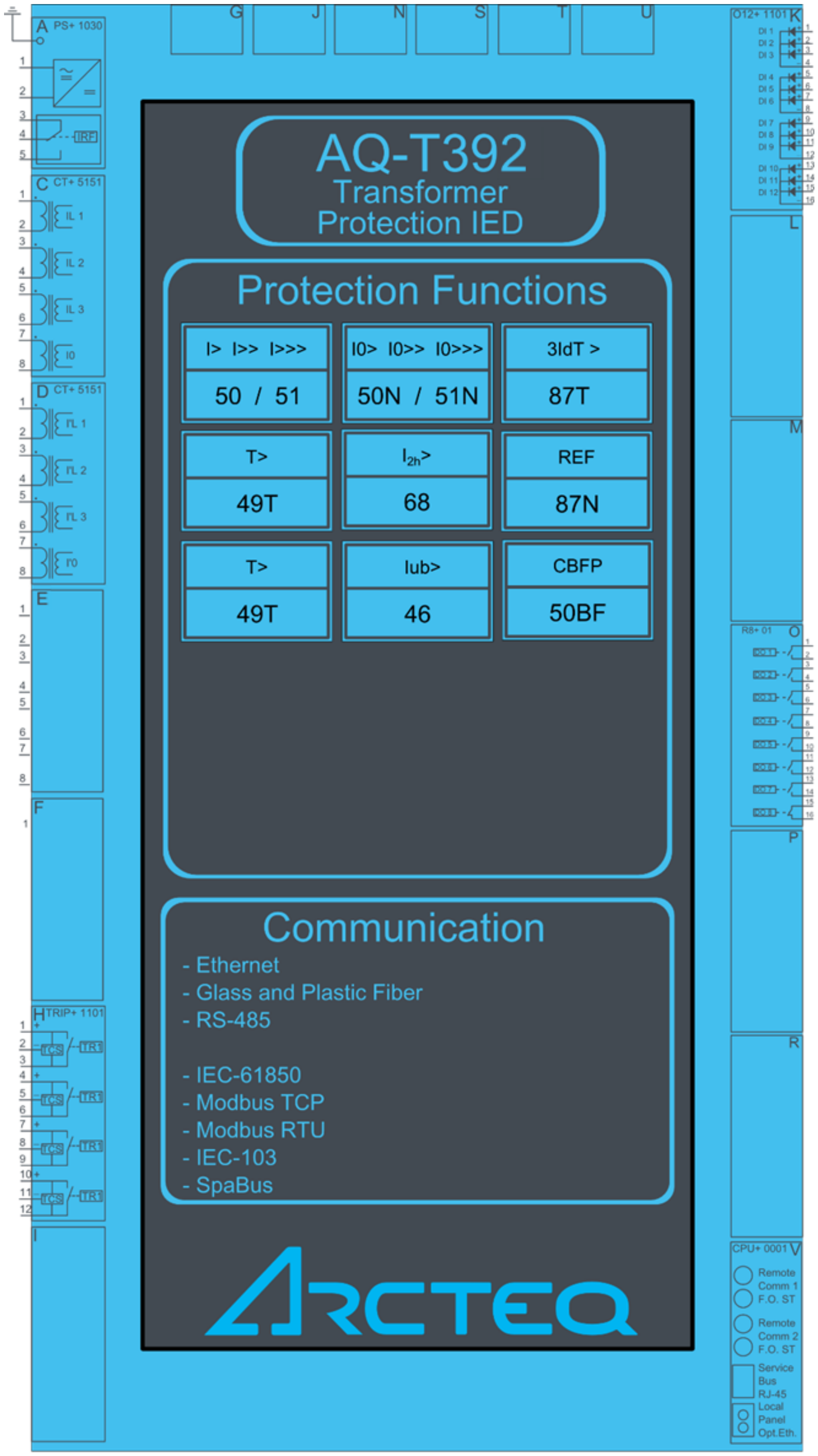


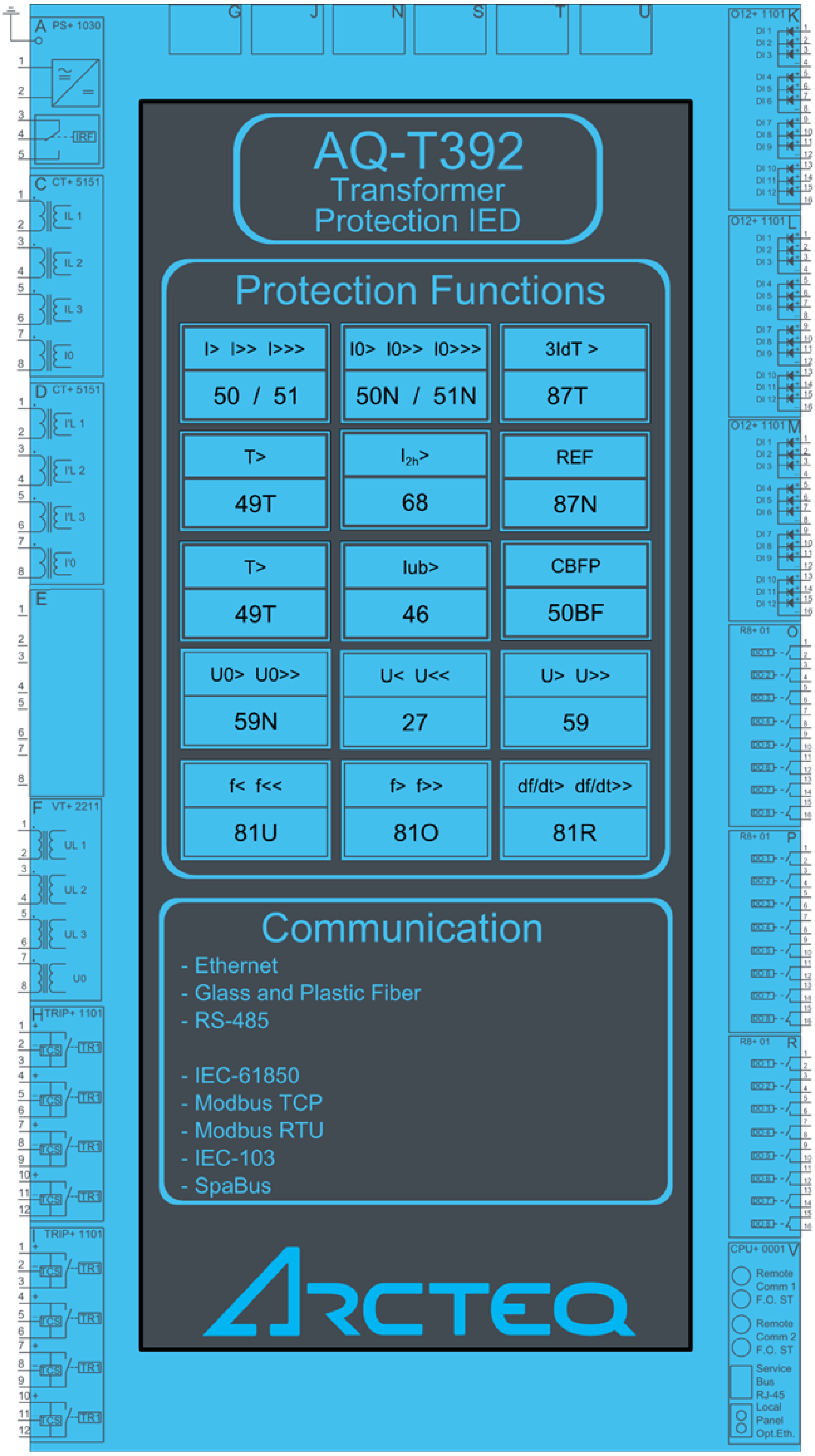
Figure 5-3 Connection example of AQ-T352 transformer protection IED.

5.4 BLOCK DIAGRAM AQ-T392 MINIMUM OPTIONS



AQ-T393_Min_Connection

5.5 Block diagram AQ-T392 all options



AQ-T393_Full_Connection

5.6 BLOCK DIAGRAM AQ-T393 MINIMUM OPTIONS

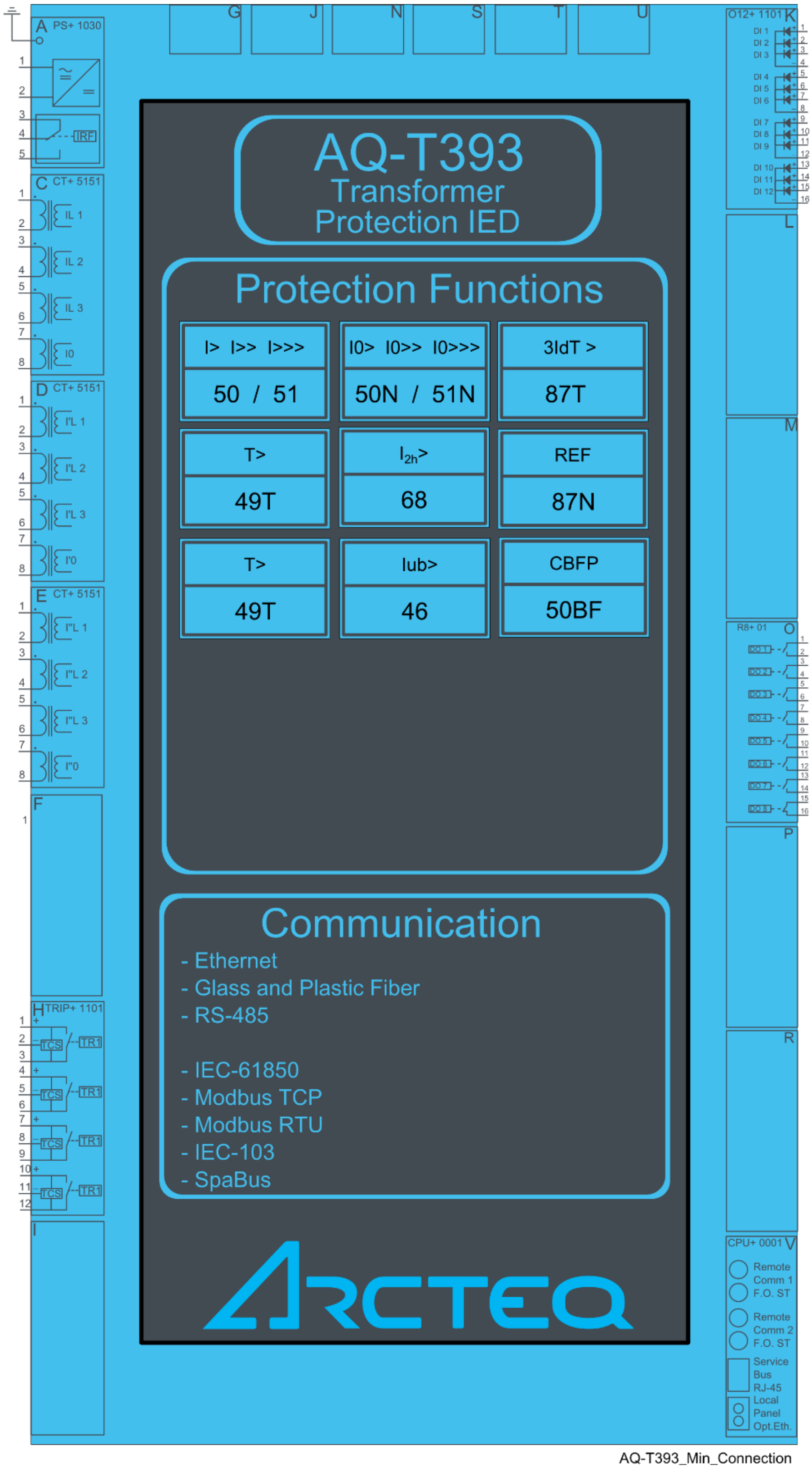


Figure 5-4 Block diagram of AQ-T393 with minimum options installed

5.7 Block diagram AQ-T393 all options

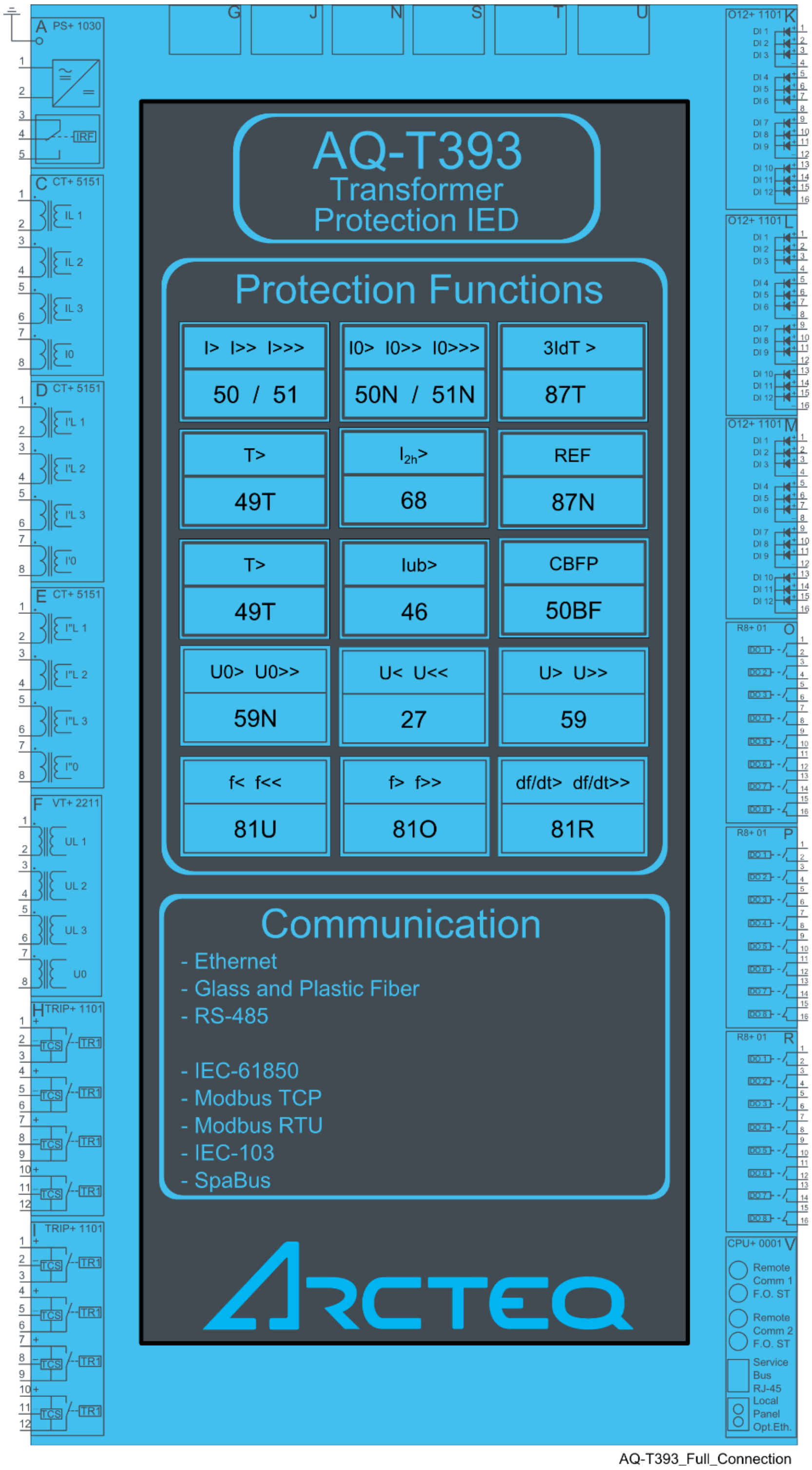


Figure 5-5 Block diagram of AQ-T393 with all options installed.

IED has six spare slots available for option cards which are not used in this example.

5.8 Connection example of AQ-T393

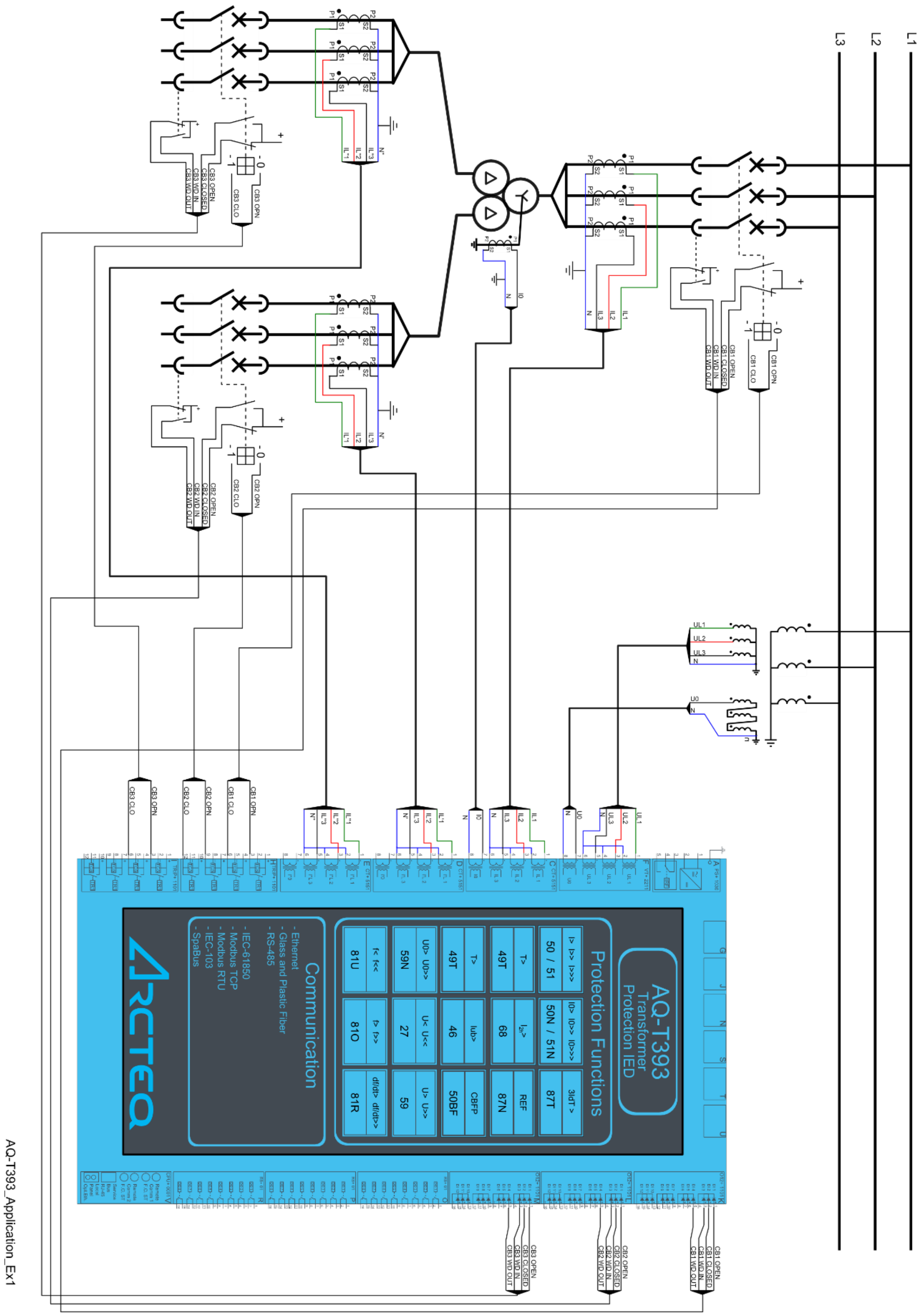


Figure 5-1 Connection example of AQ-T393 Transformer protection IED.

6 Construction and installation

6.1 Construction and installation of AQ-T352

The Arcteq AQ-T352 Transformer protection IED consists of hardware modules. Due to modular structure optional positions for the slots F, G, H and I can be user defined in the ordering of the IED to include I/O modules and other types of additional modules. An example module arrangement configuration of the AQ-T352 IED is shown in the figure below. Visit https://configurator.arcteq.fi/ to see all of the available options.

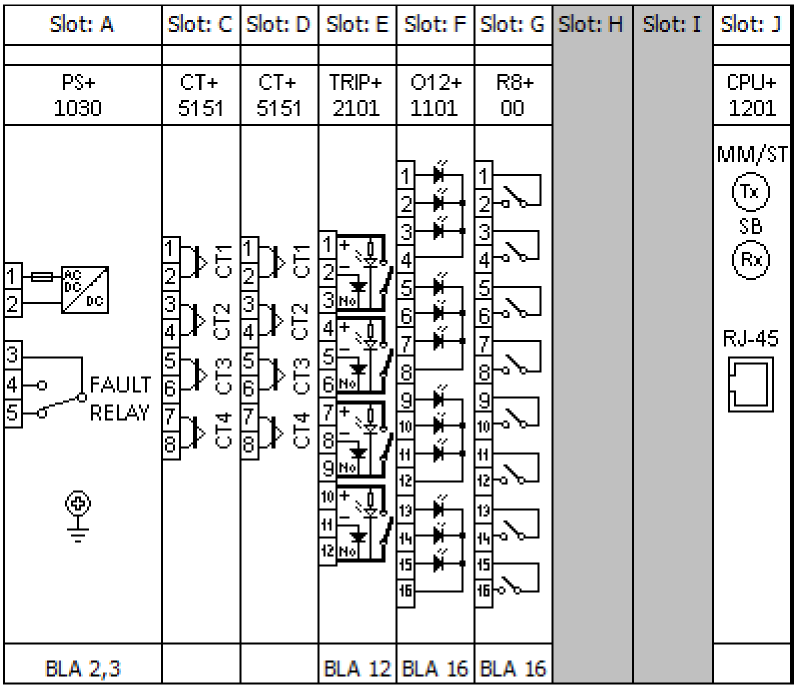


Figure 6-1. An example module arrangement configuration of the AQ-T352 IED.

Table 6-1. Hardware modules description of AQ-T352.

Position	Module identifier	Explanation
A-B	PS+ 1030	Power supply unit, 85-265 VAC, 88-300 VDC
C	CT + 5151	Analog current input module for primary currents
D	CT + 5151	Analog current input module for secondary currents
E	TRIP+ 2101	Trip relay output module, 4 tripping contacts
F	O12+ 1101	Binary input module. 12 inputs.
G	R8+ 00	Binary output module. 8 outputs.
H	Spare	-
I	Spare	-
J	CPU+ 1201	Processor and communication module

6.2 Construction and installation of AQ-T392

The Arcteq AQ-T392 Transformer protection IED consists of hardware modules. Due to modular structure optional positions for the slots J, K, L, M, N, O, P, R, S and T can be user defined in the ordering of the IED to include I/O modules and other types of additional modules. An example module arrangement configuration of the AQ-T392 IED is shown in the figure below. Visit https://configurator.arcteq.fi/ to see all of the available options.

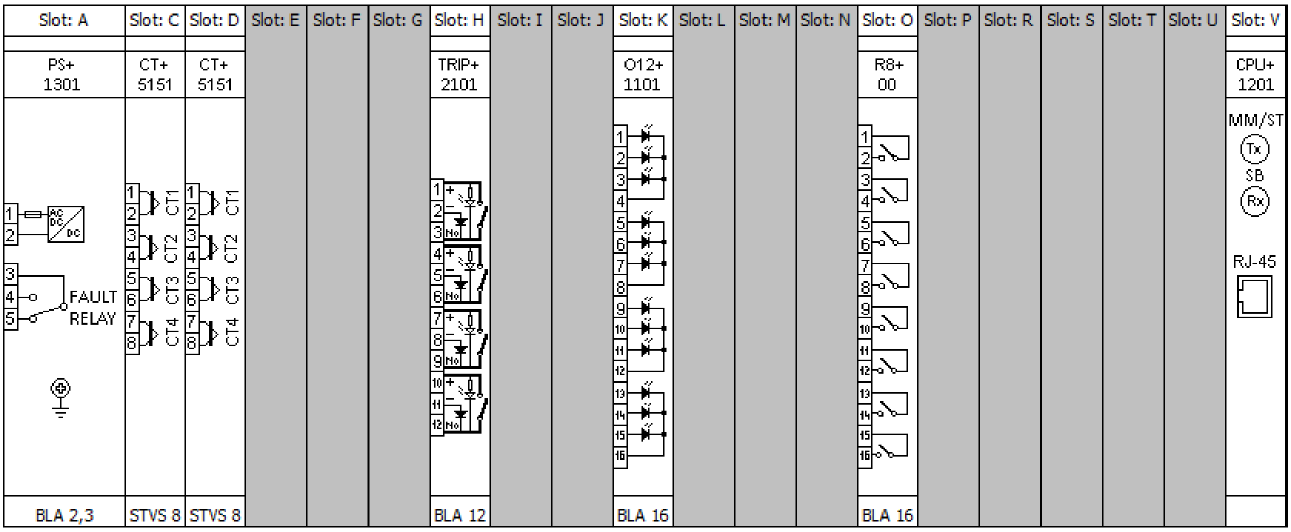


Figure 6-2. Hardware modules of the AQ-T392 basic IED.

Table 6-2. Hardware modules description of AQ-T392 basic IED.

Position	Module identifier	Explanation
A-B	PS+ 1030	Power supply unit, 85-265 VAC, 88-300 VDC
C	CT + 5151	Analog current input module for primary currents
D	CT + 5151	Analog current input module for secondary currents
E	-	-
F	-	-
G	-	-
H	TRIP+ 2101	Trip relay output module, 4 tripping contacts
I	Spare	-
J	Spare	-
K	O12+ 1101	Binary input module. 12 inputs.
L	Spare	-
M	Spare	-
N	Spare	-
O	R8+ 00	Binary output module 8 outputs.
P	Spare	-
R	Spare	-
S	Spare	-
T	Spare	-
U	-	-
V	CPU+ 1201	Processor and communication module

6.3 CONSTRUCTION AND INSTALLATION OF AQ-T393

The Arcteq AQ-T393 Transformer protection IED consists of hardware modules. Due to modular structure optional positions for the slots J, K, L, M, N, O, P, R, S and T can be user defined in the ordering of the IED to include I/O modules and other types of additional modules. An example module arrangement configuration of the AQ-T353 IED is shown in the figure below. Visit https://configurator.arcteq.fi/ to see all of the available options.

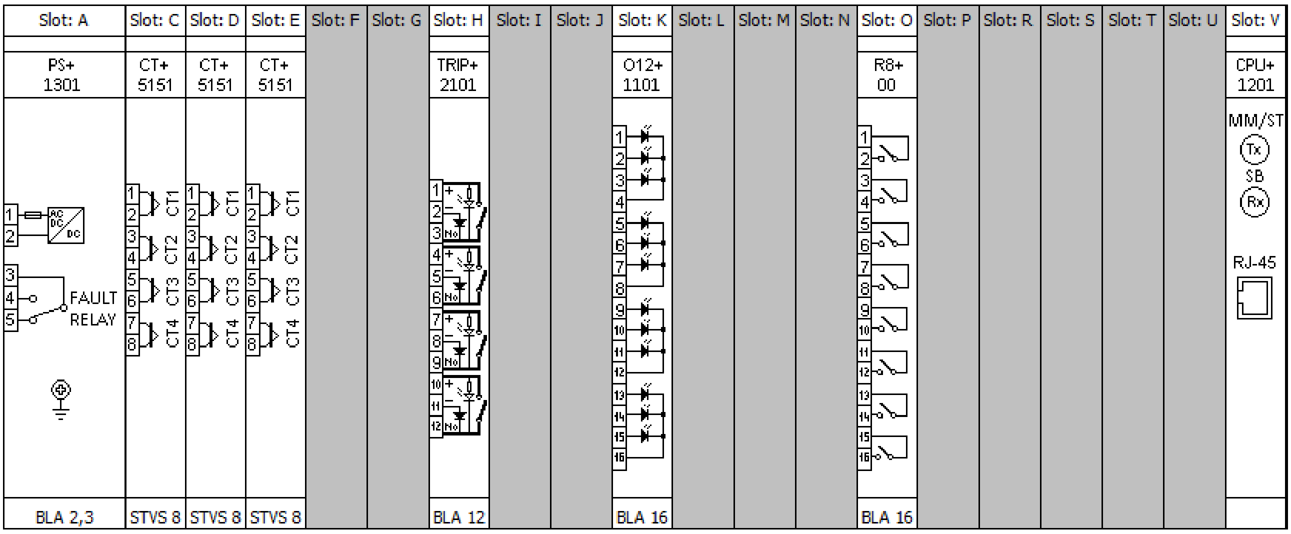


Figure 6-3. Hardware modules of the AQ-T393 basic IED.

Table 6-3. Hardware modules description of AQ-T393 basic IED.

Position	Module identifier	Explanation
A-B	PS+ 1030	Power supply unit, 85-265 VAC, 88-300 VDC
C	CT + 5151	Analog current input module for primary currents
D	CT + 5151	Analog current input module for secondary currents
E	CT + 5151	Analog current input module for tertiary currents
F	Spare	-
G	-	-
H	TRIP+ 2101	Trip relay output module, 4 tripping contacts
I	-	-
J	Spare	-
K	O12+ 1101	Binary input module. 12 inputs.
L	Spare	-
M	Spare	-
N	Spare	-
O	R8+ 00	Output module 8 outputs.
P	Spare	-
R	Spare	-
S	Spare	-
T	Spare	-
U	-	-
V	CPU+ 1201	Processor and communication module

6.4 CPU MODULE

The CPU module contains all the protection, control and communication functions of the AQ 3xx device. Dual 500 MHz high- performance Analog Devices Blackfin processors separates relay functions (RDSP) from communication and HMI functions (CDSP). Reliable communication between processors is performed via high- speed synchronous serial internal bus (SPORT).

Each processor has its own operative memory such as SDRAM and flash memories for configuration, parameter and firmware storage. CDSP's operating system (uClinux) utilizes a robust JFFS flash file system, which enables fail-safe operation and the storage of, disturbance record files, configuration and parameters.

After power-up the RDSP processor starts -up with the previously saved configuration and parameters. Generally, the power-up procedure for the RDSP and relay functions takes approx. 1 sec. That is to say, it is ready to trip within this time. CDSP's start-up procedure is longer, because its operating system needs time to build its file system, initializing user applications such as HMI functions and the IEC61850 software stack.

The built-in 5- port Ethernet switch allows AQ 3xx device to connect to IP/Ethernet- based networks. The following Ethernet ports are available:

- Station bus (100Base-FX Ethernet)
- Redundant Station bus (100Base-FX Ethernet)
- Process bus (100Base-FX Ethernet)
- EOB (Ethernet over Board) user interface
- Optional 100Base-Tx port via RJ-45 connector

Other communication

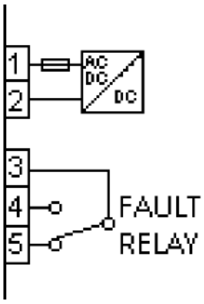
- RS422/RS485/RS232 interfaces
- Plastic or glass fiber interfaces to support legacy protocols
- Process-bus communication controller on COM+ card

6.5 POWER SUPPLY MODULE

The power supply module converts primary AC and/or DC voltage to required system voltages. Redundant power supply cards extend system availability in case of the outage of any power source and can be ordered separately if required

Figure 6-1 Connector allocation of the 30W power supply unit

"A" "B"	PS+/1030
No.	Name
1	AuxPS+
2	AuxPS-
3	Fault Relay Common
4	Fault Relay NO
5	Fault Relay NC



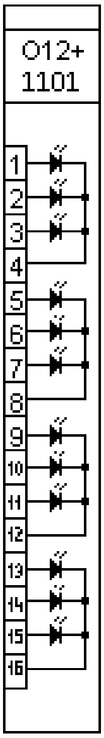
Main features of the power supply module

- 30W input
- Maximum 100ms power interruption time: measured at nominal input voltage with nominal power consumption
- IED system fault contacts (NC and NO): device fault contact and also assignable to user functions. All the three relay contact points (NO, NC, COM) are accessible to users 80V-300VDC input range, AC power is also supported
- Redundant applications which require two independent power supply modules can be ordered optionally
- On-board self-supervisory circuits: temperature and voltage monitors
- Short-circuit-protected outputs
- Efficiency: >70%
- Passive heat sink cooling
- Early power failure indication signals to the CPU the possibility of power outage, thus the CPU has enough time to save the necessary data to non-volatile memory

6.6 BINARY INPUT MODULE

The inputs are galvanic isolated and the module converts high-voltage signals to the voltage level and format of the internal circuits. This module is also used as an external IRIG-B synchronization input. Dedicated synchronization input (input channel 1) is used for this purpose.

"F"	O12+/1101
No.	Name
1	BIn_F01
2	BIn_F02
3	BIn_F03
4	Opto-(1-3)
5	BIn_F04
6	BIn_F05
7	BIn_F06
8	Opto-(4-6)
9	BIn_F07
10	BIn_F08
11	BIn_F09
12	Opto-(7-9)
13	BIn_F10
14	BIn_F11
15	BIn_F12
16	Opto-(10-12)



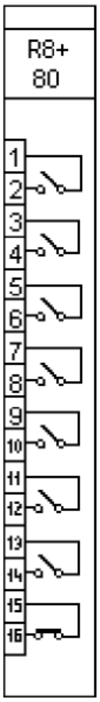
The binary input modules are

- Rated input voltage: 110/220Vdc
- Clamp voltage: falling 0.75Un, rising 0.78Un
- Digitally filtered per channel
- Current drain approx.: 2 mA per channel
- 12 inputs.
- IRIG-B timing and synchronization input

6.7 BINARY OUTPUT MODULES FOR SIGNALING

The signaling output modules can be ordered as 8 relay outputs with dry contacts.

"H"	R8+/80
No.	Name
1	BOut_H01 Common
2	BOut_H01 NO
3	BOut_H02 Common
4	BOut_H02 NO
5	BOut_H03 Common
6	BOut_H03 NO
7	BOut_H04 Common
8	BOut_H04 NO
9	BOut_H05 Common
10	BOut_H05 NO
11	BOut_H06 Common
12	BOut_H06 NC
13	BOut_H07 Common
14	BOut_H07 NO
15	BOut_H08 Common
16	BOut_H08 NC

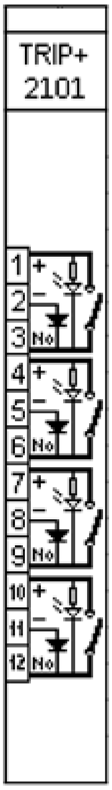


- Rated voltage: 250 V AC/DC
- Continuous carry: 8 A
- Breaking capacity, (L/R=40ms) at 220 V DC: 0,2 A
- 8 contacts, 7 NO and 1 NC

6.8 TRIPPING MODULE

The tripping module applies direct control of a circuit breaker. The module provides fast operation and is rated for heavy duty controlling.

"E"	TRIP+/2101
No.	Name
1	Trip1 +
2	Trip1 -
3	Trip1 NO
4	Trip 2 +
5	Trip 2 -
6	Trip 2 NO
7	Trip 3 +
8	Trip 3 -
9	Trip 3 NO
10	Trip 4 +
11	Trip 4 -
12	Trip 4 NO



The main characteristics of the trip module:

- 4 independent tripping circuits
- High-speed operation
- Rated voltage: 110V, 220V DC
- Continuous carry: 8 A
- Making capacity: 0.5s, 30 A
- Breaking capacity: (L/R=40ms) at 220 VDC: 4A
- Trip circuit supervision for each trip contact

6.9 VOLTAGE MEASUREMENT MODULE

For voltage related functions (over- /under -voltage, directional functions, distance function, power functions) or disturbance recorder functionality this module is needed. This module also has capability for frequency measurement.

For capacitive voltage measurement of the synchrocheck reference, the voltage measurement module can be ordered with reduced burden in channel VT4. In this module the burden is < 50 mVA.

"D"	VT+/2211
No.	Name
1	U L1->
2	U L1<-
3	U L2->
4	U L2<-
5	U L3->
6	U L3<-
7	U Bus->
8	U Bus<-

The main characteristics of the voltage measurement module:

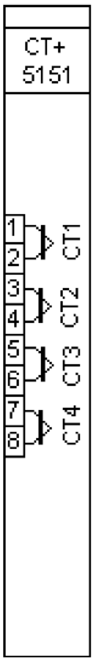
- Number of channels: 4
- Rated frequency: 50Hz, 60Hz
- Selectable rated voltage (Un): 100/√3, 100V, 200/√3, 200V by parameter
- Voltage measuring range: 0.05 Un – 1.2 Un
- Continuous voltage withstand: 250 V
- Power consumption of voltage input: ≤1 VA at 200V (with special CVT module the burden is < 50 mVA for VT4 channel)
- Relative accuracy: ±0,5 %
- Frequency measurement range: ±0,01 % at Ux 25 % of rated voltage
- Measurement of phase angle: 0.5º Ux 25 % of rated voltage

6.10 CURRENT MEASUREMENT MODULE

Current measurement module is used for measuring current transformer output current. Module includes three phase current inputs and one zero sequence current input. The nominal rated current of the input can be selected with a software parameter either 1 A or 5 A.

Table 6-4: Connector allocation of the current measurement module I

"C"	CT+/515
No.	Name
1	I L1->
2	I L1<-
3	I L2->
4	I L2<-
5	I L3->
6	I L3<-
7	I4->
8	I4<-

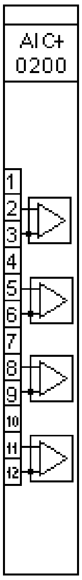


- Number of channels: 4
- Rated frequency: 50Hz, 60Hz
- Electronic iron-core flux compensation
- Low consumption: ≤0,1 VA at rated current
- Current measuring range: 35 x In
- Selectable rated current 1A/5A by parameter
- Thermal withstand: 20 A (continuously)
    - 500 A (for 1 s)
    - 1200 A (for 10 ms)
- Relative accuracy: ±0,5%
- Measurement of phase angle: 0.5º, Ix 10 % rated current

6.11 MA INPUT MODULE

The analog input module accepts transducers current outputs. The AIC module can measure unipolar and bipolar current values in wide ranges.

"T"	AIC+/0200
No.	Name
1	NU
2	Tr. TC Pos. IN
3	Tr. TC Pos. GND
4	NU
5	MAn_T02 IN
6	MAn_T02 GND
7	NU
8	MAn_T03 IN
9	MAn_T03 GND
10	NU
11	MAn_T04 IN
12	MAn_T04 GND



- Number of channels: 4
- Measurement method: 2 wire inputs with optional 15V excitation
- Relative accuracy: ± 0.5 % ± 1 digit
- Measurement ranges: ± 20 mA (typical 0-20, 4-20 mA) Rload = 56 Ω

6.12 INSTALLATION AND DIMENSIONS

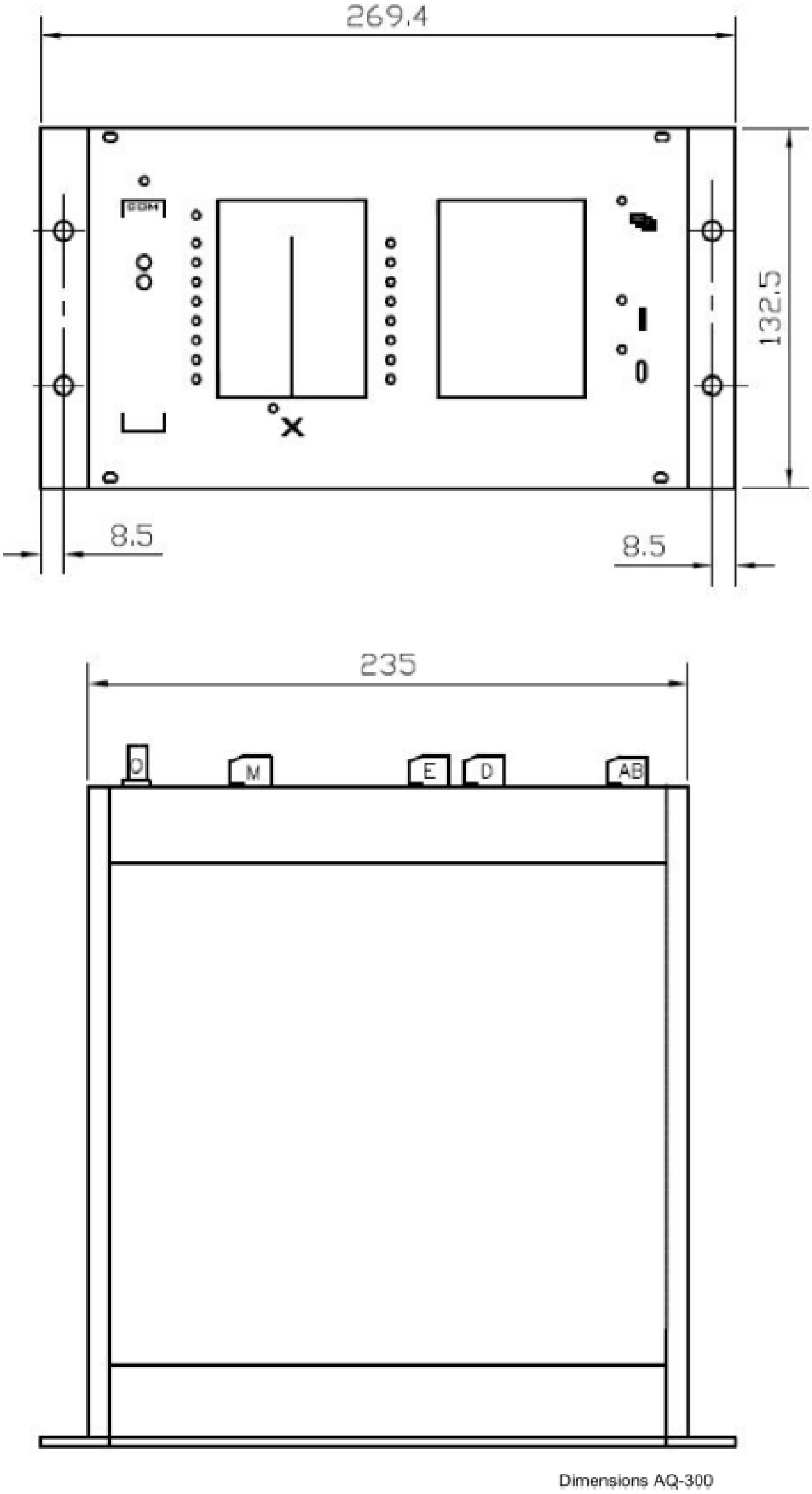


Figure 6-2: Dimensions of AQ-35x IED.

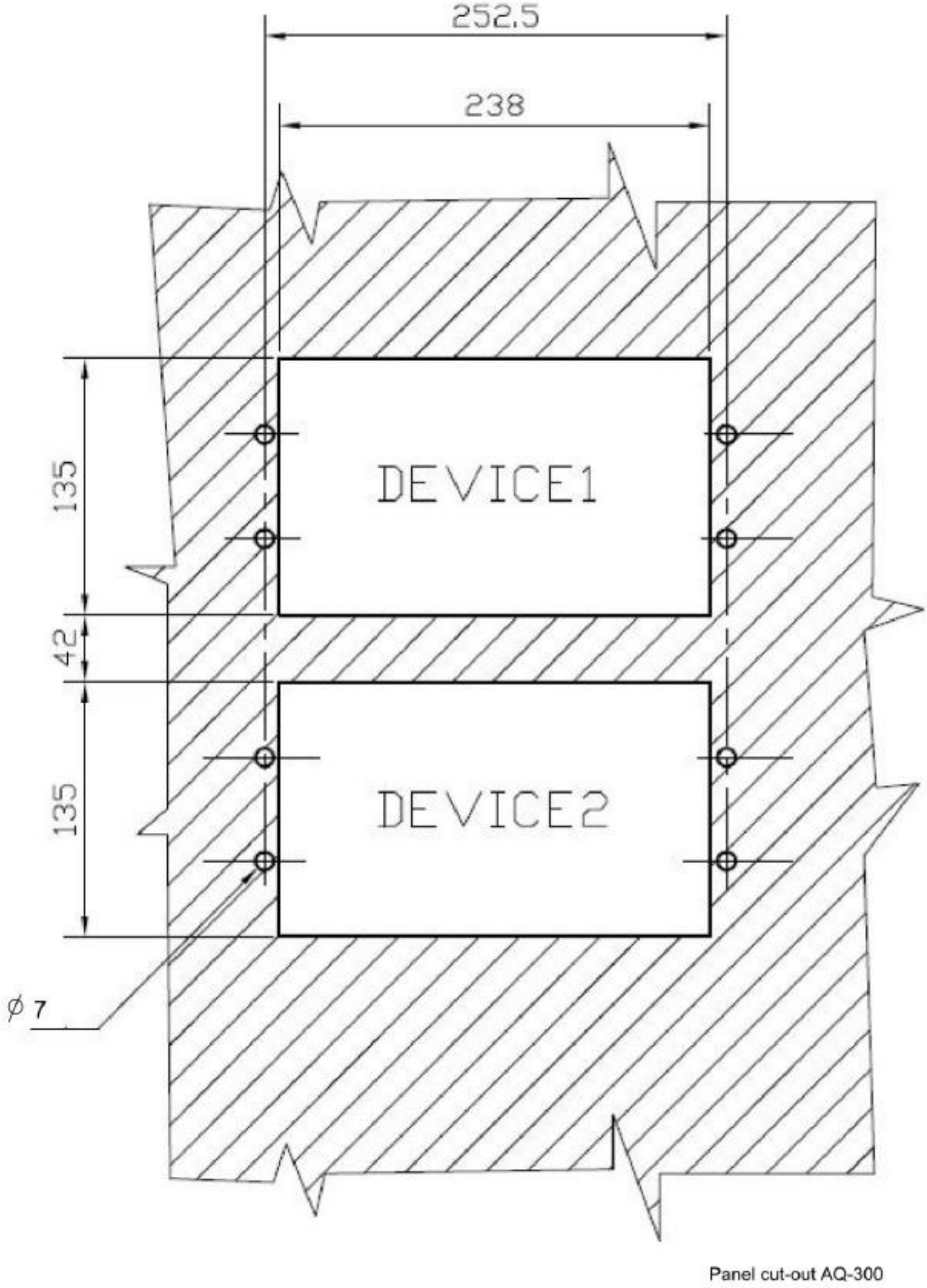


Figure 6-3: Panel cut-out and spacing of AQ-35x IED.

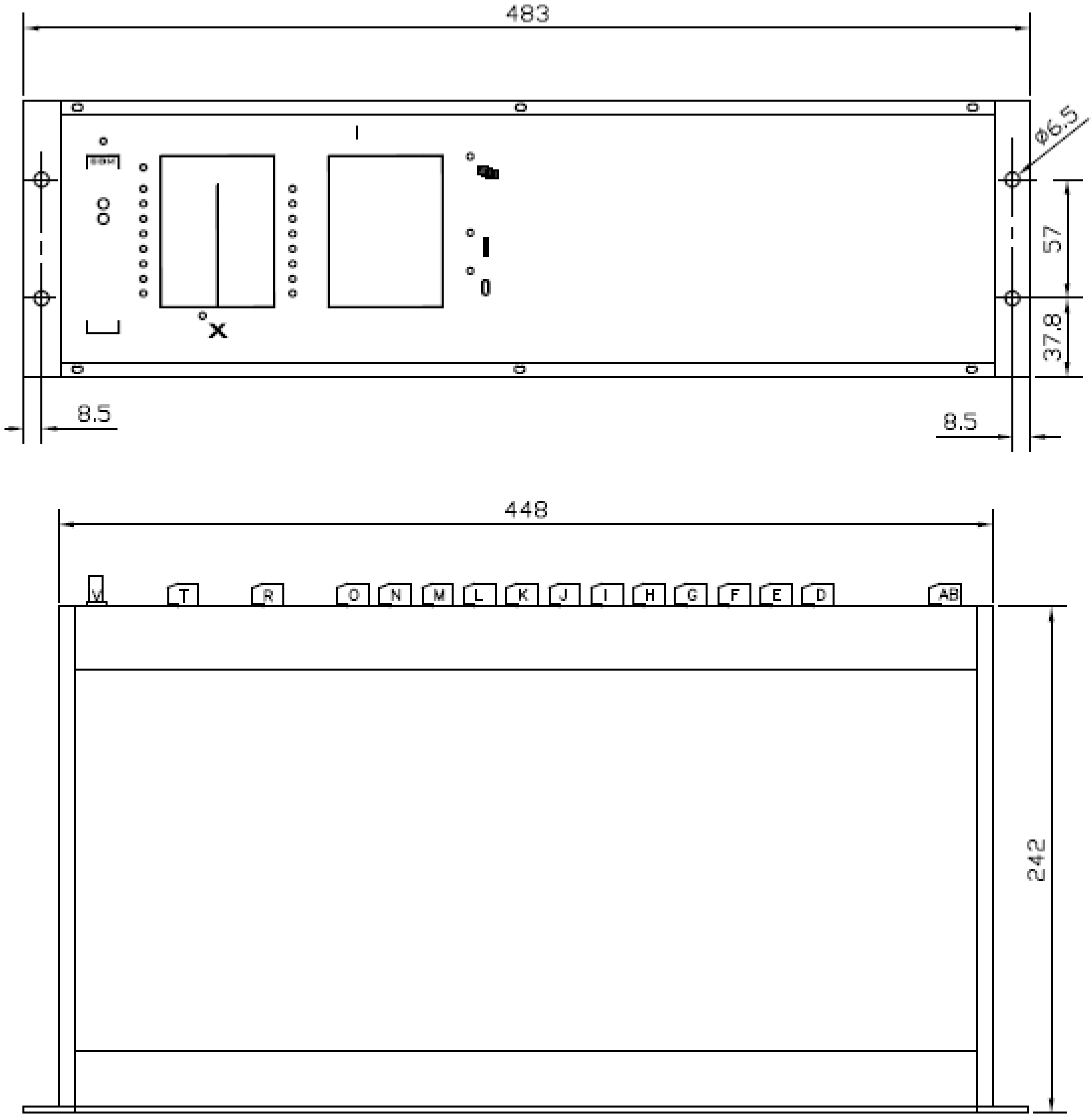


Figure 6-4: Dimensions of AQ-39x IED.

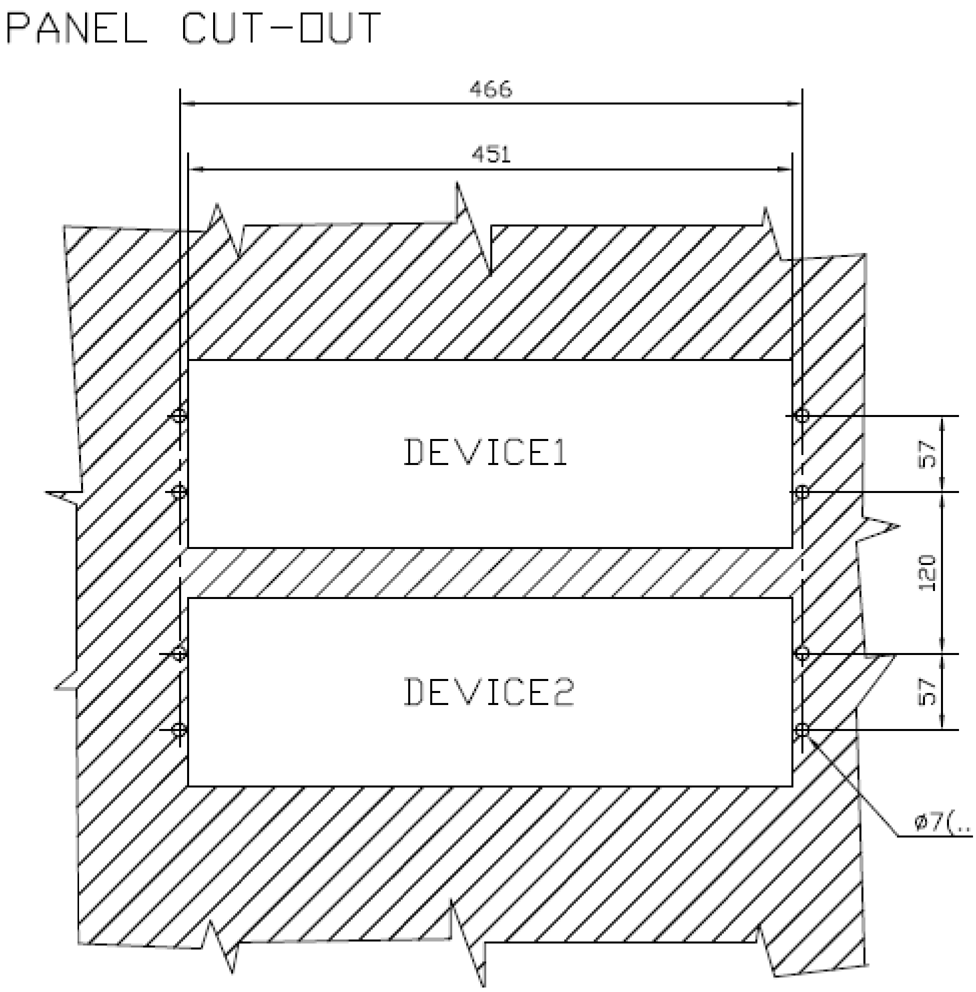


Figure 6-5: Panel cut-out and spacing of AQ-39x IED.

7 TECHNICAL DATA

7.1 PROTECTION FUNCTIONS

7.1.1 DIFFERENTIAL PROTECTION FUNCTIONS

Differential protection (87)	
Operating characteristic	2 breakpoint
Characteristics inaccuracy	<2%
Reset ratio	0,95
Operate time, unrestrained	Typically 20ms
Reset time, unrestrained	Typically 25ms
Operate time, restrained	Typically 30ms
Reset time, restrained	Typically 25ms

Restricted earth fault protection REF (87T)	
Operating characteristic	1 breakpoint
Characteristics inaccuracy	<2%
Reset ratio	0.95
Operate time	<35ms
Reset time	<25ms

7.1.2 OVERCURRENT PROTECTION FUNCTIONS

Three-phase instantaneous overcurrent protection I>>> (50)	
Operating characteristic	Instantaneous
Pick-up current inaccuracy	<2%
Reset ratio	0.95
Operate time at 2*In Peak value calculation Fourier calculation	 <15 ms <25 ms
Reset time	16 – 25 ms
Transient overreach Peak value calculation Fourier calculation	 80 % 2 %

Residual instantaneous overcurrent protection I0>>> (50N)	
Operating characteristic	Instantaneous
Picku-up current inaccuracy	<2%
Reset ratio	0.95
Operate time at 2*In Peak value calculation Fourier calculation	 <15 ms <25 ms
Reset time	16 – 25 ms
Transient overreach Peak value calculation Fourier calculation	 80 % 2 %

Three-phase time overcurrent protection I>, I>> (50/51)	
Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %
Pickup time	25 – 30ms

Residual time overcurrent protection I0>, I0>> (51N)	
Pick-up current inaccuracy	< 2%
Operation time inaccuracy	±5% or ±15ms
Reset ratio	0.95
Minimum operating time with IDMT	35ms
Reset time	Approx 35ms
Transient overreach	2 %
Pickup time	25 – 30ms

7.1.3 Voltage protection functions

Overvoltage protection function U>, U>> (59)	
Pick-up starting inaccuracy	< 0,5 %
Reset time U> → Un U> → 0	 50 ms 40 ms
Operation time inaccuracy	+ 15 ms

Undervoltage protection function U<, U<< (27)	
Pick-up starting inaccuracy	< 0,5 %
Reset time U> → Un U> → 0	 50 ms 40 ms
Operation time inaccuracy	+ 15 ms

Residual overvoltage protection function U0>, U0>> (59N)	
Pick-up starting inaccuracy	< 0,5 %
Reset time U> → Un U> → 0	 50 ms 40 ms
Operate time inaccuracy	+ 15 ms

7.1.4 Frequency protection functions

Overfrequency protection function f>, f>>, (81O)	
Operating range	40 - 60 Hz
Operating range inaccuracy	30mHz
Effective range inaccuracy	2mHz
Minimum operating time	100ms
Operation time inaccuracy	+ 10ms
Reset ratio	0,99

Underfrequency protection function f<, f<<, (81U)	
Operating range	40 - 60 Hz
Operating range inaccuracy	30mHz
Effective range inaccuracy	2mHz
Minimum operating time	100ms
Operation time inaccuracy	+ 10ms
Reset ratio	0,99

Rate of change of frequency protection function df/dt>, df/dt>> (81R)	
Effective operating range	-5 - +5Hz/sec
Pick-up inaccuracy	0,01Hz/sec
Minimum operating time	100 ms
Operation time inaccuracy	+ 15ms

7.1.5 Other protection functions

Current unbalance protection function (60)	
Pick-up starting inaccuracy at In	< 2 %
Reset ratio	0,95
Operate time	70 ms

Thermal overload protection function T>, (49)	
Operation time inaccuracy at I>1.2*Itrip	3 % or + 20ms

Breaker failure protection function CBFP, (50BF)	
Current inaccuracy	<2 %
Re-trip time	Approx. 15ms
Operation time inaccuracy	+ 5ms
Current reset time	20ms

Inrush current detection function INR2, (68)	
Current inaccuracy	<2 %
Reset ratio	0,95
Operating time	Approx. 20 ms

Overexcitation/volts per hertz protection V/Hz, (24)	
Frequency range	10…70Hz
Voltage range	10…170V secondary
Voltage measurement inaccuracy	<1% (0.5 – 1.2xUn)
Frequency measurement inaccuracy	<1% (0.8 – 1.2xfn)

7.2 CONTROL FUNCTIONS

Voltage transformer supervision function VTS, (60)	
Pick-up voltage inaccuracy	1%
Operation time inaccuracy	<20ms
Reset ratio	0.95

Current transformer supervision function CTS	
Pick-up starting inaccuracy at In	<2%
Minimum operation time	70ms
Reset ratio	0.95

Synchrocheck function du/df (25)	
Rated Voltage Un	100/200V, setting parameter
Voltage effective range	10-110 % of Un
Voltage inaccuracy	±1% of Un
Frequency effective range	47.5 – 52.5 Hz
Frequency inaccuracy	±10mHz
Phase angle inaccuracy	±3 °
Operate time inaccuracy	±3ms
Reset time	<50ms
Reset ratio	0.95

Automatic tap changer controller		
Function	**Range**	**Accuracy**
Voltage measurement	50% < U < 130%	<1%
Definite time delay		<2% or +/-20ms, whichever is greater
Inverse and “2powerN” time delay	12% < DU < 25%	<5%
	25% < DU < 50%	2% or +/- 20ms, whichever is greater

7.3 Hardware

7.3.1 Power supply module

Rated voltage	80-300Vac/dc
Maximum interruption	100ms
Maximum power consumption	30W

7.3.2 Current measurement module

Nominal current	1/5A (parameter settable) 0.2A (ordering option)
Number of channels per module	4
Rated frequency	50Hz 60Hz (ordering option)
Burden	<0.1VA at rated current
Thermal withstand	20A (continuous) 500A (for 1s) 1200A (for 10ms)
Current measurement range	0-50xIn

7.3.3 Voltage measurement module

Rated voltage Un	100/√3, 100V, 200/√3, 200V (parameter settable)
Number of channels per module	4
Rated frequency	50Hz 60Hz (ordering option)
Burden	<1VA at 200V
Voltage withstand	250V (continuous)
Voltage measurement range	0.05-1.2xUn

7.3.4 High speed trip module

Rated voltage Un	110/220Vdc
Number of outputs per module	4
Continuous carry	8A
Making capacity	30A (0.5s)
Breaking capacity	4A (L/R=40ms, 220Vdc)

7.3.5 Binary output module

Rated voltage Un	250Vac/dc
Number of outputs per module	7 (NO) + 1(NC)
Continuous carry	8A
Breaking capacity	0.2A (L/R=40ms, 220Vdc)

7.3.6 Binary input module

Rated voltage Un	110 or 220Vdc (ordering option)
Number of inputs per module	12 (in groups of 3)
Current drain	approx. 2mA per channel
Breaking capacity	0.2A (L/R=40ms, 220Vdc)

7.3.7 mA input module

Number of channels	4
Measurement method	2 wire inputs with optional 15V excitation
Relative accuracy	± 0.5 % ± 1 digit
Measurement ranges	± 20 mA (typical 0-20, 4-20 mA) Rload = 56 Ω

7.4 TESTS AND ENVIRONMENTAL CONDITIONS

7.4.1 DISTURBANCE TESTS

EMC test	CE approved and tested according to EN 50081-2, EN 50082-2
Emission - Conducted (EN 55011 class A) - Emitted (EN 55011 class A)	0.15 - 30MHz 30 - 1 000MHz
Immunity	
- Static discharge (ESD) (According to IEC244-22-2 and EN61000-4-2, class III)	Air discharge 8kV Contact discharge 6kV
- Fast transients (EFT) (According to EN61000-4-4, class III and IEC801-4, level 4)	Power supply input 4kV, 5/50ns other inputs and outputs 4kV, 5/50ns
- Surge (According to EN61000-4-5 [09/96], level 4)	Between wires 2 kV / 1.2/50µs Between wire and earth 4 kV / 1.2/50µs
- RF electromagnetic field test (According. to EN 61000-4-3, class III)	f = 80….1000 MHz 10V /m
- Conducted RF field (According. to EN 61000-4-6, class III)	f = 150 kHz….80 MHz 10V

7.4.2 VOLTAGE TESTS

Insulation test voltage acc- to IEC 60255-5	2 kV, 50Hz, 1min
Impulse test voltage acc- to IEC 60255-5	5 kV, 1.2/50us, 0.5J

7.4.3 MECHANICAL TESTS

Vibration test	2 ... 13.2 Hz ±3.5mm 13.2 ... 100Hz, ±1.0g
Shock/Bump test acc. to IEC 60255-21-2	20g, 1000 bumps/dir.

7.4.4 CASING AND PACKAGE

Protection degree (front)	IP 54 (with optional cover)
Weight	5kg net 6kg with package

7.4.5 ENVIRONMENTAL CONDITIONS

Specified ambient service temp. range	-10…+55°C
Transport and storage temp. range	-40…+70°C

8 ORDERING INFORMATION

Visit https://configurator.arcteq.fi/ to build a hardware configuration, define an ordering code and get a module layout image.

9 REFERENCE INFORMATION

Manufacturer information:

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