RELION® PROTECTION AND CONTROL

620 series ANSI

Technical Manual

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This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2014/30/EU) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2014/35/EU). This conformity is the result of tests conducted by ABB in accordance with the product standards EN 50263 and EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series and ANSI C37.90. This product complies with the UL 508 certification.

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Section 1 Introduction

1.1 This manual

The technical manual contains application and functionality descriptions and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

1.2 Intended audience

This manual addresses system engineers and installation and commissioning personnel, who use technical data during engineering, installation and commissioning, and in normal service.

The system engineer must have a thorough knowledge of protection systems, protection equipment, protection functions and the configured functional logic in the protection relays. The installation and commissioning personnel must have a basic knowledge in handling electronic equipment.

1.3 Product documentation

1.3.1 Product documentation set

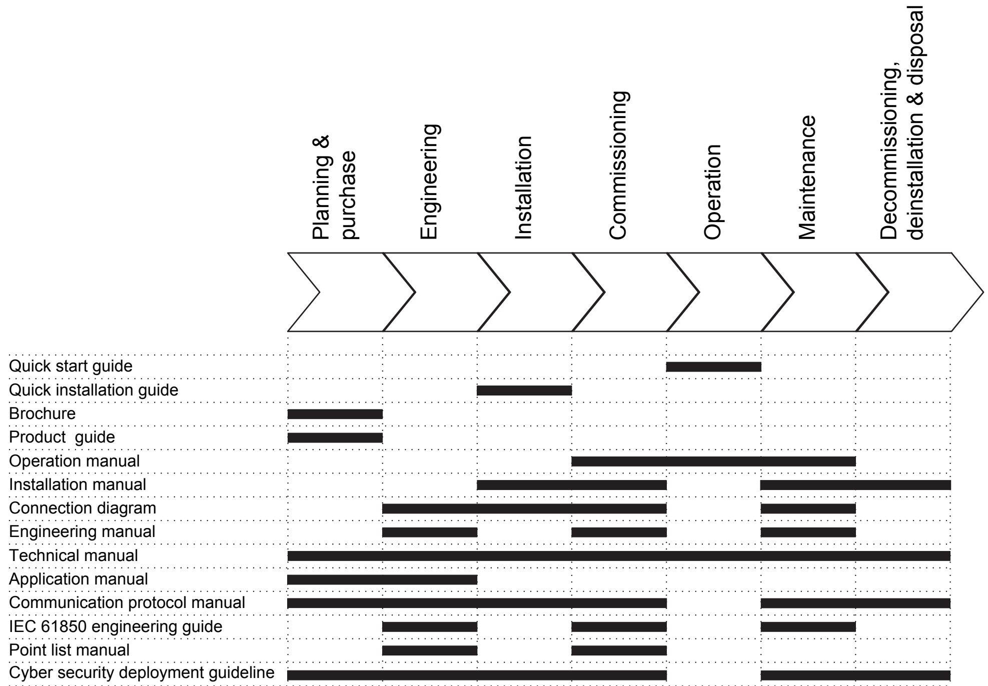

Figure 1: The intended use of documents during the product life cycle

Product series- and product-specific manuals can be downloaded from the ABB Web site http://www.abb.com/relion.

1.3.2 Document revision history

Document revision/date	Product series version	History
A/2012-10-31	2.0	First release
B/2015-11-25	2.1	Content updated with release of REM620 Ver.2.1
C/2018-10-08	2.0 and 2.1	Content updated
D/2019-05-17	2.0 and 2.1	Content updated
E/2019-05-29	2.0 and 2.1	Content updated

Download the latest documents from the ABB Web site http://www.abb.com/substationautomation.

1.3.3 Related documentation

Product series- and product-specific manuals can be downloaded from the ABB Web site http://www.abb.com/substationautomation.

1.4 Symbols and conventions

1.4.1 Symbols

The electrical warning icon indicates the presence of a hazard which could result in electrical shock.

The warning icon indicates the presence of a hazard which could result in personal injury.

The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.

The information icon alerts the reader of important facts and conditions.

The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

1.4.2 Document conventions

A particular convention may not be used in this manual.

- Abbreviations and acronyms are spelled out in the glossary. The glossary also contains definitions of important terms.
- Push button navigation in the LHMI menu structure is presented by using the push button icons.
  To navigate between the options, use  and .
- Menu paths are presented in bold.
  Select **Main menu/Settings**.
- WHMI menu names are presented in bold.
  Click **Information** in the WHMI menu structure.
- LHMI messages are shown in Courier font.
  To save the changes in nonvolatile memory, select `Yes` and press .
- Parameter names are shown in italics.
  The function can be enabled and disabled with the *Operation* setting.
- Parameter values are indicated with quotation marks.
  The corresponding parameter values are "Enabled" and "Disabled".
- Input/output messages and monitored data names are shown in Courier font.
  When the function picks up, the `PICKUP` output is set to TRUE.
- Dimensions are provided both in inches and mm. If it is not specifically mentioned, the dimension is in mm.
- Analog inputs to protection functions are shown in the technical manual for clarity. However, these inputs and connections do not appear in the application logic. The connection of these analog signals is fixed internally to the corresponding function blocks and cannot be altered by users.

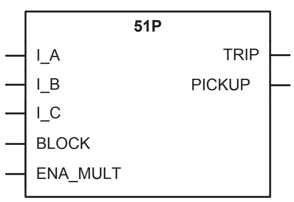

Figure 2: Function block in technical manual

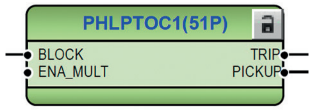

Figure 3: Function block in Application Configuration

1.4.3 Functions, codes and symbols

All available functions are listed in the table. All of them may not be applicable to all products.

Table 1: Functions included in the relays

Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Protection					
Three-phase non-directional overcurrent protection, low stage, instance 1	PHLPTOC1	3I> (1)	51P	51P	51P (1)
Three-phase non-directional overcurrent protection, low stage, instance 2	PHLPTOC2	3I> (2)			51P (2)
Three-phase non-directional overcurrent protection, low stage, instance 3	PHLPTOC3	3I> (3)			51P (3)
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	50P-1	50P-1[1)]	50P-1 (1)
Three-phase non-directional overcurrent protection, high stage, instance 2	PHHPTOC2	3I>> (2)	50P-2	50P-2[2)]	50P-2 (1)
Three-phase non-directional overcurrent protection, high stage, instance 3	PHHPTOC3	3I>> (3)			50P-1 (2)
Three-phase non-directional overcurrent protection, high stage, instance 4	PHHPTOC4	3I>> (4)			50P-2 (2)
Three-phase non-directional overcurrent protection, high stage, instance 5	PHHPTOC5	3I>> (5)			50P-1 (3)
Three-phase non-directional overcurrent protection, high stage, instance 6	PHHPTOC6	3I>> (6)			50P-2 (3)
Three-phase non-directional overcurrent protection, instantaneous stage, instance 1	PHIPTOC1	3I>>> (1)	50P-3		
Three-phase non-directional long time overcurrent protection, lower stage, instance 1	PHLTPTOC1	3I> (3)	51LT		
Three-phase directional overcurrent protection, low stage, instance 1	DPHLPDOC1	3I> -> (1)	67/51P		67/51P(1)
Three-phase directional overcurrent protection, low stage, instance 2	DPHLPDOC2	3I> -> (2)			67/51P(2)
Three-phase directional overcurrent protection, high stage, instance 1	DPHHPDOC1	3I>> -> (1)	67/50P-1		
Three-phase directional overcurrent protection, high stage, instance 2	DPHHPDOC2	3I>> -> (2)	67/50P-2		
Non-directional earth-fault protection, low stage, instance 1	EFLPTOC1	Io> (1)	51G	51G	51G
Non-directional earth-fault protection, low stage, instance 2	EFLPTOC2	Io> (2)	51N-1		51N (1)
Non-directional earth-fault protection, low stage, instance 3	EFLPTOC3	Io> (3)			51N (2)
Non-directional earth-fault protection, low stage, instance 4	EFLPTOC4	Io> (4)	50SEF		51N (3)
Non-directional earth-fault protection, high stage, instance 1	EFHPTOC1	Io>> (1)	50G-1	50G-1[1)]	50G

Table continues on next page

Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Non-directional earth-fault protection, high stage, instance 2	EFHPTOC2	Io>> (2)	50G-2	50G-2 2)	
Non-directional earth-fault protection, high stage, instance 3	EFHPTOC3	Io>> (3)	50N-1		50N-1 (1)
Non-directional earth-fault protection, high stage, instance 4	EFHPTOC4	Io>> (4)	50N-2		50N-1 (2)
Non-directional earth-fault protection, high stage, instance 5	EFHPTOC5	Io>> (5)			50N-1 (3)
Non-directional earth-fault protection, instantaneous stage, instance 1	EFIPTOC1	Io>>>(1)	50G-3		
Non-directional earth-fault protection, instantaneous stage, instance 2	EFIPTOC2	Io>>>(2)	50N-3		
Directional earth-fault protection, low stage, instance 1	DEFLPDEF1	Io> -> (1)	67/51N	67/51N	67/51N(1)
Directional earth-fault protection, low stage, instance 2	DEFLPDEF2	Io> -> (2)			67/51N(2)
Directional earth-fault protection, high stage, instance 1	DEFHPDEF1	Io>> -> (1)	67/50N-1		
Directional earth-fault protection, high stage, instance 2	DEFHPDEF2	Io>> -> (2)	67/50N-2		
Three-phase directional power protection, instance 1	DPSRDIR1	I1-> (1)	32P-1		32P(1)
Three-phase directional power protection, instance 2	DPSRDIR2	I1-> (2)			32P(2)
Ground directional power protection, instance 1	DNZSRDIR1	I2 ->, Io-> (1)	32N-1		32N(1)
Ground directional power protection, instance 2	DNZSRDIR2	I2 ->, Io-> (2)			32N(2)
Phase distance protection, instance 1	PHDSTPDIS1	Z<	21P	21P 3)	
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I2> (1)	46-1		46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	I2> (2)	46-2		46 (2)
Negative-sequence overcurrent protection, instance 3	NSPTOC3	I2> (3)			46 (3)
Phase discontinuity protection	PDNSPTOC1	I2/I1>	46PD		
Residual overvoltage protection, instance 1	ROVPTOV1	Uo> (1)	59G	59G	59G
Residual overvoltage protection, instance 2	ROVPTOV2	Uo> (2)	59N-1 (1)	59N	59N(1)
Residual overvoltage protection, instance 3	ROVPTOV3	Uo> (3)	59N-1 (2)		59N(2)
Three-phase undervoltage protection, instance 1	PHPTUV1	3U< (1)	27-1 (1)	27-1 1)	27-1 (1)
Three-phase undervoltage protection, instance 2	PHPTUV2	3U< (2)	27-2 (1)	27-2 2)	27-2 (1)
Three-phase undervoltage protection, instance 3	PHPTUV3	3U< (3)	27-1 (2)		27-1 (2)
Three-phase undervoltage protection, instance 4	PHPTUV4	3U< (4)	27-2 (2)		27-2 (2)
Three-phase overvoltage protection, instance 1	PHPTOV1	3U> (1)	59-1 (1)	59-1 1)	59-1 (1)
Three-phase overvoltage protection, instance 2	PHPTOV2	3U> (2)	59-2 (1)	59-2 2)	59-2 (1)
Three-phase overvoltage protection, instance 3	PHPTOV3	3U> (3)	59-1 (2)		59-1 (2)
Three-phase overvoltage protection, instance 4	PHPTOV4	3U> (4)	59-2 (2)		59-2 (2)
Three-phase remnant undervoltage protection, instance 1 (source 1)	REMPTUV1	3U< (1)		27R 3)	
Positive-sequence undervoltage protection, instance 1	PSPTUV1	U1< (1)		27PS	
Negative-sequence overvoltage protection, instance 1	NSPTOV1	U2> (1)	47-1 (1)	47-1 1)	47-1 (1)
Negative-sequence overvoltage protection, instance 2	NSPTOV2	U2> (2)	47-2 (1)	47-2 2)	47-2 (1)
Negative-sequence overvoltage protection, instance 3	NSPTOV3	U2> (3)	47-1 (2)		47-1 (2)
Negative-sequence overvoltage protection, instance 4	NSPTOV4	U2> (4)	47-2 (2)		47-2 (2)
Frequency protection, instance 1	FRPFRQ1	f>/f<,df/dt (1)	81-1	81-1 1)	81-1(1)
Frequency protection, instance 2	FRPFRQ2	f>/f<,df/dt (2)	81-2	81-2 2)	81-2(1)
Frequency protection, instance 3	FRPFRQ3	f>/f<,df/dt (3)			81-1(2)
Frequency protection, instance 4	FRPFRQ4	f>/f<,df/dt (4)			81-2(2)
Voltage per hertz protection, instance 1	OEPVPH1	U/f> (1)	24	24-1 3)	24-1(1)
Voltage per hertz protection, instance 2	OEPVPH2	U/f> (2)		24-2 3)	24-2(1)
Voltage per hertz protection, instance 3	OEPVPH3	U/f> (3)			24-1(2)
Voltage per hertz protection, instance 4	OEPVPH4	U/f> (4)			24-2(2)
Three-phase directional overpower protection, instance 1	DOPPDPR1	P> (1)		32O-1 3)	
Three-phase directional overpower protection, instance 2	DOPPDPR2	P> (2)		32O-2 3)	

Table continues on next page

Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Three-phase directional overpower protection, instance 3	DOPPDPR3	P> (3)		32O-3 3)	
Three-phase directional underpower protection, instance 1	DUPPDPR1	P< (1)		32U-1 3)	
Three-phase directional underpower protection, instance 2	DUPPDPR2	P< (2)		32U-2 3)	
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR1	3Ith>F	49F		
Three-phase thermal overload protection for power transformers, two time constants	T2PTTR1	3Ith>T			49T (1)
Negative-sequence overcurrent protection for motors, instance 1	MNSPTOC1	I2>M (1)		46M-1	
Negative-sequence overcurrent protection for motors, instance 2	MNSPTOC2	I2>M (2)		46M-2	
Loss of phase, instance 1	PHPTUC1	3I< (1)	37-1		37 (1)
Loss of phase, instance 2	PHPTUC2	3I< (2)			37 (2)
Loss of phase, instance 3	PHPTUC3	3I< (3)			37 (3)
Loss of load supervision, instance 1	LOFLPTUC1	3I< (1)		37M-1	
Loss of load supervision, instance 2	LOFLPTUC2	3I< (2)		37M-2	
Phase current sets summing function	CMSUM1	CSUM	CSUM		
Three-phase measurement switching	VMSWI1	VSWI	VSWI		
Motor load jam protection, instance 1	JAMPTOC1	Ist> (1)		51LR-1 1)	
Motor load jam protection, instance 2	JAMPTOC2	Ist> (2)		51LR-2 2)	
Motor start-up supervision	STTPMSU1	Is2t n<		66/51LRS	
Phase reversal protection	PREVPTOC1	I2>>		46R	
Thermal overload protection for motors	MPTTR1	3Ith>M		49M	
Motor differential protection	MPDIF1	3dI>M		87M	
High-impedance differential protection, instance 1	HIPDIF1	dHi> (1)		87A 3)	
High-impedance differential protection, instance 2	HIPDIF2	dHi> (2)		87B 3)	
High-impedance differential protection, instance 3	HIPDIF3	dHi> (3)		87C 3)	
Stabilized and instantaneous differential protection for 3W transformers	TR3PTDF1	3dI>3W			87T
Numerical stabilized low impedance restricted earth-fault protection	LREFPNDF1	dIoLo>	87LOZREF	87LOZREF 3)	87LOZREF (2)
Circuit breaker failure protection, instance 1	CCBRBRF1	3I>/Io>BF (1)	50BF-1	50BF	50BF (1)
Circuit breaker failure protection, instance 2	CCBRBRF2	3I>/Io>BF (2)	50BF-2		50BF (2)
Circuit breaker failure protection, instance 3	CCBRBRF3	3I>/Io>BF (3)			50BF (3)
Three-phase inrush detector, instance 1	INRPHAR1	3I2f>	INR		
Master trip, instance 1	TRPPTRC1	Master Trip (1)	86/94-1	86/94-1	86/94-1
Master trip, instance 2	TRPPTRC2	Master Trip (2)	86/94-2	86/94-2	86/94-2
Master trip, instance 3	TRPPTRC3	Master Trip (3)	86/94-3	86/94-3 2)	86/94-3
Master trip, instance 4	TRPPTRC4	Master Trip (4)		86/94-4 2)	
Master trip, instance 5	TRPPTRC5	Master Trip (5)		86/94-5 2)	
Master trip, instance 6	TRPPTRC6	Master Trip (6)		86/94-6 2)	
Master trip, instance 7	TRPPTRC7	Master Trip (7)		86/94-7 2)	
Master trip, instance 8	TRPPTRC8	Master Trip (8)		86/94-8 2)	
Arc protection, instance 1	ARCSARC1	ARC (1)	AFD-1	AFD-1	AFD-1(1)
Arc protection, instance 2	ARCSARC2	ARC (2)	AFD-2	AFD-2	AFD-2(2)
Arc protection, instance 3	ARCSARC3	ARC (3)	AFD-3	AFD-3	AFD-3(3)
High-impedance fault detection	PHIZ1	PHIZ1	HIZ		
Cable fault detection	RCFD1	CFD	CFD		
Load shedding and restoration, instance 1	LSHDPFRQ1	UFLS/R (1)	81LSH-1		81LSH-1(1)
Load shedding and restoration, instance 2	LSHDPFRQ2	UFLS/R (2)	81LSH-2		81LSH-2(1)

Table continues on next page

Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Load shedding and restoration, instance 3	LSHDPFRQ3	UFLS/R (3)			81LSH-3(1)
Load shedding and restoration, instance 4	LSHDPFRQ4	UFLS/R (4)			81LSH-4(1)
Load shedding and restoration, instance 5	LSHDPFRQ5	UFLS/R (5)			81LSH-1(2)
Load shedding and restoration, instance 6	LSHDPFRQ6	UFLS/R (6)			81LSH-2(2)
Load shedding and restoration, instance 7	LSHDPFRQ7	UFLS/R (7)			81LSH-3(2)
Load shedding and restoration, instance 8	LSHDPFRQ8	UFLS/R (8)			81LSH-4(2)
RTD based thermal protection, instance 1	MAPGAPC1	ThA> ThB>(1)		38-1	38-1
RTD based thermal protection, instance 2	MAPGAPC2	ThA> ThB>(2)		38-2	38-2
RTD based thermal protection, instance 3	MAPGAPC3	ThA> ThB>(3)		38-3	38-3
RTD based thermal protection, instance 4	MAPGAPC4	ThA> ThB>(4)		38-4	
RTD based thermal protection, instance 5	MAPGAPC5	ThA> ThB>(5)		38-5	
RTD based thermal protection, instance 6	MAPGAPC6	ThA> ThB>(6)		38-6	
RTD based thermal protection, instance 7	MAPGAPC7	ThA> ThB>(7)		38-7	
RTD based thermal protection, instance 8	MAPGAPC8	ThA> ThB>(8)		38-8[2)]	
RTD based thermal protection, instance 9	MAPGAPC9	ThA> ThB>(9)		38-9[2)]	
RTD based thermal protection, instance 10	MAPGAPC10	ThA> ThB>(10)		38-10[2)]	
RTD based thermal protection, instance 11	MAPGAPC11	ThA> ThB>(11)		38-11[2)]	
RTD based thermal protection, instance 12	MAPGAPC12	ThA> ThB>(12)		38-12[2)]	
RTD based thermal protection, instance 13	MAPGAPC13	ThA> ThB>(13)		38-13[2)]	
RTD based thermal protection, instance 14	MAPGAPC14	ThA> ThB>(14)		38-14[2)]	
RTD based thermal protection, instance 15	MAPGAPC15	ThA> ThB>(15)		38-15[2)]	
RTD based thermal protection, instance 16	MAPGAPC16	ThA> ThB>(16)		38-16[2)]	
RTD based thermal protection, instance 17	MAPGAPC17	ThA> ThB>(17)		38-17[2)]	
RTD based thermal protection, instance 18	MAPGAPC18	ThA> ThB>(18)		38-18[2)]	
Out of step	OOSRPSB1	φ>		78[3)]	
Power factor, instance 1	MPUPF1	PF< (1)		55-1[3)]	
Power factor, instance 2	MPUPF2	PF< (2)		55-2[3)]	
Three-phase underexcitation protection, instance 1	UEXPDIS1	X< (1)		40[3)]	
Control					
Circuit-breaker control, instance 1	CBXCBR1	I <-> O CB (1)	52-1	52	52 (1)
Circuit-breaker control, instance 2	CBXCBR2	I <-> O CB (2)	52-2		52 (2)
Circuit-breaker control, instance 3	CBXCBR3	I <-> O CB (3)			52 (3)
Emergency start-up	ESMGAPC1	ESTART		62EST	
Autoreclosing, instance 1	DARREC1	O -> I (1)	79-1		
Autoreclosing, instance 2	DARREC2	O -> I (2)	79-2		
Synchronism and energizing check, instance 1	SECRSYN1	SYNC (1)	25-1	25[3)]	
Synchronism and energizing check, instance 2	SECRSYN2	SYNC (2)	25-2		
Synchronism and energizing check, instance 3	SECRSYN3	SYNC (3)	25-3		
Condition monitoring					
Circuit-breaker condition monitoring, instance 1	SSCBR1	CBCM (1)	52CM-1	52CM	52CM (1)
Circuit-breaker condition monitoring, instance 2	SSCBR2	CBCM (2)	52CM-2		52CM (2)

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Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Circuit-breaker condition monitoring, instance 3	SSCBR3	CBCM (3)			52CM (3)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM-1	TCM-1	TCM-1
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM-2	TCM-2	TCM-2
Trip circuit supervision, instance 3	TCSSCBR3	TCS (3)			TCM-3
Current circuit supervision	CCRDIF1	MCS 3I	CCM	CCM	
Advanced current circuit supervision for transformers	CTSRCTF1	MCS 3I, I2			MCS 3I, I2
Fuse failure supervision, instance 1	SEQRFUF1	FUSEF (1)	60-1	60	60 (1)
Fuse failure supervision, instance 2	SEQRFUF2	FUSEF (2)	60-2		60 (2)
Runtime counter for machines and devices, instance 1	MDSOPT1	OPTS (1)		OPTM-1	
Runtime counter for machines and devices, instance 2	MDSOPT2	OPTS (2)		OPTM-2	
Measurement					
Three-phase current measurement, instance 1	CMMXU1	3I	IA, IB, IC	IA, IB, IC	IA, IB, IC (1)
Three-phase current measurement, instance 2	CMMXU2	3I(B)		IA, IB, IC (2)	IA, IB, IC (2)
Three-phase current measurement, instance 3	CMMXU3	3I(C)			IA, IB, IC (3)
Sequence current measurement, instance 1	CSMSQI1	I1, I2, I0	I1, I2, I0	I1, I2, I0	I1, I2, I0 (1)
Sequence current measurement, instance 2	CSMSQI2	I1, I2, I0 (B)		I1, I2, I0 (2)	I1, I2, I0 (2)
Sequence current measurement, instance 3	CSMSQI3	I1, I2, I0 (C)			I1, I2, I0 (3)
Residual current measurement, instance 1	RESCMMXU1	Io	IG	IG	IG
Three-phase voltage measurement, instance 1	VMMXU1	3U	VA, VB, VC	VA, VB, VC	VA, VB, VC (1)
Three-phase voltage measurement, instance 2	VMMXU2	3U (B)	VA, VB, VC (2)		VA, VB, VC (2)
Residual voltage measurement, instance 1	RESVMMXU1	Uo	VG	VG	VG
Residual voltage measurement, instance 2	RESVMMXU2	Uo(B)			VG
Sequence voltage measurement, instance 1	VSMSQI1	U1, U2, U0	V1, V2, V0	V1, V2, V0	V1, V2, V0 (1)
Sequence voltage measurement, instance 2	VSMSQI2	U1, U2, U0 (B)	V1, V2, V0 (2)		V1, V2, V0 (2)
Three-phase power and energy measurement, instance 1	PEMMXU1	P, E	P, E	P, E	P, E (1)
Three-phase power and energy measurement, instance 2	PEMMXU2	P, E (B)			P, E (2)
Current total demand distortion, instance 1	CMHAI1	PQM3I(1)	PQI-1		
Voltage total harmonic distortion, instance 1	VMHAI1	PQM3U(1)	PQVPH-1		
Voltage total harmonic distortion, instance 2	VMHAI2	PQM3U(2)	PQVPH-2		
Voltage variation, instance 1	PHQVVR1	PQ 3U<>(1)	PQSS-1		
Voltage unbalance, instance 1	VSQVUB1	PQMUBU(1)	PQVUB-1		
Voltage unbalance, instance 2	VSQVUB2	PQMUBU(2)	PQVUB-2		
Load profile, instance 1	LDPMSTA1	LoadProf	LoadProf	LoadProf	LoadProf
Frequency measurement, instance 1	FMMXU1	f	f	f	f
Frequency measurement, instance 2	FMMXU2	f			f
Single-phase power and energy measurement, instance 1	SPEMMXU1	SP, SE	SP, SE	SP, SE	SP, SE (1)
Single-phase power and energy measurement, instance 2	SPEMMXU2	SP, SE(B)			SP, SE (2)
Tap changer position indication	TPOSSLTC1	TPOSM			84T
Other					
Minimum pulse timer (2 pcs), instance 1	TPGAPC1	TP (1)	TP-1	TP-1	TP-1
Minimum pulse timer (2 pcs), instance 2	TPGAPC2	TP (2)	TP-2	TP-2	TP-2
Minimum pulse timer (2 pcs), instance 3	TPGAPC3	TP (3)	TP-3	TP-3	TP-3
Minimum pulse timer (2 pcs), instance 4	TPGAPC4	TP (4)	TP-4	TP-4	TP-4
Minimum pulse timer (2 pcs, second resolution), instance 1	TPSGAPC1	TPS (1)	62CLD-1	TPS (1)[3)]	
Minimum pulse timer (2 pcs, second resolution), instance 2	TPSGAPC2	TPS (2)	62CLD-3	TPS (2)[3)]	
Minimum pulse timer (2 pcs, minute resolution), instance 1	TPMGAPC1	TPM (1)	62CLD-2	TPM (1)[3)]	
Minimum pulse timer (2 pcs, minute resolution), instance 2	TPMGAPC2	TPM (2)	62CLD-4	TPM (2)[3)]	

Table continues on next page

Function	IEC 61850	IEC 60617	ANSI/C37.2 -2008		
			REF620	REM620	RET620
Pulse timer (8 pcs), instance 1	PTGAPC1	PT (1)	PT-1	PT-1	PT-1
Pulse timer (8 pcs), instance 2	PTGAPC2	PT (2)	PT-2	PT-2	PT-2
Time delay off (8 pcs), instance 1	TOFGAPC1	TOF (1)	TOF-1	TOF-1	TOF-1
Time delay off (8 pcs), instance 2	TOFGAPC2	TOF (2)	TOF-2	TOF-2	TOF- 2
Time delay off (8 pcs), instance 3	TOFGAPC3	TOF (3)	TOF-3	TOF-3	TOF-3
Time delay off (8 pcs), instance 4	TOFGAPC4	TOF (4)	TOF-4	TOF-4	TOF- 4
Time delay on (8 pcs), instance 1	TONGAPC1	TON (1)	TON -1	TON -1	TON -1
Time delay on (8 pcs), instance 2	TONGAPC2	TON (2)	TON -2	TON -2	TON -2
Time delay on (8 pcs), instance 3	TONGAPC3	TON (3)	TON -3	TON -3	TON -3
Time delay on (8 pcs), instance 4	TONGAPC4	TON (4)	TON -4	TON -4	TON -4
Set reset (8 pcs), instance 1	SRGAPC1	SR (1)	SR-1	SR-1	SR-1
Set reset (8 pcs), instance 2	SRGAPC2	SR (2)	SR-2	SR-2	SR-2
Set reset (8 pcs), instance 3	SRGAPC3	SR (3)	SR-3	SR-3	SR-3
Set reset (8 pcs), instance 4	SRGAPC4	SR (4)	SR-4	SR-4	SR-4
Move (8 pcs), instance 1	MVGAPC1	MV (1)	MV-1	MV-1	MV-1
Move (8 pcs), instance 2	MVGAPC2	MV (2)	MV-2	MV-2	MV-2
Move (8 pcs), instance 3	MVGAPC3	MV (3)	MV-3	MV-3	MV-3
Move (8 pcs), instance 4	MVGAPC4	MV (4)	MV-4	MV-4	MV-4
Move (8 pcs), instance 5	MVGAPC5	MV (5)	MV-5	MV-5	MV-5
Move (8 pcs), instance 6	MVGAPC6	MV (6)	MV-6	MV-6	MV-6
Move (8 pcs), instance 7	MVGAPC7	MV (7)	MV-7	MV-7	MV-7
Move (8 pcs), instance 8	MVGAPC8	MV (8)	MV-8	MV-8	MV-8
Move (8 pcs), instance 9	MVGAPC9	MV (9)		MV-9[2]	
Move (8 pcs), instance 10	MVGAPC10	MV (10)		MV-10[2]	
Generic control points, instance 1	SPCGGIO1	SPC(1)	CNTRL-1	CNTRL-1	CNTRL-1
Generic control points, instance 2	SPCGGIO2	SPC(2)	CNTRL-2	CNTRL-2	CNTRL-2
Generic control points, instance 3	SPCGGIO3	SPC(3)	CNTRL-3	CNTRL-3	CNTRL-3
Remote generic control points, instance 1	SPCRGGIO1	SRCR(1)	RCNTRL-1	RCNTRL-1	RCNTRL-1
Local generic control points, instance 1	SPCLGGIO1	SPCL(1)	LCNTRL-1	LCNTRL-1	LCNTRL-1
Generic up-down counters, instance 1	UDFCNT1	CTR(1)	CTR-1	CTR-1	CTR-1
Generic up-down counters, instance 2	UDFCNT2	CTR(2)	CTR-2	CTR-2	CTR-2
Generic up-down counters, instance 3	UDFCNT3	CTR(3)	CTR-3	CTR-3	CTR-3
Generic up-down counters, instance 4	UDFCNT4	CTR(4)	CTR-4	CTR-4	CTR-4
Generic up-down counters, instance 5	UDFCNT5	CTR(5)	CTR-5	CTR-5	CTR-5
Generic up-down counters, instance 6	UDFCNT6	CTR(6)	CTR-6	CTR-6	CTR-6
Generic up-down counters, instance 7	UDFCNT7	CTR(7)	CTR-7	CTR-7	CTR-7
Generic up-down counters, instance 8	UDFCNT8	CTR(8)	CTR-8	CTR-8	CTR-8
Generic up-down counters, instance 9	UDFCNT9	CTR(9)	CTR-9	CTR-9	CTR-9
Generic up-down counters, instance 10	UDFCNT10	CTR(10)	CTR-10	CTR-10	CTR-10
Generic up-down counters, instance 11	UDFCNT11	CTR(11)	CTR-11	CTR-11	CTR-11
Generic up-down counters, instance 12	UDFCNT12	CTR(12)	CTR-12	CTR-12	CTR-12
Programmable buttons (16 buttons), instance 1	FKEYGGIO1	FKEY	FKEY	FKEY	FKEY
Logging functions					
Disturbance recorder	RDRE1	DR	DFR	DFR	DFR
Fault recorder	FLTMSTA	FR	FR	FR	FR
Sequence event recorder	SER	SER	SER	SER	SER
Fault location	DRFLO	DRFLO	FLO		

1) Instance has been renamed in 620 series Ver.2.1 ANSI
2) Instance has been added in 620 series Ver 2.1 ANSI

3) Function has been added in 620 series Ver.2.1 ANSI

Section 2 620 series overview

2.1 Overview

620 series is a product family of protection relays designed for the protection, control, measurement and supervision of utility substations and industrial switchgear and equipment. The design of the protection relays has been guided by the IEC 61850 standard for communication and interoperability of substation automation devices.

The protection relays feature draw-out-type design with a variety of mounting methods, compact size and ease of use. Depending on the product, optional functionality is available at the time of order for both software and hardware, for example, autoreclosure and additional I/Os.

The 620 series protection relays support a range of communication protocols including IEC 61850 with GOOSE messaging, Modbus® and DNP3.

2.1.1 Product series version history

Product series version	Product series history
2.0	First release
2.1	Release to support HSR/PRP communication and new features in REM620 configuration C

2.1.2 PCM600 and relay connectivity package version

- Protection and Control IED Manager PCM600 Ver.2.6 or later
- IED Connectivity Package REF620 ANSI Ver.2.0 or later
- IED Connectivity Package REM620 ANSI Ver.2.1 or later
- IED Connectivity Package RET620 ANSI Ver.2.0 or later

Download connectivity packages from the ABB web site http://www.abb.com/substationautomation

2.2 Local HMI

The LHMI is used for setting, monitoring and controlling the protection relay. The LHMI comprises the display, buttons, LED indicators and communication port.

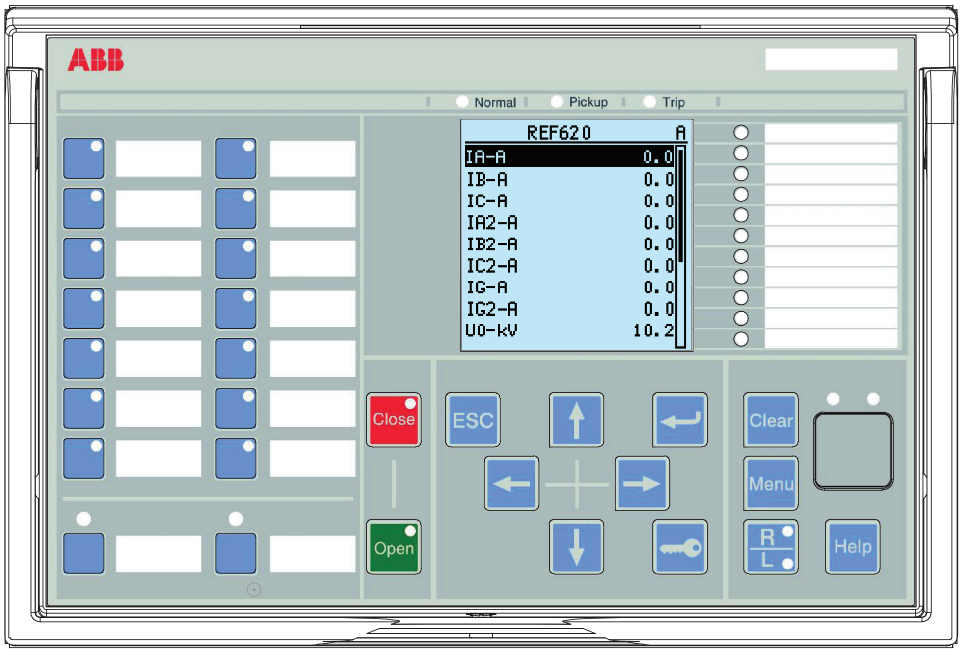


Figure 4: Example of the LHMI

2.2.1 Display

The LHMI includes a graphical display that supports one character size. The character size depends on the selected language.

Table 2: Large display

Character size[1)]	Rows in the view	Characters per row
Small, mono-spaced (6 × 12 pixels)	10	20

1) Depending on the selected language

The display view is divided into four basic areas.

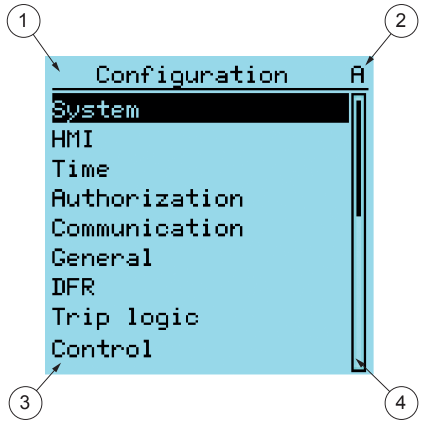


Figure 5: Display layout

1 Header

2 Icon

3 Content

4 Scroll bar (displayed when needed)

2.2.2 LEDs

The LHMI includes three protection indicators above the display: Normal, Pickup and Trip.

There are 11 matrix programmable LEDs on front of the LHMI. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI, WHMI or PCM600.

There are two additional LEDs which are embedded into the control buttons 

and 

. They represent the status of the selected breaker n (CBXCBRn).

2.2.3 Keypad

The LHMI keypad contains push buttons which are used to navigate in different views or menus. Using the push buttons, open or close commands can be given to objects in the primary circuit, for example, a circuit breaker, a contactor or a disconnector. The push buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

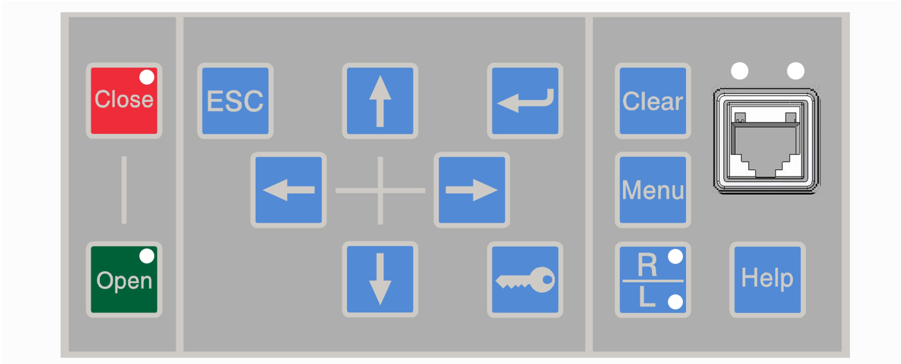


Figure 6: LHMI keypad with object control, navigation and command push buttons and RJ-45 communication port

2.2.4 Programmable push buttons with LEDs

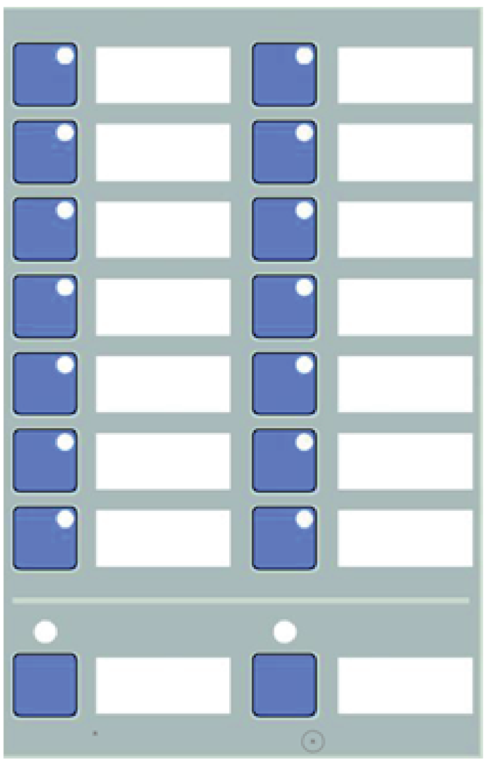


Figure 7: Programmable push buttons with LEDs

The LHMI keypad on the left side of the protection relay contains 16 programmable push buttons with red LEDs.

The buttons and LEDs are freely programmable, and they can be configured both for operation and acknowledgement purposes. That way, it is possible to get acknowledgements of the executed actions associated with the buttons. This combination can be useful, for example, for quickly selecting or changing a setting group, selecting or operating equipment, indicating field contact status or indicating or acknowledging individual alarms.

The LEDs can also be independently configured to bring general indications or important alarms to the operator's attention.

The lowest two buttons with LEDs on top are typically used for hot-line tag for the emergency operation of the circuit controlled by the protection relay.

To provide a description of the button function, it is possible to insert a paper sheet behind the transparent film next to the button.

2.3 Web HMI

The WHMI allows secure access to the protection relay via a Web browser. The supported Web browser versions are Internet Explorer 9.0, 10.0 and 11.0.

WHMI is enabled by default.

Control operations are not allowed by WHMI.

WHMI offers several functions.

- Programmable LEDs and event lists
- System supervision
- Parameter settings
- Measurement display
- DFR records
- Phasor diagram
- Single-line diagram

The menu tree structure on the WHMI is almost identical to the one on the LHMI.

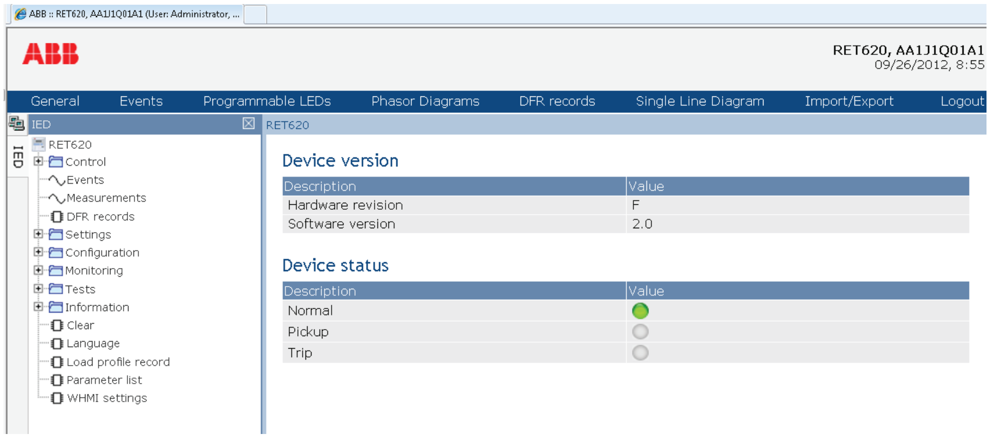


Figure 8: Example view of the WHMI

The WHMI can be accessed locally and remotely.

- Locally by connecting the laptop to the protection relay via the front communication port.
- Remotely over LAN/WAN.

2.4 Authorization

Four user categories have been predefined for the LHMI and the WHMI, each with different rights and default passwords.

The default passwords in the protection relay delivered from the factory can be changed with Administrator user rights.

User authorization is disabled by default for LHMI but WHMI always uses authorization.

Table 3: Predefined user categories

Username	User rights
VIEWER	Read only access
OPERATOR	• Selecting remote or local state with (only locally) • Changing setting groups • Controlling • Clearing indications
ENGINEER	• Changing settings • Clearing event list • Clearing DFRs and load profile record • Changing system settings such as IP address, serial baud rate or DFR settings • Setting the protection relay to test mode • Selecting language
ADMINISTRATOR	• All listed above • Changing password • Factory default activation

For user authorization for PCM600, see PCM600 documentation.

2.4.1 Audit trail

The protection relay offers a large set of event-logging functions. Critical system and protection relay security-related events are logged to a separate nonvolatile audit trail for the administrator.

Audit trail is a chronological record of system activities that allows the reconstruction and examination of the sequence of system and security-related events and changes in the protection relay. Both audit trail events and process related events can be examined and analyzed in a consistent method with the help of Event List in LHMI and WHMI and Event Viewer in PCM600.

The protection relay stores 2048 audit trail events to the nonvolatile audit trail. Additionally, 1024 process events are stored in a nonvolatile event list. Both the audit trail and event list work according to the FIFO principle. Nonvolatile memory is based on a memory type which does not need battery backup nor regular component change to maintain the memory storage.

Audit trail events related to user authorization (login, logout, violation remote and violation local) are defined according to the selected set of requirements from IEEE 1686.

The logging is based on predefined user names or user categories. The user audit trail events are accessible with IEC 61850-8-1, PCM600, LHMI and WHMI.

Table 4: Audit trail events

Audit trail event	Description
Configuration change	Configuration files changed
Firmware change	Firmware changed
Firmware change fail	Firmware change failed
Attached to retrofit test case	Unit has been attached to retrofit case
Removed from retrofit test case	Removed from retrofit test case
Setting group remote	User changed setting group remotely
Setting group local	User changed setting group locally
Control remote	DPC object control remote
Control local	DPC object control local
Test on	Test mode on
Test off	Test mode off
Reset trips	Reset latched trips (TRPPTRC*)
Setting commit	Settings have been changed
Time change	Time changed directly by the user. Note that this is not used when the protection relay is synchronised properly by the appropriate protocol (SNTP, IRIG-B, IEEE 1588 v2).
View audit log	Administrator accessed audit trail
Login	Successful login from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Logout	Successful logout from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Password change	Password changed
Firmware reset	Reset issued by user or tool
Audit overflow	Too many audit events in the time period
Violation remote	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Violation local	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.

PCM600 Event Viewer can be used to view the audit trail events and process related events. Audit trail events are visible through dedicated Security events view. Since only the administrator has the right to read audit trail, authorization must be used in PCM600. The audit trail cannot be reset, but PCM600 Event Viewer can filter data. Audit trail events can be configured to be visible also in LHMI/WHMI Event list together with process related events.

To expose the audit trail events through Event list, define the *Authority logging* level parameter via **Configuration/Authorization/Security**. This exposes audit trail events to all users.

Table 5: Comparison of authority logging levels

Audit trail event	Authority logging level					
	None	Configuration change	Setting group	Setting group, control	Settings edit	All
Configuration change		•	•	•	•	•
Firmware change		•	•	•	•	•
Setting group remote			•	•	•	•
Setting group local			•	•	•	•
Control remote				•	•	•
Control local				•	•	•
Test on				•	•	•
Test off				•	•	•
Reset trips				•	•	•
Setting commit					•	•
Time change						•
View audit log						•
Login						•
Logout						•
Password change						•
Firmware reset						•
Violation local						•
Violation remote						•

2.5 Communication

The protection relay supports different communication protocols: IEC 61850, Modbus® and DNP3 Level 2 - all using TCP/IP. DNP3 and Modbus also support serial communication. Operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication between the protection relays, is only enabled by the IEC 61850 communication protocol.

The protection relay utilizes Ethernet communication extensively for different purposes. The exact services depend on the ordered product variant and enabled functionality.

Table 6: TCP and UDP ports used for different services

Service	Port
IEC 61850	102
MODBUS	x
DNP	x
FTP	x
HTTP	x

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter setting and DFR records can be accessed using the IEC 61850 protocol. Oscillographic files are available to any Ethernet-based application in the standard COMTRADE format. The protection relay can send and receive binary signals from other devices (so called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. Further, the protection relay supports sending and receiving of analog values using GOOSE messaging. The protection relay meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard. The protection relay can simultaneously report events to five different clients on the station bus.

The protection relay can support five simultaneous clients. If PCM600 reserves one client connection, only four client connections are left, for example, for IEC 61850, DNP3 and Modbus. Only one DNP3 client can be supported at a time.

All communication connectors, except for the front port connector, are placed on integrated optional communication modules. The protection relay can be connected to Ethernet-based communication systems via the RJ-45 connector (100Base-TX) or the fiber-optic LC connector (100Base-FX).

2.5.1 Self-healing Ethernet ring

For the correct operation of self-healing loop topology, it is essential that the external switches in the network support the RSTP protocol and that it is enabled in the switches. Otherwise, connecting the loop topology can cause problems to the network. The protection relay itself does not support link-down detection or RSTP. The ring recovery process is based on the aging of the MAC addresses, and the link-up/link-down events can cause temporary breaks in communication. For a better performance of the self-healing loop, it is recommended that the external switch furthest from the protection relay loop is assigned as the root switch (bridge priority = 0) and the bridge priority increases towards the protection relay loop. The end links of the protection relay loop can be attached to the same external switch or to two adjacent external switches. A self-healing Ethernet ring requires a communication module with at least two Ethernet interfaces for all protection relays.

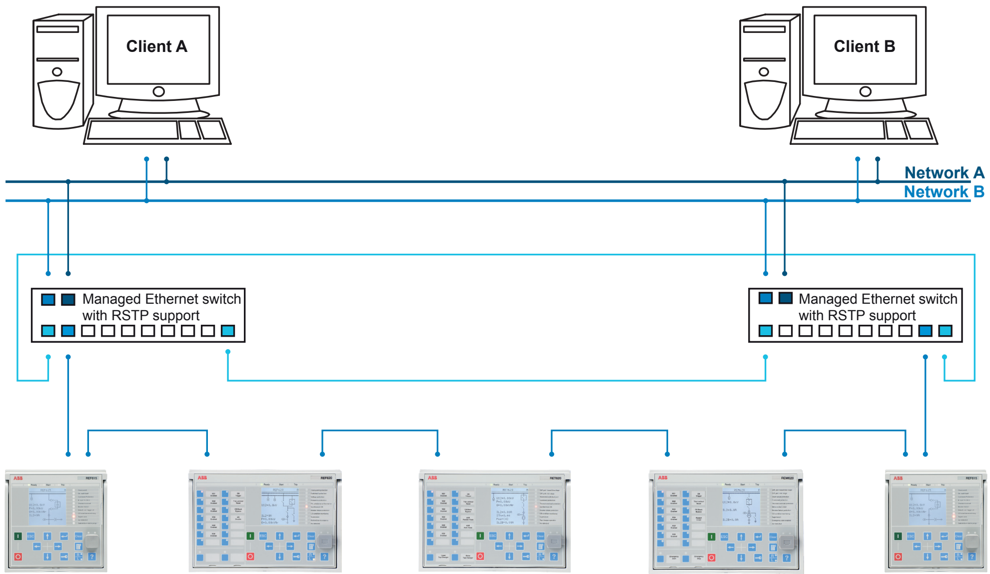


Figure 9: Self-healing Ethernet ring solution

The Ethernet ring solution supports the connection of up to 30 protection relays. If more than 30 protection relays are to be connected, it is recommended that the network is split into several rings with no more than 30 protection relays per ring.

2.5.2 Ethernet redundancy

This chapter is applicable to REM620 Ver.2.1 only.

IEC 61850 specifies a network redundancy scheme that improves the system availability for substation communication. It is based on two complementary protocols defined in the IEC 62439-3:2012 standard: parallel redundancy protocol PRP and high-availability seamless redundancy HSR protocol. Both protocols rely on the duplication of all transmitted information via two Ethernet ports for one logical network connection. Therefore, both are able to overcome the failure of a link or switch with a zero-switchover time, thus fulfilling the stringent real-time requirements for the substation automation horizontal communication and time synchronization.

PRP specifies that each device is connected in parallel to two local area networks. HSR applies the PRP principle to rings and to the rings of rings to achieve cost-effective redundancy. Thus, each device incorporates a switch element that forwards frames from port to port. The HSR/PRP option is available in REM620 Ver.2.1 only.

IEC 62439-3:2012 cancels and replaces the first edition published in 2010. These standard versions are also referred to as IEC 62439-3 Edition 1 and IEC 62439-3 Edition 2. The protection relay supports IEC 62439-3:2012 and it is not compatible with IEC 62439-3:2010.

PRP

Each PRP node, called a double attached node with PRP (DAN), is attached to two independent LANs operated in parallel. These parallel networks in PRP are called LAN A and LAN B. The networks are completely separated to ensure failure independence, and they can have different topologies. Both networks operate in parallel, thus providing zero-time recovery and continuous checking of redundancy to avoid communication failures. Non-PRP nodes, called single attached nodes (SANs), are either attached to one network only (and can therefore communicate only with DANs and SANs attached to the same network), or are attached through a redundancy box, a device that behaves like a DAN.

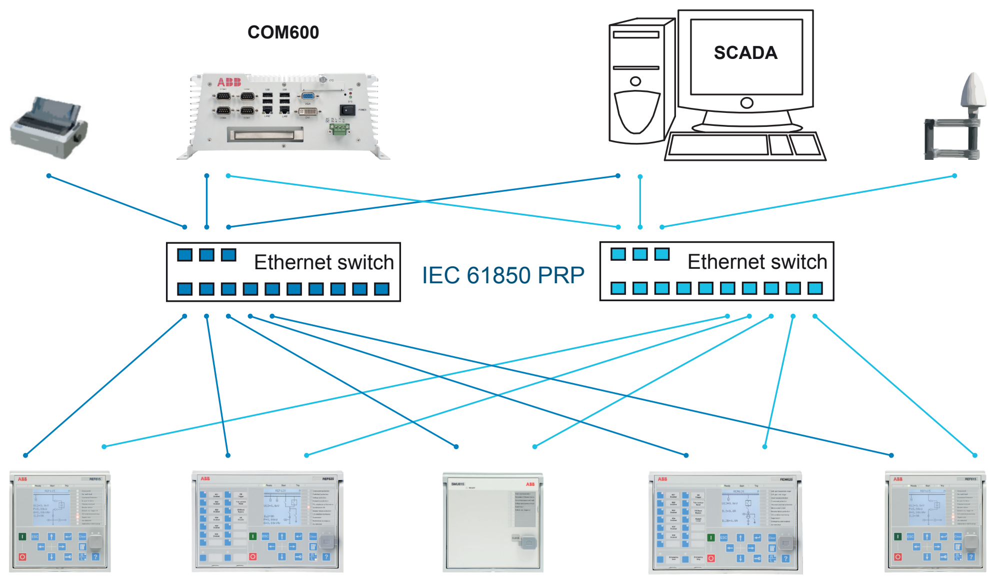


Figure 10: PRP solution

In case a laptop or a PC workstation is connected as a non-PRP node to one of the PRP networks, LAN A or LAN B, it is recommended to use a redundancy box device or an Ethernet switch with similar functionality between the PRP network and SAN to remove additional PRP information from the Ethernet frames. In some cases, default PC workstation adapters are not able to handle the maximum-length Ethernet frames with the PRP trailer.

There are different alternative ways to connect a laptop or a workstation as SAN to a PRP network.

- Via an external redundancy box (RedBox) or a switch capable of connecting to PRP and normal networks
- By connecting the node directly to LAN A or LAN B as SAN
- By connecting the node to the protection relay's interlink port

Take care to ensure that the ports marked "LAN A" and "LAN B" are used when implementing PRP. Some communication options offer a third port which should not be used for redundant Ethernet connectivity.

In a PRP network, the installer should ensure that all of the LAN A ports are connected to the same switch and that all of the LAN B ports are connected to a different switch.

HSR

HSR applies the PRP principle of parallel operation to a single ring, treating the two directions as two virtual LANs. For each frame sent, a node, DAN, sends two frames, one over each port. Both frames circulate in opposite directions over the ring and each node forwards the frames it receives, from one port to the other. When the originating node receives a frame sent to itself, it discards that to avoid loops; therefore, no ring protocol is needed. Individually attached nodes, SANs, such as laptops and printers, must be attached through a “redundancy box” that acts as a ring element. For example, a 615 or 620 series protection relay with HSR support can be used as a redundancy box.

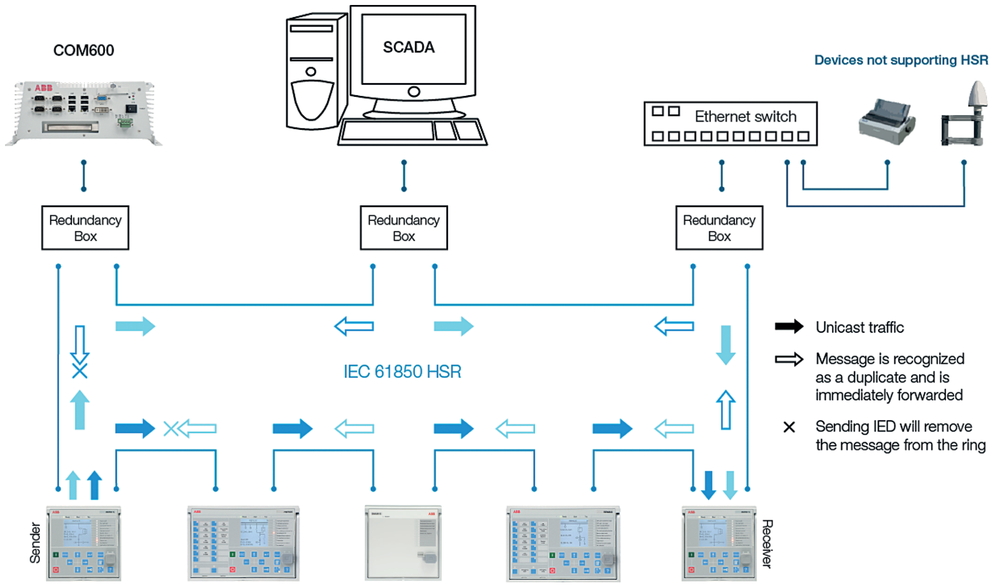


Figure 11: HSR solution

LAN A of one device should connect to LAN B in the next device in the ring. Do not connect LAN A to LAN A or LAN B to LAN B.

Section 3 Basic functions

3.1 General parameters

Table 7: Analog input settings, phase currents

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	2=1A 3=5A			3=5A	Rated secondary current
Primary current	1.0...6000.0	A	0.1	600.0	Rated primary current
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A amplitude correction factor
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B amplitude correction factor
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C amplitude correction factor
Nominal Current	39...4000	A	1	1300	Network Nominal Current (In)
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the phase CTs

Table 8: Analog input settings, residual current

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary current	1=0.2A 2=1A 3=5A			2=1A	Secondary current
Primary current	1.0...6000.0	A	0.1	120	Primary current
Amplitude corr.	0.900...1.100		0.001	1.000	Amplitude correction
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the residual CT

Table 9: Analog input settings, phase voltages

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	20.000	Primary rated voltage
Secondary voltage	60...210	V	1	100	Secondary rated voltage
VT connection	1=Wye 2=Delta 3=U12 4=UL1			2=Delta	Wye, delta, U12 or UL1 VT connection
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A Voltage phasor magnitude correction of an external voltage transformer

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Voltage input type	1=Voltage trafo 3=CVD sensor			1=Voltage trafo	Type of the voltage input

Table 10: Analog input settings, residual voltage

Parameter	Values (Range)	Unit	Step	Default	Description
Secondary voltage	60...210	V	1	100	Secondary voltage
Primary voltage	0.100...440.000	kV	0.001	11.547	Primary voltage
Amplitude corr.	0.900...1.100		0.001	1.000	Amplitude correction

Table 11: Authorization settings

Parameter	Values (Range)	Unit	Step	Default	Description
Local override	0=False[1)] 1=True[2)]			1=True	Disable authority
Remote override	0=False[3)] 1=True[4)]			1=True	Disable authority
Local viewer				0	Set password
Local operator				0	Set password
Local engineer				0	Set password
Local admin				0	Set password
Remote viewer				0	Set password
Remote operator				0	Set password
Remote engineer				0	Set password
Remote admin				0	Set password
Authority logging	1=None 2=Configuration change 3=Setting group 4=Setting group, control 5=Settings edit 6=All			4=Setting group, control	Authority logging level

1) Authorization override is disabled, LHMI password must be entered.
2) Authorization override is enabled, LHMI password is not asked.
3) Authorization override is disabled, communication tools ask password to enter the protection relay.
4) Authorization override is enabled, communication tools do not need password to enter the protection relay, except for WHMI which always requires it.

To avoid communication errors with PCM600 while authentication is enabled, ensure that appropriate credentials are used for the specific action. Confirm that the password in the IED properties is valid for the action attempted.

Table 12: Binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Threshold voltage	18...176	Vdc	2	18	Binary input threshold voltage
Input osc. level	2...50	events/s	1	30	Binary input oscillation suppression threshold
Input osc. hyst	2...50	events/s	1	10	Binary input oscillation suppression hysteresis

Table 13: Ethernet front port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.0.254	IP address for front port (fixed)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for front port

Table 14: Ethernet rear port settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.2.10	IP address for rear port(s)
Subnet mask				255.255.255.0	Subnet mask for rear port(s)
Default gateway				192.168.2.1	Default gateway for rear port(s)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for rear port(s)

Table 15: Redundancy settings

Parameter	Values (Range)	Unit	Step	Default	Description
Switch mode	Normal HSR PRP			Normal	Mode selection for Ethernet switch on Redundant communication modules. The “Normal” mode is used with normal and Self-healing Ethernet topologies.

Table 16: DIAGLCCH1 Output signals

Name	Values	Description
CHLIV	True False	Status of LAN A in HSR and PRP mode. When switch is in “HSR” or “PRP” mode, value is “True” if the protection relay is receiving supervision frames from LAN A. When the switch is in “Normal” mode, value is “True” if the protection relay is receiving Ethernet frames.
REDCHLIV	True False	Status of LAN B in HSR and PRP mode. When switch is in “HSR” or “PRP” mode, value is “True” if the protection relay is receiving supervision frames from LAN B. Disabled if *Switch mode* is “Normal”.

Table 17: XGGIO90 Output signals

Name	Values	Description
ETHLNK1	Up Down	Status of Ethernet link 1
ETHLNK2	Up Down	Status of Ethernet link 2
ETHLNK3	Up Down	Status of Ethernet link 3

Table 18: General system settings

Parameter	Values (Range)	Unit	Step	Default	Description
Rated frequency	1=50Hz 2=60Hz			1=60Hz	Rated frequency of the network
Phase rotation	1=ABC 2=ACB			1=ABC	Phase rotation order
Blocking mode	1=Freeze timer 2=Block all 3=Block TRIP output			1=Freeze timer	Behavior for function BLOCK inputs
Bay name[1)]				REF620[2)]	Bay name in system
Phase order mode	1=ABC 2=BCA 3=CAB 4=ACB 5=CBA 6=BAC			1=ABC	Selection for phase connection order
IDMT Sat point	10...50	I/I>	1	50	Overcurrent IDMT saturation point

1) Used in the protection relay's main menu header and as part of the disturbance recording identification
2) Depending on the product variant

Table 19: HMI settings

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC60617 3=ANSI			4=ANSI	FB naming convention used in protection relay
Default view	1=Measurements 2=Main menu 3=SLD			3=SLD	LHMI default view
Backlight timeout	1...60	min	1	60	LHMI backlight timeout
Web HMI mode	1=Active read only 2=Active 3=Disabled			2=Active	Web HMI functionality
Web HMI timeout	1...60	min	1	10	Web HMI login timeout
SLD symbol format	1=IEC 2=ANSI			2=ANSI	Single Line Diagram symbol format
Autoscroll delay	0...30	s	1	0	Autoscroll delay for Measurements view

Table 20: IEC 61850-8-1 MMS settings

Parameter	Values (Range)	Unit	Step	Default	Description
Unit mode	0=Nominal 1=Primary 2=Primary-Nominal			0=Nominal	IEC 61850-8-1 unit mode

Table 21: Modbus settings

Parameter	Values (Range)	Unit	Step	Default	Description
Serial port 1	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 1
Parity 1	0=none 1=odd 2=even			2=even	Parity for Serial interface 1
Address 1	1...255			1	Modbus unit address on Serial interface 1
Link mode 1	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 1
Start delay 1	0...20	char		4	Start frame delay in chars on Serial interface 1
End delay 1	0...20	char		3	End frame delay in chars on Serial interface 1
Serial port 2	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 2
Parity 2	0=none 1=odd 2=even			2=even	Parity for Serial interface 2
Address 2	1...255			2	Modbus unit address on Serial interface 2

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Link mode 2	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 2
Start delay 2	0...20			4	Start frame delay in chars on Serial interface 2
End delay 2	0...20			3	End frame delay in chars on Serial interface 2
MaxTCPClients	0...5			5	Maximum number of Modbus TCP/IP clients
TCPWriteAuthority	0=No clients 1=Reg. clients 2=All clients			2=All clients	Write authority setting for Modbus TCP/IP clients
EventID	0=Address 1=UID			0=Address	Event ID selection
TimeFormat	0=UTC 1=Local			1=Local	Time format for Modbus time stamps
ClientIP1				000.000.000.000	Modbus Registered Client 1
ClientIP2				000.000.000.000	Modbus Registered Client 2
ClientIP3				000.000.000.000	Modbus Registered Client 3
ClientIP4				000.000.000.000	Modbus Registered Client 4
ClientIP5				000.000.000.000	Modbus Registered Client 5
CtlStructPWd1				****	Password for Modbus control struct 1
CtlStructPWd2				****	Password for Modbus control struct 2
CtlStructPWd3				****	Password for Modbus control struct 3
CtlStructPWd4				****	Password for Modbus control struct 4
CtlStructPWd5				****	Password for Modbus control struct 5
CtlStructPWd6				****	Password for Modbus control struct 6
CtlStructPWd7				****	Password for Modbus control struct 7
CtlStructPWd8				****	Password for Modbus control struct 8

Table 22: DNP3 settings

Parameter	Values (Range)	Unit	Step	Default	Description
DNP physical layer	1=Serial 2=TCP/IP			2=TCP/IP	DNP physical layer
Unit address	1...65519		1	1	DNP unit address
Master address	1...65519		1	3	DNP master and UR address
Serial port	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for serial interface, when physical layer is serial.
Need time interval	0...65535	min	1	30	Period to set IIN need time bit
Time format	0=UTC 1=Local			1=Local	UTC or local. Coordinate with master.
CROB select timeout	1...65535	sec	1	10	Control Relay Output Block select timeout

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Data link confirm	0=Never 1=Only Multiframe 2=Always			0=Never	Data link confirm mode
Data link confirm TO	100...65535	ms	1	3000	Data link confirm timeout
Data link retries	0...65535		1	3	Data link retries count
Data link Rx to Tx delay	0...255	ms	1	0	Turnaround transmission delay
Data link inter char delay	0...20	char	1	4	Inter character delay for incoming messages
App layer confirm	1=Disable 2=Enable			1=Disable	Application layer confirm mode
App confirm TO	100...65535	ms	1	5000	Application layer confirm and UR timeout
App layer fragment	256...2048	bytes	1	2048	Application layer fragment size
Legacy master SBO	1=Disable 2=Enable			1=Disable	Legacy DNP Master SBO sequence number relax enable
Default Var Obj 01	1...2		1	1	1=BI; 2=BI with status.
Default Var Obj 02	1...2		1	2	1=BI event; 2=BI event with time.
Default Var Obj 30	1...4		1	2	1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag.
Default Var Obj 32	1...4		1	4	1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time.

Table 23: COM1 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber light OFF loop			0=No fiber	Fiber mode for COM1
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake 4=RS232 with handshake			1=RS485 2Wire	Serial mode for COM1
CTS delay	0...60000			0	CTS delay for COM1
RTS delay	0...60000			0	RTS delay for COM1
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM1

If this protocol does not operate as expected, check that another serial protocol is not using the same COM port.

DNP3 protocol ignores any parity setting in the COM settings group; DNP3 is defined as an 8 bit/no parity protocol with a 16-bit CRC every 16 bytes. This provides better error detection than parity.

Table 24: COM2 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber light OFF loop			0=No fiber	Fiber mode for COM2
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake 4=RS232 with handshake			1=RS485 2Wire	Serial mode for COM2
CTS delay	0...60000			0	CTS delay for COM2
RTS delay	0...60000			0	RTS delay for COM2
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM2

Table 25: Time settings

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			5=MM/DD/YYYY	Date format

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Local time offset	-720...720	min		-300	Local time offset in minutes. Set to the number of minutes difference between UTC and Local Time (e.g. -300 for the Eastern U.S) if the local time sync source delivers time in UTC. Otherwise, set to 0 for no time sync source, or if the local time sync source is in local time.
Synch source	0=None 1=SNTP 2=Modbus 5=IRIG-B 9=DNP 16=IEC60870-5-101			1=SNTP	Time synchronization source
IP SNTP primary				10.58.125.165	IP address for SNTP primary server
IP SNTP secondary				192.168.2.165	IP address for SNTP secondary server
DST on time				02:00	Daylight savings time on, time (hh:mm)
DST on date				03/08	Daylight savings time on, date
DST on day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			7=Sun	Daylight savings time on, day of week
DST offset	-720...720	min		60	Daylight savings time offset, in minutes. Set to 0 if the local time sync source delivers time in local time. Otherwise, set to 60 minutes if you are in a region that observes daylight savings time.
DST off time				02:00	Daylight savings time off, time (hh:mm)
DST off date				11/01	Daylight savings time off, date
DST off day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			7=Sun	Daylight savings time off, day of week

Table 26: Binary input signals in card location Xnnn

Name	Type	Description
Xnnn-Input m 1)2)	BOOLEAN	See the application manual for terminal connections

1) Xnnn = Slot ID, for example, X100, X110, as applicable
2) m =For example, 1, 2, depending on the serial number of the binary input in a particular BIO card

Table 27: Binary output signals in card location Xnnn

Name	Type	Default	Description
Xnnn-Pmm[1][2]	BOOLEAN	0=False	See the application manual for terminal connections

1) Xnnn = Slot ID, for example, X100, X110, as applicable
2) Pmm = For example, PO1, PO2, SO1, SO2, as applicable

Table 28: Binary input settings in card location Xnnn

Name [1]	Value	Unit	Step	Default
Input m[2] filter time	5…1000	ms		5
Input m inversion	0= False 1= True			0=False

1) Xnnn = Slot ID, for example, X100, X110, as applicable
2) m = For example, 1, 2, depending on the serial number of the binary input in a particular BIO card

3.2 Self-supervision

The protection relay's extensive self-supervision system continuously supervises the software and the electronics. It handles run-time fault situation and informs the user about a fault via the LHMI and through the communication channels.

There are two types of fault indications.

- Internal faults
- Warnings

3.2.1 Internal faults

When an internal relay fault is detected, the green Normal LED begins to flash and the self-supervision output contact is activated.

Internal fault indications have the highest priority on the LHMI. None of the other LHMI indications can override the internal fault indication.

An indication about the fault is shown as a message on the LHMI. The text `Internal Fault` with an additional text message, a code, date and time, is shown to indicate the fault type.

Different actions are taken depending on the severity of the fault. The protection relay tries to eliminate the fault by restarting. After the fault is found to be permanent, the protection relay stays in internal fault mode. All other output contacts are released and locked for the internal fault. The protection relay continues to perform internal tests during the fault situation.

If an internal fault disappears, the green Normal LED stops flashing and the protection relay returns to the normal service state. The fault indication message remains on the display until manually cleared.

The self-supervision signal output operates on the closed circuit principle. Under normal conditions the relay is energized and the contact gap 3-5 in slot X100 is closed. If the auxiliary power supply fails or an internal fault is detected, the contact gap 3-5 is opened.

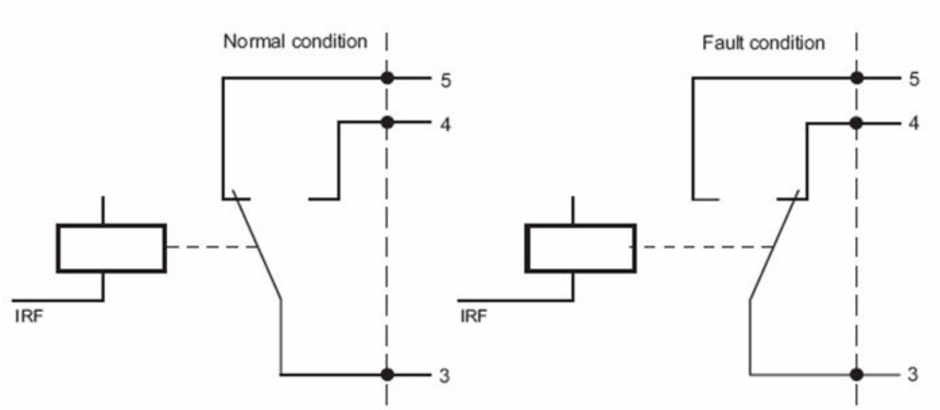


Figure 12: Output contact

The internal fault code indicates the type of internal relay fault. When a fault appears, record the code so that it can be reported to ABB customer service.

Table 29: Internal fault indications and codes

Fault indication	Fault code	Additional information
Internal Fault System error	2	An internal system error has occurred.
Internal Fault File system error	7	A file system error has occurred.
Internal Fault Test	8	Internal fault test activated manually by the user
Internal Fault SW watchdog error	10	Watchdog reset has occurred too many times within an hour.
Internal Fault SO-relay(s),X105	40	Faulty Signal Output relay(s) in card located in slot X105
Table continues on next page		

Fault indication	Fault code	Additional information
Internal Fault SO-relay(s),X115	41	Faulty Signal Output relay(s) in card located in slot X115
Internal Fault SO-relay(s),X100	43	Faulty Signal Output relay(s) in card located in slot X100
Internal Fault SO-relay(s),X110	44	Faulty Signal Output relay(s) in card located in slot X110
Internal Fault SO-relay(s),X120	45	Faulty Signal Output relay(s) in card located in slot X120
Internal Fault SO-relay(s),X130	46	Faulty Signal Output relay(s) in card located in slot X130
Internal Fault PO-relay(s),X105	50	Faulty Power Output relay(s) in card located in slot X105
Internal Fault PO-relay(s),X115	51	Faulty Power Output relay(s) in card located in slot X115
Internal Fault PO-relay(s),X100	53	Faulty Power Output relay(s) in card located in slot X100
Internal Fault PO-relay(s),X110	54	Faulty Power Output relay(s) in card located in slot X110
Internal Fault PO-relay(s),X120	55	Faulty Power Output relay(s) in card located in slot X120
Internal Fault PO-relay(s),X130	56	Faulty Power Output relay(s) in card located in slot X130
Internal Fault Light sensor error	57	Faulty ARC light sensor input(s)
Internal Fault Conf.error,X105	60	Card in slot X105 is wrong type
Internal Fault Conf.error,X115	61	Card in slot X115 is wrong type
Internal Fault Conf. error,X000	62	Card in slot X000 is wrong type
Internal Fault Conf. error,X100	63	Card in slot X100 is wrong type or does not belong to the original composition.
Internal Fault Conf. error,X110	64	Card in slot X110 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X120	65	Card in slot X120 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf.error,X130	66	Card in slot X130 is wrong type, is missing or does not belong to the original composition.
Internal Fault Card error,X105	70	Card in slot X105 is faulty.
Internal Fault Card error,X115	71	Card in slot X115 is faulty.

Table continues on next page

Fault indication	Fault code	Additional information
Internal Fault Card error,X000	72	Card in slot X000 is faulty.
Internal Fault Card error,X100	73	Card in slot X100 is faulty.
Internal Fault Card error,X110	74	Card in slot X110 is faulty.
Internal Fault Card error,X120	75	Card in slot X120 is faulty.
Internal Fault Card error,X130	76	Card in slot X130 is faulty.
Internal Fault LHMI module	79	LHMI module is faulty. The fault indication may not be seen on the LHMI during the fault.
Internal Fault RAM error	80	Error in the RAM memory on the CPU card.
Internal Fault ROM error	81	Error in the ROM memory on the CPU card.
Internal Fault EEPROM error	82	Error in the EEPROM memory on the CPU card.
Internal Fault FPGA error	83	Error in the FPGA on the CPU card.
Internal Fault RTC error	84	Error in the RTC on the CPU card.
Internal Fault RTD card error,X105	90	Card in slot X105 has RTD fault.
Internal Fault RTD card error,X110	94	Card in slot X110 has RTD fault.
Internal Fault RTD card error,X130	96	Card in slot X130 has RTD fault.

For further information on internal fault indications, see the operation manual.

3.2.2 Warnings

In case of a warning, the protection relay continues to operate except for those protection functions possibly affected by the fault, and the green Normal LED remains lit as during normal operation.

Warnings are indicated with the text `Warning` additionally provided with the name of the warning, a numeric code, and the date and time on the LHMI. The warning indication message can be manually cleared.

If a warning appears, record the name and code so that it can be provided to ABB customer service.

Table 30: Warning indications and codes

Warning indication	Warning code	Additional information
Warning System warning	2	An internal system error has occurred.
Warning Watchdog reset	10	A watchdog reset has occurred.
Warning Power down det.	11	The auxiliary supply voltage has dropped too low.
Warning IEC61850 error	20	Error when building the IEC 61850 data model
Warning Modbus error	21	Error in the Modbus communication
Warning DNP3 error	22	Error in the DNP3 communication
Warning Dataset error	24	Error in the Data set(s)
Warning Report cont. error	25	Error in the Report control block(s)
Warning GOOSE contr. error	26	Error in the GOOSE control block(s)
Warning SCL config error	27	Error in the SCL configuration file or the file is missing
Warning Logic error	28	Too many connections in the configuration
Warning SMT logic error	29	Error in the SMT connections
Warning GOOSE input error	30	Error in the GOOSE connections
ACT error	31	Error in the ACT connections
Warning GOOSE Rx. error	32	Error in the GOOSE message receiving
Warning AFL error	33	Analog channel configuration error
Warning Unack card comp.	40	A new composition has not been acknowledged/accepted.
Warning Protection comm.	50	Error in protection communication
Warning ARC1 cont. light	85	A continuous light has been detected on the ARC light input 1.
Warning ARC2 cont. light	86	A continuous light has been detected on the ARC light input 2.
Warning ARC3 cont. light	87	A continuous light has been detected on the ARC light input 3.
Warning RTD card error,X105	90	Temporary error occurred in RTD card located in slot X105

Table continues on next page

Warning indication	Warning code	Additional information
Warning RTD card error,X110	94	Temporary error occurred in RTD card located in slot X110
Warning RTD card error,X130	96	Temporary error occurred in RTD card located in slot X130.
Warning RTD measurement error in X105	100	Measurement error in RTD card located in slot X105
Warning RTD measurement error in X110	104	Measurement error in RTD card located in slot X110
Warning RTD meas. error,X130	106	Measurement error in RTD card located in slot X130

For further information on warning indications, see the operation manual.

3.3 Programmable LEDs

3.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Programmable LEDs	LED	LED	LED

3.3.2 Function block

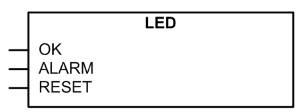


Figure 13: Function block

3.3.3 Functionality

The programmable LEDs reside on the right side of the display on the LHMI.

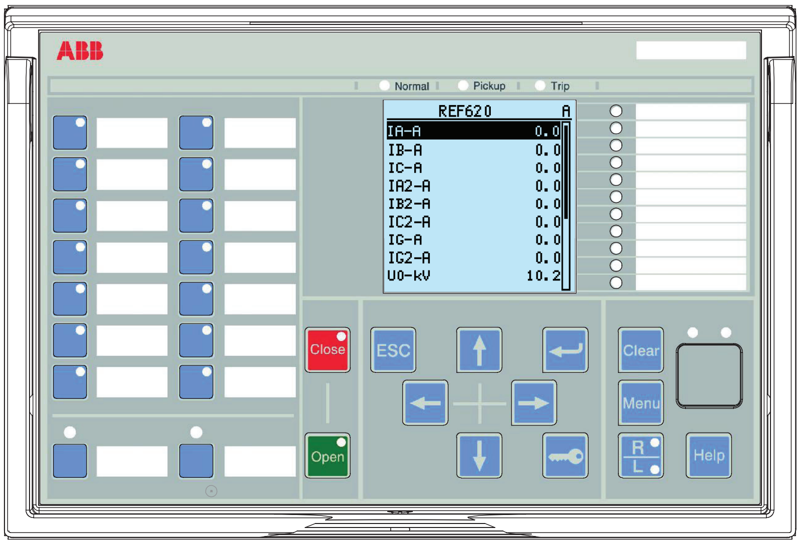


Figure 14: Programmable LEDs on the right side of the display

All the programmable LEDs in the HMI of the protection relay have two colors, green and red. For each LED, the different colors are individually controllable. For example: LEDx is green when AR is in progress and red when AR is locked out.

The red has the higher priority than the green.

The control of the LEDs is part of the SMT functionality. Each LED has two control inputs, one for each color. For the `ALARM` and `OK` inputs, the color is selectable as "Green" or "Red". The color for the `ALARM` input can be selected with the Alarm colour setting. The *Alarm colour* setting is common for all LEDs and has "Red" as default value. The `OK` input corresponds to the color that is available, with default being "Green".

Each LED is seen in the Application Configuration tool as an individual function block. Each LED has user-editable description text for event description. The state ("None", "OK", "Alarm") of each LED can also be read under a common monitored data view for programmable LEDs.

The LED status also provides a means for resetting the individual LED via communication. The LED can also be reset from configuration with the `RESET` input.

The resetting and clearing function for all LEDs is under the **Clear** menu.

The menu structure for the programmable LEDs is presented in Figure 15. The common color selection setting *Alarm colour* for all `ALARM` inputs is in the **General** menu, while the LED-specific settings are under the LED-specific menu nodes.

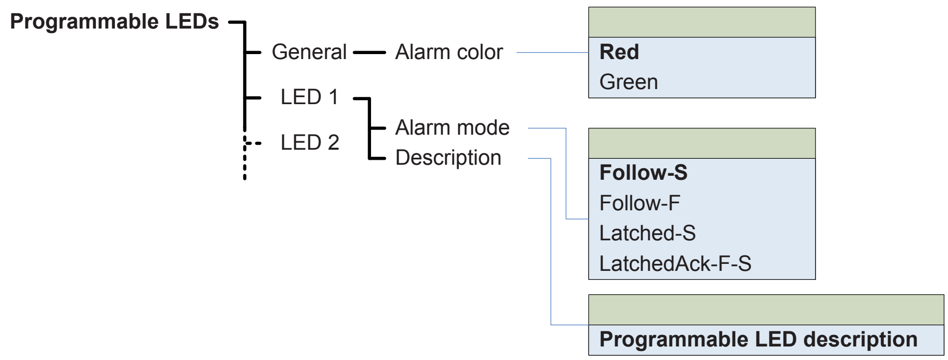


Figure 15: Menu structure

Alarm mode alternatives

The different alternatives for *Alarm mode* are "Follow-S", "Follow-F", "Latched-S" and "LatchedAck-F-S".

The *Alarm mode* setting applies only to the alarm-colored LED, which is red by default. When the LED color is of the `OK` input, it acts according to the "Follow-S" mode.

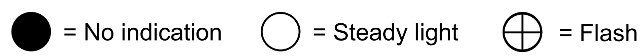


Figure 16: Symbols used in the sequence diagrams

"Follow-S": Follow Signal, ON

In this mode `ALARM` follows the input signal value, Non-latched.

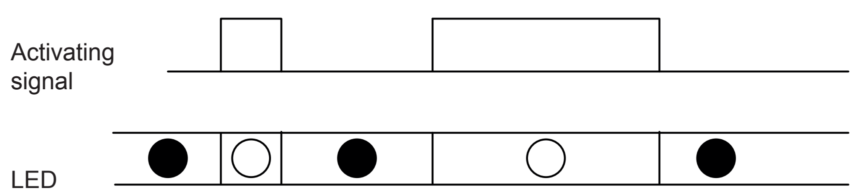


Figure 17: Operating sequence "Follow-S"

"Follow-F": Follow Signal, Flashing

Similar to "Follow-S", but instead the LED is flashing when the input is active, Non-latched.

"Latched-S": Latched, ON

This mode is a latched function. At the activation of the input signal, the alarm shows a steady light. After acknowledgement by the local operator pressing any key on the keypad, the alarm disappears.

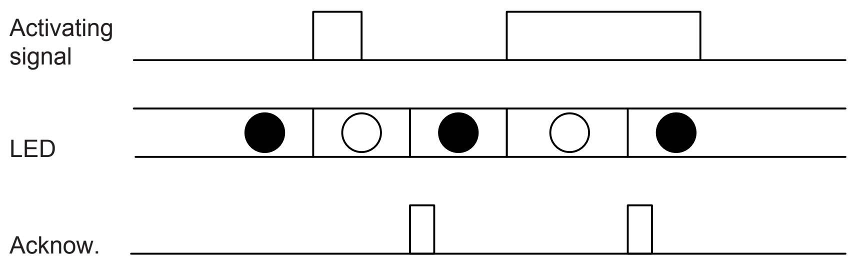


Figure 18: Operating sequence "Latched-S"

"LatchedAck-F-S": Latched, Flashing-ON

This mode is a latched function. At the activation of the input signal, the alarm starts flashing. After acknowledgement, the alarm disappears if the signal is not present and gives a steady light if the signal is present.

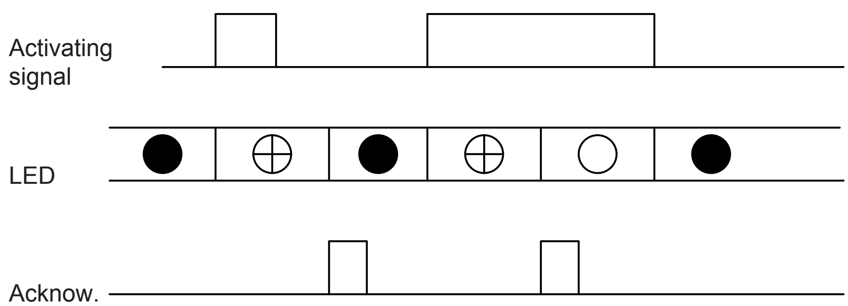


Figure 19: Operating sequence "LatchedAck-F-S"

3.3.4 Signals

Table 31: Input signals

Name	Type	Default	Description
X130-SO1	BOOLEAN	0=False	Connectors 9c-10nc-11no
X130-SO2	BOOLEAN	0=False	Connectors 12c-13nc-14no
X130-SO3	BOOLEAN	0=False	Trip output with TCS, Connectors 16-17

Table 32: LED Input signals

Name	Type	Default	Description
OK	BOOLEAN	0=False	Ok input for LED 1
ALARM	BOOLEAN	0=False	Alarm input for LED 1
RESET	BOOLEAN	0=False	Reset input for LED 1
OK	BOOLEAN	0=False	Ok input for LED 2
ALARM	BOOLEAN	0=False	Alarm input for LED 2
RESET	BOOLEAN	0=False	Reset input for LED 2
OK	BOOLEAN	0=False	Ok input for LED 3
ALARM	BOOLEAN	0=False	Alarm input for LED 3
RESET	BOOLEAN	0=False	Reset input for LED 3
OK	BOOLEAN	0=False	Ok input for LED 4
ALARM	BOOLEAN	0=False	Alarm input for LED 4
RESET	BOOLEAN	0=False	Reset input for LED 4
OK	BOOLEAN	0=False	Ok input for LED 5
ALARM	BOOLEAN	0=False	Alarm input for LED 5
RESET	BOOLEAN	0=False	Reset input for LED 5
OK	BOOLEAN	0=False	Ok input for LED 6
ALARM	BOOLEAN	0=False	Alarm input for LED 6
RESET	BOOLEAN	0=False	Reset input for LED 6
OK	BOOLEAN	0=False	Ok input for LED 7
ALARM	BOOLEAN	0=False	Alarm input for LED 7
RESET	BOOLEAN	0=False	Reset input for LED 7
OK	BOOLEAN	0=False	Ok input for LED 8
ALARM	BOOLEAN	0=False	Alarm input for LED 8
RESET	BOOLEAN	0=False	Reset input for LED 8
OK	BOOLEAN	0=False	Ok input for LED 9
ALARM	BOOLEAN	0=False	Alarm input for LED 9
RESET	BOOLEAN	0=False	Reset input for LED 9

Table continues on next page

Name	Type	Default	Description
OK	BOOLEAN	0=False	Ok input for LED 10
ALARM	BOOLEAN	0=False	Alarm input for LED 10
RESET	BOOLEAN	0=False	Reset input for LED 10
OK	BOOLEAN	0=False	Ok input for LED 11
ALARM	BOOLEAN	0=False	Alarm input for LED 11
RESET	BOOLEAN	0=False	Reset input for LED 11

3.3.5 Settings

Table 33: LED Settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 5=0..20mA			1=Not in use	Analogue input mode
Input maximum	0...20		1	20	Maximum analogue input value for mA or resistance scaling
Input minimum	0...20		1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0			10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0			-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0			10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0			10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0			-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0			-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)
Input mode	1=Not in use 2=Resistance 10=Pt100 11=Pt250 20=Ni100 21=Ni120 22=Ni250 30=Cu10			1=Not in use	Analogue input mode
Input maximum	0...2000		1	2000	Maximum analogue input value for mA or resistance scaling

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Input minimum	0...2000		1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0			10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0			-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0			10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0			10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0			-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0			-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)
Input mode	1=Not in use 2=Resistance 10=Pt100 11=Pt250 20=Ni100 21=Ni120 22=Ni250 30=Cu10			1=Not in use	Analogue input mode
Input maximum	0...2000		1	2000	Maximum analogue input value for mA or resistance scaling
Input minimum	0...2000		1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0			10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0			-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0			10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0			10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0			-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0			-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 34: Programmable LED Settings

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm colour	1=Green 2=Red			2=Red	Colour for the alarm state of the LED
Alarm mode	0=Follow-S[1)] 1=Follow-F[2)] 2=Latched-S[3)] 3=LatchedAck-F-S[4)]			0=Follow-S	Alarm mode for programmable LED 1
Description				Programmable LEDs LED 1	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 2
Description				Programmable LEDs LED 2	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 3
Description				Programmable LEDs LED 3	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 4
Description				Programmable LEDs LED 4	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 5
Description				Programmable LEDs LED 5	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 6
Description				Programmable LEDs LED 6	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 7
Description				Programmable LEDs LED 7	Programmable LED description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 8
Description				Programmable LEDs LED 8	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 9
Description				Programmable LEDs LED 9	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 10
Description				Programmable LEDs LED 10	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 11
Description				Programmable LEDs LED 11	Programmable LED description

1) Non-latched mode
2) Non-latched blinking mode
3) Latched mode
4) Latched blinking mode

3.3.6 Monitored data

Table 35: LED Monitored data

Name	Type	Values (Range)	Unit	Description
AI_DB1	FLOAT32	-10000.0...10000.0		mA input, Connectors 1-2, reported value
AI_RANGE1	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 1-2, range
AI_DB2	FLOAT32	-10000.0...10000.0		RTD input, Connectors 3-5, reported value
AI_RANGE2	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 3-5, range

Table continues on next page

Name	Type	Values (Range)	Unit	Description
AI_DB3	FLOAT32	-10000.0...10000.0		RTD input, Connectors 6-8, reported value
AI_RANGE3	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 6-8, range
Programmable LED 1	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 1
Programmable LED 2	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 2
Programmable LED 3	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 3
Programmable LED 4	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 4
Programmable LED 5	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 5
Programmable LED 6	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 6
Programmable LED 7	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 7
Programmable LED 8	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 8
Programmable LED 9	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 9
Programmable LED 10	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 10
Programmable LED 11	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 11

3.4 LED indication control

The protection relay includes a global conditioning function LEDPTRC that is used with the protection indication LEDs.

LED indication control should never be used for tripping purposes. There is a separate trip logic function TRPPTRC available in the relay configuration.

LED indication control is preconfigured in a such way that all the protection functions general pickup and trip signals are combined with this function (available as output signals OUT_PICKUP and OUT_TRIP). These signals are always internally connected to Pickup and Trip LEDs. LEDPTRC collects and combines phase information from different protection functions (available as output signals OUT_PU_A /_B /_C and OUT_TRP_A /_B /_C). There is also combined ground fault information collected from all the ground fault functions available in the relay configuration (available as output signals OUT_PU_NEUT and OUT_TRP_NEUT).

3.5 Time synchronization

The protection relay has an internal real-time clock which can be either free-running or synchronized from an external source. The real-time clock is used for time stamping events, recorded data and disturbance recordings.

The protection relay is provided with a 48 hour capacitor backup that enables the real-time clock to keep time in case of an auxiliary power failure.

The setting *Synch Source* determines the method to synchronize the real-time clock. If it is set to “None”, the clock is free-running and the settings *Date* and *Time* can be used to set the time manually. Other setting values activate a communication protocol that provides the time synchronization. Only one synchronization method can be active at a time but SNTP provides time master redundancy.

The protection relay supports SNTP, IRIG-B, DNP3 and Modbus to update the real-time clock. IRIG-B with GPS provides the best accuracy.

When Modbus TCP or DNP3 over TCP/IP is used, SNTP time synchronization should be used for better synchronization accuracy.

DNP3 can be used as a time synchronization source.

When the SNTP server IP setting is changed, the protection relay must be rebooted to activate the new IP address. The SNTP server IP settings are normally defined in the engineering phase via the SCL file.

The relay can use one of two SNTP servers, the primary or the secondary server. The primary server is mainly in use, whereas the secondary server is used if the primary server cannot be reached. While using the secondary SNTP server, the relay tries to switch back to the primary server on every third SNTP request attempt. If both the SNTP servers are offline, event time stamps have the time invalid status. The time is requested from the SNTP server every 60 seconds.

IRIG-B time synchronization requires the IRIG-B format B004/B005 according to the 200-04 IRIG-B standard. Older IRIG-B standards refer to these as B000/B001 with IEEE-1344 extensions. The synchronization time can be either UTC time or local time. As no reboot is necessary, the time synchronization starts immediately after the IRIG-B sync source is selected and the IRIG-B signal source is connected.

ABB has tested the IRIG-B with the following clock masters.

- Tekron TTM01 GPS clock with IRIG-B output
- Meinberg TCG511 controlled by GPS167
- Datum ET6000L
- Arbiter Systems 1088B

IRIG-B time synchronization requires a COM card with an IRIG-B input. Available only with some models.

3.6 Parameter setting groups

3.6.1 Function block

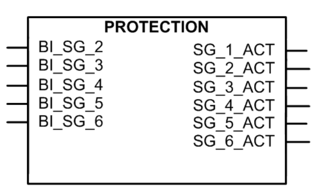


Figure 20: Function block

3.6.2 Functionality

The protection relay supports six setting groups. Each setting group contains parameters categorized as group settings inside application functions. The customer can change the active setting group at run time.

The active setting group can be changed by a parameter or via binary inputs depending on the mode selected with the **Configuration/Setting Group/SG operation mode** setting.

The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected. The setting group selection is not dependent on the `SG_x_ACT` outputs.

Table 36: Optional operation modes for setting group selection

SG operation mode	Description
Operator (Default)	Setting group can be changed with the setting **Settings/Setting group/Active group**.
Logic mode 1	Setting group can be changed with binary inputs (`BI_SG_2...BI_SG_6`). The highest `TRUE` binary input defines the active setting group.
Logic mode 2	Setting group can be changed with binary inputs where `BI_SG_4` is used for selecting setting groups 1-3 or 4-6. When binary input `BI_SG_4` is `FALSE`, setting groups 1-3 are selected with binary inputs `BI_SG_2` and `BI_SG_3`. When binary input `BI_SG_4` is `TRUE`, setting groups 4-6 are selected with binary inputs `BI_SG_5` and `BI_SG_6`.

For example, six setting groups can be controlled with three binary inputs. The *SG operation mode* is set to “Logic mode 2” and inputs `BI_SG_2` and `BI_SG_5` are connected together the same way as inputs `BI_SG_3` and `BI_SG_6`.

Table 37: SG operation mode = “Logic mode 1”

Input					
BI_SG_2	BI_SG_3	BI_SG_4	BI_SG_5	BI_SG_6	Active group
FALSE	FALSE	FALSE	FALSE	FALSE	1
TRUE	FALSE	FALSE	FALSE	FALSE	2
any	TRUE	FALSE	FALSE	FALSE	3
any	any	TRUE	FALSE	FALSE	4
any	any	any	TRUE	FALSE	5
any	any	any	any	TRUE	6

Table 38: SG operation mode = "Logic mode 2"

Input					
BI_SG_2	BI_SG_3	BI_SG_4	BI_SG_5	BI_SG_6	Active group
FALSE	FALSE	FALSE	any	any	1
TRUE	FALSE	FALSE	any	any	2
any	TRUE	FALSE	any	any	3
any	any	TRUE	FALSE	FALSE	4
any	any	TRUE	TRUE	FALSE	5
any	any	TRUE	any	TRUE	6

The setting group 1 can be copied to any other or all groups from HMI (Copy group 1).

3.7 Fault records

The protection relay has the capacity to store the records of 128 latest fault events. Fault records include fundamental or RMS current values. The records enable the user to analyze recent power system events. Each fault record (FLTRFRC) is marked with an up-counting fault number and a time stamp that is taken from the beginning of the fault.

The fault recording period begins from the pickup event of any protection function and ends if any protection function trips or the pickup(s) is restored before the trip event. If a pickup is restored without a trip event, the pickup duration shows the protection function that has picked up first.

Pickup duration that has the value of 100% indicates that a protection function has tripped during the fault and if none of the protection functions has been tripped, Pickup duration shows always values less than 100%.

The Fault recorded data Protection and Pickup duration is from the same protection function. The Fault recorded data trip time shows the time of the actual fault period.

The Trip time in the fault record is calculated based on the pickup and trip time stamps. Pickup events may be delayed to avoid false positive reporting. Therefore, the Trip time may be shorter than expected.

If some functions in relay application are sensitive to start frequently it might be advisable to set the setting parameter *Trig mode* to "From trip". Then only faults that cause an trip event trigger a new fault recording.

The fault-related current, voltage, frequency, angle values, shot pointer and the active setting group number are taken from the moment of the operate event, or from the beginning of the fault if only a pickup event occurs during the fault. The maximum current value collects the maximum fault currents during the fault. In case frequency cannot be measured, nominal frequency is used for frequency and zero for Frequency gradient and validity is set accordingly.

Measuring mode for phase current and residual current values can be selected with the *Measurement mode* setting parameter.

Table 39: FR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Trig mode	0=Trip or Pickup 1=Trip only 2=Pickup only			0=Trip or Pickup	Triggering mode
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table 40: FR Monitored data

Name	Type	Values (Range)	Unit	Description
Fault number	INT32	0...999999		Fault record number
Time and date	Timestamp			Fault record time stamp
Pickup duration	FLOAT32	0.00...100.00	%	Maximum pickup duration of all stages during the fault
Trip time	FLOAT32	0.000...999999.999	s	Trip time
Breaker clear time	FLOAT32	0.000...999999.999	s	Breaker clear time
Fault distance	FLOAT32	0.00...9999.99	pu	Distance to fault measured in pu
Fault resistance	FLOAT32	0.00...999.99	ohm	Fault resistance
Fault loop Ris	FLOAT32	-1000.00...1000.00	ohm	Resistance of fault loop
Fault loop React	FLOAT32	-1000.00...1000.00	ohm	Reactance of fault loop, PHDSTPDIS1
Setting group	INT32	1...6		Active setting group
Shot pointer	INT32	0...7		Autoreclosing shot pointer value

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Max diff current IA	FLOAT32	0.000...80.000	pu	Maximum phase A differential current
Max diff current IB	FLOAT32	0.000...80.000	pu	Maximum phase B differential current
Max diff current IC	FLOAT32	0.000...80.000	pu	Maximum phase C differential current
Diff current IA	FLOAT32	0.000...80.000	pu	Differential current phase A
Diff current IB	FLOAT32	0.000...80.000	pu	Differential current phase B
Diff current IC	FLOAT32	0.000...80.000	pu	Differential current phase C
Max bias current IA	FLOAT32	0.000...50.000	pu	Maximum phase A bias current
Max bias current IB	FLOAT32	0.000...50.000	pu	Maximum phase B bias current
Max bias current IC	FLOAT32	0.000...50.000	pu	Maximum phase C bias current
Bias current IA	FLOAT32	0.000...50.000	pu	Bias current phase A
Bias current IB	FLOAT32	0.000...50.000	pu	Bias current phase B
Bias current IC	FLOAT32	0.000...50.000	pu	Bias current phase C
Diff current IG	FLOAT32	0.000...80.000	pu	Differential current residual
Bias current IG	FLOAT32	0.000...50.000	pu	Bias current residual
Max current IA	FLOAT32	0.000...50.000	xIn	Maximum phase A current
Max current IB	FLOAT32	0.000...50.000	xIn	Maximum phase B current
Max current IC	FLOAT32	0.000...50.000	xIn	Maximum phase C current
Max current IG	FLOAT32	0.000...50.000	xIn	Maximum residual current
Current IA	FLOAT32	0.000...50.000	xIn	Phase A current
Current IB	FLOAT32	0.000...50.000	xIn	Phase B current
Current IC	FLOAT32	0.000...50.000	xIn	Phase C current
Current IG	FLOAT32	0.000...50.000	xIn	Residual current
Current I0	FLOAT32	0.000...50.000	xIn	Calculated residual current
Current I1	FLOAT32	0.000...50.000	xIn	Positive sequence current

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Current I2	FLOAT32	0.000...50.000	xIn	Negative sequence current
Max current IA2	FLOAT32	0.000...50.000	xIn	Maximum phase A current (b)
Max current IB2	FLOAT32	0.000...50.000	xIn	Maximum phase B current (b)
Max current IC2	FLOAT32	0.000...50.000	xIn	Maximum phase C current (b)
Max current IG2	FLOAT32	0.000...50.000	xIn	Maximum residual current (b)
Current IA2	FLOAT32	0.000...50.000	xIn	Maximum phase A current (b)
Current IB2	FLOAT32	0.000...50.000	xIn	Maximum phase B current (b)
Current IC2	FLOAT32	0.000...50.000	xIn	Maximum phase C current (b)
Current IG2	FLOAT32	0.000...50.000	xIn	Residual current (b)
Current I0B	FLOAT32	0.000...50.000	xIn	Calculated residual current (b)
Current I1B	FLOAT32	0.000...50.000	xIn	Positive sequence current (b)
Current I2B	FLOAT32	0.000...50.000	xIn	Negative sequence current (b)
Max current IA3	FLOAT32	0.000...50.000	xIn	Maximum phase A current (c)
Max current IB3	FLOAT32	0.000...50.000	xIn	Maximum phase B current (c)
Max current IC3	FLOAT32	0.000...50.000	xIn	Maximum phase C current (c)
Max current IG3	FLOAT32	0.000...50.000	xIn	Maximum residual current (c)
Current IA3	FLOAT32	0.000...50.000	xIn	Phase A current (c)
Current IB3	FLOAT32	0.000...50.000	xIn	Phase B current (c)
Current IC3	FLOAT32	0.000...50.000	xIn	Phase C current (c)
Current IG3	FLOAT32	0.000...50.000	xIn	Residual current (c)
Current I0-CalcC	FLOAT32	0.000...50.000	xIn	Calculated residual current (c)
Current Ps-SeqC	FLOAT32	0.000...50.000	xIn	Positive sequence current (c)
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
Current Ng-SeqC	FLOAT32	0.000...50.000	xIn	Negative sequence current (c)
Voltage VA	FLOAT32	0.000...4.000	xVn	Phase A voltage
Voltage VB	FLOAT32	0.000...4.000	xVn	Phase B voltage
Voltage VC	FLOAT32	0.000...4.000	xVn	Phase C voltage
Voltage VAB	FLOAT32	0.000...4.000	xVn	Phase A to phase B voltage
Voltage VBC	FLOAT32	0.000...4.000	xVn	Phase B to phase C voltage
Voltage VCA	FLOAT32	0.000...4.000	xVn	Phase C to phase A voltage
Voltage VG	FLOAT32	0.000...4.000	xVn	Residual voltage
Voltage V0	FLOAT32	0.000...4.000	xVn	Zero sequence voltage
Voltage V1	FLOAT32	0.000...4.000	xVn	Positive sequence voltage
Voltage V2	FLOAT32	0.000...4.000	xVn	Negative sequence voltage
Voltage VA2	FLOAT32	0.000...4.000	xVn	Phase A voltage (b)
Voltage VB2	FLOAT32	0.000...4.000	xVn	Phase B voltage (b)
Voltage VC2	FLOAT32	0.000...4.000	xVn	Phase B voltage (b)
Voltage VAB2	FLOAT32	0.000...4.000	xVn	Phase A to phase B voltage (b)
VoltageVBC2	FLOAT32	0.000...4.000	xVn	Phase B to phase C voltage (b)
Voltage VCA2	FLOAT32	0.000...4.000	xVn	Phase C to phase A voltage (b)
Voltage VG2	FLOAT32	0.000...4.000	xVn	Residual voltage (b)
Voltage Zro-SeqB	FLOAT32	0.000...4.000	xVn	Zero sequence voltage (b)
Voltage Ps-SeqB	FLOAT32	0.000...4.000	xVn	Positive sequence voltage (b)
Voltage Ng-SeqB	FLOAT32	0.000...4.000	xVn	Negative sequence voltage (b)
PTTR thermal level	FLOAT32	0.00...99.99		PTTR calculated temperature of the protected object relative to the trip level

Table continues on next page

Name	Type	Values (Range)	Unit	Description
PDNSPTOC1 rat. I2/I1	FLOAT32	0.00...999.99	%	PDNSPTOC1 ratio I2/I1 ratio I2/I1
Frequency	FLOAT32	30.00...80.00	Hz	Frequency
Frequency gradient	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient
Conductance Yo	FLOAT32	-1000.00...1000.00	mS	Conductance Yo
Susceptance Yo	FLOAT32	-1000.00...1000.00	mS	Susceptance Yo
Angle VG - IG	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current
Angle VBC - IA	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current
Angle VCA - IB	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current
Angle VAB - IC	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current
Angle VG2 - IG2	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current (b)
Angle VBC2 - IA2	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current (b)
Angle VCA2 - IB2	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current (b)
Angle VAB2 - IC2	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current (b)

3.8 Non-volatile memory

In addition to the setting values, the protection relay can store some data in the non-volatile memory.

- Up to 1024 events are stored. The stored events are visible in LHMI and WHMI only
- Recorded data
    - Fault records (up to 128)
    - Maximum demands
- Circuit breaker condition monitoring
- Latched alarm and trip LEDs' statuses

- Trip circuit lockout
- Counter values
- Load profile

3.9 Binary input

3.9.1 Binary input filter time

The filter time eliminates debounces and short disturbances on a binary input. The filter time is set for each binary input of the protection relay.

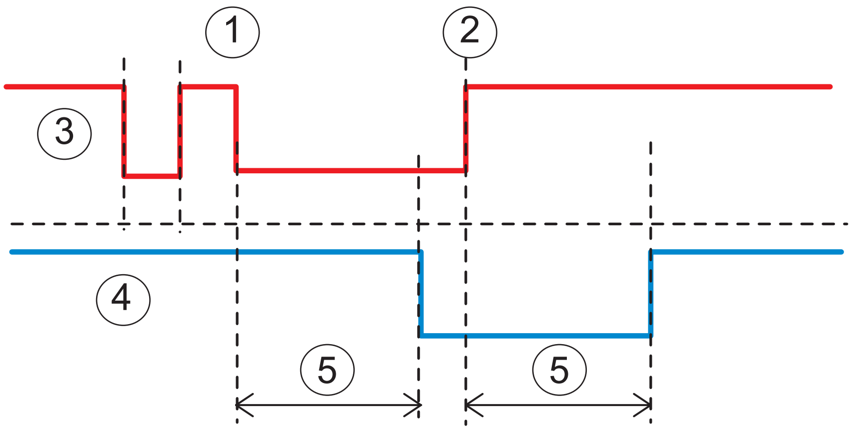


Figure 21: Binary input filtering

1 t_0

2 t_1

3 Input signal

4 Filtered input signal

5 Filter time

At the beginning, the input signal is at the high state, the short low state is filtered and no input state change is detected. The low state starting from the time t_0 exceeds the filter time, which means that the change in the input state is detected and the time tag attached to the input change is t_0. The high state starting from t_1 is detected and the time tag t_1 is attached.

Each binary input has a filter time parameter "Input # filter", where # is the number of the binary input of the module in question (for example "Input 1 filter").

Table 41: Input filter parameter values

Parameter	Values	Default
Input # filter time	5...1000 ms	5 ms

3.9.2 Binary input inversion

The parameter *Input # invert* is used to invert a binary input.

Table 42: Binary input states

Control voltage	Input # invert	State of binary input
No	0	False (0)
Yes	0	True (1)
No	1	True (0)
Yes	1	False (0)

When a binary input is inverted, the state of the input is TRUE (1) when no control voltage is applied to its terminals. Accordingly, the input state is FALSE (0) when a control voltage is applied to the terminals of the binary input.

3.9.3 Oscillation suppression

Oscillation suppression is used to reduce the load from the system when a binary input starts oscillating. A binary input is regarded as oscillating if the number of valid state changes (= number of events after filtering) during one second is equal to or greater than the set oscillation level value. During oscillation, the binary input is blocked (the status is invalid) and an event is generated. The state of the input will not change when it is blocked, that is, its state depends on the condition before blocking.

The binary input is regarded as non-oscillating if the number of valid state changes during one second is less than the set oscillation level value minus the set oscillation hysteresis value. Note that the oscillation hysteresis must be set lower than the oscillation level to enable the input to be restored from oscillation. When the input returns to a non-oscillating state, the binary input is deblocked (the status is valid) and an event is generated.

Table 43: Oscillation parameter values

Parameter	Values	Default
Input osc. level	2...50 events/s	30 events/s
Input osc. hyst	2...50 events/s	10 events/s

3.10 Binary outputs

The protection relay provides a number of binary outputs used for tripping, executing local or remote control actions of a breaker or a disconnector, and for connecting the protection relay to external annunciation equipment for indicating, signalling and recording.

Power output contacts are used when the current rating requirements of the contacts are high, for example, for controlling a breaker, such as energizing the breaker trip and closing coils.

The contacts used for external signalling, recording and indicating, the signal outputs, need to adjust to smaller currents, but they can require a minimum current (burden) to ensure a guaranteed operation.

The protection relay provides both power output and signal output contacts. To guarantee proper operation, the type of the contacts used are chosen based on the operating and reset time, continuous current rating, make and carry for short time, breaking rate and minimum connected burden. A combination of series or parallel contacts can also be used for special applications. When appropriate, a signal output can also be used to energize an external trip relay, which in turn can be confiugred to energize the breaker trip or close coils.

Using an external trip relay can require an external trip circuit supervision relay. It can also require wiring a separate trip relay contact back to the protection relay for breaker failure protection function.

All contacts are freely programmable, except the internal fault output IRF.

3.10.1 Power output contacts

Power output contacts are normally used for energizing the breaker closing coil and trip coil, external high burden lockout or trip relays.

3.10.1.1 Dual single-pole power outputs PO1 and PO2

Dual (series-connected) single-pole (normally open/form A) power output contacts PO1 and PO2 are rated for continuous current of 8 A. The contacts are normally used for closing circuit breakers and energizing high burden trip relays. They can be arranged to trip the circuit breakers when the trip circuit supervision is not available or when external trip circuit supervision relay is provided.

The power outputs are included in slot X100 of the power supply module.

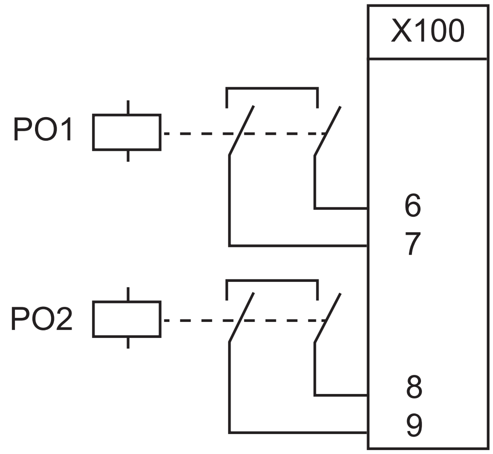


Figure 22: Dual single-pole power output contacts PO1 and PO2

3.10.1.2 Double-pole power outputs PO3 and PO4 with trip circuit supervision

The power outputs PO3 and PO4 are double-pole normally open/form A power outputs with trip circuit supervision.

When the two poles of the contacts are connected in series, they have the same technical specification as PO1 for breaking duty. The trip circuit supervision hardware and associated functionality which can supervise the breaker coil both during closing and opening condition are also provided. Contacts PO3 and PO4 are almost always used for energizing the breaker trip coils.

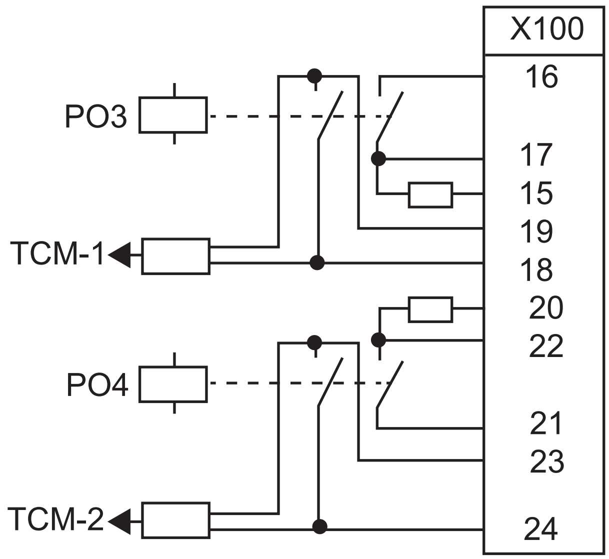


Figure 23: Double-pole power outputs PO3 and PO4 with trip circuit supervision

Power outputs PO3 and PO4 are included in the power supply module located in slot X100 of the protection relay.

3.10.1.3 Dual single-pole signal/trip output contact SO3/TO1

The dual parallel-connected, single-pole, normally open/form A output contact SO3/TO1 has a continuous rating of 5 A but has a lower breaking capacity than the other POs. When used in breaker tripping applications, an external contact, such as breaker auxiliary contact, is recommended to break the circuit. When the application requires, an optional BIO card with HSO contact can be ordered with the protection relay. A trip circuit supervision function is associated with this contact output.

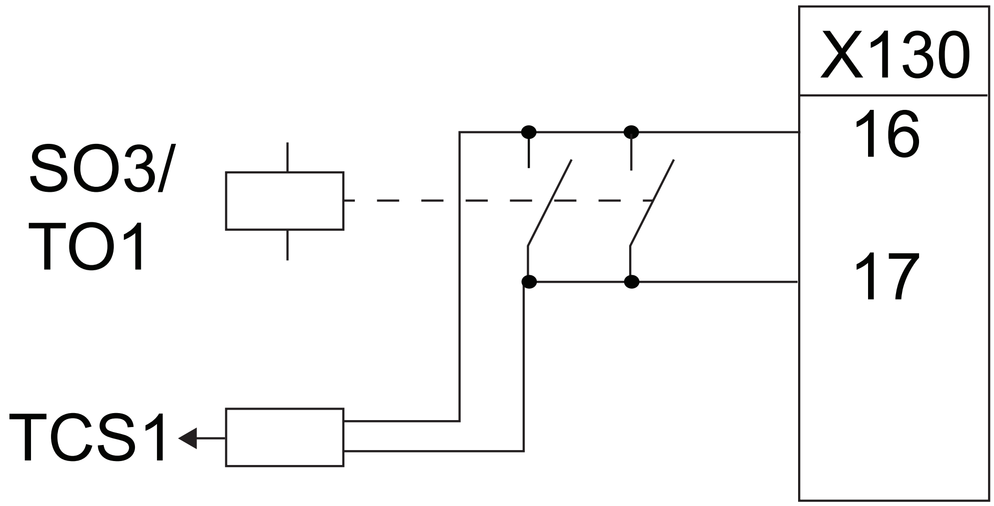


Figure 24: Signal/trip output contact SO3/TO1

The signal/trip output contact is included in the module RTD0002 located in slot X130 of the protection relay.

3.10.1.4 Dual single-pole high-speed power outputs HSO1, HSO2 and HSO3

HSO1, HSO2 and HSO3 are dual parallel connected, single-pole, normally open/form A high-speed power outputs. The high-speed power output is a hybrid discrete and electromechanical output that is rated as a power output.

The outputs are normally used in applications that require fast relay output contact activation time to achieve fast opening of a breaker, such as, arc-protection or breaker failure protection, where fast operation is required either to minimize fault effects to the equipment or to avoid a fault to expand to a larger area. With the high-speed outputs, the total time from the application to the relay output contact activation is 5...6 ms shorter than when using output contacts with conventional mechanical output relays. The high-speed power outputs have a continuous rating of 6 A. When two of HSO contacts are connected in series, the breaking rate is equal to that of output contact PO1.

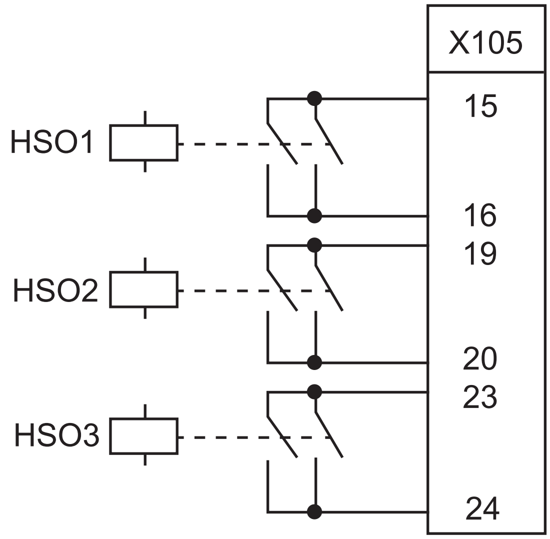


Figure 25: High-speed power outputs HSO1, HSO2 and HSO3

The reset time of the high-speed output contacts is longer than that of the conventional output contacts.

High-speed power contacts are part of the card BIO0007 with eight binary inputs and three HSOs. They are optional alternatives to conventional BIO cards of the protection relay.

3.10.2 Signal output contacts

Signal output contacts are single-pole, single (normally open/form A or change-over/form C) signal output contacts (SO1, SO2,...) or parallel connected dual contacts.

The signal output contacts are used for energizing, for example, external low burden trip relays, auxiliary relays, annunciators and LEDs.

A single signal contact is rated for a continuous current of 5 A. It has a make and carry for 0.5 seconds at 15 A.

When two contacts are connected in parallel, the relay is of a different design. It has the make and carry rating of 30 A for 0.5 seconds. This can be applied for energizing breaker close coil and tripping coil. Due to the limited breaking capacity, a breaker auxiliary contact can be required to break the circuit.

When the application requires high making and breaking duty, it is possible to use HSO contacts in the protection relay or an external interposing auxiliary relay.

3.10.2.1 Internal fault signal output IRF

The internal fault signal output (change-over/form C) IRF is a single contact included in the power supply module of the protection relay.

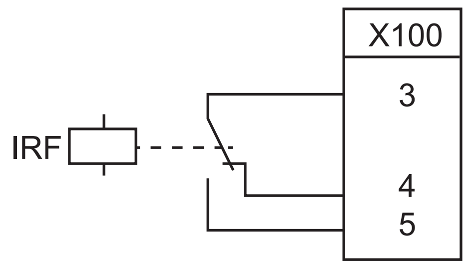


Figure 26: Internal fault signal output IRF

3.10.2.2 Signal outputs SO1 and SO2 in power supply module

Signal outputs (normally open/form A or change-over/form C) SO1 (dual parallel form C) and SO2 (single contact/form A) are part of the power supply module of the protection relay.

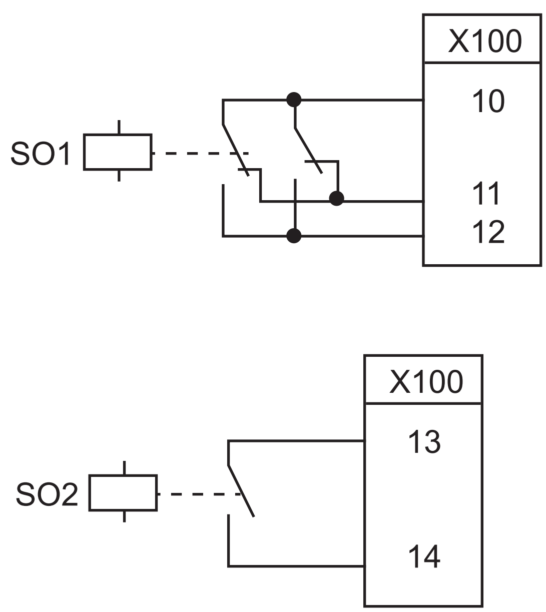


Figure 27: Signal outputs SO1 and SO2 in power supply module

3.10.2.3 Signal outputs SO1 and SO2 in RTD module

The signal ouputs SO1 and SO2 (single contact/change-over /form C) are included in the RTD0002 module.

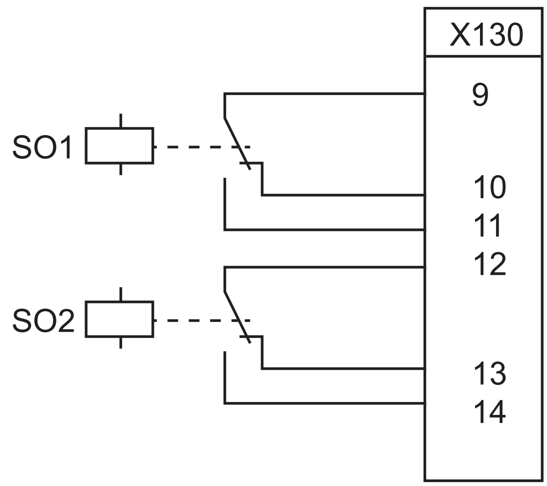


Figure 28: Signal output in RTD module

3.10.2.4 Signal outputs SO1, SO2 and SO3 in BIO0006

BIO0006 module is provided with signal outputs SO1, SO2 (dual parallel/form C) and SO3 (single/form C contact).

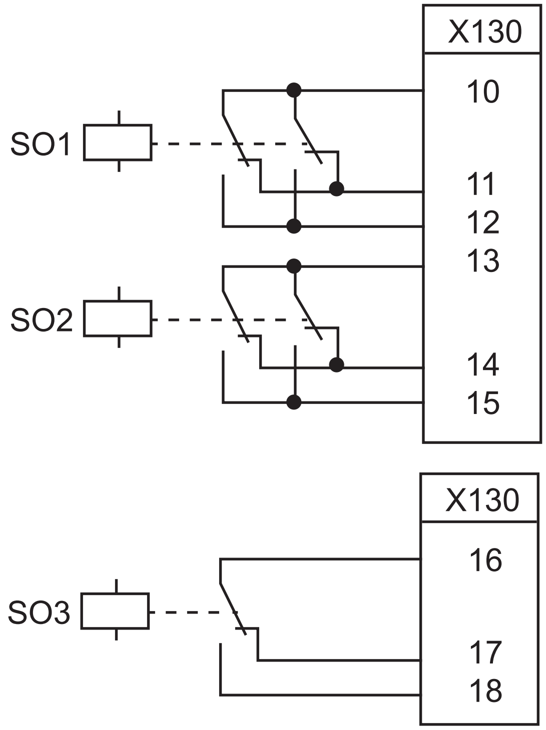


Figure 29: Signal outputs in BIO0006

3.10.2.5 Signal outputs SO1, SO2, SO3 and SO4 in BIO0005

The optional card BIO0005 provides the signal outputs SO1, SO2 SO3 and SO4. Signal outputs SO1 and SO2 are dual, parallel form C contacts; SO3 is a single form C contact, and SO4 is a single form A contact.

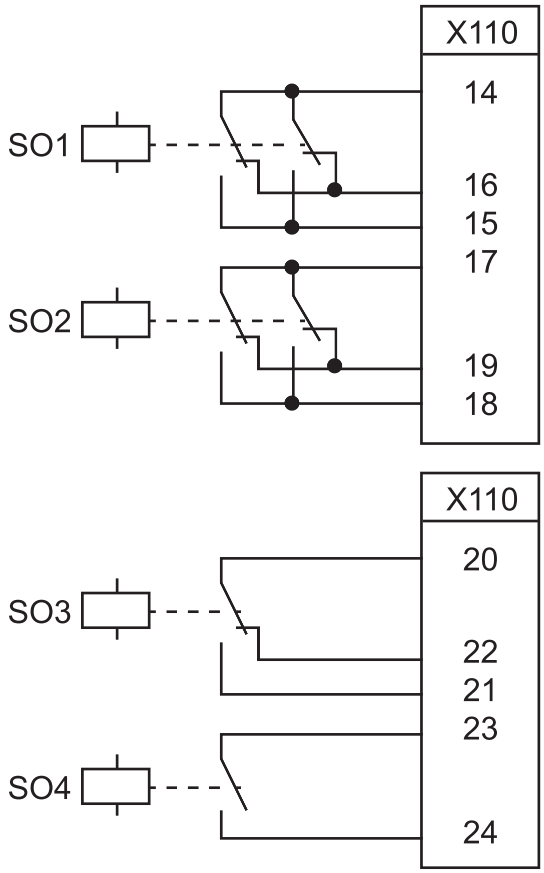


Figure 30: BIO0005 mounted in slot X110

3.11 RTD/mA inputs

3.11.1 Functionality

The RTD and mA analog input module is used for monitoring and metering current (mA), temperature (°C) and resistance (Ω). Each input can be linearly scaled for various applications, for example, transformer’s tap changer position indication. Each input has independent limit value supervision and deadband supervision functions, including warning and alarm signals.

3.11.2 Operation principle

All the inputs of the module are independent RTD and mA channels with individual protection, reference and optical isolation for each input, making them galvanically isolated from each other and from the rest of the module. However, the RTD inputs share a common ground.

3.11.2.1 Selection of input signal type

The function module inputs accept current or resistance type signals. The inputs are configured for a particular type of input type by the channel-specific *Input mode* setting. The default value for all inputs is “Not in use”, which means that the channel is not sampled at all, and the output value quality is set accordingly.

Table 44: Limits for the RTD/mA inputs

Input mode	Description
Not in use	Default selection. Used when the corresponding input is not used.
0...20 mA	Selection for analog DC milliampere current inputs in the input range of 0...20 mA.
Resistance	Selection for RTD inputs in the input range of 0...2000 Ω.
Pt100 Pt250 Ni100 Ni120 Ni250 Cu10	Selection for RTD inputs, when temperature sensor is used. All the selectable sensor types have their resistance vs. temperature characteristics stored in the module; default measuring range is -40...200°C.

3.11.2.2 Selection of output value format

Each input has independent *Value unit* settings that are used to select the unit for the channel output. The default value for the *Value unit* setting is “Dimensionless”. *Input minimum* and *Input maximum*, and *Value maximum* and *Value minimum* settings have to be adjusted according to the input channel. The default values for these settings are set to their maximum and minimum setting values.

When the channel is used for temperature sensor type, set the *Value unit* setting to “Degrees celsius”. When *Value unit* is set to “Degrees celsius”, the linear scaling is not possible, but the default range (-40…200 °C) can be set smaller with the *Value maximum* and *Value minimum* settings.

When the channel is used for DC milliampere signal and the application requires a linear scaling of the input range, the *Value unit* setting value has to be "Dimensionless”, where the input range can be linearly scaled with settings *Input minimum* and *Input maximum* to *Value minimum* and *Value maximum*. When milliampere is used as an output unit, *Value unit* has to be "Ampere”. When *Value unit* is set to “Ampere”, the linear scaling is not possible, but the default range (0…20 mA) can be set smaller with the *Value maximum* and *Value minimum* settings.

When the channel is used for resistance type signals and the application requires a linear scaling of the input range, the *Value unit* setting value has to be "Dimensionless", where the input range can be linearly scaled with the setting *Input minimum* and *Input maximum* to *Value minimum* and *Value maximum*. When resistance is used as an output unit, *Value unit* has to be "Ohm". When *Value unit* is set to "Ohm", the linear scaling is not possible, but the default range (0…2000 Ω) can be set smaller with the *Value maximum* and *Value minimum* settings.

3.11.2.3 Input linear scaling

Each RTD/mA input can be scaled linearly by the construction of a linear output function in respect to the input. The curve consists of two points, where the y-axis (*Input minimum* and *Input maximum*) defines the input range and the x-axis (*Value minimum* and *Value maximum*) is the range of the scaled value of the input.

The input scaling can be bypassed by selecting *Value unit* = "Ohm" when *Input mode* = "Resistance" is used and by selecting *Value unit* = "Ampere" when *Input mode* = "0...20 mA" is used.

Example for linear scaling

Milliampere input is used as tap changer position information. The sensor information is from 4 mA to 20 mA that is equivalent to the tap changer position from -36 to 36, respectively.

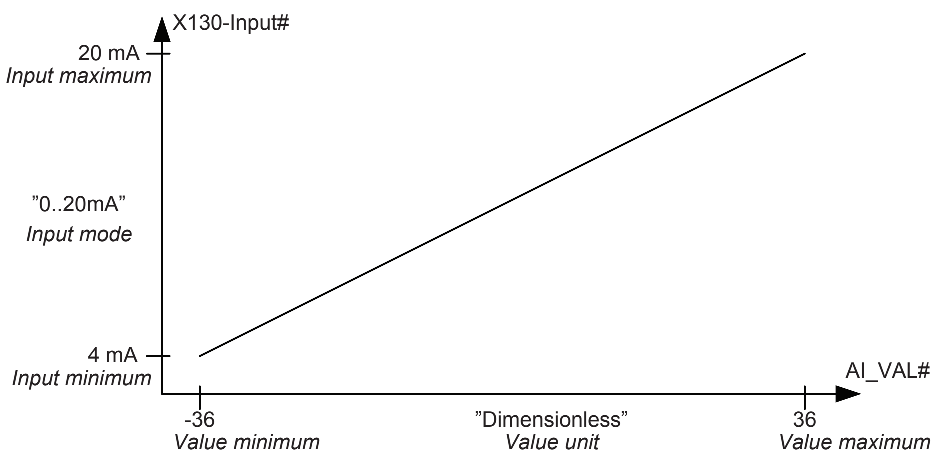


Figure 31: Milliampere input scaled to tap changer position information

3.11.2.4 Measurement chain supervision

Each input contains a functionality to monitor the input measurement chain. The circuitry monitors the RTD channels continuously and reports a circuitry break of any enabled input channel. If the measured input value is outside the limits, minimum/maximum value is shown in the corresponding output. The quality of the corresponding output is set accordingly to indicate misbehavior in the RTD/mA input.

Table 45: Function identification, limits for the RTD/mA inputs

Input	Limit value
RTD temperature, high	> 200 °C
RTD temperature, low	< -40 °C
mA current, high	> 23 mA
Resistance, high	> 2000 Ω

3.11.2.5 Self-supervision

Each input sample is validated before it is fed into the filter algorithm. The samples are validated by measuring an internally set reference current immediately after the inputs are sampled. Each RTD sensor type has expected current based on the sensor type. If the measured offset current deviates from the reference current more than 20%, the sample is discarded and the output is set to invalid. The invalid measure status deactivates as soon as the measured input signal is within the measurement offset.

3.11.2.6 Calibration

RTD and mA inputs are calibrated at the factory. The calibration circuitry monitors the RTD channels continuously and reports a circuitry break of any channel.

3.11.2.7 Limit value supervision

The limit value supervision function indicates whether the measured value of AI_INST# exceeds or falls below the set limits. All the measuring channels have an individual limit value supervision function. The measured value contains the corresponding range information AI_RANGE# and has a value in the range of 0 to 4:

- 0: “normal”
- 1: “high”
- 2: “low”
- 3: “high-high”
- 4: “low-low”

The range information changes and the new values are reported.

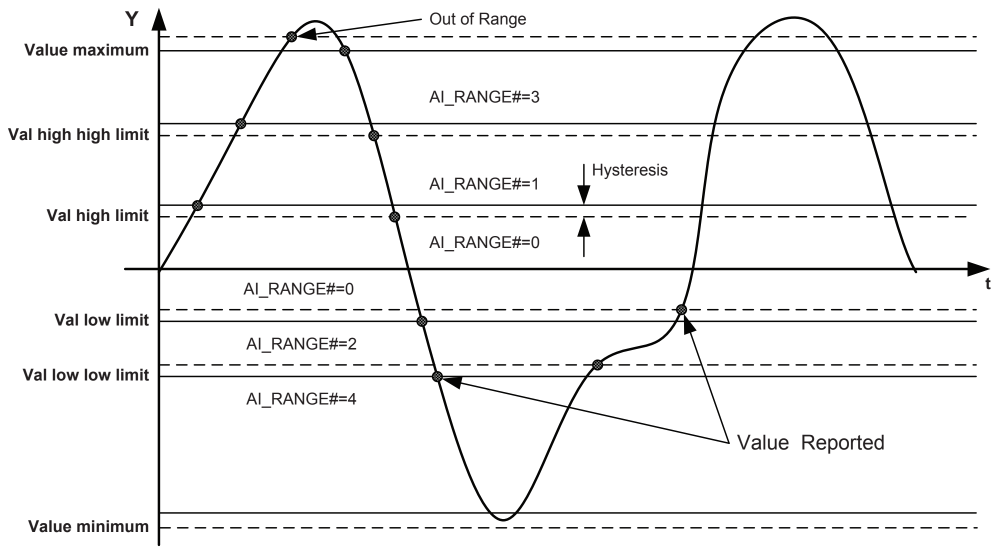


Figure 32: Limit value supervision for RTD

The range information of "High-high limit" and "Low-low limit" is combined from all measurement channels to the Boolean ALARM output. The range information of "High limit" and "Low limit" is combined from all measurement channels to the Boolean WARNING output.

Table 46: Settings for RTD analog input limit value supervision

Function	Settings for limit value supervision	
RTD analog input	Out of range	Value maximum
	High-high limit	Val high high limit
	High limit	Val high limit
	Low limit	Val low limit
	Low-low limit	Val low low limit
	Out of range	Value minimum

When the measured value exceeds either the *Value maximum* setting or the *Value minimum* setting, the corresponding quality is set to out of range and a maximum or minimum value is shown when the measured value exceeds the added hysteresis, respectively. The hysteresis is added to the extreme value of the range limit to allow the measurement slightly to exceed the limit value before it is considered out of range.

3.11.2.8 Deadband supervision

Each input has an independent deadband supervision. The deadband supervision function reports the measured value according to integrated changes over a time period.

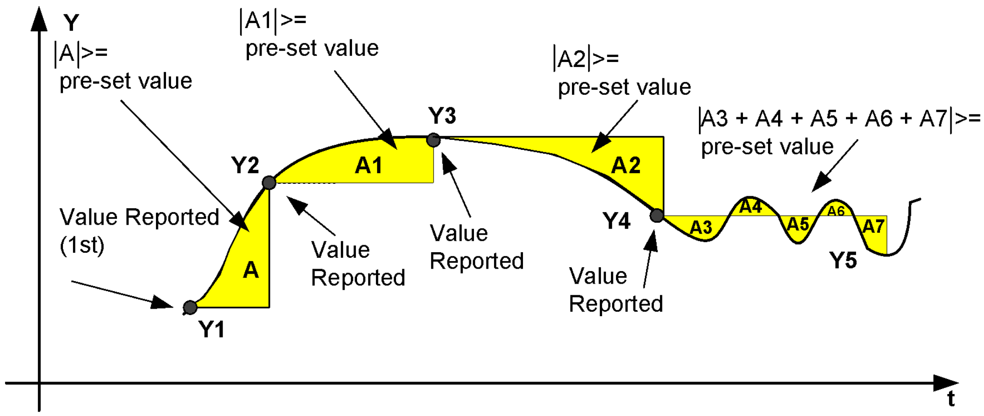


Figure 33: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *Value deadband* setting. The value represents the percentage of the difference between the maximum and minimum limits in the units of 0.001 percent * seconds. The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(\text{Value maximum - Value minimum}) \times \text{deadband} / 1000}{|\Delta Y| \times 100\%}$$

(Equation 1)

Example of X130 (RTD) analog input deadband supervision

Temperature sensor Pt100 is used in the temperature range of 15...180 °C. *Value unit* “Degrees Celsius” is used and the set values *Value minimum* and *Value maximum* are set to 15 and 180, respectively.

Value deadband = 7500 (7.5% of the total measuring range 165)

AI_VAL# = AI_DB# = 85

If AI_VAL# changes to 90, the reporting delay is:

$$t(s) = \frac{(180\,^{\circ}C - 15\,^{\circ}C) \times 7500\%s / 1000}{|90\,^{\circ}C - 85\,^{\circ}C| \times 100\%} \approx 2.5s$$

(Equation 2)

Table 47: Settings for RTD analog deadband supervision

Function	Setting	Maximum/minimum (=range)
RTD analog input	Value deadband	Value maximum / Value minimum (=20000)

Since the function can be utilized in various measurement modes, the default values are set to the extremes; thus, it is very important to set correct limit values to suit the application before the deadband supervision works properly.

3.11.2.9 RTD temperature vs. resistance

Table 48: Temperature vs. resistance

Temp °C	Platinum TCR 0.00385		Nickel TCR 0.00618			Copper TCR 0.00427
	Pt 100	Pt 250	Ni 100	Ni 120	Ni 250	Cu 10
-40	84.27	210.675	79.1	94.92	197.75	7.49
-30	88.22	220.55	84.1	100.92	210.25	-
-20	92.16	230.4	89.3	107.16	223.25	8.263
-10	96.09	240.225	94.6	113.52	236.5	-
0	100	250	100	120	250	9.035
10	103.9	259.75	105.6	126.72	264	-
20	107.79	269.475	111.2	133.44	278	9.807
30	111.67	279.175	117.1	140.52	292.75	-
40	115.54	288.85	123	147.6	307.5	10.58
50	119.4	298.5	129.1	154.92	322.75	-
60	123.24	308.1	135.3	162.36	338.25	11.352
70	127.07	317.675	141.7	170.04	354.25	-
80	130.89	327.225	148.3	177.96	370.75	12.124
90	134.7	336.75	154.9	185.88	387.25	-
100	138.5	346.25	161.8	194.16	404.5	12.897
120	146.06	365.15	176	211.2	440	13.669
140	153.58	383.95	190.9	229.08	477.25	14.442
150	-	-	198.6	238.32	496.5	-
160	161.04	402.6	206.6	247.92	516.5	15.217
180	168.46	421.15	223.2	267.84	558	-
200	175.84	439.6	240.7	288.84	601.75	-

3.11.2.10 RTD/mA input connection

RTD inputs can be used with a 2-wire or 3-wire connection with common ground. When using the 3-wire connection, it is important that all three wires connecting the sensor are symmetrical, that is, the wires are of the same type and length.

When using the 3-wire connection, it is important that all three wires connecting the sensor are symmetrical, that is, the wires are of the same type and length, hence the wire resistance is automatically compensated.

In the 2-wire connection, the lead resistance is not compensated. This scheme may be adopted when the lead resistance is negligible when compared to the RTD resistance or when the error so introduced is acceptable for the application in which it is used.

For graphical representation of the RTD and milli-ampere input connections, see RTD/mA card variants.

3.11.2.11 RTD/mA card variants

The available variants of RTD cards are 6RTD/2mA, 2RTD/1mA/3SO and 2RTD/1mA/5VT with an RTD capability. The features are similar in all three cards.

6RTD/2mA card

This card accepts two milliampere inputs and six inputs from the RTD sensors. The inputs `1` and `2` are used for current measurement, whereas inputs from `3` to `8` are used for resistance type of measurements.

RTD/mA input connection

Resistance and temperature sensors can be connected to the 6RTD/2mA board with 3-wire and 2-wire connections.

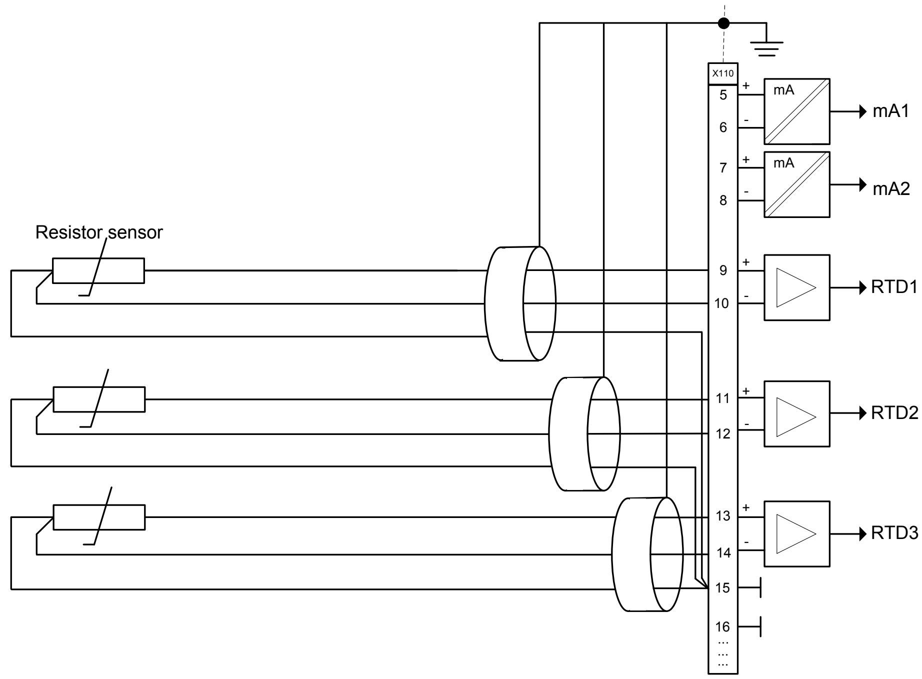


Figure 34: Three RTD sensors and two resistance sensors connected according to the 3-wire connection for 6RTD/2mA card

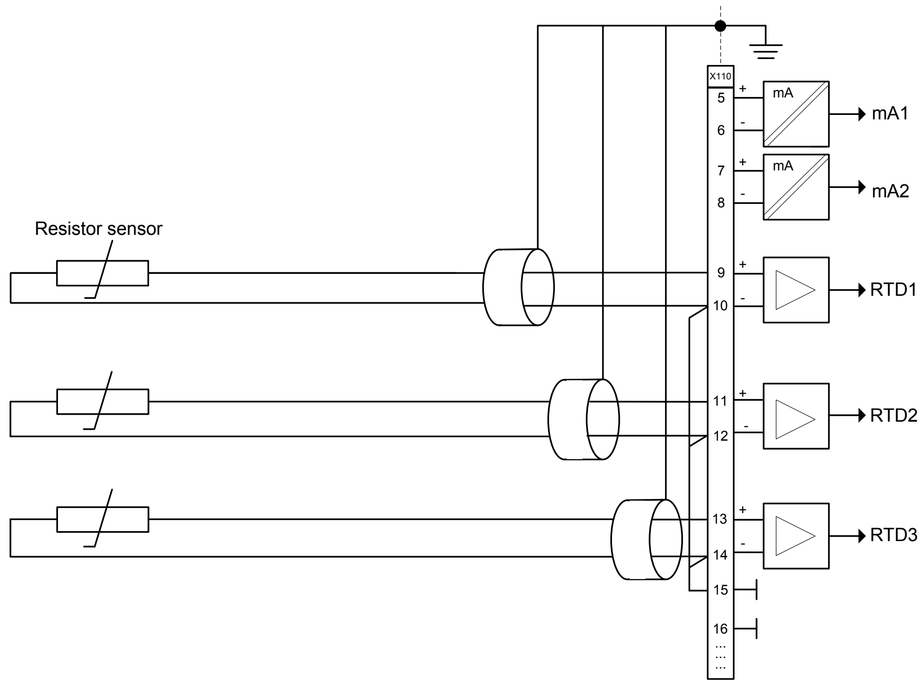


Figure 35: Three RTD sensors and two resistance sensors connected according to the 2-wire connection for 6RTD/2mA card

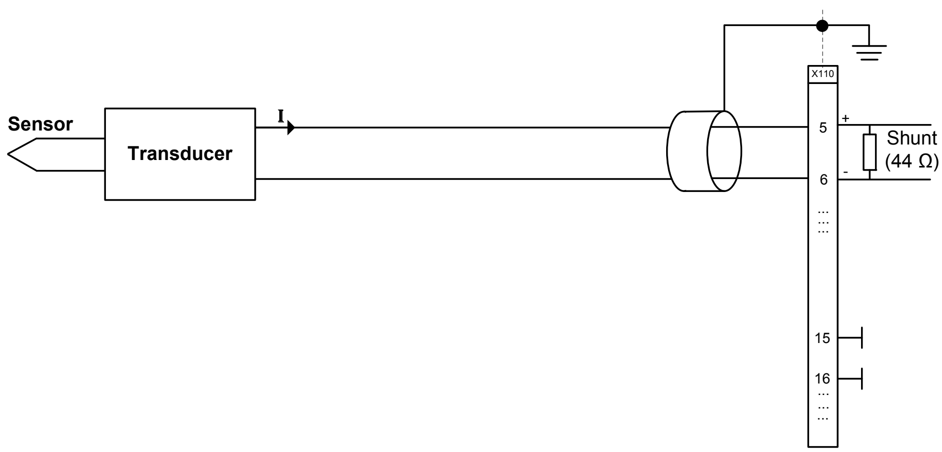


Figure 36: mA wiring connection for 6RTD/2mA card

2RTD/1mA card

This type of card accepts one milliampere input, two inputs from RTD sensors and five inputs from VTs. The Input 1 is assigned for current measurements, inputs 2 and 3 are for RTD sensors and inputs 4 to 8 are used for measuring input data from VT.

2RTD/1mA/3SO card has one milliampere input, two inputs from RTD sensors and three signal outputs. The Input 1 is assigned for current measurements, inputs 2 and 3 are for RTD sensors and outputs 4,5,6 are used signal outputs.

RTD/mA input connections

The examples of 3-wire and 2-wire connections of resistance and temperature sensors to the 2RTD/1mA board are as shown:

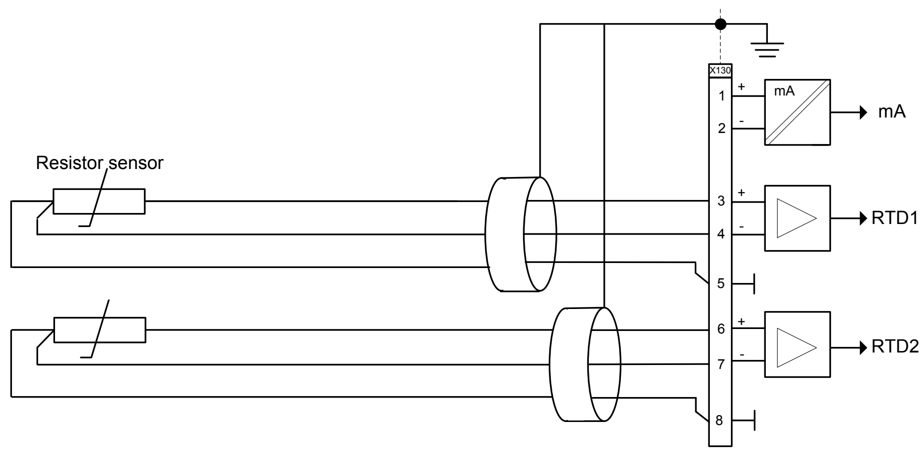


Figure 37: Two RTD and resistance sensors connected according to the 3-wire connection for RTD/mA card

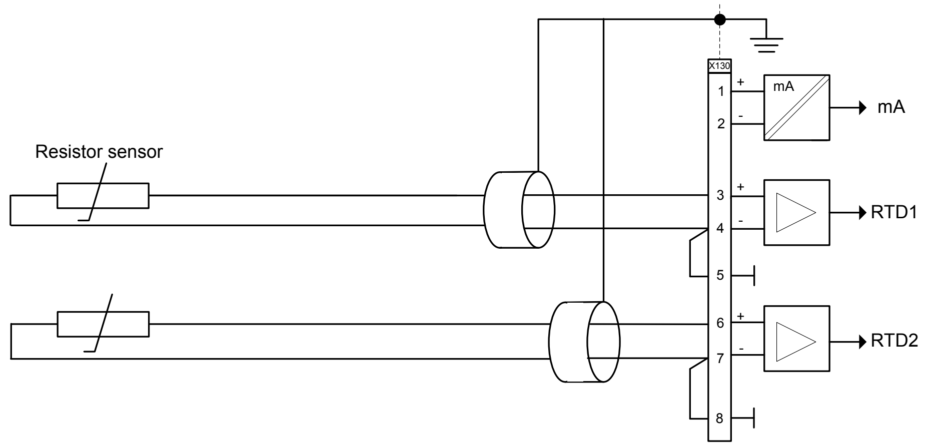


Figure 38: Two RTD and resistance sensors connected according to the 2-wire connection for RTD/mA card

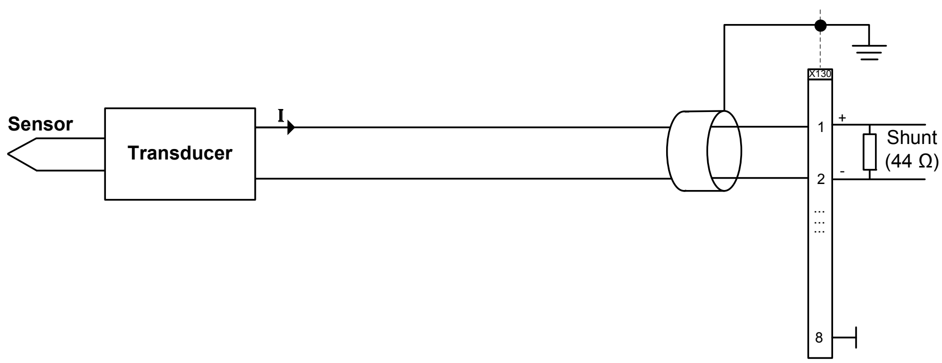


Figure 39: mA wiring connection for RTD/mA card

3.11.3 Signals

Table 49: 6RTD/2mA analog input signals

Name	Type	Description
ALARM	BOOLEAN	General alarm
WARNING	BOOLEAN	General warning
AI_VAL1	FLOAT32	mA input, Connectors 5-6, instantaneous value
AI_VAL2	FLOAT32	mA input, Connectors 7-8, instantaneous value
Table continues on next page		

Name	Type	Description
AI_VAL3	FLOAT32	RTD input, Connectors 9-10-15c, instantaneous value
AI_VAL4	FLOAT32	RTD input, Connectors 11-12-15c, instantaneous value
AI_VAL5	FLOAT32	RTD input, Connectors 13-14-15c, instantaneous value
AI_VAL6	FLOAT32	RTD input, Connectors 17-18-16c, instantaneous value
AI_VAL7	FLOAT32	RTD input, Connectors 19-20-16c, instantaneous value
AI_VAL8	FLOAT32	RTD input, Connectors 21-22-16c, instantaneous value

3.11.4 Settings

Table 50: RTD input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 2=Resistance 10=Pt100 11=Pt250 20=Ni100 21=Ni120 22=Ni250 30=Cu10			1=Not in use	Analogue input mode
Input maximum	0...2000	Ω	1	2000	Maximum analogue input value for mA or resistance scaling
Input minimum	0...2000	Ω	1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0		1	10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0		1	-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0		1	10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0		1	10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0		1	-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0		1	-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000		1	1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 51: mA input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 5=0..20mA			1=Not in use	Analogue input mode
Input maximum	0...20	mA	1	20	Maximum analogue input value for mA or resistance scaling
Input minimum	0...20	mA	1	0	Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	-10000.0...10000.0		1	10000.0	Maximum output value for scaling and supervision
Value minimum	-10000.0...10000.0		1	-10000.0	Minimum output value for scaling and supervision
Val high high limit	-10000.0...10000.0		1	10000.0	Output value high alarm limit for supervision
Value high limit	-10000.0...10000.0		1	10000.0	Output value high warning limit for supervision
Value low limit	-10000.0...10000.0		1	-10000.0	Output value low warning limit for supervision
Value low low limit	-10000.0...10000.0		1	-10000.0	Output value low alarm limit for supervision
Value deadband	100...100000		1	1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

3.11.5 Monitored data

Table 52: RTD/mA monitored data

Name	Type	Values (Range)	Unit	Description
AI_DB1	FLOAT32	-10000.0...10000.0		mA input, Connectors 5-6, reported value
AI_RANGE1	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 5-6, range
AI_DB2	FLOAT32	-10000.0...10000.0		mA input, Connectors 7-8, reported value
AI_RANGE2	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		mA input, Connectors 7-8, range
AI_DB3	FLOAT32	-10000.0...10000.0		RTD input, Connectors 9-10-15c, reported value

Table continues on next page

Name	Type	Values (Range)	Unit	Description
AI_RANGE3	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 9-10-15c, range
AI_DB4	FLOAT32	-10000.0...10000.0		RTD input, Connectors 7-8-11c, reported value
AI_RANGE4	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 7-8-11c, range
AI_DB5	FLOAT32	-10000.0...10000.0		RTD input, Connectors 9-10-11c, reported value
AI_RANGE5	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 9-10-11c, range
AI_DB6	FLOAT32	-10000.0...10000.0		RTD input, Connectors 13-14-12c, reported value
AI_RANGE6	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 13-14-12c, range
AI_DB7	FLOAT32	-10000.0...10000.0		RTD input, Connectors 15-16-12c, reported value
AI_RANGE7	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 15-16-12c, range
AI_DB8	FLOAT32	-10000.0...10000.0		RTD input, Connectors 17-18-12c, reported value
AI_RANGE8	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		RTD input, Connectors 17-18-12c, range

3.12 GOOSE function blocks

GOOSE function blocks are used for connecting incoming GOOSE data to application. They support BOOLEAN, Dbpos, Enum, FLOAT32, INT8 and INT32 data types.

Common signals

The VALID output indicates the validity of received GOOSE data, which means in case of valid, that the GOOSE communication is working and received data quality bits (if configured) indicate good process data. Invalid status is caused either by bad data quality bits or GOOSE communication failure. See IEC 61850 engineering guide for details.

The OUT output passes the received GOOSE value for the application. Default value (0) is used if VALID output indicates invalid status. The IN input is defined in the GOOSE configuration and can always be seen in SMT sheet.

Settings

The GOOSE function blocks do not have any parameters available in LHMI or PCM600.

3.12.1 GOOSERCV_BIN function block

3.12.1.1 Function block

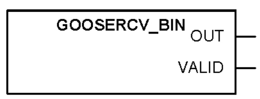


Figure 40: Function block

3.12.1.2 Functionality

The GOOSERCV_BIN function is used to connect the GOOSE binary inputs to the application.

3.12.1.3 Signals

Table 53: GOOSERCV_BIN Input signals

Name	Type	Default	Description
IN	BOOLEAN	0	Input signal

Table 54: GOOSERCV_BIN Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
VALID	BOOLEAN	Output signal

3.12.2 GOOSERCV_DP function block

3.12.2.1 Function block

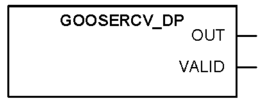


Figure 41: Function block

3.12.2.2 Functionality

The GOOSERCV_DP function is used to connect the GOOSE double binary inputs to the application.

3.12.2.3 Signals

Table 55: GOOSERCV_DP Input signals

Name	Type	Default	Description
IN	Dbpos	00	Input signal

Table 56: GOOSERCV_DP Output signals

Name	Type	Description
OUT	Dbpos	Output signal
VALID	BOOLEAN	Output signal

3.12.3 GOOSERCV_MV function block

3.12.3.1 Function block

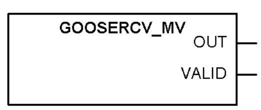


Figure 42: Function block

3.12.3.2 Functionality

The GOOSERCV_MV function is used to connect the GOOSE measured value inputs to the application.

3.12.3.3 Signals

Table 57: GOOSERCV_MV Input signals

Name	Type	Default	Description
IN	FLOAT32	0	Input signal

Table 58: GOOSERCV_MV Output signals

Name	Type	Description
OUT	FLOAT32	Output signal
VALID	BOOLEAN	Output signal

3.12.4 GOOSERCV_INT8 function block

3.12.4.1 Function block

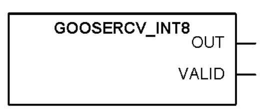


Figure 43: Function block

3.12.4.2 Functionality

The GOOSERCV_INT8 function is used to connect the GOOSE 8 bit integer inputs to the application.

3.12.4.3 Signals

Table 59: GOOSERCV_INT8 Input signals

Name	Type	Default	Description
IN	INT8	0	Input signal

Table 60: GOOSERCV_INT8 Output signals

Name	Type	Description
OUT	INT8	Output signal
VALID	BOOLEAN	Output signal

3.12.5 GOOSERCV_INTL function block

3.12.5.1 Function block

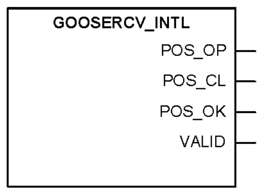


Figure 44: Function block

3.12.5.2 Functionality

The GOOSERCV_INTL function is used to connect the GOOSE double binary input to the application and extracting single binary position signals from the double binary position signal.

The OP output signal indicates that the position is open. Default value (0) is used if VALID output indicates invalid status.

The CL output signal indicates that the position is closed. Default value (0) is used if VALID output indicates invalid status.

The OK output signal indicates that the position is neither in faulty or intermediate state. The default value (0) is used if VALID output indicates invalid status.

3.12.5.3 Signals

Table 61: GOOSERCV_INTL Input signals

Name	Type	Default	Description
IN	Dbpos	00	Input signal

Table 62: GOOSERCV_INTL Output signals

Name	Type	Description
OP	BOOLEAN	Position open output signal
CL	BOOLEAN	Position closed output signal
OK	BOOLEAN	Position OK output signal
VALID	BOOLEAN	Output signal

3.12.6 GOOSERCV_CMV function block

3.12.6.1 Function block

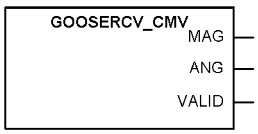


Figure 45: Function block

3.12.6.2 Functionality

The GOOSERCV_CMV function is used to connect GOOSE measured value inputs to the application. The MAG_IN (amplitude) and ANG_IN (angle) inputs are defined in the GOOSE configuration (PCM600).

The MAG output passes the received GOOSE (amplitude) value for the application. Default value (0) is used if VALID output indicates invalid status.

The ANG output passes the received GOOSE (angle) value for the application. Default value (0) is used if VALID output indicates invalid status.

3.12.6.3 Signals

Table 63: GOOSERCV_CMV Input signals

Name	Type	Default	Description
MAG_IN	FLOAT32	0	Input signal (amplitude)
ANG_IN	FLOAT32	0	Input signal (angle)

Table 64: GOOSERCV_CMV Output signals

Name	Type	Description
MAG	FLOAT32	Output signal (amplitude)
ANG	FLOAT32	Output signal (angle)
VALID	BOOLEAN	Output signal

3.12.7 GOOSERCV_ENUM function block

3.12.7.1 Function block

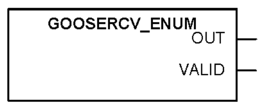


Figure 46: Function block

3.12.7.2 Functionality

The GOOSERCV_ENUM function block is used to connect GOOSE enumerator inputs to the application.

3.12.7.3 Signals

Table 65: GOOSERCV_ENUM Input signals

Name	Type	Default	Description
IN	Enum	0	Input signal

Table 66: GOOSERCV_ENUM Output signals

Name	Type	Description
OUT	Enum	Output signal
VALID	BOOLEAN	Output signal

3.12.8 GOOSERCV_INT32 function block

3.12.8.1 Function block

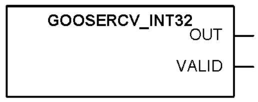


Figure 47: Function block

3.12.8.2 Functionality

The GOOSERCV_INT32 function block is used to connect GOOSE 32 bit integer inputs to the application.

3.12.8.3 Signals

Table 67: GOOSERCV_INT32 Input signals

Name	Type	Default	Description
IN	INT32	0	Input signal

Table 68: GOOSERCV_INT32 Output signals

Name	Type	Description
OUT	INT32	Output signal
VALID	BOOLEAN	Output signal

3.13 Type conversion function blocks

3.13.1 QTY_GOOD function block

3.13.1.1 Functionality

The QTY_GOOD function block evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality good of the input signal. Input signals that have no quality bits set or only test bit is set, will indicate quality good status.

3.13.1.2 Signals

Table 69: QTY_GOOD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 70: QTY_GOOD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.13.2 QTY_BAD function block

3.13.2.1 Functionality

The QTY_BAD function block evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (logic function output, binary input, application function output or received GOOSE signal). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality bad of the input signal. Input signals that have any other than test bit set, will indicate quality bad status.

3.13.2.2 Signals

Table 71: QTY_BAD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 72: QTY_BAD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.13.3 QTY_GOOSE_COMM function block

3.13.3.1 Functionality

The QTY_GOOSE_COMM function block evaluates the peer device communication status from the quality bits of the input signal and passes it as a Boolean signal to the application.

The IN input signal must be connected to the VALID signal of the GOOSE function block.

The OUT output indicates the communication status of the GOOSE function block. When the output is in the true (1) state, the GOOSE communication is active. The value false (0) indicates communication timeout.

3.13.3.2 Signals

Table 73: QTY_GOOSE_COMM Input signals

Name	Type	Default	Description
IN	BOOLEAN	0	Input signal

Table 74: QTY_GOOSE_COMM Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.13.4 T_HEALTH function block

3.13.4.1 Functionality

The T_HEALTH function evaluates enumerated data of “Health” data attribute. This function block can only be used with GOOSE.

The IN input can be connected to GOOSERCV_ENUM function block, which is receiving the LD0.LLN0.Health.stVal data attribute sent by another device.

The outputs OK, WARNING and ALARM are extracted from the enumerated input value. Only one of the outputs can be active at a time. In case the GOOSERCV_ENUM function block does not receive the value from the sending device or it is invalid, the default value (0) is used and the ALARM is activated in the T_HEALTH function block.

3.13.4.2 Signals

Table 75: T_HEALTH Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 76: T_HEALTH Output signals

Name	Type	Description
OK	BOOLEAN	Output signal
WARNING	BOOLEAN	Output signal
ALARM	BOOLEAN	Output signal

3.13.5 T_F32_INT8 function block

3.13.5.1 Functionality

T_F32_INT8 is a type conversion function.

The function converts 32-bit floating type values to 8-bit integer type. The rounding operation is included. Output value saturates if the input value is below the minimum or above the maximum value.

3.13.5.2 Function block

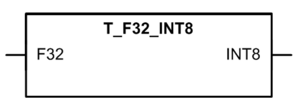


Figure 48: Function block

3.13.5.3 Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14 Configurable logic blocks

3.14.1 Standard configurable logic blocks

3.14.1.1 OR function block

Functionality

OR and OR6 are used to form general combinatory expressions with Boolean variables.

The O output is activated when at least one input has the value TRUE. The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

OR has two inputs and OR6 has six inputs.

Function block

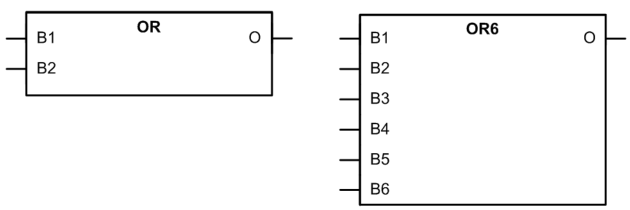


Figure 49: Function blocks

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.2 AND function block

Functionality

AND and AND6 are used to form general combinatory expressions with Boolean variables.

The default value in all inputs is logical true, which makes it possible to use only the required number of inputs and leave the rest disconnected.

AND has two inputs and AND6 has six inputs.

Function block

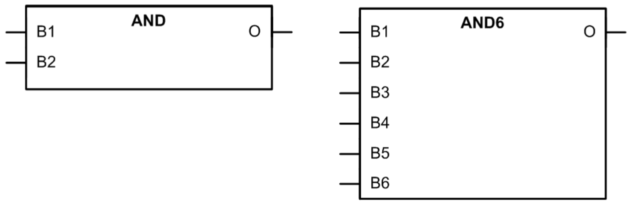


Figure 50: Function blocks

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.3 XOR function block

Functionality

The exclusive OR function XOR is used to generate combinatory expressions with Boolean variables.

The output signal is TRUE if the input signals are different and FALSE if they are equal.

Function block

Figure 51: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.4 NOT function block

Functionality

NOT is used to generate combinatory expressions with Boolean variables.

NOT inverts the input signal.

Function block

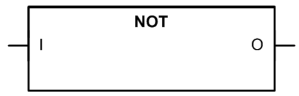


Figure 52: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.5 MAX3 function block

Functionality

The maximum function MAX3 selects the maximum value from three analog values. The disconnected inputs have the value 0.

Function block

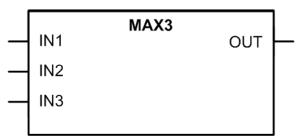


Figure 53: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.6 MIN3 function block

Functionality

The minimum function MIN3 selects the minimum value from three analog values.

If the minimum value is to be selected from two signals, connecting one of the inputs to two in MIN3 makes all the inputs to be connected.

Function block

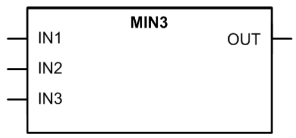


Figure 54: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.7 R_TRIG function block

Functionality

R_Trig is used as a rising edge detector.

R_Trig detects the transition from FALSE to TRUE at the CLK input. When the rising edge is detected, the element assigns the output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

Function block

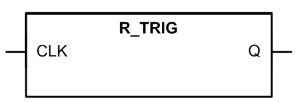


Figure 55: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.8 F_TRIG function block

Functionality

F_Trig is used as a falling edge detector.

The function detects the transition from TRUE to FALSE at the CLK input. When the falling edge is detected, the element assigns the Q output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

Function block

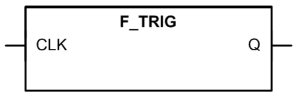


Figure 56: Function block

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.1.9 T_POS_XX function blocks

Functionality

The circuit breaker position information can be communicated with the IEC 61850 GOOSE messages. The position information is a double binary data type which is fed to the POS input.

T_POS_CL and T_POS_OP are used for extracting the circuit breaker status information. Respectively, T_POS_OK is used to validate the intermediate or faulty breaker position.

Table 77: Cross reference between circuit breaker position and the output of the function block

Circuit breaker position	Output of the function block		
	T_POS_CL	T_POS_OP	T_POS_OK
Intermediate '00'	FALSE	FALSE	FALSE
Close '01'	TRUE	FALSE	TRUE
Open '10'	FALSE	TRUE	TRUE
Faulty '11'	TRUE	TRUE	FALSE

Function block

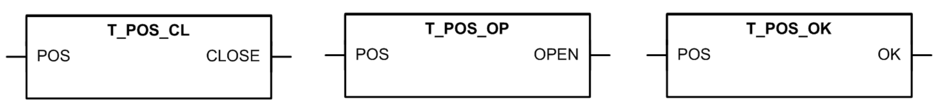


Figure 57: Function blocks

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.14.2 Local/remote control function block CONTROL

3.14.2.1 Function block

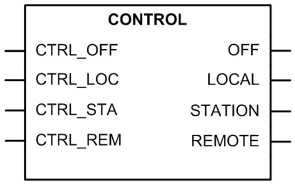


Figure 58: Function block

3.14.2.2 Functionality

Local/Remote control is by default realized through the R/L button on the front panel. The control via binary input can be enabled by setting the value of the *LR control* setting to "Binary input".

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected.

The actual state is reflected on the CONTROL function outputs. Only one output is active at a time.

Table 78: Truth table for CONTROL

Input				Output
CTRL_OFF	CTRL_LOC	CTRL_STA [1]	CTRL_REM	
TRUE	any	any	any	OFF = TRUE
FALSE	TRUE	any	any	LOCAL = TRUE
FALSE	FALSE	TRUE	any	STATION = TRUE
FALSE	FALSE	FALSE	TRUE	REMOTE = TRUE
FALSE	FALSE	FALSE	FALSE	OFF = TRUE

1) If station authority is not in use, the `CTRL_STA` input is interpreted as `CTRL_REM`.

The station authority check based on the IEC 61850 command originator category in control command can be enabled by setting the value of the *Station authority* setting to "Station, Remote" (The command originator validation is performed only if the *LR control* setting is set to "Binary input"). The station authority check is not in use by default.

3.14.2.3 Signals

Table 79: CONTROL input signals

Name	Type	Default	Description
CTRL_OFF	BOOLEAN	0	Control input OFF
CTRL_LOC	BOOLEAN	0	Control input Local
CTRL_STA	BOOLEAN	0	Control input Station
CTRL_REM	BOOLEAN	0	Control input Remote

Table 80: CONTROL output signals

Name	Type	Description
OFF	BOOLEAN	Control output OFF
LOCAL	BOOLEAN	Control output Local
STATION	BOOLEAN	Control output Station
REMOTE	BOOLEAN	Control output Remote

Table 81: CONTROL settings

Parameter	Values (Range)	Unit	Step	Default	Description
LR control	1=LR key 2=Binary input			1=LR key	LR control through LR key or binary input
Station authority	1=Not used 2=Station, Remote			1=Not used	Control command originator category usage

Table 82: Monitored data

Name	Type	Values (Range)	Unit	Description
Command response	Enum	0=No commands 1=Select open 2=Select close 3=Trip open 4=Trip close 5=Direct open 6=Direct close 7=Cancel 8=Position reached 9=Position timeout 10=Object status only 11=Object direct 12=Object select 13=RL local allowed 14=RL remote allowed 15=RL off 16=Function off 17=Function blocked 18=Command progress 19=Select timeout 20=Missing authority 21=Close not enabled 22=Open not enabled 23=Device in IRF 24=Already close 25=Wrong client 26=RL station allowed 27=RL change		Latest command response
LR state	Enum	0=Off 1=Local 2=Remote 3=Station		LR state monitoring for PCM

3.15 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the protection relay from working properly, the whole file system can be restored to the original factory state. All default settings and configuration files stored in the factory are restored. For further information on restoring factory settings, see the operation manual.

3.16 Load profile record LoadProf

3.16.1 Functionality

The protection relay is provided with a load profile recorder. The load profile feature stores the historical load data captured at a periodical time interval (demand interval). Up to 12 load quantities can be selected for recording and storing in a nonvolatile memory. The value range for the recorded load quantities is about eight times the nominal value, and values larger than that saturate. The recording time depends on a settable demand interval parameter and the amount of quantities selected. The record output is in the COMTRADE format.

3.16.1.1 Quantities

Selectable quantities are product-dependent.

Table 83: Quantity Description

Disabled	Quantity not selected
IA	Phase A current, instance 1
IB	Phase B current, instance 1
IC	Phase C current, instance 1
IG	Neutral/ground/residual current, instance 1
IA2	Phase A current, instance 2
IB2	Phase B current, instance 2
IC2	Phase C current, instance 2
IG2	Neutral/ground/residual current, instance 2
IA3	Phase A current, instance 3
IB3	Phase B current, instance 3
IC3	Phase C current, instance 3
VAB	Phase-to-phase AB voltage, instance 1
VBC	Phase-to-phase BC voltage, instance 1
VCA	Phase-to-phase CA voltage, instance 1
VA	Phase-to-ground A voltage, instance 1
VB	Phase-to-ground B voltage, instance 1
VC	Phase-to-ground C voltage, instance 1

Table continues on next page

Disabled	Quantity not selected
VAB2	Phase-to-phase AB voltage, instance 2
VBC2	Phase-to-phase BC voltage, instance 2
VCA2	Phase-to-phase CA voltage, instance 2
VA2	Phase-to-ground A voltage, instance 2
VB2	Phase-to-ground B voltage, instance 2
VC2	Phase-to-ground C voltage, instance 2
S	Apparent power, instance 1
P	Real power, instance 1
Q	Reactive power, instance 1
PF	Power factor, instance 1
S2	Apparent power, instance 2
P2	Real power, instance 2
Q2	Reactive power, instance 2
PF2	Power factor, instance 2
SA	Phase A apparent power, instance 1
SB	Phase B apparent power, instance 1
SC	Phase C apparent power, instance 1
PA	Phase A real power, instance 1
PB	Phase B real power, instance 1
PC	Phase C real power, instance 1
QA	Phase A reactive power, instance 1
QB	Phase B reactive power, instance 1
QC	Phase C reactive power, instance 1
PFA	Phase A power factor, instance 1
PFB	Phase B power factor, instance 1
PFC	Phase C power factor, instance 1
SA2	Phase A apparent power, instance 2
SB2	Phase B apparent power, instance 2
SC2	Phase C apparent power, instance 2
PA2	Phase A real power, instance 2
PB2	Phase B real power, instance 2
PC2	Phase C real power, instance 2
QA2	Phase A reactive power, instance 2
QB2	Phase B reactive power, instance 2
QC2	Phase C reactive power, instance 2

Table continues on next page

Disabled	Quantity not selected
PFA2	Phase A power factor, instance 2
PFB2	Phase B power factor, instance 2
PFC2	Phase C power factor, instance 2

If the data source for the selected quantity is removed, for example, with Application Configuration in PCM600, the load profile recorder stops recording it and the previously collected data are cleared.

3.16.1.2 Length of record

The recording capability is about 7.4 years when one quantity is recorded and the demand interval is set to 180 minutes. The recording time scales down proportionally when a shorter demand time is selected or more quantities are recorded. The recording lengths in days with different settings used are presented in Table 84. When the recording buffer is fully occupied, the oldest data are overwritten by the newest data.

Table 84: Recording capability in days with different settings

	Demand interval						
	1 minute	5 minutes	10 minutes	15 minutes	30 minutes	60 minutes	180 minutes
Amount of quantities	Recording capability in days						
1	15.2	75.8	151.6	227.4	454.9	909.7	2729.2
2	11.4	56.9	113.7	170.6	341.1	682.3	2046.9
3	9.1	45.5	91.0	136.5	272.9	545.8	1637.5
4	7.6	37.9	75.8	113.7	227.4	454.9	1364.6
5	6.5	32.5	65.0	97.5	194.9	389.9	1169.6
6	5.7	28.4	56.9	85.3	170.6	341.1	1023.4
7	5.1	25.3	50.5	75.8	151.6	303.2	909.7
8	4.5	22.7	45.5	68.2	136.5	272.9	818.8
9	4.1	20.7	41.4	62.0	124.1	248.1	744.3
10	3.8	19.0	37.9	56.9	113.7	227.4	682.3
11	3.5	17.5	35.0	52.5	105.0	209.9	629.8
12	3.2	16.2	32.5	48.7	97.5	194.9	584.8

3.16.1.3 Uploading of record

The protection relay stores the load profile COMTRADE files to the C:\LDP\COMTRADE folder. The files can be uploaded with the PCM600 tool or any appropriate computer software that can access the C:\LDP\COMTRADE folder.

The load profile record consists of two COMTRADE file types: the configuration file (.CFG) and the data file (.DAT). The file name is same for both file types.

To ensure that both the uploaded file types are generated from the same data content, the files need to be uploaded successively. Once either of the files is uploaded, the recording buffer is halted to give time to upload the other file.

Data content of the load profile record is sequentially updated. Therefore, the size attribute for both COMTRADE files is "0".

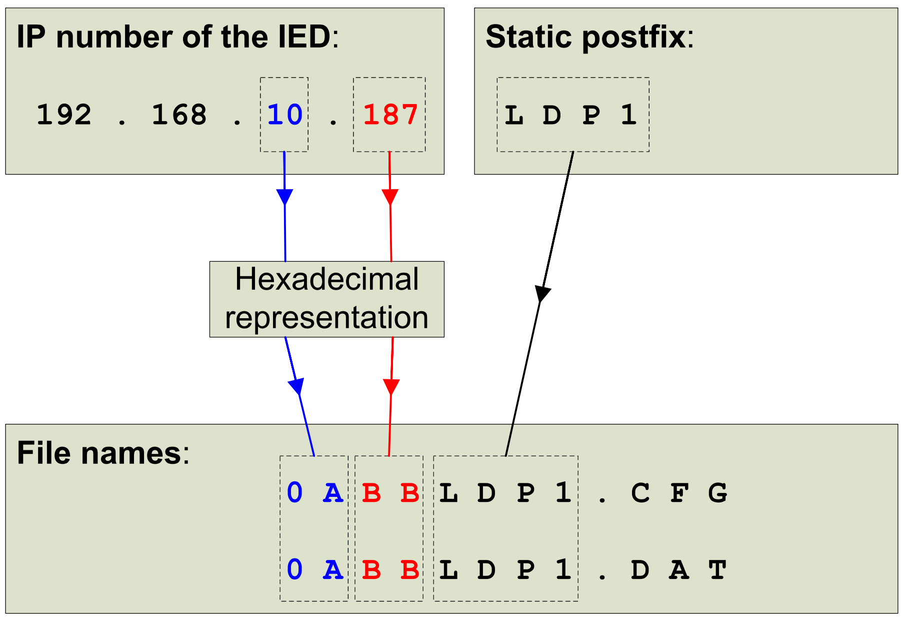


Figure 59: Load profile record file naming

3.16.1.4 Clearing of record

The load profile record can be cleared with *Reset load profile rec* via HMI, communication or the ACT input in PCM600. Clearing of the record is allowed only on the engineer and administrator authorization levels.

The load profile record is automatically cleared if the quantity selection parameters are changed or any other parameter which affects the content of the COMTRADE configuration file is changed. Also, if data source for selected quantity is removed, for example, with ACT, the load profile recorder stops recording and previously collected data are cleared.

3.16.2 Configuration

The load profile record can be configured with the PCM600 tool or any tool supporting the IEC 61850 standard.

The load profile record can be enabled or disabled with the *Operation* setting under the **Configuration/Load Profile Record** menu.

The recording buffer is filled in FIFO manner, meaning that oldest data is overwritten by newest data. If oldest data is considered important, *Mem. warning level* and *Mem. alarm level* parameters can be set to get notification about memory consumption reaching a certain level. Therefore the data can be uploaded before the oldest data gets overwritten. To re-enable notifications via *Mem. warning level* and *Mem. alarm level* parameters, the load profile record should be cleared after uploading. State change of *Mem. warning level* or *Mem. alarm level* parameters generates an event.

The IP number of the protection relay and the content of the *Bay name* setting are both included in the COMTRADE configuration file for identification purposes.

3.16.3 Signals

Table 85: LoadProf Output signals

Name	Type	Description
MEM_WARN	BOOLEAN	Recording memory warning status
MEM_ALARM	BOOLEAN	Recording memory alarm status

3.16.4 Settings

Table 86: LoadProf Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Quantity Sel 1	0=Disabled 1=IA 2=IB 3=IC 4=IG 5=IA2 6=IB2 7=IC2 8=IG2 9=VAB 10=VBC 11=VCA 12=VA 13=VB 14=VC 15=VAB2 16=VBC2 17=VCA2 18=VA2 19=VB2 20=VC2 21=S 22=P 23=Q 24=PF 25=S2 26=P2 27=Q2 28=PF2 29=SA 30=SB 31=SC 32=PA 33=PB 34=PC 35=QA 36=QB 37=QC 38=PFA 39=PFB 40=PFC 41=SA2 42=SB2 43=SC2 44=PA2 45=PB2 46=PC2 47=QA2 48=QB2 49=QC2 50=PFA2 51=PFB2 52=PFC2			0=Disabled	Select quantity to be recorded
Mem. warning level	0...100	%	1	0	Set memory warning level
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Mem. alarm level	0...100	%	1	0	Set memory alarm level

3.16.5 Monitored data

Table 87: LoadProf Monitored data

Name	Type	Values (Range)	Unit	Description
Rec. memory used	INT32	0...100	%	How much recording memory is currently used

Section 4 Protection functions

4.1 Current protection

4.1.1 Three-phase non-directional overcurrent protection 51P/50P

4.1.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase non-directional overcurrent protection, low stage	PHLPTOC	3I>	51P
Three-phase non-directional overcurrent protection, high stage	PHHPTOC	3I>>	50P-1/2
Three-phase non-directional overcurrent protection, instantaneous stage	PHIPTOC	3I>>>	50P-3

4.1.1.2 Function block

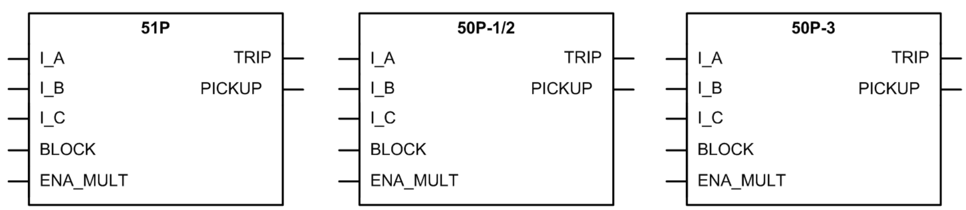


Figure 60: Function block

4.1.1.3 Functionality

The three-phase overcurrent protection 51P/50P is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection.

The function picks up when the current exceeds the set limit. The trip time characteristics for low stage 51P and high stage 50P-1/2 can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage 50P-3 always trips with the DT characteristic.

In the DT mode, the function trips after a predefined trip time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of three-phase non-directional overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

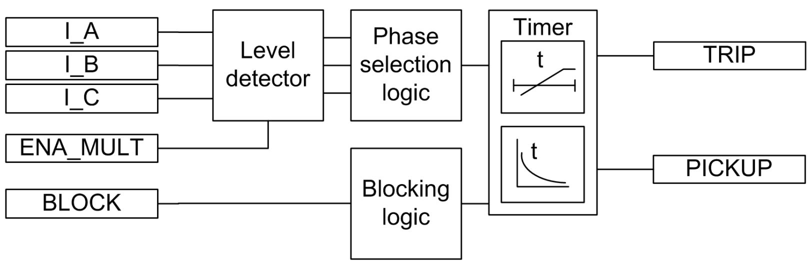


Figure 61: Functional module diagram. I_A, I_B and I_C represent phase currents.

Level detector

The measured phase currents are compared phasewise to the set *Pickup value*. If the measured value exceeds the set *Pickup value*, the level detector reports the exceeding of the value to the phase selection logic. If the `ENA_MULT` input is active, the *Pickup value* setting is multiplied by the *Pickup value Mult* setting.

Do not set the multiplier setting *Pickup value Mult* higher than necessary. If the value is too high, the function may not trip at all during an inrush followed by a fault, no matter how severe the fault is.

The pickup value multiplication is normally done when the inrush detection function (INR) is connected to the `ENA_MULT` input.

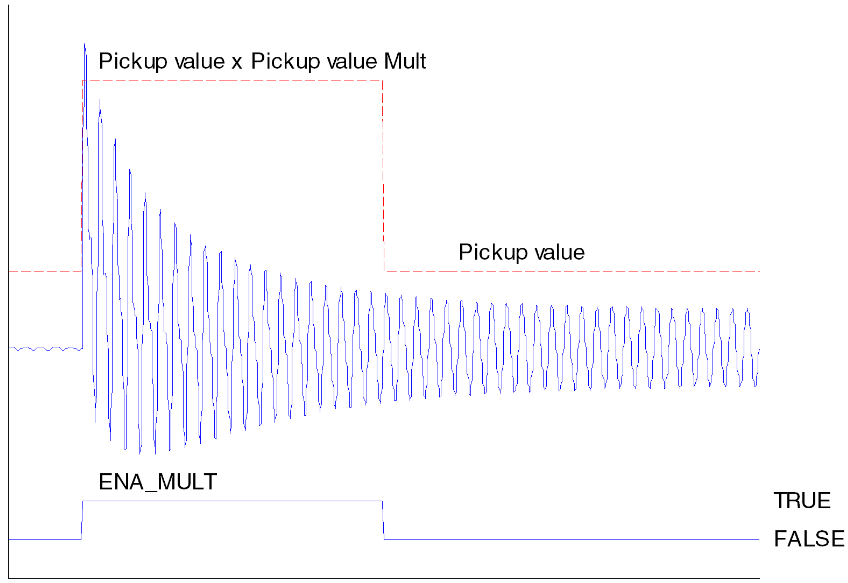


Figure 62: Pickup value behavior with `ENA_MULT` *input activated*

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of pickup phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the timer activates the `PICKUP` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the `TRIP` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the trip delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set

Reset delay time value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. If the drop-off situation continues, the reset timer is reset and the PICKUP output is deactivated.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT trip and reset times.

The setting parameter *Minimum trip time* defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.1.1.5 Measurement modes

The function operates on four alternative measurement modes: "RMS", "DFT", "Peak-to-Peak" and "P-to-P + backup". The measurement mode is selected with the setting *Measurement mode*.

Table 88: Measurement modes supported by 51P/50P stages

Measurement mode	51P	50P-1/2	50P-3
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	
P-to-P + backup			x

For a detailed description of the measurement modes, see the Measurement modes section in this manual.

4.1.1.6 Timer characteristics

51P/50P supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Trip delay time* and *Reset delay time* settings.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The DT characteristics can be chosen by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The timer characteristics supported by different stages comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 89: Timer characteristics supported by different stages

Operating curve type	51P	50P-1/2
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x

Table continues on next page

Operating curve type	51P	50P-1/2
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable	x	x
(18) RI type	x	
(19) RD type	x	

50P-3 supports only definite time characteristic.

For a detailed description of timers, see the General function block features section in this manual.

Table 90: Reset time characteristics supported by different stages

Reset curve type	51P	50P-1/2	Note
(1) Immediate	x	x	Available for all reset time curves
(2) Def time reset	x	x	Available for all reset time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

The *Type of reset curve* setting does not apply to 50P-3 or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.1.1.7 Application

51P/50P is used in several applications in the power system. The applications include but are not limited to:

- Selective overcurrent and short-circuit protection of feeders in distribution and subtransmission systems
- Backup overcurrent and short-circuit protection of power transformers and generators
- Overcurrent and short-circuit protection of various devices connected to the power system, for example shunt capacitor banks, shunt reactors and motors
- General backup protection

51P/50P is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the pickup level for the function to trip. When the number of pickup-phase settings is set to "1 out of 3", the operation of 51P/50P is enabled with the presence of high current in one-phase.

When the setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations.

Many applications require several steps using different current pickup levels and time delays. 51P/50P consists of three protection stages:

- Low 51P
- High 50P-1/2
- Instantaneous 50P-3

51P is used for overcurrent protection. The function contains several types of time-delay characteristics. 50P-1/2 and 50P-3 are used for fast clearance of very high overcurrent situations.

Transformer overcurrent protection

The purpose of transformer overcurrent protection is to operate as main protection, when differential protection is not used. It can also be used as coarse back-up protection for differential protection in faults inside the zone of protection, that is, faults occurring in incoming or outgoing feeders, in the region of transformer terminals and tank cover. This means that the magnitude range of the fault current can be very wide. The range varies from $6xI_n$ to several hundred times I_n, depending on the impedance of the transformer and the source impedance of the feeding network. From this point of view, it is clear that the operation must be both very fast and selective, which is usually achieved by using coarse current settings.

The purpose is also to protect the transformer from short circuits occurring outside the protection zone, that is through-faults. Transformer overcurrent protection also provides protection for the LV-side busbars. In this case the magnitude of the fault current is typically lower than $12xI_n$ depending on the fault location and transformer impedance. Consequently, the protection must operate as fast as possible taking into account the selectivity requirements, switching-in currents, and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in Figure 63. The low-set stage 51P operates time-selectively both in transformer and LV-side busbar faults. The high-set stage 50P-1/2 operates instantaneously making use of current selectivity only in transformer HV-side faults. If there is a possibility, that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with LV-side overcurrent protection. Inrush current detectors are used in start-up situations to multiply the current pickup value setting in each particular protection relay where the inrush current can occur. The overcurrent and contact based circuit breaker failure protection 50BF is used to confirm the protection scheme in case of circuit breaker malfunction.

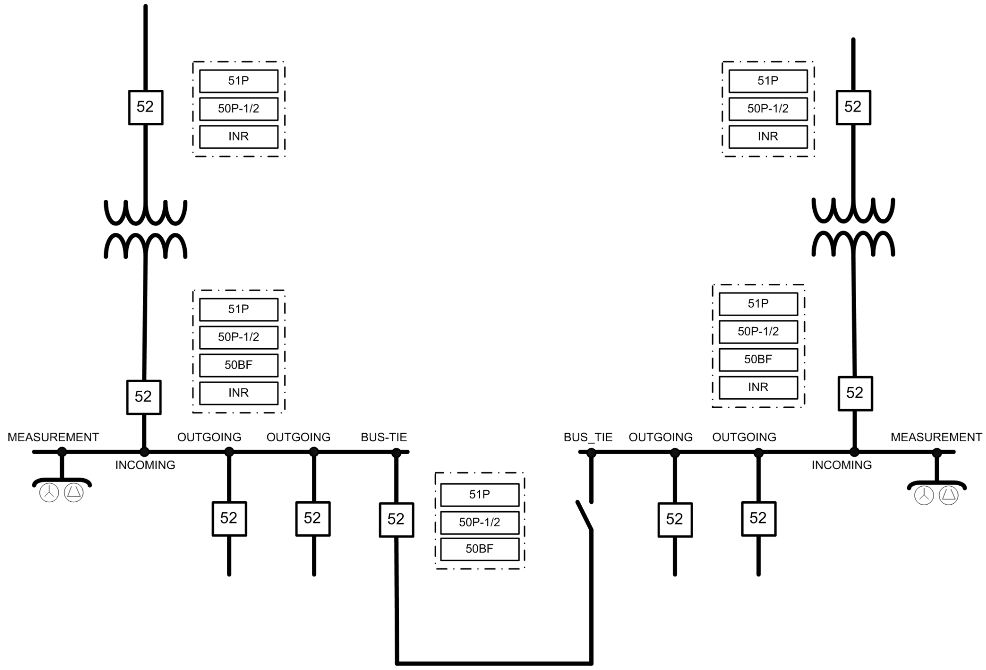


Figure 63: Example of traditional time selective transformer overcurrent protection

The operating times of the main and backup overcurrent protection of the above scheme become quite long, this applies especially in the busbar faults and also in the transformer LV-terminal faults. In order to improve the performance of the above scheme, a multiple-stage overcurrent protection with reverse blocking is proposed. Figure 64 shows this arrangement.

Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV and LV-sides provide increased security of backup protection for the transformer, busbar and also for the outgoing feeders.

Depending on the overcurrent stage in question, the selectivity of the scheme in Figure 64 is based on the operating current, operating time or blockings between successive overcurrent stages. With blocking channels, the operating time of the protection can be drastically shortened if compared to the simple time selective protection. In addition to the busbar protection, this blocking principle is applicable for the protection of transformer

LV terminals and short lines. The functionality and performance of the proposed overcurrent protections can be summarized as seen in the table.

Table 91: Proposed functionality of numerical transformer and busbar overcurrent protection. DT = definite time, IDMT = inverse definite minimum time

O/C-stage	Operating char.	Selectivity mode	Operation speed	Sensitivity
HV/51P	DT/IDMT	time selective	low	very high
HV/50P-1/2	DT	blockable/time selective	high/low	high
HV/50P-3	DT	current selective	very high	low
LV/51P	DT/IDMT	time selective	low	very high
LV/50P-1/2	DT	time selective	low	high
LV/50P-3	DT	blockable	high	high

In case the bus-tie breaker is open, the operating time of the blockable overcurrent protection is approximately 100 ms (relaying time). When the bus-tie breaker is closed, that is, the fault current flows to the faulted section of the busbar from two directions, the operation time becomes as follows: first the bus-tie relay unit trips the tie breaker in the above 100 ms, which reduces the fault current to a half. After this the incoming feeder relay unit of the faulted bus section trips the breaker in approximately 250 ms (relaying time), which becomes the total fault clearing time in this case.

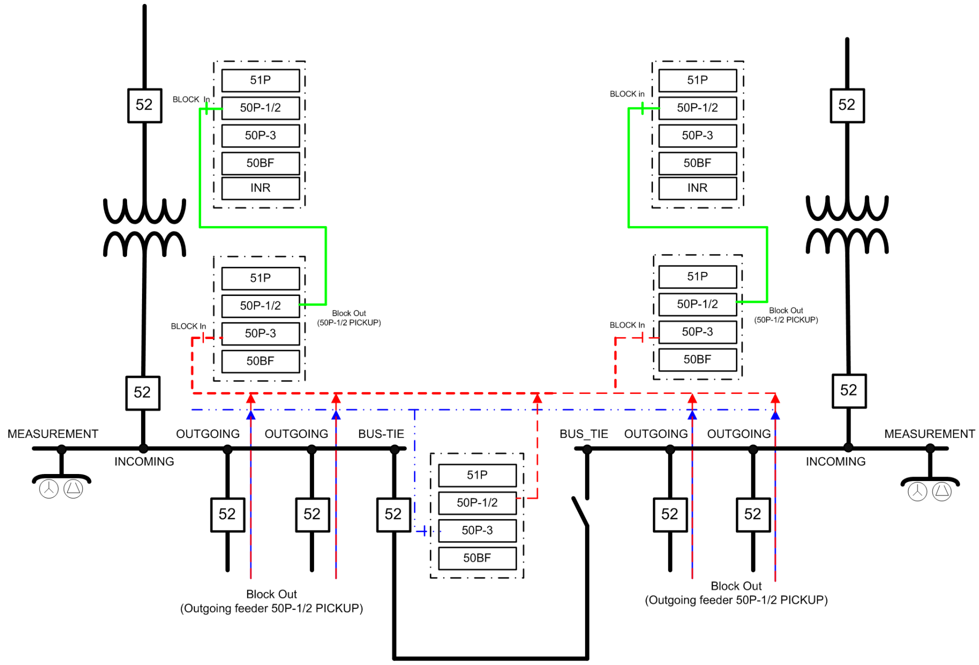


Figure 64: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown).Blocking output = digital output signal from the pickup of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is very low. Also, the effects of switching inrush currents on the setting values can be reduced by using the protection relay's logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current pickup value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, see the Measurement modes chapter in this manual.

Radial outgoing feeder overcurrent protection

The basic requirements for feeder overcurrent protection are adequate sensitivity and operation speed taking into account the minimum and maximum fault current levels along the protected line, selectivity requirements, inrush currents and the thermal and mechanical withstand of the lines to be protected.

In many cases the above requirements can be best fulfilled by using multiple-stage overcurrent units. Figure 65 shows an example of this. A brief coordination study has been carried out between the incoming and outgoing feeders.

The protection scheme is implemented with three-stage numerical overcurrent protection where the low-set stage 51P operates in IDMT-mode and the two higher stages 50P-1/2 and 50P-3 in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station, where the fault current levels are the highest, are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the pickup value multiplying input of the instantaneous stage. In this way, the pickup value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

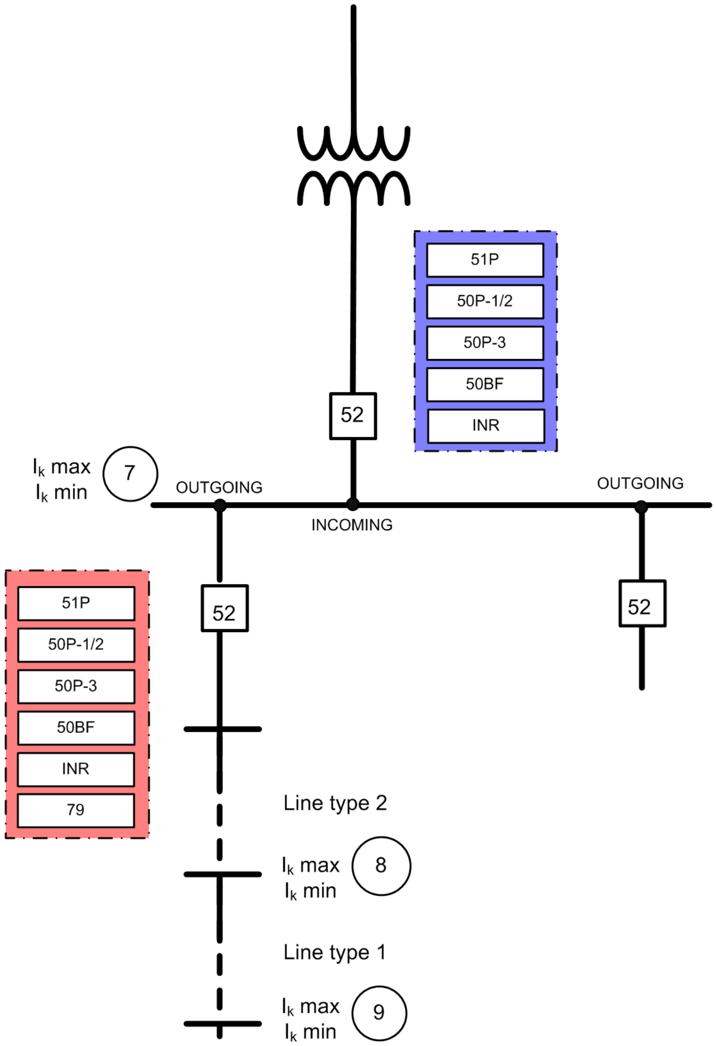


Figure 65: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneously in a coordination plan. In Figure 66, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

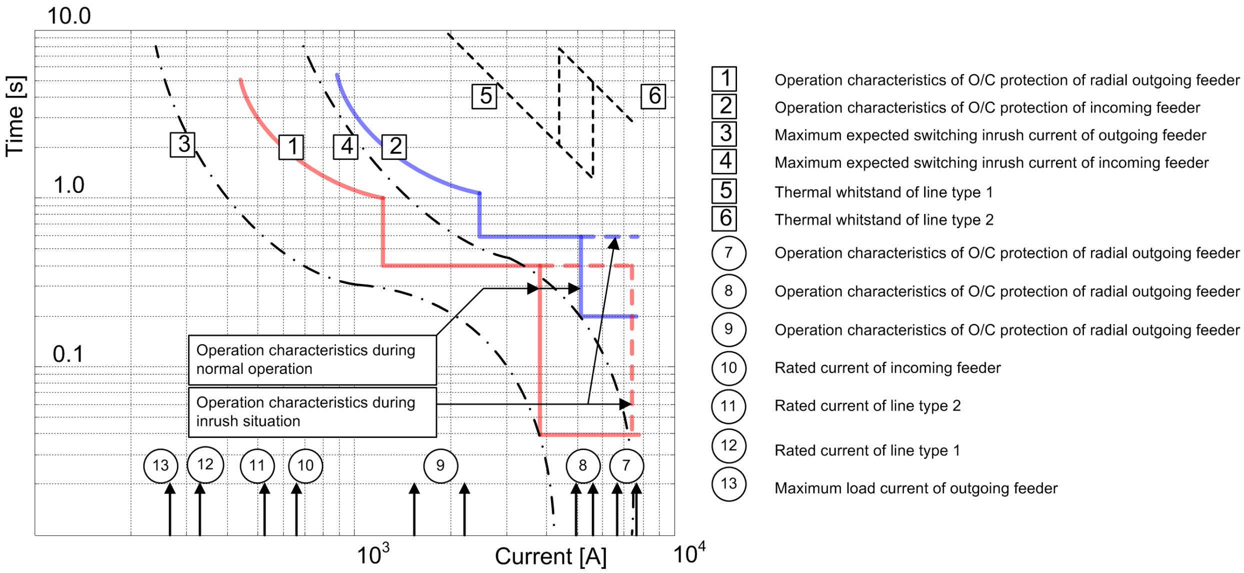


Figure 66: Example coordination of numerical multiple-stage overcurrent protection

4.1.1.8 Signals

Table 92: 51P Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 93: 50P-1/2 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 94: 50P-3 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 95: 51P Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 96: 50P-1/2 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 97: 50P-3 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.1.9 Settings

Table 98: 51P Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...5.00	xIn	0.01	1	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Trip delay time	40...200000	ms	10	40	Trip delay time
Operating curve type	1=ANSI Ext Inv 2=ANSI Very Inv 3=ANSI Norm Inv 4=ANSI Mod Inv 5=ANSI DT 6=LT Ext Inv 7=LT Very Inv 8=LT Inv 9=IEC Norm Inv 10=IEC Very Inv 11=IEC Inv 12=IEC Ext Inv 13=IEC ST Inv 14=IEC LT Inv 15=IEC DT 17=Programmable 18=RI Type 19=RD Type			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 99: 51P Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

Table 100: 50P-1/2 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.10...40.00	xIn	0.01	2	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	40...200000	ms	10	40	Trip delay time
Operating curve type	1=ANSI Ext Inv 3=ANSI Norm Inv 5=ANSI DT 9=IEC Norm Inv 10=IEC Very Inv 12=IEC Ext Inv 15=IEC DT 17=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 101: 50P-1/2 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

Table 102: 50P-3 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	1.00...40.00	xIn	0.01	4	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Trip delay time	20...200000	ms	10	20	Trip delay time

Table 103: 50P-3 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.1.10 Monitored data

Table 104: 51P Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
51P	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 105: 50P-1/2 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
50P-1_2	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 106: 50P-3 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
50P-3	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.1.11 Technical data

Table 107: 51P/50P Technical data

Characteristic		Value		
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz			
	51P	±1.5% of the set value or ±0.002 × I_n		
	50P-1/2 and 50P-3	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)		
Pickup time 1)2)		Minimum	Typical	Maximum
	50P-3: I_{Fault} = 2 × set *Pickup value* I_{Fault} = 10 × set *Pickup value*	15 ms 12 ms	16 ms 13 ms	17 ms 14 ms
	51P and 50P-1/2: I_{Fault} = 2 × set *Pickup value*	23 ms	25 ms	28 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Trip time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms 3)		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression P-to-P+backup: No suppression		

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 60 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 2.5 x I_n, *Pickup value* multiples in range of 1.5...20

4.1.2 Three-phase non-directional long time overcurrent protection 51LT

4.1.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase non-directional long time overcurrent protection	PHLTPTOC	3I>	51LT

4.1.2.2 Function block

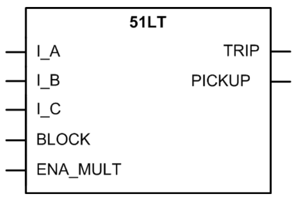


Figure 67: Function block

4.1.2.3 Functionality

The three-phase long-time overcurrent protection 51LT is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection for feeders.

The operation of this function is very similar to the 51P function except that inverse curves operating times are 10 times that of 51P.

The function also contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of three-phase long-time overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

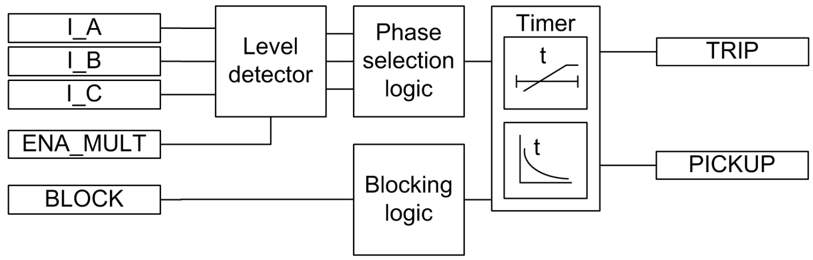


Figure 68: Functional module diagram. I_A, I_B and I_C represent phase currents.

Level detector

The measured phase currents are compared phasewise to the set *Pickup value*. If the measured value exceeds the set *Pickup value*, the level detector reports the exceeding of the value to the phase selection logic. If the `ENA_MULT` input is active, the *Pickup value* setting is multiplied by the *Pickup value Mult* setting.

The pickup value multiplication is normally done when the inrush detection function (INR) is connected to the `ENA_MULT` input.

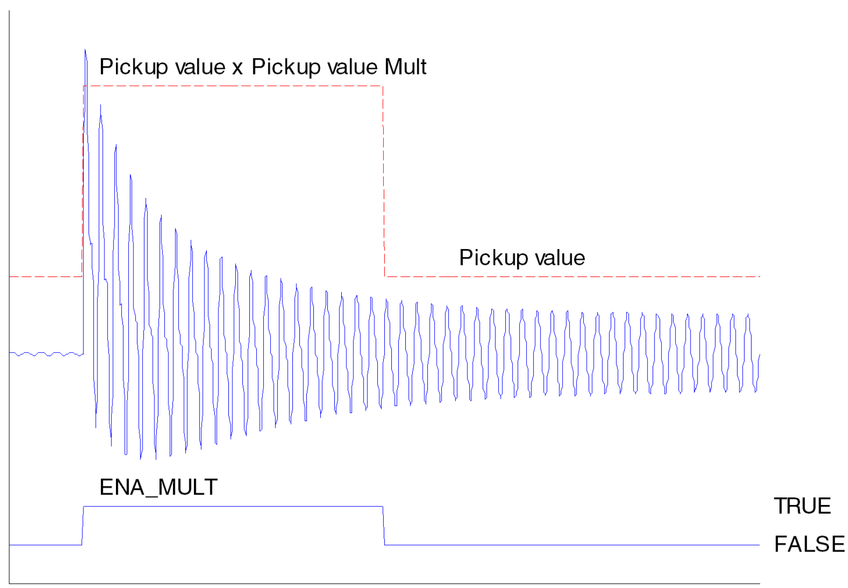


Figure 69: Pickup value behavior with `ENA_MULT` input activated

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of pickup phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the timer activates the PICKUP output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the TRIP output is activated.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting "**Configuration/System/*Blocking mode***" which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.1.2.5 Timer characteristics

51LT supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Trip delay time* and *Reset delay time* settings.

The relay provides 9 IDMT characteristics curves, of which eight comply with the IEEE C37.112 and one with the IEC 60255-3 standard. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* value "Long Definite Time".

Table 108: Timer characteristics supported

Operating curve type	51LT
(1) Long Time Extremely Inverse	x
(2) Long Time Very Inverse	x
(3) Long Time Inverse	x

Table continues on next page

Operating curve type	51LT
(4) Long Time Moderately Inverse	x
(5) Long Definite Time	x
(6) Very Long Time Extremely Inverse	x
(7) Very Long Time Very Inverse	x
(8) Very Long Time Inverse	x
(9) Long Time Normal Inverse	x
(14) IEC Long Time Inverse	x
(17) Programmable	x

For a detailed description of timers, refer to section General function block features in this manual.

Table 109: Reset time characteristics supported by different stages

Reset curve type	51LT
(1) Immediate	x
(2) Def time reset	x
(3) Inverse reset	x

4.1.2.6 Application

The long time overcurrent protection is used in special feeder protection application where operating time provided by 51P is not good enough for coordination purpose.

4.1.2.7 Signals

Table 110: 51LT Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 111: 51LT Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.2.8 Settings

Table 112: 51LT Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...5.00	xIn	0.01	2	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	1.00...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	40...200000	ms	10	40	Trip delay time
Operating curve type	1=LT Ext Inv 2=LT Very Inv 3=LT Inv 4=LT Mod Inv 5=Long DT 6=Very LT Ext Inv 7=Very LT Very Inv 8=Very LT Inv 9=LT Normal Inv 14=IEC LT Inv 17=Programmable			5=Long DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 113: 51LT Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

4.1.2.9 Monitored data

Table 114: 51LT Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
51LT	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 115: 51LT Technical data

Characteristic	Value		
Operation accuracy	Depending on the frequency of the current measured: f_n ±2 Hz		
	±1.5% of the set value or ±0.002 x In (at currents in the range of 0.1…5 x In)		
Pickup time 1)2)	Minimum	Typical	Maximum
I_{Fault} = 2 x set Pickup value	23 ms	25 ms	28 ms
Reset time	< 50 ms		
Reset ratio	Typical 0.96		
Retardation time	< 30 ms		
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms		
Trip time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms 3)		
Suppression of harmonics	RMS: No suppression DFT: -50 dB at f = n x fn, where n = 2, 3, 4, 5, … Peak-to-Peak: No suppression P-to-P+backup: No suppression		

1) Measurement mode = default (depends on stage), current before fault = 0.0 x In, fn = 60 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical
2) Includes the delay of the signal output contact
3) Maximum Pickup value = 2.5 x In, Pickup value multiples in range of 1.5 to 20

4.1.3 Three-phase directional overcurrent protection 67/51P and 67/50P

4.1.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase directional overcurrent protection, low stage	DPHLPDOC	3I> ->	67/51P
Three-phase directional overcurrent protection, high stage	DPHHPDOC	3I>> -> 3I>> ->	67/50P-1 67/50P-2

4.1.3.2 Function block

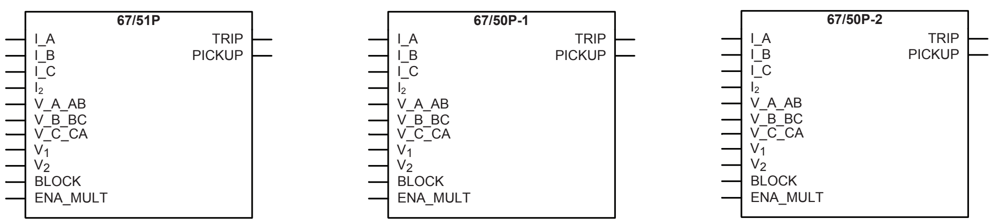


Figure 70: Function block

4.1.3.3 Functionality

The three-phase overcurrent protection 67/51P and 67/50P is used as one-phase, two-phase or three-phase directional overcurrent and short-circuit protection.

67/51P and 67/50P pick up when the value of the current exceeds the set limit and directional criterion is fulfilled. The trip time characteristics for low stage 67/51P and high stages 67/50P-1 and 67/50P-2 can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function trips after a predefined trip time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of directional overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

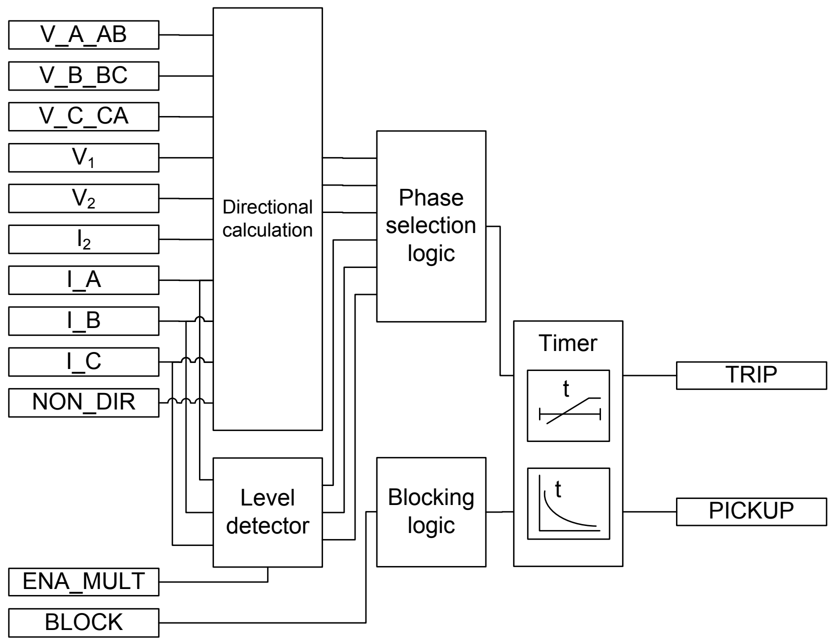


Figure 71: Functional module diagram

Directional calculation

The directional calculation compares the current phasors to the polarizing phasor. A suitable polarization quantity can be selected from the different polarization quantities, which are the positive sequence voltage, negative sequence voltage, self-polarizing (faulted) voltage and cross-polarizing voltages (healthy voltages). The polarizing method is defined with the *Pol quantity* setting.

Table 116: Polarizing quantities

Polarizing quantity	Description
Pos. seq. volt	Positive sequence voltage
Neg. seq. volt	Negative sequence voltage
Self pol	Self polarization
Cross pol	Cross polarization

The directional operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. By setting the value of

Allow Non Dir to "True", the non-directional operation is allowed when the directional information is invalid.

The *Characteristic angle* setting is used to turn the directional characteristic. The value of *Characteristic angle* should be chosen in such a way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the non-operating zone. The value of *Characteristic angle* depends on the network configuration.

Reliable operation requires both the operating and polarizing quantities to exceed certain minimum amplitude levels. The minimum amplitude level for the operating quantity (current) is set with the *Min trip current* setting. The minimum amplitude level for the polarizing quantity (voltage) is set with the *Min trip voltage* setting. If the amplitude level of the operating quantity or polarizing quantity is below the set level, the direction information of the corresponding phase is set to "Unknown".

The polarizing quantity validity can remain valid even if the amplitude of the polarizing quantity falls below the value of the *Min trip voltage* setting. In this case, the directional information is provided by a special memory function for a time defined with the *Voltage Mem time* setting.

67/51P and 67/50P is provided with a memory function to secure a reliable and correct directional protection relay operation in case of a close short circuit or a ground fault characterized by an extremely low voltage. At sudden loss of the polarization quantity, the angle difference is calculated on the basis of a fictive voltage. The fictive voltage is calculated using the positive phase sequence voltage measured before the fault occurred, assuming that the voltage is not affected by the fault. The memory function enables the function to trip up to a maximum of three seconds after a total loss of voltage. This time can be set with the *Voltage Mem time* setting. The voltage memory cannot be used for the "Negative sequence voltage" polarization because it is not possible to substitute the positive sequence voltage for negative sequence voltage without knowing the network unsymmetry level. This is the reason why the fictive voltage angle and corresponding direction information are frozen immediately for this polarization mode when the need for a voltage memory arises and these are kept frozen until the time set with *Voltage Mem time* elapses.

The value for the *Min trip voltage* setting should be carefully selected since the accuracy in low signal levels is strongly affected by the measuring device accuracy.

When the voltage falls below *Min trip voltage* at a close fault, the fictive voltage is used to determine the phase angle. The measured voltage is applied again as soon as the voltage rises above *Min trip voltage* and hysteresis. The fictive voltage is also discarded if the measured voltage stays below *Min trip voltage*and hysteresis for longer than *Voltage Mem* *time* or if the fault current disappears while the fictive voltage is in use. When the voltage is below *Min trip voltage* and hysteresis and the fictive voltage is unusable, the fault direction cannot be determined. The fictive voltage can be unusable for two reasons:

- The fictive voltage is discarded after *Voltage Mem time*
- The phase angle cannot be reliably measured before the fault situation.

67/51P and 67/50P can be forced to the non-directional operation with the `NON_DIR` input. When the `NON_DIR` input is active, 67/51P and 67/50P operate as a non-directional overcurrent protection, regardless of the *Directional mode* setting.

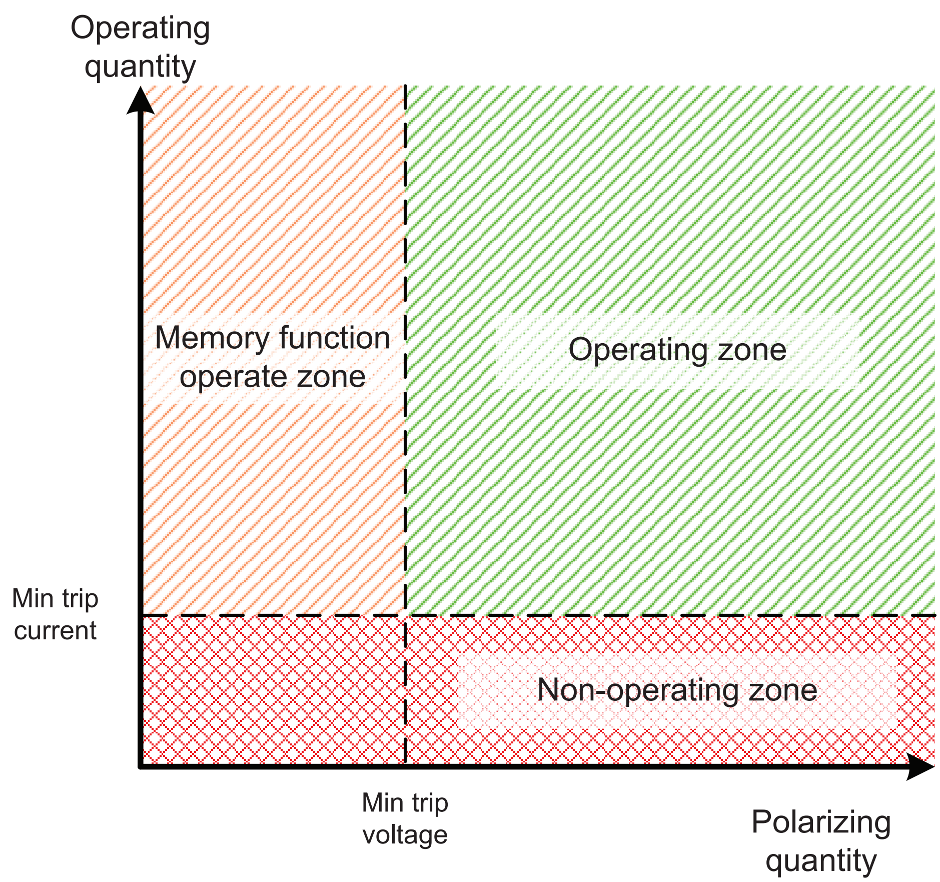


Figure 72: Operating zones at minimum magnitude levels

Level detector

The measured phase currents are compared phasewise to the set *Pickup value*. If the measured value exceeds the set *Pickup value*, the level detector reports the exceeding of the value to the phase selection logic. If the ENA_MULT input is active, the *Pickup value* setting is multiplied by the *Pickup value Mult* setting.

Do not set the multiplier setting *Pickup value Mult* higher than necessary. If the value is too high, the function may not trip at all during an inrush followed by a fault, no matter how severe the fault is.

The pickup value multiplication is normally done when the inrush detection function (INR) is connected to the ENA_MULT input.

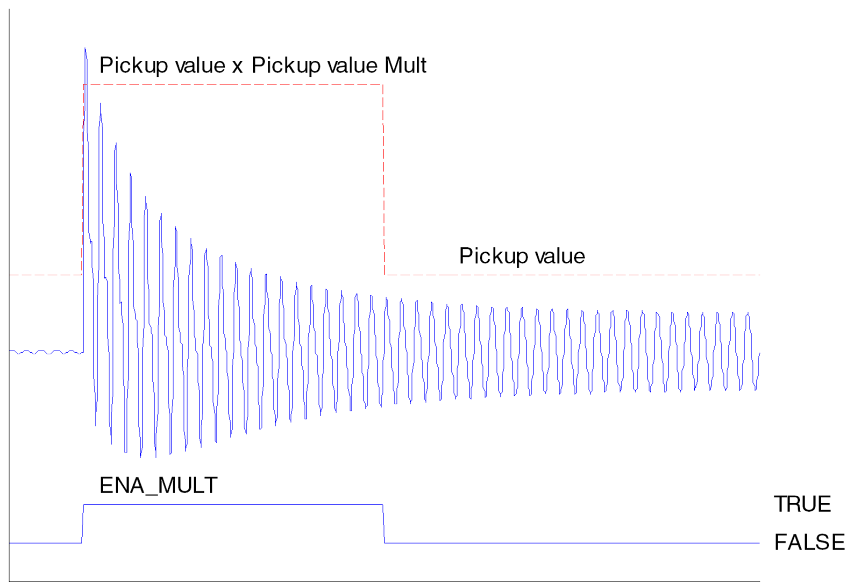


Figure 73: Pickup value behavior with ENA_MULT input activated

Phase selection logic

If the fault criteria are fulfilled in the level detector and the directional calculation, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of pickup phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the timer activates the PICKUP output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the TRIP output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the trip delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. If the drop-off situation continues, the reset timer is reset and the PICKUP output is deactivated.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT trip and reset times.

The setting parameter *Minimum trip time* defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.1.3.5 Measurement modes

The function operates on three alternative measurement modes: “RMS”, “DFT” and “Peak-to-Peak” . The measurement mode is selected with the *Measurement mode* setting.

Table 117: Measurement modes supported by 67/51P and 67/50P stages

Measurement mode	67/51P	67/50P-1 and 67/50P-2
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

4.1.3.6 Directional overcurrent characteristics

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the counterclockwise sector and the *Min forward angle* setting gives the corresponding clockwise sector, measured from the *Characteristic angle* setting.

In the backward operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, a measurement from the *Characteristic angle* setting that has been rotated 180 degrees.

Relay characteristic angle (RCA) is set positive if the operating current lags the polarizing quantity and negative if the operating current leads the polarizing quantity.

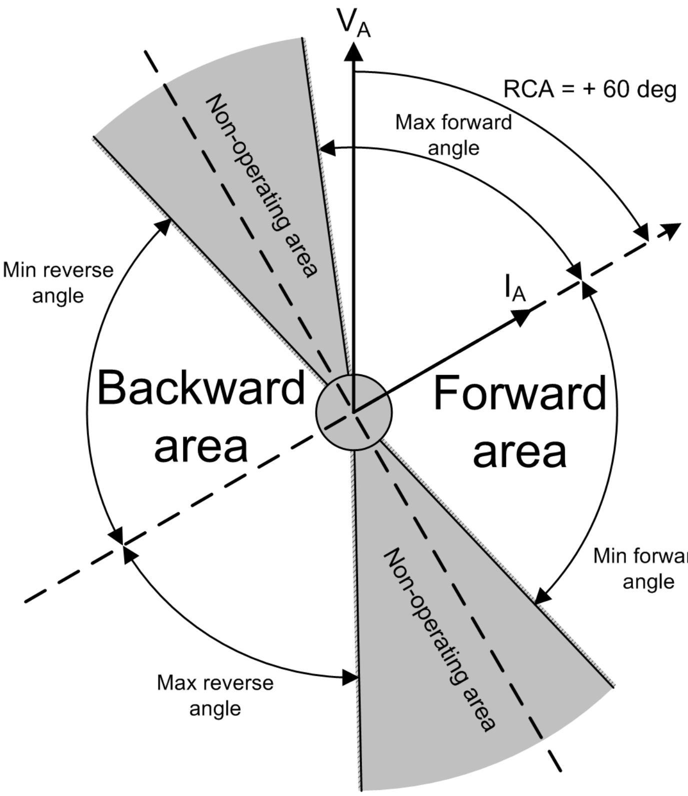


Figure 74: Configurable operating sectors

Table 118: Momentary per phase direction value for monitored data view

Criterion for per phase direction information	The value for DIR_A/_B/_C
The ANGLE_X is not in any of the defined sectors, or the direction cannot be defined due too low amplitude	0 = unknown
The ANGLE_X is in the forward sector	1 = forward
The ANGLE_X is in the reverse sector	2 = backward
(The ANGLE_X is in both forward and reverse sectors, that is, when the sectors are overlapping)	3 = both

Table 119: Momentary phase combined direction value for monitored data view

Criterion for phase combined direction information	The value for DIRECTION
The direction information (DIR_X) for all phases is unknown	0 = unknown
The direction information (DIR_X) for at least one phase is forward, none being in reverse	1 = forward
The direction information (DIR_X) for at least one phase is reverse, none being in forward	2 = backward
The direction information (DIR_X) for some phase is forward and for some phase is reverse	3 = both

FAULT_DIR gives the detected direction of the fault during fault situations, that is, when the PICKUP output is active.

Self-polarizing as polarizing method

Table 120: Equations for calculating angle difference for self-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{V}_A$	$ANGLE\_A = \varphi(\underline{V}_A) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	$\underline{I}_B$	$\underline{V}_B$	$ANGLE\_B = \varphi(\underline{V}_B) - \varphi(\underline{I}_B) - \varphi_{RCA}$
C	$\underline{I}_C$	$\underline{V}_C$	$ANGLE\_C = \varphi(\underline{V}_C) - \varphi(\underline{I}_C) - \varphi_{RCA}$
A - B	$\underline{I}_A - \underline{I}_B$	$\underline{V}_{AB}$	$ANGLE\_A = \varphi(\underline{V}_{AB}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA}$
B - C	$\underline{I}_B - \underline{I}_C$	$\underline{V}_{BC}$	$ANGLE\_B = \varphi(\underline{V}_{BC}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA}$
C - A	$\underline{I}_C - \underline{I}_A$	$\underline{V}_{CA}$	$ANGLE\_C = \varphi(\underline{V}_{CA}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA}$

In an example case of the phasors in a single-phase ground fault where the faulted phase is phase A, the angle difference between the polarizing quantity V_A and operating quantity I_A is marked as φ. In the self-polarization method, there is no need to rotate the polarizing quantity.

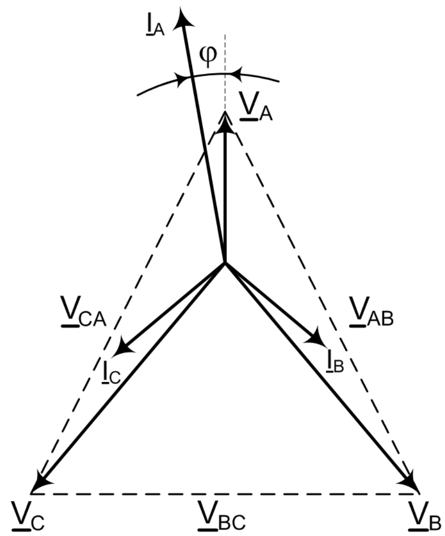


Figure 75: Single-phase ground fault, phase A

In an example case of a two-phase short-circuit failure where the fault is between phases B and C, the angle difference is measured between the polarizing quantity V_{BC} and operating quantity $\underline{I}_B$ - $\underline{I}_C$ in the self-polarizing method.

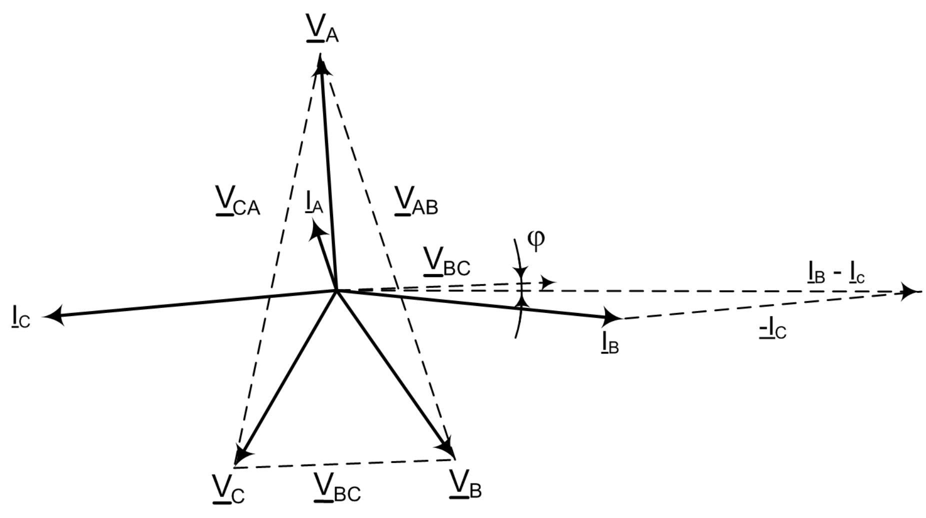


Figure 76: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 121: Equations for calculating angle difference for cross-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{V}_{BC}$	$ANGLE\_A = \varphi(\underline{V}_{BC}) - \varphi(\underline{I}_A) - \varphi_{RCA} + 90^o$
B	$\underline{I}_B$	$\underline{V}_{CA}$	$ANGLE\_B = \varphi(\underline{V}_{CA}) - \varphi(\underline{I}_B) - \varphi_{RCA} + 90^o$
C	$\underline{I}_C$	$\underline{V}_{AB}$	$ANGLE\_C = \varphi(\underline{V}_{AB}) - \varphi(\underline{I}_C) - \varphi_{RCA} + 90^o$
A - B	$\underline{I}_A - \underline{I}_B$	$\underline{V}_{BC} - \underline{V}_{CA}$	$ANGLE\_A = \varphi(\underline{V}_{BC} - \underline{V}_{CA}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 90^o$
B - C	$\underline{I}_B - \underline{I}_C$	$\underline{V}_{CA} - \underline{V}_{AB}$	$ANGLE\_B = \varphi(\underline{V}_{CA} - \underline{V}_{AB}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} + 90^o$
C - A	$\underline{I}_C - \underline{I}_A$	$\underline{V}_{AB} - \underline{V}_{BC}$	$ANGLE\_C = \varphi(\underline{V}_{AB} - \underline{V}_{BC}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 90^o$

The polarizing quantity is rotated with 90 degrees. The characteristic angle is assumed to be ~ 0 degrees.

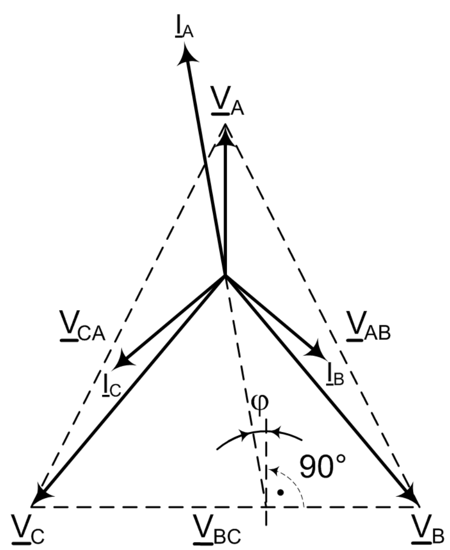


Figure 77: Single-phase ground fault, phase A

In an example of the phasors in a two-phase short-circuit failure where the fault is between the phases B and C, the angle difference is measured between the polarizing quantity $\underline{V}_{AB}$ and operating quantity $\underline{I}_B$ - $\underline{I}_C$ marked as φ.

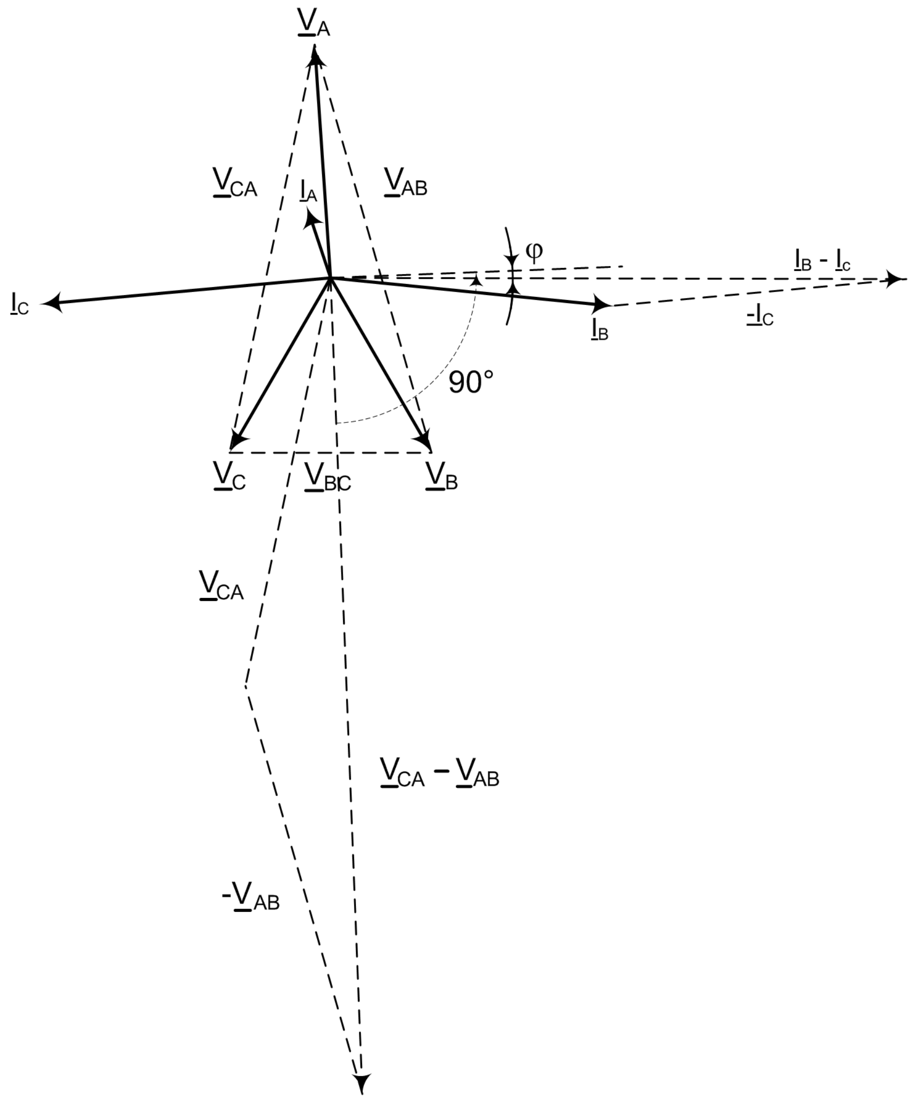


Figure 78: Two-phase short circuit, short circuit is between phases B and C

The equations are valid when network rotating direction is counter-clockwise, that is, ABC. If the network rotating direction is reversed, 180 degrees is added to the calculated angle difference. This is done automatically with a system parameter *Phase rotation*.

Negative sequence voltage as polarizing quantity

When the negative voltage is used as the polarizing quantity, the angle difference between the operating and polarizing quantity is calculated with the same formula for all fault types:

$$ANGLE\_X = \varphi(-\underline{V}2) - \varphi(\underline{I}2) - \varphi_{RCA}$$

(Equation 3)

This means that the actuating polarizing quantity is -V2.

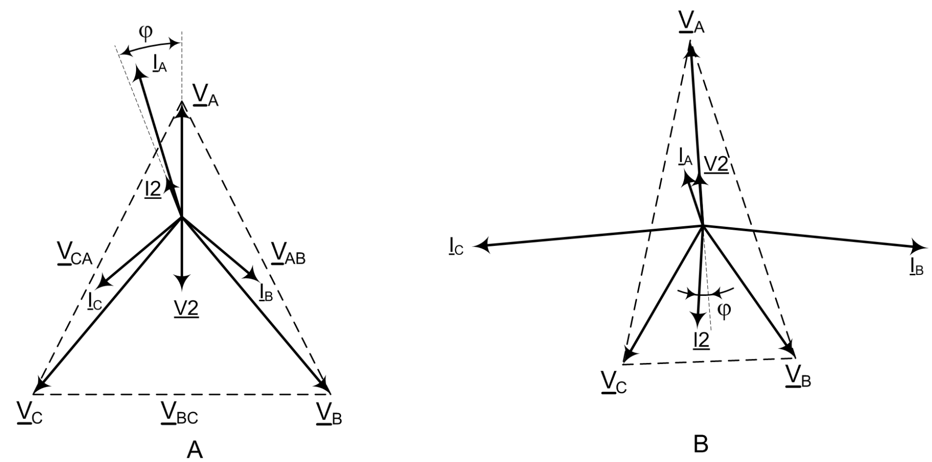


Figure 79: Phasors in a single-phase ground fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -V2

Positive sequence voltage as polarizing quantity

Table 122: Equations for calculating angle difference for positive-sequence quantity polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	I_A	V1	$ANGLE\_A = \varphi(\underline{V}1) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	I_B	V1	$ANGLE\_B = \varphi(\underline{V}1) - \varphi(\underline{I}_B) - \varphi_{RCA} - 120^\circ$
C	I_C	V1	$ANGLE\_C = \varphi(\underline{V}1) - \varphi(\underline{I}_C) - \varphi_{RCA} + 120^\circ$
Table continues on next page			

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A - B	$\underline{I}_A$ - $\underline{I}_B$	$\underline{V1}$	$ANGLE\_A = \varphi(\underline{V1}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 30^\circ$
B - C	$\underline{I}_B$ - $\underline{I}_C$	$\underline{V1}$	$ANGLE\_B = \varphi(\underline{V1}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} - 90^\circ$
C - A	$\underline{I}_C$ - $\underline{I}_A$	$\underline{V1}$	$ANGLE\_C = \varphi(\underline{V1}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$

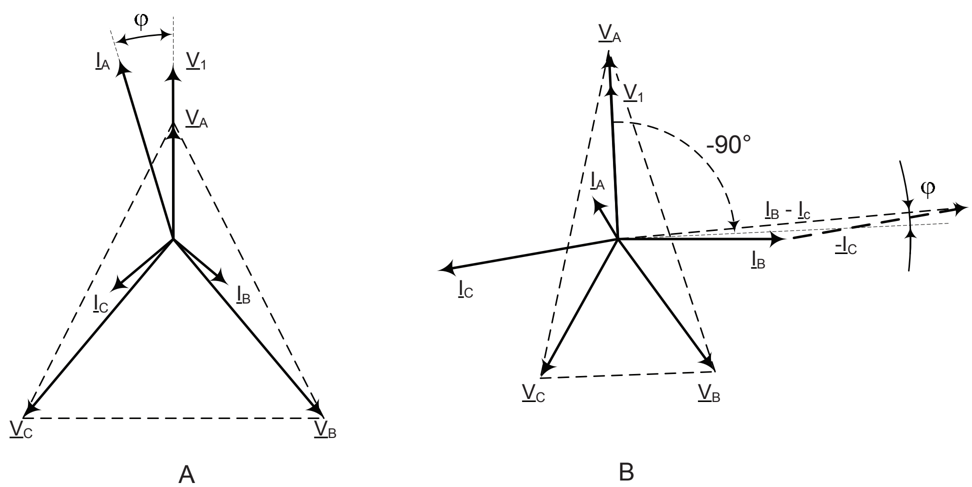


Figure 80: Phasors in a single-phase ground fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage V_1

Network rotation direction

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference needs to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The change in the network rotating direction affects the phase-to-phase voltages polarization method where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, which are, the positive sequence voltage or negative sequence voltage components, the calculation of the components are affected but the angle difference calculation remains the same. When the phase-to-ground voltages are used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the protection relay using the parameter in the HMI menu **Configuration/System/Phase rotation**. The default parameter value is "ABC".

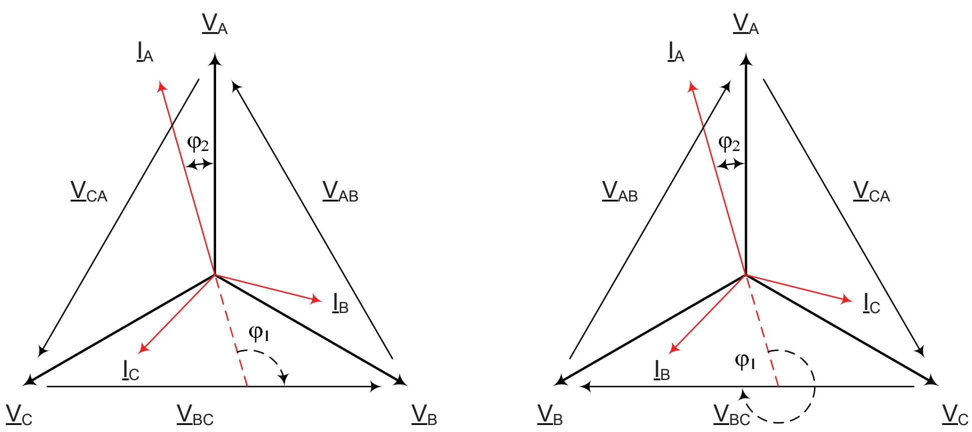


Figure 81: Examples of network rotating direction

4.1.3.7 Application

67/51P and 67/50P is used as short-circuit protection in three-phase distribution or sub transmission networks operating at 50 or 60 Hz.

In radial networks, phase overcurrent protection relays are often sufficient for the short circuit protection of lines, transformers and other equipment. The current-time characteristic should be chosen according to the common practice in the network. It is recommended to use the same current-time characteristic for all overcurrent protection relays in the network. This includes the overcurrent protection of transformers and other equipment.

The phase overcurrent protection can also be used in closed ring systems as short circuit protection. Because the setting of a phase overcurrent protection system in closed ring networks can be complicated, a large number of fault current calculations are needed. There are situations with no possibility to have the selectivity with a protection system based on overcurrent protection relays in a closed ring system.

In some applications, the possibility of obtaining the selectivity can be improved significantly if 67/51P and 67/50P is used. This can also be done in the closed ring networks and radial networks with the generation connected to the remote in the system thus giving fault current infeed in reverse direction. Directional overcurrent protection relays are also used to have a selective protection scheme, for example in case of parallel distribution lines or power transformers fed by the same single source.In ring connected supply feeders between substations or feeders with two feeding sources, 67/51P and 67/50P is also used.

Parallel lines or transformers

When the lines are connected in parallel and if a fault occurs in one of the lines, it is practical to have 67/51P and 67/50P to detect the direction of the fault. Otherwise, there is a risk that the fault situation in one part of the feeding system can de-energize the whole system connected to the LV side.

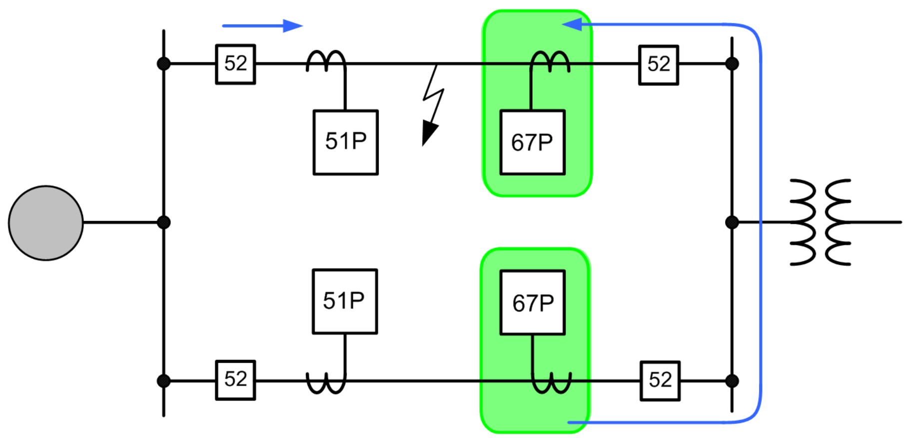


Figure 82: Overcurrent protection of parallel lines using directional protection relays

67/51P and 67/50P can be used for parallel operating transformer applications. In these applications, there is a possibility that the fault current can also be fed from the LV-side up to the HV-side. Therefore, the transformer is also equipped with directional overcurrent protection.

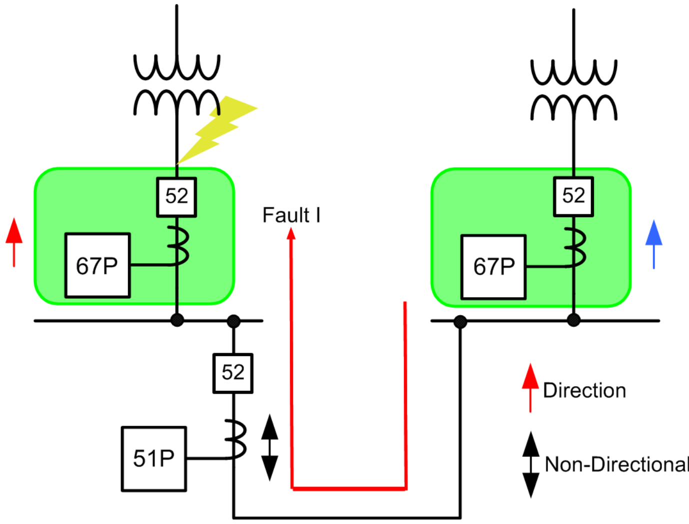


Figure 83: Overcurrent protection of parallel operating transformers

Closed ring network topology

The closed ring network topology is used in applications where electricity distribution for the consumers is secured during network fault situations. The power is fed at least from two directions which means that the current direction can be varied. The time grading between the network level stages is challenging without unnecessary delays in the time settings. In this case, it is practical to use the directional overcurrent protection relays to achieve a selective protection scheme. Directional overcurrent functions can be used in closed ring applications. The arrows define the operating direction of the directional functionality. The double arrows define the non-directional functionality where faults can be detected in both directions.

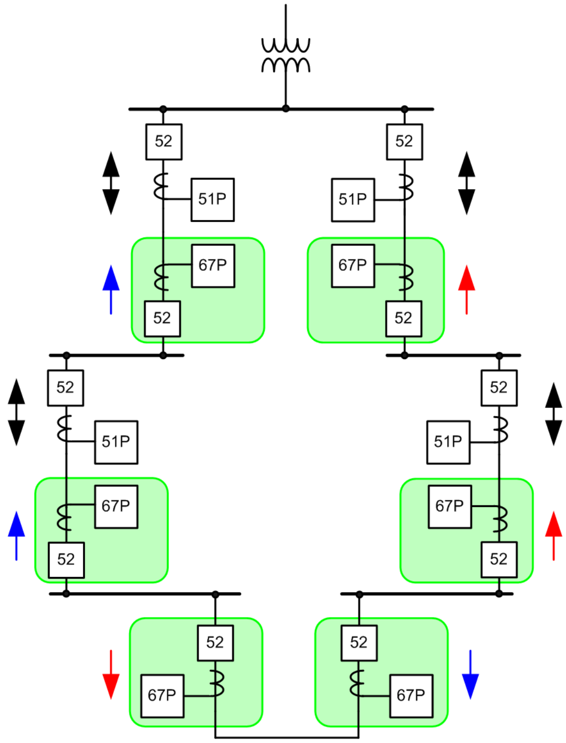


Figure 84: Closed ring network topology where feeding lines are protected with directional overcurrent protection relays

4.1.3.8 Signals

Table 123: 67/51P Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
V_A_AB	SIGNAL	0	Phase to ground voltage A or phase to phase voltage AB
V_B_BC	SIGNAL	0	Phase to ground voltage B or phase to phase voltage BC
V_C_CA	SIGNAL	0	Phase to ground voltage C or phase to phase voltage CA
V_1	SIGNAL	0	Positive phase sequence voltage
V_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 124: 67/50P Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
V_A_AB	SIGNAL	0	Phase to ground voltage A or phase to phase voltage AB
V_B_BC	SIGNAL	0	Phase to ground voltage B or phase to phase voltage BC
V_C_CA	SIGNAL	0	Phase to ground voltage C or phase to phase voltage CA
V_1	SIGNAL	0	Positive phase sequence voltage
V_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

Table 125: 67/51P Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 126: 67/50P Output signals

Name	Type	Description
PICKUP	BOOLEAN	Pickup
TRIP	BOOLEAN	Trip

4.1.3.9 Settings

Table 127: 67/51P Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...5.00	xIn	0.01	1	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	40...200000	ms	10	40	Trip delay time
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Operating curve type	1=ANSI Ext Inv 2=ANSI Very Inv 3=ANSI Norm Inv 4=ANSI Mod Inv 5=ANSI DT 6=LT Ext Inv 7=LT Very Inv 8=LT Inv 9=IEC Norm Inv 10=IEC Very Inv 11=IEC Inv 12=IEC Ext Inv 13=IEC ST Inv 14=IEC LT Inv 15=IEC DT 17=Programmable 18=RI Type 19=RD Type			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction
Pol quantity	-2=Pos. seq. volt. 1=Self pol 4=Neg. seq. volt. 5=Cross pol			5=Cross pol	Reference quantity used to determine fault direction

Table 128: 67/51P Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Min trip current	0.01...1.00	xIn	0.01	0.01	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.01	Minimum trip voltage

Table 129: 67/50P Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.10...40.00	xIn	0.01	2	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext Inv 3=ANSI Norm Inv 5=ANSI DT 9=IEC Norm Inv 10=IEC Very Inv 12=IEC Ext Inv 15=IEC DT 17=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Trip delay time	40...200000	ms	10	40	Trip delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	-2=Pos. seq. volt. 1=Self pol 4=Neg. seq. volt. 5=Cross pol			5=Cross pol	Reference quantity used to determine fault direction

Table 130: 67/50P Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min trip current	0.01...1.00	xIn	0.01	0.01	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.01	Minimum trip voltage
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation

4.1.3.10 Monitored data

Table 131: 67/51P Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
67/51P	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 132: 67/50P Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information

Table continues on next page

Name	Type	Values (Range)	Unit	Description
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
67/50P	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.3.11 Technical data

Table 133: 67/51P and 67/50P Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current/voltage measured: f_n ±2 Hz		
	67/51P	Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × V_n Phase angle: ±2°		
	67/50P-1 and 67/50P-2	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × V_n Phase angle: ±2°		
Pickup time[1)2)]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Pickup value*	38 ms	43 ms	46 ms
Reset time		<40 ms		
Table continues on next page				

Characteristic	Value
Reset ratio	Typically 0.96
Retardation time	<35 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Trip time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms[3)]
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) *Measurement mode* and *Pol quantity* = default, current before fault = 0.0 × I_n, voltage before fault = 1.0 × V_n, f_n = 60 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 2.5 × I_n, *Pickup value* multiples in range of 1.5 to 20

4.1.4 Non-directional neutral overcurrent protection 51N/50N and Non-directional ground fault protection 51G/50G

4.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Non-directional ground-fault protection, low stage	EFLPTOC	Io>	51N/G
Non-directional ground-fault protection, high stage	EFHPTOC	Io>>	50N/G-1/2
Non-directional ground-fault protection, instantaneous stage	EFIPTOC	Io>>>	50N/G-3

4.1.4.2 Function block

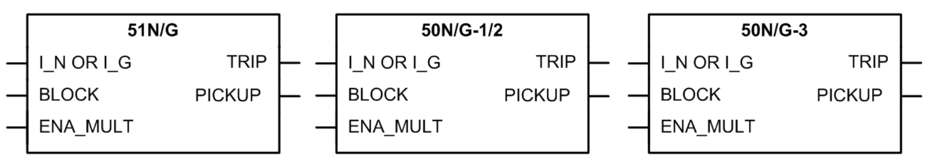


Figure 85: Function block

4.1.4.3 Functionality

The ground-fault function 51N/50N or 51G/50G is used as non-directional ground-fault protection.

The function picks up and trips when the measured (IG) or calculated (IN) ground current exceeds the set limit. The trip time characteristic for low stage 51N/G and high stage 50N/G-1/2 can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage 50N/G-3 always trips with the DT characteristic.

In the DT mode, the function trips after a predefined trip time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of non-directional ground-fault protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

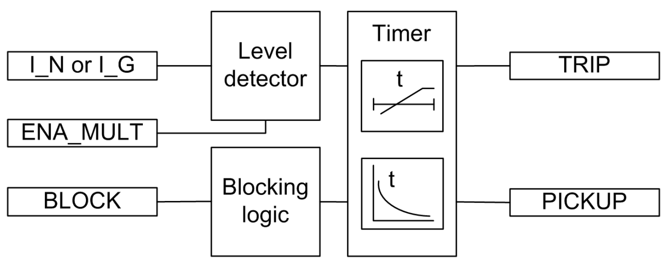


Figure 86: Functional module diagram. Io represents the residual current.

Level detector

The measured ground current is compared to the set *Pickup value*. If the measured value exceeds the set *Pickup value*, the level detector sends an enable-signal to the timer module. If the `ENA_MULT` input is active, the *Pickup value* setting is multiplied by the *Pickup value Mult* setting.

Do not set the multiplier setting *Pickup value Mult* higher than necessary. If the value is too high, the function may not trip at all during an inrush followed by a fault, no matter how severe the fault is.

The pickup value multiplication is normally done when the inrush detection function (INR) is connected to the `ENA_MULT` input.

Timer

Once activated, the timer activates the PICKUP output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the TRIP output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the trip delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. If the drop-off situation continues, the reset timer is reset and the PICKUP output is deactivated.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT trip and reset times.

The setting parameter *Minimum trip time* defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking**

mode which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.1.4.5 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 134: Measurement modes supported by 51N/50N or 51G/50G stages

Measurement mode	51N/G	50N/G-1/2	50N/G-3
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	x

For a detailed description of the measurement modes, see the Measurement modes section in this manual.

4.1.4.6 Timer characteristics

51N/50N or 51G/50G supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Trip delay time* and *Reset delay time* settings.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 135: *Timer characteristics supported by different stages*

Operating curve type	51N/G	50N/G-1/2
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

50N/G-3 supports only definite time characteristics.

For a detailed description of timers, see the General function block features section in this manual.

Table 136: *Reset time characteristics supported by different stages*

Reset curve type	51N/G	50N/G-1/2	Note
(1) Immediate	x	x	Available for all reset time curves
(2) Def time reset	x	x	Available for all reset time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

The *Type of reset curve* setting does not apply to 50N/G-3 or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.1.4.7 Application

51N/50N or 51G/50G is designed for protection and clearance of ground faults in distribution and sub-transmission networks where the neutral point is isolated or grounded via a resonance coil or through low resistance. It also applies to solidly grounded networks and ground-fault protection of different equipment connected to the power systems, such as shunt capacitor bank or shunt reactors and for backup ground-fault protection of power transformers.

Many applications require several steps using different current pickup levels and time delays. 51N/50N or 51G/50G consists of three different protection stages:

- Low 51N/G
- High 50N/G-1/2
- Instantaneous 50N/G-3.

51N/G contains several types of time-delay characteristics. 50N/G-1/2 and 50N/G-3 are used for fast clearance of serious ground faults.

4.1.4.8 Signals

Table 137: 51N/G Input signals

Name	Type	Default	Description
IN or IG	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 138: 50N/G-1/2 Input signals

Name	Type	Default	Description
IG or IN	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 139: 50N/G-3 Input signals

Name	Type	Default	Description
IG or IN	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 140: 51N/G Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 141: 50N/G-1/2 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 142: 50N/G-3 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.4.9 Settings

Table 143: 51N/G Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.010...5.000	xIn	0.005	0.5	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Trip delay time	40...200000	ms	10	40	Trip delay time
Operating curve type	1=ANSI Ext Inv 2=ANSI Very Inv 3=ANSI Norm Inv 4=ANSI Mod Inv 5=ANSI DT 6=LT Ext Inv 7=LT Very Inv 8=LT Inv 9=IEC Norm Inv 10=IEC Very Inv 11=IEC Inv 12=IEC Ext Inv 13=IEC ST Inv 14=IEC LT Inv 15=IEC DT 17=Programmable 18=RI Type 19=RD Type			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 144: 51N/G Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
IG/I0 signal Sel	1=Measured IG 2=Calculated I0			1=Measured IG	Measured IG or calculated I0

Table 145: 50N/G-1/2 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.10...40.00	xIn	0.01	1	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	40...200000	ms	10	1000	Trip delay time
Operating curve type	1=ANSI Ext Inv 3=ANSI Norm Inv 5=ANSI DT 9=IEC Norm Inv 10=IEC Very Inv 12=IEC Ext Inv 15=IEC DT 17=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 146: 50N/G-1/2 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
IG/I0 signal Sel	1=Measured IG 2=Calculated I0			1=Measured IG	Measured IG or calculated I0

Table 147: 50N/G-3 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	1.00...40.00	xIn	0.01	1.00	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Trip delay time	20...200000	ms	10	20	Trip delay time

Table 148: 50N/G-3 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
IG/I0 signal Sel	1=Measured IG 2=Calculated I0			1=Measured IG	Measured IG or calculated I0

4.1.4.10 Monitored data

Table 149: 51N/G Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
51N/G	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 150: 50N/G-1/2 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
50N/G-1/2	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 151: 50N/G-3 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
50N/G-3	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.4.11 Technical data

Table 152: 51N/G, 50N/G-1/2 & 50N/G-3 Technical data

Characteristic		Value		
	51N/G	±1.5% of the set value or ±0.002 × I_n		
	50N-1/2 & 50G-1/2 and 50N/G-3	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)		
Pickup time 1)2)		Minimum	Typical	Maximum
	50N/G-3: I_{Fault} = 2 × set Pickup value I_{Fault} = 10 × set Pickup value	 15 ms 12 ms	 16 ms 13 ms	 17 ms 14 ms
	50N-1/2 & 50G-1/2 and 51N/G: I_{Fault} = 2 × set Pickup value	23 ms	25 ms	28 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Trip time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms 3)		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression		

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 60 Hz, ground-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 2.5 × I_n, *Pickup value* multiples in range of 1.5...20

4.1.5 Directional earth-fault protection 67/51N and 67/50N

4.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional earth-fault protection, low stage	DEFLPDEF1	I0> ->(1)	67/51N
Directional earth-fault protection, high stage	DEFHPDEF1 DEFHPDEF2	I0>> ->(1) I0>> ->(2)	67/50N-1 67/50N-2

4.1.5.2 Function block

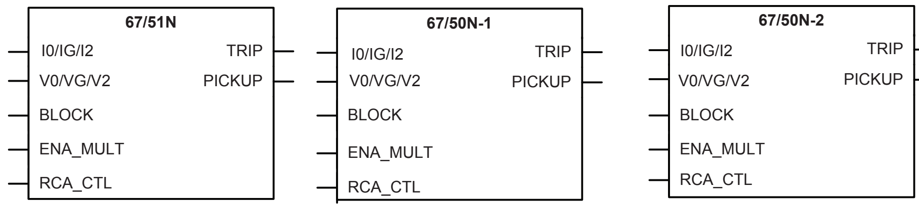


Figure 87: Function block

4.1.5.3 Functionality

The earth-fault function 67/51N and 67/50N is used as directional earth-fault protection.

There are three different polarization signals - measured zero sequence voltage, calculated zero sequence voltage and negative sequence voltage. The function picks up and trips when the zero sequence current (I_0) and zero sequence voltage ($-V_0$) exceed the set limits and the angle between them is inside the set operating sector. The function also picks up and trips when the negative sequence current (I_2) and negative sequence voltage ($-V_2$) exceed the set limits and the angle between them is inside the set operating sector. The trip time characteristic for low stage (67/51N and 67/50N-1) and high stage (67/50N-2) can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function trips after a predefined trip time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of directional earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

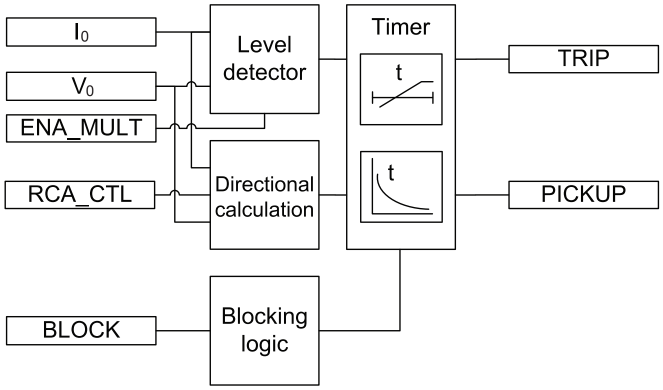


Figure 88: Functional module diagram. I_0 and V_0 represent the zero sequence current and zero sequence voltage.

Level detector

The measured ground current is compared to the set *Pickup value*. The zero sequence voltage (-Vo) also needs to be compared to the set *Voltage pickup value*. If both limits are exceeded, the level detector sends an enable-signal to the timer module. When the *Enable voltage limit* setting is set to "False", the *Voltage pickup* value has no effect and the level detection is purely based on the ground current. If the `ENA_MULT` input is active, the *Pickup value* setting is multiplied by the *Pickup value Mult* setting.

If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if the *Directional mode* was set to "Non-directional" or *Allow Non Dir* to "True". The protection relay does not accept the *Pickup value* or *Pickup value Mult* setting if the product of these settings exceeds the *Pickup value* setting range.

Do not set the multiplier setting *Pickup value Mult* higher than necessary. If the value is too high, the function may not trip at all during an inrush followed by a fault, no matter how severe the fault is.

The pickup value multiplication is normally done when the inrush detection function (INR) is connected to the `ENA_MULT` input.

Directional calculation

The directional calculation module monitors the angle between the operating current and polarizing voltage. When the angle is in the operation sector, the module sends the enable signal to the timer module. When the angle is in the operation sector, the module sends the enabling signal to the timer module.

For defining the operation sector, there are five modes available through the *Operation mode* setting.

Table 153: Operation modes

Operation mode	Description
Phase angle	The operating sectors for forward and reverse are defined with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* and *Max reverse angle*.
IoSin	The operating sectors are defined as "forward" when the mathematical expression has a positive value and "reverse" when the value is negative
IoCos	As "IoSin" mode. Only cosine is used for calculating the operation current.
Phase angle 80	The sector maximum values are frozen to 80 degrees respectively. Only *Min forward angle* and *Min reverse angle* are settable.
Phase angle 88	The sector maximum values are frozen to 88 degrees. Otherwise as "Phase angle 80" mode.

The directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "Reverse" operation. The operation criterion is selected with the *Operation mode* setting. By setting *Allow Non Dir* to "True", non-directional operation is allowed when the directional information is invalid.

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equation for calculating the negative sequence voltage component need to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The calculation of the component is affected but the angle difference calculation remains the same. When the residual voltage is used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the protection relay using the parameter in the HMI menu: **Configuration/System/Phase rotation**. The default parameter value is "ABC".

The *Characteristic angle* setting is used in the "Phase angle" mode to adjust the operation according to the method of neutral point grounding so that in an isolated network the *Characteristic angle* (φ_{RCA}) = -90° and in a compensated network φ_{RCA} = 0°. In addition, the characteristic angle can be changed via the control signal `RCA_CTL`, in which case the alternatives are -90° and 0°. The operation of `RCA_CTL` depends on the *Characteristic angle* setting.

The *Correction angle* setting can be used to improve selectivity due the inaccuracies in the measurement transformers. The setting decreases the operation sector. The correction can only be used with the "IoCos" or "IoSin" modes.

When polarizing quantity (zero sequence voltage ($-U_0$)) is inverted because of switched voltage measurement cables, the correction can be done by setting the *Pol reversal* to "True" which turns polarizing quantity by 180 degrees.

For definitions of different directional ground-fault characteristics, see the Directional ground-fault characteristics section in this manual.

The directional calculation module calculates several values which are presented in the monitored data.

Table 154: Monitored data values

Monitored data values	Description
FAULT_DIR	The detected direction of fault during fault situations, that is, when PICKUP output is active.
DIRECTION	The momentary operating direction indication output.
ANGLE	Also called operating angle, shows the angle difference between the VG (polarizing quantity) and Io (operating quantity).
ANGLE_RCA	The angle difference between the operating angle and *Characteristic angle*, that is, ANGLE_RCA = ANGLE – *Characteristic angle*.
I_OPER	The current that is used for fault detection. If the *Operation mode* setting is "Phase angle", "Phase angle 80" or "Phase angle 88", I_OPER is the measured or calculated residual current. If the *Operation mode* setting is "IoSin", I_OPER is calculated as follows I_OPER = Io x sin(ANGLE). If the *Operation mode* setting is "IoCos", I_OPER is calculated as follows I_OPER = Io x cos(ANGLE).

Monitored data values are accessible on the LHMI or through tools via communications.

Timer

Once activated, the timer activates the PICKUP output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the TRIP output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the trip delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. If the drop-off situation continues, the reset timer is reset and the `PICKUP` output is deactivated.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT trip and reset times.

The setting parameter *Minimum trip time* defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*

.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the `TRIP` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the `TRIP` output is not activated.

4.1.5.5 Directional ground-fault principles

In many cases it is difficult to achieve selective ground-fault protection based on the magnitude of zero-sequence current only. To obtain a selective ground-fault protection scheme, it is necessary to take the phase angle of I_0 into account. This is done by comparing the phase angle of I_0 to that of the zero-sequence voltage ($-V_0$).

Relay characteristic angle

The *Characteristic angle* setting, also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Angle (MTA), is used in the "Phase angle" mode to turn the directional characteristic if the expected fault current angle does not coincide with the polarizing quantity to produce the maximum torque. That is, RCA is the angle between the maximum torque line and polarizing quantity. If the polarizing quantity is in phase with the maximum torque line, RCA is 0 degrees. The angle is positive if the operating current lags the polarizing quantity and negative if it leads the polarizing quantity.

Example 1

The "Phase angle" mode is selected, compensated network (φRCA = 0 deg)

=> *Characteristic angle* = 0 deg

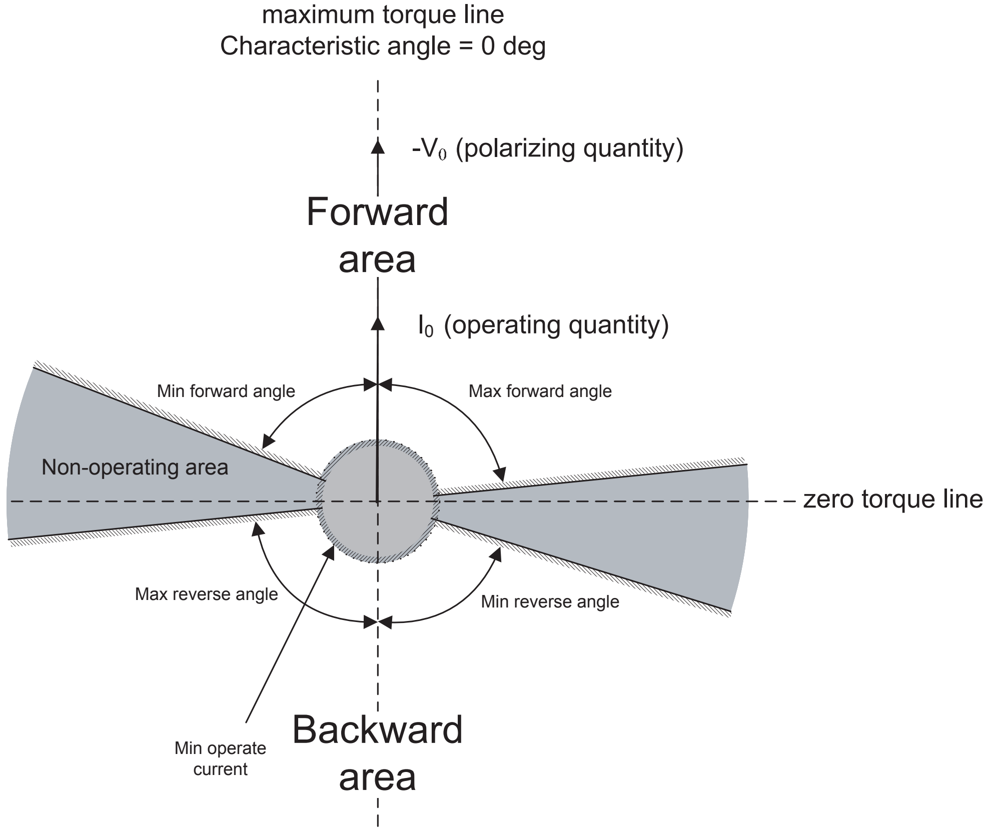


Figure 89: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network

Example 2

The "Phase angle" mode is selected, solidly grounded network (φRCA = +60 deg)

=> *Characteristic angle* = +60 deg

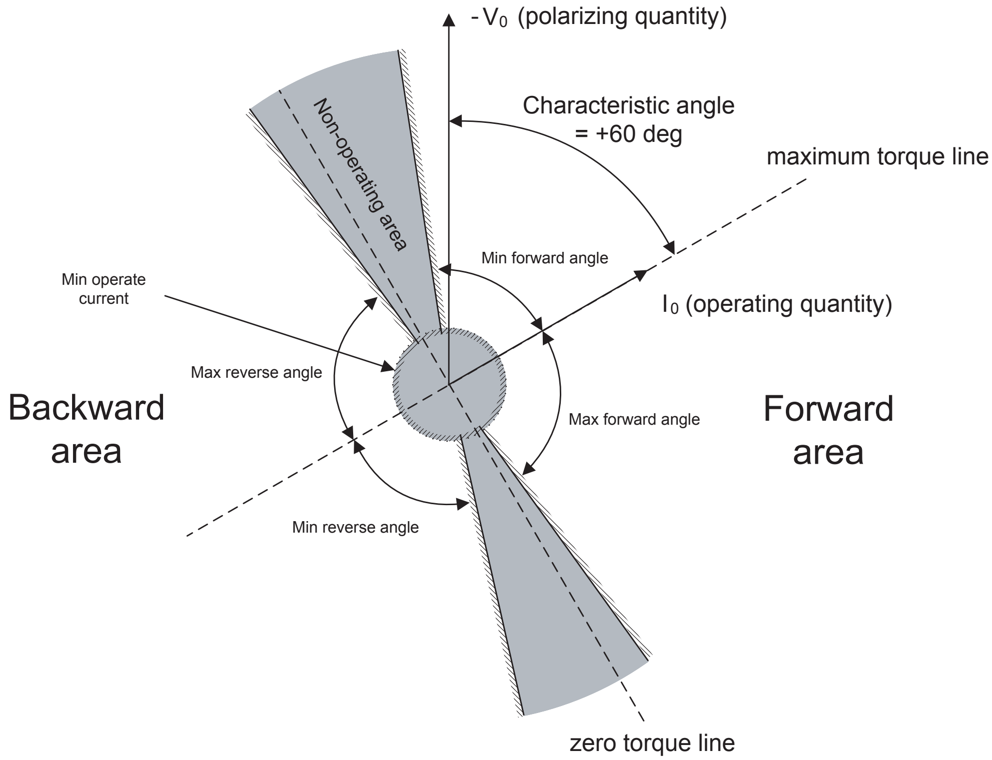


Figure 90: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly grounded network

Example 3

The "Phase angle" mode is selected, isolated network (φRCA = -90 deg)

=> *Characteristic angle* = -90 deg

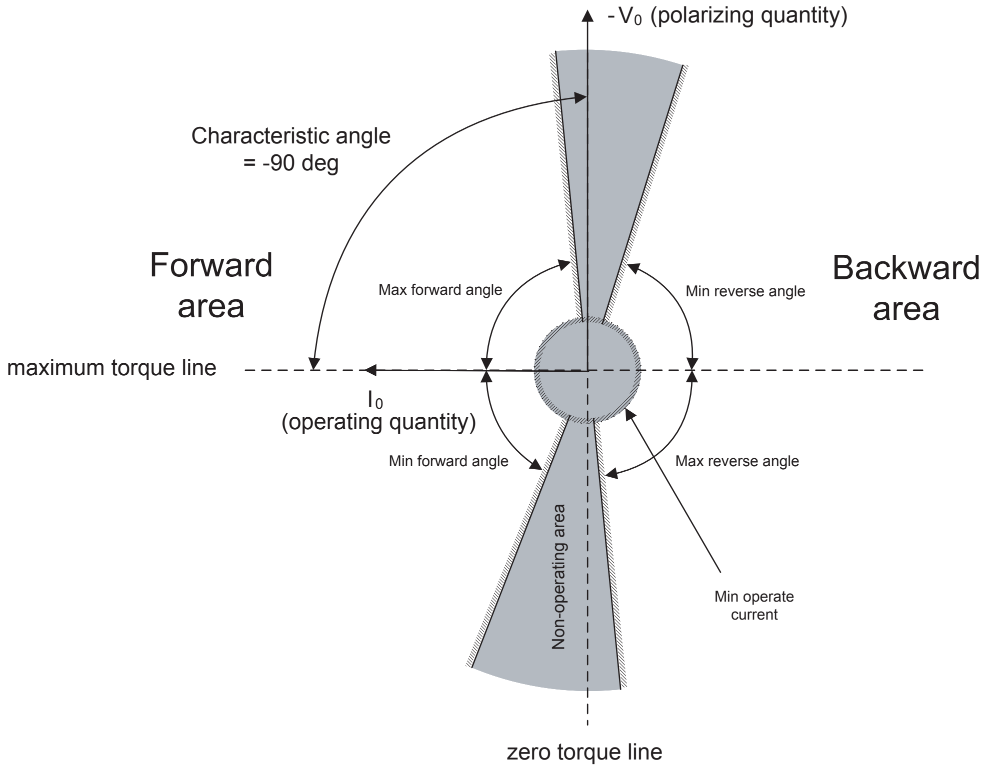


Figure 91: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network

Directional ground-fault protection in an isolated neutral network

In isolated networks, there is no intentional connection between the system neutral point and ground. The only connection is through the line-to-ground capacitances (C_0) of phases and leakage resistances (R_0). This means that the zero-sequence current is mainly capacitive and has a phase shift of –90 degrees compared to the residual voltage ($-V_0$). Consequently, the relay characteristic angle (RCA) should be set to -90 degrees and the operation criteria to "IoSin" or "Phase angle". The width of the operating sector in the phase angle criteria can be selected with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* or *Max reverse angle*. Figure 92 describes how the ground-fault current is defined in isolated neutral networks.

For definitions of different directional ground-fault characteristics, see Directional ground-fault principles.

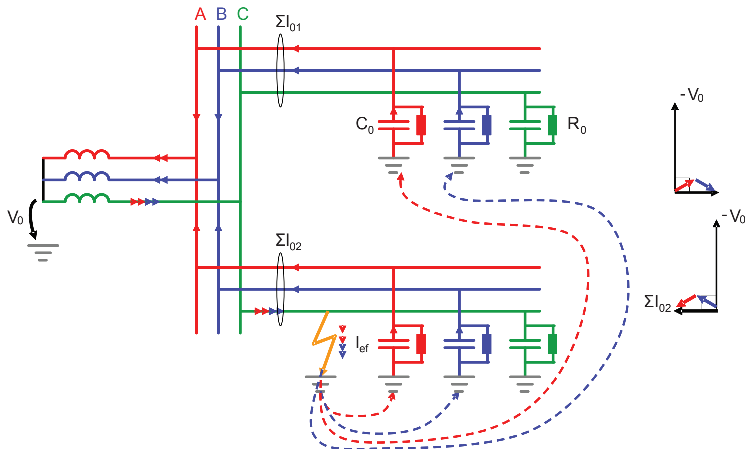


Figure 92: Ground-fault situation in an isolated network

Directional ground-fault protection in a compensated network

In compensated networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the protection relays. In this case, the selectivity is based on the measurement of the active current component. The magnitude of this component is often small and must be increased by means of a parallel resistor in the compensation equipment. When measuring the resistive part of the zero-sequence current, the relay characteristic angle (RCA) should be set to 0 degrees and the operation criteria to $I_0\cos(\varphi)$ or phase angle.

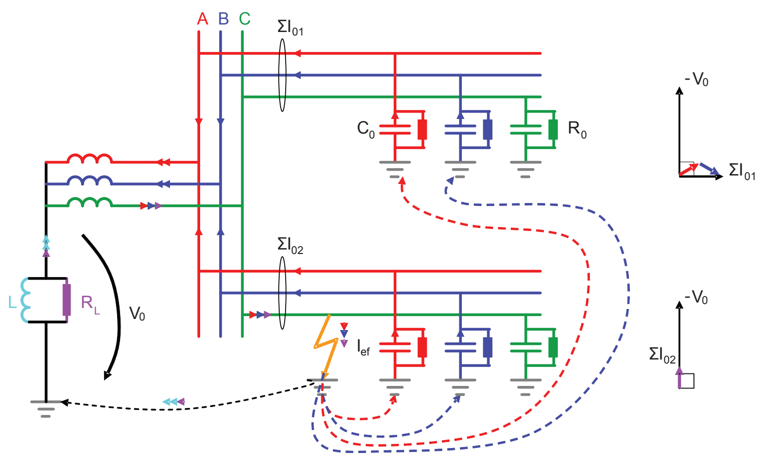


Figure 93: Ground-fault situation in a compensated network

The Petersen coil or the grounding resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the *Characteristic angle* setting accordingly. This is done with an auxiliary input in the protection relay which receives a signal from an auxiliary switch of the disconnector of the Petersen coil in compensated networks or of the grounding resistor in grounded networks. As a result, the characteristic angle is set automatically to suit the grounding method used. The RCA_CTL input can be used to change the Io characteristic:

Table 155: Relay characteristic angle control in Iosin(φ) and Iocos(φ) operation criteria

Operation mode setting:	RCA_CTL = FALSE	RCA_CTL = TRUE
Iosin	Actual operation mode: Iosin	Actual operation mode: Iocos
Iocos	Actual operation mode: Iocos	Actual operation mode: Iosin

Table 156: Characteristic angle control in phase angle operation mode

Characteristic angle setting	RCA_CTL = FALSE	RCA_CTL = TRUE
-90°	φ_{RCA} = -90°	φ_{RCA} = 0°
0°	φ_{RCA} = 0°	φ_{RCA} = -90°

Use of the extended phase angle characteristic

In addition to the RCA_CTL input, the extended phase angle characteristic can be used when the compensation coil is temporarily disconnected in compensated networks. When the extended operation area is used, the operation area is wide enough to detect ground faults selectively in compensated networks regardless of whether the compensation coil is connected or not. Therefore, the RCA_CTL input is not required if the extended operation area is used.

Sometimes the distance between the start point and the protection relay is long, which makes it impractical to apply the scheme based on signal wiring between the protection relay and the Petersen coil or the grounding resistor. This is the case when, for example, a directional ground-fault protection relay is used in an MV-switching substation some kilometers from the HV/MV-substation where the grounding facilities are located. Another example is when HV/MV-substations are connected in parallel but located far from each other.

It is easy to give the tripping sector such a width that all possible directions of the I_0-phasors of a faulty line are covered by one and the same sector. Thus, the problem of setting the characteristic angle according to the grounding status of the network is easily solved. There is no need to change any settings when a Petersen coil or a grounding resistor is switched on or off. Auxiliary switches and other pieces of extra hardware are no longer required for ensuring the selectivity of the directional ground-fault protection.

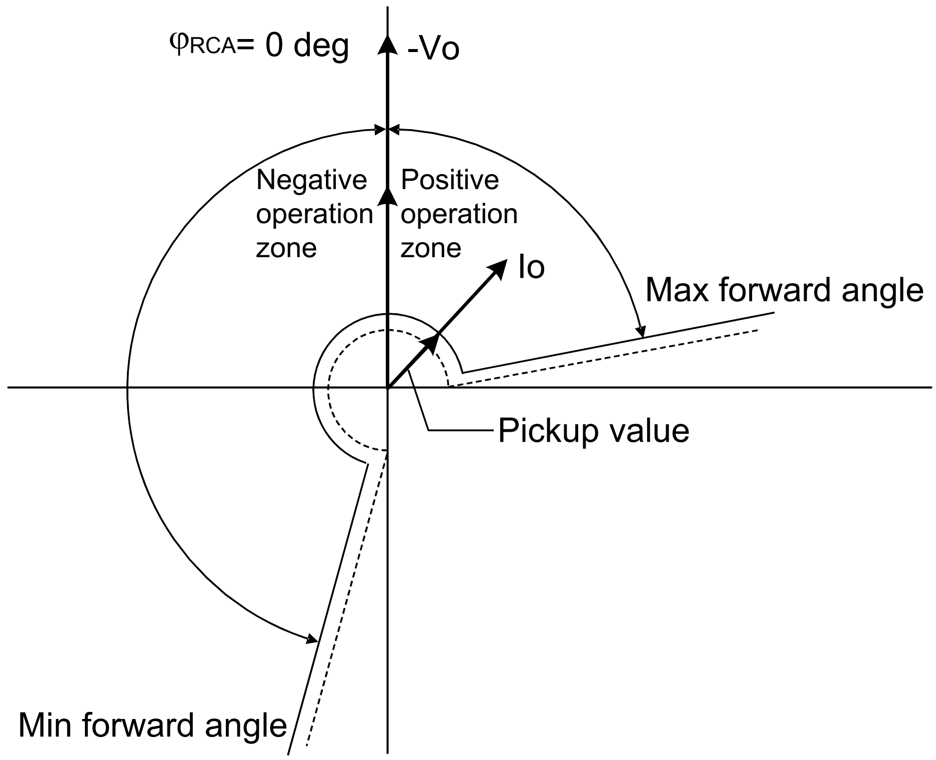


Figure 94: Extended operation area in directional ground-fault protection

4.1.5.6 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 157: Measurement modes supported by 67/51N and 67/50N stages

Measurement mode	67/51N and 67/50N-1	67/50N-2
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

For a detailed description of the measurement modes, see the Measurement modes section in this manual.

4.1.5.7 Timer characteristics

67/51N and 67/50N supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages.

Table 158: Timer characteristics supported by different stages

Operating curve type	67/51N and 67/50N-1	67/50N-2
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	
(10) IEC Very Inverse	x	
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

For a detailed description of the timers, see the General function block features section in this manual.

Table 159: Reset time characteristics supported by different stages

Reset curve type	67/51N and 67/50N-1	67/50N-2	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

4.1.5.8 Directional ground-fault characteristics

Phase angle characteristic

The operation criterion phase angle is selected with the *Operation mode* setting using the value "Phase angle".

When the phase angle criterion is used, the function indicates with the `DIRECTION` output whether the operating quantity is within the forward or reverse operation sector or within the non-directional sector.

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the clockwise sector and the *Min forward angle* setting correspondingly the counterclockwise sector, measured from the *Characteristic angle* setting.

In the reverse operation area, the *Max reverse angle* setting gives the clockwise sector and the *Min reverse angle* setting correspondingly the counterclockwise sector, measured from the complement of the *Characteristic angle* setting (180 degrees phase shift) .

The relay characteristic angle (RCA) is set to positive if the operating current lags the polarizing quantity. It is set to negative if it leads the polarizing quantity.

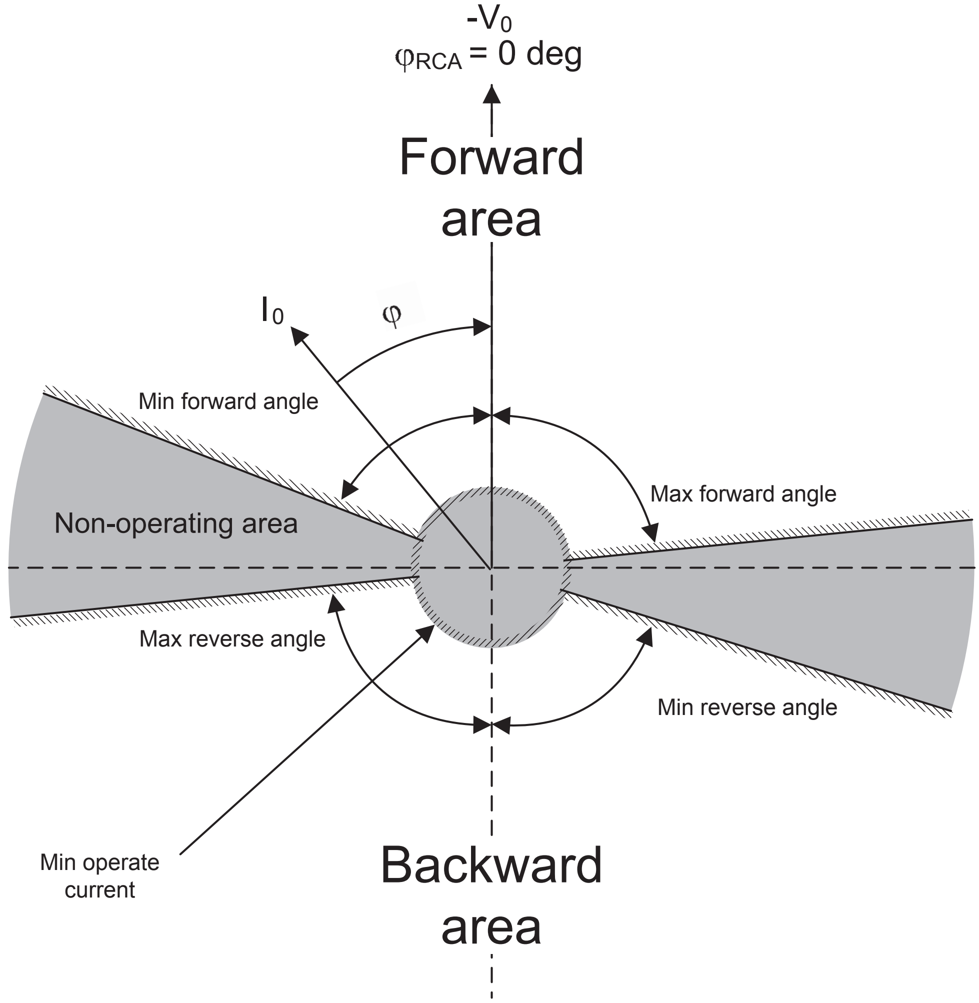


Figure 95: Configurable operating sectors in phase angle characteristic

Table 160: Momentary operating direction

Fault direction	The value for DIRECTION
Angle between the polarizing and operating quantity is not in any of the defined sectors.	0 = unknown
Angle between the polarizing and operating quantity is in the forward sector.	1= forward
Angle between the polarizing and operating quantity is in the reverse sector.	2 = backward
Angle between the polarizing and operating quantity is in both the forward and the reverse sectors, that is, the sectors are overlapping.	3 = both

Directional operation is not allowed (the setting *Allow Non Dir* is "False") when the measured polarizing or operating quantities are not valid, that is, their magnitude is below the set minimum values. The minimum values can be defined with the settings *Min trip current* and *Min trip voltage*. In case of low magnitudes, the `FAULT_DIR` and `DIRECTION` outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

The `RCA_CTL` input is used in compensated networks where the compensation coil sometimes can be disconnected. When the coil is disconnected, the compensated network becomes isolated and the *Characteristic angle* setting (φRCA) must be changed. This can be done automatically with the `RCA_CTL` input. Note that the `RCA_CTL` input only works when the *Characteristic angle* setting is set to exactly -90 degrees or 0 degrees. The value of the input affects the *Characteristic angle* setting in the following way:

Table 161: Characteristic angle control in phase angle operation mode

Characteristic angle setting	`RCA_CTL` = "False"	`RCA_CTL` = "True"
-90°	φRCA = -90°	φRCA = 0°
0°	φRCA = 0°	φRCA = -90°

Iosin(φ) and Iocos(φ) criteria

A more modern approach to directional protection is the active or reactive current measurement. The operating characteristic of the directional operation depends on the grounding principle of the network. The I_0sin(φ) characteristics is used in an isolated network, measuring the reactive component of the fault current caused by the ground capacitance. The I_0cos(φ) characteristics is used in a compensated network, measuring the active component of the fault current.

The operation criteria Iosin(φ) and Iocos(φ) are selected with the *Operation mode* setting using the values "IoSin" or "IoCos" respectively.

In isolated networks, I_0sin(φ) does not differ from the phase angle criterion, since the phase angle of the operating quantity is fairly close to -90 degrees. Furthermore, in completely compensated networks the fault current is usually mostly resistive. Therefore, the phase angle and I_0cos(φ) criteria are equally sensitive. However, if the fault is in the background network, the fault current of a sound and healthy line is almost fully capacitive and its phase angle is close to the operation area of the component. Therefore, the I_0cos(φ) characteristic is recommended, since the risk of faulty operation is smaller than with the phase angle criterion.

The angle correction setting can be used to improve selectivity. The setting decreases the operation sector. The correction can only be used with the Iosin(φ) or Iocos(φ) criterion. The `RCA_CTL` input is used to change the Io characteristic:

Table 162: Relay characteristic angle control in the IoSin and IoCos operation criteria

Operation mode:	RCA_CTL = "False"	RCA_CTL = "True"
IoSin	Actual operation criterion: Iosin(φ)	Actual operation criterion: Iocos(φ)
IoCos	Actual operation criterion: Iocos(φ)	Actual operation criterion: Iosin(φ)

When the Iosin(φ) or Iocos(φ) criterion is used, the component indicates a forward- or reverse-type fault through the FAULT_DIR and DIRECTION outputs, in which 1 equals a forward fault and 2 equals a reverse fault. Directional operation is not allowed (the *Allow non dir* setting is "False") when the measured polarizing or operating quantities are not valid, that is, when their magnitude is below the set minimum values. The minimum values can be defined with the *Min trip current* and *Min trip voltage* settings. In case of low magnitude, the FAULT_DIR and DIRECTION outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

The calculated Iosin(φ) or Iocos(φ) current used in direction determination can be read through the I_OPER monitored data. The value can be passed directly to a decisive element, which provides the final pickup and trip signals.

The I_OPER monitored data gives an absolute value of the calculated current.

The following examples show the characteristics of the different operation criteria:

Example 1.

Iosin(φ) criterion selected, forward-type fault

=> FAULT_DIR = 1

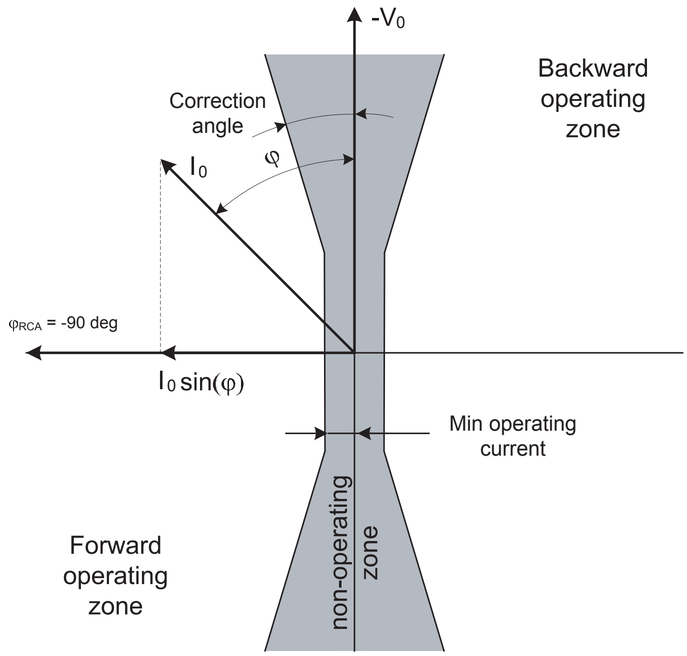


Figure 96: Operating characteristic I_0sin(φ) in forward fault

The operating sector is limited by angle correction, that is, the operating sector is 180 degrees - 2*(angle correction).

Example 2.

Iosin(φ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

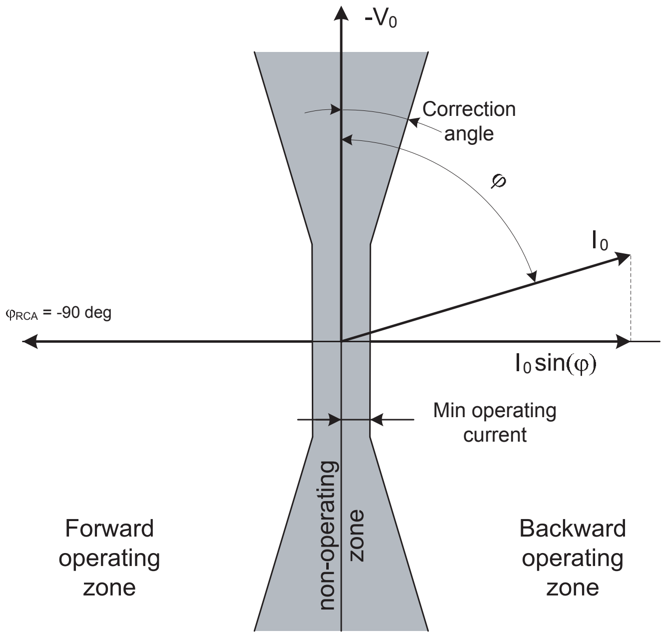


Figure 97: Operating characteristic $I_0 sin(\varphi)$ in reverse fault

Example 3.

Iocos(φ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

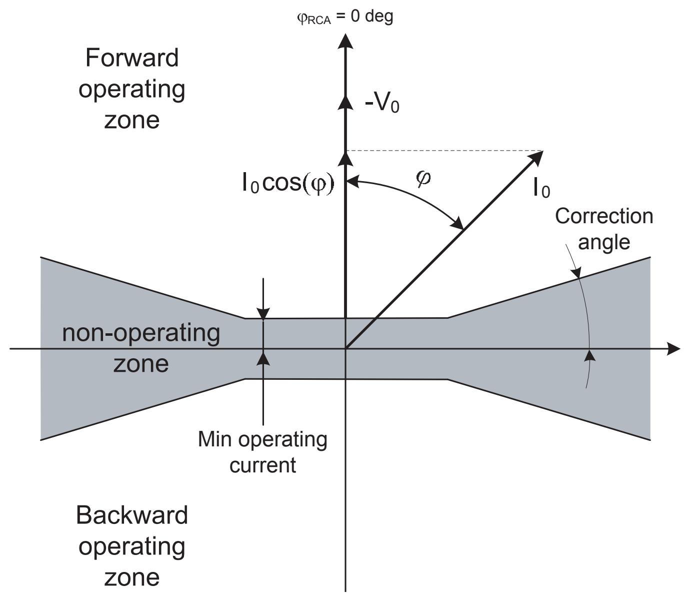


Figure 98: Operating characteristic $I_0cos(φ)$ in forward fault

Example 4.

Iocos(φ) criterion selected, reverse-type fault

`=> FAULT_DIR = 2`

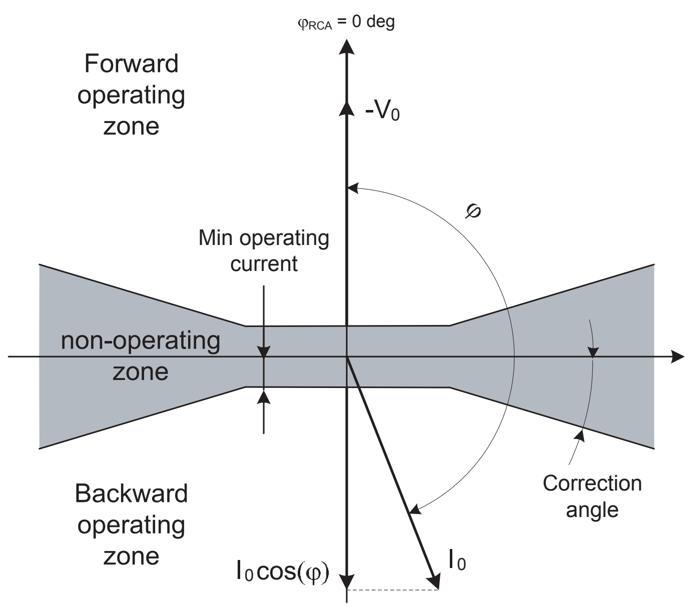


Figure 99: Operating characteristic $I_0cos(φ)$ in reverse fault

Phase angle 80

The operation criterion phase angle 80 is selected with the *Operation mode* setting by using the value "Phase angle 80".

Phase angle 80 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 80 degrees
- The sector limits of the fixed sectors are rounded.

The sector rounding is used for cancelling the CT measurement errors at low current amplitudes. When the current amplitude falls below three percent of the nominal current, the sector is reduced to 70 degrees at the fixed sector side. This makes the protection more selective, which means that the phase angle measurement errors do not cause faulty operation.

There is no sector rounding on the other side of the sector.

If the current amplitude falls below one percent of the nominal current, the direction enters the non-directional area.

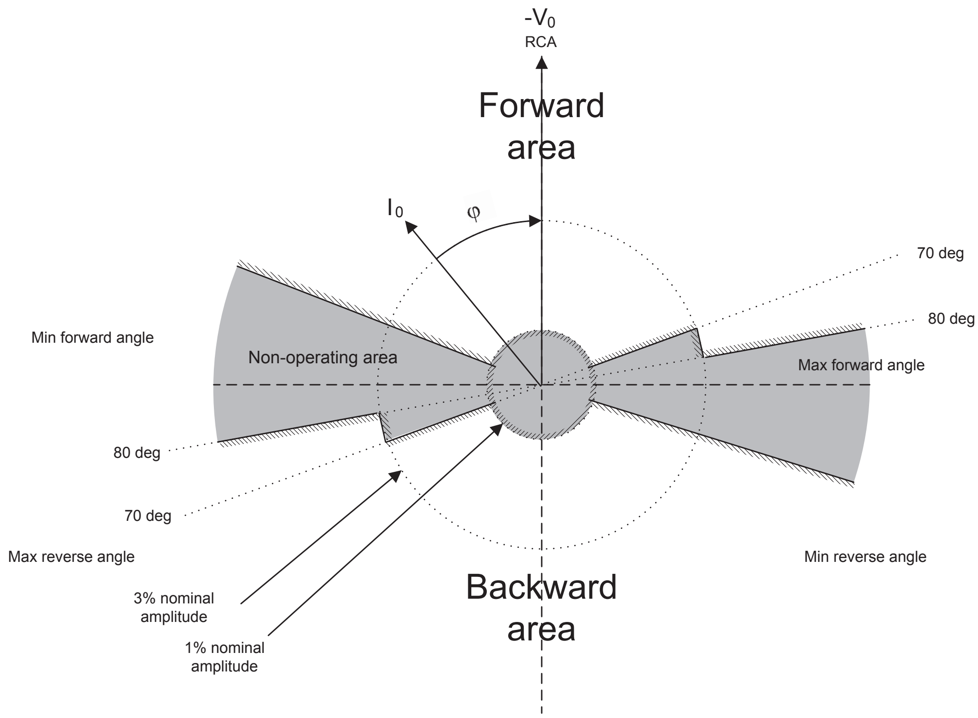


Figure 100: Operating characteristic for phase angle classic 80

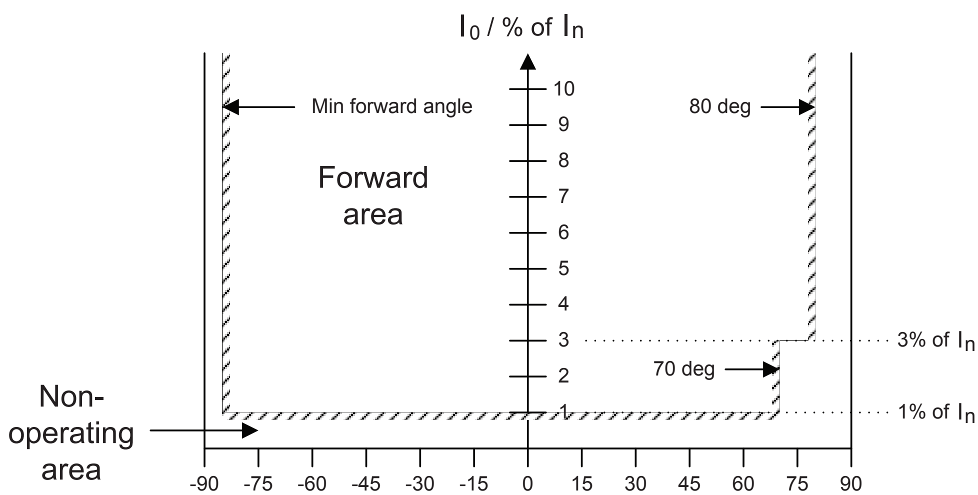


Figure 101: Phase angle classic 80 amplitude

Phase angle 88

The operation criterion phase angle 88 is selected with the *Operation mode* setting using the value "Phase angle 88".

Phase angle 88 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 88 degrees
- The sector limits of the fixed sectors are rounded.

Sector rounding in the phase angle 88 consists of three parts:

- If the current amplitude is between 1...20 percent of the nominal current, the sector limit increases linearly from 73 degrees to 85 degrees
- If the current amplitude is between 20...100 percent of the nominal current, the sector limit increases linearly from 85 degrees to 88 degrees
- If the current amplitude is more than 100 percent of the nominal current, the sector limit is 88 degrees.

There is no sector rounding on the other side of the sector.

If the current amplitude falls below one percent of the nominal current, the direction enters the non-directional area.

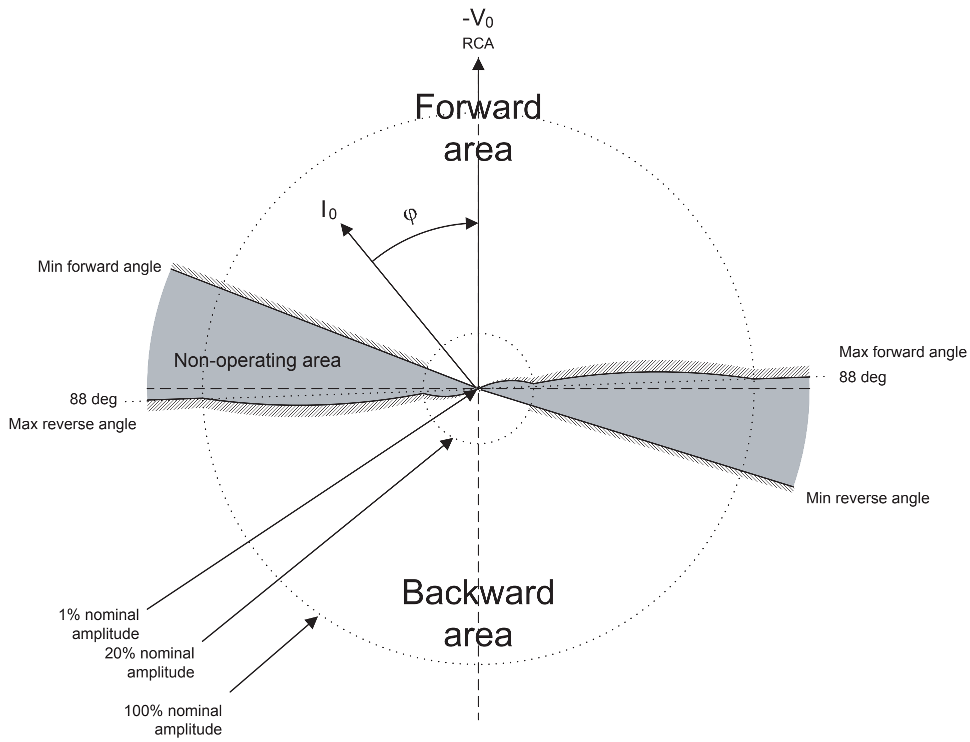


Figure 102: Operating characteristic for phase angle classic 88

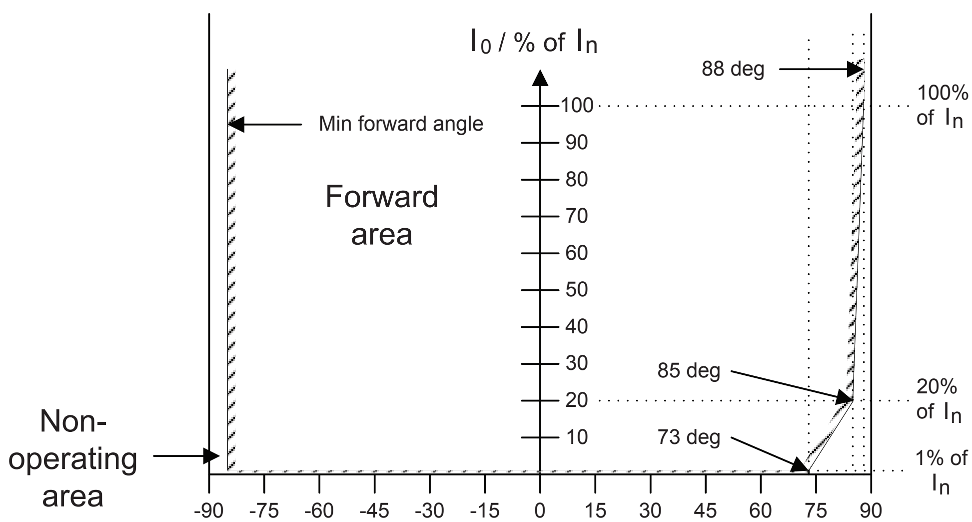


Figure 103: Phase angle classic 88 amplitude

4.1.5.9 Application

The directional earth-fault protection 67/51N and 67/50N is designed for protection and clearance of ground faults and for ground-fault protection of different equipment connected to the power systems, such as shunt capacitor banks or shunt reactors, and for backup ground-fault protection of power transformers.

Many applications require several steps using different current pickup levels and time delays. 67/51N and 67/50N consist of two different stages.

- Low 67/51N and 67/50N-1
- High 67/50N-2

67/51N and 67/50N-1 contain several types of time delay characteristics. 67/50N-2 is used for fast clearance of serious ground faults.

The protection can be based on the phase angle criterion with extended operating sector. It can also be based on measuring either the reactive part $I_0\sin(\varphi)$ or the active part $I_0\cos(\varphi)$ of the zero sequence current. In isolated networks or in networks with high impedance grounding, the phase-to-ground fault current is significantly smaller than the short-circuit currents. In addition, the magnitude of the fault current is almost independent of the fault location in the network.

The function uses the zero sequence current components $I_0\cos(\varphi)$ or $I_0\sin(\varphi)$ according to the grounding method, where φ is the angle between the zero sequence current and the reference zero sequence voltage ($-V_0$). In compensated networks, the phase angle criterion with extended operating sector can also be used. When the relay characteristic angle RCA is 0 degrees, the negative quadrant of the operation sector can be extended with the *Min forward angle* setting. The operation sector can be set between 0 and -180 degrees, so that the total operation sector is from +90 to -180 degrees. In other words, the sector can be up to 270 degrees wide. This allows the protection settings to stay the same when the resonance coil is disconnected from between the neutral point and ground.

System neutral grounding is meant to protect personnel and equipment and to reduce interference for example in telecommunication systems. The neutral grounding sets challenges for protection systems, especially for ground-fault protection.

In isolated networks, there is no intentional connection between the system neutral point and ground. The only connection is through the line-to-ground capacitances (C_0) of phases and leakage resistances (R_0). This means that the zero sequence current is mainly capacitive and has –90 degrees phase shift compared to the zero sequence voltage ($-V_0$). The characteristic angle is -90 degrees.

In resonance-grounded networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. This means that the zero sequence current is mainly resistive and has zero phase shift compared to the zero sequence voltage ($-V_0$) and the characteristic angle is 0 degrees. Often the magnitude of this component is small, and must be increased by means of a parallel resistor in the compensation equipment.

In networks where the neutral point is grounded through low resistance, the characteristic angle is also 0 degrees (for phase angle). Alternatively, Iocos(φ) operation can be used.

In solidly grounded networks, the *Characteristic angle* is typically set to +60 degrees for the phase angle. Alternatively, Iosin(φ) operation can be used with a reversal polarizing quantity. The polarizing quantity can be rotated 180 degrees by setting the *Pol reversal* parameter to "True" or by switching the polarity of the zero sequence voltage measurement wires. Although the $I_0\sin(\varphi)$ operation can be used in solidly grounded networks, the phase angle is recommended. In some applications, negative sequence polarization is preferred over zero sequence polarization. The protection relay also offers negative sequence polarization option where users can set the angle between V_2 and I_2 based on their application and practice.

Connection of measuring transformers in directional ground fault applications

The zero sequence current I_0 can be measured with a core balance current transformer or the residual connection of the phase current signals. If the neutral of the network is either isolated or grounded with high impedance, a core balance current transformer is recommended to be used in ground-fault protection. To ensure sufficient accuracy of zero sequence current measurements and consequently the selectivity of the scheme, the core balance current transformers should have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended.

Attention should be paid to make sure the measuring transformers are connected correctly so that 67/51N and 67/50N is able to detect the fault current direction without failure. As directional ground fault uses zero sequence current and zero sequence voltage ($-V_0$), the polarities of the measuring transformers must match each other and also the fault current direction. Also the grounding of the cable sheath must be taken into consideration when using core balance current transformers. The following figure describes how measuring transformers can be connected to the protection relay.

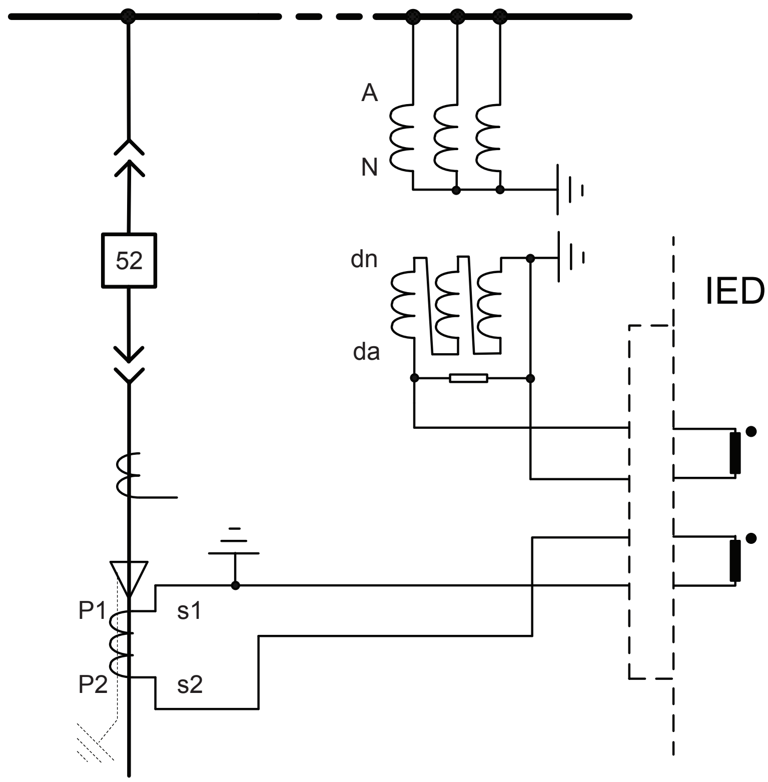


Figure 104: Connection of measuring transformers

4.1.5.10 Signals

Table 163: 67/51N and 67/50N-1 Input signals

Name	Type	Default	Description
I0 or IG or I2	SIGNAL	0	Zero Sequence current / Negative sequence current
V0 or VG or V2	SIGNAL	0	Zero Sequence voltage / Negative sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

Table 164: 67/50N-2 Input signals

Name	Type	Default	Description
I0 or IG or I2	SIGNAL	0	Zero Sequence current / Negative sequence current
V0 or VG or V2	SIGNAL	0	Zero Sequence voltage / Negative sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

Table 165: 67/51N Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

Table 166: 67/50N Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.5.11 Settings

Table 167: 67/51N Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.010...5.000	xIn[1)]	0.005	1	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Operating curve type	1=ANSI Ext Inv 2=ANSI Very Inv 3=ANSI Norm Inv 4=ANSI Mod Inv 5=ANSI DT 6=LT Ext Inv 7=LT Very Inv 8=LT Inv 9=IEC Norm Inv 10=IEC Very Inv 11=IEC Inv 12=IEC Ext Inv 13=IEC ST Inv 14=IEC LT Inv 15=IEC DT 17=Programmable 18=RI Type 19=RD Type			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Trip delay time	60...200000	ms	10	60	Trip delay time
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...180	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	80	Minimum phase angle in reverse direction
Voltage pickup value	0.010...1.000	xVn	0.001	0.010	Voltage pickup value
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

1) The value of In is determined by the *I0 signal Sel* setting. If *I0 signal Sel* = Measured IG, then In is the value set in **Configuration/Analog inputs/Current (Io, CT)/Secondary current**. If *I0 signal Sel* = Calculated I0, then In is the value set in **Configuration/Analog inputs/Current (3I, CT)/Secondary current**, since I0 is calculated by summing the phase currents.

Table 168: 67/51N Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum trip time	60...60000	ms	1	60	Minimum trip time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min trip current	0.005...1.000	xIn[1)]	0.001	0.005	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.01	Minimum trip voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
IG/I0 signal Sel	1=Measured IG 2=Calculated I0			2=Calculated I0	Selection for used Io signal[1)]
Pol signal Sel	1=Measured VG 2=Calculated V0 3=Neg. seq. volt.			2=Calculated V0	Selection for used polarization signal

1) The value of In is determined by the *I0 signal Sel* setting. If *I0 signal Sel* = Measured IG, then In is the value set in **Configuration/Analog inputs/Current (Io, CT)/Secondary current**. If *I0 signal Sel* = Calculated I0, then In is the value set in **Configuration/Analog inputs/Current (3I, CT)/Secondary current**, since I0 is calculated by summing the phase currents.

Table 169: 67/50N Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.10...40.00	xIn[1)]	0.01	0.5	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext Inv 3=ANSI Norm Inv 5=ANSI DT 15=IEC DT 17=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Trip delay time	40...200000	ms	10	60	Trip delay time

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	88	Maximum phase angle in forward direction
Max reverse angle	0...180	deg	1	88	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	88	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	88	Minimum phase angle in reverse direction
Voltage pickup value	0.010...1.000	xVn	0.001	0.010	Voltage pickup value
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

1) The value of In is determined by the *I0 signal Sel* setting. If *I0 signal Sel* = Measured IG, then In is the value set in **Configuration/Analog inputs/Current (Io, CT)/Secondary current**. If *I0 signal Sel* = Calculated I0, then In is the value set in **Configuration/Analog inputs/Current (3I, CT)/Secondary current**, since I0 is calculated by summing the phase currents.

Table 170: 67/50N Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum trip time	40...60000	ms	1	40	Minimum trip time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min trip current	0.005...1.000	xIn[1)]	0.001	0.005	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.01	Minimum trip voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
IG/I0 signal Sel	1=Measured IG 2=Calculated I0			2=Calculated I0	Selection for used Io signal[1)]
Pol signal Sel	1=Measured VG 2=Calculated V0 3=Neg. seq. volt.			2=Calculated V0	Selection for used polarization signal

1) The value of In is determined by the *I0 signal Sel* setting. If *I0 signal Sel* = Measured IG, then In is the value set in **Configuration/Analog inputs/Current (Io, CT)/Secondary current**. If *I0 signal Sel* = Calculated I0, then In is the value set in **Configuration/Analog inputs/Current (3I, CT)/Secondary current**, since I0 is calculated by summing the phase currents.

4.1.5.12 Monitored data

Table 171: 67/51N Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
I_OPER	FLOAT32	0.00...40.00		Calculated operating current
67/51N	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Table 172: 67/50N Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
I_OPER	FLOAT32	0.00...40.00		Calculated operating current
67/50N	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.5.13 Technical data

Table 173: 67/51N and 67/50N Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	67/51N and 67/50N-1	Current: ±1.5% of the set value or ±0.002 × I_n Voltage ±1.5% of the set value or ±0.002 × V_n Phase angle: ±2°		
	67/50N-2	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × V_n Phase angle: ±2°		
Pickup time [1)2)]		Minimum	Typical	Maximum
	67/50N-2 and 67/51N and 67/50N-1: I_{Fault} = 2 × set *Pickup value*	62 ms	65 ms	69 ms

Table continues on next page

Characteristic	Value
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<30 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Trip time accuracy in inverse time mode	±5.0% of the theoretical value or ±20 ms 3)
Suppression of harmonics	RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression

1) *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 60 Hz, ground-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 2.5 × I_n, *Pickup value* multiples in range of 1.5...20

4.1.6 Sensitive earth-fault protection 50SEF

4.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Non-directional sensitive earth-fault protection	EFLPTOC	Io>	50SEF

4.1.6.2 Function block

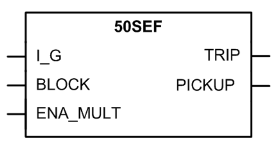


Figure 105: Function block

4.1.6.3 Functionality

A small percentage of the ground faults have very large impedance. It is possible to detect these faults by using a very sensitive earth-fault protection. It is applicable for networks where normal unbalance current level is low enough to allow for sensitive setting of 50SEF.

The function also contains a blocking functionality. It is possible to block function outputs.

4.1.6.4 Operation principle

See function 51N.

4.1.6.5 Measurement modes

See function 51N.

4.1.6.6 Timer characteristics

See function 51N.

4.1.6.7 Application

Electric power lines experience faults for many reasons. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service.

Most of these faults are ground faults. A small percentage of the ground faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high impedance faults do not pose imminent danger to power system equipment. However, they are a considerable threat to people and property. If the natural unbalance in the system is low, the sensitive earth-fault protection can be used to detect the ground fault.

4.1.6.8 Signals

See function 51N.

4.1.6.9 Settings

See function 51N.

4.1.6.10 Monitored data

See function 51N.

4.1.6.11 Technical data

See function 50N.

4.1.7 Negative-sequence overcurrent protection 46

4.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection	NSPTOC	I2>	46

4.1.7.2 Function block

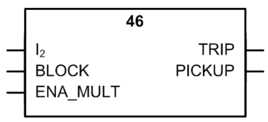


Figure 106: Function block

4.1.7.3 Functionality

The negative sequence overcurrent protection 46 is used for increasing sensitivity to detect single phasing situations, unbalanced loads due to, for example, unsymmetrical feeder voltages.

46 can also be used for detecting broken conductors.

The function is based on the measurement of the negative sequence current. In a fault situation, the function picks up when the negative sequence current exceeds the set limit. The trip time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function trips after a predefined trip time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.1.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the negative-sequence overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

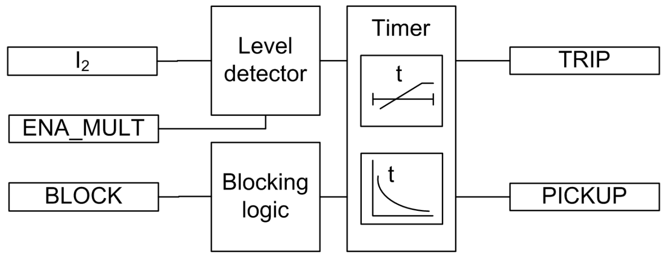


Figure 107: Functional module diagram. I_2 represents negative phase sequence current.

Level detector

The measured negative sequence current is compared to the set *Pickup value*. If the measured value exceeds the set *Pickup value*, the level detector activates the timer module. If the `ENA_MULT` input is active, the set *Pickup value* is multiplied by the set *Pickup value Mult*.

Do not set the multiplier setting *Pickup value Mult* higher than necessary. If the value is too high, the function may not trip at all during an inrush followed by a fault, no matter how severe the fault is.

Timer

Once activated, the timer activates the `PICKUP` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the `TRIP` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the trip delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type

"Inverse reset", the reset time depends on the current during the drop-off situation. If the drop-off situation continues, the reset timer is reset and the PICKUP output is deactivated.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT trip and reset times.

The setting parameter *Minimum trip time* defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.1.7.5 Application

Since the negative sequence current quantities are not present during normal, balanced load conditions, the negative sequence overcurrent protection elements can be set for faster and more sensitive operation than the normal phase-overcurrent protection for fault conditions occurring between two phases. The negative sequence overcurrent protection also provides a back-up protection functionality for the feeder ground-fault protection in solid and low resistance grounded networks.

The negative sequence overcurrent protection provides the back-up ground-fault protection on the high voltage side of a delta-wye connected power transformer for ground faults taking place on the wye-connected low voltage side. If a ground fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

Probably the most common application for the negative sequence overcurrent protection is rotating machines, where negative sequence current quantities indicate unbalanced loading conditions (unsymmetrical voltages). Unbalanced loading normally causes extensive heating of the machine and can result in severe damage even over a relatively short time period.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

4.1.7.6 Signals

Table 174: 46 Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative phase sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 175: 46 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.7.7 Settings

Table 176: 46 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.01...5.00	xIn	0.01	0.30	Pickup value
Pickup value mult	0.8...10.0		0.1	1.0	Multiplier for scaling the pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Trip delay time	40...200000	ms	10	1000	Trip delay time
Operating curve type	1=ANSI Ext Inv 2=ANSI Very Inv 3=ANSI Norm Inv 4=ANSI Mod Inv 5=ANSI DT 6=LT Ext Inv 7=LT Very Inv 8=LT Inv 9=IEC Norm Inv 10=IEC Very Inv 11=IEC Inv 12=IEC Ext Inv 13=IEC ST Inv 14=IEC LT Inv 15=IEC DT 17=Programmable 18=RI Type 19=RD Type			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 177: 46 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Minimum trip time	20...60000	ms	1	20	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

4.1.7.8 Monitored data

Table 178: 46 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
46	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.7.9 Technical data

Table 179: 46 Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Pickup time 1)2)		Minimum	Typical	Maximum
	I_{Fault} = 2 × set *Pickup value* I_{Fault} = 10 × set *Pickup value*	22 ms 14 ms	25 ms 17 ms	27 ms 19 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Trip time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms 3)		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) Negative sequence current before fault = 0.0, f_n = 60 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 2.5 × I_n, *Pickup value* multiples in range of 1.5...20

4.1.8 Phase discontinuity protection 46PD

4.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD

4.1.8.2 Function block

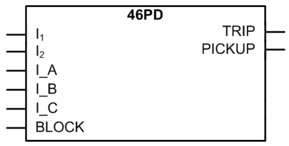


Figure 108: Function block

4.1.8.3 Functionality

The phase discontinuity protection 46PD is used for detecting unbalance situations caused by broken conductors.

The function picks up and trips when the unbalance current I_2/I_1 exceeds the set limit. To prevent faulty operation at least one phase current needs to be above the minimum level. 46PD trips with DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself, if desired.

4.1.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of phase discontinuity protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

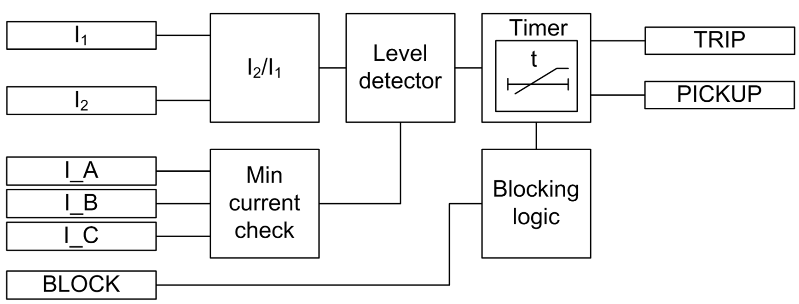


Figure 109: Functional module diagram. I_1 and I_2 represent positive and negative phase sequence currents. I_A, I_B and I_C represent phase currents.

I_2/I_1

The I_2/I_1 module calculates the ratio of the negative and positive sequence current. It reports the calculated value to the level detector.

Level detector

The level detector compares the calculated ratio of negative and positive phase sequence currents to the set *Pickup value*. If the calculated value exceeds the set *Pickup value* and the min current check module has exceeded the minimum phase current limit, the level detector reports the exceeding of the value to the timer.

Min current check

The min current check module checks whether the measured phase currents are above the set *Min phase current*. At least one of the phase currents needs to be above the set limit to enable the level detector module.

Timer

Once activated, the timer activates the `PICKUP` output. The time characteristic is according to DT. When the trip timer has reached the value set by *Trip delay time*, the `TRIP` output is activated. If the fault disappears before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the `PICKUP` output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the `TRIP` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the `TRIP` output is not activated.

4.1.8.5 Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause an increase of zero-sequence voltage and short overvoltage peaks and also oscillation in the corresponding phase.

46PD is a three-phase protection with DT characteristic, designed for detecting broken conductors in distribution and subtransmission networks. The function is applicable for both overhead lines and underground cables.

The operation of 46PD is based on the ratio of positive-sequence and negative-sequence currents. This gives better sensitivity and stability compared to plain negative-sequence current protection since the calculated ratio of positive-sequence and negative-sequence currents is relatively constant during load variations.

The unbalance of the network is detected by monitoring the negative-sequence and positive-sequence current ratio, where the negative-sequence current value is I_2 and I_1 is the positive-sequence current value. The unbalance is calculated with the equation.

$$Iratio = \frac{I_2}{I_1}$$

(Equation 4)

Broken conductor fault situation can occur in phase A in a feeder.

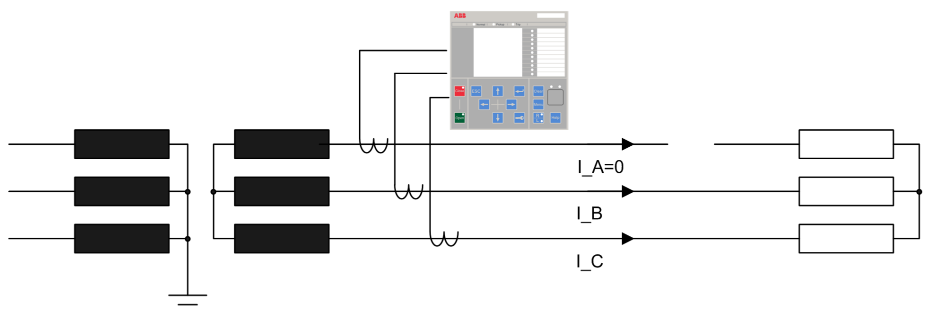


Figure 110: Broken conductor fault in phase A in a distribution or subtransmission feeder

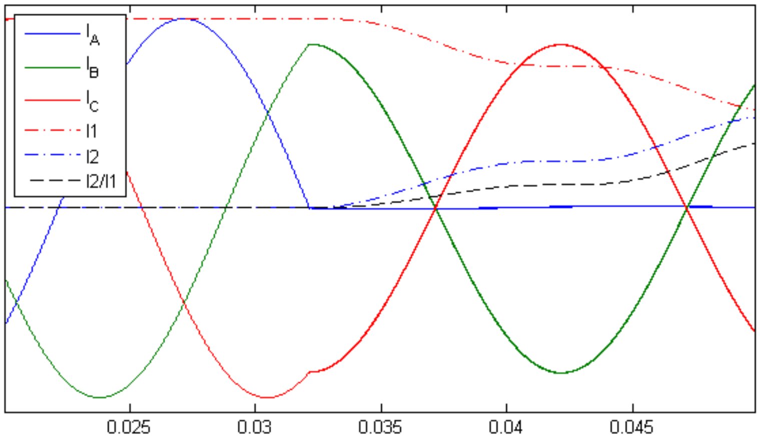


Figure 111: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative-sequence and positive-sequence currents

4.1.8.6 Signals

Table 180: 46PD Input signals

Name	Type	Default	Description
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 181: 46PD Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.8.7 Settings

Table 182: 46PD Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	10...100	%	1	10	Pickup value
Trip delay time	100...30000	ms	1	1000	Trip delay time

Table 183: 46PD Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Min phase current	0.05...0.30	xIn	0.01	0.3	Minimum phase current

4.1.8.8 Monitored data

Table 184: 46PD Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
RATIO_I2_I1	FLOAT32	0.00...999.99	%	Measured current ratio I2 / I1
46PD	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.8.9 Technical data

Table 185: 46PD Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±2% of the set value
Pickup time	<70 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.1.9 Negative-sequence overcurrent protection for motors 46M

4.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection for motors	MNSPTOC	I2>M	46M

4.1.9.2 Function block

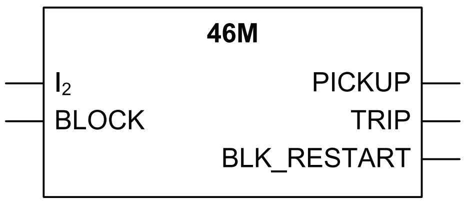


Figure 112: Function block

4.1.9.3 Functionality

The unbalance protection based on negative-sequence overcurrent protection for motors 46M protects electric motors from phase unbalance. A small voltage unbalance can produce a large negative-sequence current flow in the motor. For example, a 5 percent voltage unbalance produces a stator negative-sequence current of 30 percent of the full load current, which can severely heat the motor. 46M detects the large negative sequence current and disconnects the motor.

The function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself, if desired.

4.1.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of unbalance protection based on negative-sequence current can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

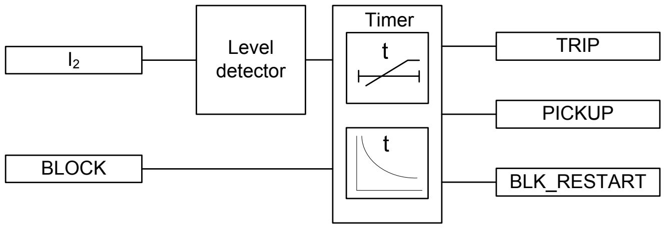


Figure 113: Functional module diagram

Level detector

The calculated negative-sequence current is compared to the *Pickup value* setting. If the measured value exceeds the *Pickup value* setting, the function activates the timer module.

Timer

Once activated, the timer activates the PICKUP output. Depending on the value of the set *Operating curve type*, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Trip delay time* in the DT mode or the maximum value defined by the inverse time curve, the TRIP output is activated.

In a drop-off situation, that is, when the value of the negative-sequence current drops below the *Pickup value* setting, the reset timer is activated and the PICKUP output resets after the time delay of *Reset delay time* for the DT characteristics. For IDMT, the reset time depends on the curve type selected.

For the IDMT curves, it is possible to define minimum and maximum trip times with the *Minimum trip time* and *Maximum trip time* settings. The *Machine time Mult* setting parameter corresponds to the machine constant, equal to the I_2^2t constant of the machine, as stated by the machine manufacturer. In case there is a mismatch between the used CT and the protected motor's nominal current values, it is possible to fit the IDMT curves for the protected motor using the *Rated current* setting.

The activation of the TRIP output activates the BLK_RESTART output. The deactivation of the TRIP output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The BLK_RESTART output is kept active until the cooling timer is exceeded. If the negative-sequence current increases above the set value during this period, the TRIP output is activated immediately.

The T_ENARESTART output indicates the duration for which the BLK_RESTART output remains active, that is, it indicates the remaining time of the cooling timer. The value is available in the monitored data view.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

4.1.9.5 Timer characteristics

46M supports both DT and IDMT characteristics. The DT timer characteristics can be selected with "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Trip delay time* and *Reset delay time* settings.

The protection relay provides two user-programmable IDMT characteristics curves, "Inv. curve A" and "Inv. curve B".

Current-based inverse definite minimum time curve (IDMT)

In inverse-time modes, the trip time depends on the momentary value of the current: the higher the current, the faster the trip time. The trip time calculation or integration starts immediately when the current exceeds the set *Pickup value* and the PICKUP output is activated.

The TRIP output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum trip time* and *Maximum trip time* settings define the minimum trip time and maximum trip time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

Inv. curve A

The inverse time equation for curve type A is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2}$$

(Equation 5)

t[s] Trip time in seconds

k Set *Machine time Mult*

I_2 Negative-sequence current

I_r Set *Rated current*

If the negative sequence current drops below the *Pickup value* setting, the reset time is defined as:

$$t[s] = a \times \left(\frac{b}{100} \right)$$

(Equation 6)

t[s]	Reset time in seconds
a	set *Cooling time*
b	percentage of pickup time elapse (PICKUP_DUR)

When the reset period is initiated, the time for which PICKUP has been active is saved. If the fault reoccurs, that is, the negative-sequence current rises above the set value during the reset period, the trip calculations are continued using the saved values. If the reset period elapses without a fault being detected, the trip timer is reset and the saved values of pickup time and integration are cleared.

Inv. curve B

The inverse time equation for curve type B is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r} \right)^2 - \left(\frac{I_S}{I_r} \right)^2}$$

(Equation 7)

t[s]	Trip time in seconds
k	*Machine time Mult*
I_2	Negative-sequence current
I_S	Set *Pickup value*
I_r	Set *Rated current*

If the fault disappears, the negative-sequence current drops below the *Pickup value* setting and the PICKUP output is deactivated. The function does not reset instantaneously. Resetting depends on the equation or the *Cooling time* setting.

The timer is reset in two ways:

- When the negative sequence current drops below pickup value, the subtraction in the denominator becomes negative and the cumulative sum starts to decrease. The decrease in the sum indicates the cooling of the machine and the cooling speed depends on the value of the negative-sequence current. If the sum reaches zero without a fault being detected, the accumulation stops and the timer is reset.

- If the reset time set through the *Cooling time* setting elapses without a fault being detected, the timer is reset.

The reset period thus continues for a time equal to the *Cooling time* setting or until the operate time decreases to zero, whichever is less.

4.1.9.6 Application

In a three-phase motor, the conditions that can lead to unbalance are single phasing, voltage unbalance from the supply and single-phase fault. The negative sequence current damages the motor during the unbalanced voltage condition, and therefore the negative sequence current is monitored to check the unbalance condition.

When the voltages supplied to an operating motor become unbalanced, the positive-sequence current remains substantially unchanged, but the negative-sequence current flows due to the unbalance. For example, if the unbalance is caused by an open circuit in any phase, a negative-sequence current flows and it is equal and opposite to the previous load current in a healthy phase. The combination of positive and negative-sequence currents produces phase currents approximately 1.7 times the previous load in each healthy phase and zero current in the open phase.

The negative-sequence currents flow through the stator windings inducing negative-sequence voltage in the rotor windings. This can result in a high rotor current that damages the rotor winding. The frequency of the induced current is approximately twice the supply frequency. Due to skin effect, the induced current with a frequency double the supply frequency encounters high rotor resistance which leads to excessive heating even with phase currents with value less than the rated current of the motor.

The negative-sequence impedance of induction or a synchronous motor is approximately equal to the locked rotor impedance, which is approximately one-sixth of the normal motor impedance, considering that the motor has a locked-rotor current of six times the rated current. Therefore, even a three percent voltage unbalance can lead to 18 percent stator negative sequence current in windings. The severity of this is indicated by a 30-40 percent increase in the motor temperature due to the extra current.

4.1.9.7 Signals

Table 186: 46M Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 187: 46M Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
BLK_RESTART	BOOLEAN	Overheated machine reconnection blocking

4.1.9.8 Settings

Table 188: 46M Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.01...0.50	xIn	0.01	0.20	Pickup value
Operating curve type	5=ANSI DT 15=IEC DT 17=Inv. Curve A 18=Inv. Curve B			5=ANSI DT	Selection of time delay curve type
Machine time Mult	5.0...100.0		0.1	5.0	Machine related time constant
Trip delay time	100...120000	ms	10	1000	Trip delay time

Table 189: 46M Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Rated current	0.30...2.00	xIn	0.01	1.00	Rated current (Ir) of the machine (used only in the IDMT)
Maximum trip time	500000...7200000	ms	1000	1000000	Max trip time regardless of the inverse characteristic
Minimum trip time	100...120000	ms	1	100	Minimum trip time for IDMT curves
Cooling time	5...7200	s	1	50	Time required to cool the machine
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.9.9 Monitored data

Table 190: 46M Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
T_ENARESTART	FLOAT32	0.00...7200.00	s	Estimated time to reset of block restart
46M	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.9.10 Technical data

Table 191: 46M Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Pickup time1)2)		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Pickup value*	22 ms	25 ms	27 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Trip time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms3)		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) Negative-sequence current before = 0.0, f_n = 60 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) *Pickup value* multiples in range of 1.10...5.00

4.1.10 Phase reversal protection 46R

4.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase reversal protection	PREVPTOC	I2>>	46R

4.1.10.2 Function block

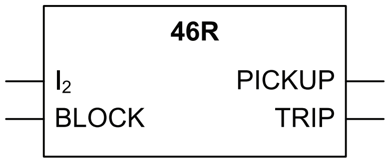


Figure 114: Function block

4.1.10.3 Functionality

The phase reversal protection 46R is used to detect the reversed connection of the phases to a three-phase motor by monitoring the negative phase sequence current I_2 of the motor.

46R picks up and trips when I_2 exceeds the set limit. 46R operates on definite time (DT) characteristics. 46R is based on the calculated I_2, and the function detects too high I_2 values during the motor startup. The excessive I_2 values are caused by incorrectly connected phases, which in turn makes the motor rotate in the opposite direction.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.1.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of phase reversal protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

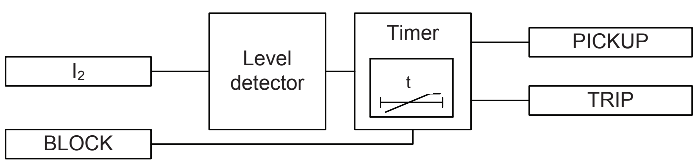


Figure 115: Functional module diagram

Level detector

The level detector compares the negative-sequence current to the set *Pickup value*. If the I_2 value exceeds the set *Pickup value*, the level detector sends an enabling signal to the timer module.

Timer

Once activated, the timer activates the PICKUP output. When the operation timer has reached the set *Trip delay time* value, the TRIP output is activated. If the fault disappears before the module trips, the reset timer is activated. If the reset timer reaches the value of 200 ms, the operation timer resets and the PICKUP output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

4.1.10.5 Application

The rotation of a motor in the reverse direction is not a desirable operating condition. When the motor drives fans and pumps, for example, and the rotation direction is reversed due to a wrong phase sequence, the driven process can be disturbed and the flow of the cooling air of the motor can become reversed too. With a motor designed only for a particular rotation direction, the reversed rotation direction can lead to an inefficient cooling of the motor due to the fan design.

In a motor, the value of the negative-sequence component of the phase currents is very negligible when compared to the positive-sequence component of the current during a healthy operating condition of the motor. But when the motor is started with the phase connections in the reverse order, the magnitude of I_2 is very high. So whenever the value of I_2 exceeds the pickup value, the function detects the reverse rotation direction and provides an operating signal that disconnects the motor from the supply.

4.1.10.6 Signals

Table 192: 46R Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 193: 46R Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.10.7 Settings

Table 194: 46R Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...1.00	xIn	0.01	0.75	Pickup value
Trip delay time	100...60000	ms	10	100	Trip delay time

Table 195: 46R Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable

4.1.10.8 Monitored data

Table 196: 46R Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
46R	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.10.9 Technical data

Table 197: 46R Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Pickup value*	22 ms	25 ms	28 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) Negative-sequence current before = 0.0, f_n = 60 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.1.11 Loss of load supervision 37M

4.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Loss of load supervision	LOFLPTUC	3I<	37M

4.1.11.2 Function block

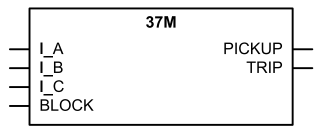


Figure 116: Function block

4.1.11.3 Functionality

The loss of load supervision 37M is used to detect a sudden load loss which is considered as a fault condition.

37M picks up when the current is less than the set limit. It operates with the definite time (DT) characteristics, which means that the function operates after a predefined trip time and resets when the fault current disappears.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.1.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the loss of load supervision can be described using a module diagram. All the modules in the diagram are explained in the next sections.

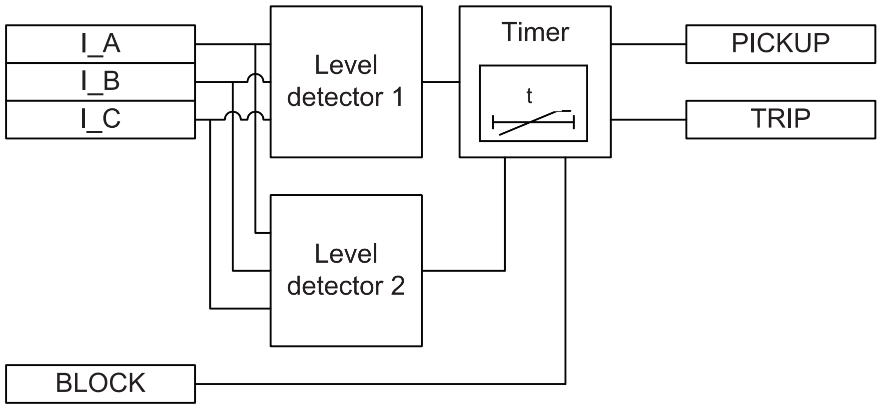


Figure 117: Functional module diagram

Level detector 1

This module compares the phase currents (RMS value) to the set *Pickup value high* setting. If all the phase current values are less than the set *Pickup value high* value, the loss of load condition is detected and an enable signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Pickup value high* value of the element.

Level detector 2

This is a low-current detection module, which monitors the de-energized condition of the motor. It compares the phase currents (RMS value) to the set *Pickup value low* setting. If any of the phase current values is less than the set *Pickup value low*, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the `PICKUP` output. The time characteristic is according to DT. When the trip timer has reached the value set by *Trip delay time*, the `TRIP` output is activated. If the fault disappears before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the `PICKUP` output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

The `BLOCK` signal blocks the operation of the function and resets the timer.

4.1.11.5 Application

When a motor runs with a load connected, it draws a current equal to a value between the no-load value and the rated current of the motor. The minimum load current can be determined by studying the characteristics of the connected load. When the current drawn by the motor is less than the minimum load current drawn, it can be inferred that the motor is either disconnected from the load or the coupling mechanism is faulty. If the motor is allowed to run in this condition, it may aggravate the fault in the coupling mechanism or harm the personnel handling the machine. Therefore, the motor has to be disconnected from the power supply as soon as the above condition is detected.

37M detects the condition by monitoring the current values and helps disconnect the motor from the power supply instantaneously or after a delay according to the requirement.

When the motor is at standstill, the current will be zero and it is not recommended to activate the trip during this time. The minimum current drawn by the motor when it is connected to the power supply is the no load current, that is, the higher pickup value current. If the current drawn is below the lower pickup value current, the motor is disconnected from the power supply. 37M detects this condition and interprets that the motor is de-energized and disables the function to prevent unnecessary trip events.

4.1.11.6 Signals

Table 198: 37M Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block all binary outputs by resetting timers

Table 199: 37M Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.1.11.7 Settings

Table 200: 37M Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value low	0.01...0.50	xIn	0.01	0.10	Current setting/Pickup value low
Pickup value high	0.01...1.00	xIn	0.01	0.50	Current setting/Pickup value high
Trip delay time	400...600000	ms	10	2000	Trip delay time

Table 201: 37M Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.11.8 Monitored data

Table 202: 37M Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
37M	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.11.9 Technical data

Table 203: 37M Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Pickup time	Typically 300 ms
Reset time	<40 ms
Reset ratio	Typically 1.04
Retardation time	<35 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms

4.1.12 Motor load jam protection 51LR

4.1.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor load jam protection	JAMPTOC	Ist>	51LR

4.1.12.2 Function block

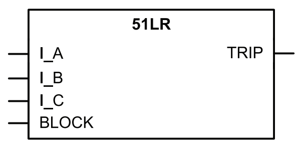


Figure 118: Function block

4.1.12.3 Functionality

The Motor load jam protection 51LR is used for protecting the motor in stall or mechanical jam situations during the running state.

When the motor is started, a separate function is used for the startup protection, and 51LR is normally blocked during the startup period. When the motor has passed the starting phase, 51LR monitors the magnitude of phase currents. The function starts when the measured current exceeds the breakdown torque level, that is, above the set limit. The operation characteristic is definite time.

The function contains a blocking functionality. It is possible to block the function outputs.

The 51LR does not provide a valid trip time in the fault records by default. If this functionality is desired, the PICKUP status must be added to the 61850 data set which also causes all 51LR pickup events to be reported. See the 61850 engineering manual for more information on how to add items to the 61850 data set.

4.1.12.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the motor load jam protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

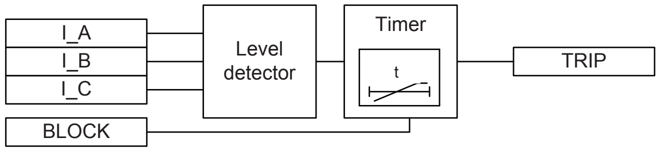


Figure 119: Functional module diagram

Level detector

The measured phase currents are compared to the set *Pickup value*. The TRMS values of the phase currents are considered for the level detection. The timer module is enabled if at least two of the measured phase currents exceed the set *Pickup value*.

Timer

Once activated, the internal `PICKUP` signal is activated. The value is available only through the Monitored data view. The time characteristic is according to DT. When the operation timer has reached the *Trip delay time* value, the `TRIP` output is activated.

When the timer has elapsed but the motor stall condition still exists, the `TRIP` output remains active until the phase currents values drop below the *Pickup value*, that is, until the stall condition persists. If the drop-off situation occurs while the trip time is still counting, the reset timer is activated. If the drop-off time exceeds the set *Reset delay time*, the trip timer is reset.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the `TRIP` output is not activated.

4.1.12.5 Application

The motor protection during stall is primarily needed to protect the motor from excessive temperature rise, as the motor draws large currents during the stall phase. This condition causes a temperature rise in the stator windings. Due to reduced speed, the temperature also rises in the rotor. The rotor temperature rise is more critical when the motor stops.

The physical and dielectric insulations of the system deteriorate with age and the deterioration is accelerated by the temperature increase. Insulation life is related to the time interval during which the insulation is maintained at a given temperature.

An induction motor stalls when the load torque value exceeds the breakdown torque value, causing the speed to decrease to zero or to some stable operating point well below the rated speed. This occurs, for example, when the applied shaft load is suddenly increased and is greater than the producing motor torque due to the bearing failures. This condition develops a motor current almost equal to the value of the locked-rotor current.

51LR is designed to protect the motor in stall or mechanical jam situations during the running state. To provide a good and reliable protection for motors in a stall situation, the temperature effects on the motor have to be kept within the allowed limits.

4.1.12.6 Signals

Table 204: 51LR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 205: 51LR Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip

4.1.12.7 Settings

Table 206: 51LR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Pickup value	0.10...10.00	xIn	0.01	2.50	Pickup value
Trip delay time	100...120000	ms	10	2000	Trip delay time
Reset delay time	0...60000	ms	1	100	Reset delay time

4.1.12.8 Monitored data

Table 207: 51LR Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP	BOOLEAN	0=False 1=True		Pickup
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
51LR	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.12.9 Technical data

Table 208: 51LR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms

4.1.13 Loss of phase 37

4.1.13.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase undercurrent protection	PHPTUC1	3I<	37

4.1.13.2 Function block

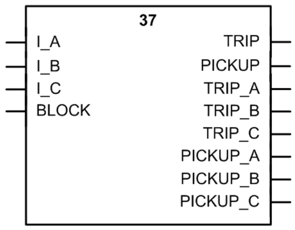


Figure 120: Function block

4.1.13.3 Functionality

The phase undercurrent protection 37 is used to detect an undercurrent that is considered as a fault condition.

37 picks up when the current is less than the set limit. Operation time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs and reset the definite timer if desired.

4.1.13.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the phase undercurrent protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

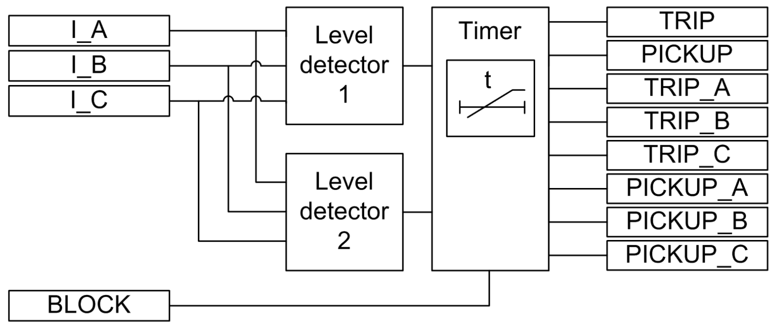


Figure 121: Functional module diagram

Level detector 1

This module compares the phase currents (RMS value) to the *Pickup value* setting. The *Operation mode* setting can be used to select the "Three Phase" or "Single Phase" mode.

If in the "Three Phase" mode all the phase current values are less than the value of the *Pickup value* setting, the condition is detected and an enabling signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Pickup value* value of the element.

If in the "Single Phase" mode any of the phase current values are less than the value of the *Pickup value* setting, the condition is detected and an enabling signal is sent to the timer. This signal is disabled after all the phase currents have exceeded the set *Pickup value* value of the element.

The protection relay does not accept the *Pickup value* to be smaller than *Current block value*.

Level detector 2

This is a low-current detection module that monitors the de-energized condition of the protected object. The module compares the phase currents (RMS value) to the *Current block value* setting. If all the phase current values are less than the *Current block value* setting, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the `PICKUP` output and the phase-specific `PICKUP_X` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Trip delay time*, the `TRIP` output and the phase-specific `TRIP_X` output are activated. If the fault disappears before the module trips, the reset timer is activated.

If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the PICKUP output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available through the monitored data view.

The BLOCK signal blocks the operation of the function and resets the timer.

4.1.13.5 Application

In some cases, smaller distribution power transformers are used where the high-side protection involves only power fuses. When one of the high-side fuses blows in a single-phase condition, knowledge of it on the secondary side is lacking. The resulting negative-sequence current leads to a premature failure due to excessive heating and breakdown of the transformer insulation. Knowledge of this condition when it occurs allows for a quick fuse replacement and saves the asset.

The *Current block value* setting can be set to zero to not block 37 with a low three-phase current. However, this results in an unnecessary event sending when the transformer or protected object is disconnected.

Phase-specific pickup and trip can give a better picture about the evolving faults when one phase has picked up first and another follows.

37 is meant to be a general protection function, so that it could be used in other cases too.

In case of undercurrent-based motor protection, see the Loss of load protection.

4.1.13.6 Signals

Table 209: 37 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block all binary outputs by resetting timers

Table 210: 37 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
TRIP_A	BOOLEAN	Trip phase A
TRIP_B	BOOLEAN	Trip phase B
TRIP_C	BOOLEAN	Trip phase C
PICKUP	BOOLEAN	Pickup
PICKUP_A	BOOLEAN	Pickup phase A
PICKUP_B	BOOLEAN	Pickup phase B
PICKUP_C	BOOLEAN	Pickup phase C

4.1.13.7 Settings

Table 211: 37 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Current block value	0.00...0.50	xIn	0.01	0.10	Low current setting to block internally
Pickup value	0.01...1.00	xIn	0.01	0.50	Current setting to pickup
Trip delay time	50...200000	ms	10	2000	Trip delay time

Table 212: 37 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Operation mode	1=Three Phase 2=Single Phase			1=Three Phase	Number of phases needed to pickup
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.13.8 Monitored data

Table 213: 37 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
37	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.1.13.9 Technical data

Table 214: 37 Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the current measured: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Pickup time	Typically <55 ms
Reset time	<40 ms
Reset ratio	Typically 1.04
Retardation time	<35 ms
Operate time accuracy in definite time mode	mode ±1.0% of the set value or ±20 ms

4.2 Voltage protection

4.2.1 Three-phase overvoltage protection 59

4.2.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overvoltage protection	PHPTOV	3U>	59

4.2.1.2 Function block

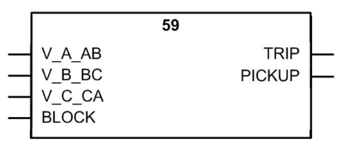


Figure 122: Function block

4.2.1.3 Functionality

The three-phase overvoltage protection 59 is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

59 includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.2.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the three-phase overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

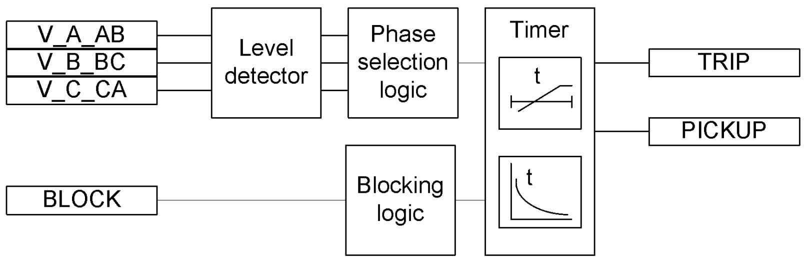


Figure 123: Functional module diagram

Level detector

The fundamental frequency component of the measured three-phase voltages are compared phase-wise to the set value of the *Pickup value* setting. If the measured value is higher than the set value of the *Pickup value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly differs from the *Pickup value* setting. After leaving the hysteresis area, the pickup condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The *Voltage selection* setting is used for selecting phase-to-ground or phase-to-phase voltages for protection.

For the voltage IDMT operation mode, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see the IDMT curve saturation of the over voltage protection section in this manual.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of pickup phases*, the phase selection logic activates the Timer.

Timer

Once activated, the Timer activates the PICKUP output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see the IDMT curves for overvoltage protection section in this manual.

When the operation timer has reached the value set by *Trip delay time* in the DT mode or the maximum value defined by the IDMT, the TRIP output is activated.

When the user-programmable IDMT curve is selected, the trip time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the trip delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected trip time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the PICKUP output is deactivated.

When the IDMT trip time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve* and *Reset delay time* settings.

Table 215: The reset time functionality when the IDMT trip time curve is selected

Type of reset curve	Description of operation
“Immediate”	The trip timer is reset instantaneously when drop-off occurs.
“Def time reset”	The trip timer is frozen during drop-off. The trip timer is reset after the set *Reset delay time* is exceeded.
“DT Lin decr rst”	The trip timer value linearly decreases during the drop-off situation. The trip timer is reset after the set *Reset delay time* is exceeded.

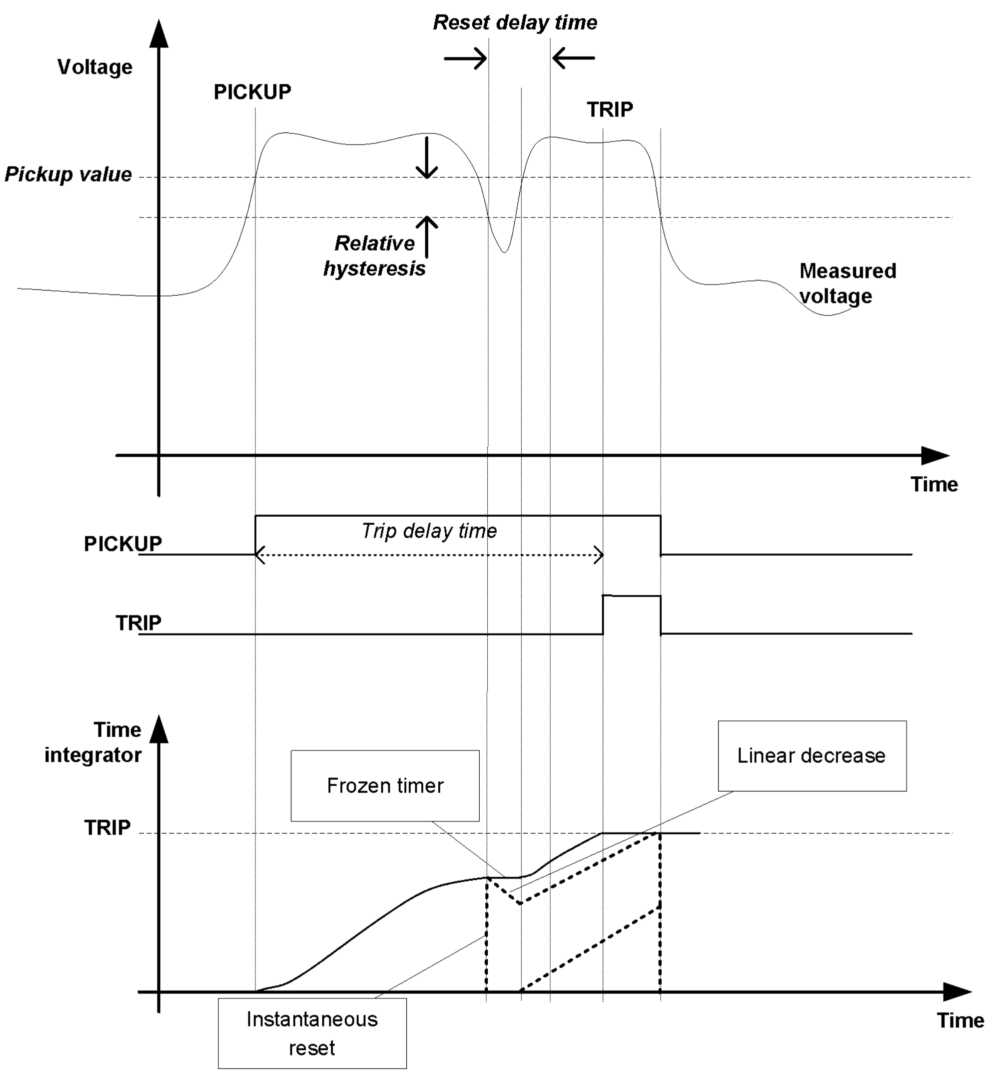


Figure 124: Behavior of different IDMT reset modes. The value for Type of reset curve is “Def time reset”. Also other reset modes are presented for the time integrator.

The *Time multiplier* setting is used for scaling the IDMT trip times.

The *Minimum trip time* setting parameter defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overvoltage protection section in this manual.

The Timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the TRIPn is blocked and the Timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

The “Freeze timers” mode of blocking has no effect during the inverse reset mode.

4.2.1.5 Timer characteristics

The operating curve types supported by 59 are:

Table 216: Timer characteristics supported by IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(17) Inv. Curve A
Table continues on next page

Operating curve type
(18) Inv. Curve B
(19) Inv. Curve C
(20) Programmable

4.2.1.6 Application

Overvoltage in a network occurs either due to the transient surges on the network or due to prolonged power frequency overvoltages. Surge arresters are used to protect the network against the transient overvoltages, but the relay's protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- The defective operation of the automatic voltage regulator when the generator is in isolated operation.
- Operation under manual control with the voltage regulator out of service. A sudden variation of load, in particular the reactive power component, gives rise to a substantial change in voltage because of the inherent large voltage regulation of a typical alternator.
- Sudden loss of load due to the tripping of outgoing feeders, leaving the generator isolated or feeding a very small load. This causes a sudden rise in the terminal voltage due to the trapped field flux and overspeed.

If a load sensitive to overvoltage remains connected, it leads to equipment damage.

It is essential to provide power frequency overvoltage protection, in the form of time delayed element, either IDMT or DT to prevent equipment damage.

4.2.1.7 Signals

Table 217: 59 Input signals

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase to ground voltage A or phase to phase voltage AB
V_B_BC	SIGNAL	0	Phase to ground voltage B or phase to phase voltage BC
V_C_CA	SIGNAL	0	Phase to ground voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 218: 59 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.1.8 Settings

Table 219: 59 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...1.60	xVn	0.01	1.10	Pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	40...300000	ms	10	40	Trip delay time
Operating curve type	5=ANSI DT 15=IEC DT 17=Inv. Curve A 18=Inv. Curve B 19=Inv. Curve C 20=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset -1=DT Lin decr rst			1=Immediate	Selection of reset curve type

Table 220: 59 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	40...60000	ms	1	40	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve parameter A	0.005...200.000			1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00			1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0			0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000			0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000			1.000	Parameter E for customer programmable curve

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve Sat Relative	0.0...3.0		0.1	2.0	Tuning parameter to avoid curve discontinuities
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.2.1.9 Monitored data

Table 221: 59 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
59	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.1.10 Technical data

Table 222: 59 Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × V_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	V_{Fault} = 1.1 × set *Pickup value*	23 ms	27 ms	30 ms
Reset time		<40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms[3)]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) *Pickup value* = 1.0 × V_n, Voltage before fault = 0.9 × V_n, f_n = 60 Hz, overvoltage in one phase-to-phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Maximum *Pickup value* = 1.20 × V_n, *Pickup value* multiples in range of 1.10...2.00

4.2.2 Three-phase undervoltage protection 27

4.2.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase undervoltage protection	PHPTUV	3U<	27

4.2.2.2 Function block

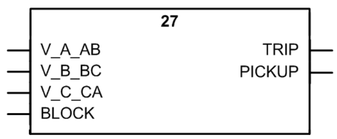


Figure 125: Function block

4.2.2.3 Functionality

The three-phase undervoltage protection 27 is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. 27 includes a settable value for the detection of undervoltage either in a single phase, two phases or three phases.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.2.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the three-phase undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

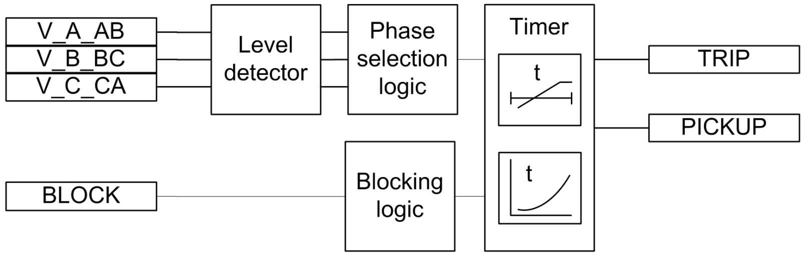


Figure 126: Functional module diagram

Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set *Pickup value*. If the measured value is lower than the set value of the *Pickup value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above or below the *Pickup value* setting. After leaving the hysteresis area, the pickup condition has to be fulfilled again and it is not sufficient for the signal to only return back to the hysteresis area.

The *Voltage selection* setting is used for selecting the phase-to-ground or phase-to-phase voltages for protection.

For the voltage IDMT mode of operation, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing unwanted operation.

For more detailed description on IDMT curves and usage of *Curve Sat Relative* setting, see the IDMT curves for under voltage protection section in this manual.

The level detector contains a low-level blocking functionality for cases where one of the measured voltages is below the desired level. This feature is useful when unnecessary pickups and trips are wanted to avoid during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to "True") and the blocking level can be set with the *Voltage block value* setting.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of pickup phases*, the phase selection logic activates the Timer.

Timer

Once activated, the Timer activates the PICKUP output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see the IDMT curves for under voltage protection section in this manual.

When the operation timer has reached the value set by *Trip delay time* in the DT mode or the maximum value defined by the IDMT, the TRIP output is activated.

When the user-programmable IDMT curve is selected, the trip time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the trip delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected trip time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the PICKUP output is deactivated.

When the IDMT trip time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve* and *Reset delay time* settings.

Table 223: The reset time functionality when the IDMT trip time curve is selected

Type of reset curve	Description of operation
“Immediate”	The trip timer is reset instantaneously when drop-off occurs
“Def time reset”	The trip timer is frozen during drop-off. The trip timer is reset after the set *Reset delay time* is exceeded
“DT Lin decr rst”	The trip timer value linearly decreases during the drop-off situation. The trip timer is reset after the set *Reset delay time* is exceeded

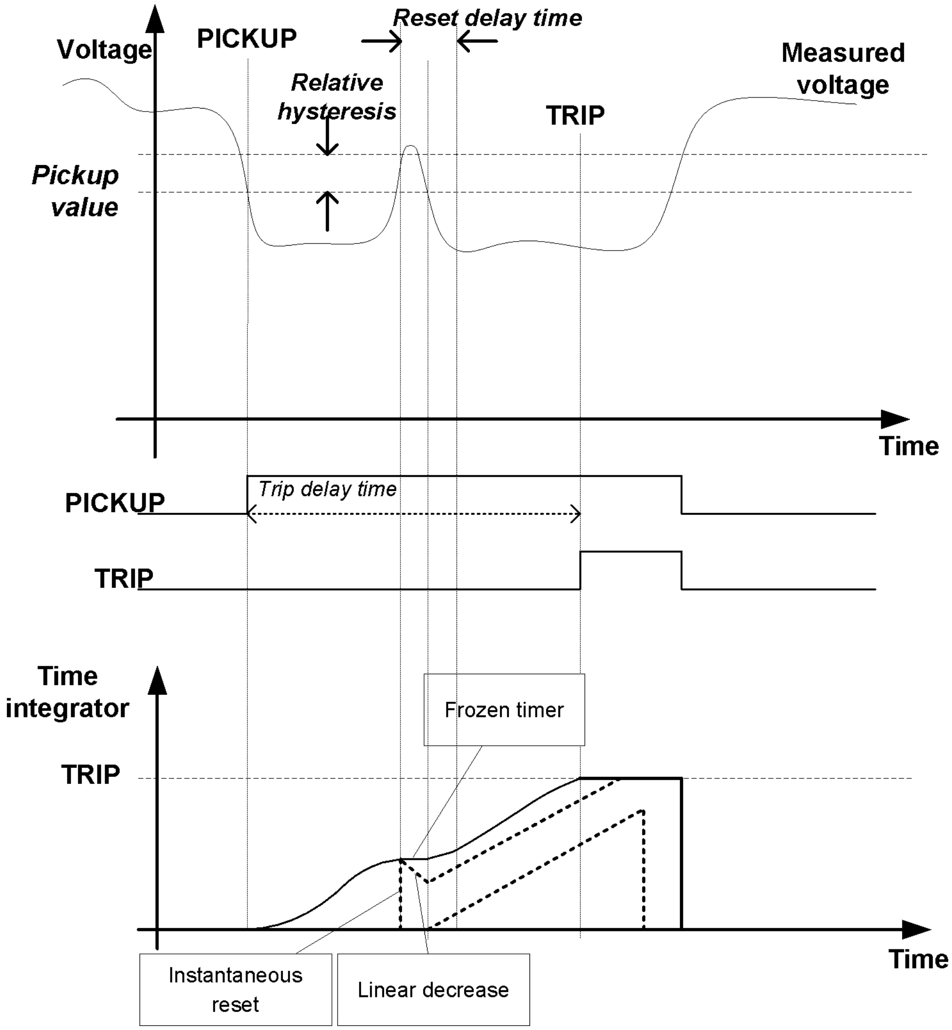


Figure 127: Behavior of different IDMT reset modes. The value for Type of reset curve is "Def time reset". Also other reset modes are presented for the time integrator.

The *Time multiplier* setting is used for scaling the IDMT trip times.

The *Minimum trip time* setting parameter defines the minimum desired trip time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum trip time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum trip time* setting. For more information, see the IDMT curves for overcurrent protection section in this manual.

The Timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

The “Freeze timers” mode of blocking has no effect during the “Inverse reset” mode.

4.2.2.5 Timer characteristics

The operating curve types supported by 27 are:

Table 224: Supported IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(21) Inv. Curve A
(22) Inv. Curve B
(23) Programmable

4.2.2.6 Application

27 is applied to power system elements, such as generators, transformers, motors and power lines, to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or a fault in the power system. 27 can be used in combination with overcurrent protections. Other applications are the detection of a no-voltage condition, for example before the energization of a high voltage line, or an automatic breaker trip in case

of a blackout. 27 is also used to initiate voltage correction measures, such as insertion of shunt capacitor banks, to compensate for a reactive load and thereby to increase the voltage.

27 can be used to disconnect from the network devices, such as electric motors, which are damaged when subjected to service under low voltage conditions. 27 deals with low voltage conditions at power system frequency. Low voltage conditions can be caused by:

- Malfunctioning of a voltage regulator or incorrect settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-ground faults (unsymmetrical voltage increase).

27 prevents sensitive equipment from running under conditions that could cause overheating and thus shorten their life time expectancy. In many cases, 27 is a useful function in circuits for local or remote automation processes in the power system.

4.2.2.7 Signals

Table 225: 27 Input signals

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase to ground voltage A or phase to phase voltage AB
V_B_BC	SIGNAL	0	Phase to ground voltage B or phase to phase voltage BC
V_C_CA	SIGNAL	0	Phase to ground voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 226: 27 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.2.8 Settings

Table 227: 27 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...1.20	xVn	0.01	0.90	Pickup value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Trip delay time	60...300000	ms	10	60	Trip delay time
Operating curve type	5=ANSI DT 15=IEC DT 21=Inv. Curve A 22=Inv. Curve B 23=Programmable			5=ANSI DT	Selection of time delay curve type
Type of reset curve	1=Immediate 2=Def time reset -1=DT Lin decr rst			1=Immediate	Selection of reset curve type

Table 228: 27 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for trip activation
Minimum trip time	60...60000	ms	1	60	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve parameter A	0.005...200.000			1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00			1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0			0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000			0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000			1.000	Parameter E for customer programmable curve
Curve Sat Relative	0.0...3.0		0.1	2.0	Tuning parameter to avoid curve discontinuities
Voltage block value	0.05...1.00	xVn	0.01	0.20	Low level blocking for undervoltage mode
Enable block value	0=False 1=True			1=True	Enable internal blocking
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.2.2.9 Monitored data

Table 229: 27 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
27	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.2.10 Technical data

Table 230: 27 Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × V_n		
Pickup time1)2)		Minimum	Typical	Maximum
	V_{Fault} = 0.9 × set *Pickup value*	62 ms	66 ms	69 ms
Reset time		<40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms3)		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) *Pickup value* = 1.0 × V_n, Voltage before fault = 1.1 × V_n, f_n = 60 Hz, undervoltage in one phase-to-phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact
3) Minimum *Pickup value* = 0.50, *Pickup value* multiples in range of 0.90...0.20

4.2.3 Residual overvoltage protection 59G/N

4.2.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual overvoltage protection	ROVPTOV	Uo>	59G/N

4.2.3.2 Function block

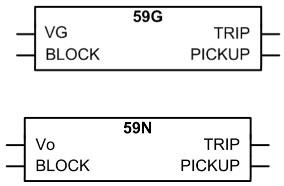


Figure 128: Function block

4.2.3.3 Functionality

The residual overvoltage protection 59G/N is used in distribution networks where the ground overvoltage can reach non-acceptable levels in, for example, high impedance grounding.

The function picks up when the ground voltage exceeds the set limit. 59G/N operates with the definite time (DT) characteristic.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.2.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of residual overvoltage protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

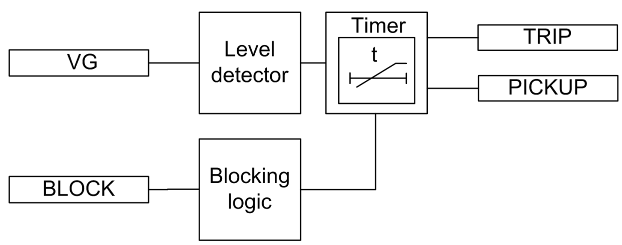


Figure 129: Functional module diagram. VG represents the ground voltage.

Level detector

The measured ground voltage is compared to the set *Pickup value*. If the value exceeds the set *Pickup value*, the level detector sends an enable signal to the timer.

Timer

Once activated, the timer activates the `PICKUP` output. The time characteristic is according to DT. When the trip timer has reached the value set by *Trip delay time*, the `TRIP` output is activated. If the fault disappears before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the `PICKUP` output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the `TRIP` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the `TRIP` output is not activated.

4.2.3.5 Application

59G is designed to be used for ground-fault protection in isolated neutral, resistance grounded or reactance grounded systems. In compensated networks, the pickup of the function can be used to control the switching device of the neutral resistor. The function can also be used for the back-up protection of feeders for busbar protection when a more dedicated busbar protection would not be justified.

In compensated and isolated neutral systems, the system neutral voltage, that is, the ground voltage, increases in case of any fault connected to ground. Depending on the type of the fault and the fault resistance, the ground voltage reaches different values. The highest ground voltage, equal to the phase-to-ground voltage, is achieved for a single-phase ground fault. The ground voltage increases approximately the same amount in the whole system and does not provide any guidance in finding the faulty component.

Therefore, this function is often used as a back-up protection or as a release signal for the feeder ground-fault protection.

The protection can also be used for the ground-fault protection of generators and motors and for the unbalance protection of capacitor banks.

The ground voltage can be calculated internally based on the measurement of the three-phase voltage. This voltage can also be measured by a single-phase voltage transformer, located between a transformer star point and ground, or by using an open-delta connection of three single-phase voltage transformers.

4.2.3.6 Signals

Table 231: 59G/N Input signals

Name	Type	Default	Description
VG	SIGNAL	0	Ground voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 232: 59G/N Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.3.7 Settings

Table 233: 59G/N Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.010...1.000	xVn	0.001	0.1	Pickup value
Trip delay time	40...300000	ms	1	40	Trip delay time

Table 234: 59G/N Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
VG/V0 Select	1=Measured VG 2=Calculated V0			1=Measured VG	Selection for used VG/V0 signal

4.2.3.8 Monitored data

Table 235: 59G/N Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
59G/N	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.3.9 Technical data

Table 236: 59N Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × V_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	V_{Fault} = 1.1 × set *Pickup value*	55 ms	57 ms	60 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) Ground voltage before fault = 0.0 × V_n, f_n = 60 Hz, ground voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.4 Negative-sequence overvoltage protection 47

4.2.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overvoltage protection	NSPTOV	U2>	47

4.2.4.2 Function block

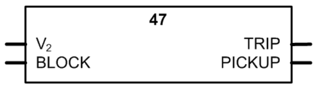


Figure 130: Function block

4.2.4.3 Functionality

The negative-sequence overvoltage protection 47 is used to detect negative-sequence overvoltage conditions. 47 is used for the protection of machines.

he function picks up when the negative-sequence voltage exceeds the set limit. 47 operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.2.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the negative-sequence overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

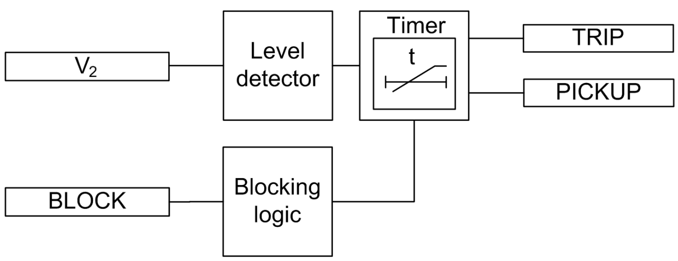


Figure 131: Functional module diagram. V_2 is used for representing negative phase sequence voltage.

Level detector

The calculated negative-sequence voltage is compared to the set *Pickup value* setting. If the value exceeds the set *Pickup value*, the level detector enables the timer.

Timer

Once activated, the timer activates the PICKUP output. The time characteristic is according to DT. When the operation timer has reached the value set by *Trip delay time*, the TRIP output is activated if the overvoltage condition persists. If the negative-sequence voltage normalizes before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the PICKUP output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.2.4.5 Application

A continuous or temporary voltage unbalance can appear in the network for various reasons. The voltage unbalance mainly occurs due to broken conductors or asymmetrical loads and is characterized by the appearance of a negative-sequence component of the voltage. In rotating machines, the voltage unbalance results in a current unbalance, which heats the rotors of the machines. The rotating machines, therefore, do not tolerate a continuous negative-sequence voltage higher than typically 1-2 percent x V_n.

The negative-sequence component current I_2, drawn by an asynchronous or a synchronous machine, is linearly proportional to the negative-sequence component voltage V_2. When V_2 is P% of V_n, I_2 is typically about 5 x P% x I_n.

The negative-sequence overcurrent 46 blocks are used to accomplish a selective protection against the voltage and current unbalance for each machine separately. Alternatively, the protection can be implemented with the 47 function, monitoring the voltage unbalance of the busbar.

If the machines have an unbalance protection of their own, the 47 operation can be applied as a backup protection or it can be used as an alarm. The latter can be applied when it is not required to trip loads tolerating voltage unbalance better than the rotating machines.

If there is a considerable degree of voltage unbalance in the network, the rotating machines should not be connected to the network at all. This logic can be implemented by inhibiting the closure of the circuit breaker if the 47 operation has started. This scheme also prevents connecting the machine to the network if the phase sequence of the network is not correct.

An appropriate value for the setting parameter *Voltage pickup value* is approximately 3 percent of V_n. A suitable value for the setting parameter *Trip delay time* depends on the application. If the 47 operation is used as a backup protection, the trip time should be set in accordance with the trip time of 46 used as the main protection. If the 47 operation is used as the main protection, the trip time should be approximately one second.

4.2.4.6 Signals

Table 237: 47 Input signals

Name	Type	Default	Description
V_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 238: 47 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.4.7 Settings

Table 239: 47 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.010...1.000	xVn	0.001	0.03	Pickup value
Trip delay time	40...120000	ms	1	40	Trip delay time

Table 240: 47 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time

4.2.4.8 Monitored data

Table 241: 47 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
47	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.4.9 Technical data

Table 242: 47 Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × V_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	V_{Fault} = 1.1 × set *Pickup value* V_{Fault} = 2.0 × set *Pickup value*	33 ms 25 ms	35 ms 27 ms	38 ms 30 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) Negative-sequence voltage before fault = 0.0 × V_n, f_n = 60 Hz, negative-sequence overvoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.5 Positive-sequence undervoltage protection 27PS

4.2.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence undervoltage protection	PSPTUV	U1<	27PS

4.2.5.2 Function block

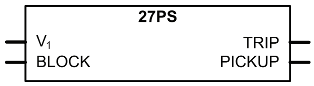


Figure 132: Function block

4.2.5.3 Functionality

The positive-sequence undervoltage protection 27PS is used to detect positive-sequence undervoltage conditions. 27PS is used for the protection of small power generation plants. The function helps in isolating an embedded plant from a fault line when the fault current fed by the plant is too low to cause an overcurrent function to pickup but high enough to maintain the arc. Fast isolation of all the fault current sources is necessary for a successful autoreclosure from the network-end circuit breaker.

The function picks up when the positive-sequence voltage drops below the set limit. 27PS operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.2.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of the positive-sequence undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

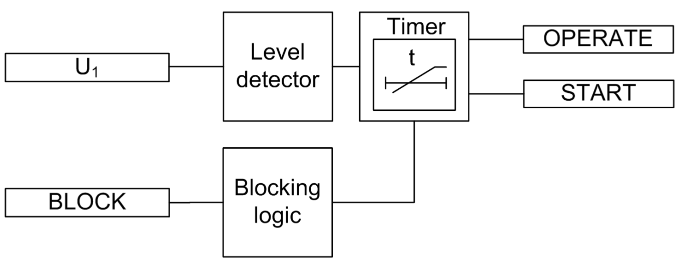


Figure 133: Functional module diagram. V_1 is used for representing positive phase sequence voltage.

Level detector

The calculated positive-sequence voltage is compared to the set *Pickup value* setting. If the value drops below the set *Pickup value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Pickup value* setting. After leaving the hysteresis area, the pickup condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The level detector contains a low-level blocking functionality for cases where the positive-sequence voltage is below the desired level. This feature is useful when it is wanted to avoid unnecessary pickups and trips during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to “True”) and the blocking level can be set with the *Voltage block value* setting.

Timer

Once activated, the timer activates the `PICKUP` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Trip delay time*, the `TRIP` output is activated if the undervoltage condition persists. If the positive-sequence voltage normalizes before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the trip timer resets and the `PICKUP` output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the `TRIP` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the `TRIP` output is not activated.

4.2.5.5 Application

27PS can be applied for protecting a power station used for embedded generation when network faults like short circuits or phase-to-ground faults in a transmission or a distribution line cause a potentially dangerous situations for the power station. A network fault can be dangerous for the power station for various reasons. The operation of the protection can cause an islanding condition, also called a loss-of-mains condition, in which a part of the network, that is, an island fed by the power station, is isolated from the rest of the network. There is then a risk of an autoreclosure taking place when the voltages of different parts of the network do not synchronize, which is a straining incident for the power station. Another risk is that the generator can lose synchronism during the network fault. A sufficiently fast trip of the utility circuit breaker of the power station can avoid these risks.

The lower the three-phase symmetrical voltage of the network is, the higher is the probability that the generator loses the synchronism. The positive-sequence voltage is also available during asymmetrical faults. It is a more appropriate criterion for detecting the risk of loss of synchronism than, for example, the lowest phase-to-phase voltage.

Analyzing the loss of synchronism of a generator is rather complicated and requires a model of the generator with its prime mover and controllers. The generator can be able to trip synchronously even if the voltage drops by a few tens of percent for some hundreds of milliseconds. The setting of 27PS is thus determined by the need to protect the power station from the risks of the islanding conditions since that requires a higher setting value.

The loss of synchronism of a generator means that the generator is unable to operate as a generator with the network frequency but enters into an unstable condition in which it operates by turns as a generator and a motor. Such a condition stresses the generator thermally and mechanically. This kind of loss of synchronism should not be mixed with the one between an island and the utility network. In the islanding situation, the condition of the generator itself is normal but the phase angle and the frequency of the phase-to-phase voltage can be different from the corresponding voltage in the rest of the network. The island can have a frequency of its own relatively fast when fed by a small power station with a low inertia.

27PS complements other loss-of-grid protection principles based on the frequency and voltage operation.

Motor stalling and failure to start can lead to a continuous undervoltage. The positive-sequence undervoltage is used as a backup protection against the motor stall condition.

4.2.5.6 Signals

Table 243: 27PS Input signals

Name	Type	Default	Description
V_1	SIGNAL	0	Positive phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 244: 27PS Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.5.7 Settings

Table 245: 27PS Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.010...1.200	xUn	0.001	0.500	Pickup value
Trip delay time	40...120000	ms	10	40	Trip delay time
Voltage block value	0.01...1.00	xUn	0.01	0.20	Internal blocking level
Enable block value	0=False 1=True			1=True	Enable Internal Blocking

Table 246: 27PS Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.2.5.8 Monitored data

Table 247: 27PS Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
27PS	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.5.9 Technical data

Table 248: 27PS Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × V_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	V_{Fault} = 0.99 × set *Pickup value* V_{Fault} = 0.9 × set *Pickup value*	52 ms 44 ms	55 ms 46 ms	57 ms 49 ms
Reset time		<40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1) *Pickup value* = 1.0 × V_n, Positive sequence voltage before fault = 1.1 × V_n, f_n = 60 Hz, positive sequence undervoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.6 Voltage per hertz protection 24

4.2.6.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage per hertz protection	OEPVPH	U/f>	24

4.2.6.2 Function block

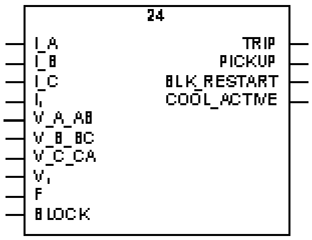


Figure 134: Function block

4.2.6.3 Functionality

The overexcitation protection 24 is used to protect generators and power transformers against an excessive flux density and saturation of the magnetic core.

The function calculates the V/f ratio (volts/hertz) proportional to the excitation level of the generator or transformer and compares this value to the setting limit. The function picks up when the excitation level exceeds the set limit and trips when the set tripping time has elapsed. The tripping time characteristic can be selected to be either definite time (DT) or overexcitation inverse definite minimum time (overexcitation type IDMT).

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself, if desired.

4.2.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of the overexcitation protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

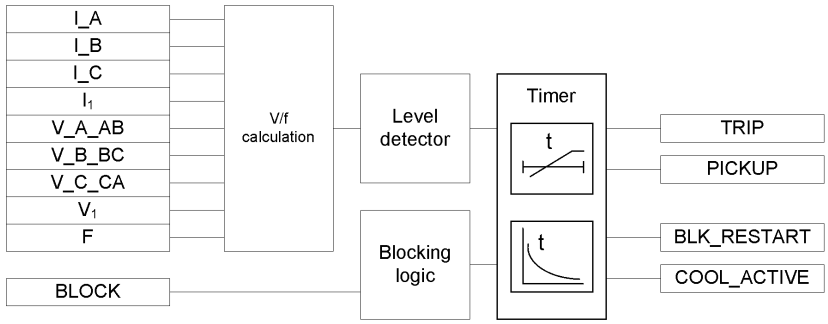


Figure 135: Functional module diagram

V/f calculation

This module calculates the V/f ratio, that is, the excitation level from the internal induced voltage (E) and frequency. The actual measured voltage (V_m) deviates from the internal induced voltage (emf) E, a value the equipment has to withstand. This voltage compensation is based on the load current (I_L) and the leakage reactance (X_{leak}) of the equipment. The leakage reactance of the transformer or generator is set through the *Leakage React* setting in percentage of the Z base.

The internal induced voltage (E) is calculated from the measured voltage. The settings *Voltage selection* and *Phase supervision* determine which voltages and currents are to be used. If the *Voltage selection* setting is set to "phase-to-ground" or "phase-to-phase", the *Phase supervision* setting is used for determining which phases or phase-to-phase voltages ("A or AB", "B or BC" and "C or CA") and currents are to be used for the calculation of the induced voltage.

Table 249: Voltages and currents used for induced voltage (emf) E calculation

Voltage selection setting	Phase supervision setting	Calculation of internal induced voltage (emf) E[1)]
phase-to-ground	A or AB	$\overline{E} = \sqrt{3} \times \left(\overline{V_A} + \overline{I_A} \times (j \times X_{leak}) \right)$
phase-to-ground	B or BC	$\overline{E} = \sqrt{3} \times \left(\overline{V_B} + \overline{I_B} \times (j \times X_{leak}) \right)$
phase-to-ground	C or CA	$\overline{E} = \sqrt{3} \times \left(\overline{V_C} + \overline{I_C} \times (j \times X_{leak}) \right)$
phase-to-phase	A or AB	$\overline{E} = \overline{V_{AB}} + \left((\overline{I_A} - \overline{I_B}) \times (j \times X_{leak}) \right)$
Table continues on next page		

Voltage selection setting	Phase supervision setting	Calculation of internal induced voltage (emf) E[1)]
phase-to-phase	B or BC	$\overline{E} = \overline{V_{BC}} + \left((\overline{I_B} - \overline{I_C}) \times (j \times X_{leak}) \right)$
phase-to-phase	C or CA	$\overline{E} = \overline{V_{CA}} + \left((\overline{I_C} - \overline{I_A}) \times (j \times X_{leak}) \right)$
Pos sequence	N/A	$\overline{E} = \sqrt{3} \times \left(\overline{V_1} + \overline{I_1} \times (j \times X_{leak}) \right)$

1) Voltages, currents and the leakage reactance X_{leak} in the calculations are given in volts, amps and ohms.

If all three phase or phase-to-phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

If the leakage reactance of the protected equipment is unknown or if the measured voltage (V_m) is to be used in the excitation level calculation, then by setting the leakage reactance value to zero the calculated induced voltage (E) is equal to the measured voltage.

The calculated V/f ratio is scaled to a value based on the nominal V_n/f_n ratio. However, the highest allowed continuous voltage (in % V_n) can be defined by setting the parameter *Voltage Max Cont* to change the basis of the voltage. The measured voltage is compared to the new base value to obtain the excitation level.

The excitation level (M) can be calculated:

$$M = \frac{\frac{E}{f_m}}{\frac{V_n}{f_n} \cdot \frac{Volt\ Max\ continuous}{100}}$$

(Equation 8)

M excitation level (V/f ratio or volts/hertz) in pu

E internal induced voltage (emf)

f_m measured frequency

V_n nominal phase-to-phase voltage

f_n nominal frequency

If the input frequency (f_m) is less than 20 percent of the nominal frequency (f_n), the calculation of the excitation level is disabled and forced to zero value. This means that the function is blocked from picking up and tripping during a low-frequency condition.

The calculated excitation level (V/f ratio or volts/hertz) VOLTPERHZ is available in the Monitored data view.

Level detector

Level detector compares the calculated excitation level to the *Pickup value* setting. If the excitation level exceeds the set limit, the module sends an enabling signal to start Timer.

Timer

Once activated, Timer activates the `PICKUP` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the trip timer has reached the value set by *Trip delay time* in the DT mode or the value defined by the inverse time curve, the `TRIP` output is activated.

In a drop-off situation, that is, when the excitation level drops below *Pickup value* before the function trips, the reset timer is activated and the `PICKUP` output resets after the time delay of *Reset delay time* for the DT characteristics. For the IDMT curves, the reset operation is as described in the Timer characteristics chapter.

For the IDMT curves, it is possible to define the maximum and minimum trip times via the *Minimum trip time* and *Maximum trip time* settings. The *Maximum trip time* setting is used to prevent infinite pickup situations at low degrees of overexcitation. The *Time multiplier* setting is used for scaling the IDMT trip times.

The activation of the `TRIP` output activates the `BLK_RESTART` output.

The beginning of the cooling process deactivates the `TRIP` output and activates the `COOL_ACTIVE` output. `COOL_ACTIVE` is kept active during the cooling process. If a new overexcitation start ceases cooling, `COOL_ACTIVE` is deactivated during that start time. `BLK_RESTART` is kept active until the set total cooling time has elapsed. It means that even during the new overexcitation start ceases cooling, `BLK_RESTART` is kept active. Due to the updated cooling time, the `BLK_RESTART` activation time is prolonged with these new starts during cooling. A new overexcitation start during cooling does not immediately reactivate `TRIP`, but `PICKUP` is first activated and a new `TRIP` activation depends on the already run cooling time. If, for example, 60 percent of the set cooling time has run before a new start, 40 percent of the operating time is needed to reactivate `TRIP`.

The `T_ENARESTART` output indicates in seconds the duration for which the `BLK_RESTART` output still remains active. The value is available in the Monitored data view.

Timer calculates the pickup duration value PICKUP_DUR, which indicates the percentage ratio of the pickup situation and the set trip time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.2.6.5 Timer characteristics

24 supports both DT and IDMT characteristics. The DT timer characteristics can be selected as "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Trip delay time* and *Reset delay time* settings.

24 also supports four overexcitation IDMT characteristic curves: "OvExt IDMT Crv1", "OvExt IDMT Crv2", "OvExt IDMT Crv3" and "OvExt IDMT Crv4".

Overexcitation inverse definite minimum time curve (IDMT)

In the inverse time modes, the trip time depends on the momentary value of the excitation: the higher the excitation level, the shorter the trip time. The trip time calculation or integration starts immediately when the excitation level exceeds the set *Pickup value* and the PICKUP output is activated.

The TRIP output is activated when the cumulative sum of the integrator calculating the overexcitation situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum trip time* and *Maximum trip time* settings define the minimum trip time and maximum trip time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

The tripping time of the function block can vary much between different operating curve types even if other setting parameters for the curves were not changed.

Once activated, the timer activates the PICKUP output for the IDMT curves. If the excitation level drops below the *Pickup value* setting before the function trips, the reset timer is activated. If the fault reoccurs during the reset time, the tripping calculation is made based on the effects of the period when PICKUP was previously active. This is intended to allow a tripping condition to occur in less time to account for the heating effects from the previous active pickup period.

When the fault disappears, the reset time can be calculated:

$$resettime = \left(\frac{PICKUP\_DUR}{100} \right) \cdot Cooling\,time$$

(Equation 9)

For the IDMT curves, when the fault disappears, the integral value calculated during PICKUP is continuously decremented by a constant that causes its value to become zero when the reset time elapses during the reset period. If a fault reoccurs, the integration continues from the current integral value and the pickup time is adjusted, as shown in Figure 136. The pickup time becomes the value at the time when the fault dropped off minus the amount of reset time that occurred. If the reset period elapses without a fault being detected, the saved values of the pickup time and integration are cleared.

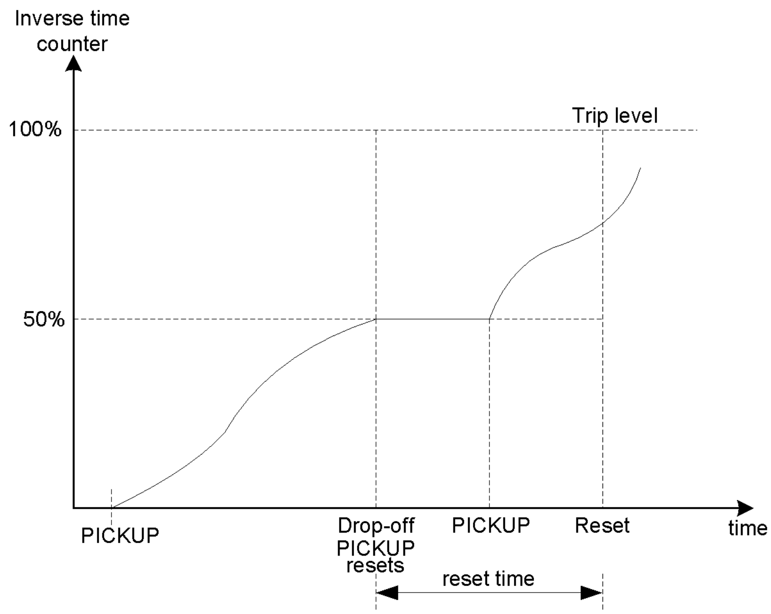


Figure 136: An example of a delayed reset in the inverse time characteristics. When the pickup becomes active during the reset period, the trip time counter continues from the level corresponding to the drop-off (reset time = 0.50 · Cooling time)

Overexcitation IDMT curves 1, 2 and 3

The base equation for the IDMT curves "OvExt IDMT Crv1", "OvExt IDMT Crv2" and "OvExt IDMT Crv3" is:

$$t(s) = 60 \cdot e^{\left(\frac{ak+b-100M}{c}\right)}$$

(Equation 10)

t(s)	the trip time in seconds
M	excitation level (V/f ratio or volts/hertz) in pu
k	the *Time multiplier* setting

The constant "60" in Equation 10 converts time from minutes to seconds.

Table 250: Parameters a, b and c for different IDMT curves

Operating curve type setting	a	b	c
OvExt IDMT Crv1	2.5	115.00	4.886
OvExt IDMT Crv2	2.5	113.50	3.040
OvExt IDMT Crv3	2.5	108.75	2.443

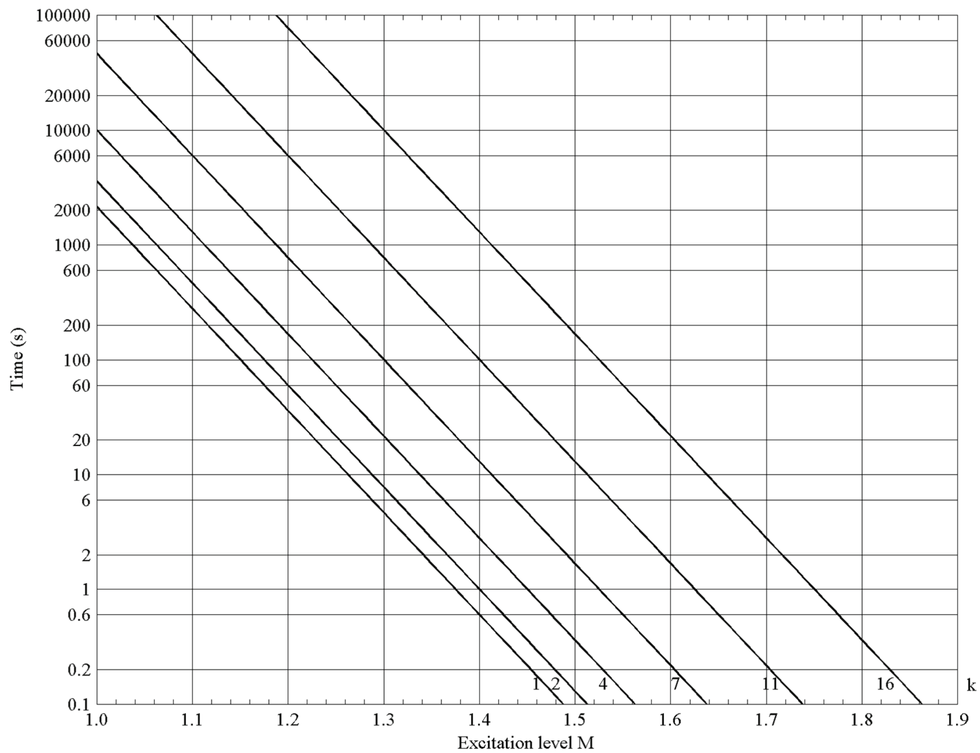


Figure 137: Trip time curves for the overexcitation IDMT curve ("OvExt IDMT Crv1") for parameters a = 2.5, b = 115.0 and c = 4.886

Overexcitation IDMT curve 4

The base equation for the IDMT curve “OvExt IDMT Crv4” is:

$$t(s) = \frac{d}{1000} + \frac{0.18k}{(M-1)^2}$$

(Equation 11)

t(s) the trip time in seconds

d the *Constant delay* setting in seconds

M the excitation value (V/f ratio or volts/hertz) in pu

k the *Time multiplier* setting

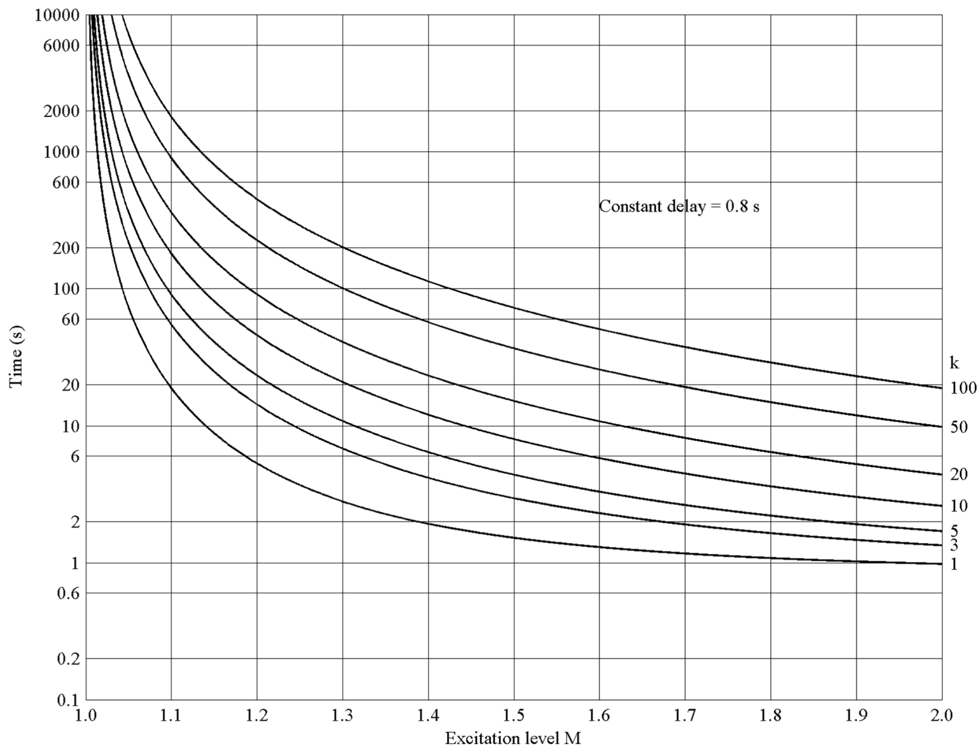


Figure 138: Trip time curves for the overexcitation IDMT curve 4 ("OvExt IDMT Crv4") for different values of the Time multiplier setting when the Constant delay is 800 milliseconds

The activation of the `TRIP` output activates the `BLK_RESTART` output.

For the IDMT characteristic "OvExt IDMT Crv4", the deactivation of the `TRIP` output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The `COOL_ACTIVE` output is kept active until the cooling timer is reset, whereas the `BLK_RESTART` output remains active until the timer exceeds the value to enable the restart time, given in Equation 12. The *Restart Ena level* setting determines the level when BLK_RESTART should be released.

$$enable\ restart\ time = \left(\frac{100 - Ena\ restart\ level}{100} \right) \cdot Cooling\ time$$

(Equation 12)

If the excitation level increases above the set value when BLK_RESTART is active, the TRIP output is activated immediately.

If the excitation level increases above the set value when BLK_RESTART is not active but COOL_ACTIVE is active, the TRIP output is not activated instantly. In this case, the remaining part of the cooling timer affects the calculation of the trip timer as shown in Figure 139. This compensates for the heating effect and makes the overall trip time shorter.

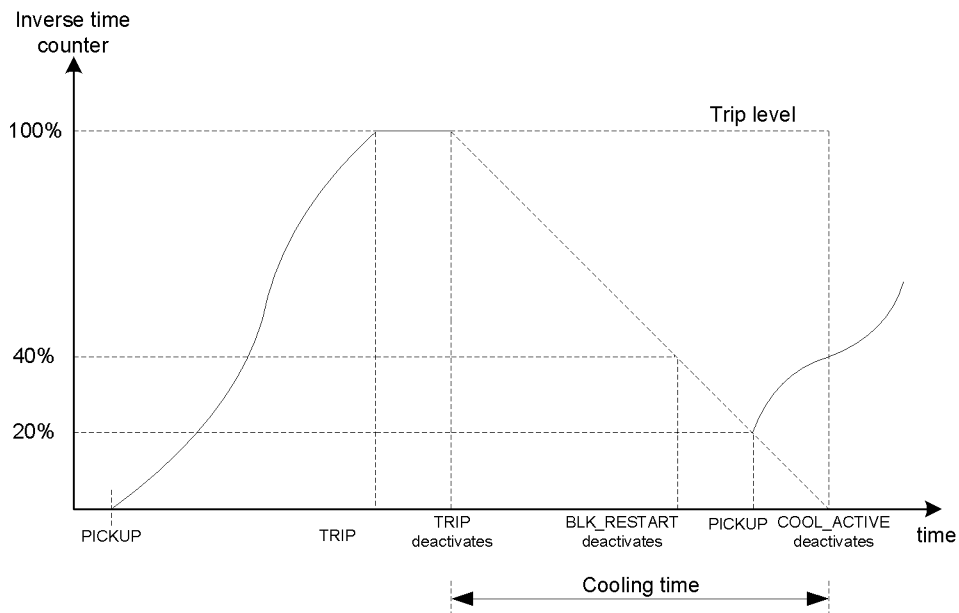


Figure 139: Example of an inverse time counter operation if TRIP occurs when BLK_RESTART is not active but COOL_ACTIVE is active. (The Restart Ena level setting is considered to be 40 percent)

4.2.6.6 Application

If the laminated core of a power transformer or generator is subjected to a magnetic flux density beyond its designed limits, the leakage flux increases. This results in a heavy hysteresis and eddy current losses in the non-laminated parts. These losses can cause excessive heating and severe damage to the insulation and adjacent parts in a relatively short time.

Overvoltage, underfrequency or a combination of the two, results in an excessive flux density level. Since the flux density is directly proportional to the voltage and inversely proportional to the frequency, the overexcitation protection calculates the relative V/Hz ratio instead of measuring the flux density directly. The nominal level (nominal voltage at nominal frequency) is usually considered as the 100 percent level, which can be exceeded slightly based on the design.

The greatest risk for overexcitation exists in a thermal power station when the generator-transformer unit is disconnected from the rest of the network or in the network islands where high voltages or low frequencies can occur.

Overexcitation can occur during the start-up and shutdown of the generator if the field current is not properly adjusted. The loss-of-load or load shedding can also result in overexcitation if the voltage control and frequency governor do not function properly. The low frequency in a system isolated from the main network can result in overexcitation if the voltage-regulating system maintains a normal voltage.

Overexcitation protection for the transformer is generally provided by the generator overexcitation protection, which uses the VTs connected to the generator terminals. The curves that define the generator and transformer V/Hz limits must be coordinated properly to protect both equipment.

If the generator can be operated with a leading power factor, the high-side voltage of the transformer can have a higher pu V/Hz than the generator V/Hz. This needs to be considered in a proper overexcitation protection of the transformer. Also, measurement for the voltage must not be taken from any winding where OLTC is located.

It is assumed that overexcitation is a symmetrical phenomenon caused by events such as loss-of-load. A high phase-to-ground voltage does not mean overexcitation. For example, in an ungrounded power system, a single-phase-to-ground fault means high voltages of the healthy two phases to ground but no overexcitation on any winding. The phase-to-phase voltages remain essentially unchanged. An important voltage to be considered for the overexcitation is the voltage between the two ends of each winding.

Example calculations for overexcitation protection

Example 1

Nominal values of the machine

Nominal phase-to-phase voltage (V_n)	11000 V
Nominal phase current (I_n)	7455 A
Nominal frequency (f_n)	50 Hz

Leakage reactance (X_{leak})	20% or 0.2 pu

Measured voltage and load currents of the machine

Phase A-to-phase B voltage (V_{AB})	11500∠0° V
Phase A current (I_A)	5600∠-63.57° A
Phase B current (I_B)	5600∠176.42° A
Measured frequency (f_m)	49.98 Hz
The setting *Voltage Max Cont*	100%
The setting *Voltage selection*	phase-to-phase
The setting *Phase supervision*	A or AB

The pu leakage reactance X_{leakPU} is converted to ohms.

$$X_{leak\Omega} = X_{leakPU} \cdot \left(V_n \big/ \left(I_n \cdot \sqrt{3} \right) \right) = 0.2 \cdot \left(11000 \big/ \left(7455 \cdot \sqrt{3} \right) \right) = 0.170378\ ohms$$

(Equation 13)

The internal induced voltage E of the machine is calculated.

$$\overline{E} = \overline{V_{AB}} + (\overline{I_A} - \overline{I_B}) \cdot (jX_{leak})$$

(Equation 14)

E = 11500∠0°+ (5600∠-63.57°- 5600∠176.42°) · (0.170378∠90°) = 12490 V

The excitation level M of the machine is calculated.

$$Excitation\,level\ M = \frac{12490 \big/ 49.98}{11000 \big/ 50 \cdot 1.00} = 1.1359$$

(Equation 15)

Example 2

The situation and the data are according to Example 1. In this case, the manufacturer of the machine allows the continuous operation at 105 percent of the nominal voltage at the rated load and this value to be used as the base for overexcitation.

Usually, the V/f characteristics are specified so that the ratio is 1.00 at the nominal voltage and nominal frequency. Therefore, the value 100 percent for the setting *Voltage Max Cont* is recommended.

If the *Voltage Max Cont* setting is 105 percent, the excitation level M of the machine is calculated with the equation.

$$Excitation\,level\;M = \frac{12490/49.98}{11000/50 \cdot 1.05} = 1.0818$$

(Equation 16)

Example 3

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv2". The corresponding example settings for the IDMT curve operation are given as: *Pickup value* = 110%, *Voltage Max Cont* = 100%, *Time multiplier* = 4, *Maximum trip time* = 1000000 milliseconds and *Minimum trip time* = 1000 milliseconds.

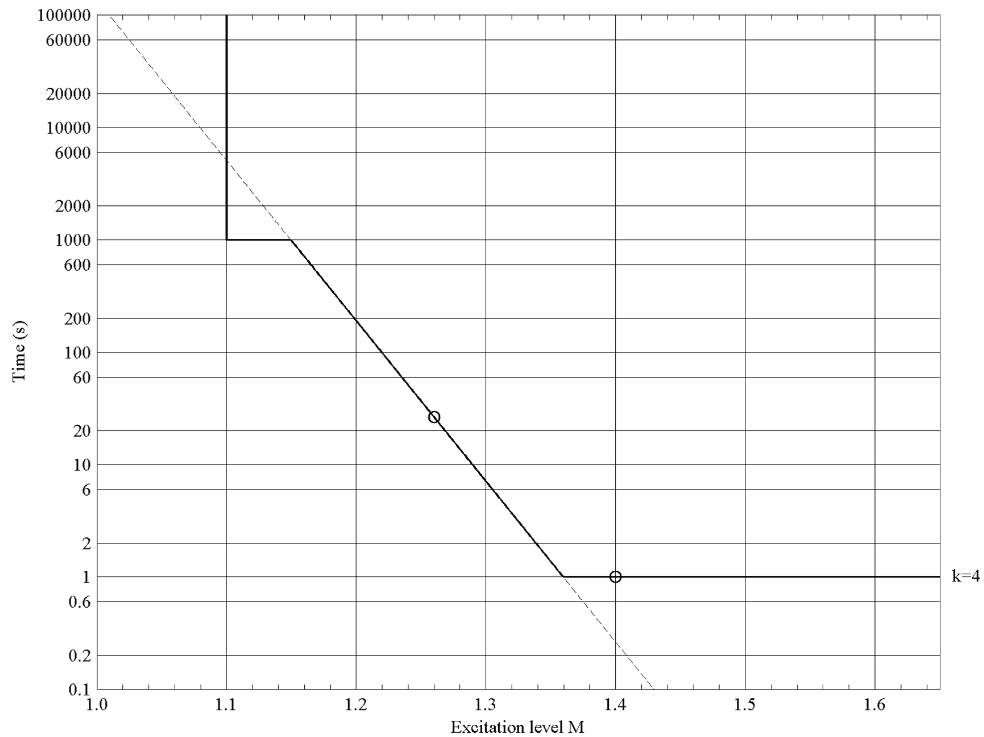


Figure 140: Tripping curve of "OvExt IDMT Crv2" based on the settings specified in example 3. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.26, the tripping occurs after 26360 milliseconds as per the marked dot in Figure 140. For the excitation level of 1.4, the second dot in Figure 140, the curve "OvExt IDMT Crv2" gives 260 milliseconds as per Equation 10, but the *Minimum trip time* setting limits the trip time to 1000 milliseconds. The *Maximum trip time* setting limits the trip time to 1000000 milliseconds if the excitation level stays between 1.1 and 1.16.

In general, however, the excitation level seldom remains constant. Therefore, the exact trip times in any inverse time mode are difficult to predict.

Example 4

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv4". The corresponding example settings for the IDMT curve operation are given as: *Pickup value* = 110%, *Voltage Max Cont* = 100%, *Time multiplier* = 5, *Maximum trip time* = 3600000 milliseconds and *Constant delay* = 800 milliseconds.

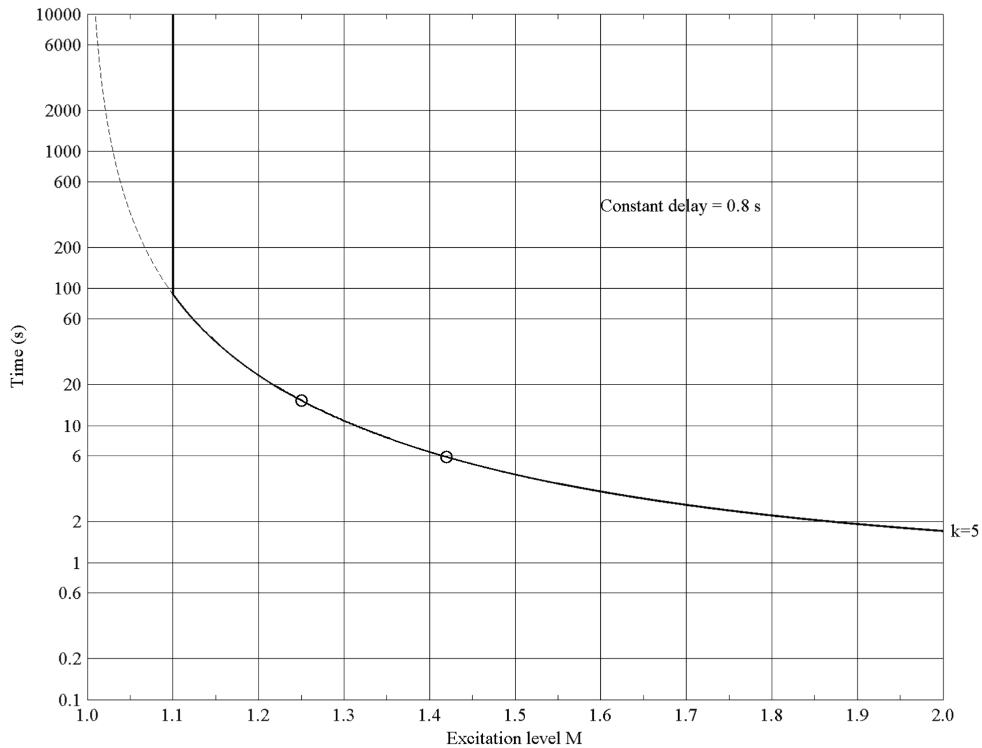


Figure 141: Tripping curve of "OvExt IDMT Crv4" based on the specified settings. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.25, the tripping occurs after 15200 milliseconds. At the excitation level of 1.42, the time to tripping would be 5900 milliseconds as per the two dots in Figure 141. In this case, the setting *Maximum trip time* = 3600000 milliseconds does not limit the maximum trip time because the trip time at *Pickup value* = 110% (1.1 pu) is approximately 75000 milliseconds.

4.2.6.7 Signals

Table 251: 24 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_1	SIGNAL	0	Positive-phase sequence current
Table continues on next page			

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase-to-ground voltage A or phase-to-phase voltage AB
V_B_BC	SIGNAL	0	Phase-to-ground voltage B or phase-to-phase voltage BC
V_C_CA	SIGNAL	0	Phase-to-ground voltage C or phase-to-phase voltage CA
V_1	SIGNAL	0	Positive-phase sequence voltage
F	SIGNAL	0	Measured frequency
BLOCK	BOOLEAN	0=False	Block signal

Table 252: 24 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
BLK_RESTART	BOOLEAN	Signal for blocking reconnection of an overheated machine
COOL_ACTIVE	BOOLEAN	Signal to indicate machine is in cooling process

4.2.6.8 Settings

Table 253: 24 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	100...200	%	1	100	Over excitation pickup value
Operating curve type	5=ANSI DT 15=IEC DT 17=OvExt IDMT Crv1 18=OvExt IDMT Crv2 19=OvExt IDMT Crv3 20=OvExt IDMT Crv4			5=ANSI DT	Selection of time delay curve type
Time multiplier	0.1...100.0		0.1	3.0	Time multiplier for Overexcitation IDMT curves
Trip delay time	200...200000	ms	10	500	Trip delay time in definite- time mode

Table 254: 24 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Mode Disable/Enable
Cooling time	5...10000	s	1	600	Time required to cool the machine
Constant delay	100...120000	ms	10	800	Parameter constant delay
Reset delay time	0...60000	ms	10	100	Resetting time of the trip time counter in DT mode
Maximum trip time	500000...10000000	ms	10	1000000	Maximum trip time for IDMT curves
Minimum trip time	200...60000	ms	10	200	Minimum trip time for IDMT curves
Restart Ena level	0...100	%	1	0	Determines the level in % when block restart is released
Voltage selection	1=phase-to-earth 2=phase-to-phase 3=pos sequence			3=pos sequence	Selection of phase / phase-to-phase / pos sequence voltages
Phase selection	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Parameter for phase selection
Leakage React	0.0...50.0	%	0.1	0.0	Leakage reactance of the machine
Voltage Max Cont	80...160	%	1	110	Maximum allowed continuous operating voltage ratio

4.2.6.9 Monitored data

Table 255: 24 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time (in %)
T_ENARESTART	INT32	0...10000	s	Estimated time to reset of block restart
VOLTPERHZ	FLOAT32	0.00...10.00	pu	Excitation level, i.e U/f ratio or Volts/Hertz
24	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.6.10 Technical data

Table 256: 24 Technical data

Characteristic	Value	
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz	
	±2.5% of the set value or 0.01 × Ub/f	
Pickup time[1)2)]	Frequency change	Typically 200 ms (±20 ms)
	Voltage change	Typically 100 ms (±20 ms)
Reset time	<60 ms	
Reset ratio	Typically 0.96	
Retardation time	<45 ms	
Operate time accuracy in definite-time mode	±1.0% of the set value or ±20 ms	
Operate time accuracy in inverse-time mode	±5.0% of the theoretical value or ±50 ms	

1) Results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.2.7 Three-phase remnant undervoltage protection 27R

4.2.7.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase remnant undervoltage protection	REMPTUV	3U<	27R

4.2.7.2 Function block

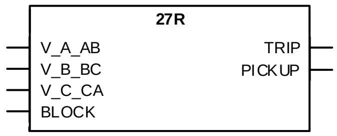


Figure 142: Function block

4.2.7.3 Functionality

Systems with critical motor applications may provide backup power sources to those motors that can be switched in when an undervoltage on the original power source is detected. The 27R function is used, after primary power has been removed, to monitor for an undervoltage condition over a decaying frequency before allowing re-application of backup power.

When the power to a motor is suddenly lost, the motor terminal voltage does not immediately fall to zero but remains as the rotating motor now acts as a generator producing its own voltage. This remanent voltage decays as the motor slows to a stop at a rate depending on the motor and load. Re-applying a power source while the remanent voltage is still present can result in damage to the motor shaft and windings.

The three-phase undervoltage protection 27R operates over the range of 10...70 Hz so it can monitor the voltage while the motor is slowing and prevent application of the backup power until the motor voltage has decayed to a safe level. 27R includes a settable value for the detection of undervoltage either in a single phase, two phases, or all three phases.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.2.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the three-phase undervoltage protection functionality can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

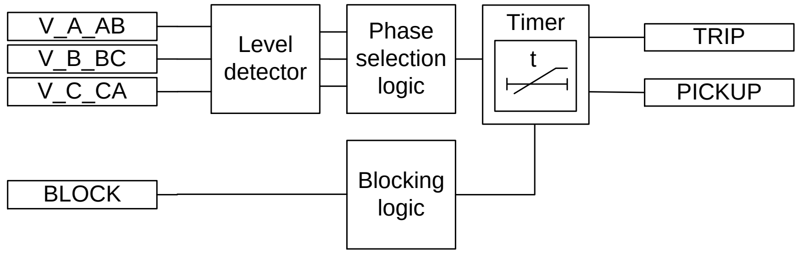


Figure 143: Functional module diagram

Level detector

The fundamental frequency component of the measured three-phase voltages over the range of 10...70 Hz is compared phase-wise to the set *Pickup value* . If the measured value is lower than the set value of the *Pickup value* setting, the Level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above or below the *Pickup value* setting. After leaving the hysteresis area, the pickup condition has to be fulfilled again and it is not sufficient for the signal to only return back to the hysteresis area.

The *Voltage selection* setting is used for selecting the phase-to-earth or phase-to-phase voltages for protection.

Phase selection logic

If the fault criteria are fulfilled in the Level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of pickup phases*, the phase selection logic activates the Timer.

Timer

Once activated, the Timer activates the `PICKUP` output. The time characteristic is definite time only.

When the trip timer has reached the value set by *Trip delay time*, the `TRIP` output is activated.

In a drop-off situation, that is, when a fault suddenly disappears before the trip delay is exceeded, the reset state is activated. The reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the `PICKUP` output is deactivated.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay program. The influence of the BLOCK input signal activation is preselected with the global *Blocking mode* setting.

The Blocking mode setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.2.7.5 Application

Systems with critical motor applications provide backup power sources to those motors that can be switched in when an undervoltage on the original power source is detected. The three-phase undervoltage protection 27R is used to monitor for an undervoltage condition over a decaying frequency after original power is lost, before allowing re-application of backup power. An independent undervoltage function, operating at nominal frequency, can be used to detect the original loss of primary power and initiate the transfer to backup power. 27R provides a permissive signal indicating when restoration of backup power can be completed safely.

When the power to a motor is suddenly lost, the motor terminal voltage does not immediately fall to zero but remains as the rotating motor now acts as a generator producing its own voltage. This remnant voltage decays as the motor slows to a stop at a rate depending on the motor and load. Applying the backup power source while the remnant voltage is still present can result in damage to the motor shaft and windings.

27R operates over the range of 10...70 Hz so it can monitor the voltage while the motor is slowing and prevent transfer of the backup power until the motor voltage has decayed to a safe level. The undervoltage setting is typically set 20...30 percent of rated voltage. There is also a time delay setting to ensure that the remnant voltage remains below the undervoltage setting for the set time. 27R includes a settable value for the detection of undervoltage in either a single phase, two phases, or in all three phases. This setting value should always be set for three phases in the remnant undervoltage application but can be changed if 27R is used as a standard undervoltage function.

The function contains a self-blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.2.7.6 Signals

Table 257: 27R Input signals

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase to ground voltage A or phase to phase voltage AB
V_B_BC	SIGNAL	0	Phase to ground voltage B or phase to phase voltage BC
V_C_CA	SIGNAL	0	Phase to ground voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 258: 27R Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.2.7.7 Settings

Table 259: 27R Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.05...1.20	xUn	0.01	0.25	Pickup value
Trip delay time	100...300000	ms	100	100	Trip delay time

Table 260: 27R Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Num of pickup phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			3=3 out of 3	Number of phases required for trip activation
Minimum trip time	100...60000	ms	100	100	Minimum trip time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.2.7.8 Monitored data

Table 261: 27R Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
REM_V_A	FLOAT32	0.00...4.00	xUn	Remanent voltage on phase A
REM_V_B	FLOAT32	0.00...4.00	xUn	Remanent voltage on phase B
REM_V_C	FLOAT32	0.00...4.00	xUn	Remanent voltage on phase C
27R	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.2.7.9 Technical data

Table 262: 27R Technical data

Characteristic	Value		
Operation accuracy	±4% of setting or ±0.01 × V_n (70 Hz > = f > 20 Hz)		
	±10% of setting (20 Hz > = f ≥ 10 Hz)		
Pickup time[1)]	Minimum	Typical	Maximum
	30 ms	75 ms	140 ms
Reset time	<180 ms		
Reset ratio	Depends on the relative hysteresis setting		
Retardation time	<45 ms		
Operate time accuracy[2)]	±1.0% of the set value or ±20 ms		
Suppression of harmonics	Operates only in RMS mode		

1) Includes the delay of the signal output contact
2) Operate time delays do not account for variation due to pickup delay

4.3 Frequency protection

4.3.1 Frequency protection 81

4.3.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency protection	FRPFRQ	f>/f<,df/dt	81

4.3.1.2 Function block

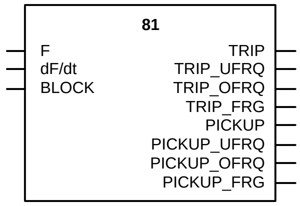


Figure 144: Function block

4.3.1.3 Functionality

The frequency protection 81 is used to protect network components against abnormal frequency conditions.

The function provides basic overfrequency, underfrequency and frequency rate-of-change protection. Additionally, it is possible to use combined criteria to achieve even more sophisticated protection schemes for the system.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

4.3.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the frequency protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

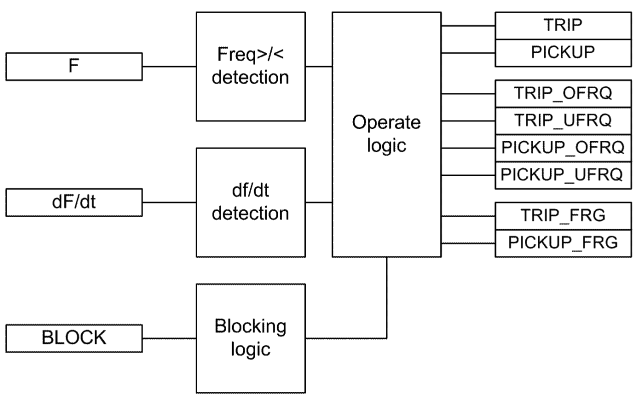


Figure 145: Functional module diagram

Over/under frequency detection

The frequency detection module includes an overfrequency or underfrequency detection based on the *Operation mode* setting.

In the "Freq>" mode, the measured frequency is compared to the set *Pickup value Freq>*. If the measured value exceeds the set value of the *Pickup value Freq>* setting, the module reports the exceeding of the value to the trip logic module.

In the "Freq<" mode, the measured frequency is compared to the set *Pickup value Freq<*. If the measured value is lower than the set value of the *Pickup value Freq<* setting, the module reports the value to the trip logic module.

df/dt detection

The frequency gradient detection module includes a detection for a positive or negative rate-of-change (gradient) of frequency based on the set *Pickup value df/dt* value. The negative rate-of-change protection is selected when the set value is negative. The positive rate-of-change protection is selected when the set value is positive. When the frequency gradient protection is selected and the gradient exceeds the set *Pickup value df/dt* value, the module reports the exceeding of the value to the trip logic module.

The protection relay does not accept the set value "0.00" for the *Pickup value df/dt* setting.

Operate logic

This module is used for combining different protection criteria based on the frequency and the frequency gradient measurement to achieve a more sophisticated behavior of the function. The criteria are selected with the *Operation mode* setting.

Table 263: Operation modes for operation logic

Operation mode	Description
Freq<	The function trips independently as the underfrequency ("Freq<") protection function. When the measured frequency is below the set value of the *Pickup value Freq<* setting, the module activates the PICKUP and PICKUP_UFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Trip Tm Freq* setting, the TRIP and TRIP_UFRQ outputs are activated. If the frequency restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the trip timer resets and the PICKUP and PICKUP_UFRQ outputs are deactivated.
Freq>	The function trips independently as the overfrequency ("Freq>") protection function. When the measured frequency exceeds the set value of the *Pickup value Freq>* setting, the module activates the PICKUP and PICKUP_OFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Trip Tm Freq* setting, the TRIP and TRIP_OFRQ outputs are activated. If the frequency restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the trip timer resets and the PICKUP and PICKUP_OFRQ outputs are deactivated.
df/dt	The function trips independently as the frequency gradient ("df/dt"), rate-of-change, protection function. When the frequency gradient exceeds the set value of the *Pickup value df/dt* setting, the module activates the PICKUP and PICKUP_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Trip Tm df/dt* setting, the TRIP and TRIP_FRG outputs are activated. If the frequency gradient restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the trip timer resets and the PICKUP and PICKUP_FRG outputs are deactivated.
Table continues on next page	

Operation mode	Description
Freq< + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency is below the set value of the *Pickup value Freq<* setting, the frequency gradient protection is enabled. After the frequency has dropped below the set value, the frequency gradient is compared to the set value of the *Pickup value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the PICKUP and PICKUP_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Trip Tm df/dt* setting, the TRIP and TRIP_FRG outputs are activated. If the frequency gradient restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the trip timer resets and the PICKUP and PICKUP_FRG outputs are deactivated. The TRIP_UFRQ output is not active when this operation mode is used.
Table continues on next page	

Operation mode	Description
Freq> + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency exceeds the set value of the *Pickup value Freq>* setting, the frequency gradient protection is enabled. After the frequency exceeds the set value, the frequency gradient is compared to the set value of the *Pickup value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the PICKUP and PICKUP_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Trip Tm df/dt* setting, the TRIP and TRIP_FRG outputs are activated. If the frequency gradient restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the trip timer resets and the PICKUP and PICKUP_FRG outputs are deactivated. The TRIP_OFRQ output is not active when this operation mode is used.
Freq< OR df/dt	A parallel operation between the protection methods is enabled. The PICKUP output is activated when either of the measured values of the protection module exceeds its set value. Detailed information about the active module is available at the PICKUP_UFRQ and PICKUP_FRG outputs. The shortest trip delay time from the set *Trip Tm Freq* or *Trip Tm df/dt* is dominant regarding the TRIP output. The time characteristic is according to DT. The characteristic that activates the TRIP output can be seen from the TRIP_UFRQ or TRIP_FRG output. If the frequency gradient restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the trip timer resets and the PICKUP_FRG output is deactivated. If the frequency restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the trip timer resets and the PICKUP_UFRQ output is deactivated.

Table continues on next page

Operation mode	Description
Freq> OR df/dt	A parallel operation between the protection methods is enabled. The PICKUP output is activated when either of the measured values of the protection module exceeds its set value. Detailed information about the active module is available at the PICKUP_OFRQ and PICKUP_FRG outputs. The shortest trip delay time from the set *Trip Tm Freq* or *Trip Tm df/dt* is dominant regarding the TRIP output. The time characteristic is according to DT. The characteristic that activates the TRIP output can be seen from the TRIP_OFRQ or TRIP_FRG output. If the frequency gradient restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the trip timer resets and the PICKUP_FRG output is deactivated. If the frequency restores before the module trips, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the trip timer resets and the PICKUP_UFRQ output is deactivated.

The module calculates the pickup duration value PICKUP_DUR which indicates the percentage ratio of the pickup situation and set trip time DT. The pickup duration is available according to the selected value of the *Operation mode* setting.

Table 264: Pickup duration value

Operation mode in use	Available pickup duration value
Freq<	ST_DUR_UFRQ
Freq>	ST_DUR_OFRQ
df/dt	ST_DUR_FRG

The combined pickup duration PICKUP_DUR indicates the maximum percentage ratio of the active protection modes. The values are available via the Monitored data view.

If there is a sharp frequency change in the waveform it can result in a prolonged operate time. The reason is that the frequency algorithm does not see it as a change in frequency, but as a loss of mains situation. In this case frequency protection is delayed with 160 ms to give room for vector shift protection to operate.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.3.1.5 Application

The frequency protection function uses the positive phase-sequence voltage to measure the frequency reliably and accurately.

The system frequency stability is one of the main principles in the distribution and transmission network maintenance. To protect all frequency-sensitive electrical apparatus in the network, the departure from the allowed band for a safe operation should be inhibited.

The overfrequency protection is applicable in all situations where high levels of the fundamental frequency of a power system voltage must be reliably detected. The high fundamental frequency in a power system indicates an unbalance between production and consumption. In this case, the available generation is too large compared to the power demanded by the load connected to the power grid. This can occur due to a sudden loss of a significant amount of load or due to failures in the turbine governor system. If the situation continues and escalates, the power system loses its stability.

The underfrequency is applicable in all situations where a reliable detection of a low fundamental power system voltage frequency is needed. The low fundamental frequency in a power system indicates that the generated power is too low to meet the demands of the load connected to the power grid.

The underfrequency can occur as a result of the overload of generators operating in an isolated system. It can also occur as a result of a serious fault in the power system due to the deficit of generation when compared to the load. This can happen due to a fault in the grid system on the transmission lines that link two parts of the system. As a result, the system splits into two with one part having the excess load and the other part the corresponding deficit.

The frequency gradient is applicable in all the situations where the change of the fundamental power system voltage frequency should be detected reliably. The frequency gradient can be used for both increasing and decreasing the frequencies. This function provides an output signal suitable for load shedding, generator shedding, generator boosting, set point change in sub-transmission DC systems and gas turbine startup. The frequency gradient is often used in combination with a low frequency signal, especially in smaller power systems where the loss of a large generator requires quick remedial actions to secure the power system integrity. In such situations, the load shedding actions are required at a rather high frequency level. However, in combination with a large negative frequency gradient, the underfrequency protection can be used at a high setting.

4.3.1.6 Signals

Table 265: 81 Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 266: 81 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
OPR_OFRQ	BOOLEAN	Trip signal for overfrequency
OPR_UFRQ	BOOLEAN	Trip signal for underfrequency
OPR_FRG	BOOLEAN	Trip signal for frequency gradient
PICKUP	BOOLEAN	Pickup
ST_OFRQ	BOOLEAN	Pickup signal for overfrequency
ST_UFRQ	BOOLEAN	Pickup signal for underfrequency
ST_FRG	BOOLEAN	Pickup signal for frequency gradient

4.3.1.7 Settings

Table 267: 81 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Trip mode	1=Freq< 2=Freq> 3=df/dt 4=Freq< + df/dt 5=Freq> + df/dt 6=Freq< OR df/dt 7=Freq> OR df/dt			1=Freq<	Frequency protection trip mode selection
Pickup value Freq>	0.900...1.200	xFn	0.001	1.050	Frequency pickup value overfrequency
Pickup value Freq<	0.800...1.100	xFn	0.001	0.950	Frequency pickup value underfrequency
Pickup value df/dt	-0.200...0.200	xFn /s	0.005	0.010	Frequency pickup value rate of change
Trip Tm Freq	80...200000	ms	10	200	Trip delay time for frequency
Trip Tm df/dt	120...200000	ms	10	400	Trip delay time for frequency rate of change

Table 268: 81 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Reset delay Tm Freq	0...60000	ms	1	0	Reset delay time for frequency
Reset delay Tm df/dt	0...60000	ms	1	0	Reset delay time for rate of change

4.3.1.8 Monitored data

Table 269: 81 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Pickup duration
ST_DUR_OFRQ	FLOAT32	0.00...100.00	%	Pickup duration
ST_DUR_UFRQ	FLOAT32	0.00...100.00	%	Pickup duration
ST_DUR_FRG	FLOAT32	0.00...100.00	%	Pickup duration
81	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.3.1.9 Technical data

Table 270: 81 Technical data

Characteristic		Value
Operation accuracy	f>/f<	±10 mHz
	df/dt	±100 mHz/s (in range |df/dt| <5 Hz/s) ±2.0% of the set value (in range 5 Hz/s < |df/dt| < 15 Hz/s)
Pickup time	f>/f<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Trip time accuracy		±1.0% of the set value or ±30 ms

4.3.2 Load shedding and restoration 81LSH

4.3.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load shedding and restoration	LSHDPFRQ	UFLS/R	81LSH

4.3.2.2 Function block

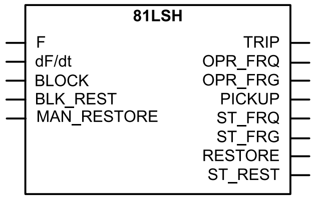


Figure 146: Function block

4.3.2.3 Functionality

The load-shedding and restoration function 81LSH is capable of performing load-shedding based on underfrequency and the rate of change of the frequency. The load that is shed during the frequency disturbance can be restored once the frequency has stabilized to the normal level.

The measured system frequency is compared to the set value to detect the underfrequency condition. The measured rate of change of frequency (df/dt) is compared to the set value to detect a high frequency reduction rate. The combination of the detected underfrequency and the high df/dt is used for the activation of the load-shedding. There is a definite time delay between the detection of the underfrequency and high df/dt and the activation of 81LSH. This time delay can be set and it is used to prevent unwanted load-shedding actions when the system frequency recovers to the normal level.

Throughout this document, “high df/dt” is used to mean “a high rate of change of the frequency in negative direction.”

Once the frequency has stabilized, 81LSH can restore the load that is shed during the frequency disturbance. The restoration is possible manually or automatically.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.3.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the load-shedding and restoration function can be described using a module diagram. All the modules are explained in the next sections.

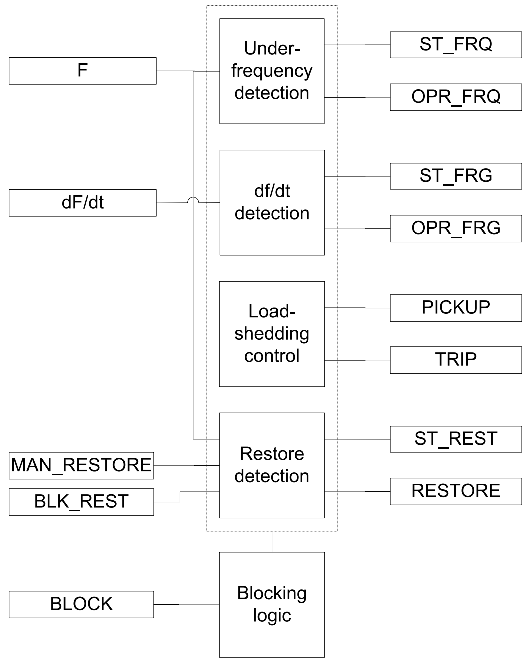


Figure 147: Functional module diagram

Underfrequency detection

The underfrequency detection measures the input frequency calculated from the voltage signal. An underfrequency is detected when the measured frequency drops below the set value of the *Pickup value Freq* setting.

The underfrequency detection module includes a timer with the definite time (DT) characteristics. Upon detection of underfrequency, operation timer activates the ST_FRQ output. When the underfrequency timer has reached the value set by *Trip Tm Freq*, the OPR_FRQ output is activated if the underfrequency condition still persists. If the frequency becomes normal before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the timer resets and the ST_FRQ output is deactivated.

df/dt detection

The df/dt detection measures the input frequency calculated from the voltage signal and calculates its gradient. A high df/dt condition is detected by comparing the gradient to the *Pickup value df/dt* setting.The df/dt detection is activated when the frequency gradient decreases at a faster rate than the set value of *Pickup value df/dt*.

The df/dt detection module includes a timer with the DT characteristics. Upon detection of df/dt, operation timer activates the ST_FRG output. When the timer has reached the value set by *Trip Tm df/dt*, the OPR_FRG output is activated if the df/dt condition still persists. If df/dt becomes normal before the module trips, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_FRG output is deactivated.

Load-shedding control

The way of load-shedding, that is, whether to operate based on underfrequency or high df/dt or both, is defined with the *Load shed mode* user setting. The valid operation modes for the *Load shed mode* settings are "Freq<", "Freq< AND df/dt" and "Freq< OR df/dt".

Once the selected operation mode conditions are satisfied, the PICKUP and TRIP output signals are activated.

When the PICKUP output is active, the percentage of the elapsed delay time can be monitored through PICKUP_DUR which is available as monitored data.

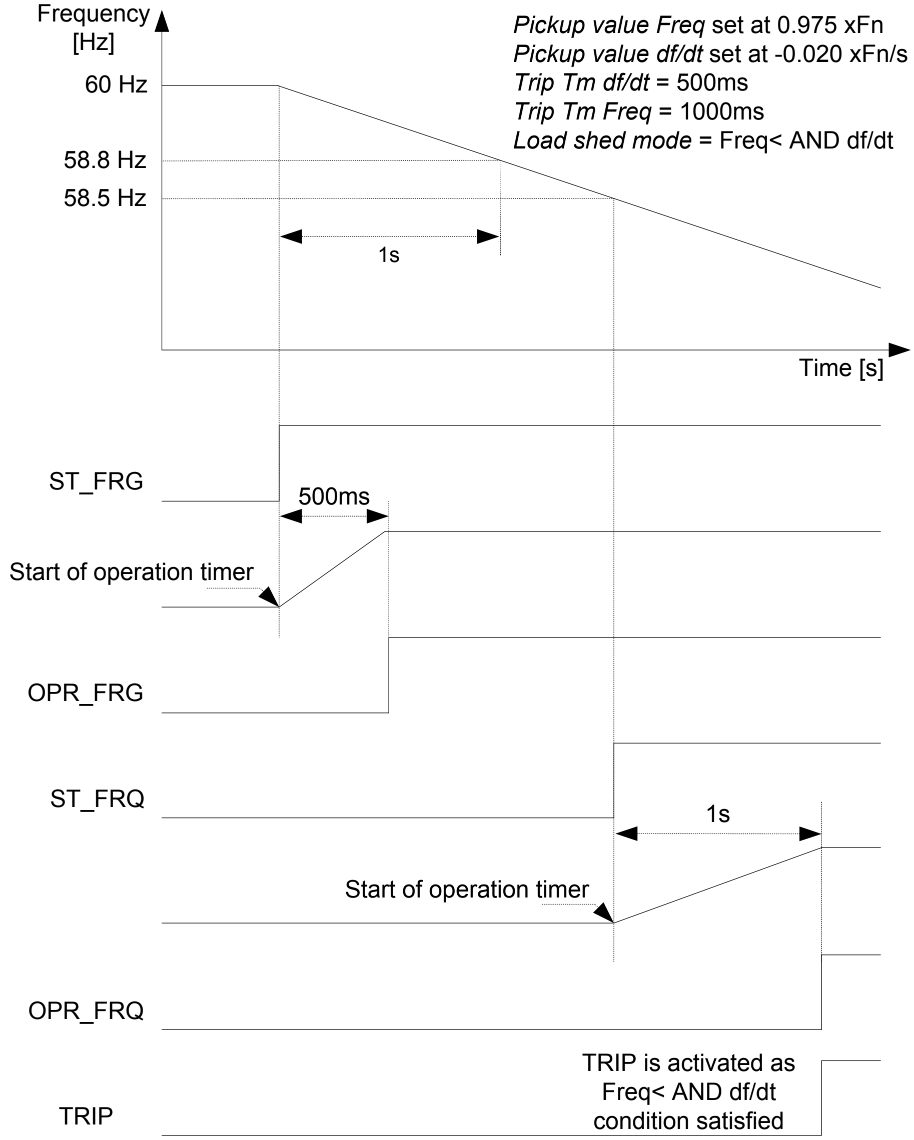


Figure 148: Load-shedding operation in the “Freq< AND df/dt>” mode when both Freq< and df/dt conditions are satisfied (Rated frequency=60 Hz)

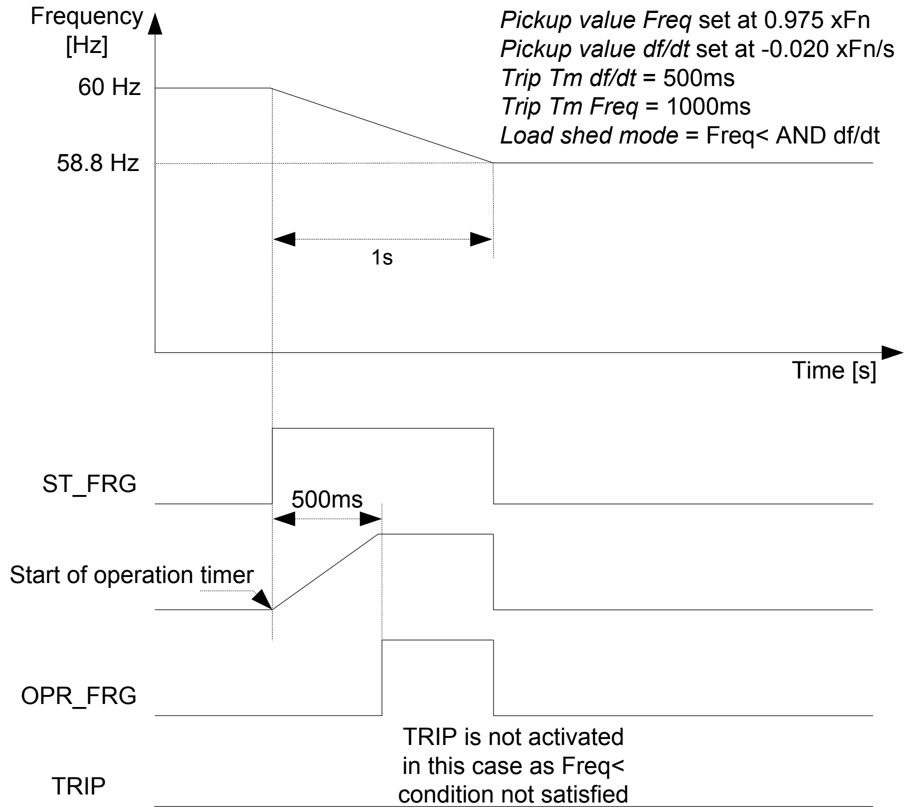


Figure 149: Load-shedding operation in the "Freq< AND df/dt>" mode when only the df/dt condition is satisfied (Rated frequency=60 Hz)

Restore detection

If after the activation of the `TRIP` input the frequency recovers to a level above the *Restore pickup Val* setting, the `RESTORE` signal output is activated. The `RESTORE` output remains active for a 100 ms. The *Restore mode* setting is used to select the restoring mode to be "Disabled", "Auto" or "Manual".

Restoring mode	Description
Disabled	Load restoration is disabled.
Auto	In the “Auto” mode, input frequency is continuously compared to the *Restore pickup Val* setting. The restore detection module includes a timer with the DT characteristics. Upon detection of restoring, the operation timer activates the ST_REST output. When the timer has reached the value of the *Restore delay time* setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the *Restore pickup Val* before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_REST start output is deactivated.
Manual	In the “Manual” mode, a manual restoration is possible through the MAN_RESTORE input or via communication. The ST_REST output is activated if the MAN_RESTORE command is available and the frequency has exceeded the *Restore pickup Val* setting. The manual restoration includes a timer with the DT characteristics. When the timer has reached the set value of the *Restore delay time* setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the *Restore pickup Val* setting before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_REST start output is deactivated.

A condition can arise where the restoring operation needs to be canceled. Activating the BLK_REST input for the "Auto" or "Manual" modes cancels the restoring operation. In the "Manual" restoring mode, the cancellation happens even if MAN_RESTORE is present.

Once the RESTORE output command is cancelled, the reactivation of RESTORE is possible only after the reactivation of the TRIP output, that is, when the next load-shedding operation is detected.

If there is a sharp frequency change in the waveform it can result in a prolonged operate time. The reason is that the frequency algorithm does not see it as a change in frequency, but as a loss of mains situation. In this case frequency protection is delayed with 160 ms to give room for vector shift protection to operate.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** that selects the blocking mode. The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the *Blocking mode* global setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP, OPR_FRQ and OPR_FRG outputs are not activated.

4.3.2.5 Application

An AC power system operates at a defined rated frequency. The nominal frequency in most systems in the world is 50 Hz or 60 Hz. The system operation is such that the operating frequency remains approximately at the nominal frequency value by a small margin. The safe margin of operation is usually less than ±0.5 Hz. The system frequency stability is one of the main concerns in the transmission and distribution network operation and control. To protect the frequency-sensitive electrical equipment in the network, departure from the allowed band for safe operation should be inhibited.

Any increase in the connected load requires an increase in the real power generation to maintain the system frequency. Frequency variations form whenever there are system conditions that result in an unbalance between the generation and load. The rate of change of the frequency represents the magnitude of the difference between the load and generation. A reduction in frequency and a negative rate of change of the frequency are observed when the load is greater than the generation, and an increase in the frequency along with a positive rate of change of the frequency are observed if the generation is greater than the load. The rate of change of the frequency is used for a faster decision of load-shedding. In an underfrequency situation, the load-shedding trips out the unimportant loads to stabilize the network. Thus, loads are normally prioritized so that the less important loads are shed before the important loads.

During the operation of some of the protective schemes or other system emergencies, the power system is divided into small islands. There is always a load - generation imbalance in such islands that leads to a deviation in the operating frequency from the nominal frequency. This off-nominal frequency operation is harmful to power system components like turbines and motors. Therefore, such situation must be prevented from continuing. The frequency-based load-shedding scheme should be applied to restore the operation of the system to normal frequency. This is achieved by quickly creating the load - generation balance by disconnecting the load.

As the formation of the system islands is not always predefined, several load-shedding relays are required to be deployed at various places near the load centers. A quick shedding of a large amount of load from one place can cause a significant disturbance in the system. The load-shedding scheme can be made most effective if the shedding of load feeders is distributed and discrete, that is, the loads are shed at various locations and in distinct steps until the system frequency reaches the acceptable limits.

Due to the action of load-shedding schemes, the system recovers from the disturbance and the operating frequency value recovers towards the nominal frequency. The load that was shed during the disturbance can be restored. The load-restoring operation should be done stepwise in such a way that it does not lead the system back to the emergency condition. This is done through an operator intervention or in case of remote location through an automatic load restoration function. The load restoration function also detects the system frequency and restores the load if the system frequency remains above the value of the set restoration frequency for a predefined duration.

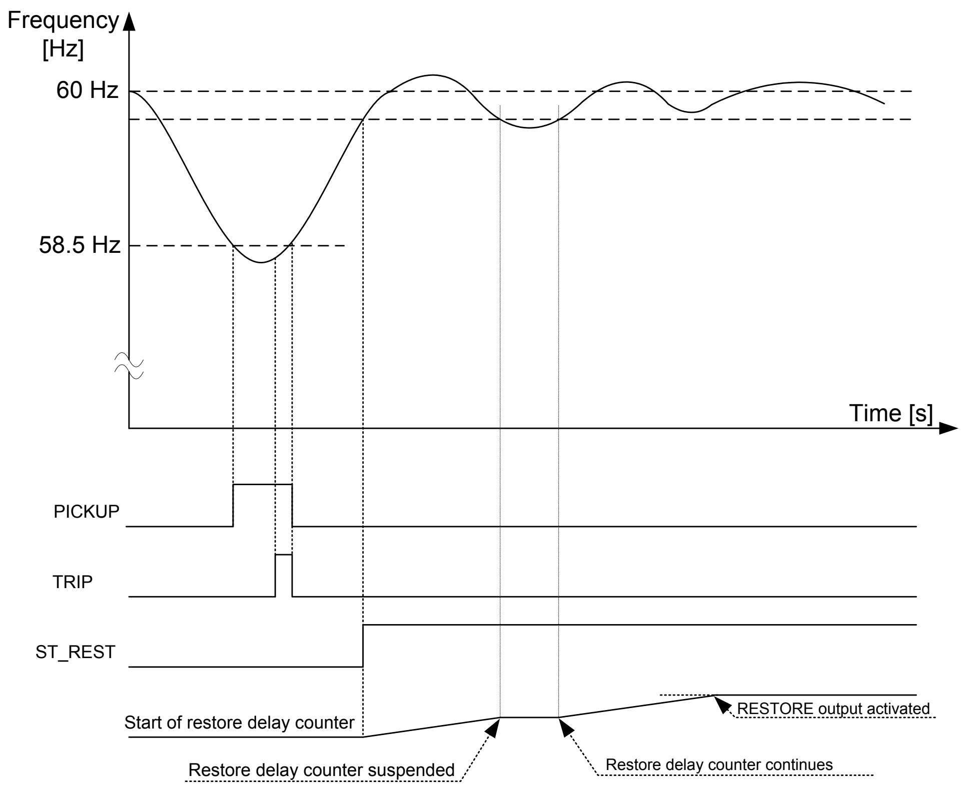


Figure 150: Operation of the load-shedding function

Power system protection by load-shedding

The decision on the amount of load that is required to be shed is taken through the measurement of frequency and the rate of change of frequency (df/dt). At a single location, many steps of load-shedding can be defined based on different criteria of the frequency and df/dt. Typically, the load-shedding is performed in six or four steps with each shedding increasing the portion of load from five to twenty-five percent of full load within a few seconds. After every shedding, the system frequency is read back and further shedding actions are taken only if necessary. In order to take the effect of any transient, a sufficient time delay should be set.

The value of the setting has to be well below the lowest occurring normal frequency and well above the lowest acceptable frequency of the system. The setting level, the number of steps and the distance between two steps (in time or in frequency) depend on the characteristics of the power system under consideration. The size of the largest loss of generation compared to the size of the power system is a critical parameter. In large systems, the load-shedding can be set at a high frequency level and the time delay is normally not critical. In small systems, the frequency pickup level has to be set at a low value and the time delay must be short.

If a moderate system operates at 50 Hz, an underfrequency should be set for different steps from 49.2 Hz to 47.5 Hz in steps of 0.3 – 0.4 Hz. The operating time for the underfrequency can be set from a few seconds to a few fractions of a second stepwise from a higher frequency value to a lower frequency value.

Table 271: Setting for a five-step underfrequency operation

Load-shedding steps	Pickup value Freq setting	Trip Tm Freq setting
1	0.984 · Fn (59 Hz)	45000 ms
2	0.978 · Fn (58.7 Hz)	30000 ms
3	0.968 · Fn (58.1 Hz)	15000 ms
4	0.958 · Fn (57.5 Hz)	5000ms
5	0.950 · Fn (57 Hz)	500 ms

The rate of change of frequency function is not instantaneous since the function needs time to supply a stable value. It is recommended to have a time delay long enough to take care of the signal noise.

Small industrial systems can experience the rate of change of frequency as large as 5 Hz/s due to a single event. Even large power systems can form small islands with a large imbalance between the load and generation when severe faults or combinations of faults are cleared. Up to 3 Hz/s has been experienced when a small island becomes isolated from a large system. For normal severe disturbances in large power systems, the rate of change of the frequency is much less, often just a fraction of 1.0 Hz/s.

Similarly, the setting for df/dt can be from 0.1 Hz/s to 1.2 Hz/s in steps of 0.1 Hz/s to 0.3 Hz/s for large distributed power networks, with the operating time varying from a few seconds to a few fractions of a second. Here, the operating time should be kept in minimum for the higher df/dt setting.

Table 272: Setting for a five-step df/dt< operation

Load-shedding steps	Pickup value df/dt setting	Trip Tm df/dt setting
1	-0.005 · Fn /s (-0.25 Hz/s)	8000 ms
2	-0.010 · Fn /s (-0.25 Hz/s)	2000 ms
3	-0.015 · Fn /s (-0.25 Hz/s)	1000 ms
4	-0.020 · Fn /s (-0.25 Hz/s)	500 ms
5	-0.025 · Fn /s (-0.25 Hz/s)	250 ms

Once the frequency has stabilized, the shed load can be restored. The restoring operation should be done stepwise, taking care that it does not lead the system back to the emergency condition.

Table 273: Setting for a five-step restoring operation

Load-shedding steps	Restoring pickup Val setting	Restore delay time setting
1	0.990 · Fn (59.4 Hz)	200000 ms
2	0.990 · Fn (59.4 Hz)	160000 ms
3	0.990 · Fn (59.4 Hz)	100000 ms
4	0.990 · Fn (59.4 Hz)	50000 ms
5	0.990 · Fn (59.4 Hz)	10000 ms

4.3.2.6 Signals

Table 274: 81LSH Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_REST	BOOLEAN	0=False	Block restore
MAN_RESTORE	BOOLEAN	0=False	Manual restore signal

Table 275: 81LSH Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip of load shedding
OPR_FRQ	BOOLEAN	Trip signal for under frequency
OPR_FRG	BOOLEAN	Trip signal for high df/dt
PICKUP	BOOLEAN	Pickup
ST_FRQ	BOOLEAN	Pick-Up signal for under frequency detection

Table continues on next page

Name	Type	Description
ST_FRG	BOOLEAN	Pick-Up signal for high df/dt detection
RESTORE	BOOLEAN	Restore signal for load restoring purposes
ST_REST	BOOLEAN	Restore frequency attained and restore timer started

4.3.2.7 Settings

Table 276: 81LSH Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Load shed mode	1=Freq< 6=Freq< OR df/dt 8=Freq< AND df/dt			1=Freq<	Set the operation mode for load shedding function
Restore mode	1=Disabled 2=Auto 3=Manual			1=Disabled	Mode of operation of restore functionality
Pickup value Freq	0.800...1.200	xFn	0.001	0.975	Frequency setting/pickup value
Pickup value df/dt	-0.200...-0.005	xFn /s	0.005	-0.010	Setting of frequency gradient for df/dt detection
Trip Tm Freq	80...200000	ms	10	200	Time delay to trip for under frequency stage
Trip Tm df/dt	120...200000	ms	10	200	Time delay to trip for df/dt stage
Restore pickup Val	0.800...1.200	xFn	0.001	0.998	Restore frequency setting value
Restore delay time	80...200000	ms	10	300	Time delay to restore

Table 277: 81LSH Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	50	Time delay after which the definite timers will reset

4.3.2.8 Monitored data

Table 278: 81LSH Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Pickup duration
81LSH	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.3.2.9 Technical data

Table 279: 81LSH Technical data

Characteristic		Value
Operation accuracy	f<	±10 mHz
	df/dt	±100 mHz/s (in range |df/dt| < 5 Hz/s) ± 2.0% of the set value (in range 5 Hz/s < |df/dt| < 15 Hz/s)
Pickup time	f<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Trip time accuracy		±1.0% of the set value or ±30 ms

4.4 Power protection

4.4.1 Three-phase directional power protection 32P

4.4.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase directional power protection	DPSRDIR	I1->	32P

4.4.1.2 Function block

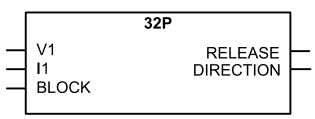


Figure 151: Function block

4.4.1.3 Functionality

The three-phase directional power protection 32P is used to detect positive-sequence power direction. The output of the function is used for blocking or releasing other functions in protection scheme.

The directional positive-sequence power protection contains a blocking functionality which blocks function output and resets Timer.

32P executes on the direction of positive-sequence power and not the value. If overpower or underpower is needed, refer to 32O and 32U. 32P is generally used for directional controls.

4.4.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of 32P can be described with a module diagram. All the modules in the diagram are explained in the next sections.

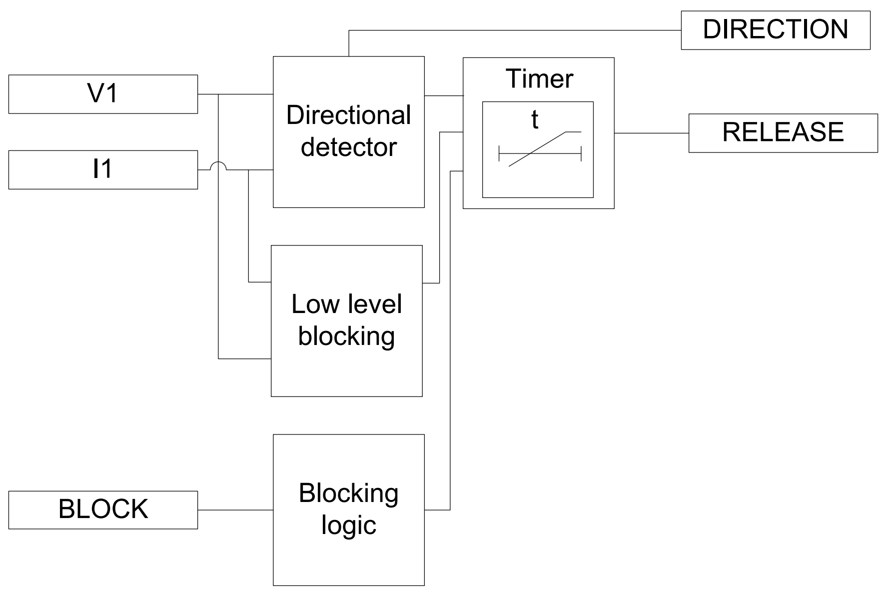


Figure 152: Functional module diagram

Directional detector

The Directional detector module compares the angle of the positive-sequence current I1 to the angle of the positive-sequence voltage V1. Using the positive-sequence voltage angle as reference, the positive-sequence current angle is compared to the *Characteristic angle* setting. If the angular difference is within the operating sector selected with the *Directional mode* setting, the Enable signal is sent to Timer.

The operating sector is defined by the setting *Min forward angle*, *Max forward angle*, *Min reverse angle* and *Max reverse angle*. The options that can be selected for the *Directional mode* setting are “Forward” and “Reverse”.

The sector limits are always given as positive degree values.

The *Characteristic angle* setting is also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Line.

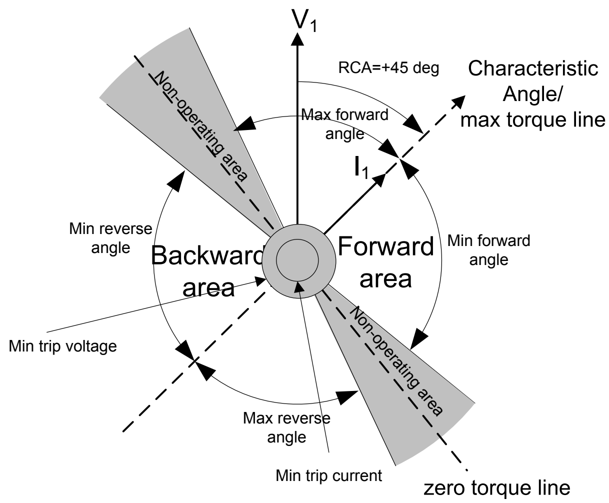


Figure 153: Configurable directional settings

Low-level blocking

For a reliable operation, signal levels should be greater than the minimum level. If they are not greater than the minimum level, Timer is blocked. If the amplitude of the positive-sequence current is greater than the *Min trip current* value and the positive-sequence voltage amplitude is greater than the *Min trip voltage* value, the Enable signal is sent to Timer.

Timer

Once activated, the internal operating timer is started. The Timer characteristic is according to definite time DT. When Timer has reached the value of *Release delay time*, the RELEASE output is activated. If a drop-off situation happens, that is, if the operating current moves outside the operating sector or signal amplitudes drop below the minimum level before *Release delay time* is exceeded, the Timer reset state is activated. If the drop-off continues for more than *Reset delay time*, Timer is deactivated.

Blocking logic

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates the RELEASE output and resets Timer.

4.4.1.5 Application

The three-phase directional power protection 32P improves the possibility to obtain a selective function of the overcurrent protection in meshed networks. 32P is used to block or release other overcurrent protection functions.

4.4.1.6 Signals

Table 280: 32P Input signals

Name	Type	Default	Description
V1	REAL	0.0	Positive sequence voltage
I1	REAL	0.0	Positive sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 281: 32P Output signals

Name	Type	Description
RELEASE	BOOLEAN	direction signal
DIRECTION	Enum	Direction information

4.4.1.7 Settings

Table 282: 32P Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Release delay time	0...1000	ms	1	10	Release delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	88	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	88	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	88	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	88	Minimum phase angle in reverse direction
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode

Table 283: 32P Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Min trip current	0.01...1.00	xIn	0.01	0.10	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.30	Minimum trip voltage

4.4.1.8 Monitored data

Table 284: 32P Monitored data

Name	Type	Values (Range)	Unit	Description
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
32P	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.4.2 Ground directional power protection 32N

4.4.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Ground directional power protection	DNZSRDIR	I2->, Io->	32N

4.4.2.2 Function block

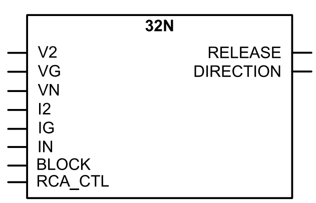


Figure 154: Function block

4.4.2.3 Functionality

Ground directional power protection 32N is used to detect negative or residual power direction. The output of the function is used for blocking or releasing other functions in protection scheme.

In negative-sequence voltage selection, if the angle difference between negative-sequence voltage and negative-sequence current is in a predefined direction (either in forward or reverse direction), 32N gives a release signal after a definite time delay.

In residual voltage selection, if the angle difference between residual voltage and residual current is in a predefined direction (either in forward or reverse direction), 32N gives release signal after a definite time delay.

This function contains a blocking functionality which blocks the function output and resets Timer.

32N executes on the direction of either negative-sequence or zero-sequence power and not the value. 32N is generally used for directional controls.

4.4.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of directional negative/zero sequence power protection (32N) can be described with a module diagram. All the modules in the diagram are explained in the next sections.

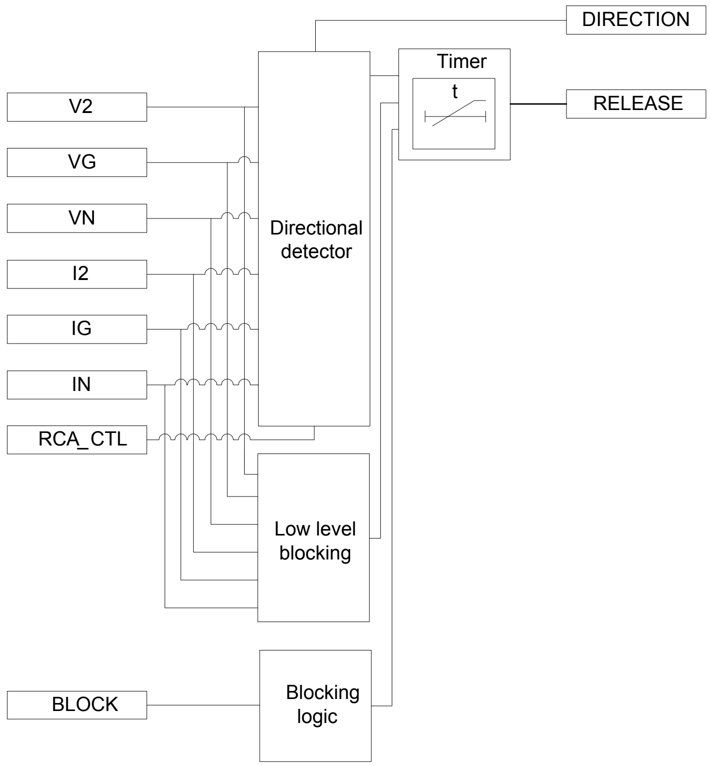


Figure 155: Functional module diagram

Directional detector

When "Neg. seq. volt." selection is made using *Pol signal Sel*, the Directional detector module compares the angle of the negative-sequence current (I2) to the negative-sequence voltage (-V2). Using the negative-sequence voltage angle as the reference, the negative-sequence current angle is compared to the *Characteristic angle* setting. If the angle difference is within the operating sector selected by *Direction mode* setting, the Enable signal is sent to Timer.

The value of *Characteristic angle* should be chosen in such way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the backward zone.

The operating sector is defined by the settings *Max forward angle*, *Max reverse angle*, *Min forward angle* and *Min reverse angle*. The options that can be selected for *Directional mode* settings are “Forward” and “Reverse”.

Characteristic angle is also known as Relay Characteristic Angle RCA, Relay Base Angle or Maximum Torque Line.

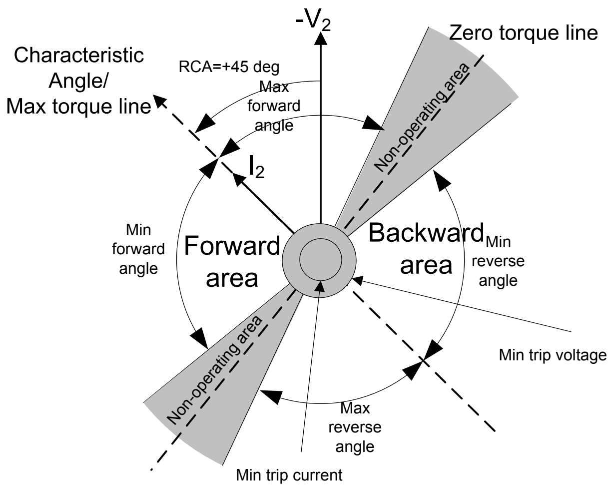


Figure 156: Configurable directional setting when "Neg. seq. volt." selection is made using Pol signal Sel.

When "Measured VG" or "Calculated VN" voltage selection is made using *Pol signal Sel* setting, the directional detector module compares the angle of the residual current to the residual voltage. Using the residual voltage as reference, the residual current angle is compared to the *Characteristic angle* setting. If the angle difference is within the operating sector selected by the *Directional mode* setting, the Enable signal is sent to Timer.

"Measured IG" or "Calculated IN" (residual current) can be selected with the *Io signal Sel* setting.
The "Measured VG", "Calculated VN" (residual voltage) can be selected with the *Pol signal Sel* setting.

The polarizing quantity (residual voltage) is inverted because of switched voltage measurement cables, the correction can be done by setting the *Pol reversal* setting to "True", which rotates the polarizing quantity by 180 degrees.

The operating sector is defined by the settings *Max forward angle*, *Max reverse angle*, *Min forward angle* and *Min reverse angle*. The options that can be selected for the *Directional mode* settings are "Forward" and "Reverse".

The directional characteristic for the measured or calculated residual power is same.

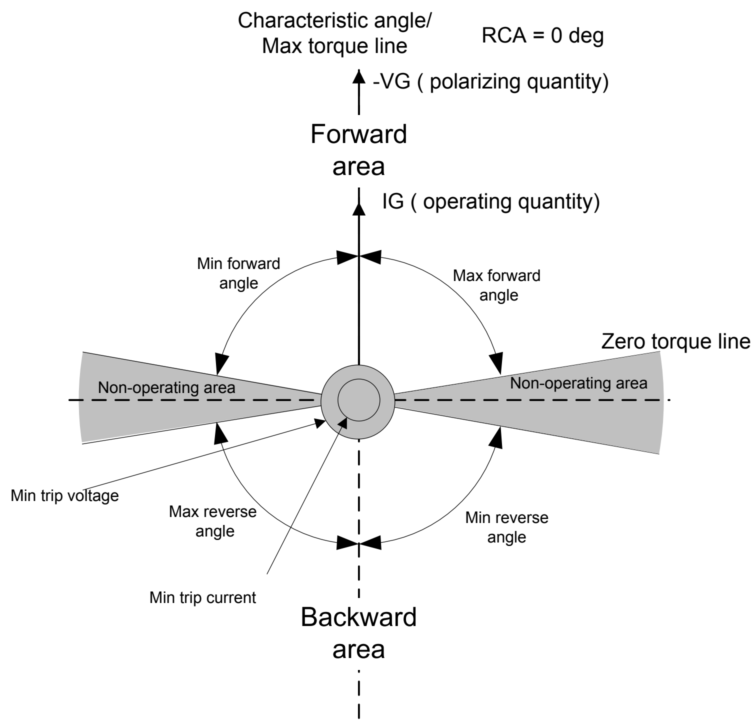


Figure 157: Configurable directional setting for "Measured VG" or "Calculated VN" (residual voltage) using Pol signal Sel setting

The *Characteristic angle* setting is done based on method of grounding employed in the network. For example, in case of an isolated network, *Characteristic angle* is set to -90°, and in case of a compensated network, *Characteristic angle* is set to 0° and 60° for solidly grounded systems. In general *Characteristic angle* is selected so that it matches close to the expected fault angle value, which results in maximum sensitivity. *Characteristic angle* can be set anywhere between -179° to +180°. The figures show examples of the operating area with RCA set to +60° and -90°, respectively.

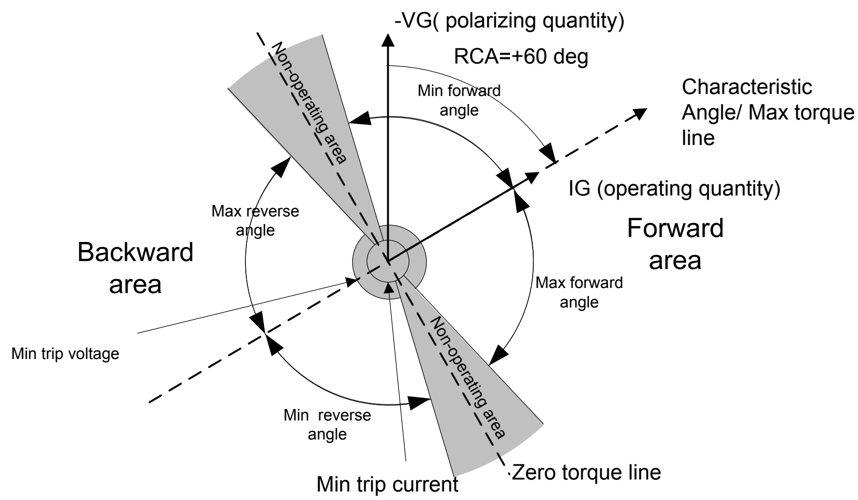


Figure 158: *Configurable directional characteristics (RCA =+60˚) for a solidly grounded network*

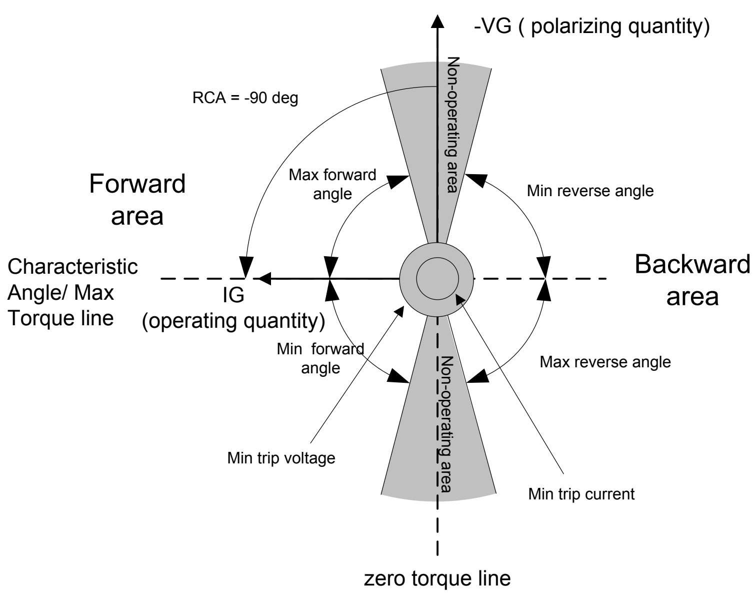


Figure 159: *Configurable directional characteristics (RCA = -90˚) for an isolated network*

Characteristic angle should be set to a positive value if the operating signal IG or IN lags the polarizing quantity –VG or –VN, respectively, and a negative value if operating signal IG or IN leads the polarizing quantity –VG or –VN, respectively.

Table 285: Recommended Characteristic angle setting for different network

Type of network	Characteristic angle recommended
Compensated network	0°
Solidly grounded network	+60°
Isolated network	-90°

The *Characteristic angle* setting is adjusted to the operation according to the method of neutral-point grounding, so that in an isolated network *Characteristic angle* is -90° and in a compensated network 0°. In addition, *Characteristic angle* can be changed via the control signal RCA_CTL, in which case the alternatives are -90° and 0°. The operation of the `RCA_CTL` input depends on the *Characteristic angle* setting.

The Peterson coil or the grounding resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the *Characteristic angle* settings accordingly. This is done with an auxiliary input in the relay which receives a signal from an auxiliary switch of the disconnector of the Peterson coil in compensated networks or of the grounding resistor in grounded network as a result the *Characteristic angle* is set automatically to suit the grounding method.

Table 286: Characteristic angle control for the `RCA_CTL` condition

Characteristic angle Setting	`RCA_CTL`=FALSE	`RCA_CTL`=TRUE
-90°	*Characteristic angle* =-90°	*Characteristic angle* = 0°
0°	*Characteristic angle* = 0°	*Characteristic angle* =-90°

Low-level blocking

For a reliable operation, signal levels should be greater than the minimum level. If they are not greater than the minimum level, Timer is blocked.

In the "Neg. seq. volt." polarization selection using *Pol signal Sel*, if the amplitude of the negative-sequence current is greater than the *Min trip current* value and the negative-sequence voltage amplitude is greater than the *Min trip voltage* value, the enabling signal is sent to Timer.

In the "Measured VG" or "Calculated VN" polarization selection using *Pol signal Sel*, if the amplitude of the residual current is greater than the *Min trip current* value and residual voltage amplitude is greater than the *Min trip voltage* value, the enabling signal is sent to Timer.

Timer

Once activated, the internal operating timer is started. The Timer characteristic is according to DT. When Timer has reached the value of *Release delay time*, the RELEASE output is activated. If a drop-off situation happens, that is, if the operating current moves out of the operating sector or signal amplitudes drop below the minimum levels, before *Release delay time* is exceeded, the Timer reset state is activated. If the drop-off continues for more than *Reset delay time*, Timer is deactivated.

Blocking logic

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates RELEASE output and resets Timer.

4.4.2.5 Application

The ground directional power protection 32N improves the possibility to obtain selective function of the overcurrent protection in meshed networks. 32N is used to block or release other overcurrent protection functions.

4.4.2.6 Signals

Table 287: 32N Input signals

Name	Type	Default	Description
V2	REAL	0	Negative sequence voltage
VG	REAL	0	Measured residual voltage or Ground voltage
VN	REAL	0	Calculated residual voltage or Neutral voltage
I2	REAL0	0	Negative sequence current
IG	REAL	0	Measured residual current or Ground current
IN	REAL	0	Calculated residual current or Neutral current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

Table 288: 32N Output signals

Name	Type	Description
RELEASE	BOOLEAN	direction signal
DIRECTION	Enum	Direction information

4.4.2.7 Settings

Table 289: 32N Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Release delay time	0...1000	ms	10	10	Release delay time
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...180	deg	1	88	Maximum phase angle in forward direction
Min forward angle	0...180	deg	1	88	Minimum phase angle in forward direction
Max reverse angle	0...180	deg	1	88	Maximum phase angle in reverse direction
Min reverse angle	0...180	deg	1	88	Minimum phase angle in reverse direction

Table 290: 32N Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
Min trip current	0.01...1.00	xIn	0.01	0.10	Minimum trip current
Min trip voltage	0.01...1.00	xVn	0.01	0.30	Minimum trip voltage
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
IG/I0 Sel	1=Measured IG 2=Calculated I0			2=Calculated I0	IG/I0 selection
Pol signal Sel	1=Measured VG 2=Calculated V0 3=Neg. seq. volt.			2=Calculated V0	Selection for used polarization signal

4.4.2.8 Monitored data

Table 291: 32N Monitored data

Name	Type	Values (Range)	Unit	Description
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
32N	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.4.3 Three-phase directional overpower protection 32O

4.4.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEE C37.2 device number
Three-phase directional overpower protection	DOPPDPR	P>	32O

4.4.3.2 Function block

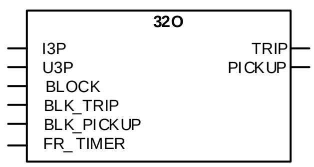


Figure 160: Function block

4.4.3.3 Functionality

The directional overpower protection 32O can be used as generator protection against delivering excessive power beyond its capacity to the grid, against generator running like motor, against motor running like generator and protecting motor which consumes more reactive power due to loss of field. It can also be used in feeder protection for indicating overload on the distribution system, to indicate that a customer is supplying power into the grid and for protecting the transformer from delivering an excessive load.

The function starts and operates when the measured power exceeds the set limit and in a specified direction. The operate time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.4.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of 32O can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

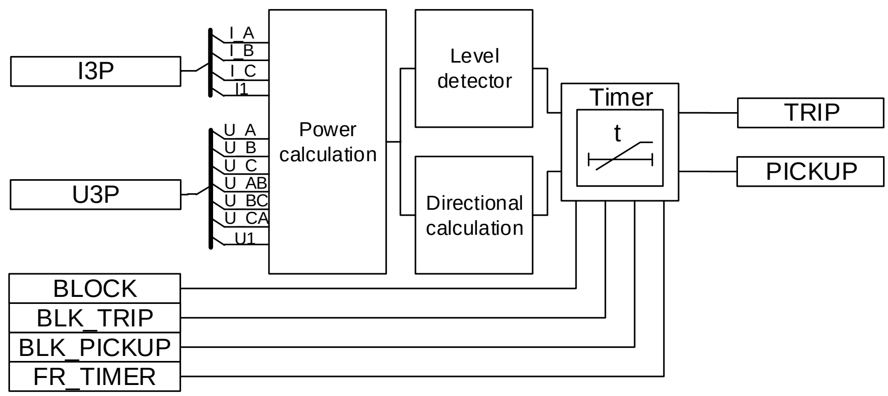


Figure 161: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltages and currents. The *Measurement mode* setting determines which voltages and currents are used. It is also possible to use positive-sequence components for calculating the apparent power which makes the determination of power insensitive to a possible asymmetry in currents or voltages and corresponds to the real load on the prime mover of the generator.

Table 292: Voltages and currents used in apparent power calculation

Measurement mode setting	Voltage and currents used in power calculation
PhsA, PhsB, PhsC	U_A, U_B, U_C, I_A, I_B, I_C
Arone	U_AB, U_BC, I_A, I_C
Pos Seq	{U_A,U_BU_C} or {U_AB,U_BC,U_CA} and I_A, I_B, I_C
PhsAB	U_AB,I_A,I_B
PhsBC	U_BC,I_B,I_C
PhsCA	U_CA,I_C,I_A
PhsA	U_A,I_A
PhsB	U_B,I_B
PhsC	U_C,IC

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

The calculated powers S, P, Q and the power factor angle PF_ANGL are available in the Monitored data view.

Level detector

The Level detector compares the magnitude of the measured apparent power to the set *Start value*. If the measured value exceeds the set *Start value*, the Level detector sends an enabling signal to the Timer module.

Directional calculation

The Directional calculation module monitors the direction of the apparent power. When the apparent power flow is in the operating area, the module sends the enabling signal to the Timer module. The directional operation can be selected with the combination of the settings *Directional mode* and *Power angle*. The selectable options for the *Directional mode* setting are "Forward" and "Reverse". The *Power angle* setting can be used to set the power direction between the reactive and active power.

A typical error is, for example, that the VT or CT poles are wrongly connected. This is seen as a power flow opposite to that of the intended direction. The *Pol Reversal* setting can be used to correct the situation. By setting the value to "Yes", the measured apparent power is turned 180 degrees.

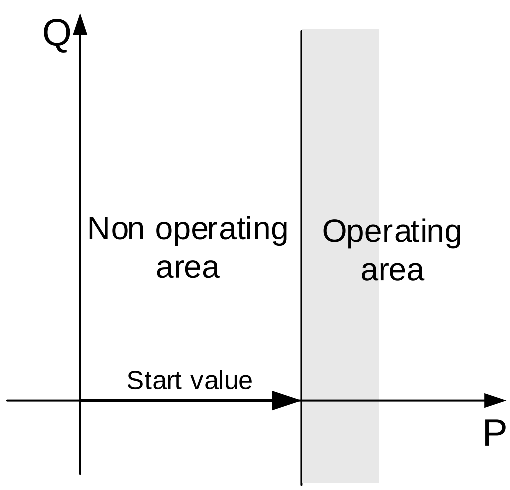


Figure 162: Operating characteristics with the Start Value setting, the Power angle setting being 0 and Directional mode "Forward"

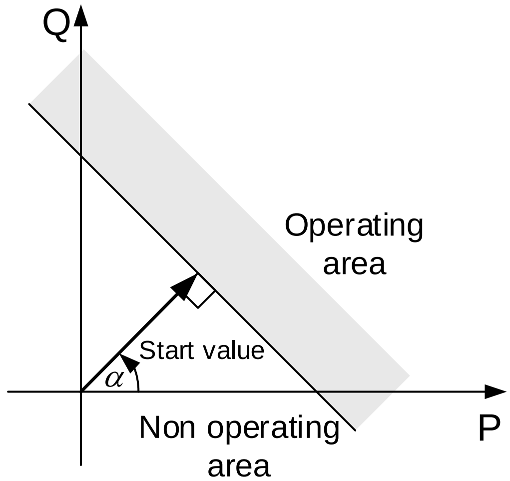


Figure 163: Operating characteristics with the Start Value setting, Power angle (α) being +45 and Directional mode "Forward"

Timer

Once activated, the Timer activates the PICKUP output. The time characteristics are according to DT. When the operation timer has reached the value of *Trip delay time*, the TRIP output is activated. If a drop-off situation happens, that is, the value of power drops below *Pickup value* before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the PICKUP output is deactivated.

The Timer calculates the start duration value PICKUP_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the Monitored data view.

Blocking logic

The binary input BLOCK can be used to block the module. The activation of the BLOCK input deactivates all outputs and resets internal timer. The binary input BLK_PICKUP can be used to block the PICKUP signal. The binary input BLK_TRIP can be used to block the TRIP signal. The operation timer counting can be frozen on the prevailing value by activation of the FR_TIMER input.

4.4.3.5 Application

32O is used to provide protection against an excessive power flow in the set operating direction. The main application is the protection of generators and turbines. It can also be used in feeder protection applications, for example, the ring network.

32O in the forward direction can be used to protect the generators or motors from delivering or consuming excess power. For example, the generator overpower protection can be used to shed a noncritical feeder load or to start parallel generators. A synchronous motor may start consuming more reactive power in case of loss of excitation, in which case the forward overpower protection is used to detect such condition.

The 32O function has many applications when used as reverse power protection. A generator in a power plant converts mechanical energy to electrical energy. Sometimes the mechanical power from a prime mover may decrease to a limit that it does not cover the internal losses. The synchronous generator becomes a synchronous motor and starts importing power from the system. The effect of a generator acting as a motor implies no risk to the machine but can cause damage to the prime mover. The extent of the damage depends on the type of the prime mover.

Steam turbines become overheated easily if the steam flow drops too low or if the steam ceases to flow through the turbine. The break of a main steam pipe, damage to one or more blades in the steam turbine or an inadvertent closing of the main stop valves are typical causes for the low steam flow. The steam turbines of turbo generators can be protected during a low steam flow with the overpower protection operating in reverse direction. Hydroturbines tolerate reverse power much better than steam turbines do. There is a risk that the turbine runner moves axially and touches stationary parts. They are not always strong enough to withstand the associated stresses.

A hydroturbine that rotates in water with the closed wicket gates draws about 10% of the rated power from the rest of the power system if the intake is blocked due to ice, snow, branches or leaves. A complete blockage of the intake may cause cavitations. If there is only air in the hydroturbine, the power demand drops to about 3%. The risk of damages to the hydroturbines can justify the reverse operation of the overpower protection in unattended plants.

Whenever a low value of the reverse power setting is required, an underpower protection should also be used in conjunction with 32O. The limit depends on the CT and VT accuracy.

Diesel engines should have overpower protection in reverse direction. The generator takes about 15% or more of its rated power from the system. A stiff engine may require 25% of the rated power to motor it. A well run engine may need no more than 5%. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Reverse overpower can also act as an alternative for an under excitation protection in case of small generators. If the field excitation is reduced, the generator may start importing the reactive power, making the generator run as an asynchronous generator. A synchronous generator is not designed to work asynchronously and may become damaged due to heating in the damper windings or heating in the rotor due to slip frequency current.

When operated in reverse power direction, 32O can be used as an alarm if the power flowing from the industry is feeding the grid, which may not be desired as per the rules and regulations of the utility owning the grid.

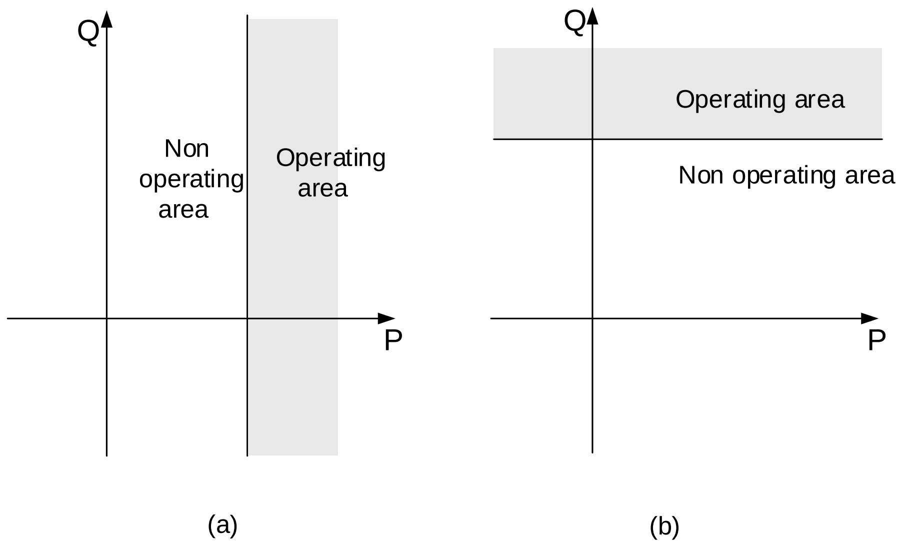


Figure 164: Forward active overpower characteristics (a) and forward reactive overpower characteristics (b)

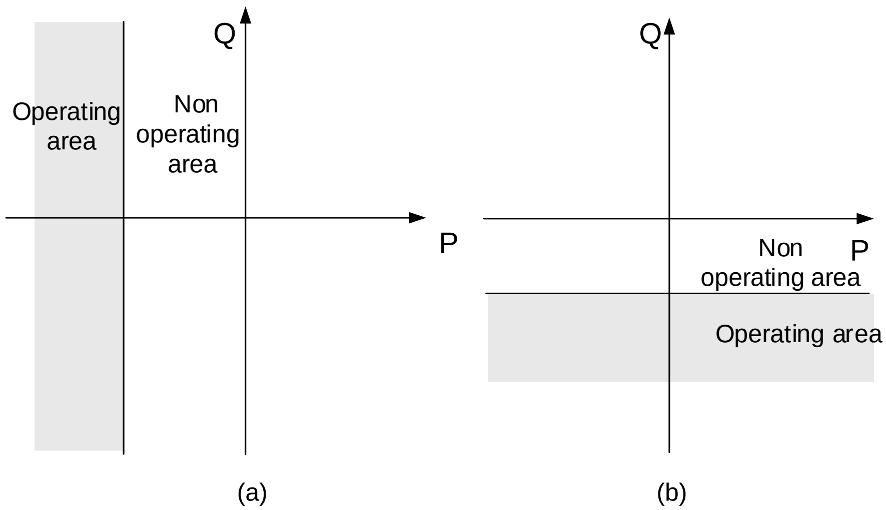


Figure 165: Reverse active overpower characteristics (a) and reverse reactive overpower characteristics (b)

4.4.3.6 Signals

Table 293: 32O Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	0.0	Group signal for current inputs
U3P	GROUP SIGNAL	0.0	Group signal for voltage inputs
BLOCK	BOOLEAN	FALSE	Block signal for activating the blocking mode
BLK_TRIP	BOOLEAN	FALSE	Block signal for operate output
BLK_PICKUP	BOOLEAN	FALSE	Block signal for start
FR_TIMER	BOOLEAN	FALSE	Freeze signal for timer

Table 294: 32O Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.4.3.7 Settings

Table 295: 32O Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.01...2.00	%Sn	0.01	1.00	Pickup value
Trip delay time	40...300000	ms	10	40	Trip delay time
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Power angle	-90...90	deg	1	0	Adjustable angle for power

Table 296: 32O Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Enable / Disable
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			3=Pos Seq	Selection of power calculation method
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction

4.4.3.8 Monitored data

Table 297: 32O Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	-160.000...160.000	xSn	Apparent power
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
32O	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.4.3.9 Technical data

Table 298: 32O Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±3% of the set value or ±0.002 × S_n Phase angle: ±2°
Pickup time[1)2)]	Typically 20 ms (±15 ms)
Reset time	<40 ms
Reset ratio	Typically 0.94
Redardation time	<45 ms
Operate time accuracy	±1.0% of the set value of ±20 ms

1) Based on nominal voltage and frequency
2) Includes the delay of the signal output contact

4.4.4 Three-phase directional underpower protection 32U

4.4.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase directional underpower protection	DUPPDPR	P<	32U

4.4.4.2 Function block

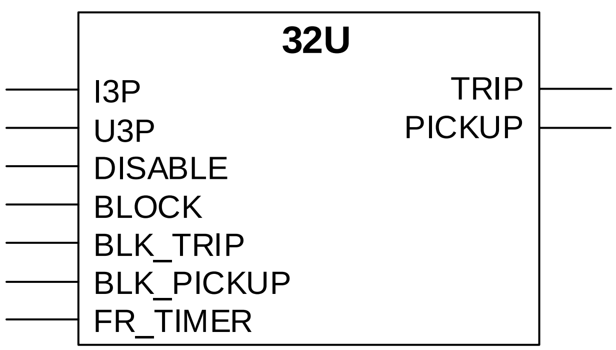


Figure 166: Function block

4.4.4.3 Functionality

The underpower protection 32U is used for protecting generators and prime movers against the effects of very low power outputs or reverse power condition.

The function operates when the measured active power falls below the set value. The operating characteristics are according to definite time DT.

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.4.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of 32U can be described using a module diagram. All the modules in the diagram are explained in the next sections.

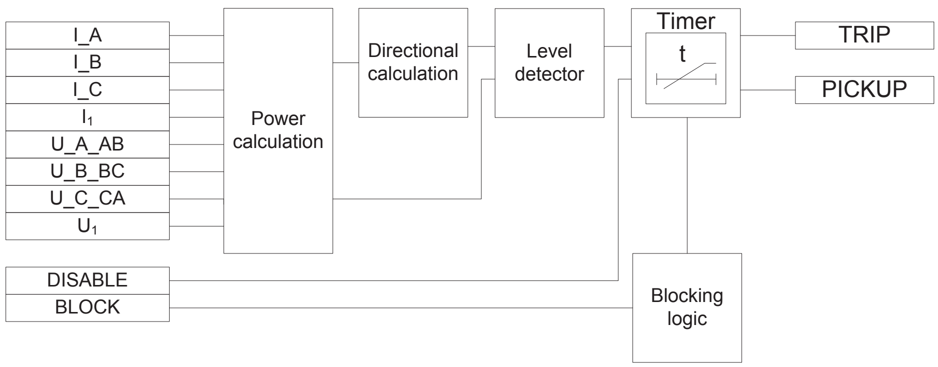


Figure 167: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltage and current measurements as described in Table. The *Measurement mode* setting determines which voltage and current measurements are to be used.

It is also possible to use positive-sequence components for calculating apparent power, which makes the determination of power insensitive to the possible asymmetry in currents or voltages and corresponds to the real load of the prime mover of the generator.

Table 299: Power calculation

Measurement mode setting	Power calculation
PhsA, PhsB, PhsC	U_A, U_B, U_C, I_A, I_B, I_C
Arone	U_AB, U_BC, I_A, I_C
Pos Seq	{U_A, U_B, U_C} or {U_AB, U_BC, U_CA} and I_A, I_B, I_C
PhsAB	U_AB, I_A, I_B
PhsBC	U_BC, I_B, I_C
PhsCA	U_CA, I_C, I_A
PhsA	U_A, I_A
PhsB	U_B, I_B
PhsC	U_C, I_C

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended (default).

Depending on the set *Measurement mode*, the power calculation calculates active power, reactive power and apparent power values from the available set of measurements. The calculated powers S, P, Q and the power factor angle, PF_ANGL, are available in the Monitored data.

Directional calculation

The Directional calculation determines the direction of the measured power. The measured power is considered to be in the forward direction if the active power is positive, else it is considered to be in the reverse direction.

If the polarity of the measured power is opposite to normal, the correction can be done by setting *Pol reversal* to "Yes", which rotates the apparent power by 180 degrees.

Level detector

The Level detector compares the calculated value of the active power with a set *Start value*. If the calculated value of the active power falls below *Start value* in the forward direction or if the measured power is in the reverse direction, the Level detector enables the Timer module.

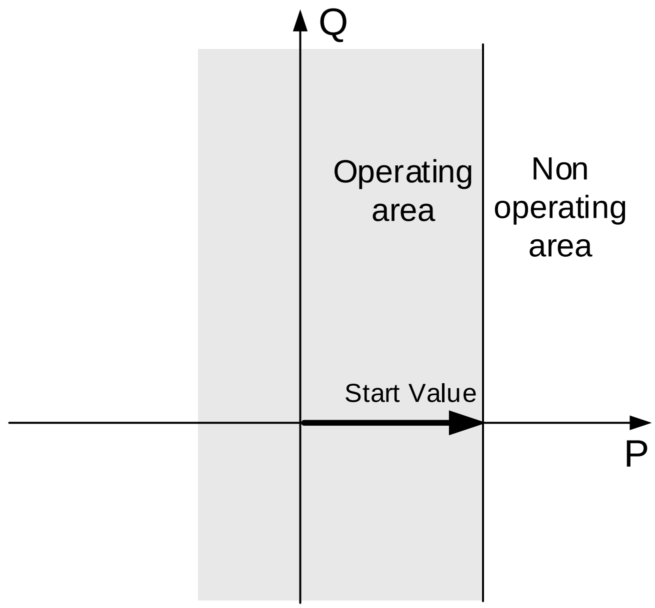


Figure 168: Operating characteristics of 32U with setting Start value

Timer

Once activated, the Timer activates the `PICKUP` output. The time characteristics are according to DT. When the operation timer has reached the value of *Trip delay time*, the `TRIP` output is activated. In a drop-off situation, that is, if the underpower condition disappears before the operation delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the `PICKUP` output is deactivated.

The `DISABLE` input can be used to coordinate the correct operation during the generator start-up situation. By activating the `DISABLE` signal, both the `PICKUP` and `TRIP` outputs are blocked. Once the `DISABLE` signal is deactivated, the Timer remains blocked for an additional time duration as set through the setting *Disable time*.

Blocking logic

The binary input `BLOCK` can be used to block the module. The activation of the `BLOCK` input deactivates all binary outputs and resets internal timer. The binary input `BLK_PICKUP` can be used to block the `PICKUP` signal. The binary input `BLK_TRIP` can be used to block the TRIP signal. The operation timer counting can be frozen on the prevailing value by activation of the FR_TIMER input.

4.4.4.5 Application

The task of a generator in a power plant is to convert mechanical energy into electrical energy. Sometimes the mechanical power from the prime mover may decrease so much that it does not cover the internal losses. The task of an underpower protection is to protect the generator from very low power output conditions.

Steam turbines become easily overheated if the steam flow becomes too low or if the steam ceases to flow through the turbine. Hydro turbine of the Kaplan type may be damaged due to the fact that the turbine blade surfs on the water and sets up axial pressure on the bearing. Diesel engines may be damaged due to insufficient lubrication.

If the generator size is very large, it is uneconomical to continue running it with low generated power. In the reverse power condition, large generators draw a considerable amount of power from the rest of the system to feed their internal losses. Hence, it is desirable to disconnect the generator in such situations.

In case of the parallel-connected generators, for example, the load of one generator may be so low that it is better to disconnect it and let the remaining generators feed the network.

Where a low value of power setting is required, for example less than 2%, the correction parameters should be used to compensate for the measuring errors. The manufacturer of the measuring devices is to be contacted for information on the measuring errors.
If the measuring errors are not compensated for, the underpower setting should not be lower than the sum of the current-measuring and voltage-measuring errors.
For example, if the error of the current-measuring device is 2% and that of the voltage-measuring device is 1%, the minimum setting is (2 + 1)% = 3%.

4.4.4.6 Signals

Table 300: 32U Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	0.0	Group signal for current inputs
U3P	GROUP SIGNAL	0.0	Group signal for voltage inputs
BLOCK	BOOLEAN	FALSE	Block signal for activating the blocking mode
Table continues on next page			

Name	Type	Default	Description
DISABLE	BOOLEAN	FALSE	Signal to block the function during generator startup
BLK_TRIP	BOOLEAN	FALSE	Block signal for operate output
BLK_PICKUP	BOOLEAN	FALSE	Block signal for start
FR_TIMER	BOOLEAN	FALSE	Freeze signal for timer

Table 301: 32U Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.4.4.7 Settings

Table 302: 32U Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	0.01...2.00	xSn	0.01	0.10	Pickup value
Trip delay time	40...300000	ms	10	40	Trip delay time

Table 303: 32U Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Opeartion
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			3=Pos Seq	Selection of power calculation method
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction
Disable time	0...60000	ms	1000	0	Additional wait time after CB closing

4.4.4.8 Monitored data

Table 304: 32U Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	-160.000...160.000	xSn	Apparent power
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
32U	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.4.4.9 Technical data

Table 305: 32U Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±3% of the set value or ±0.002 × S_n
Pickup time[1)2)]	Typically 20 ms (±15 ms)
Reset time	<400 ms
Reset ratio	Typically 0.94
Retardation time	<45 ms
Trip time accuracy	±1.0% of the set value of ±20 ms

1) Based on nominal voltage and frequency
2) Includes the delay of the signal output contact

4.4.5 Power factor 55

4.4.5.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Power factor	MPUPF	PF<	55

4.4.5.2 Function block

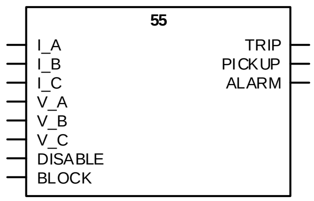


Figure 169: Function block

4.4.5.3 Functionality

The under power factor function 55 is used to provide out-of-step and loss of, or under excitation protection for small synchronous motors and generators. The function calculates the power factor and uses a threshold of under power factor as an indication of an out-of-step and/or loss of excitation condition.

In addition, the function can be applied as a power factor controller.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself, if desired.

4.4.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of 55 can be described using a module diagram. All the modules in the diagram are explained in the next sections.

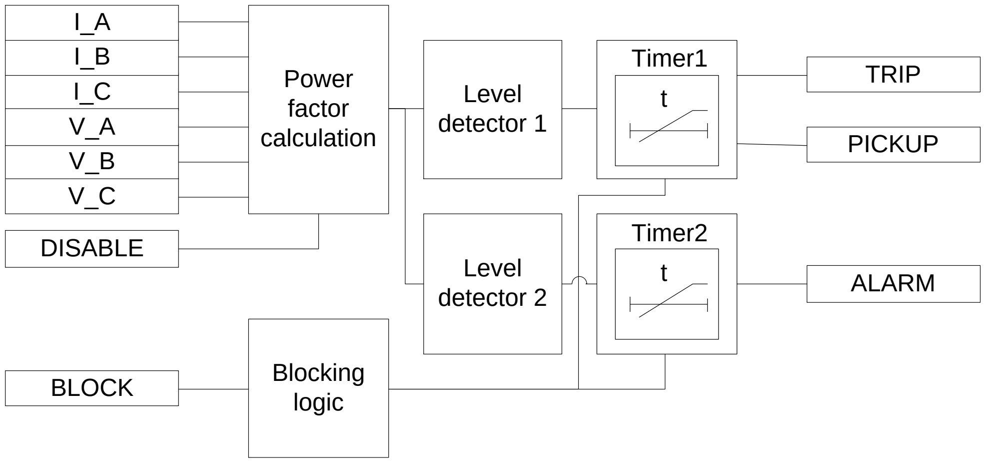


Figure 170: Functional module diagram

Power factor calculation

This module calculates three phase power factor using phase currents and voltages.

The three-phase power is calculated from the fundamental frequency components (DFT) of the phase-to-earth voltages and phase-to-earth currents.

$$\overline{S} = \overline{U}_A \cdot \overline{I}_A^* + \overline{U}_B \cdot \overline{I}_B^* + \overline{U}_C \cdot \overline{I}_C^*$$

(Equation 17)

$$P = Re(\overline{S})$$

(Equation 18)

$$PF = \frac{P}{|\overline{S}|}$$

(Equation 19)

Figure 171 shows the resulting sign of the power factor. This should be consistent with the settings in the power and energy metering function of the relay.

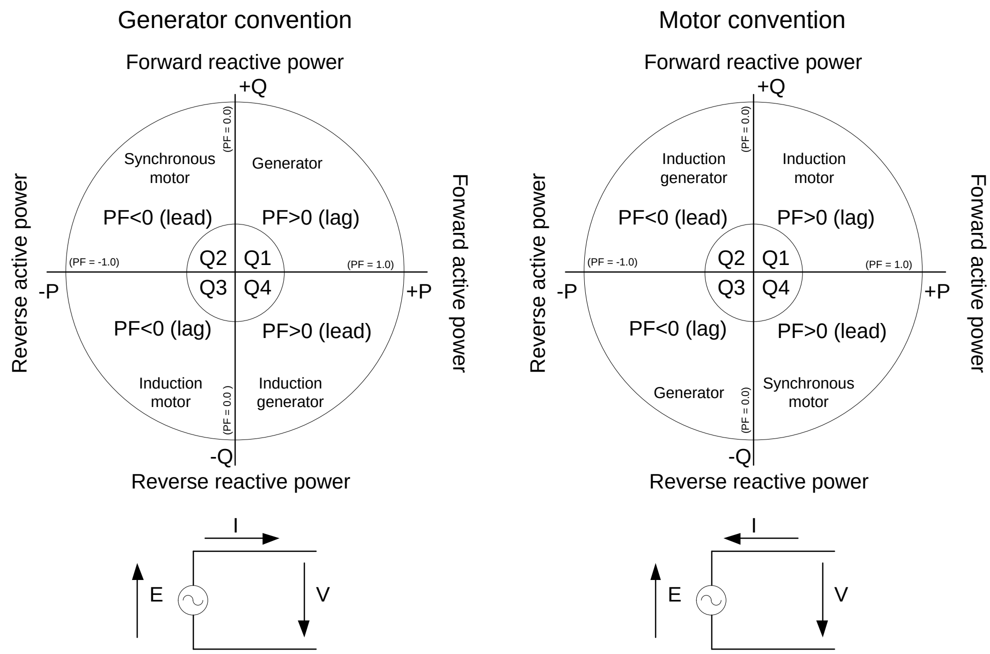


Figure 171: Power factor quadrant

If the polarity of the voltage signal is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to “Yes”, which rotates the power factor vector by 180 degrees.

If the magnitude of all three phase currents or voltages are respectively less than *Current block value* and *Voltage block value* settings, the power factor is set as unity that is 1.00 and the function is disabled internally.

The `DISABLE` input can be used to coordinate the correct operation during the start-up situation. By activating the DISABLE signal, the power factor calculation is blocked. Once the DISABLE signal is deactivated, the function remains blocked for additional time duration as set through the setting *Disable time*.

Level detector 1

The Level detector 1 compares the calculated power factor to the set *Pickup value*. If the power factor value goes below the set *Pickup value* in the direction as defined by *Dir pickup value*, the Level detector sends an enabling signal to the Timer 1 module.

Level detector 2

The Level detector 2 compares the calculated power factor to the set *Alarm value*. If the power factor value goes below the set *Alarm value* in the direction as defined by *Dir alarm value*, the Level detector sends an enabling signal to the Timer 2 module.

Timer 1

Once activated, the Timer 1 activates the PICKUP output. The timer characteristic is according to DT. When the trip timer has reached the value set by *Pickup delay time* in the DT mode, the TRIP output is activated. If a drop-off situation occurs, that is, a power factor improves and exceeds the *Pickup reset value* in the direction as defined by *Dir pickup reset value* before the trip delay is exceeded or either magnitude of all three phase current or voltages goes below *Current block value* and *Voltage block value* respectively, the timer reset state is activated. The reset timer depends on the *Reset delay time* setting.

The Timer 1 calculates the start duration value PICKUP_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

Timer 2

Once activated, the Timer 2 activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time* in the DT mode, the ALARM output is activated. If a drop-off situation occurs, that is, a power factor improves and exceeds the *Alarm reset value* in the direction as defined by *Dir alarm reset value* before the alarm delay is exceeded or either magnitude of all three phase current or voltages goes below *Current block value* and *Voltage block value* respectively, the timer reset state is activated. The reset timer depends on the *Reset delay time* setting.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.4.5.5 Application

The 55 function can be used to detect loss of excitation or for power factor correction. Synchronous motors are mostly operated at leading power factor and its operation as lagging power for extended period can be used an indication of an out-of-step condition possibly caused by under or loss of excitation. To detect such a situation, the relay is typically set to operate when the current into a motor lags more than 30 degrees, that is, a power factor goes below +0.87 lagging.

The function provides alarm facility which can be used as an early indication that the power factor is moving outside the allowable range; therefore the *Alarm value* setting should be set higher than the *Pickup value*. The delay time for alarm should also be set as low as possible, only long enough to prevent spurious activation of the output.

In a power factor correction application, the `ALARM` and `PICKUP` outputs can be used as controls to switch in capacitive loads when the *Alarm value* and *Pickup value* settings, respectively, are exceeded. The `ALARM` output is set for a higher value to add the first corrective load and the `PICKUP` output set for a second stage of corrective load, if needed. The *Pickup reset value* and *Alarm reset value* settings allow their respective outputs to remain activated to maintain the correction after power factor rises as a result, but to drop out after it reaches a level where corrective capacitive loading is no longer needed.

There are two general applications which can best utilize under power factor protection; power-factor control and loss of excitation.

When applying the function for power-factor control, both the pickup value and the pickup reset value should be the same sign (positive/negative) as well as the same direction (leading/lagging). Additionally, the absolute value of the pickup reset value should be greater than or equal to the absolute value of the pickup value. This allows the function to properly control any power factor controls within the system.

When applying the function for loss of excitation, both the pickup value and the pickup reset value should be the same sign (positive/negative), but the directions should be different (leading/lagging). This application is well-suited to protect against back-spinning. In this case the pickup reset value will only come into play once the system provides power in the opposite quadrant of the pickup value, for example, lagging PF turns to leading PF.

4.4.5.6 Signals

Table 306: 55 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0.0	Phase A current
I_B	SIGNAL	0.0	Phase B current
I_C	SIGNAL	0.0	Phase C current
V_A	SIGNAL	0.0	Phase to earth voltage A
V_B	SIGNAL	0.0	Phase to earth voltage B
V_C	SIGNAL	0.0	Phase to earth voltage C
DISABLE	BOOLEAN	0=False	Signal to block the function during machine startup
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 307: 55 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
ALARM	BOOLEAN	Alarm

4.4.5.7 Settings

Table 308: 55 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Dir pickup value	1=Lagging 2=Leading			1=Lagging	PF direction for pickup value
Dir pickup reset value	1=Lagging 2=Leading			1=Lagging	PF direction for pickup reset value
Dir alarm value	1=Lagging 2=Leading			1=Lagging	PF direction for alarm value
Dir alarm reset value	1=Lagging 2=Leading			1=Lagging	PF direction for alarm reset value
Pickup value	-0.99...0.99		0.01	0.80	Pickup value
Pickup reset value	-0.99...0.99		0.01	0.85	Value at which pickup resets, drops out
Alarm value	-0.99...0.99		0.01	0.85	Alarm pickup value
Alarm reset value	-0.99...0.99		0.01	0.90	Value at which alarm resets, drops out
Trip delay time	100...300000	ms	1	500	Time delay for operation
Alarm delay time	100...300000	ms	1	500	Time delay for alarm

Table 309: 55 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Current block value	0.05...0.65	xIn	0.01	0.10	Current block value (minimum operating current)
Voltage block value	0.05...0.50	xUn	0.01	0.10	Voltage block value (minimum operating voltage)
Reset delay time	0...60000	ms	1	20	Reset delay time
Disable time	0...60000	ms		5000	Additional time for which function is disabled after removal of DISABLE input
Voltage reversal	0=No 1=Yes			0=No	Rotates the PF by 180 degrees

4.4.5.8 Monitored data

Table 310: 55 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
PF	FLOAT32	-1.00...1.00		Calculated value of the 3–phase power factor
55	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.4.5.9 Technical data

Table 311: 55 Technical data

Characteristic	Value
Operation accuracy	Dependent on the frequency of the current measured: f_n ±2 Hz
	±0.018 for power factor
Operate time accuracy	±(1.0% or 30 ms)
Suppression of harmonics	DFT: -60 dB at f = n × f_n, where n = 2, 3, 4, 5, 6, 7
Reset time	<40 ms

4.5 Thermal protection

4.5.1 Three-phase thermal protection for feeders, cables and distribution transformers 49F

4.5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR	3Ith>	49F

4.5.1.2 Function block

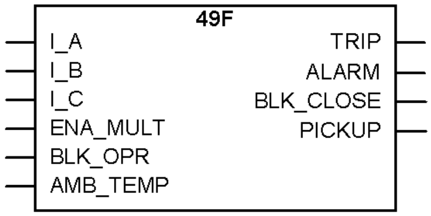


Figure 172: Function block

4.5.1.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function for power lines as well.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the thermal overload function 49F allows the protected circuit to operate closer to the thermal limits.

An alarm gives an early warning to allow operators to take action before the line trips. The early warning is based on the three-phase current measuring function using a thermal model with first order thermal loss with the settable time constant. If the temperature rise continues the function will operate based on the thermal model of the line.

Re-energizing of the line after a thermal overload operation can be inhibited for a time to allow the line to cool. The time for the line to cool is estimated by the thermal model.

4.5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the three-phase thermal protection for feeders, cables and distribution transformers can be described using a module diagram. All the modules in the diagram are explained in the next sections.

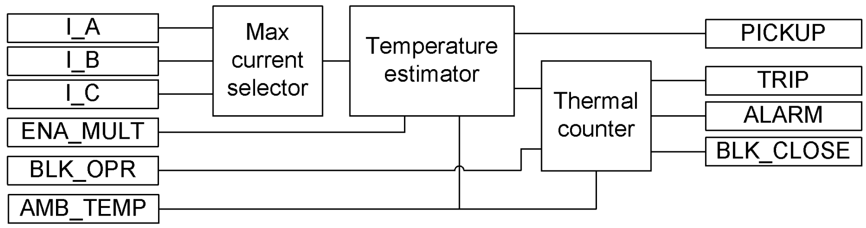


Figure 173: Functional module diagram. I_A, I_B and I_C represent phase currents.

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the temperature estimator.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

(Equation 20)

I	the largest phase current
I_{ref}	set *Current reference*
T_{ref}	set *Temperature rise*

The ambient temperature is added to the calculated final temperature rise estimation, and the ambient temperature value used in the calculation is also available in the monitored data as TEMP_AMB in degrees. If the final temperature estimation is larger than the set *Maximum temperature*, the PICKUP output is activated.

Current reference and *Temperature rise* setting values are used in the final temperature estimation together with the ambient temperature. It is suggested to set these values to the maximum steady state current allowed for the line or cable under emergency operation for a few hours per years. Current values with the corresponding conductor temperatures are given in cable manuals. These values are given for conditions such as ground temperatures, ambient air temperature, the way of cable laying and ground thermal resistivity.

Thermal counter

The actual temperature at the actual execution cycle is calculated as:

$$\Theta_n = \Theta_{n-1} + \left(\Theta_{final} - \Theta_{n-1}\right) \cdot \left(1 - e^{-\frac{\Delta t}{\tau}}\right)$$

(Equation 21)

Θ_n	calculated present temperature
Θ_{n-1}	calculated temperature at previous time step
Θ_{final}	calculated final temperature with actual current
Δt	time step between calculation of actual temperature
τ	thermal time constant for the protected device (line or cable), set *Time constant*

The actual temperature of the protected component (line or cable) is calculated by adding the ambient temperature to the calculated temperature, as shown above. The ambient temperature can be given a constant value or it can be measured. The calculated component temperature can be monitored as it is exported from the function as a real figure.

When the component temperature reaches the set alarm level *Alarm value*, the output signal ALARM is set. When the component temperature reaches the set trip level *Maximum temperature*, the TRIP output is activated. The TRIP signal pulse length is fixed to 100 ms

There is also a calculation of the present time to operation with the present current. This calculation is only monitored if the final temperature is calculated to be above the operation temperature. If the final temperature is below the operation temperature, maximum estimated time to trip is monitored. The value is available in the monitored data view as T_TRIP in seconds:

$$t_{trip} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{trip}}{\Theta_{final} - \Theta_n}\right)$$

(Equation 22)

After operating, caused by the thermal overload protection function, there can be a lockout to reconnect the tripped circuit. The lockout output BLK_CLOSE is activated at the same time when the TRIP output is activated and is not reset until the device temperature has cooled down below the set value of the *Reclose temperature* setting. BLK_CLOSE works also as hysteresis for the TRIP signal preventing a new TRIP signal activation until BLK_CLOSE has reset. The *Maximum temperature* value must be set at least 2 degrees above the set value of *Reclose temperature*.

The time to lockout release is calculated, that is, the calculation of the cooling time to a set value. The calculated temperature can be reset to its initial value (the *Initial temperature* setting) via a control parameter that is located under the clear menu. This is useful during testing when secondary injected current has given a calculated false temperature level.

$$t_{lockout\_release} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{lockout\_release}}{\Theta_{final} - \Theta_{n}}\right)$$

(Equation 23)

Here the final temperature is equal to the set or measured ambient temperature.

In some applications, the measured current can involve a number of parallel lines. This is often used for cable lines where one bay connects several parallel cables. By setting the *Current multiplier* parameter to the number of parallel lines (cables), the actual current on one line is used in the protection algorithm. To activate this option, the ENA_MULT input must be activated.

The ambient temperature can be measured with the RTD measurement. The measured temperature value is then connected, for example, from the RTD/mA output of the X130 (RTD) function to the AMB_TEMP input of 49F.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the AMB_TEMP input. The *Env temperature Set* setting is also used when the ambient temperature measurement connected to 49F is set to “Not in use” in the X130 (RTD) function.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the protection relay is powered up, the function is disabled and enabled back or reset through the Clear menu. The temperature is also stored in the nonvolatile memory and restored in case the protection relay is restarted.

The thermal time constant of the protected circuit is given in seconds with the *Time constant* setting. Please see cable manufacturers manuals for further details.

4.5.1.5 Application

The lines and cables in the power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses will be higher than expected. As a consequence, the temperature of the conductors will increase. If the temperature of the lines and cables becomes too high it can cause damage. For example:

- The sag of overhead lines can reach an unacceptable value.
- An aluminum conductor will be destroyed if the temperature becomes too high
- Overheating can damage the insulation on cables which in turn increase the risk of phase-to-phase or phase-to-ground faults.

In stressed situations in the power system, the lines and cables may be required to be overloaded for a limited time. This should be done without any risk for the above-mentioned risks.

The thermal overload protection provides information that makes temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously. This estimation is made by using a thermal model of the line/cable that is based on the current measurement.

If the temperature of the protected object reaches a set warning level, a signal is given to the operator. This enables actions in the power system to be done before dangerous temperatures are reached. If the temperature continues to increase to the maximum allowed temperature value, the protection initiates a trip of the protected line.

4.5.1.6 Signals

Table 312: 49F Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
ENA_MULT	BOOLEAN	0=False	Enable Current multiplier
BLK_OPR	BOOLEAN	0=False	Block signal for trip outputs
TEMP_AMB	FLOAT32	0	The ambient temperature used in the calculation

Table 313: 49F Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.5.1.7 Settings

Table 314: 49F Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature set	-50...100	°C	1	40	Ambient temperature used when AmbiSens is set to Off
Current multiplier	1...5		1	1	Current multiplier when function is used for parallel lines
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature
Temperature raise	0.0...200.0	°C	0.1	75.0	End temperature rise above ambient
Time constant	60...60000	s	1	2700	Time constant of the line in seconds.
Maximum temperature	20.0...200.0	°C	0.1	90.0	Temperature level for trip
Alarm value	20.0...150.0	°C	0.1	80.0	Temperature level for pickup (alarm)
Reclose temperature	20.0...150.0	°C	0.1	70.0	Temperature for reset of block reclose after trip

Table 315: 49F Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Initial temperature	-50.0...100.0	°C	0.1	0.0	Temperature raise above ambient temperature at startup

4.5.1.8 Monitored data

Table 316: 49F Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the trip level
T_TRIP	INT32	0...60000	s	Estimated time to trip
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE
49F	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.5.1.9 Technical data

Table 317: 49F Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Trip time accuracy[1)]	±2.0% of the theoretical value or ±0.50 s

1) Overload current > 1.2 × Trip level temperature

4.5.2 Three-phase thermal overload protection for power transformers, two time constants 49T

4.5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal overload protection for power transformers, two time constants	T2PTTR	3Ith>T	49T

4.5.2.2 Function block

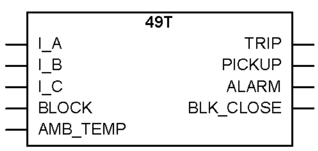


Figure 174: Function block

4.5.2.3 Functionality

The three-phase thermal overload, two time constant protection function 49T protects the transformer mainly from short-time overloads. The transformer is protected from long-time overloads with the oil temperature detector included in its equipment.

The alarm signal gives an early warning to allow the operators to take action before the transformer trips. The early warning is based on the three-phase current measuring function using a thermal model with two settable time constants. If the temperature rise continues, 49T operates based on the thermal model of the transformer.

After a thermal overload operation, the re-energizing of the transformer is inhibited during the transformer cooling time. The transformer cooling is estimated with a thermal model.

4.5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the three-phase thermal overload, two time constant protection for power transformers can be described using a module diagram. All the modules in the diagram are explained in the next sections.

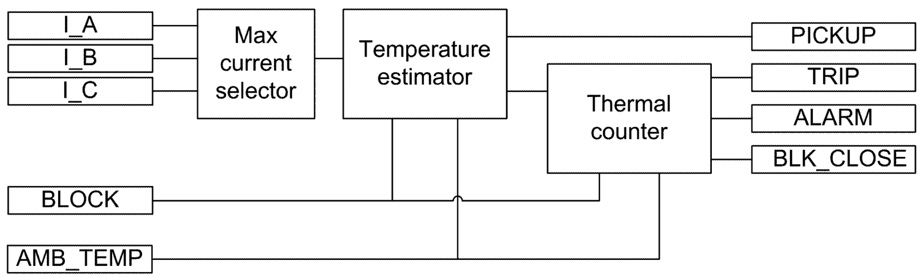


Figure 175: Functional module diagram

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the thermal estimator.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref}$$

(Equation 24)

I highest measured phase current

I_{ref} the set value of the *Current reference* setting

T_{ref} the set value of the *Temperature rise* setting (temperature rise (°C) with the steady-state current I_{ref}

The ambient temperature value is added to the calculated final temperature rise estimation. If the total value of temperature is higher than the set trip temperature level, the `PICKUP` output is activated.

The *Current reference* setting is a steady-state current that gives the steady-state end temperature value *Temperature rise*. It gives a setting value corresponding to the rated power of the transformer.

The *Temperature rise* setting is used when the value of the reference temperature rise corresponds to the *Current reference* value. The temperature values with the corresponding transformer load currents are usually given by transformer manufacturers.

Thermal counter

49T applies the thermal model of two time constants for temperature measurement. The temperature rise in degrees Celsius (°C) is calculated from the highest of the three-phase currents according to the expression:

$$\Delta\Theta = \left[p * \left(\frac{I}{I_{ref}} \right)^2 * T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 1}} \right) + \left[(1-p) \cdot \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 2}} \right)$$

(Equation 25)

ΔΘ	calculated temperature rise (°C) in transformer
I	measured phase current with the highest TRMS value
Iref	the set value of the *Current reference* setting (rated current of the protected object)
Tref	the set value of the *Temperature rise* setting (temperature rise setting (°C) with the steady-state current I_{ref})
p	the set value of the *Weighting factor p* setting (weighting factor for the short time constant)
Δt	time step between the calculation of the actual temperature
τ_1	the set value of the *Short time constant* setting (the short heating / cooling time constant)
τ_2	the set value of the *Long time constant* setting (the long heating / cooling time constant)

The warming and cooling following the two time-constant thermal curve is a characteristic of transformers. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. The *Short time constant* setting describes the warming of the transformer with respect to windings. The *Long time constant* setting describes the warming of the transformer with respect to the oil. Using the two time-constant model, the protection relay is able to follow both fast and slow changes in the temperature of the protected object.

The *Weighting factor p* setting is the weighting factor between *Short time constant* τ_1 and *Long time constant* τ_2. The higher the value of the *Weighting factor p* setting, the larger is the share of the steep part of the heating curve. When *Weighting factor p* =1, only *Short-time constant* is used. When *Weighting factor p* = 0, only *Long time constant* is used.

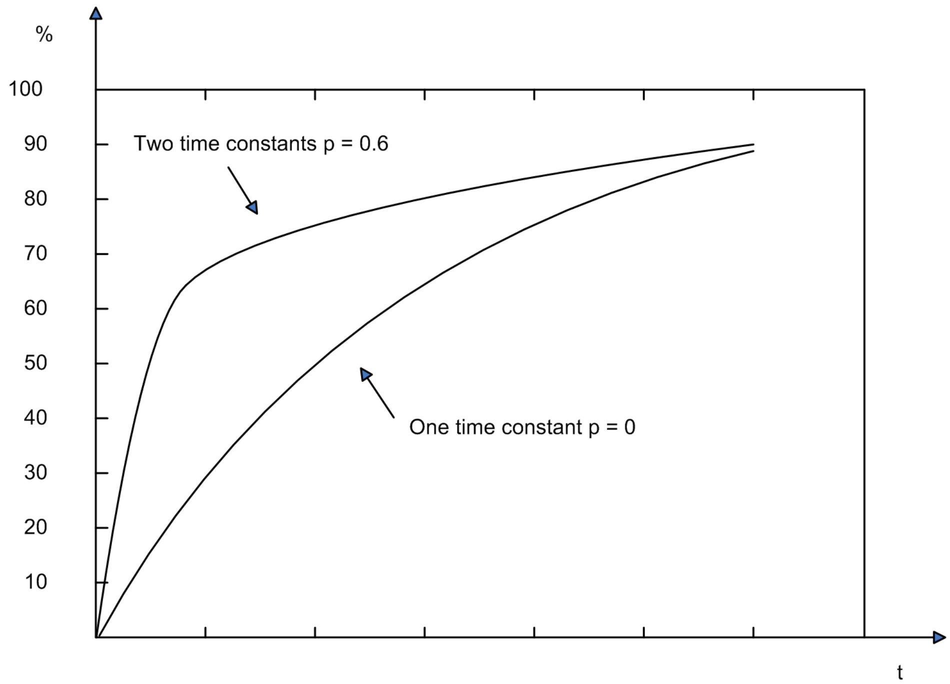


Figure 176: Effect of the Weighting factor p factor and the difference between the two time constants and one time constant models

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

(Equation 26)

Θ	temperature in transformer (°C)
$\Delta\Theta$	calculated temperature rise (°C) in transformer
Θ_{amb}	set value of the *Env temperature Set* setting or measured ambient temperature

The ambient temperature can be measured with RTD measurement. The measured temperature value is connected, for example, from the RTD/mA output of the X130 (RTD) function to the `AMB_TEMP` input of 49T.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the `AMB_TEMP` input. The *Env* *temperature Set* setting is also used when the ambient temperature measurement connected to 49T is set to “Not in use” in the X130 (RTD) function.

The temperature calculation is initiated from the value defined with the *Initial temperature* and *Max temperature* setting parameters. The initial value is a percentage of *Max temperature* defined by *Initial temperature*. This is done when the protection relay is powered up or the function is disabled and enabled back or reset through the Clear menu. The temperature is stored in a nonvolatile memory and restored if the protection relay is restarted.

The *Max temperature* setting defines the maximum temperature of the transformer in degrees Celsius (°C). The value of the *Max temperature* setting is usually given by transformer manufacturers. The actual alarm, operating and lockout temperatures for 49T are given as a percentage value of the *Max temperature* setting.

When the transformer temperature reaches the alarm level defined with the *Alarm temperature* setting, the `ALARM` output signal is set. When the transformer temperature reaches the trip level value defined with the *Operate temperature* setting, the `TRIP` output is activated. The `TRIP` output is deactivated when the value of the measured current falls below 10 percent of the *Current Reference* value or the calculated temperature value falls below *Operate temperature*.

There is also a calculation of the present time to operation with the present current. `T_TRIP` calculation is only monitored if the final temperature is calculated to be above the operation temperature. If the final temperature is below the operation temperature, maximum estimated time to trip is monitored. The value is available in the monitored data view.

After operating, there can be a lockout to reconnect the tripped circuit due to the thermal overload protection function. The `BLK_CLOSE` lockout output is activated when the device temperature is above the *Reclose temperature* lockout release temperature setting value. The time to lockout release `T_ENA_CLOSE` is also calculated. The value is available in the monitored data view.

4.5.2.5 Application

The transformers in a power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses are higher than expected. This results in a rise in transformer temperature. If the temperature rise is too high, the equipment is damaged:

- Insulation within the transformer ages faster, which in turn increases the risk of internal phase-to-phase or phase-to-ground faults.
- Possible hotspots forming within the transformer degrade the quality of the transformer oil.

During stressed situations in power systems, it is required to overload the transformers for a limited time without any risks. The thermal overload protection provides information and makes temporary overloading of transformers possible.

The permissible load level of a power transformer is highly dependent on the transformer cooling system. The two main principles are:

- ONAN: The air is naturally circulated to the coolers without fans, and the oil is naturally circulated without pumps.
- OFAF: The coolers have fans to force air for cooling, and pumps to force the circulation of the transformer oil.

The protection has several parameter sets located in the setting groups, for example one for a non-forced cooling and one for a forced cooling situation. Both the permissive steady-state loading level as well as the thermal time constant are influenced by the transformer cooling system. The active setting group can be changed by a parameter, or through a binary input if the binary input is enabled for it. This feature can be used for transformers where forced cooling is taken out of operation or extra cooling is switched on. The parameters can also be changed when a fan or pump fails to operate.

The thermal overload protection continuously estimates the internal heat content, that is, the temperature of the transformer. This estimation is made by using a thermal model of the transformer which is based on the current measurement.

If the heat content of the protected transformer reaches the set alarm level, a signal is given to the operator. This enables the action that needs to be taken in the power systems before the temperature reaches a high value. If the temperature continues to rise to the trip value, the protection initiates the trip of the protected transformer.

After the trip, the transformer needs to cool down to a temperature level where the transformer can be taken into service again. 49T continues to estimate the heat content of the transformer during this cooling period using a set cooling time constant. The energizing of the transformer is blocked until the heat content is reduced to the set level.

The thermal curve of two time constants is typical for a transformer. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. If the manufacturer does not state any other value, the *Long time constant* can be set to 4920 s (82 minutes) for a distribution transformer and 7260 s (121 minutes) for a supply transformer. The corresponding *Short time constants* are 306 s (5.1 minutes) and 456 s (7.6 minutes).

If the manufacturer of the power transformer has stated only one, that is, a single time constant, it can be converted to two time constants. The single time constant is also used by itself if the p-factor *Weighting factor p* setting is set to zero and the time constant value is set to the value of the *Long time constant* setting. The thermal image corresponds to the one time constant model in that case.

Table 318: *Conversion table between one and two time constants*

Single time constant (min)	*Short time constant* (min)	*Long time constant* (min)	*Weighting factor p*
10	1.1	17	0.4
15	1.6	25	0.4
20	2.1	33	0.4
25	2.6	41	0.4
30	3.1	49	0.4
35	3.6	58	0.4
40	4.1	60	0.4
45	4.8	75	0.4
50	5.1	82	0.4
55	5.6	90	0.4
60	6.1	98	0.4
65	6.7	107	0.4
70	7.2	115	0.4
75	7.8	124	0.4

The default *Max temperature* setting is 105°C. This value is chosen since even though the IEC 60076-7 standard recommends 98°C as the maximum allowable temperature in long-time loading, the standard also states that a transformer can withstand the emergency loading for weeks or even months, which may produce the winding temperature of 140°C. Therefore, 105°C is a safe maximum temperature value for a transformer if the *Max temperature* setting value is not given by the transformer manufacturer.

4.5.2.6 Signals

Table 319: *49T Input signals*

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for the function
TEMP_AMB	FLOAT32	0	The ambient temperature used in the calculation

Table 320: 49T Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.5.2.7 Settings

Table 321: 49T Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature Set	-50...100	°C	1	40	Ambient temperature used when no external temperature measurement available
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature
Temperature rise	0.0...200.0	°C	0.1	78.0	End temperature rise above ambient
Maximum temperature	0.0...200.0	°C	0.1	105.0	Temperature level for trip
Trip temperature	80.0...120.0	%	0.1	100.0	Trip temperature, percent value
Alarm temperature	40.0...100.0	%	0.1	90.0	Alarm temperature, percent value
Reclose temperature	40.0...100.0	%	0.1	60.0	Temperature for reset of block reclose after trip
Short time constant	6...60000	s	1	450	Short time constant in seconds
Long time constant	60...60000	s	1	7200	Long time constant in seconds
Weighting factor p	0.00...1.00		0.01	0.40	Weighting factor of the short time constant

Table 322: 49T Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Initial temperature, percent value	0.0...100.0	%	0.1	80.0	Temperature raise at startup

4.5.2.8 Monitored data

Table 323: 49T Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the trip level
T_TRIP	INT32	0...60000	s	Estimated time to trip
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE in seconds
49T	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.5.2.9 Technical data

Table 324: 49T Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 x I_n (at currents in the range of 0.01...4.00 x I_n)
Trip time accuracy[1)]	±2.0% of the theoretical value or ±0.50 s

1) Overload current > 1.2 x Trip level temperature

4.5.3 Thermal overload protection for motors 49M

4.5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Thermal overload protection for motors	MPTTR	3Ith>M	49M

4.5.3.2 Function block

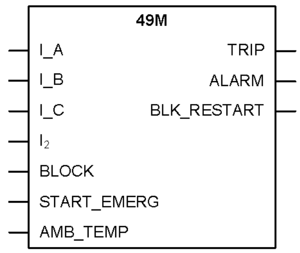


Figure 177: Function block

4.5.3.3 Functionality

Thermal overload protection for motors function 49M protects the electric motors from overheating. 49M models the thermal behavior of motor on the basis of the measured load current and disconnects the motor when the thermal content reaches 100 percent. The thermal overload conditions are the most often encountered abnormal conditions in industrial motor applications. The thermal overload conditions are typically the result of an abnormal rise in the motor running current, which produces an increase in the thermal dissipation of the motor and temperature or reduces cooling. 49M prevents an electric motor from drawing excessive current and overheating, which causes the premature insulation failures of the windings and, in worst cases, burning out of the motors.

4.5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the motor thermal overload protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

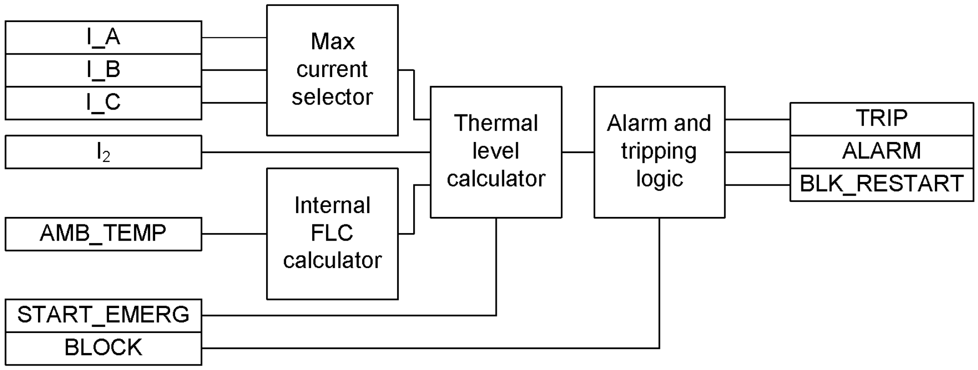


Figure 178: Functional module diagram

Max current selector

Max current selector selects the highest measured TRMS phase current and reports it to Thermal level calculator.

Internal FLC calculator

Full load current (FLC) of the motor is defined by the manufacturer at an ambient temperature of 40°C. Special considerations are required with an application where the ambient temperature of a motor exceeds or remains below 40°C. A motor operating at a higher temperature, even if at or below rated load, can subject the motor windings to excessive temperature similar to that resulting from overload operation at normal ambient temperature. The motor rating has to be appropriately reduced for operation in such high ambient temperatures. Similarly, when the ambient temperature is considerably lower than the nominal 40°C, the motor can be slightly overloaded. For calculating thermal level it is better that the FLC values are scaled for different temperatures. The scaled currents are known as internal FLC. An internal FLC is calculated based on the ambient temperature shown in the table. The *Env temperature mode* setting defines whether the thermal level calculations are based on FLC or internal FLC.

When the value of the *Env temperature mode* setting is set to the "FLC Only" mode, no internal FLC is calculated. Instead, the FLC given in the data sheet of the manufacturer is used. When the value of the *Env temperature mode* setting is set to "Set Amb Temp" mode, the internal FLC is calculated based on the ambient temperature taken as an input through the *Env temperature Set* setting. When the *Env temperature mode* setting is on "Use input" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs) using the AMB_TEMP input.

Table 325: Modification of internal FLC

Ambient Temperature T_{amb}	Internal FLC
<20°C	FLC x 1.09
20 to <40°C	FLC x (1.18 - T_{amb} x 0.09/20)
40°C	FLC
>40 to 65°C	FLC x (1 –[(T_{amb} -40)/100])
>65°C	FLC x 0.75

The ambient temperature is used for calculating thermal level and it is available in the monitored data view from the `TEMP_AMB` output. The activation of the `BLOCK` input does not affect the `TEMP_AMB` output.

When the *Env temperature mode* setting is on "Use input" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs) using the AMB_TEMP input.

The *Env temperature Set* setting is used:

- If the ambient temperature measurement value is not connected to the AMB_TEMP input in ACT.
- When the ambient temperature measurement connected to 49M is set to "Not in use" in the RTD function.
- In case of any errors or malfunctioning in the RTD output.

Thermal level calculator

The module calculates the thermal load considering the TRMS and negative-sequence currents. The heating up of the motor is determined by the square value of the load current.

However, in case of unbalanced phase currents, the negative-sequence current also causes additional heating. By deploying a protection based on both current components, abnormal heating of the motor is avoided.

The thermal load is calculated based on different situations or operations and it also depends on the phase current level. The equations used for the heating calculations are:

$$\theta_B = \left[\left(\frac{I}{k \times I_r}\right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r}\right)^2\right] \times \left(1 - e^{-t/\tau}\right) \times p\%$$

(Equation 27)

$$\theta_A = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau} \right) \times 100\%$$

(Equation 28)

I	TRMS value of the measured max of phase currents
I_r	set *Rated current*, FLC or internal FLC
I_2	measured negative sequence current
k	set value of *Overload factor*
K_2	set value of *Negative Seq factor*
p	set value of *Weighting factor*
τ	time constant

The equation θ_B is used when the values of all the phase currents are below the overload limit, that is, k x I_r. The equation θ_A is used when the value of any one of the phase currents exceeds the overload limit.

During overload condition, the thermal level calculator calculates the value of θ_B in background, and when the overload ends the thermal level is brought linearly from θ_A to θ_B with a speed of 1.66 percent per second. For the motor at standstill, that is, when the current is below the value of 0.12 x I_r, the cooling is expressed as:

$$\theta = \theta_{02} \times e^{\frac{-t}{\tau}}$$

(Equation 29)

θ_{02}	initial thermal level when cooling begins

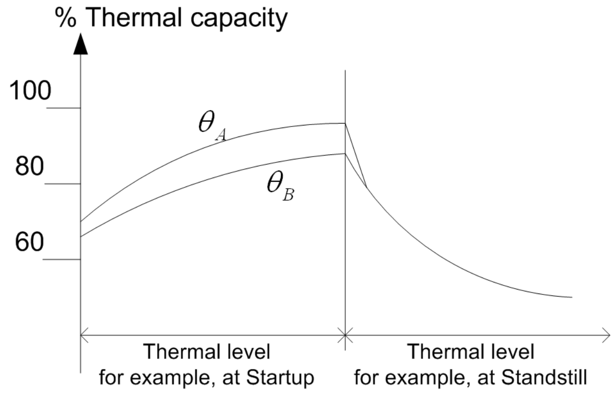


Figure 179: Thermal behavior

The required overload factor and negative sequence current heating effect factor are set by the values of the *Overload factor* and *Negative Seq factor* settings.

In order to accurately calculate the motor thermal condition, different time constants are used in the above equations. These time constants are employed based on different motor running conditions, for example starting, normal or stop, and are set through the *Time constant start*, *Time constant normal* and *Time constant stop* settings. Only one time constant is valid at a time.

Table 326: Time constant and the respective phase current values

Time constant (tau) in use	Phase current
Time constant start	Any current whose value is over 2.5 x I_r
Time constant normal	Any current whose value is over 0.12 x I_r and all currents are below 2.5 x I_r
Time constant stop	All the currents whose values are below 0.12 x I_r

The *Weighting factor p* setting determines the ratio of the thermal increase of the two curves θ_A and θ_B.

The thermal level at the power-up of the protection relay is defined by the *Initial thermal Val* setting.

The temperature calculation is initiated from the value defined in the *Initial thermal Val* setting. This is done if the protection relay is powered up or the function is disabled and enabled back or reset through the Clear menu.

The calculated temperature of the protected object relative to the operate level, the `TEMP_RL` output, is available through the monitored data view. The activation of the `BLOCK` input does not affect the calculated temperature.

The thermal level at the beginning of the startup condition of a motor and at the end of the startup condition is available in the monitored data view at the THERMLEV_ST and THERMLEV_END outputs respectively. The activation of the BLOCK input does not have any effect on these outputs.

Alarm and tripping logic

The module generates alarm, restart inhibit and tripping signals.

When the thermal level exceeds the set value of the *Alarm thermal value* setting, the ALARM output is activated. Sometimes a condition arises when it becomes necessary to inhibit the restarting of a motor, for example in case of some extreme starting condition like long starting time. If the thermal content exceeds the set value of the *Restart thermal val* setting, the BLK_RESTART output is activated. The time for the next possible motor startup is available through the monitored data view from the T_ENARESTART output. The T_ENARESTART output estimates the time for the BLK_RESTART deactivation considering as if the motor is stopped.

On the rising edge of the emergency start signal START_EMERG is set high, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor startup, even though the thermal level has exceeded the restart inhibit level.

When the thermal content reaches 100 percent, the TRIP output is activated. The TRIP output is deactivated when the value of the measured current falls below 12 percent of *Rated current* or the thermal content drops below 100 percent.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and TRIP outputs.

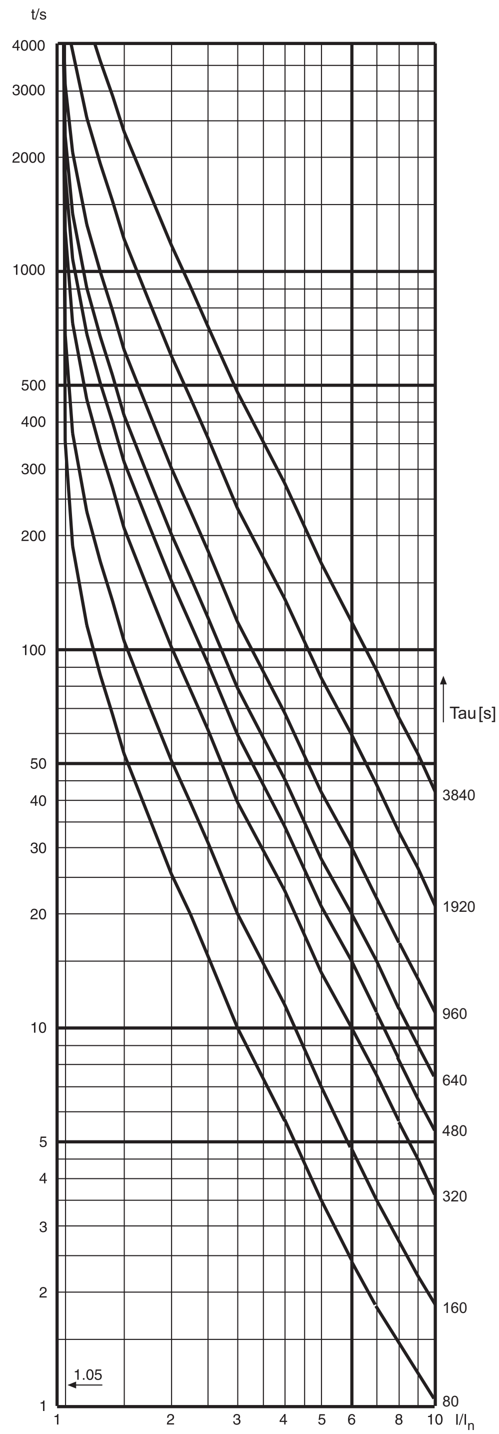


Figure 180: Trip curves when no prior load and p=20...100 %. Overload factor = 1.05.

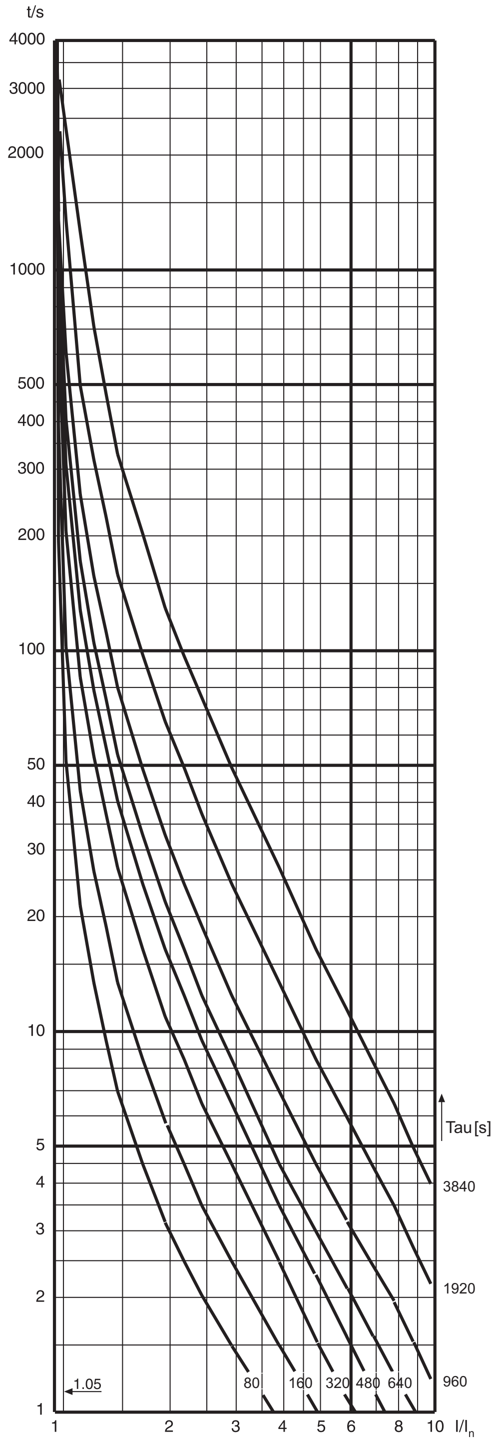


Figure 181: Trip curves at prior load 1 x FLC and p=100 %, Overload factor = 1.05.

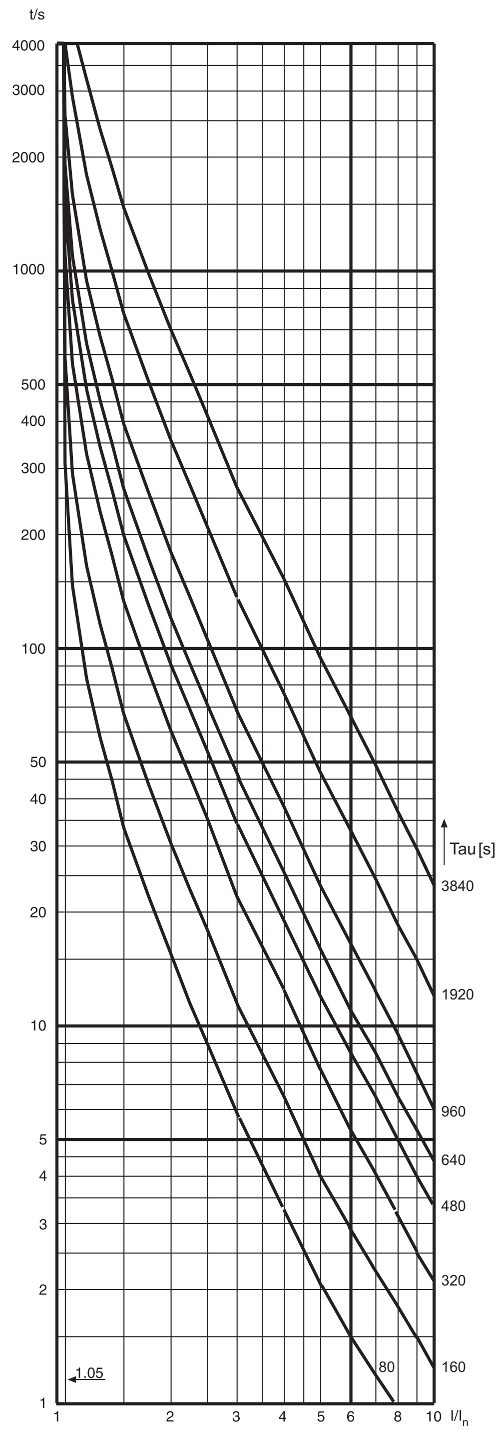


Figure 182: Trip curves at prior load 1 x FLC and p=50 %. Overload factor = 1.05.

4.5.3.5 Application

49M is intended to limit the motor thermal level to predetermined values during the abnormal motor operating conditions. This prevents a premature motor insulation failure.

The abnormal conditions result in overheating and include overload, stalling, failure to start, high ambient temperature, restricted motor ventilation, reduced speed operation, frequent starting or jogging, high or low line voltage or frequency, mechanical failure of the driven load, improper installation and unbalanced line voltage or single phasing. The protection of insulation failure by the implementation of current sensing cannot detect some of these conditions, such as restricted ventilation. Similarly, the protection by sensing temperature alone can be inadequate in cases like frequent starting or jogging. The thermal overload protection addresses these deficiencies to a larger extent by deploying a motor thermal model based on load current.

The thermal load is calculated using the true RMS phase value and negative sequence value of the current. The heating up of the motor is determined by the square value of the load current. However, while calculating the thermal level, the rated current should be re-rated or de-rated depending on the value of the ambient temperature. Apart from current, the rate at which motor heats up or cools is governed by the time constant of the motor.

Setting the weighting factor

There are two thermal curves: one which characterizes the short-time loads and long-time overloads and which is also used for tripping and another which is used for monitoring the thermal condition of the motor. The value of the *Weighting factor p* setting determines the ratio of the thermal increase of the two curves.

When the *Weighting factor p* setting is 100 percent, a pure single time constant thermal unit is produced which is used for application with the cables. As presented in Figure 183, the hot curve with the value of *Weighting factor p* being 100 percent only allows an operate time which is about 10 percent of that with no prior load. For example, when the set time constant is 640 seconds, the operate time with the prior load 1 x FLC (full Load Current) and overload factor 1.05 is only 2 seconds, even if the motor could withstand at least 5 to 6 seconds. To allow the use of the full capacity of the motor, a lower value of *Weighting factor p* should be used.

Normally, an approximate value of half of the thermal capacity is used when the motor is running at full load. Thus by setting *Weighting factor p* to 50 percent, the protection relay notifies a 45 to 50 percent thermal capacity use at full load.

For direct-on-line started motors with hot spot tendencies, the value of *Weighting factor p* is typically set to 50 percent, which will properly distinguish between short-time thermal stress and long-time thermal history. After a short period of thermal stress, for example a motor startup, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed startups increases.

When protecting the objects without hot spot tendencies, for example motors started with soft starters, and cables, the value of *Weighting factor p* is set to 100 percent. With the value of *Weighting factor p* set to 100 percent, the thermal level decreases slowly after a heavy load condition. This makes the protection suitable for applications where no hot spots are expected. Only in special cases where the thermal overload protection is required to follow the characteristics of the object to be protected more closely and the thermal capacity of the object is very well known, a value between 50 and 100 percent is required.

For motor applications where, for example, two hot starts are allowed instead of three cold starts, the value of the setting *Weighting factor p* being 40 percent has proven to be useful. Setting the value of *Weighting factor p* significantly below 50 percent should be handled carefully as there is a possibility to overload the protected object as a thermal unit might allow too many hot starts or the thermal history of the motor has not been taken into account sufficiently.

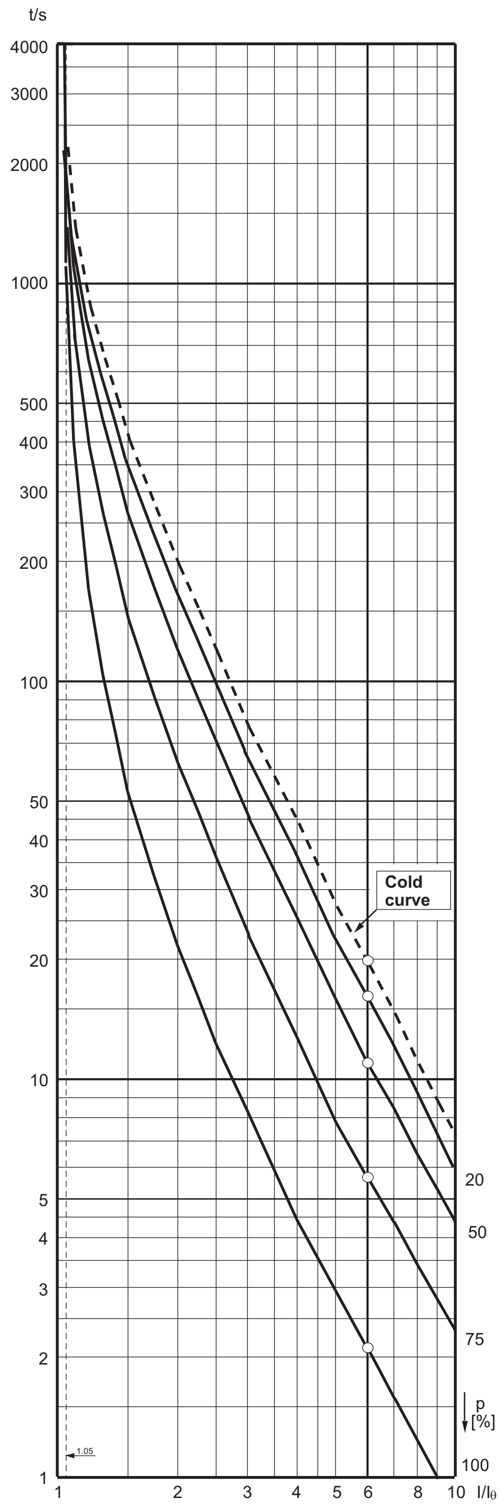

t/s
4000
3000
2000
1000
500
400
300
200
100
50
40
30
20
10
5
4
3
2
1
1
2
3
4
5
6
8
10
I/Iθ
Cold curve
20
50
75
p [%]
100
1.05

Figure 183: The influence of Weighting factor p at prior load 1xFLC, timeconstant = 640 sec, and Overload factor = 1.05

Setting the overload factor

The value of *Overload factor* defines the highest permissible continuous load. The recommended value is 1.05.

Setting the negative sequence factor

During the unbalance condition, the symmetry of the stator currents is disturbed and a counter-rotating negative sequence component current is set up. An increased stator current causes additional heating in the stator and the negative sequence component current excessive heating in the rotor. Also mechanical problems like rotor vibration can occur.

The most common cause of unbalance for three-phase motors is the loss of phase resulting in an open fuse, connector or conductor. Often mechanical problems can be more severe than the heating effects and therefore a separate unbalance protection is used.

Unbalances in other connected loads in the same busbar can also affect the motor. A voltage unbalance typically produces 5 to 7 times higher current unbalance. Because the thermal overload protection is based on the highest TRMS value of the phase current, the additional heating in stator winding is automatically taken into account. For more accurate thermal modeling, the *Negative Seq factor* setting is used for taking account of the rotor heating effect.

$$Negative\,Seq\;factor = \frac{R_{R2}}{R_{R1}}$$

(Equation 30)

R_{R2} rotor negative sequence resistance

R_{R1} rotor positive sequence resistance

A conservative estimate for the setting can be calculated:

$$Negative\,Seq\;factor = \frac{175}{I_{LR}^2}$$

I_{LR} locked rotor current (multiple of set *Rated current*). The same as the startup current at the beginning of the motor startup.

For example, if the rated current of a motor is 230 A, startup current is 5.7 x I_r,

$$Negative\,Seq\;factor = \frac{175}{5.7^2} = 5.4$$

Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left(\frac{startup\,time\,of\;the\,motor}{operate\,time\,when\,no\;prior\,load} \times 100\% + margin \right)$$

(Equation 31)

For example, the motor startup time is 11 seconds, start-up current 6 x rated and *Time constant start* is set for 800 seconds. Using the trip curve with no prior load, the operation time at 6 x rated current is 25 seconds, one motor startup uses 11/25 ≈ 45 percent of the thermal capacity of the motor. Therefore, the restart disable level must be set to below 100 percent - 45 percent = 55 percent, for example to 50 percent (100 percent - (45 percent + margin), where margin is 5 percent).

Setting the thermal alarm level

Tripping due to high overload is avoided by reducing the load of the motor on a prior alarm.

The value of *Alarm thermal value* is set to a level which allows the use of the full thermal capacity of the motor without causing a trip due to a long overload time. Generally, the prior alarm level is set to a value of 80 to 90 percent of the trip level.

4.5.3.6 Signals

Table 327: 49M Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I2	SIGNAL	0	Negative sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
START_EMERG	BOOLEAN	0=False	Signal for indicating the need for emergency start
TEMP_AMB	FLOAT32	0	The ambient temperature used in the calculation

Table 328: 49M Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
ALARM	BOOLEAN	Thermal Alarm
BLK_RESTART	BOOLEAN	Thermal overload indicator, to inhibit restart

4.5.3.7 Settings

Table 329: 49M Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Overload factor	1.00...1.20		0.01	1.05	Overload factor (k)
Alarm thermal value	50.0...100.0	%	0.1	95.0	Thermal level above which function gives an alarm
Restart thermal Val	20.0...80.0	%	0.1	40.0	Thermal level above which function inhibits motor restarting
Negative Seq factor	0.0...10.0		0.1	6	Heating effect factor for negative sequence current
Weighting factor p	20.0...100.0	%	0.1	50.0	Weighting factor (p)
Time constant normal	80...4000	s	1	320	Motor time constant during the normal operation of motor
Time constant start	80...4000	s	1	320	Motor time constant during the start of motor
Time constant stop	80...8000	s	1	500	Motor time constant during the standstill condition of motor
Env temperature mode	1=FLC Only 2=Use input 3=Set Amb Temp			1=FLC Only	Mode of measuring ambient temperature
Env temperature Set	-20.0...70.0	°C	0.1	40.0	Ambient temperature used when no external temperature measurement available

Table 330: 49M Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Rated current	0.30...2.00	xIn	0.01	1.00	Rated current (FLC) of the motor
Initial thermal Val	0.0...100.0	%	0.1	74.0	Initial thermal level of the motor

4.5.3.8 Monitored data

Table 331: 49M Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP_RL	FLOAT32	0.00...9.99		The calculated temperature of the protected object relative to the trip level
THERMLEV_ST	FLOAT32	0.00...9.99		Thermal level at beginning of motor startup
THERMLEV_END	FLOAT32	0.00...9.99		Thermal level at the end of motor startup situation
T_ENARESTART	INT32	0...99999	s	Estimated time to reset of block restart
49M	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.5.3.9 Technical data

Table 332: 49M Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 x I_n (at currents in the range of 0.01...4.00 x I_n)
Trip time accuracy[1)]	±2.0% of the theoretical value or ±0.50 s

1) Overload current > 1.2 x Operate level temperature

4.6 Differential protection

4.6.1 Motor differential protection 87M

4.6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor differential protection	MPDIF	3dI>M	87M

4.6.1.2 Function block

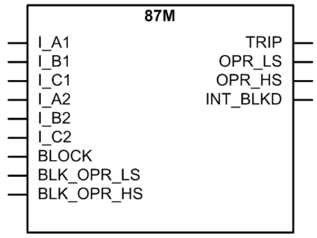


Figure 184: Function block

4.6.1.3 Functionality

Motor winding failure protection 87M is a unit protection function. The possibility of internal failures of the motor is relatively low. However, the consequences in terms of cost and production loss are often serious, which makes the differential protection an important protection function.

The stability of the differential protection is enhanced by a DC restraint feature. This feature decreases the sensitivity of the differential protection optionally for a temporary time period to avoid an unnecessary disconnection of the motor during the external faults that have a fault current with high DC currents. 87M also includes a CT saturation-based blocking which prevents unnecessary tripping in case of the detection of the magnetizing inrush currents which can be present at the switching operations, overvoltages or external faults.

4.6.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the motor differential protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

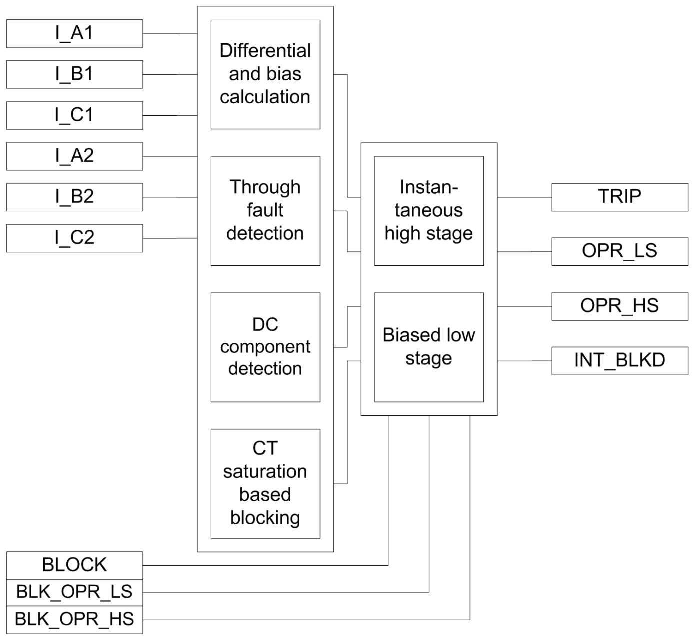


Figure 185: Functional module diagram

Differential and bias calculation

Differential calculation module calculates the differential current. The differential current is the difference in current between the phase and neutral sides of the machine. The phase currents $\bar{I}_1$ and $\bar{I}_2$ denote the fundamental frequency components on the phase and neutral sides of the current. The amplitude of the differential current I_d is obtained using the equation (assuming that the positive direction of the current is towards the machine):

$$I_d = \left|\bar{I}_1 + \bar{I}_2\right|$$

(Equation 32)

During normal conditions, there is no fault in the area protected by the function block, so the currents $\bar{I}_1$ and $\bar{I}_2$ are equal and the differential current $I_d = 0$. However, in practice some differential current exists due to inaccuracies in the current transformer on the phase and neutral sides, but it is very small during normal conditions.

The module calculates the differential current for all three phases.

The low-stage differential protection is stabilized with a bias current. The bias current is also known as the stabilizing current. Stabilization means that the differential current required for tripping increases according to the bias current and the operation characteristics. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

The traditional way for calculating the stabilized current is:

$$I_b = \left| \frac{\bar{I}_1 - \bar{I}_2}{2} \right|$$

(Equation 33)

The module calculates the bias current for all three phases.

Through-fault detection

Through-fault (TF) detection module is for detecting whether the fault is external, that is, going through, or internal. This information is essential for ensuring the correct operation of the protection in case of the CT saturation.

- In a through-fault situation, CTs can saturate because of a high fault current magnitude. Such AC saturation does not happen immediately when the fault begins. Thus, the TF module sees the fault as external because the bias current is high but the differential current remains low. If the AC saturation then occurs, a CT saturation-based blocking is allowed to work to prevent tripping.
- Normally, the phase angle between the machine neutral and line side CTs is 180 degrees. If an internal fault occurs during a through fault, an angle less than 50 degrees clearly indicates an internal fault and the TF module overrules, that is, deblocks the presence of any blocking due to CT saturation.

CT saturation-based blocking

Higher currents during the motor startup or abnormally high magnetizing currents at an overvoltage (transformer-fed motor) or an external fault may saturate the current transformers. The uneven saturation of the star and line side CTs (for example, due to burden differences) may lead to a differential current which can cause a differential protection to trip. This module blocks the operation of 87M biased low stage internally in case of the CT saturation. Once the blocking is activated, it is held for a certain time after the blocking conditions have ceased to be fulfilled.

DC component detection

On detection of a DC component, the function temporarily desensitizes the differential protection. The functioning of this module depends on the *DC restrain Enable* setting. The DC components are continuously extracted from the three instantaneous differential currents. The highest DC component of all three is taken as a kind of DC restraint in a sense that the highest effective, temporary sensitivity of the protection is temporarily decreased as a function of this highest DC offset. The calculated DC restraint current is not allowed to decay (from its highest ever measured value) faster than with a time constant of one second. The value of the temporarily effective sensitivity limit is limited upwards to the rated current of the machine or 3.3 times that of *Low trip value*, whichever is smaller. The temporary extra limit decays exponentially from its maximum value with a time constant of one second.

This feature should be used in case of networks where very long time constants are expected. The temporary sensitivity limit is higher to the set operating characteristics. In other words, the temporary limit has superposed the unchanged operating characteristics and temporarily determines the highest sensitivity of the protection. The temporary sensitivity is less than the sensitivity in section 1 of the operating characteristic and is supposed to prevent an unwanted trip during the external faults with lower currents.

Restrained differential (low stage)

The current differential protection needs to be biased because of the possible appearance of a differential current which can be due to something else than an actual fault in the motor. In case of differential protection, a false differential current can be caused by:

- CT errors
- CT saturation at high currents passing through the motor

The differential current caused by CT errors increases at the same percent ratio as the load current.

The high currents passing through the protected object can be caused by the through fault. Therefore, the operation of the differential protection is biased with respect to the load current. In the biased differential protection, the higher the differential current required for the protection of operation, the higher the load current.

Based on the conditions checked from the through-fault module, the DC (component) detection module and the CT saturation-based blocking modules, the biased low-stage module decides whether the differential current is due to the internal faults or some false reason. In case of detection of the TF, DC or CT saturation, the internal differential blocking signal is generated, which in turn blocks the operating signal. In case of internal faults, the operation of the differential protection is affected by the bias current .

The *Low trip value* setting for the stabilized stage of the function block is determined with the equation:

$$Low\,trip\,value = \frac{I_{d1}}{I_n} \cdot 100\%$$

(Equation 34)

The *Slope section 2* setting is determined correspondingly:

$$Slope\,section\,2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 35)

The end of the first section *End section 1* can be set at a desired point within the range of 0 to 100 percent (or % I_n). Accordingly, the end of the second section *End section 2* can be set within the range of 100 percent to 300 percent (or % I_n).

The slope of the operating characteristic for the function block varies in different parts of the range.

In section 1, where $0.0 < I_b/I_n <$ *End section 1*, the differential current required for tripping is constant. The value of the differential current is the same as the *Low trip value* setting selected for the function block. The *Low trip value* setting allows for small inaccuracies of the current transformers but it can also be used to influence the overall level of the operating characteristic.

Section 2, where *End section 1* $< I_b/I_n <$ *End section 2*, is called the influence area of the setting *Slope section 2*. In this section, variations in *End section 2* affect the slope of the characteristic, that is, how big the change in the differential current required for tripping is in comparison to the change in the load current. The *End section 2* setting allows for CT errors.

In section 3, where $I_b/I_n >$ *End section 2*, the slope of the characteristic is constant. The slope is 100 percent, which means that an increase in the differential current is equal to the corresponding increase in the stabilizing current.

The required differential current for tripping at a certain stabilizing current level can be calculated using the formulae:

For a stabilizing current lower than *End section 1*

$$I_{doperate}[\%I_n] = \text{Set } \textit{Low trip values}$$

(Equation 36)

For a stabilizing current higher than *End section 1* but lower than *End section 2*

$$I_{doperate}[\%I_n] = \textit{Low trip value} + (I_b[\%I_n] - \textit{End section 1}) \cdot \textit{Slope section } 2$$

(Equation 37)

For higher stabilizing current values exceeding *End section 2*

$$I_{doperate}[\%I_n] = \textit{Low trip value} + (\textit{End section } 2 - \textit{End section } 1) \cdot \textit{Slope section } 2 + (I_b[\%I_n] - \textit{End section } 2)$$

(Equation 38)

When the differential current exceeds the operating value determined by the operating characteristics, the OPR_LS output is activated. The TRIP output is always activated when the OPR_LS output activates.

The trip signal due to the biased stage can be blocked by the activation of the BLK_OPR_LS or BLOCK input. Also, when the operation of the biased low stage is blocked by the waveform blocking functionality, the INT_BLKD output is activated according to the phase information.

The phase angle difference between the two currents I_A1 and I_A2 is theoretically 180 electrical degrees for the external fault and 0 electrical degrees for the internal fault conditions. If the phase angle difference is less than 50 electrical degrees or if the biasing current drops below 30 percent of the differential current, a fault has most likely occurred in the area protected by 87M. Then the internal blocking signals (CT saturation and DC blocking) of the biased stage are inhibited.

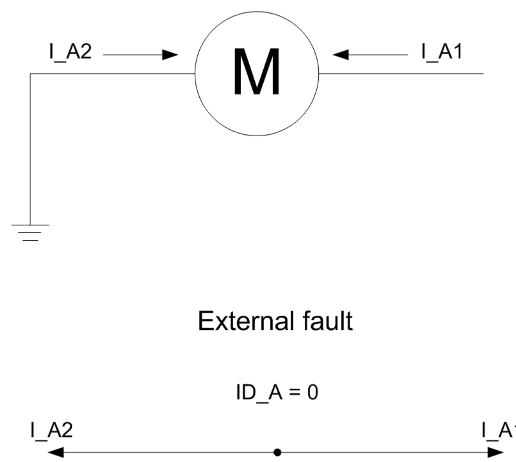


Figure 186: Positive direction of current

Unrestrained differential (high stage)

The differential protection includes an unbiased instantaneous high stage. The instantaneous stage trips and the OPR_HS output is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous peak values of the differential current exceed 2.5 · *High operate value*. The factor 2.5 (= 1.8 · √2) is due to the maximum asymmetric short circuit current.

The TRIP output is always activated when the OPR_HS output activates.

The internal blocking signals of the function block do not prevent the operation of the instantaneous stage. When required, the trip signal due to instantaneous operation can be blocked by the binary inputs BLK_OPR_HS or BLOCK.

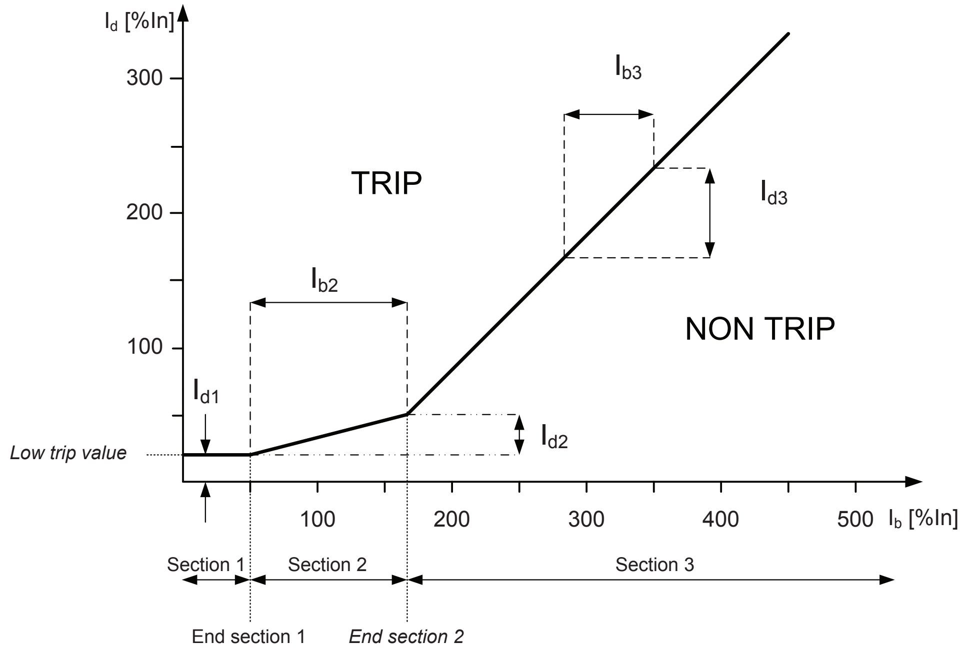


Figure 187: Operating characteristic for the stabilized stage of the generator differential protection function

4.6.1.5 Application

The differential protection works on the principle of calculating the differential current at the two ends of the winding, that is, the current entering the winding is compared to the current exiting the winding. In case of any internal fault, the currents entering and exiting the winding are different, which results in a differential current, which is then used as a base for generating the operating signal. Due to this principle, the differential protection does not trip during external faults. However, it should be noted that interturn faults in the same phase are usually not detected unless they developed into some other kind of fault.

The short circuit between the phases of the stator windings normally causes large fault currents. The short circuit creates a risk of damages to the insulation, windings and stator core. The large short circuit currents cause large current forces which can damage other components in the machine. The short circuit can also initiate explosion and fire. When a short circuit occurs in a machine, there is a damage that has to be repaired. The severity and the repair time depend on the degree of damage, which is highly dependent on the fault time. The fast fault clearance of this fault type is of greatest importance to limit the damages and the economic loss.

To limit the damages in connection to the stator winding short circuits, the fault clearance time must be as short as possible (instantaneous). The fault current contributions from both the external power system (via the machine or the block circuit breaker) and from the machine itself must be disconnected as fast as possible.

The DC restraint feature should be used in case of an application with a long DC time constant in the fault currents is present. This fault current may be of a lesser magnitude (less than rated current) but is unpleasant and tends to saturate the CT and trip the differential protection for external faults. This feature is effective at moderate through-currents and ineffective at higher through-currents.

Although the short circuit fault current is normally very large, that is, significantly larger than the rated current of the machine, it is possible that a short circuit can occur between phases close to the neutral point of the machine, causing a relatively small fault current. The fault current fed from the synchronous machine can also be limited due to a low excitation of the synchronous generator. This is normally the case at the run-up of the synchronous machine, before synchronization to the network. Therefore, it is desired that the detection of the machine phase-to-phase short circuits shall be relatively sensitive, thus detecting the small fault currents.

It is also important that the machine short circuit protection does not trip for external faults when a large fault current is fed from the machine. To combine fast fault clearance, sensitivity and selectivity, the machine current differential protection is normally the best alternative for the phase-to-phase short circuits.

The risk of an unwanted differential protection operation caused by the current transformer saturation is a universal differential protection problem. If a big synchronous machine is tripped in connection to an external short circuit, it gives an increased risk of a power system collapse. Besides, there is a production loss for every unwanted trip of the machine. Therefore, preventing the unwanted disconnection of machines has a great economical value.

Recommendations for current transformers

The more important the object to be protected is, the more attention is paid to the current transformers. It is not normally possible to dimension the current transformers so that they repeat the currents with high DC components without saturating when the residual flux of the current transformer is high. The differential protection function block operates reliably even though the current transformers are partially saturated.

The accuracy class recommended for current transformers to be used with the differential function block is 5P, in which the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the actual accuracy limit factor F_a corresponding to the actual CT burden can be calculated on the basis of the rated accuracy limit factor F_n (ALF) at the rated burden, the rated burden S_n, the internal burden S_{in} and the actual burden S_a of the current transformer.

$$F_a = F_n \cdot \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 39)

Example 1

The rated burden S_n of the current transformer 5P20 is 10 VA, the secondary rated current 5A, the internal resistance R_{in} = 0.07 Ω and the rated accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is S_{in} = (5A)² × 0.07 Ω = 1.75 VA. The input impedance of the protection relay at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is S_a = (5A)² × (0.113 + 0.020) Ω = 3.33 VA. Thus, the accuracy limit factor F_a corresponding to the actual burden is about 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1 A while the repeatability simultaneously improves.

At faults occurring in the protected area, the fault currents can be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for an instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure that the trip times of the protection relay comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection must fulfill the requirement:

$$F_a > K_r \cdot Ik_{\max} \cdot (T_{dc} \cdot \omega \cdot (1 - e^{\frac{-T_m}{T_{dc}}}) + 1)$$

(Equation 40)

Ik_{max}	The maximum through-going fault current (in I_R) at which the protection is not allowed to trip
T_{dc}	The primary DC time constant related to Ik_{max}
ω	The angular frequency, that is, 2 x π x f_n
T_m	The time to saturate, that is, the duration of the saturation-free transformation
K_r	The remanence factor 1/(1-r), where r is the maximum remanence flux in pu from the saturation flux

The parameter r is the maximum remanence flux density in the CT core in pu from the saturation flux density. The value of the parameter r depends on the magnetic material used and also on the construction of the CT. For instance, if the value r = 0.4, the remanence flux density can be 40 percent of the saturation flux density. The manufacturer of the CT has to be contacted when an accurate value for the parameter r is needed. The value r = 0.4 is recommended to be used when an accurate value is not available.

The required minimum time-to-saturate T_m in 87M is half-fundamental cycle period (8.33 ms when f_n = 60 Hz).

Two typical cases are considered for the determination of the sufficient actual accuracy limit factor F_a:

1. A fault occurring at the substation bus.

   The protection must be stable at a fault arising during a normal operating situation. The reenergizing of the transformer against a bus fault leads to very high fault currents and thermal stress. Therefore, reenergizing is not preferred in this case. The remanence can be neglected.
   The maximum through-going fault current Ik_{max} is typically 6 I_R for a motor. At a short circuit fault close to the supply transformer, the DC time constant T_{dc} of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

   Ik_{max} = 6 I_R
   T_{dc} = 100 ms
   ω = 120π Hz
   T_m 8.33 ms
   K_r = 1

   Equation 40 with these values gives the result:

$$F_a > K_r \cdot Ik_{\max} \cdot (T_{dc} \cdot \omega \cdot (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

2. Reenergizing against a fault occurring further down in the network.

   The protection must be stable also during reenergization against a fault on the line. In this case, the existence of remanence is very probable. It is assumed to be 40 percent here.
   On the other hand, the fault current is now smaller and since the ratio of the resistance and reactance is greater in this location, having a full DC offset is not possible.

Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, assumed to be 50 ms here.
Assuming the maximum fault current is 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

Ik_{max}	= 0.7 × 6 = 4.2 (I_R)
T_{dc}	= 50 ms
ω	= 120π Hz
T_m	8.33 ms
K_r	= 1/(1-0.4) = 1.6667

Equation 40 with these values gives the result:

$$F_a > K_r \cdot Ik_{\max} \cdot 0.9 \cdot (T_{dc} \cdot \omega \cdot (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

If the actual burden of the current transformer S_a in the accuracy limit factor equation cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation.

1. A current transformer with a higher rated burden S_n can be chosen (which also means a higher rated accurate limit F_n).
2. A current transformer with a higher nominal primary current I_{1n} (but the same rated burden) can be chosen.

Alternative 2 is more cost-effective and therefore often better, although the sensitivity of the scheme is slightly reduced.

Example 2

Here the actions according to alternative 2 are taken to improve the actual accuracy limit factor.

$$F_a = \left(\frac{I_R CT}{I_R Motor} \right) \cdot F_n$$

(Equation 41)

I_RCT	rated primary current of the CT, for example, 1500A
I_RMotor	rated current of the motor under protection, for example, 1000A
F_n	rated accuracy limit factor of the CT, for example, 30
F_a	actual accuracy limit factor due to oversizing the CT, substituting the values in the equation, F_a = 45

In differential protection it is important that the accuracy limit factors F_a of the phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides are to be as close to each other as possible. If high inrush or start currents with high DC components pass through the protected object when it is connected to the network, special attention is required for the performance and the burdens of the current transformers and the settings of the function block.

Connection of current transformers

The connections of the main current transformers are designated as Type 1 and Type 2. If the earthings of the current transformers are either inside or outside the area to be protected, the setting *CT connection type* is of "Type 1" as shown in Figure 188. If the earthing of the current transformers are both inside and outside the area to be protected, the setting *CT connection type* is of "Type 2" as shown in Figure 189.

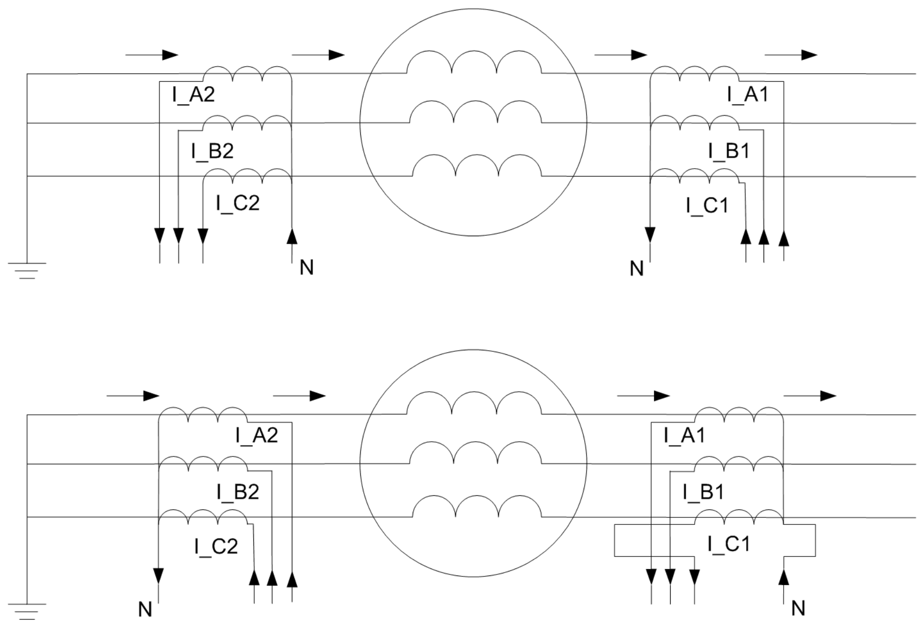


Figure 188: Connection of current transformer of Type 1

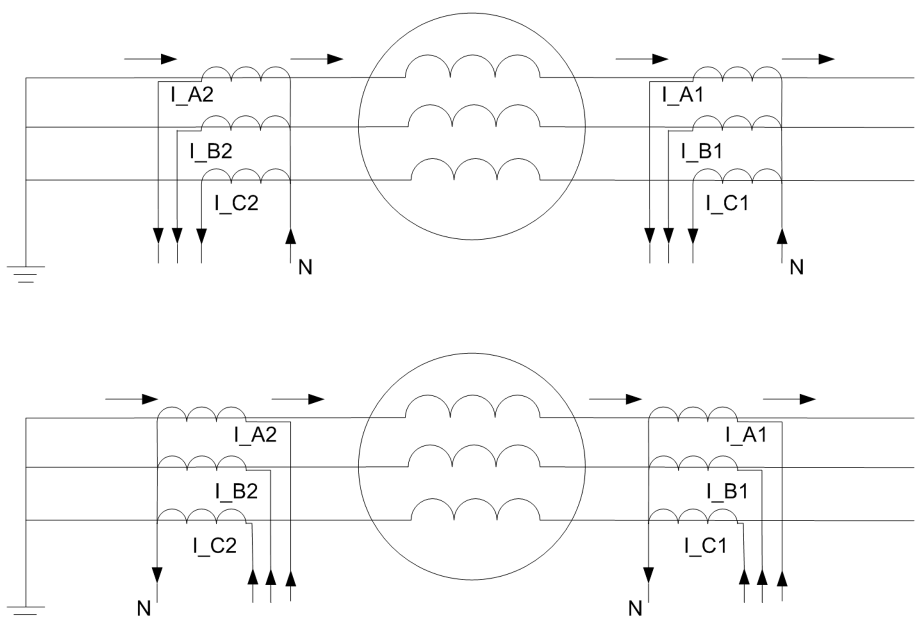


Figure 189: Connection of current transformer of Type 2

Saturation of current transformers

There are basically two types of saturation phenomena that have to be detected: the AC saturation and the DC saturation. The AC saturation is caused by a high fault current where the CT magnetic flux exceeds its maximum value. As a result, the secondary current is distorted as shown in Figure 190. A DC component in the current also causes the flux to increase until the CT saturates. This is known as DC saturation.

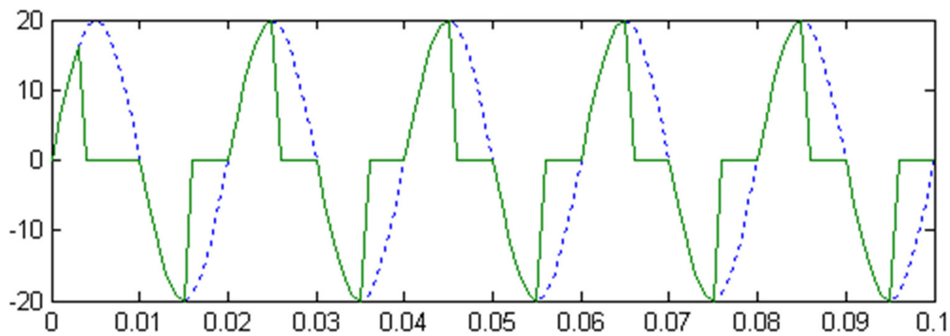


Figure 190: AC saturation

When having a short circuit in a power line, the short circuit current contains a DC component. The magnitude of the DC component depends on the phase angle when the short circuit occurs. Figure 191 shows the secondary current of the CT in the fault situation. Because of the DC component, the flux reaches its maximum value at 0.07 seconds, causing saturation. As the DC component decays, the CT recovers gradually from the saturation.

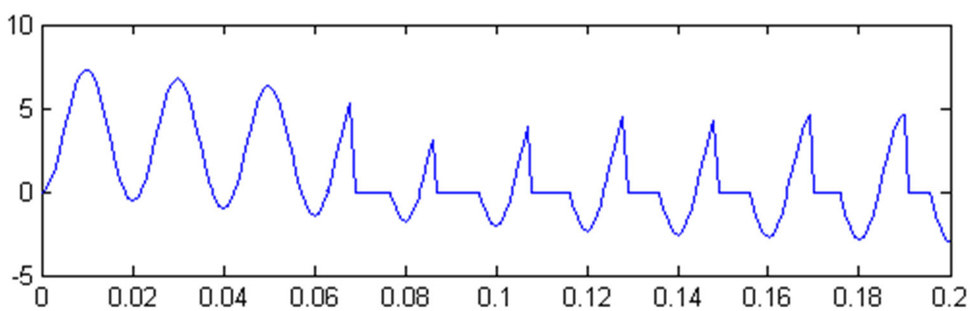


Figure 191: DC saturation

4.6.1.6 Signals

Table 333: 87M Input signals

Name	Type	Default	Description
I_A1	SIGNAL	0	Current ID for getting current values for phase A, winding 1
I_B1	SIGNAL	0	Current ID for getting current values for phase B, winding 1
I_C1	SIGNAL	0	Current ID for getting current values for phase C, winding 1
I_A2	SIGNAL	0	Current ID for getting current values for phase A, winding 2
I_B2	SIGNAL	0	Current ID for getting current values for phase B, winding 2
I_C2	SIGNAL	0	Current ID for getting current values for phase C, winding 2
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_OPR_LS	BOOLEAN	0=False	Blocks trip outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks trip outputs from instantaneous stage

Table 334: 87M Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
OPR_LS	BOOLEAN	Trip from low set
OPR_HS	BOOLEAN	Trip from high set
INT_BLKD	BOOLEAN	Internal block status

4.6.1.7 Settings

Table 335: 87M Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Low trip value	5...30	%Ir	1	5	Basic setting for the stabilized stage pickup
High trip value	100...1000	%Ir	10	500	Instantaneous stage trip value
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 1	0...100	%Ir	1	50	Turn-point between the first and the second line of the operating characteristics
End section 2	100...300	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics
DC restrain enable	0=False 1=True			0=False	Setting for enabling DC restrain feature

Table 336: 87M Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected current transformers
CT ratio Cor Line	0.40...4.00		0.01	1.00	CT ratio correction, line side
CT ratio Cor Neut	0.40...4.00		0.01	1.00	CT ratio correction, neutral side

4.6.1.8 Monitored data

Table 337: 87M Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Trip phase A
OPR_B	BOOLEAN	0=False 1=True		Trip phase B
OPR_C	BOOLEAN	0=False 1=True		Trip phase C
INT_BLKD_A	BOOLEAN	0=False 1=True		Internal block status phase A
INT_BLKD_B	BOOLEAN	0=False 1=True		Internal block status phase B
INT_BLKD_C	BOOLEAN	0=False 1=True		Internal block status phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Biasing current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Biasing current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Biasing current phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, line side
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, line side
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, line side
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle Phase AB, neutral side
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle Phase B-C, neutral side

Table continues on next page

Name	Type	Values (Range)	Unit	Description
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle Phase CA, neutral side
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase C
87M	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.6.1.9 Technical data

Table 338: 87M Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: fn ±2 Hz		
		±3% of the set value or ±0.002 x In		
Operate time [1)2)]	Low stage High stage	Minimum	Typical	Maximum
		36 ms 12 ms	40 ms 17 ms	42 ms 22 ms
Reset time		< 40 ms		
Reset ratio		Typical 0.95		
Retardation time		< 20 ms		

1) Fn = 60 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the high speed power output contact

4.6.2 Stabilized and instantaneous differential protection for 3W transformers 87T

4.6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differential protection for 3W transformers	TR3PTDF	3dI>3W	87T

4.6.2.2 Function block

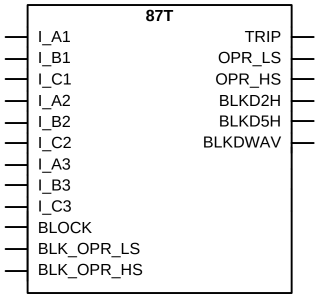


Figure 192: Function block

4.6.2.3 Functionality

The transformer differential protection 87T provides up to three three-phase current sets or restraints designed for protection of two-winding or three-winding transformers and generator-transformer blocks with a possibility to have two three-phase current sets either on the winding 1 or winding 2 side in case of two-winding transformer protection. The function includes a biased low stage and an instantaneous high stage.

The biased low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. The second harmonic restraint, together with waveform-based algorithms, ensures that the low stage does not trip due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not trip on apparent differential current caused by a harmless transformer overexcitation.

The instantaneous high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with tap changer position compensation. The correction of transformation ratio due to changes in tap position is done automatically based on the tap changer status information provided to the function through input.

4.6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of transformer differential protection can be described with a module diagram. All the modules in the diagram are explained in the next sections.

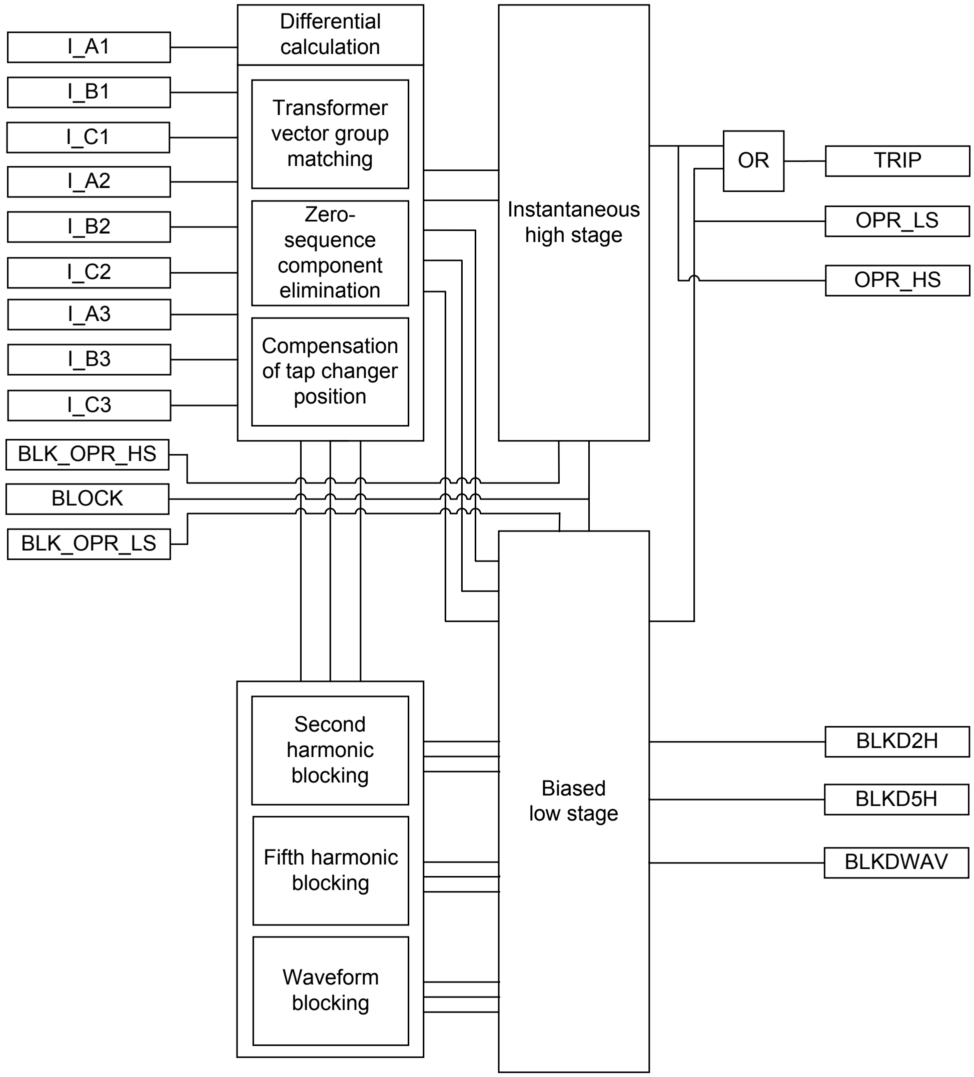


Figure 193: Functional module diagram. I_x1, I_x2 and I_x3 represent phase currents of winding 1, winding 2 and winding 3 or restraint of winding 1 or 2.

Differential calculation

87T operates phasewise on the difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object

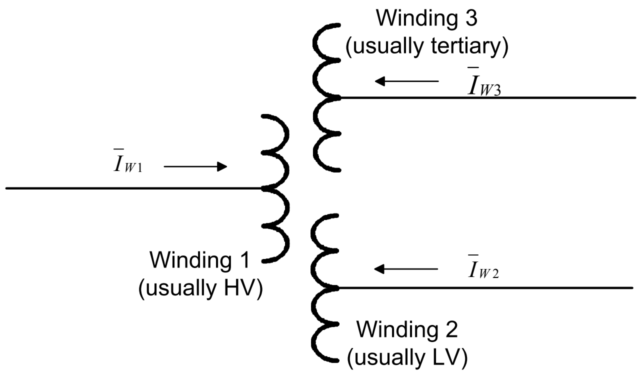


Figure 194: Single-line diagram presentation of the positive direction of the currents in a three-winding transformer

The normalized amplitude of the differential current per phase I_d is obtained using the equation:

$$I_d = \left| \bar{I}_{W1} + \bar{I}_{W2} + \bar{I}_{W3} \right|$$

(Equation 42)

In a normal situation, no fault occurs in the area protected by 87T. Then the currents I_{W1}, I_{W2} and I_{W3} cancel each other and the differential current I_d is zero. In practice, however, the differential current deviates from zero in normal situations. In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current causes the differential current, caused by the CT inaccuracies and the tap changer position, to grow at the same percentage rate.

In a biased differential protection relay in normal operation or during external faults, the higher the load current is the higher the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{\left|\bar{I}_X - \bar{I}_Y - \bar{I}_Z\right|}{2}$$

(Equation 43)

Where current I_X is the one of the normalized currents I_{W1}, I_{W2} and I_{W3} determined by the angle differences between the currents and their amplitudes. The currents I_Y and I_Z are the remaining two currents.

The I_X is selected based on one of the criteria below.

- The angle between I_X and I_Y and also between I_X and I_Z is over 120 degrees while the amplitude of I_X is not less than 0.9 x MAX(| I_X|, | I_Y|, | I_Z|)
- The one with the highest amplitude (I_X = MAX(| I_X|, | I_Y|, | I_Z|))

In case of a two-winding transformer having additional restraint (additional three-phase current set) either on the winding 1 or winding 2 side, it occupies the current I_{W3}. This assures that if the currents of the opposite direction are measured in the restraints (through current), meaning the current is passing the protected zone, this current affects the bias current of the differential protection.

If the biasing current is small compared to the differential current or if the phase angle between the currents of two windings with the highest phase current (in case of three-winding transformer) or the phase angle between the compared phase currents (in case of two-winding transformer) is close to zero, a fault has most certainly occurred in the area protected by the differential protection relay. The operating value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

Transformer vector group matching

The phase differences of the winding 1 and winding 2 currents (winding 1 and winding 3 in case of three-winding transformer) that are caused by the vector groups of the power transformer are numerically compensated in the function. The matching of the phase difference is based on generalized transform. The *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3* settings determine the current phase angle difference between the windings 1 and 2 and between 1 and 3 correspondingly.

The vector group matching can be set in the resolution of 0.1°, which allows for cycloconverter applications with a phase angle difference of, for example, 7.5° between windings.

When the phase shift setting between the windings is 0.0 degrees and *CT connection type* is according to "Type 2", the phase angle of the phase currents connected to the protection relay from the corresponding windings does not change. When the phase shift setting between windings is 180.0 degrees, the phase currents from the other winding turns 180° in the protection relay.

The transform is first applied to the set of 3 line currents on the winding 1 side of the power transformer, and then on the set of 3 line currents on the winding 2 side. In this case, the power transformer winding 1 side is taken as a reference with zero phase shift, while the winding 2 side has a phase shift Θ.

The *Phase Ref winding* setting can be used to give the possibility to define which of the windings is the reference. The phase reference can be selected from *Phase Ref winding* as “Winding 1", "Winding 2" or "Winding 3". The currents in the winding selected as the phase reference are not modified (except regarding the possible removal of zero-sequence current if needed) when the currents in other windings are matched with the reference winding (if the set phase shift between the windings is not zero).

Zero-sequence component elimination

If the zero-sequence component is to be removed on one, two or all sides of the transformer, the *Zro A elimination* setting can be used. In case one or more windings is delta-connected and there is no separate neutral grounding transformer on that winding, zero-sequence component removal is not recommended to be selected. There is no path for the zero-sequence current to flow in such a winding.

Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated according to the actual tap changer position. The position information is provided for the protection function through the tap position indication function 84T.

Typically, the tap changer is located within the HV winding, that is, winding 1 of the power transformer. The *Tapped winding* setting parameter specifies whether the tap changer is connected to winding 1, winding 2 or winding 3. The *Tapped winding* setting parameter is also used to enable or disable the automatic adaptation to the tap changer position. The possible values are "Not in use" (1), "Winding 1"(2), "Winding 2" (3), "Winding 3" (4).

There can be only one tap changer in the transformer, that is, the function can take into account and compensate only for one tap changer.

The *Tap nominal* setting parameter provides the number of the tap which results in the nominal voltage and current. When the current tap position deviates from this value, the input current values where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps and the direction of the deviation from the nominal tap and the percentage change in the voltage resulting from a deviation of one tap step. The percentage value is set via the *Step of tap* setting.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* settings. The *Min winding tap* setting gives the tap position number resulting the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max winding tap* setting gives the tap position number resulting the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* settings help the tap position compensation algorithm find the direction of the compensation. This ensures also that if the current tap position information is corrupted for some reason, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

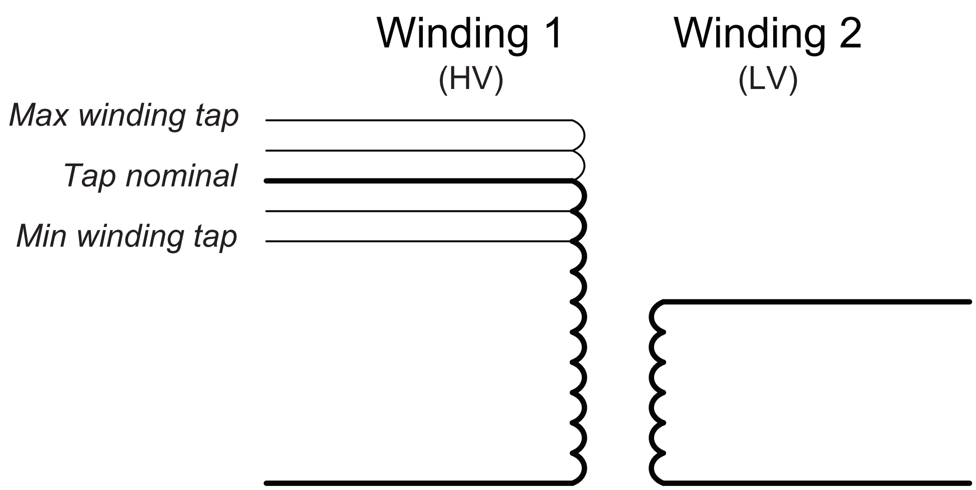


Figure 195: Simplified presentation of the HV and LV windings in the case of two-winding transformer with demonstration of the settings Max winding tap, Min winding tap and Tap nominal.

The position value is available in the monitored data view on LHMI or through other communication tools in the tap position indication function 84T. When the quality of the `TAP_POS` input value is not good, the position information in the `TAP_POS` input is not used, but the last value with the good quality information is used instead. In addition, the minimum sensitivity of the biased stage, set by the *Low trip value* setting, is automatically desensitized with the total range of the tap position correction. The new acting low trip value can be calculated.

$$Desensitized\ Low\,trip\ value = Low\,trip\ value + ABS\ (Max\ winding\ tap - Min\ winding\ tap) \times Step\ of\ tap$$

(Equation 45)

Second harmonic blocking

Transformer-magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current may be many times the rated current, and the half-life can be up to several seconds. To the differential protection relay, the inrush current represents a differential current that causes the protection relay to trip almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking of the biased low stage of the protection relay at magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic to the fundamental frequency component of the differential current (Id2f / Id1f).

The blocking also prevents an unwanted trip at recovery and a sympathetic magnetizing inrush. At recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to the fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1-connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, the subtraction of them in a delta compensation results in a very small second harmonic component.

Because of the small second harmonic component, some action needs to be taken to avoid false tripping of the phase having a too low ratio of the second harmonic to the fundamental component. One way could be to block all phases always when the second harmonic blocking conditions are fulfilled at least in one phase. The other way is to calculate weighted ratios of the second harmonic to the fundamental for each phase using the original ratios of the phases. The latter option is used here.

The ratio to be used for the second harmonic blocking is calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the concerned phase is of the most weight compared to the ratios of the other two phases (weighting factors are four, one and one, where four is the factor of the phase concerned). The trip of the restrained differential on the concerned phase is blocked if the weighted ratio of that phase is above the set *Pickup value 2.H* blocking limit and if the blocking is enabled through the *Restraint mode* setting.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a stable blocking scheme at connection inrush currents.

The connection of the power transformer against a fault inside the protected area does not delay the operation of the tripping, because in such a situation the blocking based on the second harmonic of the differential current is prevented by a separate algorithm based on the different waveform and the different rate of change of the normal inrush current and the inrush current containing the fault current. The algorithm does not eliminate the blocking at inrush currents, unless there is a fault in the protected area.

The feature can be enabled and disabled through the *Harmonic deblock 2.H* setting.

Fifth harmonic blocking

The inhibition of the protection relay operation in situations of overexcitation is based on the ratio of the fifth harmonic to the fundamental component of the differential current (Id5f / Id1f). The ratio is calculated separately for each phase without weighting factors. If the ratio exceeds the set value of *Pickup value 5.H* and blocking is enabled through the *Restraint mode* setting, the operation of the biased stage of the protection relay in the concerned phase is blocked.

At dangerous levels of overvoltage which may cause damage to the transformer, the blocking can be automatically eliminated. The blocking is removed if the ratio of the fifth harmonic to the fundamental component of the differential current exceeds the set value of the *Stop value 5.H* setting, and the blocking removal is enabled. The enabling and disabling of deblocking feature is done through the *Harmonic deblock 5.H* setting.

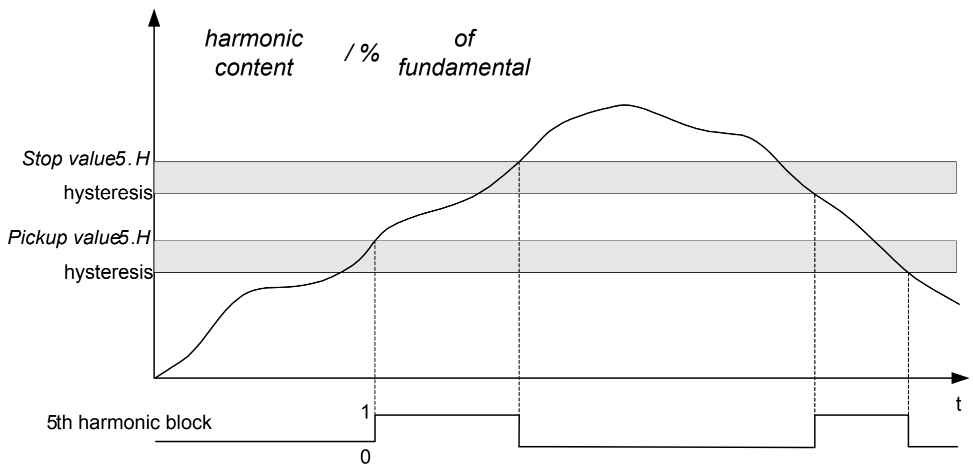


Figure 196: The fifth harmonic blocking limits and the operation when both blocking and deblocking features are enabled through the Harmonic deblock 5.H setting

Fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between TRUE and FALSE. The required consecutive fulfillments of the condition can be counted using the blocking counter. When the condition is not fulfilled, the counter is decreased (if >0).

Also fifth harmonic deblocking (based on the higher limit, *Stop value 5.H*, if enabled with *Harmonic deblock 5.H*) has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Waveform blocking

The biased low stage can always be blocked with waveform blocking. It cannot be disabled with *Restraint mode*. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for the low-current periods of differential current during the inrush and external fault.

Reset of the blocking

All three blocking signals, that is, waveform and the second and fifth harmonic, have a counter or time limit which holds the blocking on for a certain time after the blocking conditions have ceased to be fulfilled. The deblocking takes place when the counters or time have elapsed. This is a normal case of deblocking.

The blocking signals can be reset immediately if a very high differential current is measured or if the phase difference (angle between) of the compared currents is close to zero (in normal situation, the phase difference is 180 degrees).

Biased low stage

Biasing of the current differential protection is needed since a possible appearance of a differential current can also be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, there can be several reasons for the false differential current.

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents
- Transformer overexcitation during overvoltage situations
- Transformer overexcitation during underfrequency situations
- CT saturation at high currents passing through the transformer

Differential current caused by CT errors and tap changer position increases at the same percent ratio as the load current increase.

In the protection of generators, the false differential current can be caused by:

- CT errors
- CT saturation at high currents flowing through the generator

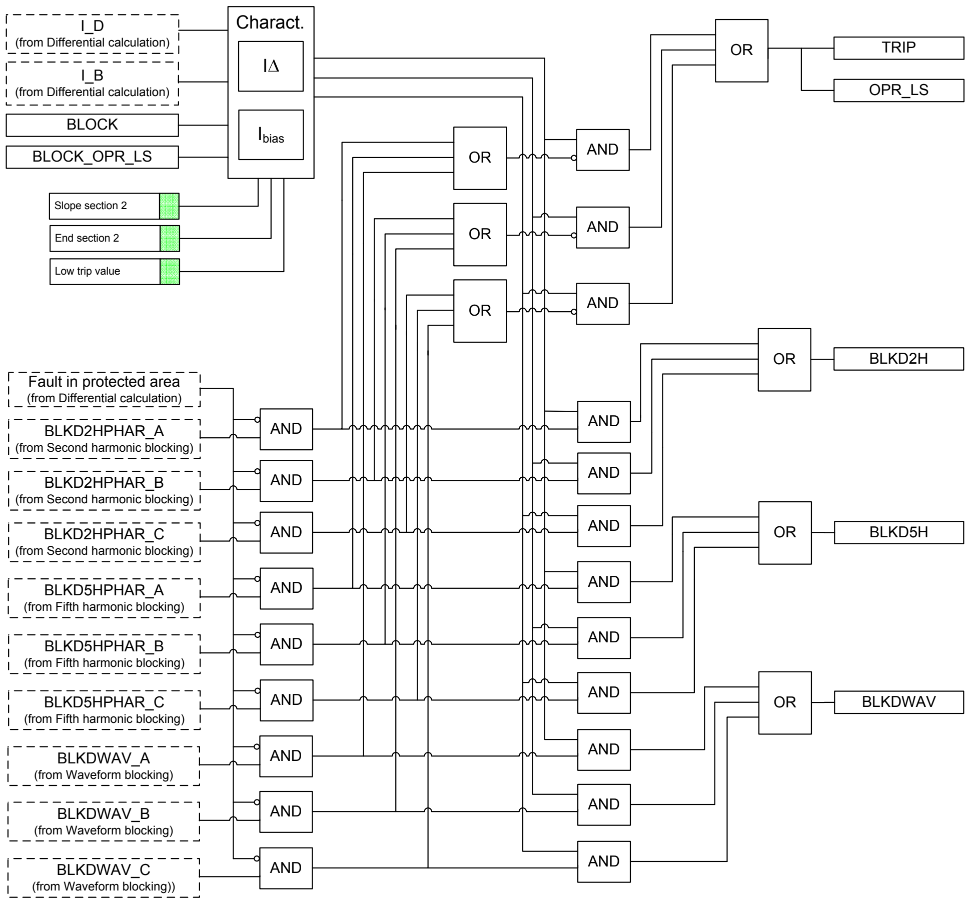


Figure 197: Operation logic of the biased low stage

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the large currents fed by the transformer in a motor startup or transformer inrush situations. Therefore, the operation of the differential protection is biased in respect to the load current. In biased differential protection, the higher the differential current required for the protection to operate, the higher the load current.

The operation characteristic of the biased low stage is determined by *Low trip value*, *Slope section 2* and the second turning point setting of the operating characteristic curve, *End section 2* (the first turning point and the slope of the last part of the characteristic are fixed). The settings are the same for each phase. When the differential current exceeds the operating value determined by the operating characteristic, the differential function is activated. If the differential current stays above the operating value continuously for a suitable period, which is 1.1 times the fundamental cycle, the `OPR_LS` output is activated. The `TRIP` output is always activated when the `OPR_LS` output is activated.

The stage can be blocked internally by the second or the fifth harmonic restraint, or by special algorithms detecting the inrush and current transformer saturation at external faults. When the operation of the biased low stage is blocked by the second harmonic blocking functionality, the BLKD2H output is activated.

The BLKD5H output is activated when the biased low stage is blocked by the fifth harmonic blocking functionality. Correspondingly, when the operation of the biased low stage is blocked by waveform blocking functionality, the BLKDWAV output is activated according to the phase information.

When required, the operating outputs of the biased low stage can be blocked by the external control signals BLK_OPR_LS and BLOCK.

The operation of the protection relay is affected by the biasing as shown graphically by the operating characteristic.

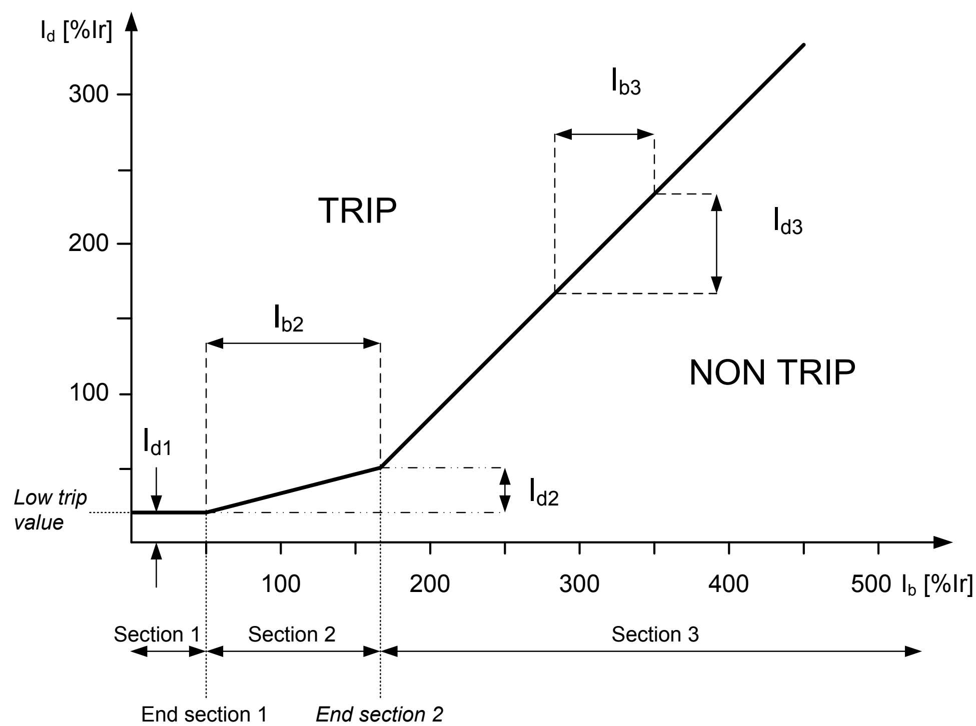


Figure 198: Operation characteristic for biased operation of 87T

The *Low trip value* setting of the biased stage of the differential function is determined according to the operating characteristics curve:

$$Low\,trip\,value = Id1$$

(Equation 46)

The *Slope section 2* setting is determined correspondingly:

$$Slope\ section\ 2 = Id2/Ib2 \times 100\ \%$$

(Equation 47)

The second turning point *End section 2* can be set in the range of 100 percent to 500 percent.

The slope of operating characteristic curve of the differential function varies in three different sections of the range.

Table 339: Different sections of the range and its operation

Sections	Operation
Section 1	In section 1, where 0 percent Ir < Ib < *End section 1*, with *End section 1* being fixed to 50 percent Ir, the differential current required for tripping is constant. The value of the differential current is the same as the *Low trip value* selected for the function. The *Low trip value* setting basically allows for the no-load current of the power transformer and small inaccuracies of the current transformers, but it can also be used to influence the overall level of the operation characteristic. At the rated current, the no-load losses of the power transformer are about 0.2 percent. If the supply voltage of the power transformer suddenly increases due to operational disturbances, the magnetizing current of the transformer increases as well. In general, the magnetic flux density of the transformer is rather high at the rated voltage and the rise in voltage by a few percent causes the magnetizing current to increase by tens of percent. This should be considered in *Low trip value*.
Section 2	Section 2, where *End section 1* < Ib < *End section 2*, is called the influence area of *Slope section 2*. In this section, the variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping in comparison with the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends basically on the starting ratio.
Section 3	In section 3, where Ib > *End section 2*, the slope of the characteristic is constant. The slope is 100 percent, which means that the increase in the differential current is equal to the corresponding increase in the biasing current.

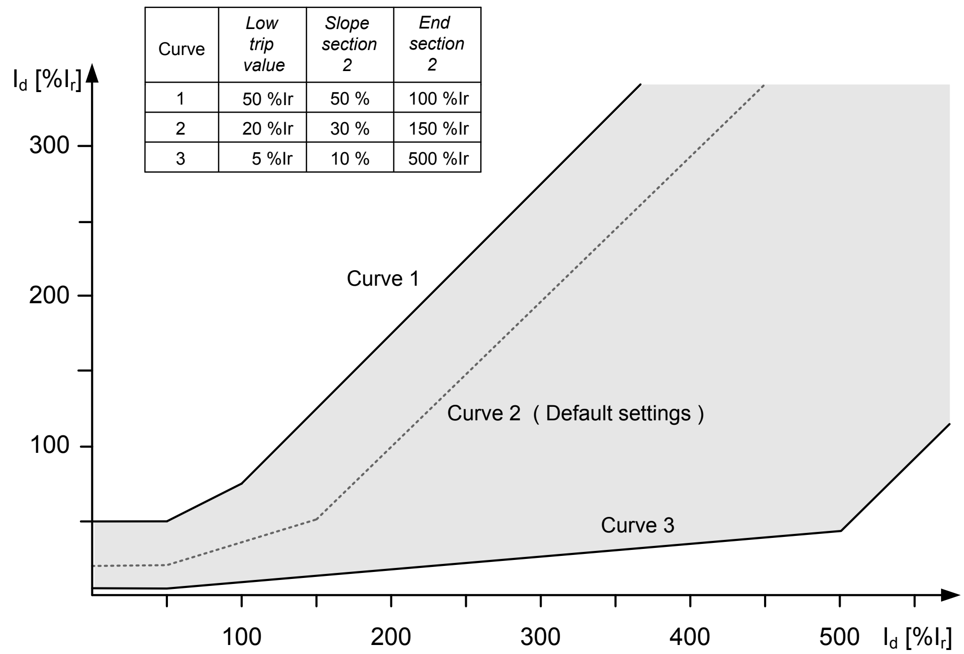


Figure 199: Setting range for Biased low stage

If the biasing current is small compared to differential current or if the phase angle between the current of two windings with the highest phase current is close to zero (normally, the phase difference is 180 degrees) or the phase angle between the compared phase currents (in case of two-winding transformer) is close to zero, a fault has most certainly occurred in the area protected by the differential protection relay. The internal blocking signals of the biased stage are inhibited.

The operation of the differential protection is based on the fundamental frequency components. The operation is accurate and stable: the DC component and harmonics of the current do not cause unwanted operations.

Instantaneous high stage

Instantaneous high stage can be enabled or disabled with the *Enable high set* setting. The corresponding parameter values are "True" and "False".

The operation of Instantaneous high stage is not biased. The instantaneous stage trips and the OPR_HS output is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set operation value *High trip value* or when the instantaneous value of the differential current exceeds 2.5 x *High trip value*. The value 2.5 (=1.8 x √2) is due to the maximum asymmetric short circuit current.

If the biasing current is small compared to differential current, or if the phase angle between the current of two windings with the highest phase current is close to zero (normally, the phase difference is 180 degrees) or the phase angle between the compared phase currents (in case of two winding transformer) is close to zero, a fault has occurred in the area protected by the differential protection. Then the trip value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

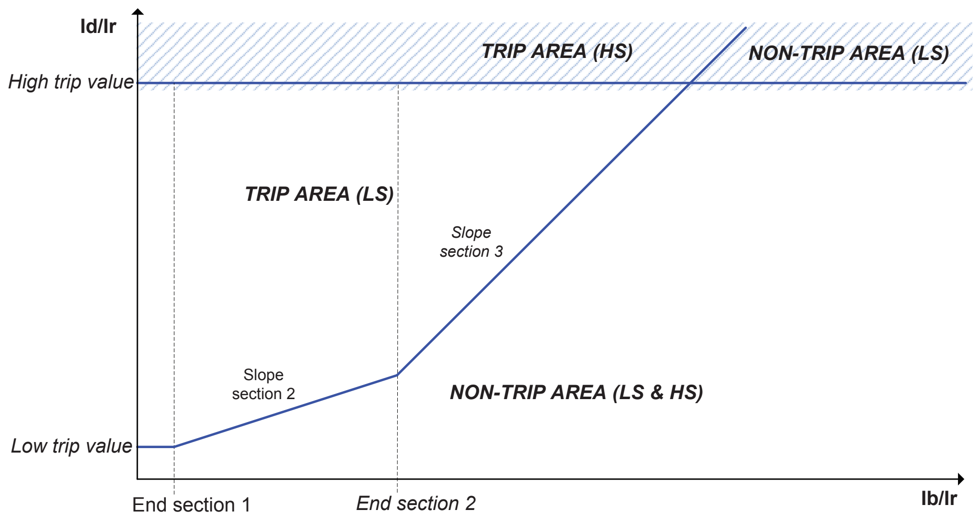


Figure 200: Operating characteristics of the protection. LS stands for Biased low stage and HS for Instantaneous high stage.

The TRIP output is always activated with the OPR_HS output. The internal blocking signals of the differential function do not prevent the operating signal of the instantaneous differential current stage from being activated. When required, the trip outputs of Instantaneous high stage can be blocked by the external control signals BLK_OPR_HS or BLOCK.

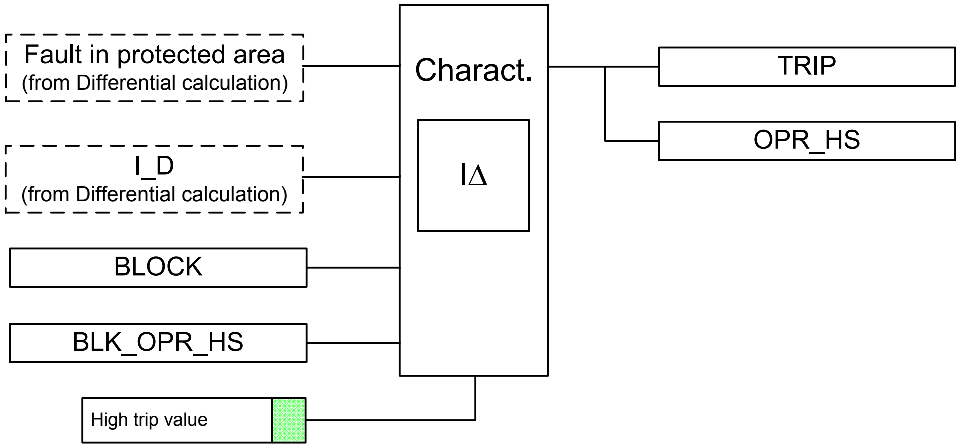


Figure 201: Operation logic of Instantaneous high stage

External blocking functionality

The 87T has three inputs for blocking.

Blocking functionality	Description
`BLOCK`	When active (TRUE), the operation of the function is blocked, only measurement value outputs are updated.
`BLK_OPR_LS`	When active (TRUE), 87T acts normally except that the `OPR_LS` output is not active or activated in any circumstances. Additionally, the `TRIP` output can be activated only by Instantaneous high stage (if not blocked as well).
`BLK_OPR_HS`	When active (TRUE), 87T operates normally except that the `OPR_HS` output is not active or activated in any circumstances. Additionally, the `TRIP` output can be activated only by Biased low stage (if not blocked as well).

4.6.2.5 CT connections and transformation ratio correction

The combinations of the connections of the primary current transformers are designated as "Type 1" and "Type 2". The type needs to be selected separately for the combination of CT connections on the winding 1 and 2 sides as well as for the combination of CT connections on the winding 1 and 3 sides in case of three-winding transformer.

- If the positive directions of the winding 1 and winding 2 relay currents are opposite, the setting parameter *CT connection 1-2* is "Type 1", as shown in Figure 202
- If the positive directions of the winding 1 and winding 2 relay currents are equal, the setting parameter *CT connection 1-2* is "Type 2", as shown in Figure 203
- The default value of the *CT connection 1-2* settings is "Type 1".
- The same applies for the *CT connection 1-3* settings.

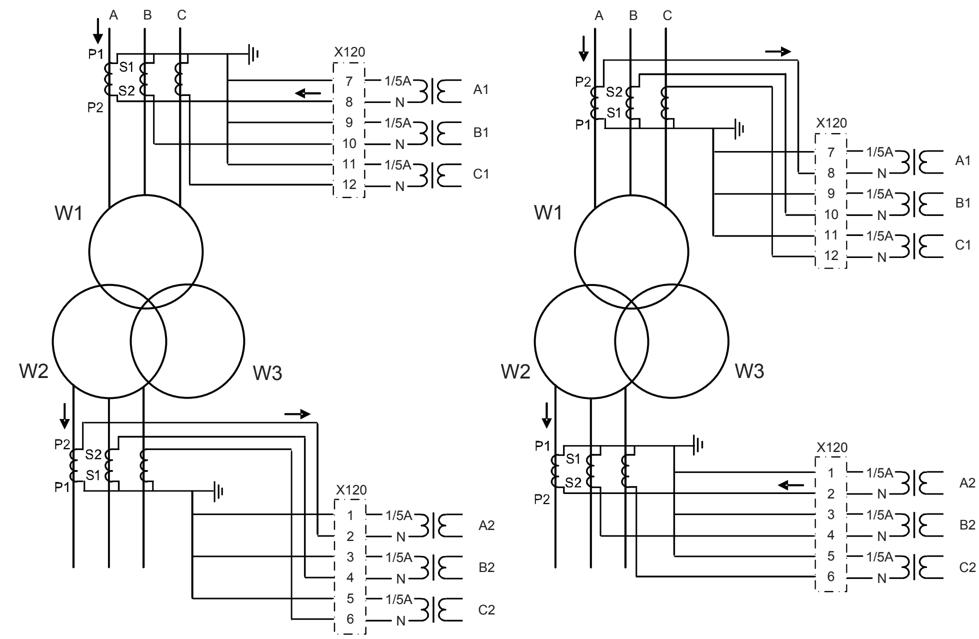


Figure 202: Connection of current transformers of Type 1 and example of currents during external fault

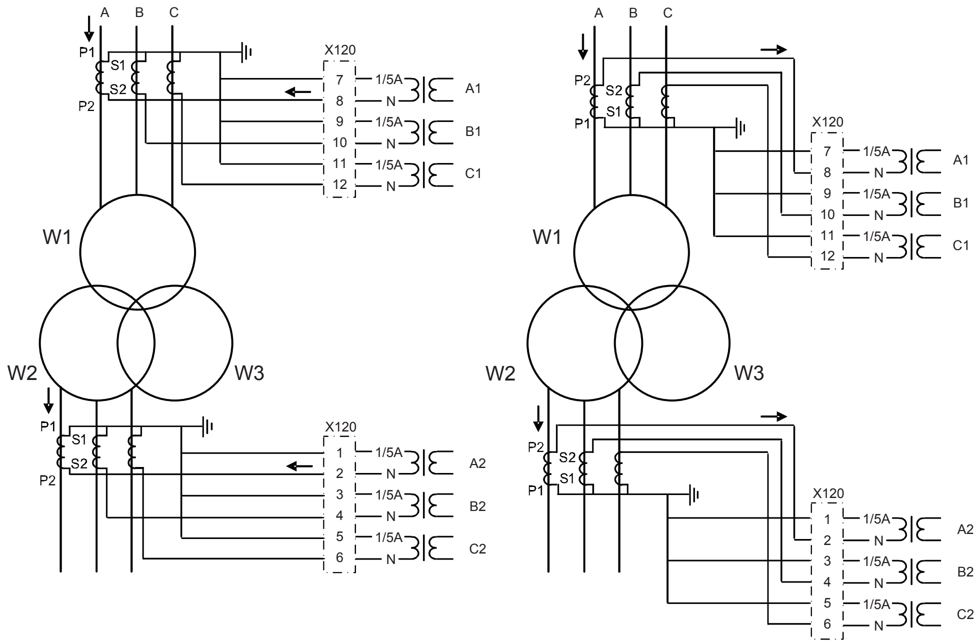


Figure 203: Connection of current transformers of Type 2 and example of currents during external fault

In case of three-winding transformer, the above consideration applies between winding 1 and winding 2. A similar consideration is done between winding 1 and winding 3 using the *CT connection 1-3* setting.

If the rated primary current of the current transformers is not equal to the rated current of the power transformer on the concerned side of the transformer, the setting parameters *CT ratio Cor Wnd 1*, *CT ratio Cor Wnd 2* and *CT ratio Cor 3* must be used for correcting the transformation ratios. *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* are used to correct the ratios on winding 1 and 2 while the use of *CT ratio Cor 3* depends on the setting *Current group 3 type*. If *Current group 3 type* is "Tertiary", the *CT ratio Cor 3* setting is used to correct the ratios on the winding 3. If *Current group 3 type* is "Wnd 2 restraint", the ratio correction is made to the ratios of the second restraint on winding 2. If *Current group 3 type* is "Wnd 1 restraint", the ratio correction is made to the ratios of the second restraint on winding 1.

4.6.2.6 Application

The transformer differential protection is a unit protection. It acts as the main protection of transformers in case of winding failure. The protective zone of a differential protection includes the transformer itself and the bus work or cables between the current transformer and the power transformer. When bushing current transformers are used for the differential protection relay, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. Such a busbar protection includes the bus work or cables between the circuit breaker and the power transformer. The internal electrical faults are serious and cause immediate damage. The short circuits and ground faults in the windings and terminals are normally detected by the differential protection. Interturn faults, which are flashovers between conductors within the same physical winding, are also possible to detect if a large enough number of turns are short-circuited. Interturn faults are the most difficult transformer winding faults to detect with electrical protections. A small interturn fault including just a few turns results in an undetectable amount of current until it develops into a ground fault. For this reason, it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations for external faults.

It is important that the faulty transformer is disconnected as fast as possible. As the differential protection is a unit protection, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. The differential protection should not operate to faults outside the protective zone.

A transformer differential protection compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by the differential protection must take into consideration changes to voltages, currents and phase angles. The traditional 87T required auxiliary transformers for the correction of the phase shift and ratio. The numerical microprocessor-based differential algorithm as implemented in 87T compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during a normal load or external faults if the turns ratio and phase shift are correctly compensated. However, there are several different phenomena other than internal faults that cause unwanted and false differential currents. There can be several main reasons for unwanted differential currents.

- Mismatch due to varying tap changer positions
- Different characteristics, loads and operating conditions of the current transformers
- Zero-sequence currents that only flow on one side of the power transformer
- Normal magnetizing currents
- Magnetizing inrush currents
- Overexcitation of magnetizing currents

87T is designed mainly for protection of two-winding or three-winding transformers. 87T can also be utilized for the protection of generator-transformer blocks as well as short cables and overhead lines. If the distance between the measuring points is relatively long in line protection, interposing CTs might be needed to reduce the burden of the CTs. For the interposing CT, the accuracy limit factor must fulfill the same requirements as the main CTs. The interposing CT imposes an additional burden to the main CTs.

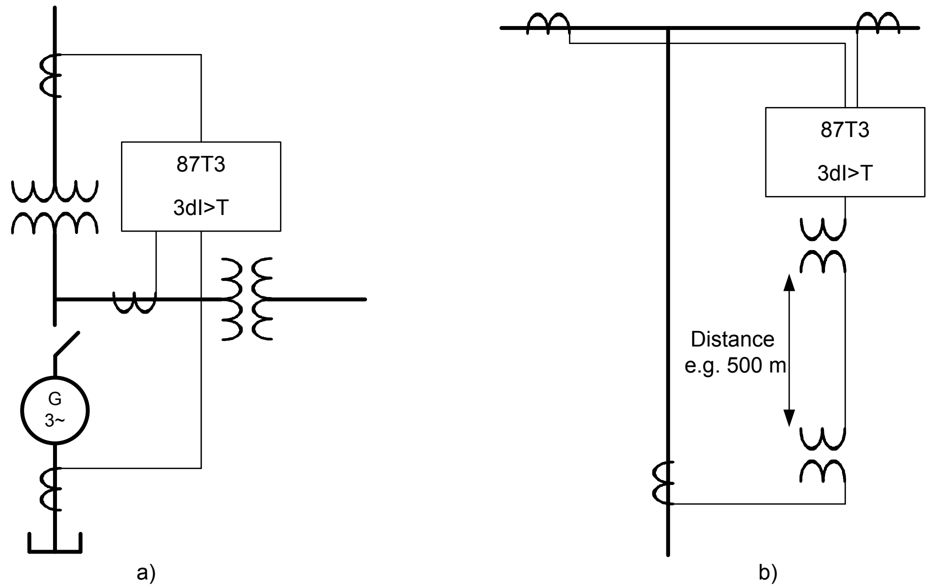


Figure 204: Differential protection of generator-transformer block and short cable or line

87T can be used in three-winding transformer applications or two-winding transformer applications with two output or two input feeders.

If the CTs connected to the two output or input feeders have the same ratio, follow the description below.

On the double-feeder side of the two-winding power transformer, the currents from the other feeder are connected to the third three-phase current set of the protection relay (*Current group 3 type* to be set as "Wnd 2 restraint").

It is also possible that the double-feeder side is on the input side of the transformer (*Current group 3 type* to be set as "Wnd 1 restraint").

If the CTs connected to the two output or input feeders have a different ratio, follow the description below.

In three-winding transformer applications, currents from the winding 3 are always connected to the third three-phase current input set of the protection relay (*Current group 3 type* to be set as "Tertiary").

In the normal two-winding transformer application with one set of three-phase currents on both sides of the transformer, the *Current group 3 type* setting must be set as "Not in use".

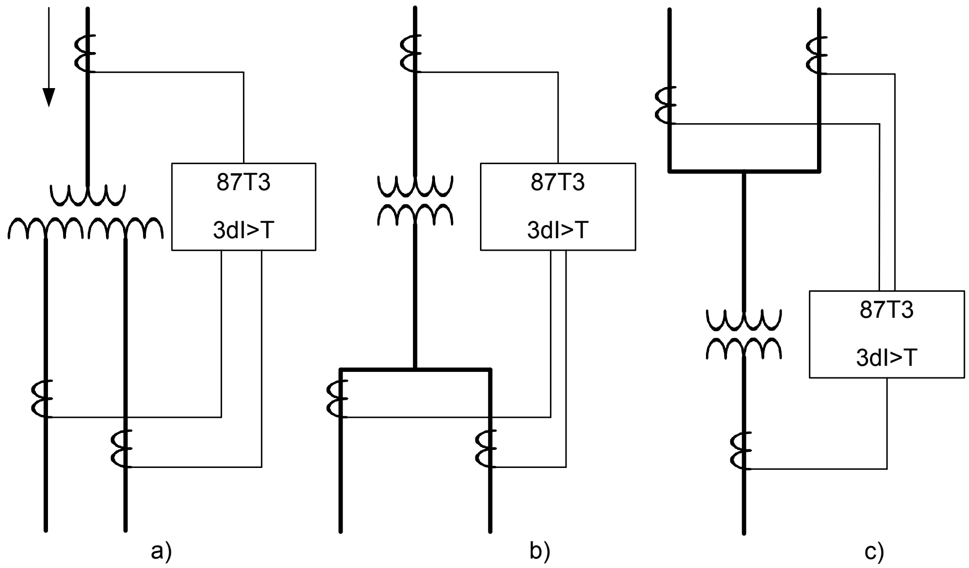


Figure 205: Differential protection of three-winding transformer, transformer with two output feeders and transformer with two input feeders

Transforming ratio correction of CTs

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on all sides of the power transformer with the CT ratio correction settings.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 48)

I_{nT} rated load of the power transformer

S_n rated power of the power transformer

U_n rated phase-to-phase voltage

Two-winding transformer with one set of currents on both sides of the transformer.

The rated power of the transformer is 25 MVA, the ratio of the CTs on the 110 kV side is 300/1 and that on the 21 kV side is 1000/1.

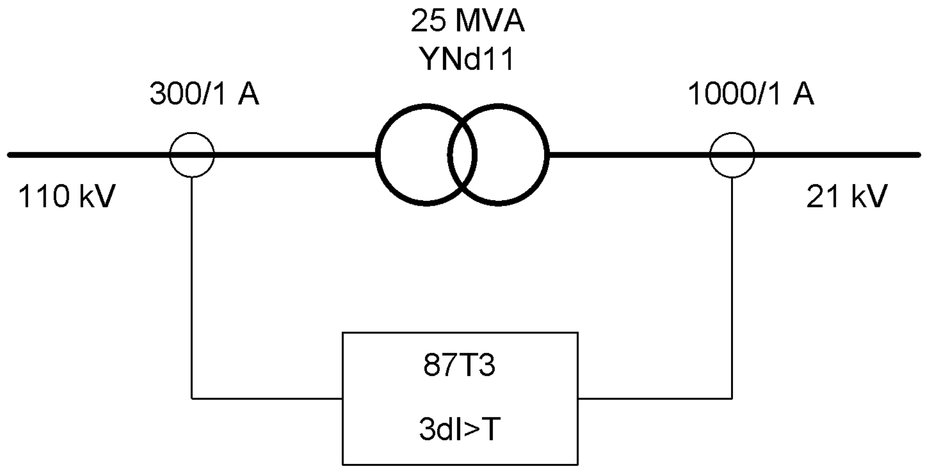


Figure 206: Example of two-winding power transformer differential protection

The rated load of the transformer can be calculated.

HV side: I_{nT_Wnd1} = 25 MVA / (1.732 x 110 kV) = 131.2 A

LV side: I_{nT_Wnd2} = 25 MVA / (1.732 x 21 kV) = 687.3 A

87T settings:

CT ratio Cor Wnd 1 = 300 A / 131.2 A = 2.29

CT ratio Cor Wnd 2 = 1000 A / 687.3 A = 1.45

CT ratio Cor Wnd 3 is not applicable in this case

Vector group matching and elimination of the zero-sequence component

The vector group of the power transformer is numerically matched on the windings on different sides of the transformer by the *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the function.

If the neutral of a star-connected power transformer is grounded, any ground fault in the network is perceived by the protection as differential current. The elimination of the zero-sequence-component can be selected to be on or off for that winding by the *Zro A elimination* setting. By default, the elimination is not done for any winding.

Commissioning

The settings for the connection group compensation (*CT connection 1-2*, *Phase shift Wnd 1-2* and in case of three-winding transformer also *CT connection 1-3* and *Phase shift Wnd 1-3* settings) can be verified by monitoring the angle values (I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2, I_ANGL_C2_A2, I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 and in case of three-winding transformer also I_ANGL_A3_B3, I_ANGL_B3_C3, I_ANGL_C3_A3, I_ANGL_A1_A3, I_ANGL_B1_B3 and I_ANGL_C1_C3) when injecting the current into the transformer. These angle values are calculated from the compensated currents.

When a station service transformer is available, it can be used to provide current into the winding 1 side, for example, HV windings, while the winding 2 side, for example, LV windings are short-circuited, as shown in figure 207 (in case of three-winding transformer, the tertiary winding side would be short-circuited). This way the current can flow both in high-voltage and low-voltage windings (and in winding 3 in case of three-winding transformer). The commissioning signals can also be provided through other means. The currents need to be at least 0.015 p.u. to allow the phase current and angle monitoring.

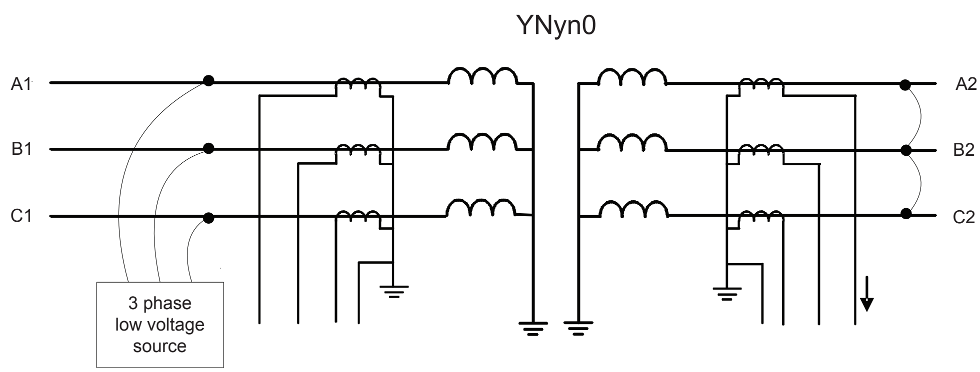


Figure 207: Low-voltage test arrangement. The three-phase low-voltage source can be the station service transformer, for example.

The control setting *Tapped winding* should be set to value "Not in use" to ensure that the monitored current values are not scaled by the automatic adaptation to the tap changer position. When only the angle values are taken, this is not needed since the angle values are not affected by the tap changer position.

When injecting the currents into the HV winding, the angle values I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2, and in case of three winding transformer, I_ANGL_A3_B3, I_ANGL_B3_C3 and I_ANGL_C3_A3, should be +120.

If this is not the case, the phase order may be wrong or the polarity of one current transformer differs from the polarities of the other current transformers on the same side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 show -120 degrees, the phase order is wrong on winding 1, for example, the high-voltage side. If the angle values I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 show -120 degrees, the phase order is wrong on winding 2, for example, the low-voltage side. If the angle values I_ANGL_A3_B3, I_ANGL_B3_C3 and I_ANGL_C3_A3 show -120 degrees, the phase order is wrong on winding 3, for example, the tertiary side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 do not show the same value (+120 degrees), the polarity of one current transformer may be wrong. For example, if the polarity of the current transformer measuring IL2 is wrong, the I_ANGL_A1_B1 show -60 degrees, I_ANGL_B1_C1 show -60 degrees and _ANGL_C1_A1 show +120 degrees.

When the phase order and the angle values are correct, the angle values I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 should show ±180 degrees and in case of three-winding transformer, also the angle values I_ANGL_A1_A3, I_ANGL_B1_B3 and I_ANGL_C1_C3 should show ±180 degrees. There can be several reasons if this is not the case. If the angle values are 0, most probably the value given for CT connection 1-2 (or CT connection 1-3) is wrong. If the angle values are something else, the value for *Phase shift Wnd 1-2* or *Phase shift Wnd 1-3* can be wrong.

Table 340: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match with the actual CT connections on winding 1, 2 and 3

Angle output name	Angle value	Possible reason if not Ok
I_ANGL_A1_B1	+120	Ok
I_ANGL_B1_C1	+120	Ok
I_ANGL_C1_A1	+120	Ok
I_ANGL_A2_B2	+120	Ok
I_ANGL_B2_C2	+120	Ok
I_ANGL_C2_A2	+120	Ok
I_ANGL_A3_B3	+120	Ok
I_ANGL_B3_C3	+120	Ok
I_ANGL_C3_A3	+120	Ok
I_ANGL_A1_A2	±180	Ok
I_ANGL_B1_B2	±180	Ok
I_ANGL_C1_C2	±180	Ok
I_ANGL_A1_A3	±180	Ok
I_ANGL_B1_B3	±180	Ok
I_ANGL_C1_C3	±180	Ok

Table 341: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match with the actual CT connections on winding 1, 2 and 3 but the phase order is wrong on winding 1

Angle output name	Angle value	Possible reason if not Ok
I_ANGL_A1_B1	-120	Wrong phase order
I_ANGL_B1_C1	-120	Wrong phase order
I_ANGL_C1_A1	-120	Wrong phase order
I_ANGL_A2_B2	+120	Ok
I_ANGL_B2_C2	+120	Ok
I_ANGL_C2_A2	+120	Ok
I_ANGL_A3_B3	+120	Ok
I_ANGL_B3_C3	+120	Ok
I_ANGL_C3_A3	+120	Ok
I_ANGL_A1_A2	+60	Winding 1 phase B connected as phase A
I_ANGL_B1_B2	-60	Winding 1 phase A connected as phase B
I_ANGL_C1_C2	±180	Ok
I_ANGL_A1_A3	+60	Winding 1 phase B connected as phase A
I_ANGL_B1_B3	-60	Winding 1 phase A connected as phase B
I_ANGL_C1_C3	±180	Ok

Table 342: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match with the actual CT connections on winding 1, 2 and 3 but the phase order is wrong on winding 2

Angle output name	Angle value	Possible reason if not Ok
I_ANGL_A1_B1	+120	Ok
I_ANGL_B1_C1	+120	Ok
I_ANGL_C1_A1	+120	Ok
I_ANGL_A2_B2	-120	Wrong phase order
I_ANGL_B2_C2	-120	Wrong phase order
I_ANGL_C2_A2	-120	Wrong phase order
I_ANGL_A3_B3	+120	Ok
I_ANGL_B3_C3	+120	Ok
I_ANGL_C3_A3	+120	Ok
I_ANGL_A1_A2	-60	Winding 2 phase B connected as phase A
I_ANGL_B1_B2	+60	Winding 2 phase A connected as phase B
I_ANGL_C1_C2	±180	Ok
Table continues on next page		

Angle output name	Angle value	Possible reason if not Ok
I_ANGL_A1_A3	±180	Ok
I_ANGL_B1_B3	±180	Ok
I_ANGL_C1_C3	±180	Ok

Table 343: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match with the actual CT connections on winding 1, 2 and 3 but the phase B polarity is wrong compared to other phases on winding 2

Angle output name	Angle value	Possible reason if not Ok
I_ANGL_A1_B1	+120	Ok
I_ANGL_B1_C1	+120	Ok
I_ANGL_C1_A1	+120	Ok
I_ANGL_A2_B2	-60	Wrong polarity phase B
I_ANGL_B2_C2	-60	Wrong polarity phase B
I_ANGL_C2_A2	+120	Ok
I_ANGL_A3_B3	+120	Ok
I_ANGL_B3_C3	+120	Ok
I_ANGL_C3_A3	+120	Ok
I_ANGL_A1_A2	±180	Ok
I_ANGL_B1_B2	0	Winding 2, wrong polarity phase B
I_ANGL_C1_C2	±180	Ok
I_ANGL_A1_A3	±180	Ok
I_ANGL_B1_B3	±180	Ok
I_ANGL_C1_C3	±180	Ok

4.6.2.7 Recommendations for current transformers

The more important the object to be protected, the more attention should be paid to the current transformers. Normally, it is not possible to dimension the current transformers so that they repeat currents with high DC components without saturating when the residual flux of the current transformer is high. 87T operates reliably even though the current transformers are partially saturated. The purpose of the following current transformer recommendations is to secure the stability of the relay at high through-currents and the quick and sensitive operation of the relay at faults occurring in the protected area where the fault currents can be high.

The accuracy class recommended for current transformers to be used with 87T is 5P, in which the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the accuracy limit factor F_a corresponding to the actual CT burden can be calculated on the basis of the rated accuracy limit factor F_n (ALF) at the rated burden, the rated burden S_n, the internal burden S_{in} and the actual burden S_a of the current transformer can be calculated.

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 49)

Example 1

In the example, the rated burden S_n of the CTs 5P20 is 10 VA, the secondary rated current 5A, the internal resistance $R_{in} = 0.07\ \Omega$ and the accuracy limit factor F_n(ALF) corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is S_{in} = (5A)2 x 0.07 Ω = 1.75 VA. The input impedance of the relay at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is S_a =(5A)2 x (0.113 + 0.020) Ω = 3.33 VA. Thus the accuracy limit factor F_a corresponding to the actual burden is 46.

The CT burden can grow considerably at the rated current of 5A. At the rated current of 1A, the actual burden of the current transformer decreases, while the repeatability simultaneously improves.

At faults occurring in the protected area, the fault currents can be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is enough that the current transformers are capable of repeating, during the first cycle, the current required for instantaneous tripping.

The current transformers should be able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault, to secure that the operating times of the protection relay comply with the times stated in the section "Technical Data".

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection fulfill the requirement of the equation.

$$Fa > K_r \ I_{kmax} \times (T_{dc} \times \omega \times (1 - e^{-Tm/Tdc}) + 1)$$

(Equation 50)

I_{kmax} the maximum through-going fault current (in p.u.) at which the protection is not allowed to operate

T_{dc} the primary DC time constant related to I_{kmax}

ω the angular frequency, i.e. 2 x π x fn

T_m the time to saturate, that is, the duration of the saturation-free transformation

K_r the remanence factor, 1/(1-r).

The parameter *r* gives the maximum remanence flux density in the CT core. The value of the parameter *r* depends on the magnetic material used and on the construction of the CT. For example, the value *r* = "0.4" means that the remanence flux density may be 40 percent of the saturation flux density. The manufacturer of the CT should be contacted when an accurate value for the parameter *r* is needed. The value *r* = "0.4" is recommended to be used when an accurate value is not available.

The minimum time to saturate (T_m) in 87T is 8.33 ms (when fn = 60 Hz).

Two typical cases considered for the determination of the sufficient accuracy limit factor (F_a) are a fault occurring at the substation bus and re-energizing against a fault occurring further down in the network.

A fault occurring at the substation bus

The protection must be stable at a fault arising during a normal operating situation. Re-energizing the transformer against a bus fault leads to very high fault currents and thermal stress. Therefore, re-energizing is not preferred in this case.

With this assumption the remanence can be neglected.

The maximum through-going fault current I_{kmax} is typically 10 p.u. for a substation main transformer. At a short circuit fault close to the supply transformer, the DC time constant (T_{dc}) of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

$$F_a > K_r \times I_{kmax} \times (T_{dc} \times \omega \times (1 - e^{-Tm/Tdc}) + 1) \approx 40$$

(Equation 51)

I_{kmax}	10 (p.u.)
T_{dc}	100 (ms)
ω	100π (Hz)
T_m	10 (ms)
K_r	1

Re-energizing against a fault occurring further down in the network.

The protection must be stable during the re-energization against a fault on the line. In this case, the existence of remanence is very probable. In this example, it is 40 percent.

The fault current is now smaller and since the ratio of the resistance to the reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, here 50 ms.

Assuming a maximum fault current is 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

$$F_a > K_r \times I_{kmax} \times 0.9 \times (T_{dc} \times \omega \times (1 - e^{-Tm/Tdc}) + 1) \approx 40$$

(Equation 52)

I_{kmax}	0.7 x 10 = 7 (p.u.)
T_{dc}	50 (ms)
ω	100π (Hz)
T_m	10 (ms)
K_r	1/(1-0.4) = 1.6667

If the actual burden of the current transformer (S_a) in Equation 49 cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation.

- A current transformer with a higher rated burden S_n can be chosen (which also means a higher rated accuracy limit F_n) or
- A current transformer with a higher nominal primary current $I1_n$ (but the same rated burden) can be chosen.

Example 2

Assuming that the actions according to the current transformer with a higher nominal primary current $I1_n$ (but the same rated burden) is taken to improve the actual accuracy limit factor (F_a):

I_{rTR} = 1000 A	rated secondary current of the transformer
I_{rCT} = 1500 A	rated primary current of the CT on the transformer secondary side
F_n = 30	rated accuracy limit factor of the CT
$F_a = (I_{rCT} / I_{rTR}) \times F_n$	actual accuracy limit factor due to oversizing the CT

$F_a = (1500/1000) \times 30 = 45$

In differential protection it is important that the accuracy limit factors (F_a) of phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides should be as equal as possible. If high inrush or start currents with high DC components flow through the protected object when it is connected to the network, a special attention should be paid to the performance and the burdens of the current transformers and to the settings of the function block.

4.6.2.8 Signals

Table 344: 87T3 Input signals

Name	Type	Default	Description
I_A1	SIGNAL	0	Current ID for getting current values for phase A, winding 1
I_B1	SIGNAL	0	Current ID for getting current values for phase B, winding 1
I_C1	SIGNAL	0	Current ID for getting current values for phase C, winding 1
I_A2	SIGNAL	0	Current ID for getting current values for phase A, winding 2
I_B2	SIGNAL	0	Current ID for getting current values for phase B, winding 2
I_C2	SIGNAL	0	Current ID for getting current values for phase C, winding 2
I_A3	SIGNAL	0	Current ID for getting current values for phase 1, tertiary side or LV restraint
I_B3	SIGNAL	0	Current ID for getting current values for phase 2, tertiary side or LV restraint

Table continues on next page

Name	Type	Default	Description
I_C3	SIGNAL	0	Current ID for getting current values for phase 3, tertiary side or LV restraint
BLOCK	BOOLEAN	0=False	Block
BLK_OPR_LS	BOOLEAN	0=False	Blocks trip outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks trip outputs from instantaneous stage

Table 345: 87T3 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip combined
OPR_LS	BOOLEAN	Trip from low set
OPR_HS	BOOLEAN	Trip from high set
BLKD2H	BOOLEAN	2nd harmonic restraint block status
BLKD5H	BOOLEAN	5th harmonic restraint block status
BLKDWAV	BOOLEAN	Waveform blocking status

4.6.2.9 Settings

Table 346: 87T3 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
High trip value	500...3000	%Ir	10	1000	Instantaneous stage setting
Enable high set	0=False 1=True			1=True	Enable high set stage
Low trip value	5...50	%Ir	1	20	Basic setting for biased operation
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 2	100...500	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics
Restraint mode	-1=2.h + 5.h + wav 5=Waveform 6=2.h + waveform 7=5.h + waveform			-1=2.h + 5.h + wav	Restraint mode
Pickup value 2.H	7...20	%	1	15	2. harmonic blocking ratio
Pickup value 5.H	10...50	%	1	35	5. harmonic blocking ratio
Stop value 5.H	10...50	%	1	35	5. harmonic blocking ratio
Harmonic deblock 2.	0=False 1=True			1=True	2. harmonic deblocking in case of switch on to fault
Harmonic deblock 5.	0=False 1=True			0=False	5. harmonic deblocking in case of severe overvoltage

Table 347: 87T3 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable/ Enable
Current group 3 type	1=Not in use 2=Winding 3 3=Wnd 1 restraint 4=Wnd 2 restraint			2=Winding 3	Type of the third set/group of current inputs
CT connection 1-2	1=Type 1 2=Type 2			1=Type 1	CT connection type consideration between current groups 1 and 2
CT connection 1-3	1=Type 1 2=Type 2			1=Type 1	CT connection type consideration between current groups 1 and 3
Phase Ref winding	2=Winding 1 3=Winding 2 4=Winding 3			2=Winding 1	Reference winding for vector group matching
Zro A elimination	1=Not eliminated 2=Winding 1 3=Winding 2 4=Winding 1 and 2 5=Winding 3 6=Winding 1 and 3 7=Winding 2 and 3 8=Winding 1, 2, 3			1=Not eliminated	Elimination of the zero-sequence current
Phase shift Wnd 1-2	0.0...359.9	deg	0.1	0.0	Setting the phase shift between winding 1 and 2 in degrees
Phase shift Wnd 1-3	0.0...359.9	deg	0.1	0.0	Setting the phase shift between winding 1 and 3 in degrees
Min winding tap	-36...36		1	36	The tap position number resulting the minimum number of effective winding turns on the side of the transformer where the tap changer is.
Max winding tap	-36...36		1	0	The tap position number resulting the maximum number of effective winding turns on the side of the transformer where the tap changer is.
Tap nominal	-36...36		1	18	The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer)
Tapped winding	1=Not in use 2=Winding 1 3=Winding 2 4=Winding 3			1=Not in use	The winding where the tap changer is connected to
Step of tap	0.60...9.00	%	0.01	1.50	The percentage change in voltage corresponding one step of the tap changer
CT ratio Cor Wnd 1	0.20...5.00		0.01	1.00	CT ratio correction, winding 1
CT ratio Cor Wnd 2	0.20...5.00		0.01	1.00	CT ratio correction, winding 2
CT ratio Cor 3	0.20...5.00		0.01	1.00	CT ratio correction, current group 3

4.6.2.10 Monitored data

Table 348: 87T3 Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Trip phase A
OPR_B	BOOLEAN	0=False 1=True		Trip phase B
OPR_C	BOOLEAN	0=False 1=True		Trip phase C
BLKD2H_A	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase A status
BLKD2H_B	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase B status
BLKD2H_C	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase C status
BLKD5H_A	BOOLEAN	0=False 1=True		5th harmonic restraint block phase A status
BLKD5H_B	BOOLEAN	0=False 1=True		5th harmonic restraint block phase B status
BLKD5H_C	BOOLEAN	0=False 1=True		5th harmonic restraint block phase C status
BLKDWAV_A	BOOLEAN	0=False 1=True		Waveform blocking phase A status
BLKDWAV_B	BOOLEAN	0=False 1=True		Waveform blocking phase B status
BLKDWAV_C	BOOLEAN	0=False 1=True		Waveform blocking phase C status
BLKD2HPHAR	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, combined
BLKD2HPHAR_A	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase A
BLKD2HPHAR_B	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase B
BLKD2HPHAR_C	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase C
BLKD5HPHAR	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, combined
BLKD5HPHAR_A	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase A
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
BLKD5HPHAR_B	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase B
BLKD5HPHAR_C	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase C
I_AMPL_A1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase A
I_AMPL_B1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase B
I_AMPL_C1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase C
I_AMPL_A2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase A
I_AMPL_B2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase B
I_AMPL_C2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase C
I_AMPL_A3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase A
I_AMPL_B3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase B
I_AMPL_C3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential Current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential Current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential Current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Restraint current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Restraint current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Restraint current phase C
I_2H_RAT_A	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase A
I_2H_RAT_B	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase B
I_2H_RAT_C	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
I_5H_RAT_A	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase A
I_5H_RAT_B	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase B
I_5H_RAT_C	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 1
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 1
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 1
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 2
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 2
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 2
I_ANGL_A3_B3	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 3
I_ANGL_B3_C3	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 3
I_ANGL_C3_A3	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 3
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase C
I_ANGL_A1_A3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase A
I_ANGL_B1_B3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase B
I_ANGL_C1_C3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase C
87T3	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.6.2.11 Technical data

Table 349: 87T3 technical data

Parameter		Accuracy/value		
Pickup accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±3.0% of the set value or ±0.002 × I_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	Low stage High stage	34 ms 19 ms	39 ms 21 ms	44 ms 22 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		

1) Current before fault = 0.0 × In, f_n = 60 Hz. Injected differential current = 2.0 × set trip value.
2) Includes the delay of the output contact value. f_n = 60 Hz.

4.6.3 Numerical stabilized low impedance restricted earth-fault protection 87L0ZREF

4.6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Numerical stabilized low impedance restricted earth-fault protection	LREFPNDF	dIoLo>	87LOZREF

4.6.3.2 Function block

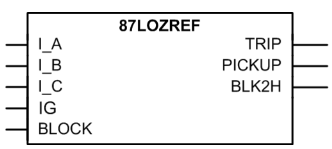


Figure 208: Function block

4.6.3.3 Functionality

Numerical stabilized low impedance restricted earth-fault protection 87LOZREF for a two winding transformer is based on the numerically stabilized differential current principle. No external stabilizing resistor or non-linear resistor are required.

The fundamental components of the currents are used for calculating the residual current of the phase currents, the neutral current, differential currents and stabilizing currents. The operating characteristics are according to the definite time.

87LOZREF contains a blocking functionality. The neutral current second harmonic is used for blocking during the transformer inrush situation. It is also possible to block function outputs, timers or the function itself, if desired.

4.6.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of 87LOZREF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

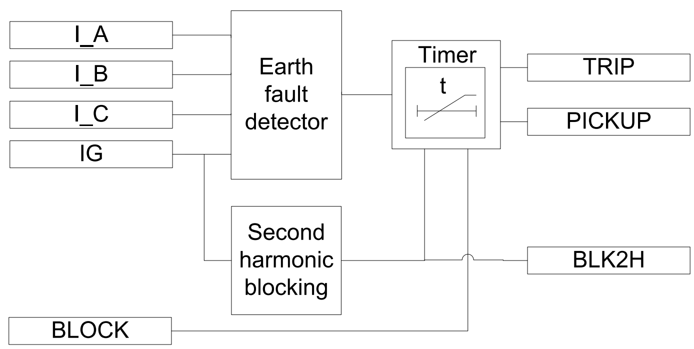


Figure 209: Functional module diagram

Ground-fault detector

The operation is based on comparing the amplitude and the phase difference between the sum of the fundamental frequency component of the phase currents (ΣI, residual current) and the fundamental frequency component of the neutral current (IG) flowing in the conductor between the transformer or generator's neutral point and ground. The differential current is calculated as the absolute value of the difference between the residual current (the sum of the fundamental frequency components of the phase currents I_A, I_B and I_C) and the neutral current. The directional differential current ID_COSPHI is the product of the differential current and cosφ. The value is available in the monitored data view.

$$ID\_COSPHI = (|\overline{\Sigma I} - \overline{Io}|) \times \cos\varphi$$

(Equation 53)

$\overline{\Sigma I}$	Residual current
φ	Phase difference between the residual and neutral currents
$\overline{Io}$	Neutral current

A ground fault occurring in the protected area, that is, between the phase CTs and the neutral connection CT, causes a differential current. The directions, that is, the phase difference of the residual current and the neutral current, are considered in the operation criteria to maintain selectivity. A correct value for *CT connection type* is determined by the connection polarities of the current transformer.

The current transformer ratio mismatch between the phase current transformer and neutral current transformer (residual current in the analog input settings) is taken into account by the function with the properly set analog input setting values.

During a ground fault in the protected area, the currents ΣI and IG are directed towards the protected area. The factor cosφ is 1 when the phase difference of the residual current and the neutral current is 180 degrees, that is, when the currents are in opposite direction at the ground faults within the protected area. Similarly, ID_COSPHI is specified to be 0 when the phase difference between the residual current and the neutral current is less than 90 degrees in situations where there is no ground fault in the protected area. Thus tripping is possible only when the phase difference between the residual current and the neutral current is above 90 degrees.

The stabilizing current IB used by the stabilizing current principle is calculated as an average of the phase currents in the windings to be protected. The value is available in the monitored data view.

$$IB = \frac{|\overline{I\_A}| + |\overline{I\_B}| + |\overline{I\_C}|}{3}$$

(Equation 54)

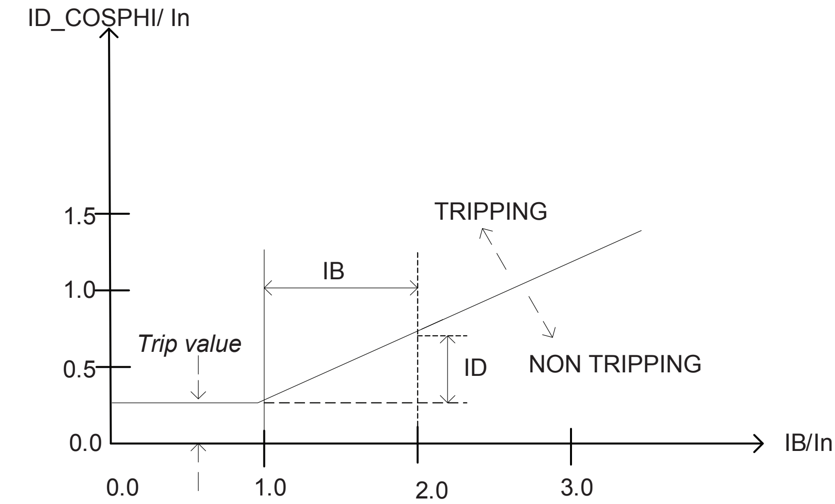


Figure 210: Operating characteristics of the stabilized ground-fault protection function

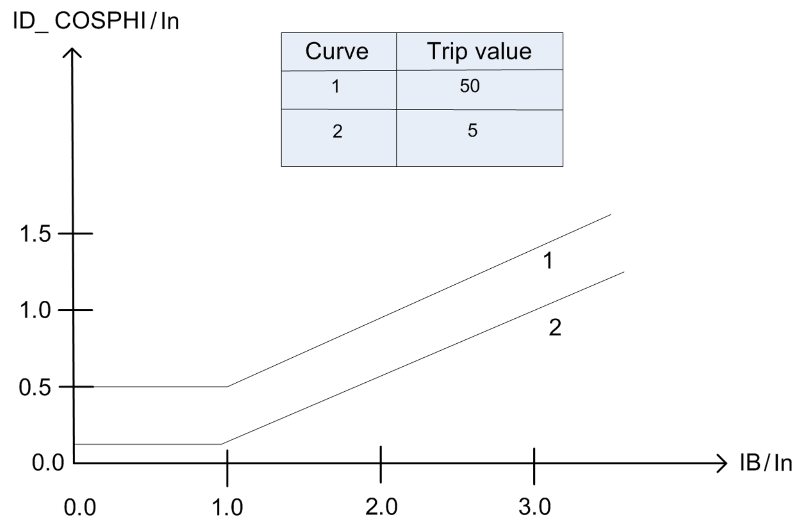


Figure 211: Setting range of the operating characteristics for the stabilized differential current principle of the ground-fault protection function

The *Trip value* setting is used for defining the characteristics of the function. The differential current value required for tripping is constant at the stabilizing current values 0.0 < IB/In < 1.0, where In is the nominal current, and the In in this context refers to the nominal of the phase current inputs. When the stabilizing current is higher than 1.0, the slope of the operation characteristic (ID/IB) is constant at 50 percent. Different operating characteristics are possible based on the *Trip value* setting.

To calculate the directional differential current ID_COSPHI, the fundamental frequency amplitude of both the residual and neutral currents has to be above 4 percent of In. If neither or only one condition is fulfilled at a time, the cosφ term is forced to 1. After the conditions are fulfilled, both currents must stay above 2 percent of In to allow the continuous calculation of the cosφ term.

Second harmonic blocking

This module compares the ratio of the current second harmonic (IG_2H) and IG to the set value *Pickup value 2.H*. If the ratio (IG_2H / IG) value exceeds the set value, the `BLK2H` output is activated.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer connected to the network.

The second harmonic blocking is disabled when *Restraint mode* is set to "None" and enabled when set to "Harmonic2".

Timer

Once activated, the Timer activates the `PICKUP` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Minimum trip time*, the `TRIP` output is activated. If the fault disappears before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the reset timer resets and the `PICKUP` output is deactivated.

The Timer calculates the pickup duration value PICKUP_DUR which indicates the percentage ratio of the pickup situation and the set trip time. The value is available through the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the `TRIP` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the

TRIP output is not activated. The activation of the output of the second harmonic blocking signal BLK2H deactivates the TRIP output.

4.6.3.5 Application

A ground-fault protection using an overcurrent element does not adequately protect the transformer winding in general and the 87LOZREF winding in particular.

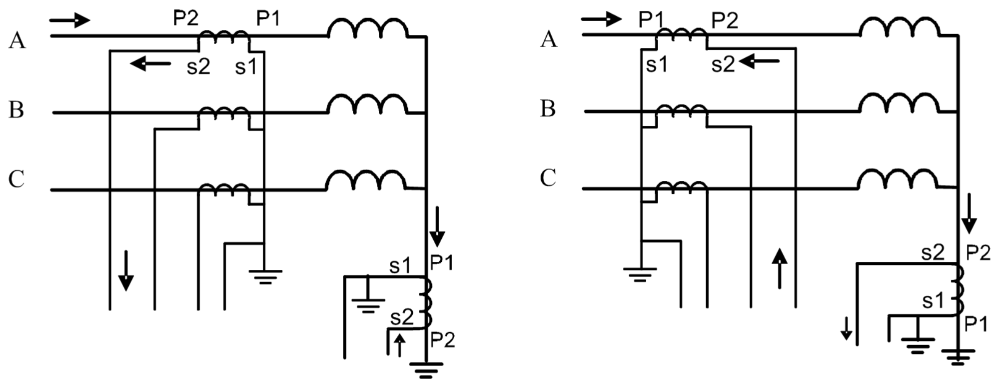
The restricted ground-fault protection is mainly used as a unit protection for the transformer windings. 80LOZREF is a sensitive protection applied to protect the 87LOZREF winding of a transformer. This protection system remains stable for all the faults outside the protected zone.

87LOZREF provides a higher sensitivity for the detection of ground faults than the overall transformer differential protection. This is a high-speed unit protection scheme applied to the 87LOZREF winding of the transformer. In 87LOZREF, the difference of the fundamental component of all three phase currents and the neutral current is provided to the differential element to detect the ground fault in the transformer winding based on the numerical stabilized differential current principle.

Connection of current transformers

The connections of the main CTs are designated as "Type 1" and "Type 2". In case the groundings of the current transformers on the phase side and the neutral side are both either inside or outside the area to be protected, the setting parameter *CT connection type* is "Type 1".

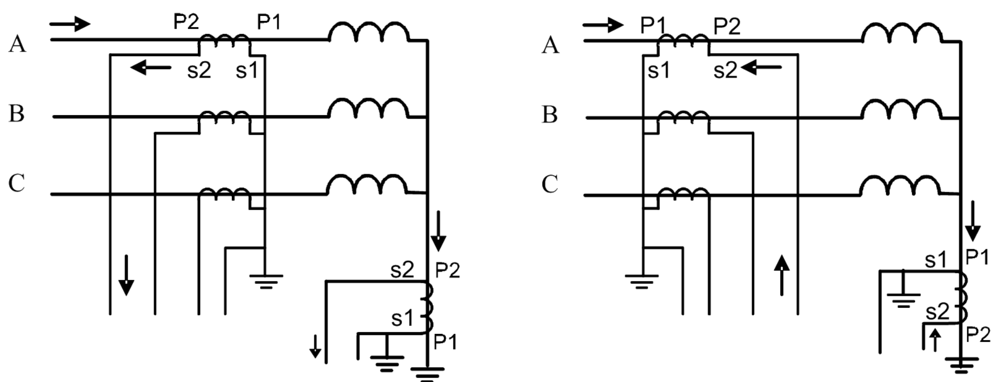
If the grounding of the current transformers on the phase side is inside the area to be protected and the neutral side is outside the area to be protected or vice versa, the setting parameter *CT connection type* is "Type 2".



a. Both groundings are inside area to be protected

b. Both groundings are outside area to be protected

Figure 212: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external ground-fault situation.



a. Phase grounding is inside and neutral grounding is outside area to be protected

b. Phase grounding is outside and neutral grounding is inside area to be protected

Figure 213: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external ground-fault situation.

Internal and external faults

87LOZREF does not respond to any faults outside the protected zone. An external fault is detected by checking the phase angle difference of the neutral current and the sum of the phase currents. When the difference is less than 90 degrees, the operation is internally restrained or blocked. Hence the protection is not sensitive to an external fault.

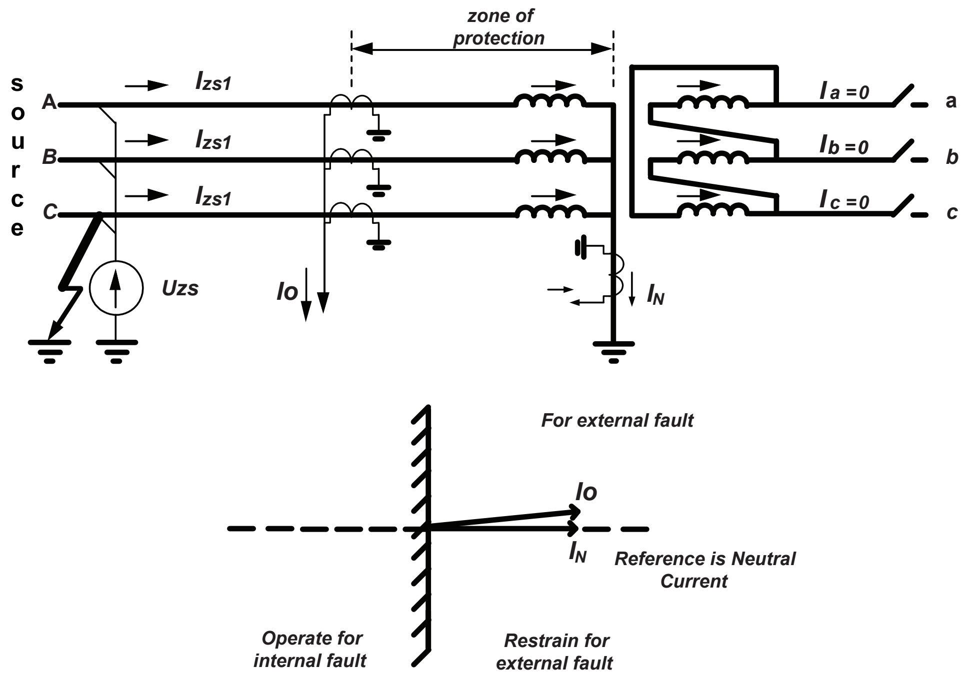


Figure 214: Current flow in all the CTs for an external fault

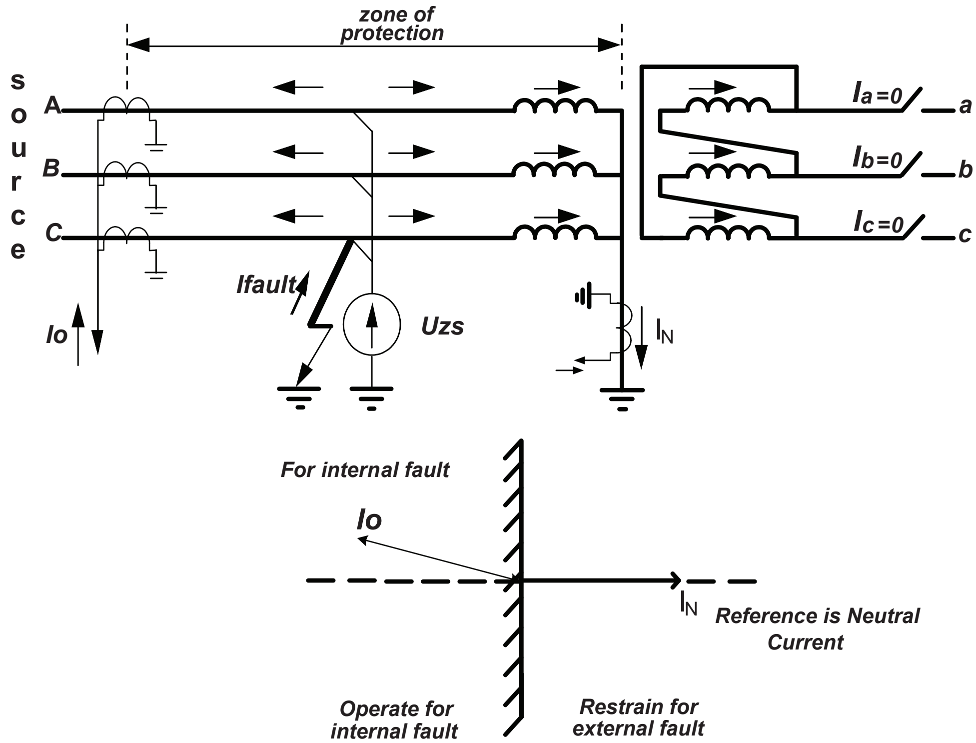


Figure 215: Current flow in all the CTs for an internal fault

87LOZREF does not respond to phase-to-phase faults either, as in this case the fault current flows between the two line CTs and so the neutral CT does not experience this fault current.

87LOZREF is normally applied when the transformer is solidly grounded because in this case the fault current is high enough and the ground fault can be detected easily.

Blocking based on the second harmonic of the neutral current

The transformer magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current can be many times the rated current, and the halving time can be up to several seconds. For the differential protection relay, the inrush current represents the differential current, which causes the protection relay to trip almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer already connected to the network.

Blocking the starting of the restricted ground-fault protection at the magnetizing inrush is based on the ratio of the second harmonic and the fundamental frequency amplitudes of the neutral current IG_2H / IG. Typically, the second harmonic content of the neutral current at the magnetizing inrush is higher than that of the phase currents.

4.6.3.6 Signals

Table 350: 87LOZREF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_0	SIGNAL	0	Zero-sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 351: 87LOZREF Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup
BLK2H	BOOLEAN	2nd harmonic block

4.6.3.7 Settings

Table 352: 87LOZREF Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Trip value	5...50	%In	1	5	Trip value
Minimum trip time	40...300000	ms	1	40	Minimum trip time
Restraint mode	1=None 2=Harmonic2			1=None	Restraint mode
Pickup value 2.H	10...50	%In	1	50	The ratio of the 2. harmonic to fundamental component required for blocking

Table 353: 87LOZREF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time
CT connection type	1=Type 1 2=Type 2			2=Type 2	CT connection type

4.6.3.8 Monitored data

Table 354: 87LOZREF Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
RES2H	BOOLEAN	0=False 1=True		2nd harmonic restraint
IDIFF	FLOAT32	0.00...80.00	xIn	Differential current
IBIAS	FLOAT32	0.00...80.00	xIn	Stabilization current
87LOZREF	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.6.3.9 Technical data

Table 355: 87LOZREF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±2.5% of the set value or ±0.002 x I_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Trip value*	37 ms	40 ms	45 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Trip time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …		

1) Current before fault = 0.0, f_n = 60 Hz, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.6.4 High-impedance differential protection 87

4.6.4.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance differential protection	HIPDIF	dHi>	87

4.6.4.2 Function block

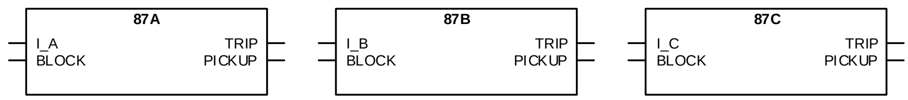


Figure 216: Function block

4.6.4.3 Functionality

High-impedance differential protection 87 is a general differential protection. It provides a phase-segregated short circuit protection for the busbar. However, the function can also be used for providing generator, motor, transformer and reactor protection.

The function starts and operates when the differential current exceeds the set limit. The operate time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block the function outputs, timer or the whole function.

4.6.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the high-impedance differential protection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

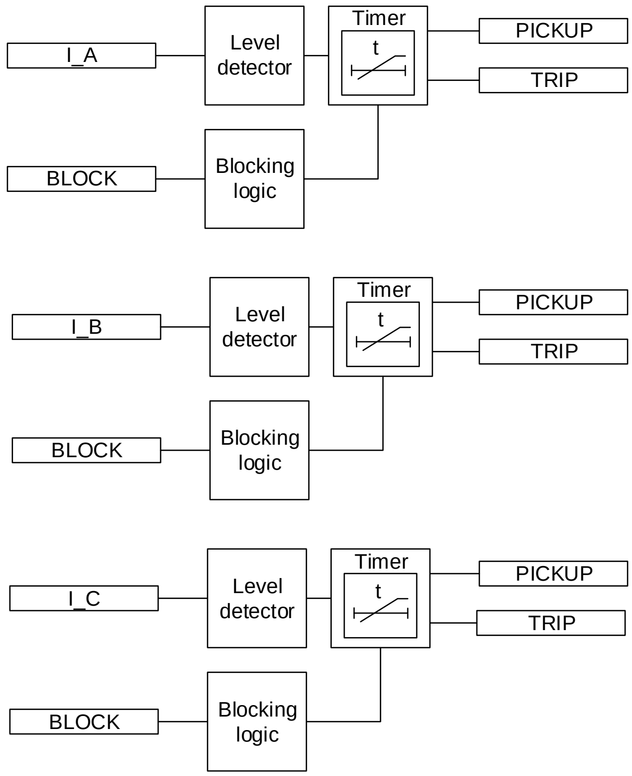


Figure 217: Functional module diagram

The module diagram illustrates all the phases of the function. Functionality for phases A, B and C is identical.

All three phases have independent settings.

Level detector

The module compares differential currents I_A calculated by the peak-to-peak measurement mode to the set *Operate value*. The Timer module is activated if the differential current exceeds the value of the *Operate value* setting.

Timer

Once activated, Timer activates the PICKUP output. The time characteristic is according to DT. When the operation timer reaches the value set by *Trip delay time*, the TRIP output is activated. If the fault disappears before the module operates, the reset timer is activated.

If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the PICKUP output is deactivated.

Timer calculates the start duration PICKUP_DUR value, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

The activation of the BLOCK input resets Timer and deactivates the PICKUP and TRIP outputs.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

4.6.4.5 Application

87 provides a secure and dependable protection scheme against all types of faults.The high-impedance principle is used for differential protection due to its capability to manage the through-faults also with the heavy current transformer (CT) saturation.

High-impedance principle

The phase currents are measured from both the incoming and the outgoing feeder sides of the busbar. The secondary of the current transformer in each phase is connected in parallel with a protection relay measuring branch. Hence, the relay measures only the difference of the currents. In an ideal situation, there is a differential current to operate the relay only if there is a fault between the CTs, that is, inside the protected zone.

If there is a fault outside the zone, a high current, known as the through-fault current, can go through the protected object. This can cause partial saturation in the CTs. The relay operation is avoided with a stabilizing resistor (R_S) in the protection relay measuring branch. R_S increases the impedance of the protection relay; hence the name high-impedance differential scheme.

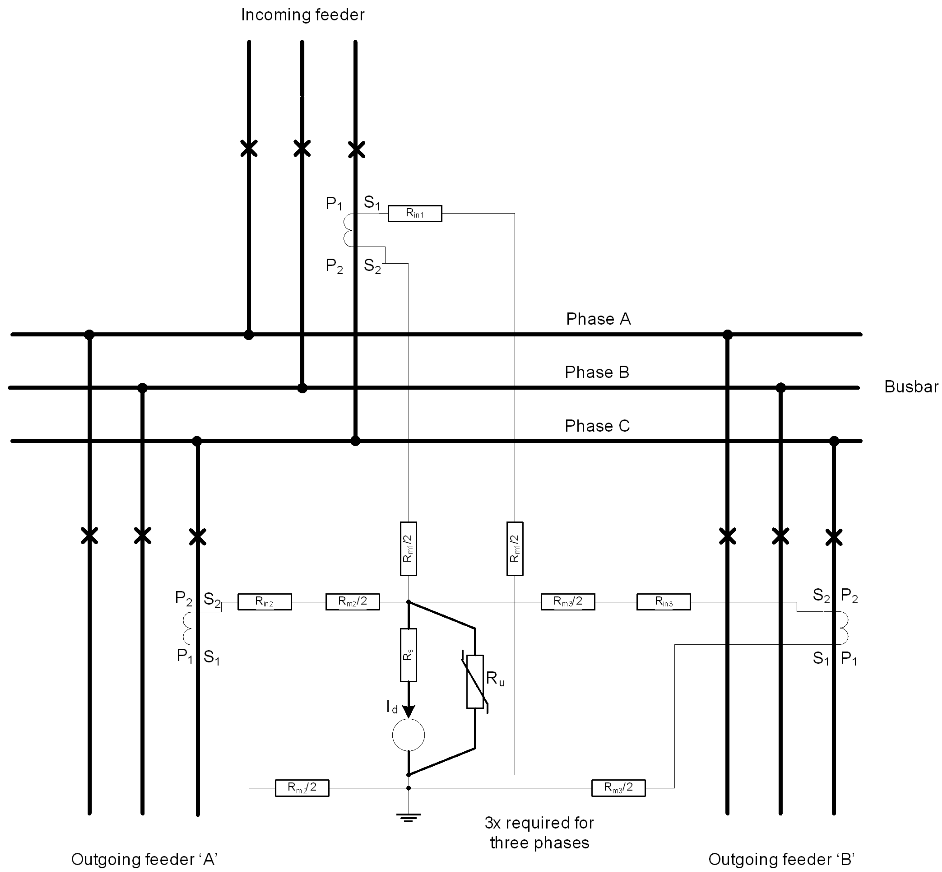


Figure 218: Phase-segregated bus differential protection based on high-impedance principle

CT secondary winding resistances (R_{in}) and connection wire resistances ($R_m/2$) are also shown in Figure 219.

Figure 219 demonstrates a simplified circuit consisting only of one incoming and outgoing feeder. To keep it simple, the voltage-dependent resistor (R_u) is not included. The wiring resistances are presented as total wiring resistances R_{m1} and R_{m2}.

R_{m1} is the maximum wiring resistance concerning all incoming feeder sets, whereas R_{m2} is the maximum wiring resistance concerning all outgoing feeder sets.

The lower part of Figure 219 shows the voltage balance when there is no fault in the system and no CT saturation.

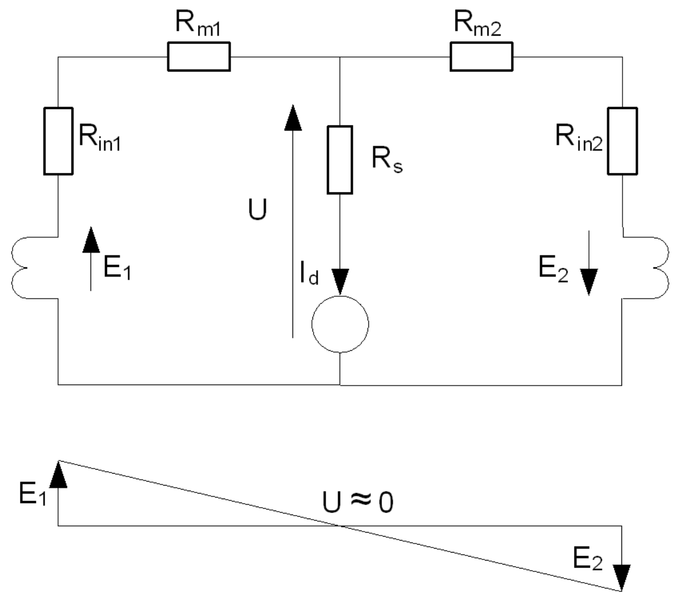


Figure 219: Equivalent circuit when there is no fault or CT saturation

When there is no fault, the CT secondary currents and their emf voltages, E_1 and E_2, are opposite and the protection relay measuring branch has no voltage or current. If an in-zone fault occurs, the secondary currents have the same direction. The relay measures the sum of the currents as a differential and trips the circuit breaker. If the fault current goes through only one CT, its secondary emf magnetizes the opposite CT, that is, $E_1 \approx E_2$.

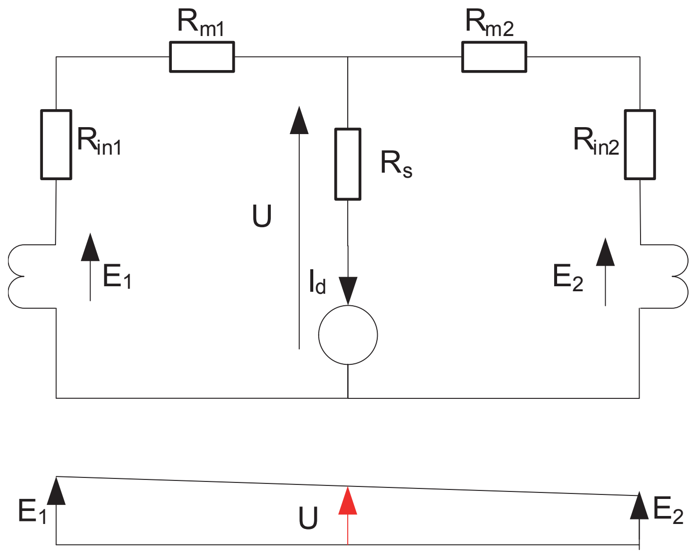


Figure 220: Equivalent circuit in case of in-zone fault

Figure 221 shows CT saturation at a through-fault, that is, out-of-zone, situation. The magnetization impedance of a saturated CT is almost zero. The saturated CT winding can be presented as a short circuit. When one CT is saturated, the current of the non-saturated CT follows two paths, one through the protection relay measuring branch (R_s + relay) and the other through the saturated CT ($R_m + R_{in2}$).

The protection relay must not operate during the saturation. This is achieved by increasing the relay impedance by using the stabilizing resistor (R_s) which forces the majority of the differential current to flow through the saturated CT. As a result, the relay operation is avoided, that is, the relay operation is stabilized against the CT saturation at through-fault current. The stabilizing voltage V_s is the basis of all calculations.

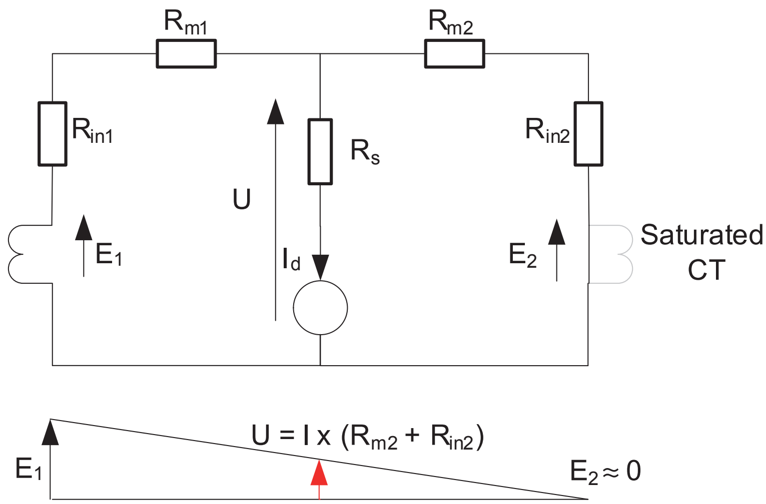


Figure 221: Equivalent circuit in case of the CT saturation at through-fault

The CT saturation happens most likely in the case of an in-zone fault. This is not a problem, because although the operation remains stable (non-operative) during the saturated parts of the CT secondary current waveform, the non-saturated part of the current waveform causes the protection to operate.

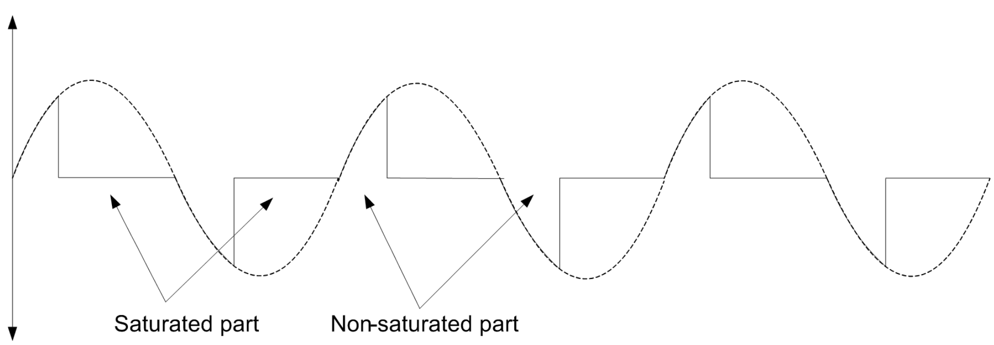


Figure 222: Secondary waveform of a saturated CT

The secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the protection relay because of the stabilizing resistance and CT saturation. A voltage dependent resistor (VDR, R_u) is used to limit the voltage as shown in Figure 218.

Busbar protection scheme

The basic concept for any bus differential protection relay is a direct use of Kirchoff's first law that the sum of all currents connected to one differential protection zone is zero. If the sum is not zero, an internal fault has occurred. In other words, as seen by the busbar differential protection, the sum of all currents that flow into the protection zone, that is, currents with positive value, must be equal to currents that flow out of the protection zone, that is, currents with negative value, at any instant of time.

Figure 223 shows an example of a phase segregated single busbar protection employing high-impedance differential protection. The example system consists of a single incoming busbar feeder and two outgoing busbar feeders. The CTs from both the outgoing busbar feeders and the incoming busbar feeders are connected in parallel with the polarity. During normal load conditions, the total instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. A fault in the busbar results in an imbalance between the incoming and the outgoing current. The difference current flows through the protection relay, which generates a trip signal.

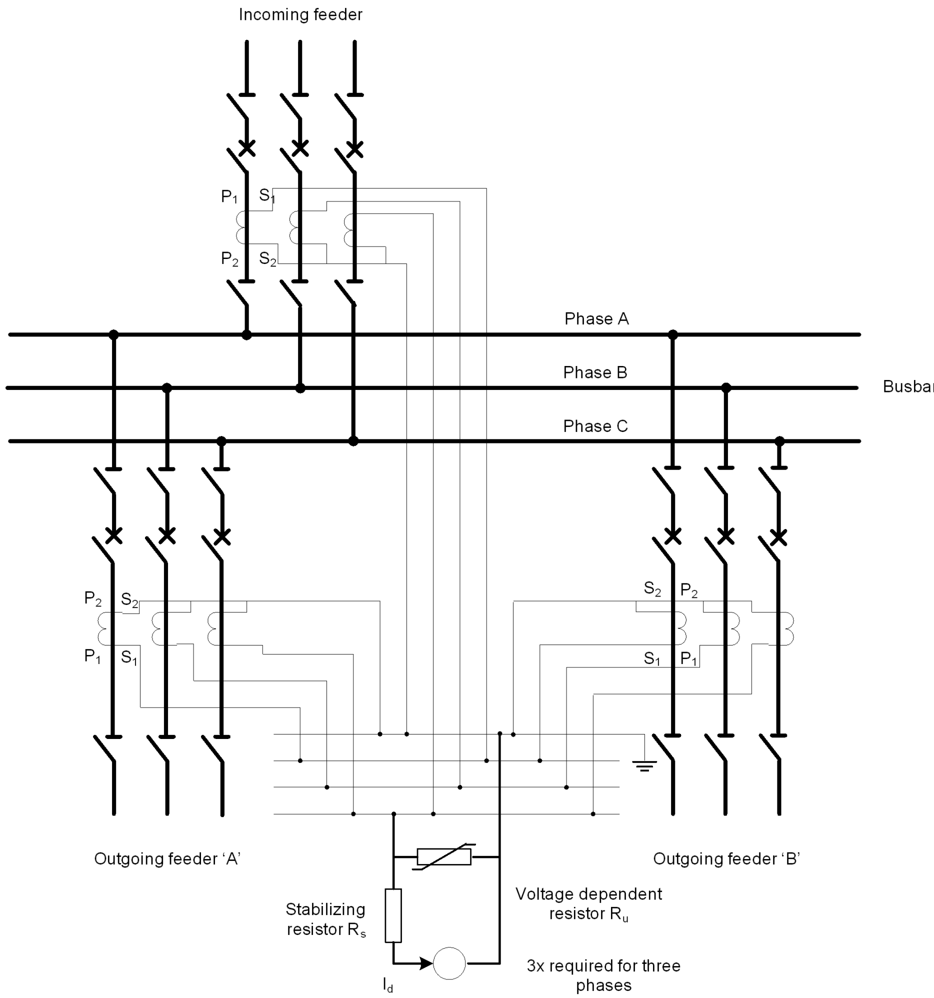


Figure 223: Phase-segregated single busbar protection employing high-impedance differential protection

Figure shows an example for a system consisting of two busbar section coupled with a bus coupler. Each busbar section consists of two feeders and both sections are provided with a separate differential protection to form different zones. The formed zones overlap at the bus coupler.

When the bus coupler is in the open position, each section of the busbar handles the current flow independently, that is, the instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. The difference current is no longer zero with a fault in the busbar and the protection operates.

With the bus coupler in the closed position, the current also flows from one busbar section to another busbar section. Thus, the current flowing through the bus coupler needs to be considered in calculating differential current. During normal condition, the summation of the current on each bus section is zero. However, if there is a fault in any busbar section, the difference current is no longer zero and the protection operates.

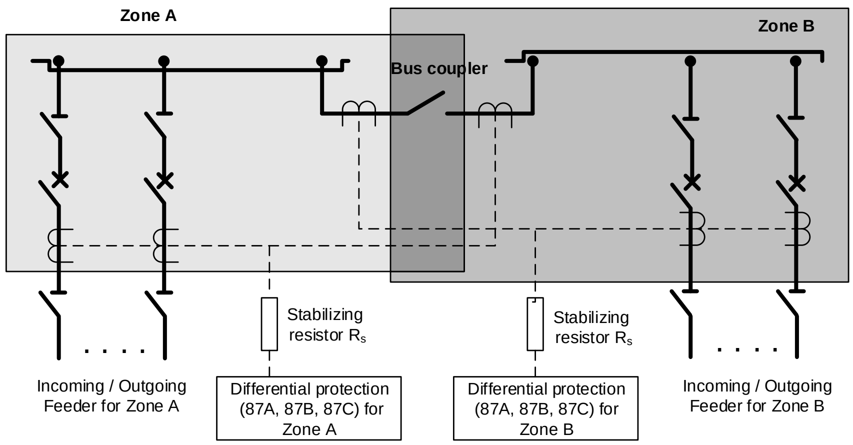


Figure 224: Differential protection on busbar with bus coupler (Single-phase representation)

Another example of differential protection employed on bus transfer scheme is shown in Figure 225. Basic principle of operation remains same.

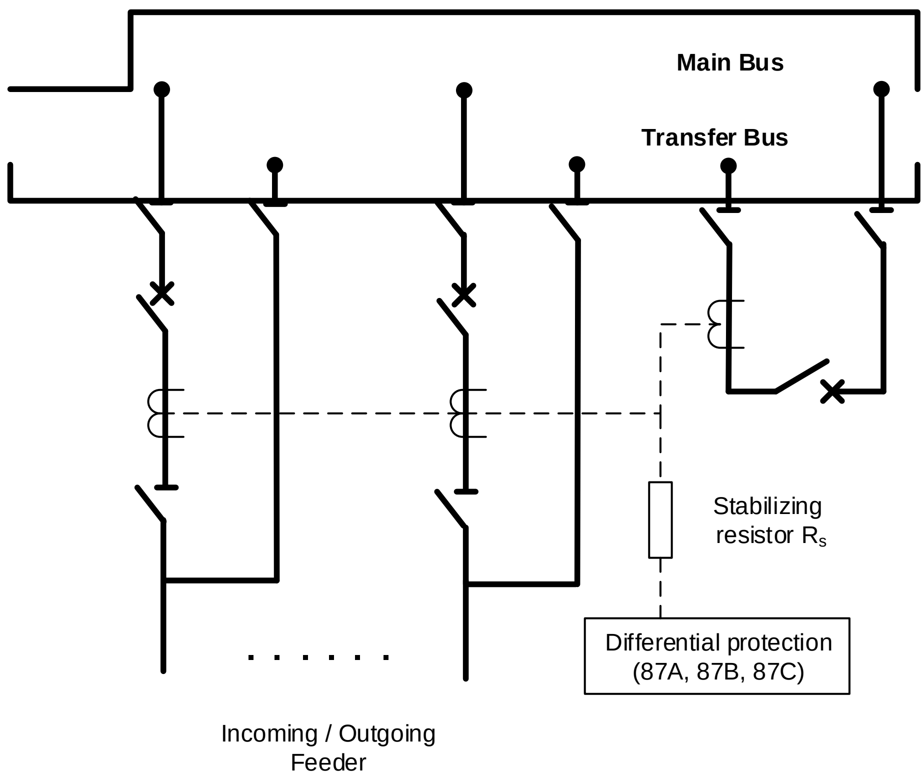


Figure 225: Differential protection on Bus transfer scheme (Single phase representation)

Figure 226shows an arrangement of double busbar scheme with two feeders and a bus coupler. Here both the buses, main bus and reserve bus are protected by two separate 3-phase high impedance function. Here it is important that along with current input, logic also needs to be created for feeding correct current input to the differential protection. This logic is created by hard wires connection and using disconnector positions.

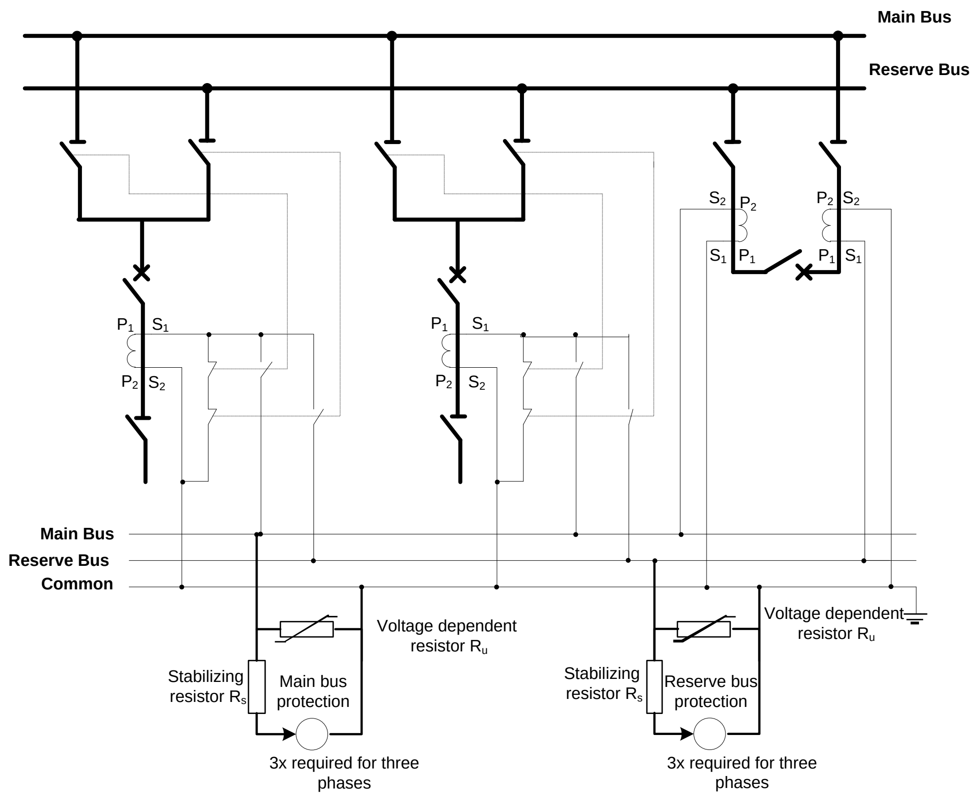


Figure 226: Differential protection on double busbar scheme with bus coupler scheme (Single phase representation)

4.6.4.6 Current transformer requirements for differential protection

The sensitivity and the reliability of the protection depends on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all the CTs have an identical constructions, that is, they have an equal burden and characteristics and are of the same type, preferably from the same manufacturing batch. If the CT characteristics and burden values are not equal, calculations for each branch in the scheme should be performed separately and the worst-case results should be used. In Figure 227, the CT winding resistance and the burden of the branches are not equal, and hence, the maximum burden equal to 3.2 Ω should be used for calculating the stabilized voltage.

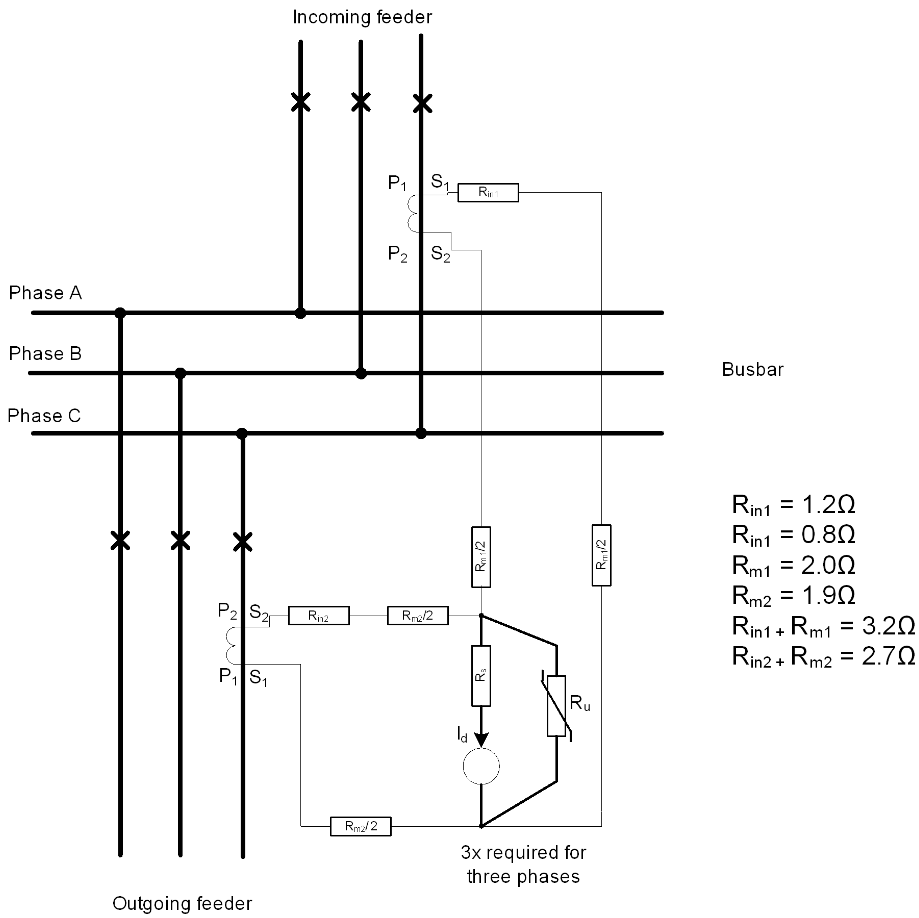


Figure 227: High-impedance busbar differential protection with different CT burden value on each feeder

First, the stabilizing voltage, that is, the voltage appearing across the measuring branch during the out-of-zone fault, is calculated assuming that one of the CTs connected in parallel is fully saturated. The stabilizing voltage can be calculated using the formula:

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 55)

I_{kmax} the highest through-fault current in primary amps. The highest earth-fault or short circuit current during the out-of-zone fault.

n the turns ratio of the CT

R_{in} the secondary winding resistance of the CT in ohms

R_m the resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the protection relay through the differential circuit during a fault condition inside the protection zone. To ensure this, the knee point voltage U_{kn} must be at least two times higher than the stabilizing voltage U_s.

The required knee point voltage U_{kn} of the current transformer is calculated using the formula:

$$U_{kn} \geq 2 \times U_s$$

(Equation 56)

U_{kn} the knee point voltage

U_s the stabilizing voltage

The factor two is used when a delay in the operating time of the protection is not acceptable. To prevent the knee point voltage from rising too high, CTs with the secondary winding resistance same as the resistance of the measuring loop should be used.

As the impedance of the protection relay is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated using the formula:

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 57)

R_s the resistance of the stabilizing resistor

U_s the stabilizing voltage of the protection relay

I_{rs} the value of the *Operate value* setting in secondary amps

The stabilizing resistor should be capable to dissipate high energy within a very short time; therefore, a wire wound-type resistor must be used. The minimum rated power should be a few tens of watts because of the possible CT inaccuracy which might cause some current through the stabilizing resistor in a normal load situation.

If U_{kn} is high or U_s is low, a resistor with a higher power rating is needed. Often the resistor manufacturers allow 10 times the rated power for 5 seconds. Thus, the power of the resistor can be calculated using the formula:

$$\frac{U_{kn}^2}{R_s \times 10}$$

(Equation 58)

The actual sensitivity of the protection is affected by the protection relay setting, the magnetizing currents of the CTs connected in parallel and the shunting effect of the voltage-dependent resistor (VDR). The value of the primary current I_{prim} at which the protection relay operates at a certain setting can be calculated using the formula:

$$I_{prim} = n \times (I_{rs} + I_u + m \times I_m)$$

(Equation 59)

I_{prim}	the primary current at which the protection is to start
n	the turn ratio of the current transformer
I_{rs}	the value of the *Operate value* setting
I_u	the leakage current flowing through the VDR at the U_s voltage
m	the number of current transformers included in the protection per phase
I_m	the magnetizing current per current transformer at the U_s voltage

The I_e value given in many catalogs is the excitation current at the knee point voltage.

Assuming $U_{kn} \approx 2 \times U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for Equation 59.

The selection of current transformers can be divided into procedures:

1. The rated current I_n of the feeder should be known. The value of I_n also affects how high I_{kmax} is.
2. The rated primary current I_{1n} of the CT must be higher than the rated current of the feeder.
   The choice of the CT also specifies R_{in}.
3. The required U_{kn} is calculated using Equation 56. If U_{kn} of the CT is not high enough, enough, another CT has to be selected. The value of U_{kn} is given by the manufacturer in the case of Class X current transformers or it can be estimated using Equation 60.
4. The sensitivity I_{prim} is calculated using Equation 59. If the achieved sensitivity is sufficient, the present CT is chosen. If a better sensitivity is needed, a CT with a bigger core is chosen.

If other than Class X CTs are used, an estimate for U_{kn} is calculated using the equation:

$$U_{kn} = 0.8 \times F_n \times I_{2n} \times \left(R_{in} + \frac{S_n}{I_{2n}^2} \right)$$

(Equation 60)

F_n the rated accuracy limit factor corresponding to the rated burden S_n

I_{2n} the rated secondary current of the CT

R_{in} the secondary internal resistance of the CT

S_n the volt-amp rating of the CT

The formulas are based on selecting the CTs according to Equation 56, results in an absolutely stable scheme. In some cases, it is possible to achieve stability with the knee point voltages lower than stated in the formulas. The conditions in the network, however, must be known well enough to ensure the stability.

1. If $U_{kn} \geq 2 \times U_s$, faster protection relay operations are secure.
2. If $U_{kn} \geq 1.5 \times U_s$ and $< 2 \times U_s$, protection relay operation can be slightly prolonged and should be studied case by case.
   If $U_{kn} < 1.5 \times U_s$, the protection relay operation is jeopardized. Another CT has to be chosen.

The need for the VDR depends on certain conditions.

First, voltage U_{max}, ignoring the CT saturation during the fault, is calculated using the formula:

$$U_{max} = \frac{I_{k\,max\,in}}{n} \times \left(R_{in} + R_m + R_s \right) \approx \frac{I_{k\,max\,in}}{n} \times R_s$$

(Equation 61)

I_{kmaxin} the maximum fault current inside the zone in primary amps

n the turns ratio of the CT

R_{in} the internal resistance of the CT in ohms

R_m the resistance of the longest loop of the CT secondary circuit in ohms

R_s the resistance of the stabilized resistor in ohms

Next, the peak voltage û, which includes the CT saturation, is calculated using the formula (given by P.Mathews, 1955):

$$\hat{u} = 2\sqrt{2U_{kn}\left(U_{max} - U_{kn}\right)}$$

(Equation 62)

U_{kn} the knee point voltage of the CT

The VDR is recommended when the peak voltage û ≥ 2kV, which is the insulation level for which the protection relay is tested.

The maximum fault current in case of a fault inside the zone is considered to be 12.6 kA in primary, CT is of 1250/5 A (ratio n = 240), knee point voltage is 81 V and the stabilizing resistor is 330 Ohms.

$$U_{\max} = \frac{12600A}{240} \times 330\ \Omega = 17325\ V$$

(Equation 63)

$$\hat{u} = 2\sqrt{2 \times 81 \times (17325 - 81)} \approx 3.34kV$$

(Equation 64)

As the peak voltage û is 3.2 kV, VDR must be used. If the $R_s$is smaller, VDR could be avoided. However, the value of R_s depends on the operation current and stabilizing voltage of the protection relay. Thus, either a higher setting should be used or the stabilizing voltage should be lowered.

As the peak voltage û = 3.2 kV, VDR must be used. If the R_s is smaller, VDR can be avoided.

The value of R_s depends on the protection relay operating current and the stabilizing voltage. Therefore, either a higher setting in the protection relay or a lower stabilizing voltage must be used.

4.6.4.7 Example calculations for busbar high-impedance differential protection

The protected object in the example for busbar differential protection is a single-bus system with two zones of protection.

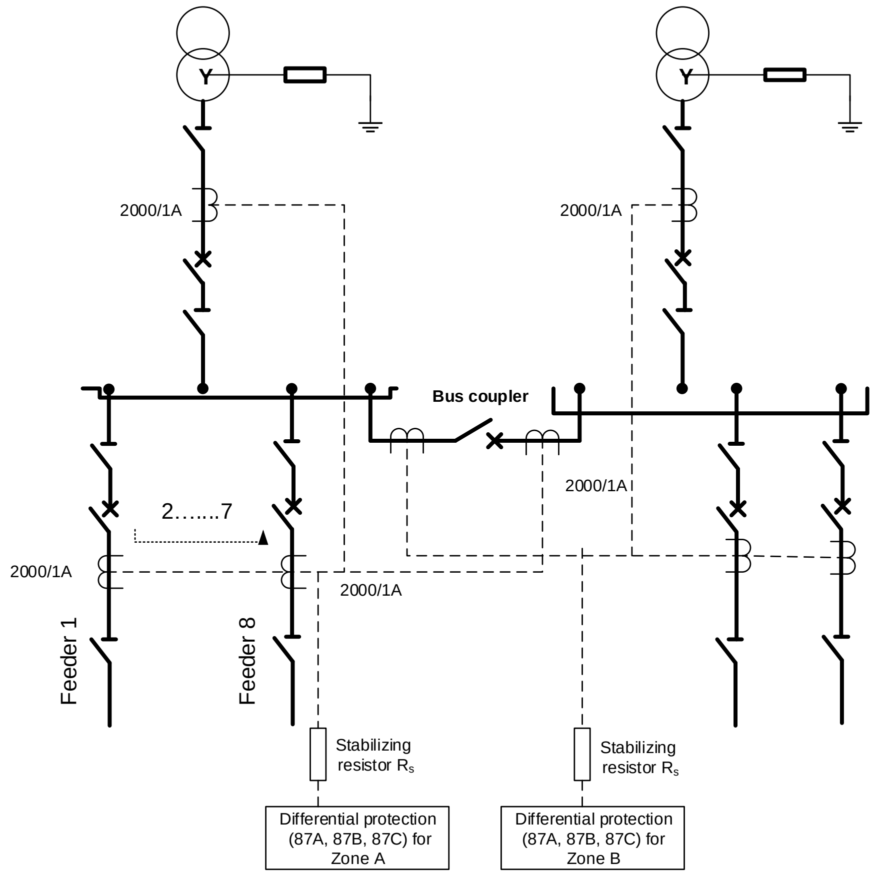


Figure 228: Example for busbar differential protection

Bus data:

V_n	20 kV
I_n	2000 A
I_{kmax}	25 kA

10 feeders per protected zone including bus coupler and incomer.

CT data is assumed to be:

CT	2000/1 A
R_{in}	15.75 Ω
V_{kn}	436 V
I_e	<7 mA (at U_{kn})
R_m	1Ω

The stabilizing voltage is calculated using the formula:

$$V_s = \frac{25000A}{2000}(15.75\Omega + 1.\Omega) \approx 209.37\ V$$

(Equation 65)

In this case, the requirement for the current transformer knee point voltage is fulfilled because $V_{kn} > 2V_s$.

The magnetizing curve of the CT is assumed to be linear. The magnetizing current at the stabilizing voltage can be estimated as:

$$I_m = \frac{V_s}{V_{kn}} \cdot I_e$$

(Equation 66)

$$I_m = \frac{209.37V}{436V} \cdot 7mA \approx 3.4mA$$

(Equation 67)

To obtain adequate protection stability, the setting current I_{rs} must be at the minimum of the sum of magnetizing currents of all connected CTs.

$$I_{rs} = 10 \cdot 3.4mA \approx 34\,mA$$

(Equation 68)

The sensitivity of the stabilizing resistor is calculated based on Equation 69.

$$R_S = \frac{209.37\ V}{0.034A} \approx 6160\,\Omega$$

(Equation 69)

The calculated value is the maximum value for the stabilizing resistor. If the value is not available, the next available value below should be selected and the protection relay setting current is tuned according to the selected resistor. For example, in this case, the resistance value 5900 Ω is used.

$$I_{rs} = \frac{209.37V}{5900\,\Omega} \approx 35\,mA$$

(Equation 70)

The sensitivity of the protection is obtained as per Equation 71, assuming $I_u = 0$.

$$I_{prim} = 2000 \cdot (0.035\,A + 10 \cdot 0.0034\,A + 0\,A) \approx 140A$$

(Equation 71)

The power of the stabilizing resistor is calculated:

$$P \geq \frac{(436V)^2}{5900\Omega} \approx 32W$$

(Equation 72)

Based onEquation 73 and Equation 74, the need for voltage-dependent resistor is checked.

$$V_{max} = \frac{25000A}{2000}(5900\Omega + 15.75\Omega + 1.00\Omega) \approx 74.0kV$$

(Equation 73)

$$\breve{u} = 2 \cdot \sqrt{2 \cdot 436V \cdot (74000V - 436V)} \approx 16.0kV$$

(Equation 74)

The voltage-dependent resistor (one for each phase) is needed in this case as the voltage during the fault is higher than 2 kV.

The leakage current through the VDR at the stabilizing voltage can be available from the VDR manual, assuming that to be approximately 2 mA at stabilizing voltage

$$Iu \approx 0.002A$$

(Equation 75)

The sensitivity of the protection can be recalculated taking into account the leakage current through the VDR as per Equation 76.

$$I_{prim} = 2000 \cdot (0.035A + 10 \cdot 0.0034A + 0.002A) \approx 142A$$

(Equation 76)

4.6.4.8 Signals

Table 356: 87 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 357: 87 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.6.4.9 Settings

Table 358: 87 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Trip value	1...200	%In	1	5	Trip value, percentage of the nominal current
Minimum trip time	20...300000	ms	10	20	Minimum trip time

Table 359: 87 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	10	20	Reset delay time

4.6.4.10 Monitored data

Table 360: 87 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
87	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.6.4.11 Technical data

Table 361: 87A, 87B, 87C Technical data

<table>
<tr><th colspan="2">Characteristic</th><th colspan="3">Value</th></tr>
<tr><td colspan="2" rowspan="2">Operation accuracy</td><td colspan="3">Depending on the frequency of the current measured: f_n ±2 Hz</td></tr>
<tr><td colspan="3">±1.5% of the set value or ±0.002 × I_n</td></tr>
<tr><td rowspan="3">Pickup time 1)2)</td><td></td><td>Minimum</td><td>Typical</td><td>Maximum</td></tr>
<tr><td>I_{Fault} = 2.0 × set Pickup value</td><td>12 ms</td><td>16 ms</td><td>24 ms</td></tr>
<tr><td>I_{Fault} = 10 × set Pickup value</td><td>10 ms</td><td>12 ms</td><td>14 ms</td></tr>
<tr><td colspan="2">Reset time</td><td colspan="3"><40 ms</td></tr>
<tr><td colspan="5">Table continues on next page</td></tr>
</table>

Characteristic	Value
Reset ratio	Typically 0.96
Retardation time	<35 ms
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms

1) Measurement mode = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

4.7 Impedance protection

4.7.1 Phase distance protection 21P

4.7.1.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase distance protection	PHDSTPDIS	Z<	21P

4.7.1.2 Function block

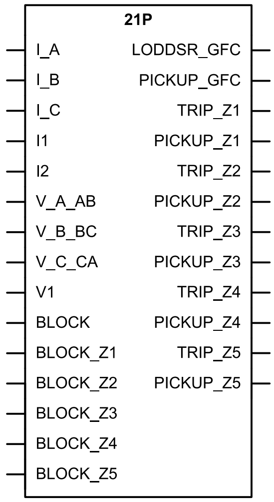


Figure 229: Function block

4.7.1.3 Functionality

The phase step distance protection function 21P can be used for the short circuit protection of distribution networks. 21P operates selectively for two-phase and three-phase short circuits.

21P supports mho (circular) characteristics. It has five flexible and configurable zones for protection (Z1…Z5). Directionality, reach and line angle for each zone can be set independently from each other.

21P has a separate and independent impedance measurement for phase-to-phase and three-phase fault loop in each distance protection zone. The memory voltage is used with the three-phase impedance measurement elements to secure the correct directional measurement in case of close-in three-phase faults.

The operation of 21P is based on the impedance-mapping approach, where the fault loop impedance is calculated first and then compared to the zone boundaries. If the impedance is recognized inside the operation zone, the corresponding trip output is activated after the trip time has elapsed.

The impedance measurement is based on the full-cycle DFT-filtered current and voltage phasors. Thus, the typical operating times are less than two cycles.

4.7.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”. Additionally, each zone can be "On" or "Off" individually with the help of the *Operation Znx* setting. When selected "On", the particular zone is enabled, and respectively "Off" means a particular zone is disabled.

The operation of the phase step distance protection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

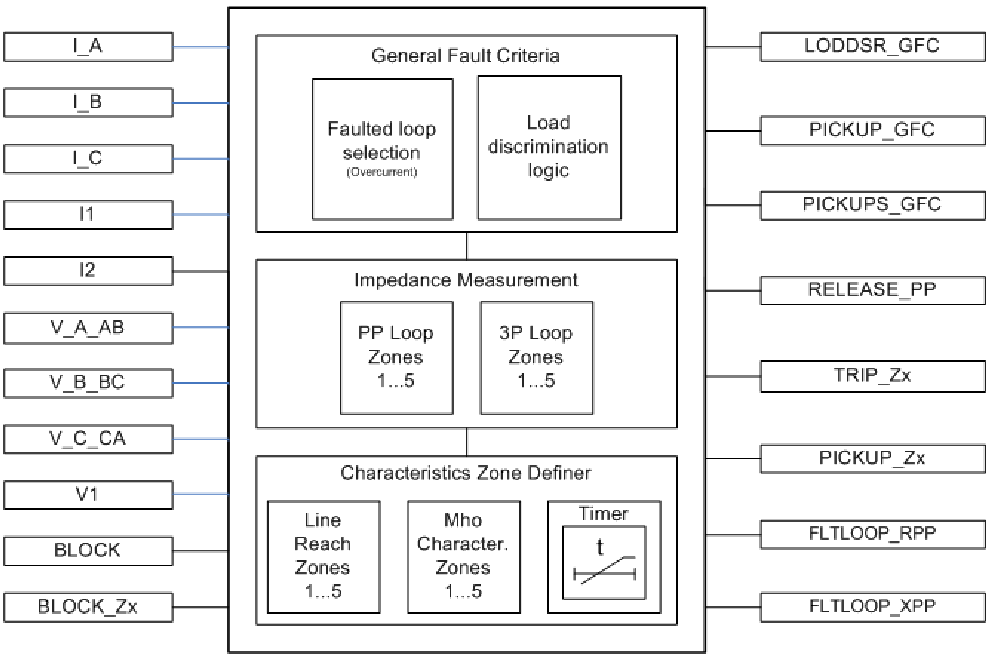


Figure 230: Functional module diagram

General Fault Criteria

The proper operation of 21P requires all three-phase currents and phase-to-phase or phase-to-ground voltages to be available for measurement.

Reliable identification of fault and faulty phase(s) is done in a module called General Fault Criteria or GFC. This function is compulsory to release the correct impedance-measuring elements of the protection zones and to guarantee a selective operation of the phase distance protection.

In GFC, the overcurrent method is used for identifying the faulty phase(s). The magnitude of each phase current is compared to the *Ph Str A Ph Sel GFC* setting. If the phase current magnitude exceeds the set limit, the respective phase is identified as faulty.

The activation of the PICKUP_GFC output indicates a two-phase or three-phase short circuit. The identification of the faulty phases is indicated in output PICKUPS_GFC. Depending on the faulty phases, the corresponding impedance-measuring elements in zones are released and indicated in the RELEASE_PP output.

Table 362: Pickup of the overcurrent elements and the respective outputs

Pickup of over-current element	PICKUP_GFC	PICKUPS_GFC	RELEASE_PP
IA> & IB>	TRUE	AB Fault	AB
IB> & IC>	TRUE	BC Fault	BC
IC> & IA>	TRUE	CA Fault	CA
IA> & IB> & IC>	TRUE	ABC Fault	ABC

To prevent undesired tripping due to large loads, an optional load discrimination logic can be enabled by the *Load Dsr mode GFC* setting. When selected "On", the load discrimination is enabled and respectively "Off" means the load discrimination is disabled. When load discrimination logic is enabled, the load impedance is estimated continuously with three phase-to-phase impedance measuring elements:

$$\underline{Z}_{AB} = (\underline{\mathrm{V}}_{\mathrm{A}} - \underline{\mathrm{V}}_{\mathrm{B}}) / (\underline{\mathrm{I}}_{\mathrm{A}} - \underline{\mathrm{I}}_{\mathrm{B}})$$

(Equation 77)

$$\underline{Z}_{BC} = (\underline{\mathrm{V}}_{\mathrm{B}} - \underline{\mathrm{V}}_{\mathrm{C}}) / (\underline{\mathrm{I}}_{\mathrm{B}} - \underline{\mathrm{I}}_{\mathrm{C}})$$

(Equation 78)

$$\underline{Z}_{CA} = (\underline{\mathrm{V}}_{\mathrm{C}} - \underline{\mathrm{V}}_{\mathrm{A}}) / (\underline{\mathrm{I}}_{\mathrm{C}} - \underline{\mathrm{I}}_{\mathrm{A}})$$

(Equation 79)

The load discrimination logic reserves an area for load impedance in the impedance plane (RX-plane) defined by the *Ris reach load GFC* and *Angle load area GFC* settings.

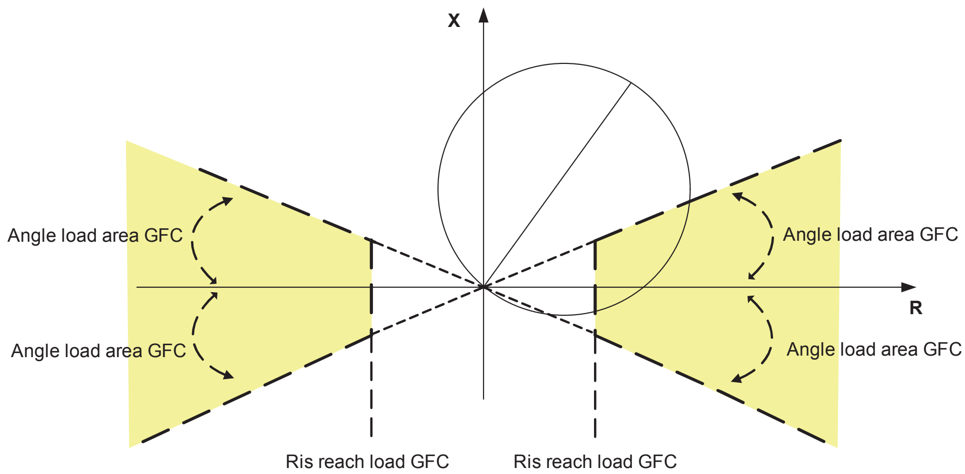


Figure 231: Circular (mho) characteristics with load discrimination logic enabled

Before releasing the phase-to-phase or three-phase fault measuring impedance elements of zones, the measured load impedance is evaluated with the load discrimination logic. If the load impedance is detected inside the sector reserved for load impedance, the zone release is blocked. The activation of the load discrimination requires all phase-to-phase voltages to exceed the *Load Dsr Ena V GFC* setting. The activation of the load discrimination logic is indicated by the LODDSR_GFC output signal.

Impedance measurement

21P provides three independent phase-to-phase measuring elements per zone and the three-phase fault is measured with a dedicated measurement element.

Impedance measurement module measures the impedance of a particular faulty loop when GFC module releases the loop. The measurement is based on the full-cycle DFT-filtered current and voltage phasors. This gives a typical operating time of less than two cycles.

21P operation is based on the impedance-mapping approach, where the fault loop impedance is calculated and compared to the zone boundaries. If the impedance is recognized inside the operation zone, the corresponding trip output TRIP_Zx (x = 1…5) is activated after the *Time delay Znx*, x = 1…5 setting is elapsed.

The calculated fault loop impedance of zone 1 can be read from the *FLTLOOP_RPP* and *FLTLOOP_XPP* settings in the monitored data. It can also be seen in the fault record.

Phase-to-phase impedance measurement

The phase-to-phase impedance measurement for a particular loop is performed on the receipt of the phase-to-phase release signal from the GFC module. Phase-to-phase impedance measuring elements provide basic protection against the phase-to-phase short circuit fault in all networks, regardless of the position of the neutral point.

The reach of phase-to-phase measuring elements is based on the loop impedance. The reach is calculated using the equation:

$$Z_1 + \frac{R_F}{2} = (R_1 + \frac{R_F}{2}) + j(X_1)$$

(Equation 80)

R1 = Positive-sequence resistance from measuring point to fault location

X1 = Positive-sequence reactance from measuring point to fault location

RF = Physical fault resistance between phases, for example, arc resistance

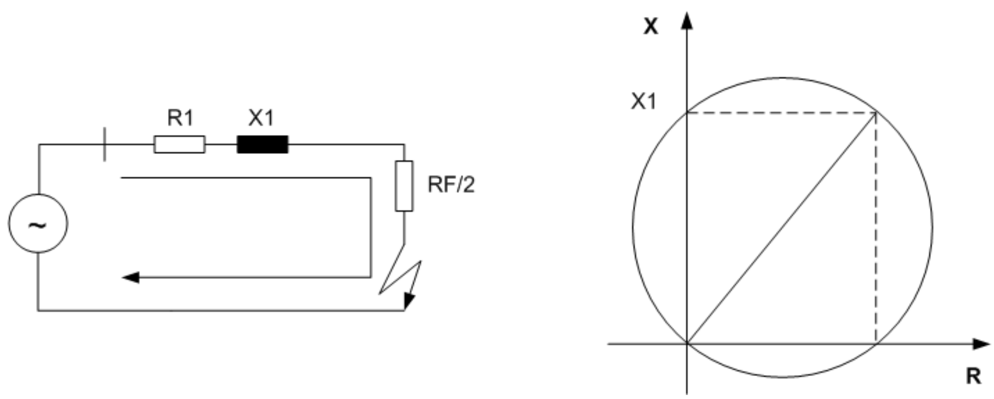


Figure 232: Fault loop impedance model for phase-to-phase impedance measuring

If the impedance measured falls in the region of operation, the trip timer activates the `PICKUP_Zx` (x = 1…5) output for that zone. When the trip timer has reached the set "Time delay Znx" (x = 1…5) value, the `TRIP_Zx` (x = 1…5) output is activated for that zone.

Optional supervision function for phase-to-phase impedance measurement can be enabled per zone by *Ph Seq A check Znx* (x = 1…5) setting. When *Ph Seq A check Znx* is enabled, it is required that negative sequence current should exceed the *Neg Seq value Znx* setting to release the phase-to-phase impedance measuring element.

Three-phase impedance measurement

A dedicated three-phase impedance measurement loop is activated on the receipt of the three-phase release signal from the GFC module. The three-phase impedance measuring element provides a basic protection for a three-phase short circuit fault. The measuring element utilizes the positive-sequence quantities for a fault loop impedance measurement, which increases the accuracy by reducing the influence of the line parameter asymmetry. This is advantageous especially in case of non-transposed lines.

The reach of three-phase measuring element is based on the loop impedance. The reach is calculated using the equation:

$$Z_1 + R_F = (R_1 + R_F) + j(X_1)$$

(Equation 81)

R1 = Positive-sequence resistance from measuring point to the fault location

X1 = Positive-sequence reactance from measuring point to the fault location

RF = Physical fault resistance per phase, for example, arc resistance

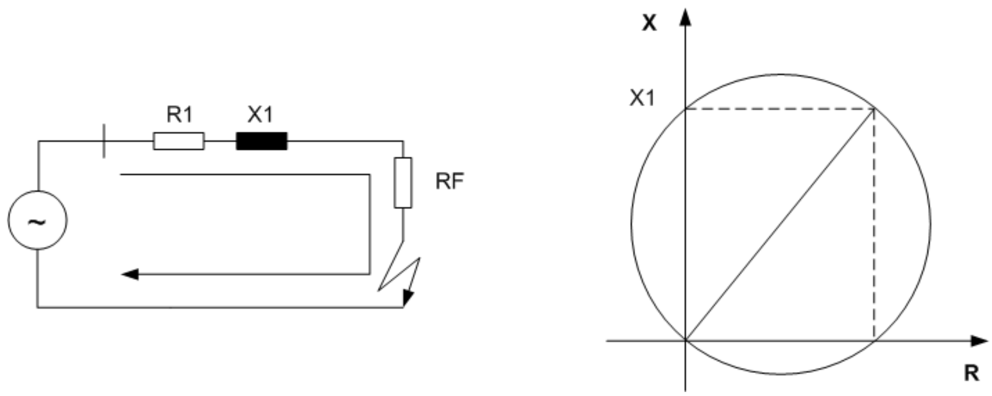


Figure 233: Fault loop impedance model for three-phase impedance measuring element

If the impedance measured falls in the operation region, the trip timer activates the `PICKUP_Zx` (x = 1…5) output for that zone. When the trip timer has reached the set *Time delay Znx* (x = 1…5) value, the `TRIP_Zx` (x = 1…5) output is activated for that zone.

Optional supervision function for three-phase impedance measurement can be enabled with the *Ph Seq A check Znx* (x = 1…5) setting. When *Ph Seq A check Znx* is enabled, the positive-sequence current should exceed the *Pos Seq value Znx* setting to release the three-phase impedance measuring element.

The memory voltage is used with the three-phase impedance measurement elements if the positive-sequence voltage becomes too low. This assures the correct directional measurement in case of the close-in three-phase faults, where the voltages on all three phases are close to zero. The duration of the memory voltage is defined with the *Voltage Mem time* setting. Default value is six cycles (= 100 ms, fn = 60 Hz).

Distance characteristics zone definer

This module defines the protection zone characteristics. There are totally five independently configurable mho zones, whose line reach, angle and directionality can be set individually for each zone. Each zone can be enabled or disabled individually with the *Operation Znx* setting, where x = 1...5. When selected "On", the zone is enabled and respectively "Off" means zone is disabled. The line reach of zone is defined in primary ohms.

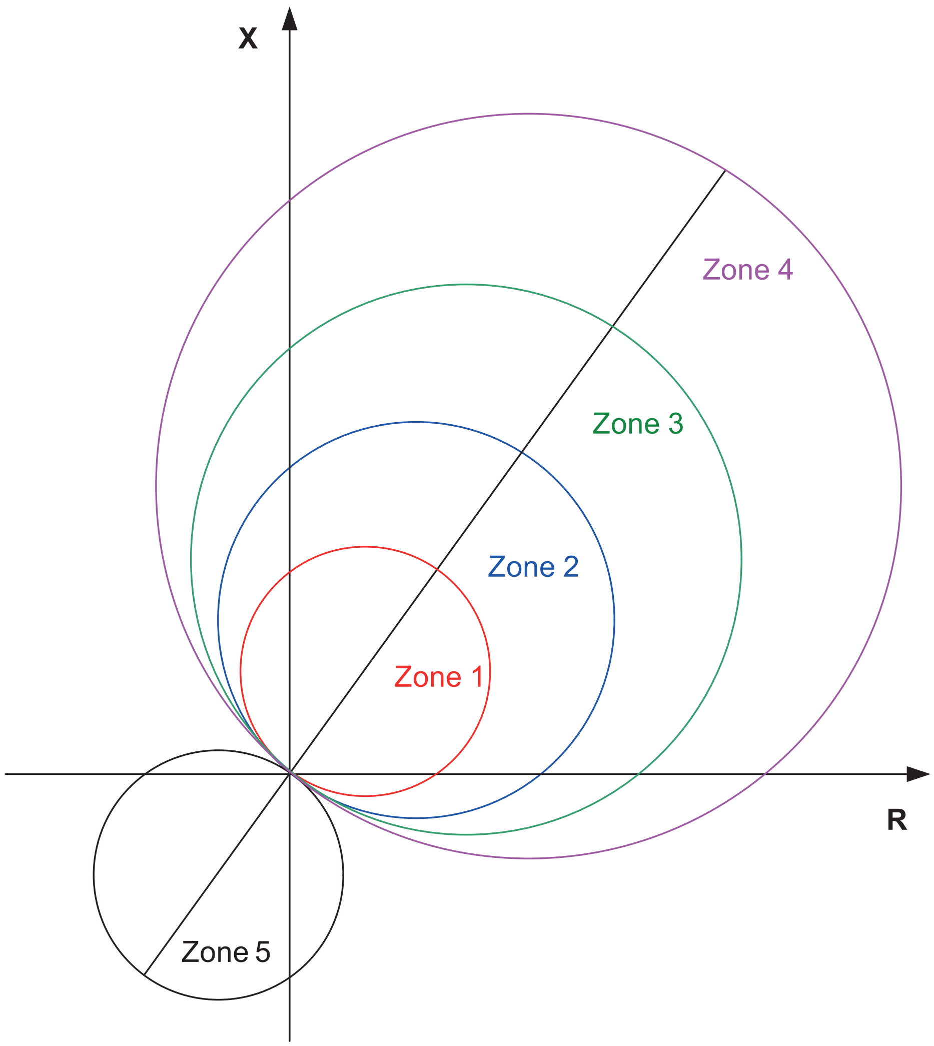


Figure 234: Phase distance zones with zones 1 to 4 forward and zone 5 reverse

Defining mho (circular) zone characteristics

The directionality of a particular zone is defined with the *Directional mode Znx* (x = 1…5) setting. When selected "Forward", the zone trips on faults in forward direction and respectively "Reverse" means the zone trips on faults in reverse direction.

The reach of the zone is defined by the settings *Z1 zone x* (x = 1…5) and *Z1 angle zone x* (x = 1...5) respectively.

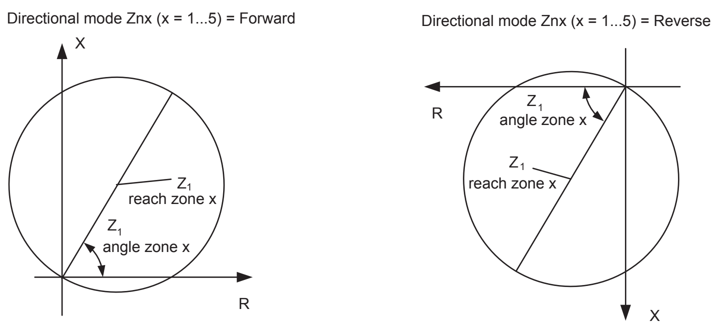


Figure 235: Line reach for phase-to-phase or three-phase impedance measuring elements

The actual resistive reach of the mho characteristic depends on the selected polarization method defined by the *Pol quantity* setting, which can be set to "Cross Pol" or "Pos. seq. volt.". The "Cross Pol" or "Pos. seq. volt." polarizations provide a variable mho feature insuring protection near the origin of the RX-diagram.

Table 363: Polarization methods and corresponding polarization voltages

Fault loop	Cross Pol	Pos. seq. volt.
ZAB	j·(VBC - VCA)/√3	V1·√3·1∠30°
ZBC	j·(VCA - VAB)/√3	V1·√3·1∠-90°
ZCA	j·(VAB - VBC)/√3	V1·√3·1∠150°
ZABC	V1[1)]	

1) Regardless of the selected polarization method, the three-phase fault measuring element always uses positive-sequence voltage for polarization. Memory voltage is included in the polarization voltage to secure directionality if the positive-sequence voltage becomes too small.

In the case of cross-polarization, the polarization voltage is in the quadrature to the fault loop voltage. The phase angle of polarization voltage is rotated 90 degrees to match the original fault loop voltage. The cross-polarization expands the tripping characteristic according to the prevailing system conditions, that is, in case of short circuit faults, the circle expands as a function of positive-sequence source impedance magnitude $Z_{1source}$. This provides a variable mho feature insuring protection near the origin of the RX-diagram.

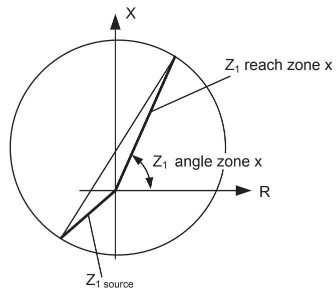


Figure 236: Mho (circular) operating characteristics with cross polarization

In the case of positive-sequence polarization, the polarization voltage is the positive-sequence voltage. The voltage phase angle is rotated to match the original fault loop voltage. Positive-sequence polarization expands the tripping characteristic according to the prevailing system conditions, that is, in the case of short circuit faults the circle expands as a function of source impedance magnitude Z1source/2 as shown in the curve for mho (circular) operating characteristics with a positive-sequence polarization. This provides a variable mho feature insuring protection near the origin of the RX-diagram.

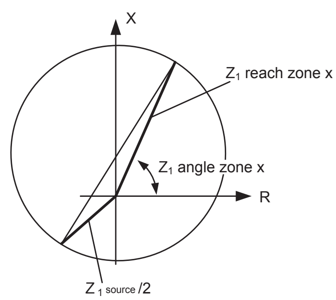


Figure 237: Mho (circular) operating characteristics with positive-sequence polarization

In case of cross- and positive-sequence polarization; the expansion of the mho circle is a positive feature as the fault resistance coverage is increased. The reach of the zone is not affected by the expansion. The greatest expansion is gained with the cross-polarization.

4.7.1.5 Application

21P provides a fast and reliable protection for overhead lines and power cables. 21P is applied in distribution and sub-transmission networks where three-phase tripping is allowed for phase-to-phase or three-phase faults.

Typically, these networks are operated in ring or meshed type of configurations. It is also a characteristic for these networks that the switching state is changed frequently due to daily operation and load flow considerations. The networks also include varying capacities of a distributed generation. This makes it impossible to apply simple overcurrent-based schemes. In these kinds of networks, 21P is used to provide a fast and selective protection for overhead lines and power cables. It can also be applied for radial feeders to increase the sensitivity of the protection, especially if the short circuit power of the source is low or if it is changing due to network operation.

From the selectivity point of view, it is advantageous that in the protection chain all functions in different positions trip according to the same measuring principle. Therefore, 21P can also be applied for the backup protection of main transformers and buses. This way, the selectivity with the distance protection of the outgoing lines is easier to achieve.

21P is suitable as a basic protection function against two-phase and three-phase faults in all kinds of networks, regardless of the position of the neutral point.

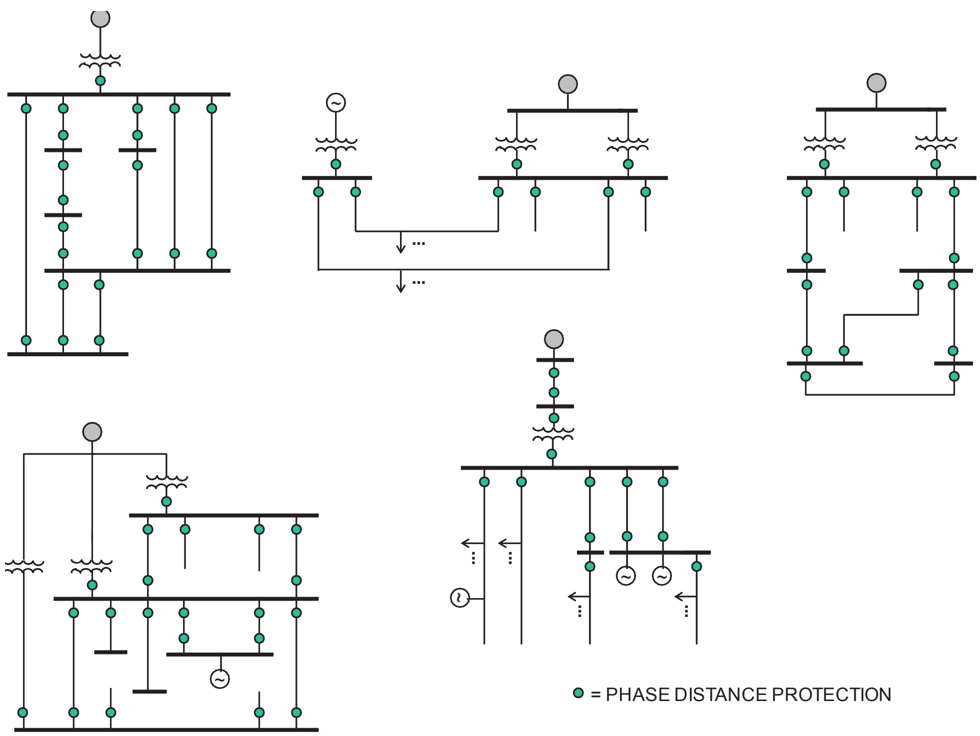


Figure 238: Typical network configurations for 21P

4.7.1.6 Signals

Table 364: 21P Input signals

Name	Type	Default	Description
I_A	SIGNAL	0.0	Phase A current
I_B	SIGNAL	0.0	Phase B current
I_C	SIGNAL	0.0	Phase C current
I1	SIGNAL	0.0	Positive sequence current
I2	SIGNAL	0.0	Negative sequence current
V_A_AB	SIGNAL	0.0	Phase-to-ground voltage A or phase-to-phase voltage AB
V_B_BC	SIGNAL	0.0	Phase-to-ground voltage B or phase-to-phase voltage BC
V_C_CA	SIGNAL	0.0	Phase-to-ground voltage C or phase-to-phase voltage CA
V1	SIGNAL	0.0	Positive sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLOCK_Z1	BOOLEAN	0=False	Block zone 1
BLOCK_Z2	BOOLEAN	0=False	Block zone 2
BLOCK_Z3	BOOLEAN	0=False	Block zone 3
BLOCK_Z4	BOOLEAN	0=False	Block zone 4
BLOCK_Z5	BOOLEAN	0=False	Block zone 5

Table 365: 21P Output signals

Name	Type	Description
TRIP_Z1	BOOLEAN	Trip, Z1
TRIP_Z2	BOOLEAN	Trip, Z2
TRIP_Z3	BOOLEAN	Trip, Z3
TRIP_Z4	BOOLEAN	Trip, Z4
TRIP_Z5	BOOLEAN	Trip, Z5
PICKUP_Z1	BOOLEAN	Pickup, Z1
PICKUP_Z2	BOOLEAN	Pickup, Z2
PICKUP_Z3	BOOLEAN	Pickup, Z3
PICKUP_Z4	BOOLEAN	Pickup, Z4
PICKUP_Z5	BOOLEAN	Pickup, Z5
LODDSR_GFC	BOOLEAN	Pickup signal for load discrimination logic
PICKUP_GFC	BOOLEAN	Pickup, GFC

4.7.1.7 Settings

Table 366: 21P Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pol quantity	-2=Pos. seq. volt. 5=Cross pol			5=Cross pol	Mho polarization method for zones
Voltage Mem time	0...3000	ms	10	100	Voltage memory time
Ph Str A Ph Sel GFC	0.10...10.00	xIn	0.01	2.00	Phase current pickup value, PSL
Load Dsr mode GFC	0=False 1=True			0=False	Enable load discrimination, PSL
Load Dsr Ena V GFC	0.0...1.0	xUn	0.1	0.9	Voltage limit for enabling load descrimination, PSL
Ris reach load GFC	0.10...1000.00	ohm	0.01	80.00	Resistive reach for load discrimination, PSL
Angle load area GFC	5.0...45.0	deg	0.1	25.0	Load discrimination angle, PSL
Directional mode Zn1	2=Forward 3=Reverse			2=Forward	Directional mode, zone Z1
Z1 reach zone 1	0.10...1000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z1
Z1 angle zone 1	10.0...90.0	deg	0.1	45.0	Positive sequence line angle, Zone Z1
Trip delay Zn1	30...200000	ms	10	30	Time delay to trip of PP/3P-loops, Zone Z1
Ph Seq A check Zn1	0=False 1=True			0=False	Enable optional phase sequence supervision for PP/3P-loops, Zone Z1
Min Ps Seq A Zn1	0.10...10.00	xIn	0.01	0.10	Minimum Pos. seq. current for 3P-loop, Zone Z1
Min Ng Seq A Zn1	0.10...10.00	xIn	0.01	0.10	Minimum Neg. seq. current for PP-loop, Zone Z1
Directional mode Zn2	2=Forward 3=Reverse			2=Forward	Directional mode, Zone Z2
Z1 reach zone 2	0.10...1000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z2
Z1 angle zone 2	10.0...90.0	deg	0.1	45.0	Positive sequence zone reach, Zone Z2
Trip delay Zn2	30...200000	ms	10	30	Time delay to trip of PP/3P-loops, Zone Z2
Ph Seq A check Zn2	0=False 1=True			0=False	Enable optional phase sequence supervision for PP/3P-loops, Zone Z2
Min Ps Seq A Zn2	0.10...10.00	xIn	0.01	0.10	Minimum Pos. seq. current for 3P-loop, Zone 2
Min Ng Seq A Zn2	0.10...10.00	xIn	0.01	0.10	Minimum Neg. seq. current for PP-loop, Zone 2
Directional mode Zn3	2=Forward 3=Reverse			2=Forward	Directional mode, Zone Z3
Z1 reach zone 3	0.10...1000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z3
Z1 angle zone 3	10.0...90.0	deg	0.1	45.0	Positive sequence line angle, Zone Z3
Trip delay Zn3	30...200000	ms	10	30	Time delay to trip of PP/3P-loops, Zone Z3
Ph Seq A check Zn3	0=False 1=True			0=False	Enable optional phase sequence supervision for PP/3P-loops, Zone Z3
Min Ps Seq A Zn3	0.10...10.00	xIn	0.01	0.10	Minimum Pos. seq. current for 3P-loop, Zone 3

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Min Ng Seq A Zn3	0.10...10.00	xIn	0.01	0.10	Minimum Neg. seq. current for PP-loop, Zone 3
Directional mode Zn4	2=Forward 3=Reverse			2=Forward	Directional mode, Zone Z4
Z1 reach zone 4	0.10...1000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z4
Z1 angle zone 4	10.0...90.0	deg	0.1	45.0	Positive sequence line angle, Zone Z4
Trip delay Zn4	30...200000	ms	10	30	Time delay to trip of PP/3P-loops, Zone Z4
Ph Seq A check Zn4	0=False 1=True			0=False	Enable optional phase sequence supervision for PP/3P-loops, Zone Z4
Min Ps Seq A Zn4	0.10...10.00	xIn	0.01	0.10	Minimum Pos. seq. current for 3P-loop, Zone 4
Min Ng Seq A Zn4	0.10...10.00	xIn	0.01	0.10	Minimum Neg. seq. current for PP-loop, Zone 4
Directional mode Zn5	2=Forward 3=Reverse			2=Forward	Directional mode, Zone Z5
Z1 reach zone 5	0.10...1000.00	ohm	0.01	56.57	Positive sequence zone reach, Zone Z5
Z1 angle zone 5	10.0...90.0	deg	0.1	45.0	Positive sequence line angle, Zone Z5
Trip delay Zn5	30...200000	ms	10	30	Time delay to trip of PP/3P-loops, Zone Z5
Ph Seq A check Zn5	0=False 1=True			0=False	Enable optional phase sequence supervision for PP/3P-loops, Zone Z5
Min Ps Seq A Zn5	0.10...10.00	xIn	0.01	0.10	Minimum Pos. seq. current for 3P-loop, Zone 5
Min Ng Seq A Zn5	0.10...10.00	xIn	0.01	0.10	Minimum Neg. seq. current for PP-loop, Zone 5

Table 367: 21P Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Operation Zn1	1=enable 5=disable			1=enable	Operation Disable / Enable, Zone 1
Operation Zn2	1=enable 5=disable			1=enable	Operation Disable / Enable, Zone Z2
Operation Zn3	1=enable 5=disable			1=enable	Operation Disable / Enable, Zone Z3
Operation Zn4	1=enable 5=disable			1=enable	Operation Disable / Enable, Zone Z4
Operation Zn5	1=enable 5=disable			1=enable	Operation Disable / Enable, Zone Z5

4.7.1.8 Monitored data

Table 368: 21P Monitored data

Name	Type	Values (Range)	Unit	Description
RELEASE_PP	Enum	0=No fault 4=BC Fault 5=CA Fault 6=ABC Fault 7=AB Fault		Release signals for PP/3P loops, GFC
STARTS_GFC	Enum	0=No fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Phase pickup signals packed, GFC
FLTLOOP_RPP	FLOAT32	-1000.00...1000.00	ohm	Real part of the PP/3P-loop impedance, zone Z1
FLTLOOP_XPP	FLOAT32	-1000.00...1000.00	ohm	Imaginary part of the PP/3P-loop impedance, zone Z1
21P	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.7.1.9 Technical data

Table 369: 21P Technical data

Characteristic	Value
Pickup accuracy	Depending on the frequency of the current measured: f_n ±2 Hz
	Current: ±1.5 % of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n Impedance: ±2.0% of the set value or ±0.1 Ω Phase angle: ±2°
Pickup time[1)2)]	Typically 23 ms
Reset time	<40 ms
Reset ratio	Typically 0.96
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50dB at f = n × f_n, where n = 2, 3, 4, 5,…

1) Includes the delay of the signal output contact
2) Relates to pickup signals of the zones Z1...Z5

4.7.2 Out of step 78

4.7.2.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Out of step protection	OOSRPSB	φ>	78

4.7.2.2 Function block

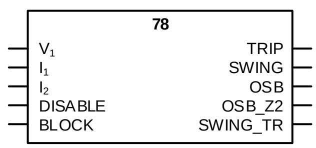


Figure 239: Function block

4.7.2.3 Functionality

The out of step protection function 78 detects out of step conditions by monitoring impedance.

The protection uses two impedance measurement elements known as inner and outer blinders on mho characteristics with a timer. The function calculates the impedance. If the measured impedance stays between inner and outer blinder for a predetermined time and moves farther inside the inner blinder, then an out of step condition is indicated. Trip is generated if out of step is indicated and impedance moves out of mho characteristics. The mho characteristic can be divided into two zones so separate trips can be generated based on the zone. Tripping can also be selected to occur when the impedance is on the way into the zone or for when the impedance is on the way out of the zone.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

4.7.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of 78 can be described using a module diagram. All the modules in the diagram are explained in the next sections.

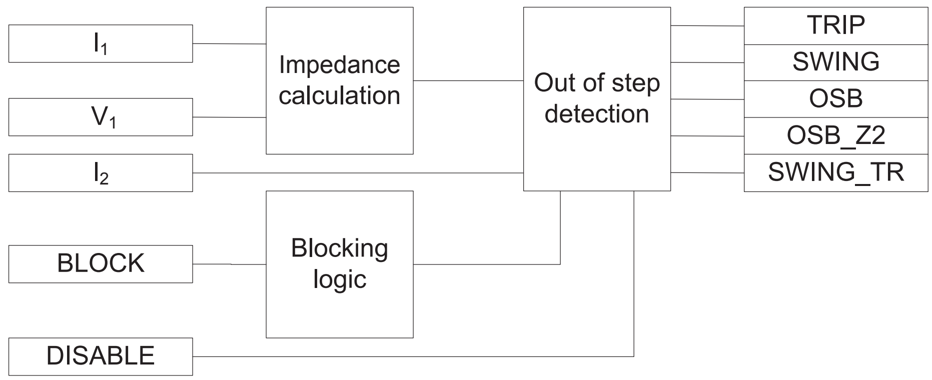


Figure 240: Functional module diagram

Impedance calculation

This module calculates the positive-sequence impedance (Z1) using positive-sequence voltage and current. For the module to calculate impedance it is required that the positive-sequence current is above *Min Ps Seq current* setting and the negative-sequence current is below the *Max Ng Seq current* setting.

The calculated positive-sequence impedance amplitude Z1_AMPL and angle Z1_ANGLE are available in ohms and degrees, respectively, in the Monitored data view.

The calculated impedance is converted to ohms as the operating characteristics are defined with the ohm settings.

Out of step detection

The operating characteristic is a circular offset mho on the impedance plane with two pair of blinders. The mho characteristic is defined with the *Forward reach*, *Reverse reach*, and *Impedance angle* settings. *Forward reach* defines the impedance from the origin to the edge of circle on the top side. *Reverse reach* defines the impedance from the origin to the edge of the circle on the bottom side. The diameter of the mho characteristics is the sum of *Forward reach* and *Reverse reach* settings. Two sets of blinders are defined by *Inner* *blinder R* and *Outer blinder R* intercepting at R-axis. The blinders are at the same angle as the *Impedance angle*. The second blinder of each outer and inner pair is automatically made symmetrical with the origin of the R-X plane.

For a correct operation, it is required that the setting for *Inner blinder R* is less than the setting for *Outer blinder R*.

The circular mho characteristic can be further divided into two zones by setting *Zone 2 enable* to “Yes”. The boundary between zones is set using the setting *Zone 1 reach*. The lower portion of the circle, Zone 1, is separated from the upper portion, Zone 2, by a line, perpendicular to the blinders, located at a set percentage of the *Forward reach* setting from the origin.

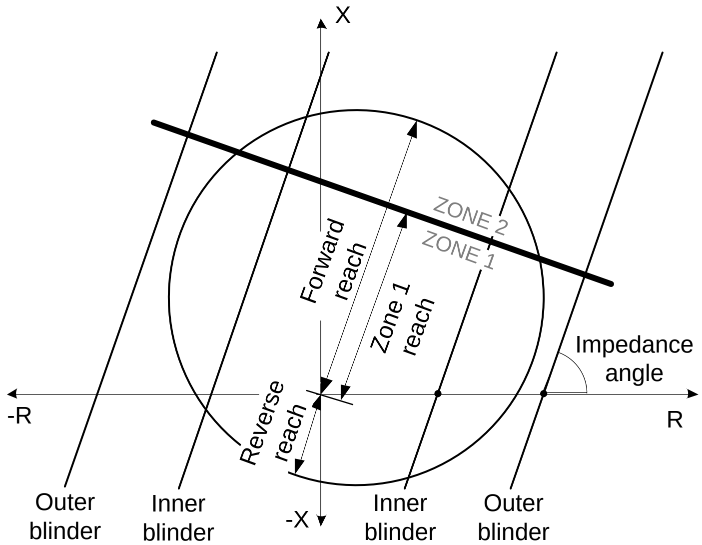


Figure 241: Operating region for out of step with double blinder

A third zone, Zone 3, can be enabled by setting *Zone 3 enable* to “Yes”. Zone 3 is defined to include the area outside of the circular mho characteristic but inside a larger circle centered on the origin that represents impedance with the magnitude of the minimum positive-sequence current defined by setting *Min Ps Seq current* and the rated positive-sequence voltage. Figure 242 shows the three zones. Settings that determine the shape of the zones should be coordinated with the settings for any distance protection functions.

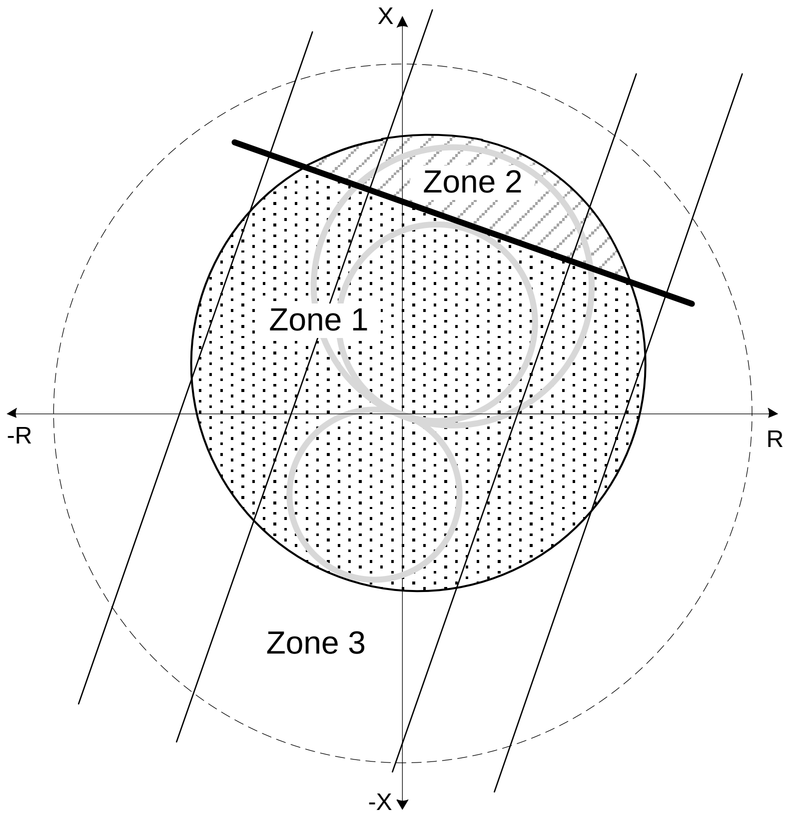


Figure 242: Defined zones

Out of step condition is a symmetrical event, so out of step detection is enabled only if the negative-sequence current is below the *Max Ng Seq current* setting.

The impedance is continuously monitored for detecting an out of step condition. When the impedance enters inside from the outer blinder, the out of step detection timer is triggered. If impedance remains between outer and inner blinder for the duration of the *Swing time* setting, output `SWING` is activated. If the impedance enters the mho circle in zone 1, out of step blocking (OSB) for zone 1 is detected and output `OSB` is activated, or if the impedance enters the mho circle in zone 2, OSB for zone 2 is detected and output `OSB_Z2` is activated if setting *Zone 2 enable* is set to “Yes”. The `OSB` or `OSB_Z2` output deactivates when impedance exits and remains outside the mho circle and the inner blinder for a duration of five cycles.

Activation of the `TRIP` output depends on the *Oos trip mode* selected. *Trip mode* options available are “Way in”, “Way out”, and “Adaptive”. If the “Way in” option is selected, the function triggers the delay timer after detecting an OSB condition. When the set *Trip delay time* has elapsed, the `TRIP` output is activated.

If “Way out” option is selected, after detecting an OSB condition, the function further checks if impedance exits the outer blinder. On exiting the outer blinder, Way out timer defined by *Trip delay time* setting is triggered and the respective zone slip counter is incremented after the set *Trip delay time* has elapsed. If the slip counter value is equal to the set number of slips in the respective enabled zone, the TRIP output is activated. Increment of slip counter triggers also the Reset timer. All of the zone slip counters reset after the set *Reset time* has elapsed and the impedance does not cross into the outer blinder again, or on activation of the TRIP output.

When the “Way out” option is selected, the breaker open time, if known, can be incorporated to optimize breaker trip time when a trip command is issued. The ideal time for the breaker to interrupt current is when the swing angle approaches zero. If the swing angle is δ_0 when the impedance exits the outer blinder, the dynamic Trip delay, T_{od}, can be set as shown in Equation 82.

$$T_{od} = \frac{1 - 2 \cdot f_{slip} \cdot (T_{co} + BrkropenTm)}{2 \cdot f_{slip}}$$

(Equation 82)

T_{od}	Dynamic Trip delay
T_{co}	The time for the impedance to travel from the center impedance line (where the swing angle is π radians) to the outer blinder on the opposite side from which it entered.
BrkopenTm	Set *Breaker open time*
f_{slip}	Slip frequency

The *Breaker open time* setting should include the time from when the relay issues a trip command to the time when the breaker receives the command. The function uses the *Breaker open time* setting to determine the trip delay time if it is not set to “0”. If the *Breaker open time* is set to “0”, the function does not dynamically calculate a trip delay but uses the fixed *Trip delay time* before activating the TRIP output.

The slip frequency is calculated using Equation 83.

$$f_{slip} = \frac{\delta_i - \delta_0}{2 \cdot \pi \cdot T_{oi}}$$

(Equation 83)

f_{slip}	Slip frequency
T_{oi}	The time for the impedance to pass from the outer to the inner blinder.
δ_0	Swing angle at the outer blinder
δ_I	Swing angle at the inner blinder

The swing angles, δ_0 and δ_I, are estimated from the measured impedance when crossing the blinders. It is the difference in these quantities that is important for determining the slip frequency.

If the “Adaptive” option is selected, after detecting an OSB condition, the function further examines the slip frequency f_{slip}, *V dip time* setting, and swing angle at the outer blinder (δ_0) to determine if the trip is asserted on the way in or on the way out. Tripping is done on the way in, entering the mho circle from an inner blinder, if the relationship in Equation 84 is true.

$$f_{slip} \leq \frac{(\pi - \delta_0)}{\pi \cdot VoltagedipTm}$$

(Equation 84)

f_{slip}	Slip frequency
δ_0	Swing angle at the outer blinder
VoltagedipTm	Set *V dip time*

Otherwise, tripping is done on the way out, when the impedance exits an outer blinder and the swing repeats for the set *Max number slips* count in the respective enabled zone that the swing has passed through.

If the *Swing time* has elapsed but the impedance exits the inner blinder and continues through the opposite blinders without passing through the mho circle, the `SWING` output is activated. The `SWING` output remains activated for a time determined by the *Reset time* setting unless another swing occurs before the reset time expires causing the output to remain active for another *Reset time* interval. If this swing is repeated for the set *Max Num slips Zn3* count and the *Zone 3 enable* setting is “Yes”, the `SWING_TR` output is activated. The `SWING_TR` output remains activated for a time determined by the *Trip dropout time* setting.

If the “Adaptive” option is selected and an OSB condition is not detected, but the impedance enters the mho circle after remaining between the inner and outer blinders for greater than 1.5 cycles, the function assumes a severe swing and assert the `TRIP` output.

The drop out delay for `TRIP` output can be set by *Trip dropout time* setting.

If the polarity of the voltage signal is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to “Yes”, which rotates the impedance vector by 180 degrees.

The `DISABLE` input can be used to coordinate the correct operation during the start-up situation. The function is blocked by activating the DISABLE signal. Once the DISABLE signal is deactivated, the function remains blocked (outputs disabled) for additional time duration as set through the setting *Disable time*.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System /Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block TRIP output” mode, the function operates normally but the TRIP output is not activated.

4.7.2.5 Application

Out of step protection functions detect stable power swings and out of step conditions based on the fact that the voltage/current variation during a power swing is slow compared to the step change during a fault. Both faults and power swings may cause the measured impedance to enter into the operating characteristic of a distance relay element. The apparent impedance moves from the pre-fault value to a fault value in a very short time, a few milliseconds, during a fault condition. However, the rate of change of the impedance is much slower during a power swing or out of step condition than during a fault depending on the slip frequency of the out of step. The impedance measurement should not be used by itself to distinguish between a fault condition and an out of step condition from a phase fault. The fundamental method for discriminating between faults and power swings is to track the rate of change of the measured impedance.

The function measures the rate of change of the impedance using two impedance measurement elements known as blinders together with a timing device. If the measured impedance stays between the blinders for a predetermined time, the function declares a power swing condition and asserts an output that can be used to block the distance protection. However, if the impedance passes the inner blinder and exits on the other side of the mho characteristics (that is, the resistive component of impedance has opposite sign as at the time of point of entry) an out of step tripping is issued by the function. Figure 243 gives an example of out of step detection.

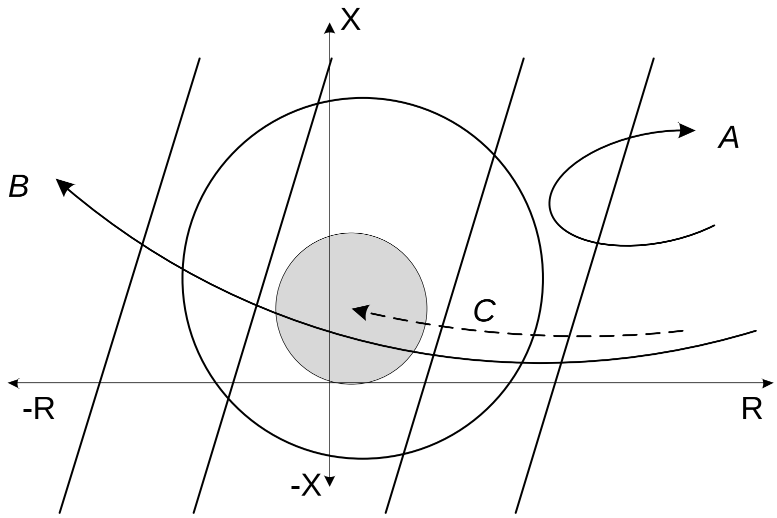


Figure 243: Example of out of step detection

The shaded region indicates a fault zone in a distance protection function. For curve A, the impedance moves into the out of step zone and leaves slowly, indicating the occurrence of a swing that quickly stabilizes. For curve B, the impedance moves slowly into the out of step zone and exits the zone indicating that the network is becoming unstable. For curve C, impedance rapidly moves into, and remains in, the fault zone indicating an actual fault and not an out of step condition.

4.7.2.6 Signals

Table 370: 78 Input signals

Name	Type	Default	Description
V_1	SIGNAL	0.0	Positive phase sequence voltage
I_1	SIGNAL	0.0	Positive phase sequence current
I_2	SIGNAL	0.0	Negative phase sequence current
DISABLE	BOOLEAN	0=False	Signal to block the function during starting of motor or generator
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 371: 78 Output signals

Name	Type	Description
TRIP	BOOLEAN	OOS Trip
SWING_TR	BOOLEAN	Swing trip output
SWING	BOOLEAN	Swing output
OSB	BOOLEAN	OOS block zone 1
OSB_Z2	BOOLEAN	OOS block zone 2

4.7.2.7 Settings

Table 372: 78 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Oos trip mode	1=Way in 2=Way out 3=Adaptive			2=Way out	OOS trip mode
Forward Reach	0.00...6000.00	ohm	0.01	1000.00	Forward reach of mho circle
Reverse Reach	0.00...6000.00	ohm	0.01	100.00	Reverse reach of mho circle
Inner blinder R	1.00...6000.00	ohm	0.01	150.00	Inner blinder at R axis
Outer blinder R	1.01...10000.00	ohm	0.01	400.00	Outer blinder at R axis
Impedance angle	10.0...90.0	deg	0.1	90.0	Angle of mho circle and blinders
Zone 1 reach	1...100	%	1	70	Reach of zone 1 into mho circle
Max number slips	1...10		1	1	Number of pole slips before tripping zone 1
Max num. slips zn2	1...20		1	1	Number of pole slips before tripping zone 2
Max num. slips zn3	1...20		1	1	Number of pole slips before tripping zone 3
Swing time	0...300000	ms	10	500	Time between blinders for swing
Trip delay time	0...60000	ms	10	300	Delay after OOS trip detected
Trip dropout time	0...60000	ms	10	100	Time trip output remains active
V dip time	500...5000	ms	10	2000	Voltage dip time
Zone 2 enable	1=Yes 0=No			0=No	Enable zone 2 feature
Zone 3 enable	1=Yes 0=No			0=No	Enable zone 3 feature

Table 373: 78 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Min Ps Seq current	0.01...10.00	xIn	0.01	0.10	Minimum positive sequence current for operation
Max Ng Seq current	0.01...10.00	xIn	0.01	0.20	Maximum negative sequence current for operation
Breaker open Time	0...300	ms	1	30	Time for breaker to open aftercommand
Disable time	0...60000	ms	10	5000	Added dropout time for DISABLE input
Reset time	0...60000	ms	10	5000	Time to reset OOS condition and counters
Voltage reversal	0=No 1=Yes			0=No	Rotate voltage signals by 180 degrees

4.7.2.8 Monitored data

Table 374: 78 Monitored data

Name	Type	Values (Range)	Unit	Description
SWING	BOOLEAN	0=False 1=True		Swing output
Z1_AMPL	FLOAT32	0.00...99999.00	ohm	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-179...180	deg	Positive sequence impedance phase angle
78	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.7.2.9 Technical data

Table 375: 78 Technical data

Characteristic	Value
Impedance measurement accuracy	Z1_Amplitude: ±(1.0% or 0.1 Ω)
	Z1_Angle: 1°
Suppression of harmonics	DFT: -60 dB at f = n × f_n, where n = 2, 3, 4, 5, 6, 7
Reset time	±1.0% of the set value or ±40 ms

4.7.3 Three-phase underexcitation protection 40

4.7.3.1 Identification

This function is available in REM620 Ver.2.1 only.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underexcitation protection	UEXPDIS	X<	40

4.7.3.2 Function block

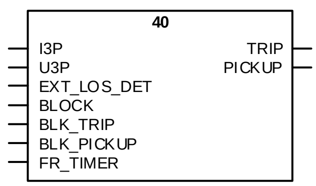


Figure 244: Function block

4.7.3.3 Functionality

The three-phase underexcitation protection 40 is used to protect the synchronous machine against the underexcitation or loss of excitation condition.

The protection is based on the offset-mho circular characteristics on the impedance plane. The function calculates the apparent impedance from the machine terminal voltages and currents. If the impedance vector enters the offset-mho circle, the function gives the operating signal after a set definite time. The operating time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself, if desired.

4.7.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "Enable" and "Disable".

The operation of the three-phase underexcitation protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

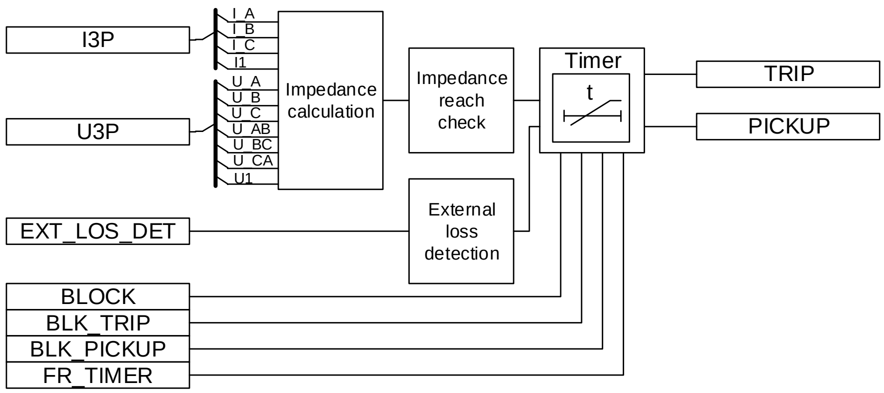


Figure 245: Functional module diagram

Impedance calculation

This module calculates the apparent impedance based on the selected voltages and currents. The *Measurement mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If the *Measurement mode* is set to "1Phase-earth" or "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase or phase-phase voltages ("A or AB", "B or BC" and "C or CA") and currents should be used for calculating the impedance.

Table 376: Voltages and currents used in impedance calculation

Measurement mode	Phase Sel for Z Clc	Voltages and currents
1Phase-earth	A or AB	U_A, I_A
1Phase-earth	B or BC	U_B, I_B
1Phase-earth	C or CA	U_C, I_C
1Phase-phase	A or AB	U_AB, I_A, I_B
1Phase-phase	B or BC	U_BC, I_B, I_C
1Phase-phase	C or CA	U_CA, I_C, I_A
Table continues on next page		

Measurement mode	Phase Sel for Z Clc	Voltages and currents
3Phase-earth	N/A	U_A, U_B, U_C, I_A, I_B, I_C
3Phase-phase	N/A	U_AB, U_BC, U_CA, I_A, I_B, I_C
Pos seqn	N/A	{ U_A,U_B,U_C } or { U_AB,U_BC,U_CA } and I_A, I_B, I_C

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

If the polarity of the voltage signals is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to "Yes", which rotates the impedance vector by 180 degrees.

If the magnitude of the voltage is less than $0.05 \cdot U_N$, the calculated impedance is not reliable and the impedance calculation is disabled. U_N is the rated phase-to-phase voltage.

The calculated impedance magnitudes and angles are available in the Monitored data view. The impedance angles are provided between -180...180 degrees.

The calculated apparent impedance is converted to pu impedance as the operating characteristics are defined with the pu settings.

Impedance reach check

The operating characteristic is a circular offset mho on the impedance plane. The operating characteristics are defined with the *Offset*, *Diameter* and *Displacement* settings. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the Timer.

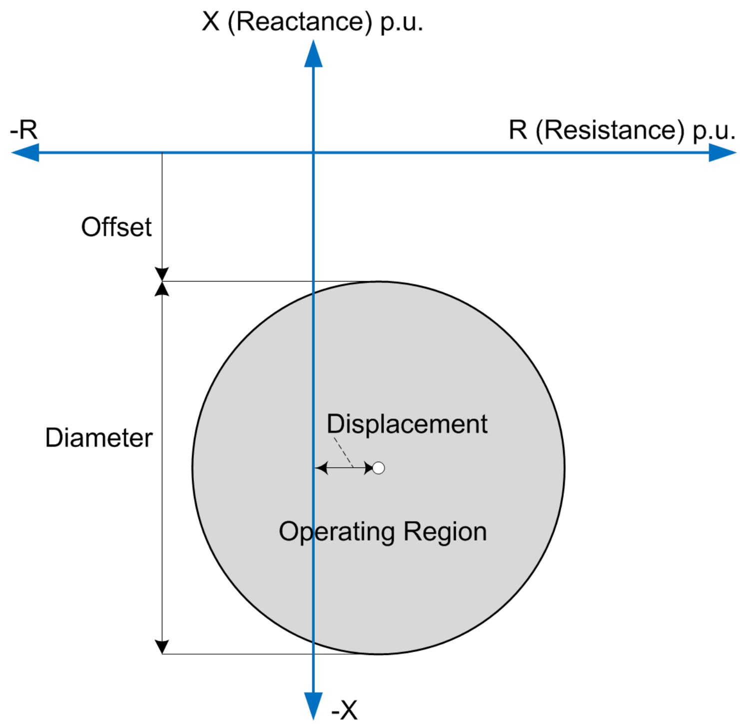


Figure 246: Operating region of the impedance mho circle

A fault in Automatic Voltage Regulator (AVR) or in the excitation system may cause a total loss of excitation. A short circuit on the slip rings reduces the excitation voltage to zero. This causes a gradual reduction of the excitation current and eventually a loss of excitation. An open circuit in the field circuit also causes a loss of excitation. These are typical examples which cause underexcitation in synchronous machines. This module detects the underexcitation condition for the above cases when the calculated impedance enters the operating characteristics.

External loss detection

The module checks the status information of the excitation system. It is activated when the *External Los Det Ena* setting is set to "Enable". The total loss of excitation current or a failure in the excitation system is indicated by connecting the external binary signal to the `EXT_LOS_DET` input. The Timer is enabled immediately when the `EXT_LOS_DET` input is activated.

Timer

Once activated, the Timer activates the `PICKUP` output. The time characteristic is according to DT. When the duration of the underexcitation exceeds the set definite *Operate delay time*, the `TRIP` output is activated. If the impedance locus moves out of the offset-mho operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the PICKUP output is deactivated.

The Timer calculates the start duration value PICKUP_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the Monitored data view.

Blocking logic

The activation of the BLOCK input deactivates all binary outputs and resets internal timers. The binary input BLK_PICKUP can be used to block the PICKUP signal. The binary input BLK_TRIP can be used to block the TRIP signal. The operation timer counting can be frozen on the prevailing value by activation of the FR_TIMER input.

4.7.3.5 Application

There are limits for the underexcitation of a synchronous machine. A reduction of the excitation current weakens the coupling between the rotor and the external power system. The machine may lose the synchronism and start to operate like an induction machine, which increases the consumption of the reactive power. Even if the machine does not lose synchronism, it is not recommended to operate in this state. The underexcitation causes excessive heating in the end region of the stator winding. This can damage the insulation of the stator winding and even the iron core.

The underexcitation also causes the generator to operate in the asynchronous mode. This increases the rotor speed, which causes heating in the rotor iron and damps the windings. A high intake of the reactive power from the network during underexcitation causes problems in the network, for example voltage dip, stability and power swings. Power swings stress the prime mover, causing for example turbine blade cavitation and mechanical stress in the gearbox.

The capability curve of a synchronous generator describes the underexcitation capability of the machine. An excessive capacitive load on the synchronous machine causes it to lose synchronization with the power grid. The reason is the steady-state stability limit as defined by the load angle being 90°, which can only be reached when the unit is underexcited.

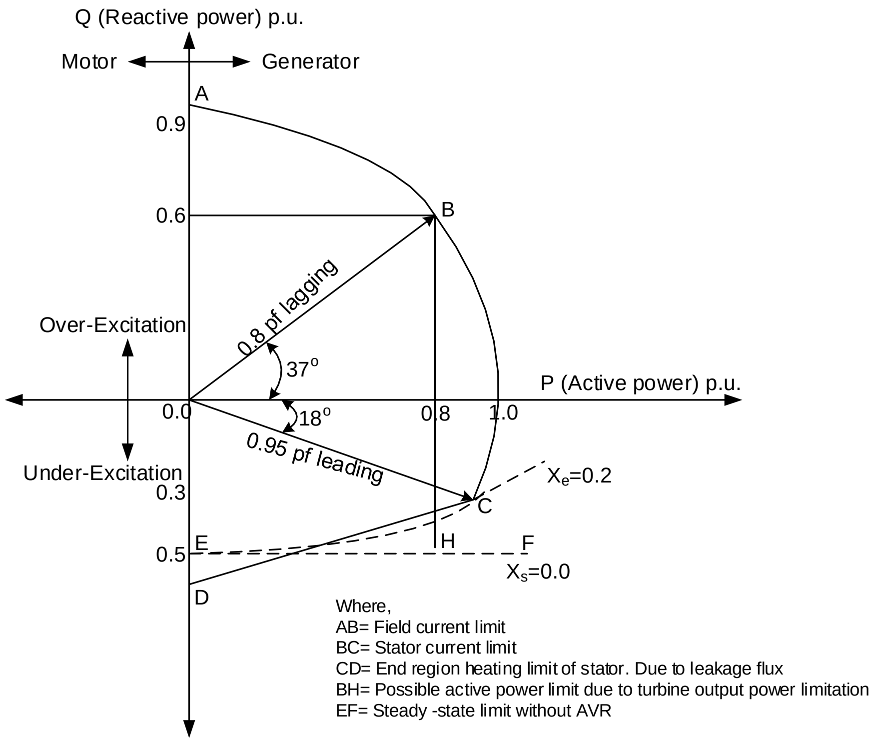


Figure 247: Capability curve of a synchronous generator

UEXPDIS protects the synchronous machines against an unstable operation due to loss of excitation. A partial or total loss of excitation causes a reactive power intake from the network to the machine, and the reactance of the system viewed from the machine terminals turns negative. This kind of drop-of-reactance condition can be detected by measuring the impedance of the system.

The operating characteristic is an offset-mho circle in the impedance plane, and the circle is parameterized with the *Offset*, *Diameter* and *Displacement* setting values.

Table 377: Parameters of the circle

Setting values	Description
Offset	Distance of the top of the circle from the R-axis. This is usually set equal to - x_d'/2, where x_d' is the transient reactance of the machine. The sign of the setting value determines the top of the circle regarding the R-axis. If the sign is negative, the circle lies below the R-axis.
Diameter	Normally set equal to the machine's synchronous reactance x_d, which determines the size of the impedance circle.
Displacement	Displacement of the center of the circle from the reactance axis or the R-coordinate of the center. The setting can be used to adjust the sensitivity of the underexcitation protection. If the sign of the setting is positive, the circle is shifted to the right, that is, closer to the normal operating point. Respectively, if the sign is negative, the circle is shifted to the left and thus moves away from the normal operating point.

The setting parameters of the off-set mho circle are to be given in pu values. The base impedance (Z_N) in ohms is:

$$Z_N = \left| \frac{U_N^{\ 2}}{S_N} \right|$$

(Equation 85)

U_N rated (phase-to-phase) voltage in kV

S_N rated power of the protected machine in MVA

The corresponding calculation to convert ohms to pu values is:

$$X_{pu} = \frac{X_{ohm}}{Z_N}$$

(Equation 86)

X_{pu} pu value

X_{ohm} reactance in ohms

Z_N base impedance

Example of impedance locus in underexcitation

In an example of a typical impedance locus, once the impedance locus enters the relay operation characteristics, the relay operates after a settable definite time.

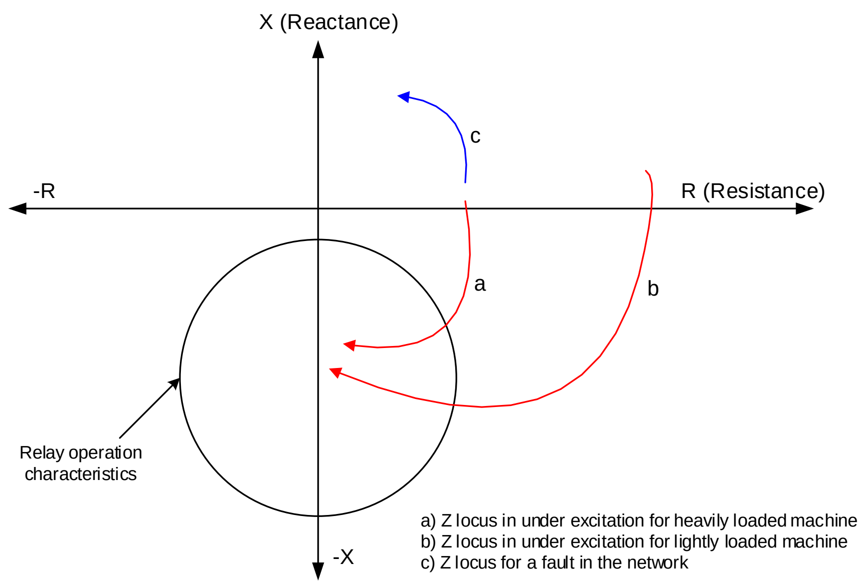


Figure 248: Typical impedance locus in underexcitation: a) heavy load b) light load c) fault in the network

4.7.3.6 Base values

In this function block, some of the settings are set in per unit (pu). These pu values are relational to certain base values, for example the values given in A, kV and kVA. The protection relay supports alternative base value groups for the phase current or voltage-related settings, for example "Phase Grp 1", "Phase Grp 2" and "Phase Grp 3". Similarly, "Residual Grp 1", "Residual Grp 2" and "Residual Grp 3" are supported for the residual current or voltage-related settings. One of the groups must be selected to be used with the *Base value Sel phase* or *Base value Sel Res* settings.

4.7.3.7 Signals

Table 378: 40 Input signals

Name	Type	Default	Description
I3P	GROUP SIGNAL	0.0	Group signal for current inputs
U3P	GROUP SIGNAL	0.0	Group signal for voltage inputs
EXT_LOS_DET	BOOLEAN	0=False	External signal for excitation loss detection

Table continues on next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_TRIP	BOOLEAN	FALSE	Block signal for operate output
BLK_PICKUP	BOOLEAN	FALSE	Block signal for start
FR_TIMER	BOOLEAN	FALSE	Freeze signal for timer

Table 379: 40 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

4.7.3.8 Settings

Table 380: 40 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Diameter	1...6000	%Zn	1	200	Diameter of the Mho diagram
Offset	-1000...1000	%Zn	1	-10	Offset of top of the impedance circle from the R-axis
Displacement	-1000...1000	%Zn	1	0	Displacement of impedance circle centre from the X-axis
Trip delay time	60...200000	ms	10	5000	Trip delay time

Table 381: 40 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	10	3000	Reset delay time
External Los Det Ena	0=Disable 1=Enable			1=Enable	Enable external excitation loss detection
Voltage reversal	0=No 1=Yes			0=No	Rotate voltage signals by 180 degrees
Impedance Meas mode	1=1Phase-to-earth 2=1Phase-to-phase 3=3Phase-to-earth 4=3Phase-to-phase 5=Pos sequence			5=Pos sequence	Select voltage and currents for impedance calculation
Phase Sel for Z Clc	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Voltage phase selection

4.7.3.9 Monitored data

Table 382: 40 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time (in %)
Z_AMPL_A	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase A
Z_ANGLE_A	FLOAT32	-180.00...180.00	deg	Impedance angle phase A
Z_AMPL_B	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase B
Z_ANGLE_B	FLOAT32	-180.00...180.00	deg	Impedance angle phase B
Z_AMPL_C	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase C
Z_ANGLE_C	FLOAT32	-180.00...180.00	deg	Impedance angle phase C
Z_AMPL_AB	FLOAT32	0.00...200.00	xZn	Phase-to-phase A-B impedance amplitude
Z_ANGLE_AB	FLOAT32	-180.00...180.00	deg	Phase-to-phase A-B impedance phase angle
Z_AMPL_BC	FLOAT32	0.00...200.00	xZn	Phase-to-phase B-C impedance amplitude
Z_ANGLE_BC	FLOAT32	-180.00...180.00	deg	Phase-to-phase B-C impedance phase angle
Z_AMPL_CA	FLOAT32	0.00...200.00	xZn	Phase-to-phase C-A impedance amplitude
Z_ANGLE_CA	FLOAT32	-180.00...180.00	deg	Phase-to-phase C-A impedance phase angle
Z1_AMPL	FLOAT32	0.00...200.00	xZn	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180.00...180.00	deg	Positive sequence impedance phase angle
40	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

4.7.3.10 Technical data

Table 383: 40 Technical data

Characteristic	Value
Operation accuracy	At frequency $f = f_n$
	±3.0% of the set value or ±0.2% Zb
Pickup time	Typically 45 ms (±15 ms)
Reset time	<50 ms
Table continues on next page	

Characteristic	Value
Reset ratio	Typically 1.04
Retardation time	Total retardation time when the impedance returns from the operating circle <40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms

Section 5 Protection-related functions

5.1 Three-phase inrush detector INR

5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase inrush detector	INRPHAR	3I2f>	INR

5.1.2 Function block

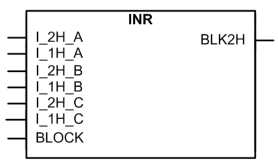


Figure 249: Function block

5.1.3 Functionality

Three-phase inrush detector INR is used to coordinate transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal BLK2H is activated once the numerically derived ratio of second harmonic current I_2H and the fundamental frequency current I_1H exceeds the set value.

The trip time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of an inrush current detection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

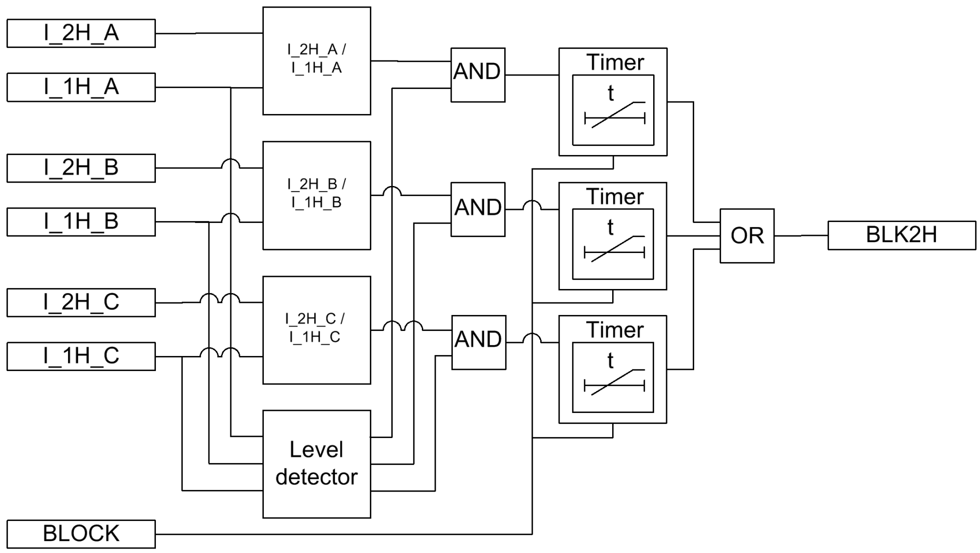


Figure 250: Functional module diagram. I_1H and I_2H represent fundamental and second harmonic values of phase currents.

I_2H/I_1H

This module calculates the ratio of the second harmonic (I_2H) and fundamental frequency (I_1H) phase currents. The calculated value is compared to the set *Pickup value*. If the calculated value exceeds the set *Pickup value*, the module output is activated.

Level detector

The output of the phase specific level detector is activated when the fundamental frequency current I_1H exceeds five percent of the nominal current.

Timer

Once activated, the timer runs until the set *Trip delay time* value. The time characteristic is according to DT. When the trip timer has reached the *Trip delay time* value, the `BLK2H` output is activated. After the timer has elapsed and the inrush situation still exists, the `BLK2H` signal remains active until the I_2H/I_1H ratio drops below the value set for the ratio in all phases, that is, until the inrush situation is over. If the drop-off situation occurs within the trip time up counting, the reset timer is activated. If the drop-off time exceeds *Reset delay time*, the trip timer is reset.

The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the BLOCK input prevents the BLK2H output from being activated.

It is recommended to use the second harmonic and the waveform based inrush blocking from the transformer differential protection function 87T if available.

5.1.5 Application

Transformer protections require high stability to avoid tripping during magnetizing inrush conditions. A typical example of an inrush detector application is doubling the pickup value of an overcurrent protection during inrush detection.

The inrush detection function can be used to selectively block overcurrent and ground-fault function stages when the ratio of second harmonic component over the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

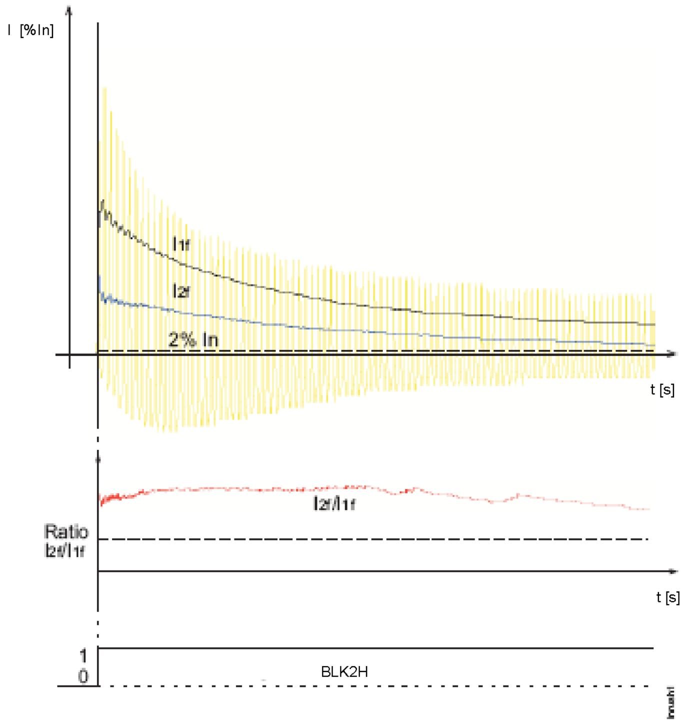


Figure 251: Inrush current in transformer

5.1.6 Signals

Table 384: INR Input signals

Name	Type	Default	Description
I_2H_A	SIGNAL	0	Second harmonic phase A current
I_1H_A	SIGNAL	0	Fundamental frequency phase A current
I_2H_B	SIGNAL	0	Second harmonic phase B current
I_1H_B	SIGNAL	0	Fundamental frequency phase B current
I_2H_C	SIGNAL	0	Second harmonic phase C current
I_1H_C	SIGNAL	0	Fundamental frequency phase C current
BLOCK	BOOLEAN	0=False	Block input status

Table 385: INR Output signals

Name	Type	Description
BLK2H	BOOLEAN	Second harmonic based block

5.1.7 Settings

Table 386: INR Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	5...100	%	1	20	Ratio of the 2. to the 1. harmonic leading to restraint
Trip delay time	20...60000	ms	1	20	Trip delay time

Table 387: INR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Reset delay time	0...60000	ms	1	20	Reset delay time

5.1.8 Monitored data

Table 388: INR Monitored data

Name	Type	Values (Range)	Unit	Description
INR	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.1.9 Technical data

Table 389: INR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement: ±1.5% of the set value or ±0.002 × I_n Ratio I2f/I1f measurement: ±5.0% of the set value
Reset time	+35 ms / -0 ms
Reset ratio	Typically 0.96
Trip time accuracy	20 ms / -10 ms

5.2 Circuit breaker failure protection 50BF

5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker failure protection	CCBRBRF	3I>/Io>BF	50BF

5.2.2 Function block

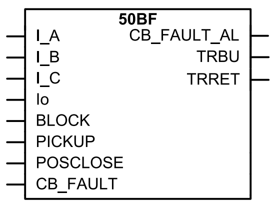


Figure 252: Function block

5.2.3 Functionality

The breaker failure function 50BF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The pickup command is always a default for three-phase operation. 50BF includes a three-phase conditional or unconditional re-trip function, and also a three-phase conditional back-up trip function.

50BF uses the same levels of current detection for both re-trip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a re-trip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the breaker failure protection can be described using a module diagram. All the modules in the diagram are explained in the next sections. Also further information on the retrip and backup trip logics is given in sub-module diagrams.

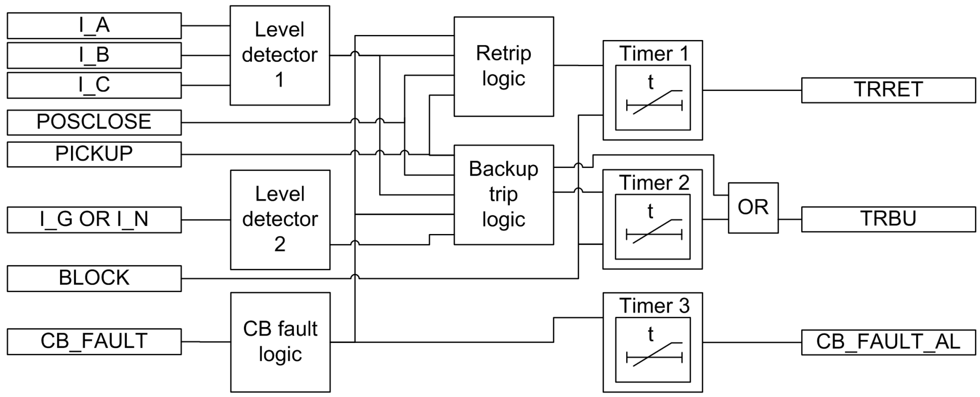


Figure 253: Functional module diagram. I_A, I_B and I_C represent phase currents and Io residual current.

Level detector 1

The measured phase currents are compared phasewise to the set *Current value*. If the measured value exceeds the set *Current value*, the level detector reports the exceeding of the value to the start, retrip and backup trip logics. The parameter should be set low enough so that breaker failure situations with small fault current or high load current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection.

Level detector 2

The measured residual current is compared to the set *Current value Res*. If the measured value exceeds the set *Current value Res*, the level detector reports the exceeding of the value to the pickup and backup trip logics. In high-impedance grounded systems, the residual current at phase-to-ground faults is normally much smaller than the short circuit currents. To detect a breaker failure at single-phase ground faults in these systems, it is necessary to measure the residual current separately. In effectively grounded systems, also the setting of the ground-fault current protection can be chosen at a relatively low current level. The current setting should be chosen in accordance with the setting of the sensitive ground-fault protection.

Start logic

The start logic is used to manage the starting of the timer 1 and timer 2. It also resets the function after the circuit breaker failure is handled. On the rising edge of the `PICKUP` input, the enabling signal is send to the timer 1 and timer 2.

Function resetting is prohibited in 150 ms after TRRET or TRBU is set. The 150 ms time elapse is provided to prevent malfunctioning due to oscillation in the starting signal.

In case the setting *Start latching mode* is set to "Level sensitive", the CCBRBRF is reset immediately after the PICKUP signal is deactivated. The recommended setting value is "Rising edge".

The resetting of the function depends on the *CB failure mode* setting.

- If *CB failure mode* is set to "Current", the resetting logic further depends on the *CB failure trip mode* setting.
    - If *CB failure trip mode* is set to "1 out of 3", the resetting logic requires that the values of all the phase currents drop below the *Current value* setting.
    - If *CB failure trip mode* is set to "1 out of 4", the resetting logic requires that the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.
    - If *CB failure trip mode* is set to "2 out of 4", the resetting logic requires that the values of all the phase currents drop below the *Current value* setting.
- If *CB failure mode* is set to the "Breaker status" mode, the resetting logic requires that the circuit breaker is in the open condition.
- If the *CB failure mode* setting is set to "Both", the resetting logic requires that the circuit breaker is in the open condition and the values of the phase currents and the residual current drops below the *Current value* and *Current value Res* setting respectively.

The activation of the `BLOCK` input resets the function.

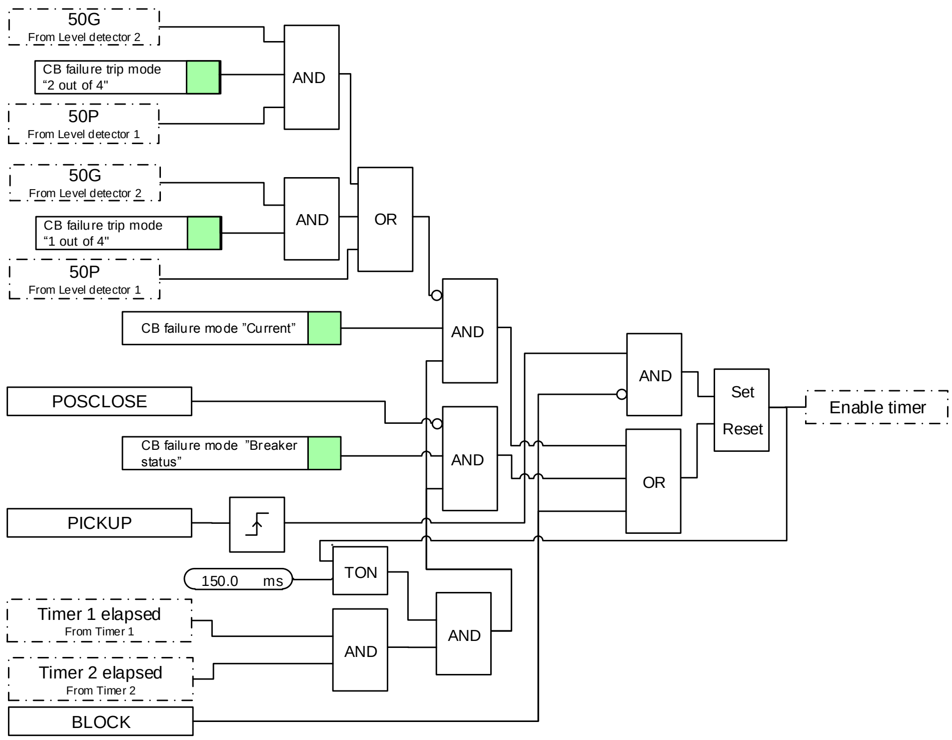


Figure 254: Start logic

Timer 1

Once activated, the timer runs until the set *Retrip time* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the value set with *Retrip time*, the retrip logic is activated. A typical setting is 0...50 ms.

Timer 2

Once activated, the timer runs until the set *CB failure delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*, the backup trip logic is activated. The value of this setting is made as low as possible at the same time as any unwanted operation is avoided. A typical setting is 90 - 150 ms, which is also dependent on the retrip timer.

The minimum time delay for the CB failure delay can be estimated as:

$$CBfailuredelay \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 87)

t_{cbopen}	maximum opening time for the circuit breaker
t_{BFP_reset}	maximum time for the breaker failure protection to detect the correct breaker function (the current criteria reset)
t_{margin}	safety margin

It is often required that the total fault clearance time is less than the given critical time. This time often depends on the ability to maintain transient stability in case of a fault close to a power plant.

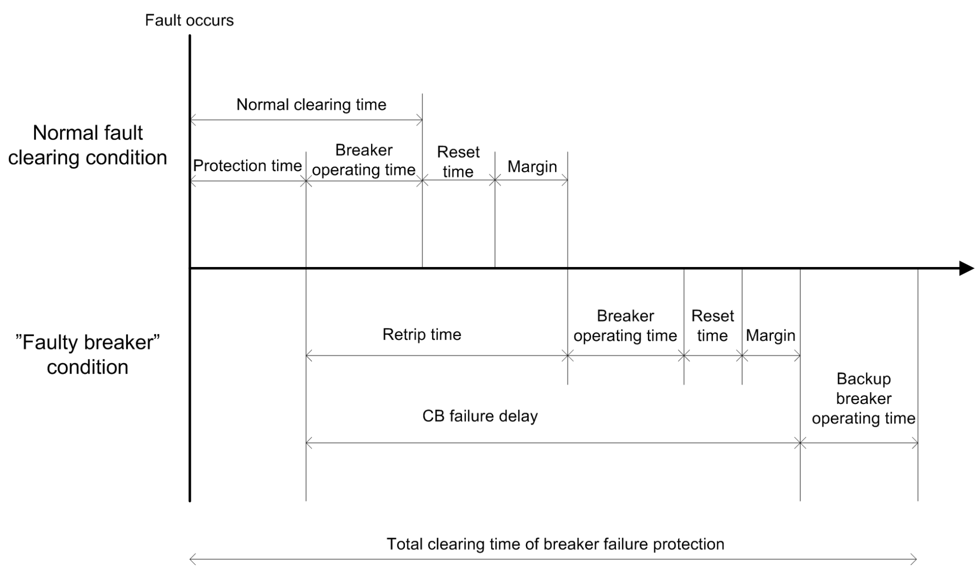


Figure 255: Timeline of the breaker failure protection

Timer 3

This module is activated by the `CB_FAULT` signal. Once activated, the timer runs until the set *CB fault delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value *CB fault delay*, the `CB_FAULT_AL` output is activated. After the set time, an alarm is given so that the circuit breaker can be repaired. A typical value is 5 s.

Retrip logic

The retrip logic provides the `TRRET` output, which can be used to give a retrip signal for the main circuit breaker. Timer 1 activates the retrip logic. The operation of the retrip logic depends on the *CB fail retrip mode* setting.

- The retrip logic is inactive if the *CB fail retrip mode* setting is set to "Disabled".
- If *CB fail retrip mode* is set to the "Current check" mode, the activation of the retrip output TRRET depends on the *CB failure mode* setting.
  - If *CB failure mode* is set to the "Current" mode, TRRET is activated when the value of any phase current exceeds the *Current value* setting. The TRRET output remains active for the time set with the *Trip pulse time* setting or until all phase current values drop below the *Current value* setting, whichever is longer.
  - If *CB failure mode* is set to the "Breaker status" mode, TRRET is activated if the circuit breaker is in the closed position. The TRRET output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
  - If *CB failure mode* is set to "Both", TRRET is activated when either of the "Breaker status" or "Current" mode condition is satisfied.
- If *CB fail retrip mode* is set to the "Without check" mode, TRRET is activated once the timer 1 is activated without checking the current level. The TRRET output remains active for a fixed time set with the *Trip pulse timer* setting.

The activation of the BLOCK input or the CB_FAULT_AL output deactivates the TRRET output.

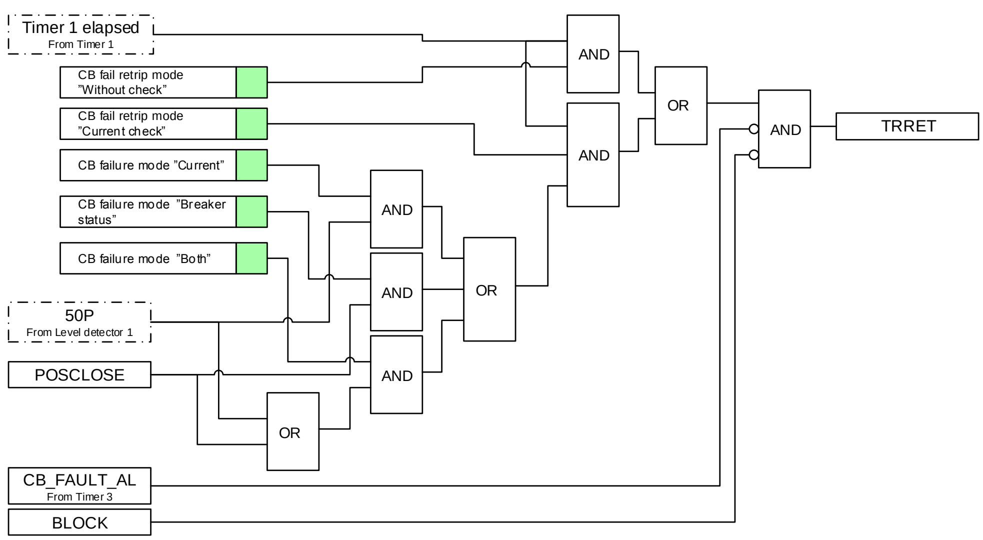


Figure 256: Retrip logic

Backup trip logic

The backup trip logic provides the TRBU output which can be used to trip the upstream backup circuit breaker when the main circuit breaker fails to clear the fault. The backup trip logic is activated by the timer 2 module or timer-enabling signal from the start logic module (rising edge of the PICKUP input detected), and simultaneously CB_FAULT_AL is active. The operation of the backup logic depends on the *CB failure mode* setting.

- If the *CB failure mode* is set to "Current", the activation of TRBU depends on the *CB failure trip mode* setting.
  - If *CB failure trip mode* is set to "1 out of 3", the failure detection is based on any of the phase currents exceeding the *Current value* setting. Once TRBU is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents drop below the *Current value* setting, whichever takes longer.
  - If *CB failure trip mode* is set to "1 out of 4", the failure detection is based on either a phase current or a residual current exceeding the *Current value* or *Current value Res* setting respectively. Once TRBU is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents or residual currents drop below the *Current value* and *Current value Res* setting respectively, whichever takes longer.
  - If *CB failure trip mode* is set to "2 out of 4", the failure detection requires that a phase current and a residual current both exceed the *Current value* and *Current value Res* setting respectively or two phase currents exceeding the *Current value*. Once TRBU is activated, it remains active for the time set with the *Trip pulse time* setting or until the values of all the phase currents drop below the *Current value*, whichever takes longer.

In most applications, "1 out of 3" is sufficient.

- If the *CB failure mode* is set to "Breaker status", the TRBU output is activated if the circuit breaker is in the closed position. Once activated, the TRBU output remains active for the time set with the *Trip pulse time* setting or the time the circuit breaker is in the closed position, whichever is longer.
- If the *CB failure mode* setting is set to "Both", TRBU is activated when the "Breaker status" or "Current" mode conditions are satisfied.

The activation of the BLOCK input deactivates the TRBU output.

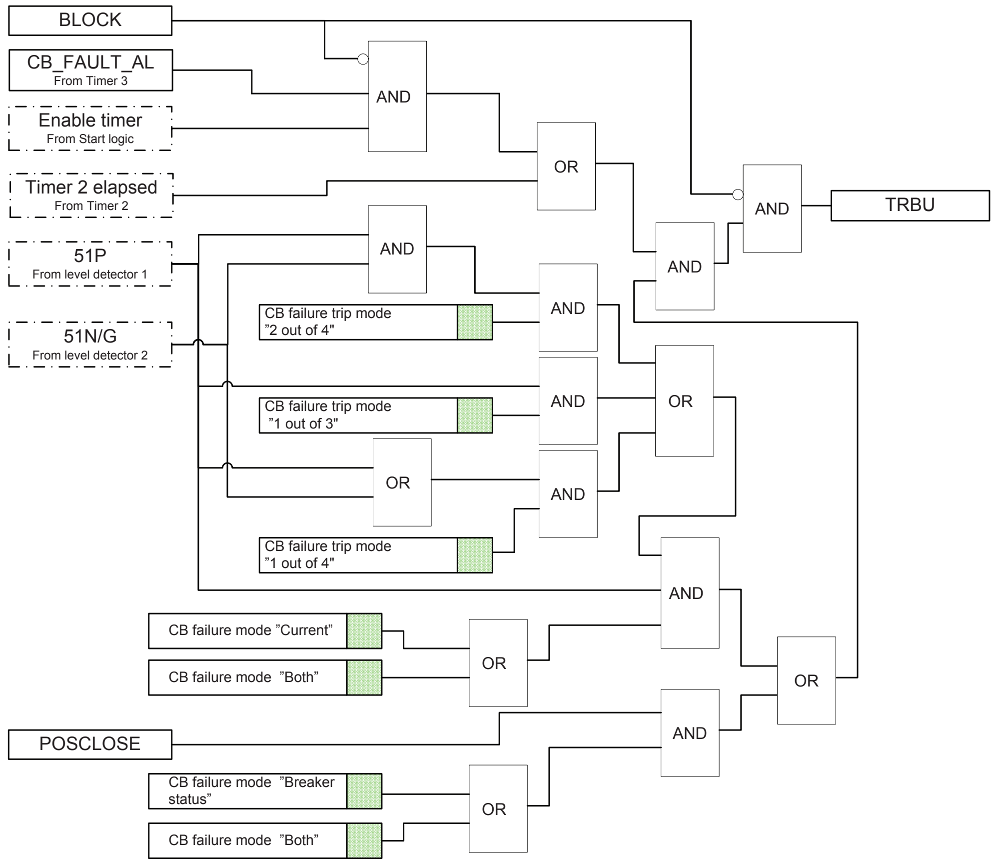


Figure 257: Backup trip logic

5.2.5 Application

The n-1 criterion is often used in the design of a fault clearance system. This means that the fault is cleared even if some component in the fault clearance system is faulty. A circuit breaker is a necessary component in the fault clearance system. For practical and economical reasons, it is not feasible to duplicate the circuit breaker for the protected component, but breaker failure protection is used instead.

The breaker failure function issues a backup trip command to up-stream circuit breakers in case the original circuit breaker fails to trip for the protected component. The detection of a failure to break the current through the breaker is made by measuring the current or by detecting the remaining trip signal (unconditional).

50BF can also retrip. This means that a second trip signal is sent to the protected circuit breaker. The retrip function is used to increase the operational reliability of the breaker.

The function can also be used to avoid backup tripping of several breakers in case mistakes occur during protection relay maintenance and tests.

50BF is initiated by operating different protection functions or digital logics inside the protection relay. It is also possible to initiate the function externally through a binary input.

50BF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the pickup input is set to true. When the pre-defined time setting is exceeded, 50BF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The backup trip timer is also initiated at the same time as the retrip timer. If 50BF detects a failure in tripping the fault within the set backup delay time, which is longer than the retrip time, it sends a backup trip signal to the chosen backup breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The backup trip always includes a current check criterion. This means that the criterion for a breaker failure is that there is a current flow through the circuit breaker after the set backup delay time.

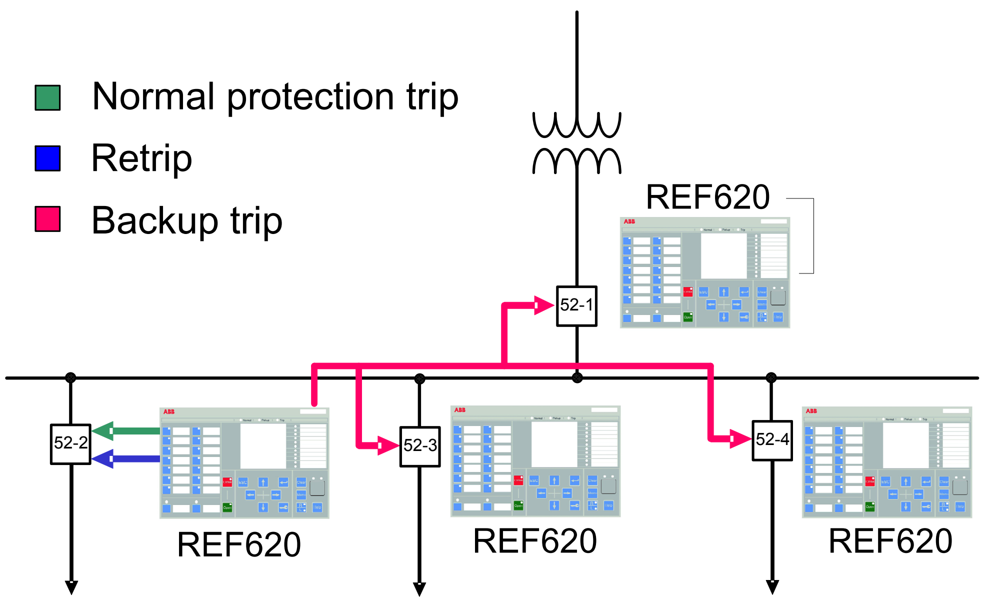


Figure 258: Typical breaker failure protection scheme in distribution substations

5.2.6 Signals

Table 390: 50BF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_N	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block CBFP operation
PICKUP	BOOLEAN	0=False	CBFP pickup command
POSCLOSE	BOOLEAN	0=False	CB in closed position
CB_FAULT	BOOLEAN	0=False	CB faulty and unable to trip

Table 391: 50BF Output signals

Name	Type	Description
CB_FAULT_AL	BOOLEAN	Delayed CB failure alarm
TRBU	BOOLEAN	Backup trip
TRRET	BOOLEAN	Retrip

5.2.7 Settings

Table 392: 50BF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Current value	0.05...2.00	xIn	0.05	0.30	Operating phase current
Current value Res	0.05...1.00	xIn	0.05	0.30	Operating residual current
CB failure trip mode	1=2 out of 4 2=1 out of 3 3=1 out of 4			2=1 out of 3	Backup trip current check mode
CB failure mode	1=Current 2=Breaker status 3=Both			1=Current	Operating mode of function
CB fail retrip mode	1=Disabled 2=Without Check 3=Current check			1=Disabled	Operating mode of retrip logic
Retrip time	0...60000	ms	10	20	Delay timer for retrip
CB failure delay	0...60000	ms	10	150	Delay timer for backup trip
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
CB fault delay	0...60000	ms	10	5000	Circuit breaker faulty delay
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Phase current measurement mode of function
Trip pulse time	0...60000	ms	10	150	Pulse length of retrip and backup trip outputs

5.2.8 Monitored data

Table 393: 50BF Monitored data

Name	Type	Values (Range)	Unit	Description
50BF	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.2.9 Technical data

Table 394: 50BF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Trip time accuracy	±1.0% of the set value or ±20 ms

5.3 Master trip 86/94

5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Master trip	TRPPTRC	Master Trip	86/94

5.3.2 Function block

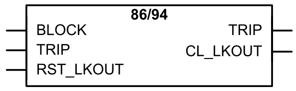


Figure 259: Function block

5.3.3 Functionality

The master trip function 86/94 is intended to be used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The user can set the minimum trip pulse length when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

When the 86/94 function is disabled, all trip outputs which are intended to go through the function to the circuit breaker trip coil are blocked!

The operation of the tripping logic function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

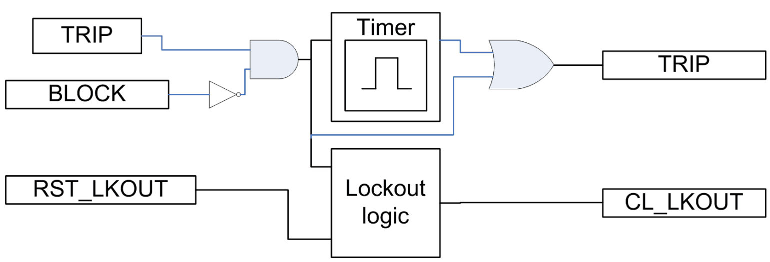


Figure 260: Functional module diagram

Timer

The duration of a trip output signal from 86/94 can be adjusted with the *Trip pulse time* setting when the "Non-latched" operation mode is used. The pulse length should be long enough to secure the opening of the breaker. For three-pole tripping, 86/94 has a single input TRIP, through which all trip output signals are routed from the protection functions within the protection relay, or from external protection functions via one or more of the protection relay's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the protection relay's binary outputs, and also to other functions within the protection relay requiring this signal.

The BLOCK input blocks the TRIP output and resets the timer.

Lockout logic

The CL_LKOUT and TRIP outputs can be blocked with the BLOCK input.

Table 395: Operation modes for the 86/94 trip output

Mode	Operation
Non-latched	The *Trip pulse length* parameter gives the minimum pulse length for TRIP
Latched	TRIP is latched ; both local and remote clearing is possible.
Lockout	TRIP is locked and can be cleared only locally via menu or the RST_LKOUT input.

5.3.5 Application

All trip signals from different protection functions are routed through the trip logic. The most simplified application of the logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the protection relay is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, 86/94 can block the 52 closing.

The 86/94 function is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used. The two instances of the PTRC function are identical, only the names of the functions, 86/94-1 and 86/94-2, are different. Therefore, all references made to only 86/94-1 apply to 86/94-2 as well.

The inputs from the protection functions are connected to the TRIP input. Usually, a logic block OR is required to combine the different function outputs to this input. The TRIP output is connected to the digital outputs on the IO board. This signal can also be used for other purposes within the protection relay, for example when starting the breaker failure protection.

86/94 is used for simple three-phase tripping applications.

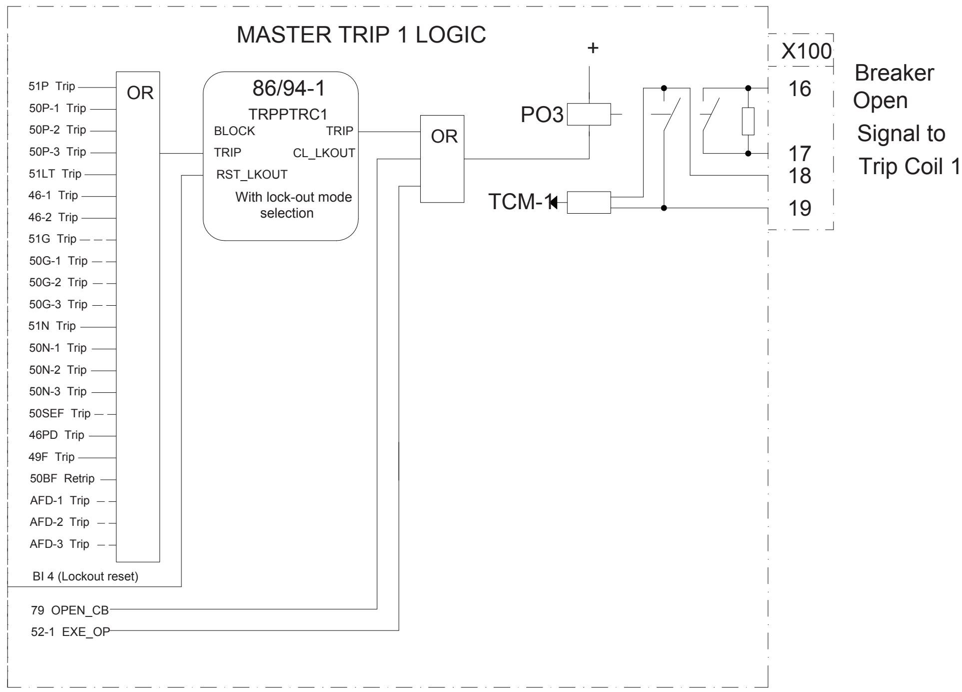


Figure 261: Typical 86/94 connection

5.3.6 Signals

Table 396: 86/94 Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block of function
TRIP	BOOLEAN	0=False	Trip
RST_LKOUT	BOOLEAN	0=False	Input for resetting the circuit breaker lockout function

Table 397: 86/94 Output signals

Name	Type	Description
TRIP	BOOLEAN	General trip output signal
CL_LKOUT	BOOLEAN	Circuit breaker lockout output (set until reset)

5.3.7 Settings

Table 398: 86/94 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Trip pulse time	20...60000	ms	1	150	Minimum duration of trip output signal
Trip output mode	1=Non-latched 2=Latched 3=Lockout			1=Non-latched	Select the operation mode for trip output

5.3.8 Monitored data

Table 399: 86/94 Monitored data

Name	Type	Values (Range)	Unit	Description
86/94	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.4 High-impedance fault detection HIZ

5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance fault detection	PHIZ	PHIZ	HIZ

5.4.2 Function block

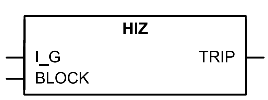


Figure 262: Function block

5.4.3 Functionality

A small percentage of ground faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a substantial threat to humans and properties; people can touch or get close to conductors carrying large amounts of energy.

ABB has developed a patented technology (US Patent 7,069,116 B2 June 27, 2006, US Patent 7,085,659 B2 August 1, 2006) to detect a high-impedance fault.

The high-impedance fault detection function HIZ also contains a blocking functionality. It is possible to block function outputs, if desired.

5.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

HIZ uses a multi-algorithm approach. Each algorithm uses various features of ground currents to detect a high-impedance fault.

Although the HIZ algorithm is very sophisticated, the setting required to operate the function is simple. The *Security Level* setting, with the setting range of 1 to 10, is set to strike a balance between the extremes of security and dependability which together constitute the reliability of any system. The setting value “10” is more secure than “1”.

The higher the *Security Level* setting, the lower the probability of false detection, but the system might miss out some genuine fault. On the other hand, a lower setting would make the system operate more dependably for high-impedance faults in the line, but the operation is more likely for other transients in the system.

It is hence recommended to set the value midway to “5” initially. Based on experience and confidence gained in a particular application, the setting can be moved either side.

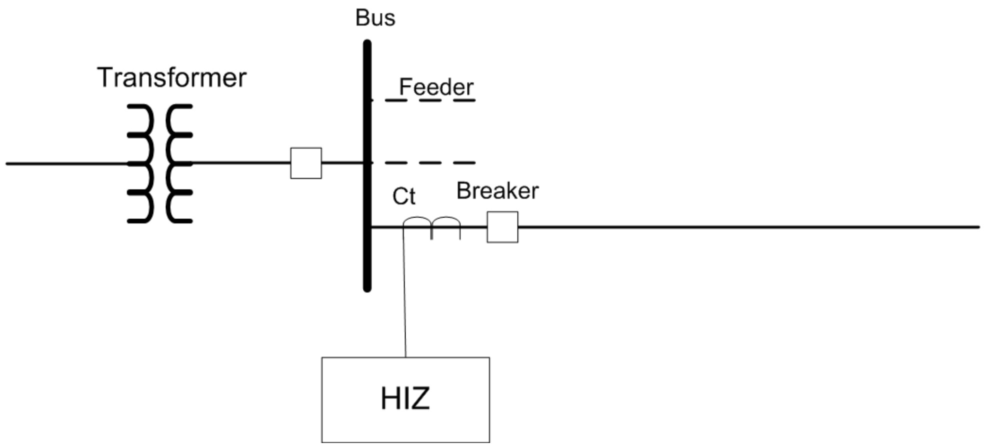


Figure 263: Electrical power system equipped with HIZ

Power system signals are acquired, filtered and then processed by individual high-impedance fault detection algorithm. The results of these individual algorithms are further processed by a decision logic to provide the detection decision. The decision logic can be modified depending on the application requirement.

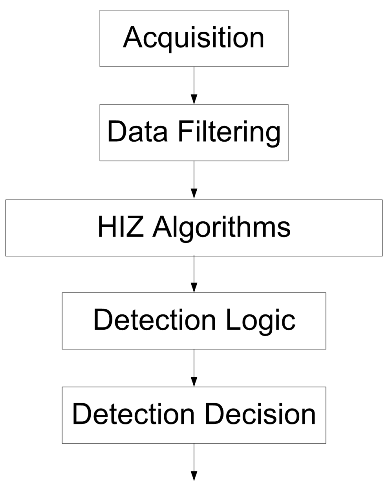


Figure 264: Block diagram of HIZ

HIZ is based on algorithms that use line residual current signatures which are considered non-stationary, temporally volatile and of various burst duration. All harmonic and non-harmonic components within the available data window can play a vital role in the high-impedance fault detection. A major challenge is to develop a data model that acknowledges that high-impedance faults could take place at any time within the observation window of the signal and could be delayed randomly and attenuated substantially. The model is motivated by extensive research, actual experimental observations in the laboratory, field testing and what traditionally represents an accurate depiction of a non-stationary signal with a time-dependent spectrum.

Figure 265: Validation of HIZ on gravel

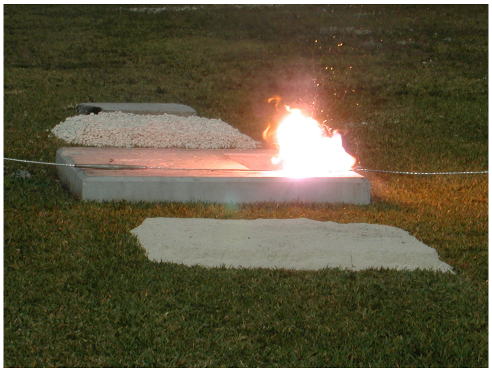


Figure 266: Validation of HIZ on concrete

Figure 267: Validation of HIZ on sand

Figure 268: Validation of HIZ on grass

5.4.5 Application

Electric power lines experience faults for many reasons. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service.

Most of the electrical network faults are ground faults. Conventional protection systems based on overcurrent, impedance or other principles are suitable for detecting relatively low-impedance faults which have a relatively large fault current.

However, a small percentage of the ground faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a considerable threat to people and property. The IEEE Power System Relay Committee working group on High Impedance Fault Detection Technology defines High Impedance Faults as those that 'do not produce enough fault current to be detectable by conventional overcurrent relays or fuses.

High-impedance fault (HIZ) detection requires a different approach than that for conventional low-impedance faults. Reliable detection of HIZ provides safety to humans and animals. HIZ detection can also prevent fire and minimize property damage. ABB has developed innovative technology for high-impedance fault detection with over seven years of research resulting in many successful field tests.

5.4.6 Signals

Table 400: HIZ Input signals

Name	Type	Default	Description
IG	SIGNAL	0	Line residual current measured using SEF CT or phase CT
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 401: HIZ Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip

5.4.7 Settings

Table 402: HIZ Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Security level	1...10		1	5	Security Level

Table 403: HIZ Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=Enable 5=Disable			5=Disable	Operation Disable / Enable
System type	1=Grounded 2=Ungrounded			1=Grounded	System Type

5.4.8 Monitored data

Table 404: HIZ Monitored data

Name	Type	Values (Range)	Unit	Description
Position	Enum	0=intermediate 1=open 2=closed 3=faulty		Position
HIZ	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.5 Arc protection AFD

5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Arc protection	ARCSARC	ARC	AFD

5.5.2 Function block

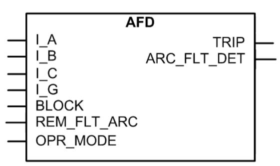


Figure 269: Function block

5.5.3 Functionality

The arc protection AFD detects arc situations in air insulated metal-clad switchgears caused by, for example, human errors during maintenance or insulation breakdown during operation.

The function detects light from an arc either locally or via a remote light signal. The function also monitors phase and ground currents to be able to make accurate decisions on ongoing arcing situations.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of arc protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

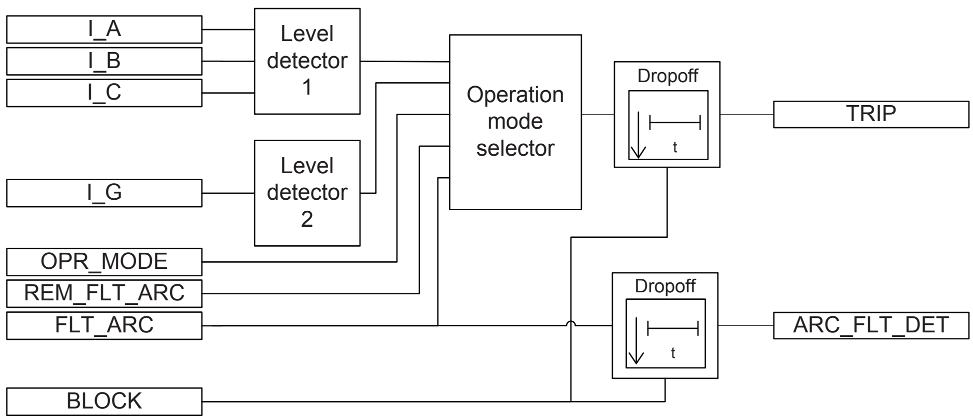


Figure 270: Functional module diagram. I_A, I_B and I_C represent phase currents.

Level detector 1

The measured phase currents are compared phasewise to the set *Phase pickup value*. If the measured value exceeds the set *Phase pickup value*, the level detector reports the exceeding of the value to the operation mode selector.

Level detector 2

The measured ground currents are compared to the set *Ground pickup value*. If the measured value exceeds the set *Ground pickup value*, the level detector reports the exceeding of the value to the operation mode selector.

Operation mode selector

Depending on the *Operation mode* setting, the operation mode selector makes sure that all required criteria are fulfilled for a reliable decision of an arc fault situation. The user can select either "Light+current", "Light only" or "BI controlled" operation mode. The operation is based on both current and light information in “Light+current” mode, on light information only in “Light only” mode or on remotely controlled information in “BI controlled” mode. When the "BI controlled" mode is in use and the `OPR_MODE` input is activated, the operation of the function is based on light information only. When the OPR_MODE input is deactivated, the operation of the function is based on both light and current information. When the required criteria are met, the drop-off timer is activated.

Drop-off timer

Once activated, the drop-off timer remains active until the input is deactivated or at least during the drop-off time. The BLOCK signal can be used to block the TRIP signal or the light signal output ARC_FLT_DET.

5.5.5 Application

The arc protection can be realized as a stand-alone function in a single relay or as a station-wide arc protection, including several protection relays. If realized as a station-wide arc protection, different tripping schemes can be selected for the operation of the circuit breakers of the incoming and outgoing feeders. Consequently, the relays in the station can, for example, be set to trip the circuit breaker of either the incoming or the outgoing feeder, depending on the fault location in the switchgear. For maximum safety, the relays can be set to always trip both the circuit breaker of the incoming feeder and that of the outgoing feeder.

The arc protection consists of:

- Optional arc light detection hardware with automatic backlight compensation for lens type sensors
- Light signal output ARC_FLT_DET for routing indication of locally detected light signal to another relay
- Protection stage with phase- and ground-fault current measurement.

The function detects light from an arc either locally or via a remote light signal. Locally, the light is detected by lens sensors connected to the inputs Light sensor 1, Light sensor 2, or Light sensor 3 on the communication module of the relay. The lens sensors can be placed, for example, in the busbar compartment, the breaker compartment, and the cable compartment of the metal-clad cubicle.

The light detected by the lens sensors is compared to an automatically adjusted reference level. Light sensor 1, Light sensor 2, and Light sensor 3 inputs have their own reference levels. When the light exceeds the reference level of one of the inputs, the light is detected locally. When the light has been detected locally or remotely and, depending on the operation mode, if one or several phase currents exceed the set *Phase pickup value* limit, or the ground-fault current the set *Ground pickup value* limit, the arc protection stage generates a trip signal. The stage is reset in 30 ms, after all three-phase currents and the ground-fault current have fallen below the set current limits.

The light signal output from an arc protection stage ARC_FLT_DET is activated immediately in the detection of light in all situations. A station-wide arc protection is realized by routing the light signal output to an output contact connected to a binary input of another relay, or by routing the light signal output through the communication to an input of another relay.

It is possible to block the tripping and the light signal output of the arc protection stage with a binary input or a signal from another function block.

Cover unused inputs with dust caps.

Arc protection with one protection relay

In installations, with limited possibilities to realize signalling between protection relays protecting incoming and outgoing feeders, or if only the protection relay for the incoming feeder is to be exchanged, an arc protection with a lower protective level can be achieved with one protection relay. An arc protection with one protection relay only is realized by installing two arc lens sensors connected to the protection relay protecting the incoming feeder to detect an arc on the busbar. In arc detection, the arc protection stage trips the circuit breaker of the incoming feeder. The maximum recommended installation distance between the two lens sensors in the busbar area is six meters and the maximum distance from a lens sensor to the end of the busbar is three meters.

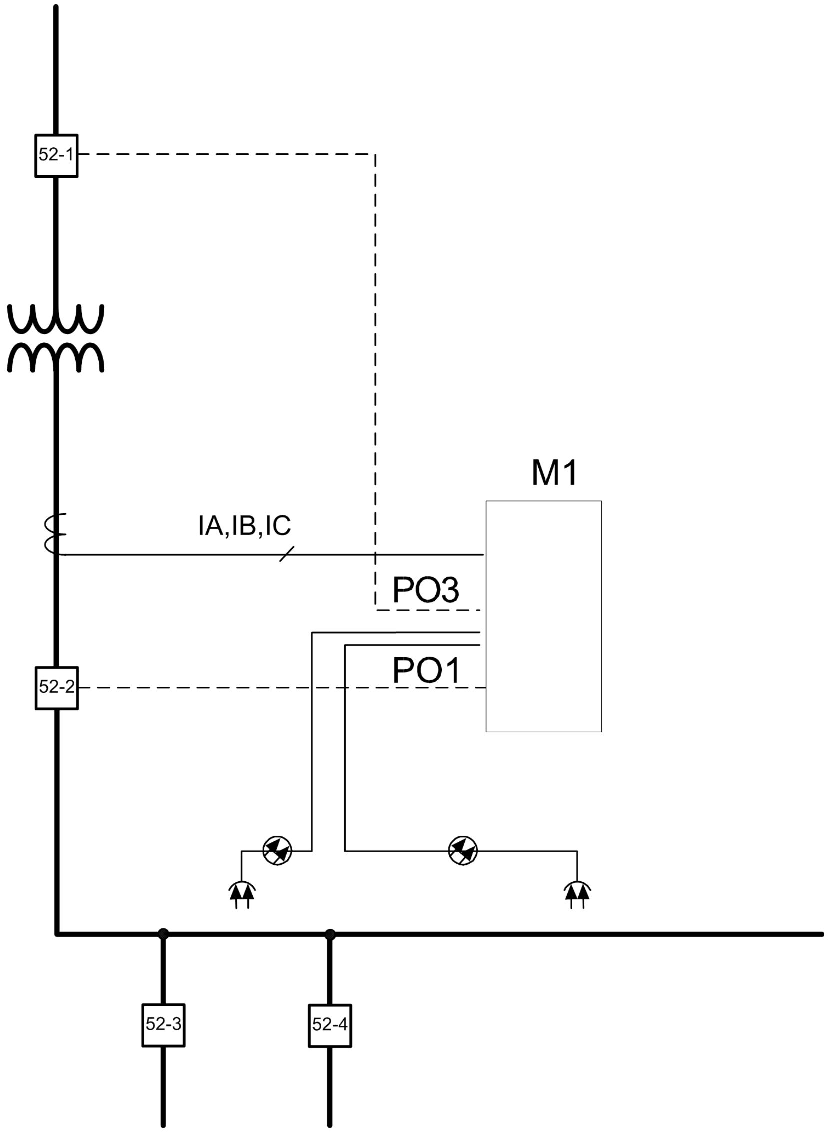


Figure 271: Arc protection with one protection relay

Arc protection with several protection relays

When using several protection relays, the protection relay protecting the outgoing feeder trips the circuit breaker of the outgoing feeder when detecting an arc at the cable terminations. If the protection relay protecting the outgoing feeder detects an arc on the busbar or in the breaker compartment via one of the other lens sensors, it will generate a signal to the protection relay protecting the incoming feeder. When detecting the signal, the protection relay protecting the incoming feeder trips the circuit breaker of the incoming feeder and generates an external trip signal to all protection relays protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders. For maximum safety, the protection relays can be configured to trip all the circuit breakers regardless of where the arc is detected.

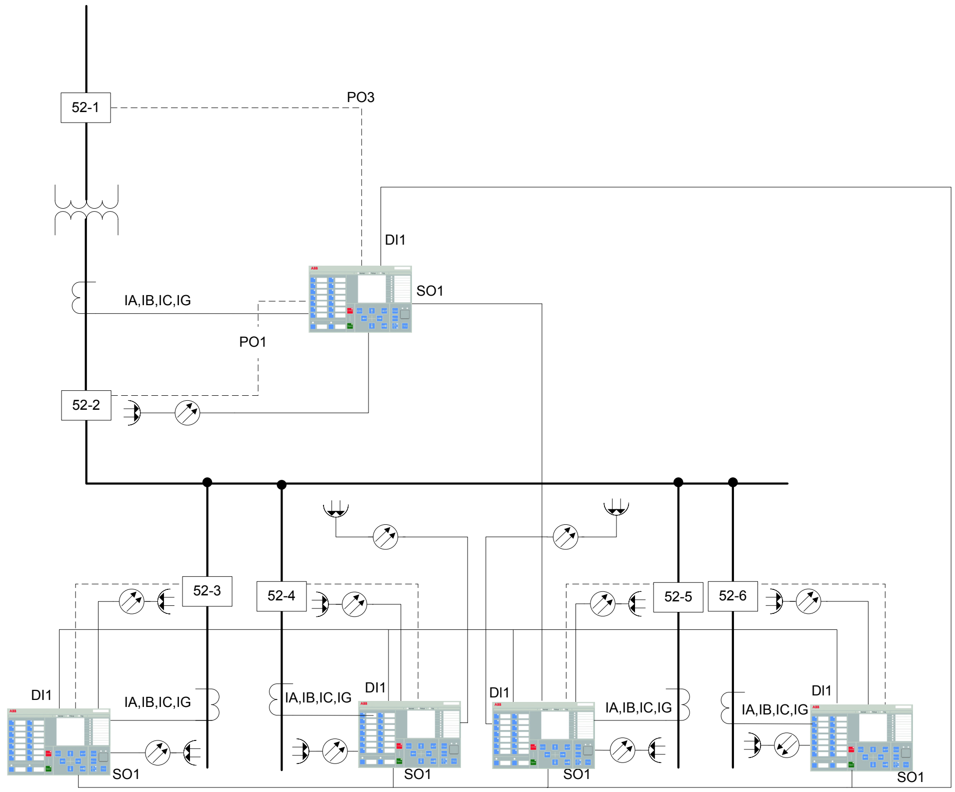


Figure 272: Arc protection with several protection relays

Arc protection with several protection relays and a separate arc protection system

When realizing an arc protection with both protection relays and a separate arc protection system, the cable terminations of the outgoing feeders are protected by protection relays using one lens sensor for each protection relay. The busbar and the incoming feeder are protected by the sensor loop of the separate arc protection system. With arc detection at the cable terminations, an protection relay trips the circuit breaker of the outgoing feeder. However, when detecting an arc on the busbar, the separate arc protection system trips the circuit breaker of the incoming feeder and generates an external trip signal to all protection relays protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders.

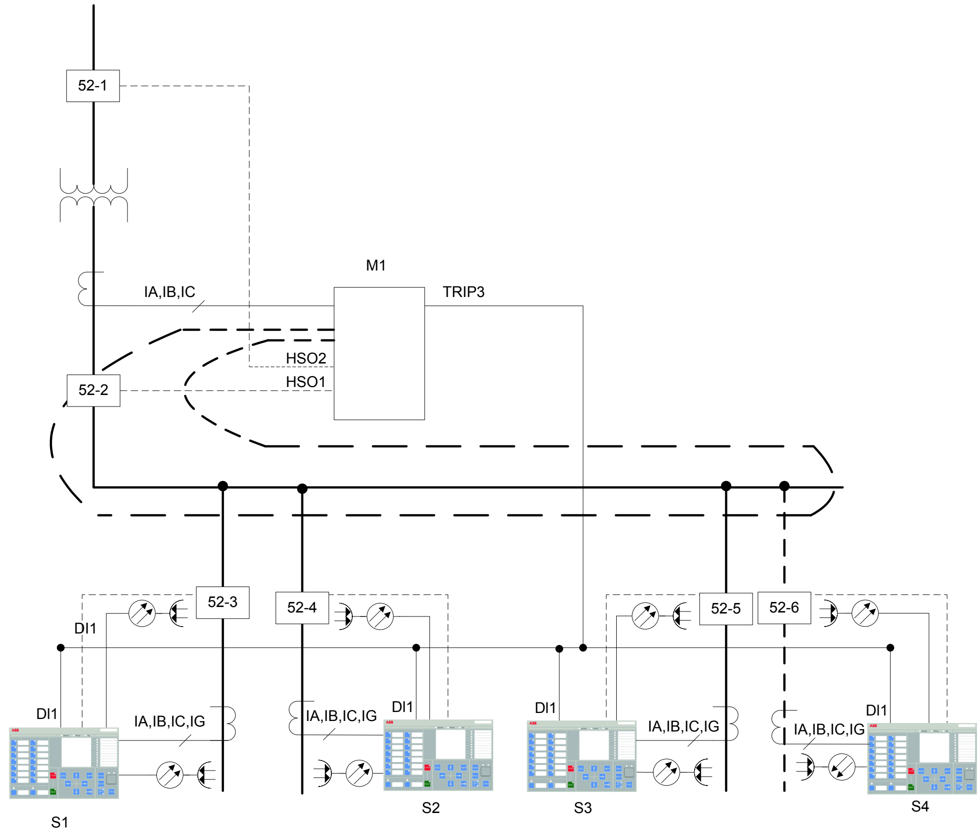


Figure 273: Arc protection with several protection relays and a separate arc protection system

5.5.6 Signals

Table 405: AFD Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_G	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs
REM_FLT_ARC	BOOLEAN	0=False	Remote Fault arc detected
OPR_MODE	BOOLEAN	0=False	Operation mode input

Table 406: AFD Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
ARC_FLT_DET	BOOLEAN	Fault arc detected=light signal output

5.5.7 Settings

Table 407: AFD Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Phase pickup value	0.50...40.00	xIn	0.01	2.50	Operating phase current
Ground pickup value	0.05...8.00	xIn	0.01	0.20	Operating residual current
Operation mode	1=Light+current 2=Light only 3=BI controlled			1=Light+current	Operation mode

Table 408: AFD Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable

5.5.8 Monitored data

Table 409: AFD Monitored data

Name	Type	Values (Range)	Unit	Description
AFD	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.5.9 Technical data

Table 410: AFD Technical data

<table>
<tr><th colspan="2">Characteristic</th><th colspan="3">Value</th></tr>
<tr><td colspan="2">Operation accuracy</td><td colspan="3">±3% of the set value or ±0.01 × I_n</td></tr>
<tr><td rowspan="2">Trip time</td><td rowspan="2">Operation mode = "Light only"</td><td>Minimum</td><td>Typical</td><td>Maximum</td></tr>
<tr><td>9 ms</td><td>10 ms</td><td>12 ms</td></tr>
<tr><td colspan="2">Reset time</td><td colspan="3"><40 ms</td></tr>
<tr><td colspan="2">Reset ratio</td><td colspan="3">Typically 0.96</td></tr>
</table>

5.6 RTD based thermal protection 38

5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
RTD based thermal protection	MAPGAPC	ThA> ThB>	38

5.6.2 Function block

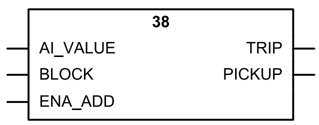


Figure 274: Function block

5.6.3 Functionality

The RTD based thermal protection function 38 is used as a general protection with many possible application areas as it has flexible measuring and setting facilities. The function can be used as an under- or overprotection with a settable absolute hysteresis limit. The function operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself, if desired.

If the quality of the input signal is not good, the function is blocked. Also, in case several RTD inputs are connected through the MAX3 function block into the 38 input - quality of all RTD inputs must be good.

5.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of 38 can be described using a module diagram. All the modules in the diagram are explained in the next sections.

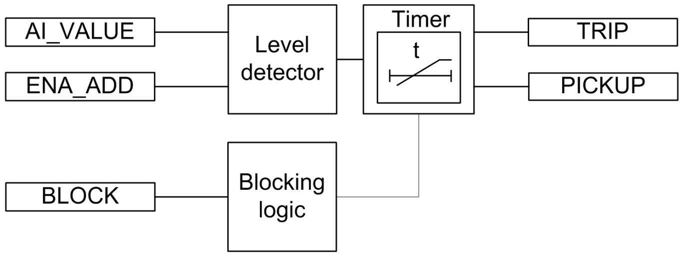


Figure 275: Functional module diagram

Level detector

The level detector compares AI_VALUE to the *Start value* setting. The *Operation mode* setting defines the direction of the level detector.

Table 411: Operation mode types

Operation Mode	Description
"Under"	If the input signal AI_VALUE is lower than the set value of the "Start value" setting, the level detector enables the timer module.
"Over"	If the input signal AI_VALUE exceeds the set value of the *Start value* setting, the level detector enables the timer module.

The *Absolute hysteresis* setting can be used for preventing unnecessary oscillations if the input signal is slightly above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area. If the ENA_ADD input is activated, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. The resulting threshold value for the comparator can be increased or decreased depending on the sign and value of the *Start value Add* setting.

Timer

Once activated, the timer activates the PICKUP output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the TRIP output is activated. If the pickup condition disappears before the module trips, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the PICKUP output is deactivated.

The timer calculates the pickup duration value PICKUP_DUR, which indicates the ratio of the pickup situation and the set trip time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration/System/Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the trip timer is frozen to the prevailing value, but the TRIP output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block TRIP output" mode, the function operates normally but the TRIP output is not activated.

5.6.5 Application

The function block can be used for any general analog signal protection, either underprotection or overprotection. The setting range is wide, allowing various protection schemes for the function. Thus, the absolute hysteresis can be set to a value that suits the application.

The temperature protection using the RTD sensors can be done using the function block. The measured temperature can be fed from the RTD sensor to the function input that detects too high temperatures in the motor bearings or windings, for example. When the ENA_ADD input is enabled, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. This allows a temporal increase or decrease of the level detector depending on the sign and value of the *Start value Add* setting, for example, when the emergency start is activated. If, for example, *Start value* is 100, *Start value Add* is 20 and the ENA_ADD input is active, the input signal needs to rise above 120 before MAP trips.

5.6.6 Signals

Table 412: 38 Input signals

Name	Type	Default	Description
AI_VALUE	FLOAT32	0.0	Analogue input value
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_ADD	BOOLEAN	0=False	Enable pickup added

Table 413: 38 Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

5.6.7 Settings

Table 414: 38 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup value	-10000.0...10000.0		0.1	100	Pickup value
Pickup value Add	-100.0...100.0		0.1	0.0	Pickup value Add
Trip delay time	0...200000	ms	100	0	Trip delay time

Table 415: 38 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Operation mode	1=Over 2=Under			1=Over	Operation mode
Reset delay time	0...60000	ms	100	0	Reset delay time
Absolute hysteresis	0.01...100.00		0.01	0.10	Absolute hysteresis for operation

5.6.8 Monitored data

Table 416: 38 Monitored data

Name	Type	Values (Range)	Unit	Description
PICKUP_DUR	FLOAT32	0.00...100.00	%	Ratio of pickup time / trip time
MAP	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

5.6.9 Technical data

Table 417: 38 Technical data

Characteristic	Value
Operation accuracy	±1.0% of the set value or ±20 ms

Section 6 Supervision functions

6.1 Circuit-breaker condition monitoring 52CM

6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker condition monitoring	SSCBR	CBCM	52CM

6.1.2 Function block

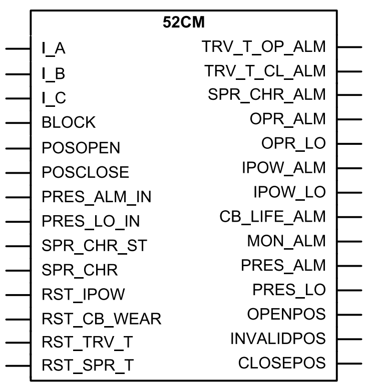


Figure 276: Function block

6.1.3 Functionality

The circuit breaker condition monitoring function 52CM is used to monitor different parameters of the circuit breaker. The breaker requires maintenance when the number of operations has reached a predefined value. For proper functioning of the circuit breaker, it is essential to monitor the circuit breaker operation, spring charge indication, breaker wear, travel time, number of operation cycles and accumulated energy. The energy is calculated from the measured input currents as a sum of $I^y t$ values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

6.1.4 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring sub-functions. The functions can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”. The operation counters are cleared when *Operation* is set to “Disable”.

The operation of the functions can be described with a module diagram. All the modules in the diagram are explained in the next sections.

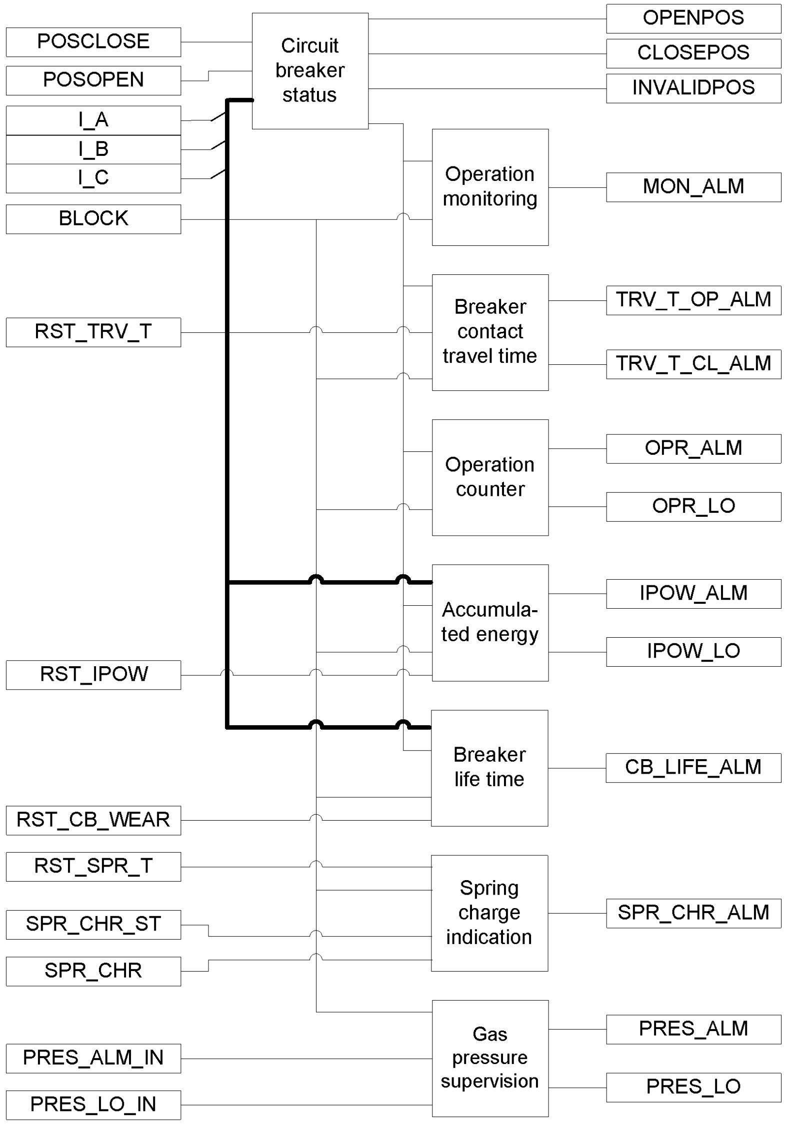


Figure 277: Functional module diagram

6.1.4.1 Circuit breaker status

The Circuit breaker status sub-function monitors the position of the circuit breaker, that is, whether the breaker is in open, closed or invalid position. The operation of the breaker status monitoring can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

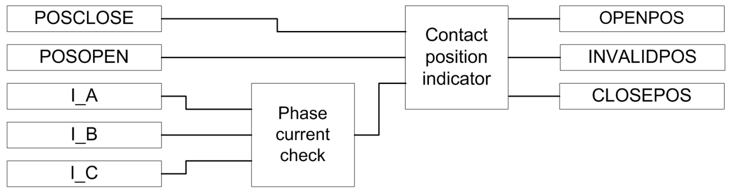


Figure 278: Functional module diagram for monitoring circuit breaker status

Phase current check

This module compares the three phase currents to the setting *Acc stop current*. If the current in a phase exceeds the set level, information about the phase is reported to the contact position indicator module.

Contact position indicator

The OPENPOS output is activated when the auxiliary input contact POSCLOSE is FALSE, the POSOPEN input is TRUE and all the phase currents are below the setting *Acc stop current*.

The CLOSEPOS output is activated when the auxiliary POSOPEN input is FALSE and the POSCLOSE input is TRUE.

The INVALIDPOS output is activated when both the auxiliary contacts have the same value, that is, both are in the same logical level, or if the auxiliary input contact POSCLOSE is FALSE and the POSOPEN input is TRUE and any of the phase currents exceed the setting Acc stop current.

The status of the breaker is indicated by the binary outputs OPENPOS, INVALIDPOS and CLOSEPOS for open, invalid and closed position respectively.

6.1.4.2 Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring subfunction is to indicate if the circuit breaker has not been operated for a long time.

The operation of the circuit breaker operation monitoring can be described with a module diagram. All the modules in the diagram are explained in the next sections.

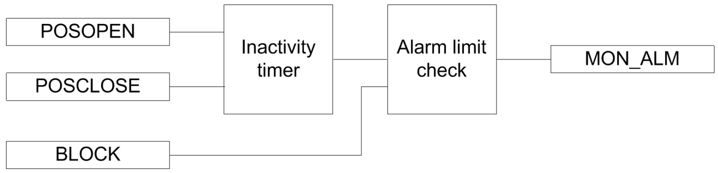


Figure 279: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

Inactivity timer

The module calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. The calculation is done by monitoring the states of the POSOPEN and POSCLOSE auxiliary contacts.

The inactive days INA_DAYS is available in the monitored data view. It is also possible to set the initial inactive days with the *Ini inactive days* parameter.

Alarm limit check

When the inactive days exceed the limit value defined with the *Inactive Alm days* setting, the MON_ALM alarm is initiated. The time in hours at which this alarm is activated can be set with the *Inactive Alm hours* parameter as coordinates of UTC. The alarm signal MON_ALM can be blocked by activating the binary input BLOCK.

6.1.4.3 Breaker contact travel time

The Breaker contact travel time module calculates the breaker contact travel time for the closing and opening operation. The operation of the breaker contact travel time measurement can be described with a module diagram. All the modules in the diagram are explained in the next sections.

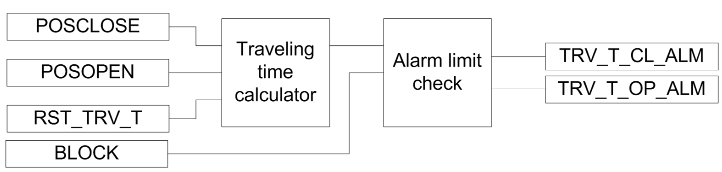


Figure 280: Functional module diagram for breaker contact travel time

Traveling time calculator

The opening travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. The travel time is also measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

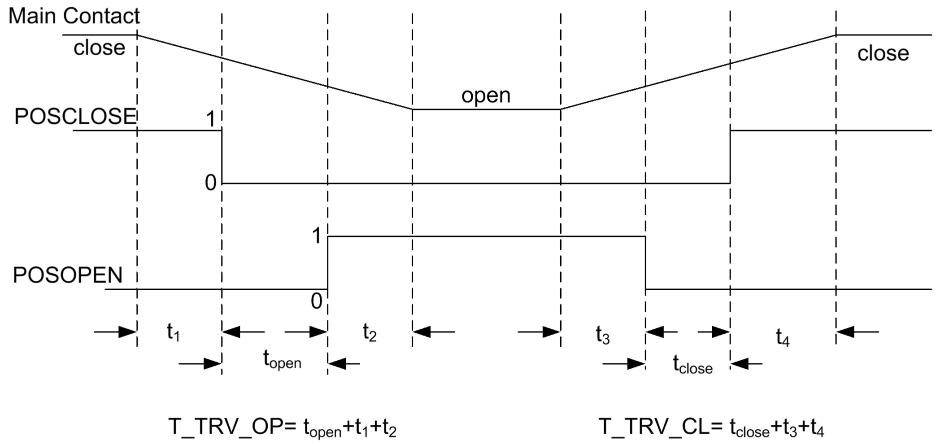


Figure 281: Travel time calculation

There is a time difference t_1 between the start of the main contact opening and the opening of the POSCLOSE auxiliary contact. Similarly, there is a time gap t_2 between the time when the POSOPEN auxiliary contact opens and the main contact is completely open. To incorporate the time $t_1 + t_2$, a correction factor needs to be added with t_{open} to get the actual opening time. This factor is added with the *Opening time Cor* (= $t_1 + t_2$) setting. The closing time is calculated by adding the value set with the *Closing time Cor* ($t_3 + t_4$) setting to the measured closing time.

The last measured opening travel time T_TRV_OP and the closing travel time T_TRV_CL are available in the monitored data view on the LHMI or through tools via communications.

Alarm limit check

When the measured opening travel time is longer than the value set with the *Open alarm time* setting, the TRV_T_OP_ALM output is activated. Respectively, when the measured closing travel time is longer than the value set with the *Close alarm time* setting, the TRV_T_CL_ALM output is activated.

It is also possible to block the TRV_T_CL_ALM and TRV_T_OP_ALM alarm signals by activating the BLOCK input.

6.1.4.4 Operation counter

The operation counter subfunction calculates the number of breaker operation cycles. The opening and closing operations are both included in one operation cycle. The operation counter value is updated after each opening operation.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

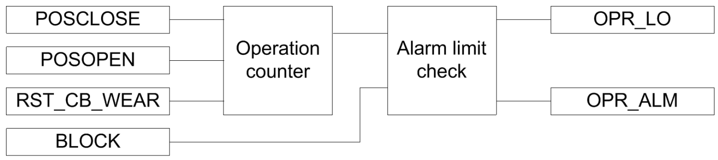


Figure 282: Functional module diagram for counting circuit breaker operations

Operation counter

The operation counter counts the number of operations based on the state change of the binary auxiliary contacts inputs POSCLOSE and POSOPEN.

The number of operations NO_OPR is available in the monitored data view on the LHMI or through tools via communications. The old circuit breaker operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter and by setting the parameter *CBCMx rem.life* in the clear menu from WHMI or LHMI.

Alarm limit check

The OPR_ALM operation alarm is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the *Lockout Op number* setting, the OPR_LO output is activated.

The binary outputs OPR_LO and OPR_ALM are deactivated when the BLOCK input is activated.

6.1.4.5 Accumulation of $I^y t$

Accumulation of the $I^y t$ module calculates the accumulated energy.

The operation of the module can be described with a module diagram. All the modules in the diagram are explained in the next sections.

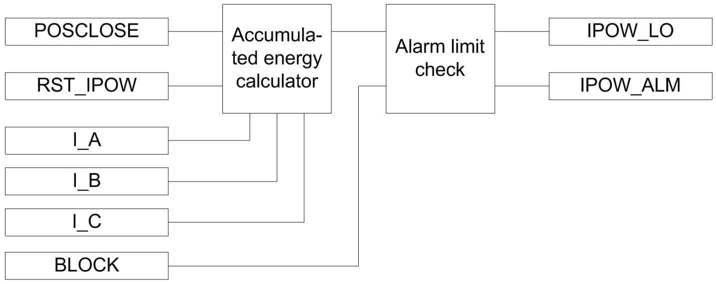


Figure 283: Functional module diagram for calculating accumulative energy and alarm

Accumulated energy calculator

This module calculates the accumulated energy $I^y t$ [$(kA)^y s$]. The factor y is set with the *Current exponent* setting.

The calculation is initiated with the `POSCLOSE` input opening events. It ends when the RMS current becomes lower than the *Acc stop current* setting value.

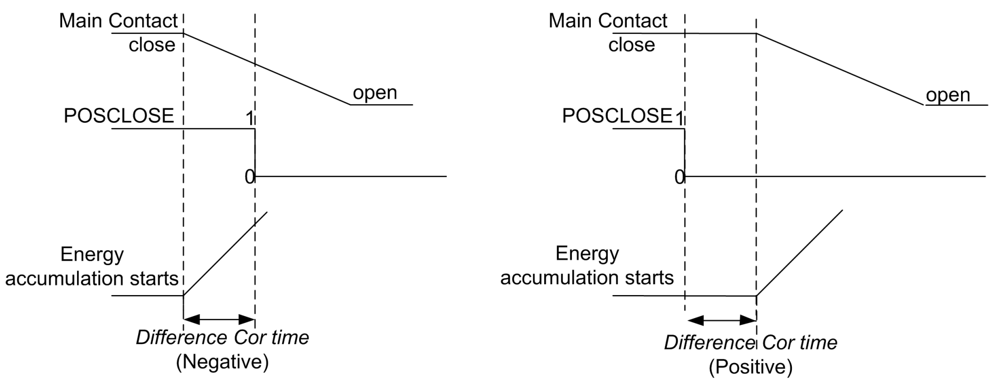


Figure 284: Significance of the Difference Cor time setting

The *Difference Cor time* setting is used instead of the auxiliary contact to accumulate the energy from the time the main contact opens. If the setting is positive, the calculation of energy starts after the auxiliary contact has opened and when the delay is equal to the value set with the *Difference Cor time* setting. When the setting is negative, the calculation starts in advance by the correction time before the auxiliary contact opens.

The accumulated energy outputs `IPOW_A (_B, _C)` are available in the monitored data view on the LHMI or through tools via communications. The values can be reset by setting the parameter *CBCMx acc. energy* setting to true in the clear menu from WHMI or LHMI.

Alarm limit check

The IPOW_ALM alarm is activated when the accumulated energy exceeds the value set with the *Alm Acc currents Pwr* threshold setting. However, when the energy exceeds the limit value set with the *LO Acc currents Pwr* threshold setting, the IPOW_LO output is activated.

The IPOW_ALM and IPOW_LO outputs can be blocked by activating the binary input BLOCK.

6.1.4.6 Remaining life of circuit breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer. The remaining life is decremented at least with one when the circuit breaker is opened.

The operation of the remaining life of the circuit breaker subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

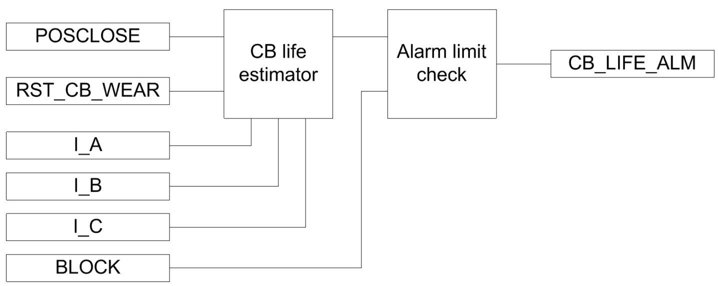


Figure 285: Functional module diagram for estimating the life of the circuit breaker

Circuit breaker life estimator

The circuit breaker life estimator module calculates the remaining life of the circuit breaker. If the tripping current is less than the rated operating current set with the *Rated Op current* setting, the remaining operation of the breaker reduces by one operation. If the tripping current is more than the rated fault current set with the *Rated fault current* setting, the possible operations are zero. The remaining life of the tripping current in between these two values is calculated based on the trip curve given by the manufacturer. The *Op number rated* and *Op number fault* parameters set the number of operations the breaker can perform at the rated current and at the rated fault current, respectively.

The remaining life is calculated separately for all three phases and it is available as a monitored data value CB_LIFE_A (_B, _C). The values can be cleared by setting the parameter *CB wear values* in the clear menu from WHMI or LHMI.

Clearing *CB wear values* also resets the operation counter.

Alarm limit check

When the remaining life of any phase drops below the *Life alarm level* threshold setting, the corresponding circuit breaker life alarm CB_LIFE_ALM is activated.

It is possible to deactivate the CB_LIFE_ALM alarm signal by activating the binary input BLOCK. The old circuit breaker operation counter value can be taken into use by writing the value to the *Initial CB Rmn life* parameter and resetting the value via the clear menu from WHMI or LHMI.

6.1.4.7 Circuit breaker spring-charged indication

The circuit breaker spring-charged indication subfunction calculates the spring charging time.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

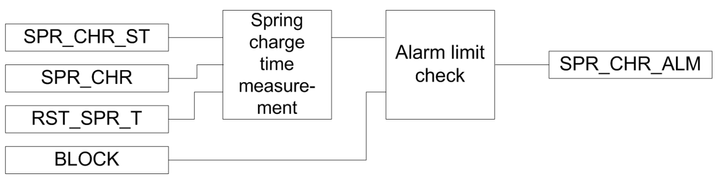


Figure 286: Functional module diagram for circuit breaker spring-charged indication and alarm

Spring charge time measurement

Two binary inputs, SPR_CHR_ST and SPR_CHR, indicate spring charging started and spring charged, respectively. The spring-charging time is calculated from the difference of these two signal timings.

The spring charging time T_SPR_CHR is available in the monitored data view on the LHMI or through tools via communications.

Alarm limit check

If the time taken by the spring to charge is more than the value set with the *Spring charge time* setting, the subfunction generates the SPR_CHR_ALM alarm.

It is possible to block the SPR_CHR_ALM alarm signal by activating the BLOCK binary input.

6.1.4.8 Gas pressure supervision

The gas pressure supervision subfunction monitors the gas pressure inside the arc chamber.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

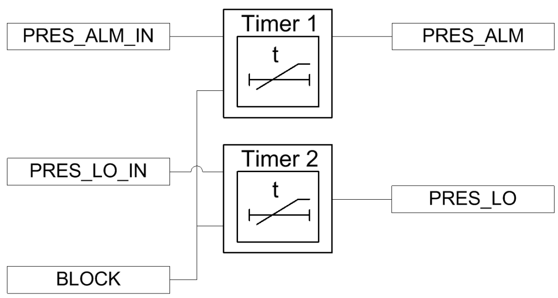


Figure 287: Functional module diagram for circuit breaker gas pressure alarm

The gas pressure is monitored through the binary input signals PRES_LO_IN and PRES_ALM_IN.

Timer 1

When the PRES_ALM_IN binary input is activated, the PRES_ALM alarm is activated after a time delay set with the *Pressure alarm time* setting. The PRES_ALM alarm can be blocked by activating the BLOCK input.

Timer 2

If the pressure drops further to a very low level, the PRES_LO_IN binary input becomes high, activating the lockout alarm PRES_LO after a time delay set with the *Pres lockout time* setting. The PRES_LO alarm can be blocked by activating the BLOCK input.

6.1.5 Application

52CM includes different metering and monitoring subfunctions.

Circuit breaker status

Circuit breaker status monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position.

Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring is to indicate that the circuit breaker has not been operated for a long time. The function calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. There is also the possibility to set an initial inactive day.

Breaker contact travel time

High traveling times indicate the need for the maintenance of the circuit breaker mechanism. Therefore, detecting excessive traveling time is needed. During the opening cycle operation, the main contact starts opening. The auxiliary contact A opens, the auxiliary contact B closes and the main contact reaches its opening position. During the closing cycle, the first main contact starts closing. The auxiliary contact B opens, the auxiliary contact A closes and the main contact reaches its closed position. The travel times are calculated based on the state changes of the auxiliary contacts and the adding correction factor to consider the time difference of the main contact's and the auxiliary contact's position change.

Operation counter

Routine maintenance of the breaker, such as lubricating breaker mechanism, is generally based on a number of operations. A suitable threshold setting to raise an alarm when the number of operation cycle exceeds the set limit helps preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

The change of state can be detected from the binary input of the auxiliary contact. There is a possibility to set an initial value for the counter which can be used to initialize this functionality after a period of operation or in case of refurbished primary equipment.

Accumulation of I^yt

Accumulation of I^yt calculates the accumulated energy ΣI^yt, where the factor y is known as the current exponent. The factor y depends on the type of the circuit breaker. For oil circuit breakers, the factor y is normally 2. In case of a high-voltage system, the factor y can be 1.4...1.5.

Remaining life of the breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer.

Example for estimating the remaining life of a circuit breaker

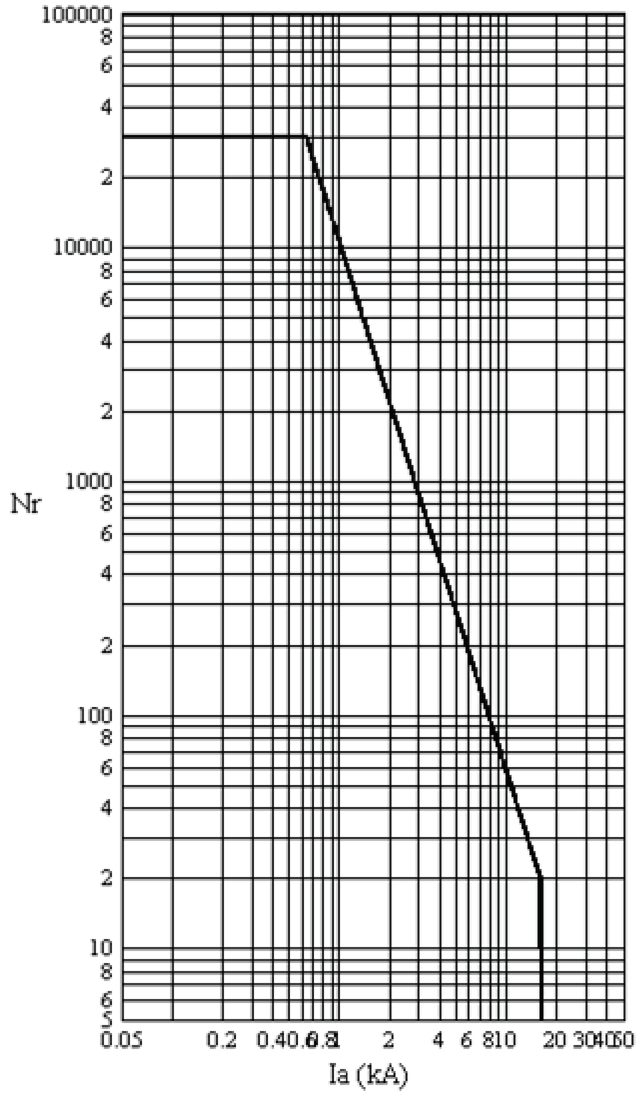


Figure 288: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

Nr	the number of closing-opening operations allowed for the circuit breaker
Ia	the current at the time of tripping of the circuit breaker

Calculation of Directional Coef

The directional coefficient is calculated according to the formula:

$$Directional\,Coef = \frac{\log\left(\frac{B}{A}\right)}{\log\left(\frac{I_f}{I_r}\right)} = -2.2609$$

(Equation 88)

I_r	Rated operating current = 630 A
I_f	Rated fault current = 16 kA
A	Op number rated = 30000
B	Op number fault = 20

Calculation for estimating the remaining life

Figure 288 shows that there are 30,000 possible operations at the rated operating current of 630 A and 20 operations at the rated fault current 16 kA. Therefore, if the tripping current is 10 kA, one operation at 10 kA is equivalent to 30,000/60=500 operations at the rated current. It is also assumed that prior to this tripping, the remaining life of the circuit breaker is 15,000 operations. Therefore, after one operation of 10 kA, the remaining life of the circuit breaker is 15,000-500=14,500 at the rated operating current.

Spring-charged indication

For normal operation of the circuit breaker, the circuit breaker spring should be charged within a specified time. Therefore, detecting long spring-charging time indicates that it is time for the circuit breaker maintenance. The last value of the spring-charging time can be used as a service value.

Gas pressure supervision

The gas pressure supervision monitors the gas pressure inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operations are locked. A binary input is available based on the pressure levels in the function, and alarms are generated based on these inputs.

6.1.6 Signals

Table 418: 52CM Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block input status
Table continues on next page			

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for closeposition of apparatus from I/O
PRES_ALM_IN	BOOLEAN	0=False	Binary pressure alarm input
PRES_LO_IN	BOOLEAN	0=False	Binary pressure input for lockout indication
SPR_CHR_ST	BOOLEAN	0=False	CB spring charging started input
SPR_CHR	BOOLEAN	0=False	CB spring charged input
RST_IPOW	BOOLEAN	0=False	Reset accumulation energy
RST_CB_WEAR	BOOLEAN	0=False	Reset input for CB remaining life and operation counter
RST_TRV_T	BOOLEAN	0=False	Reset input for CB closing and opening travel times
RST_SPR_T	BOOLEAN	0=False	Reset input for the charging time of the CB spring

Table 419: 52CM Output signals

Name	Type	Description
TRV_T_OP_ALM	BOOLEAN	CB open travel time exceeded set value
TRV_T_CL_ALM	BOOLEAN	CB close travel time exceeded set value
SPR_CHR_ALM	BOOLEAN	Spring charging time has crossed the set value
OPR_ALM	BOOLEAN	Number of CB operations exceeds alarm limit
OPR_LO	BOOLEAN	Number of CB operations exceeds lockout limit
IPOW_ALM	BOOLEAN	Accumulated currents power (Iyt),exceeded alarm limit
IPOW_LO	BOOLEAN	Accumulated currents power (Iyt),exceeded lockout limit
CB_LIFE_ALM	BOOLEAN	Remaining life of CB exceeded alarm limit
MON_ALM	BOOLEAN	CB 'not tripped for long time' alarm
PRES_ALM	BOOLEAN	Pressure below alarm level
PRES_LO	BOOLEAN	Pressure below lockout level
OPENPOS	BOOLEAN	CB is in open position
INVALIDPOS	BOOLEAN	CB is in invalid position (not positively open or closed)
CLOSEPOS	BOOLEAN	CB is in closed position

6.1.7 Settings

Table 420: 52CM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Acc stop current	5.00...500.00	A	0.01	10.00	RMS current setting below which engy acm stops
Open alarm time	0...200	ms	1	40	Alarm level setting for open travel time in ms
Close alarm time	0...200	ms	1	40	Alarm level Setting for close travel time in ms
Opening time Cor	0...100	ms	1	10	Correction factor for open travel time in ms
Closing time Cor	0...100	ms	1	10	Correction factor for CB close travel time in ms
Spring charge time	0...60000	ms	10	1000	Setting of alarm for spring charging time of CB in ms
Counter initial Val	0...9999		1	0	The operation numbers counter initialization value
Alarm Op number	0...9999		1	200	Alarm limit for number of operations
Lockout Op number	0...9999		1	300	Lock out limit for number of operations
Current exponent	0.00...2.00		0.01	2.00	Current exponent setting for energy calculation
Difference Cor time	-10...10	ms	1	5	Corr. factor for time dif in aux. and main contacts open time
Alm Acc currents Pwr	0.00...20000.00		0.01	2500.00	Setting of alarm level for accumulated currents power
LO Acc currents Pwr	0.00...20000.00		0.01	2500.00	Lockout limit setting for accumulated currents power
Ini Acc currents Pwr	0.00...20000.00		0.01	0.00	Initial value for accumulation energy (Iyt)
Directional Coef	-3.00...-0.50		0.01	-1.50	Directional coefficient for CB life calculation
Initial CB Rmn life	0...9999		1	5000	Initial value for the CB remaining life
Rated Op current	100.00...5000.00	A	0.01	1000.00	Rated operating current of the breaker
Rated fault current	500.00...75000.00	A	0.01	5000.00	Rated fault current of the breaker
Op number rated	1...99999		1	10000	Number of operations possible at rated current
Op number fault	1...10000		1	1000	Number of operations possible at rated fault current
Life alarm level	0...99999		1	500	Alarm level for CB remaining life
Pressure alarm time	0...60000	ms	1	10	Time delay for gas pressure alarm in ms
Pres lockout time	0...60000	ms	10	10	Time delay for gas pressure lockout in ms
Inactive Alm days	0...9999		1	2000	Alarm limit value of the inactive days counter
Ini inactive days	0...9999		1	0	Initial value of the inactive days counter
Inactive Alm hours	0...23	h	1	0	Alarm time of the inactive days counter in hours

6.1.8 Monitored data

Table 421: 52CM Monitored data

Name	Type	Values (Range)	Unit	Description
T_TRV_OP	FLOAT32	0...60000	ms	Travel time of the CB during opening operation
T_TRV_CL	FLOAT32	0...60000	ms	Travel time of the CB during closing operation
T_SPR_CHR	FLOAT32	0.00...99.99	s	The charging time of the CB spring
NO_OPR	INT32	0...99999		Number of CB operation cycle
INA_DAYS	INT32	0...9999		The number of days CB has been inactive
CB_LIFE_A	INT32	-9999...9999		CB Remaining life phase A
CB_LIFE_B	INT32	-9999...9999		CB Remaining life phase B
CB_LIFE_C	INT32	-9999...9999		CB Remaining life phase C
IPOW_A	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase A
IPOW_B	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase B
IPOW_C	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase C
52CM	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.1.9 Technical data

Table 422: 52CM Technical data

Characteristic	Value
Current measuring accuracy	±1.5% or ±0.002 x I_n (at currents in the range of 0.1…10 x I_n) ±5.0% (at currents in the range of 10…40 x I_n)
Operate time accuracy	±1.0% of the set value or ±20 ms
Travelling time measurement	+10 ms / -0 ms

6.2 Trip circuit supervision TCM

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Trip circuit supervision	TCSSCBR	TCS	TCM

6.2.2 Function block

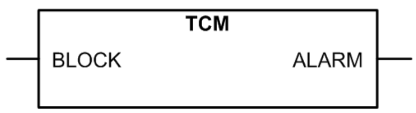


Figure 289: Function block

6.2.3 Functionality

The trip circuit supervision function TCM is designed for supervision of control circuits. A fault in a control circuit is detected by using a dedicated output contact that contains the monitoring functionality. The failure of a circuit is reported to the corresponding function block in the relay configuration.

The function picks up and trips when TCM detects a trip circuit failure. The trip time characteristic for the function is of the definite time (DT) type. The function trips after a predefined operating time and resets when the fault disappears.

The function contains a blocking functionality. Blocking deactivates the `ALARM` output and resets the timer.

6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of trip circuit supervision can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

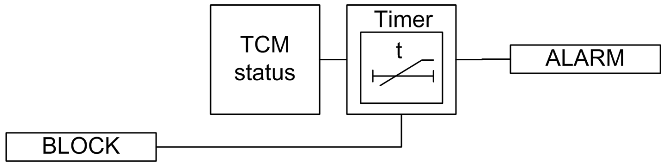


Figure 290: Functional module diagram

TCM status

This module receives the trip circuit status from the hardware. A detected failure in the trip circuit activates the timer.

Timer

Once activated, the timer runs until the set value *Trip delay time* is elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value, the `ALARM` output is activated. If a drop-off situation occurs during the trip time up counting, the reset timer is activated. If the drop-off time exceeds *Reset delay time*, the trip timer is reset.

The `BLOCK` input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the `BLOCK` input prevents the `ALARM` output to be activated.

6.2.5 Application

TCM detects faults in the electrical control circuit of the circuit breaker. The function can supervise both open and closed coil circuits. This supervision is necessary to find out the vitality of the control circuits continuously.

Figure 291 shows an application of the trip circuit supervision function use. The best solution is to connect an external R_{ext} shunt resistor in parallel with the circuit breaker internal contact. Although the circuit breaker internal contact is open, TCM can see the trip circuit through R_{ext}. The R_{ext} resistor should have such a resistance that the current through the resistance remains small, that is, it does not harm or overload the circuit breaker's trip coil.

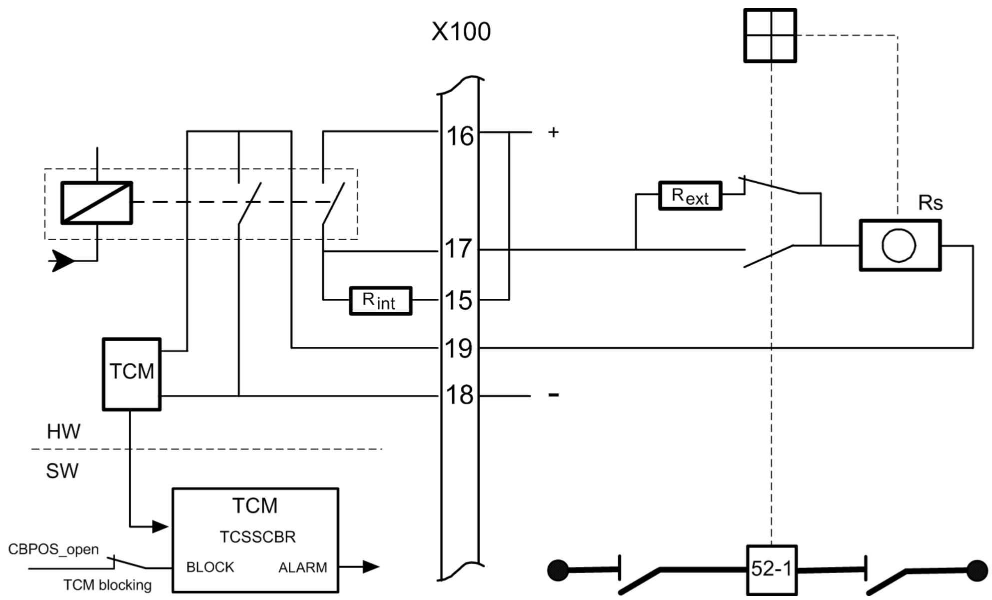


Figure 291: Operating principle of the trip-circuit supervision with an external resistor. The TCM blocking switch is not required since the external resistor is used.

If TCM is required only in a closed position, the external shunt resistance can be omitted. When the circuit breaker is in the open position, the TCM sees the situation as a faulty circuit. One way to avoid TCM operation in this situation would be to block the supervision function whenever the circuit breaker is open.

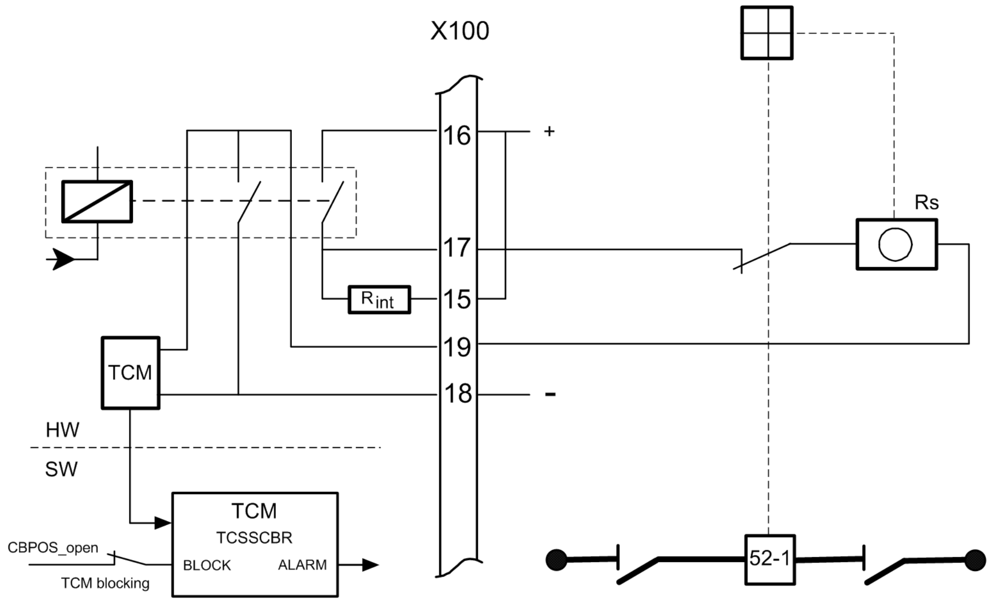


Figure 292: Operating principle of the trip-circuit supervision without an external resistor. The circuit breaker open indication is set to block TCM when the circuit breaker is open.

Trip circuit supervision and other trip contacts

It is typical that the trip circuit contains more than one trip contact in parallel, for example in transformer feeders where the trip of a Buchholz relay is connected in parallel with the feeder terminal and other relays involved. The supervising current cannot detect if one or all the other contacts connected in parallel are not connected properly.

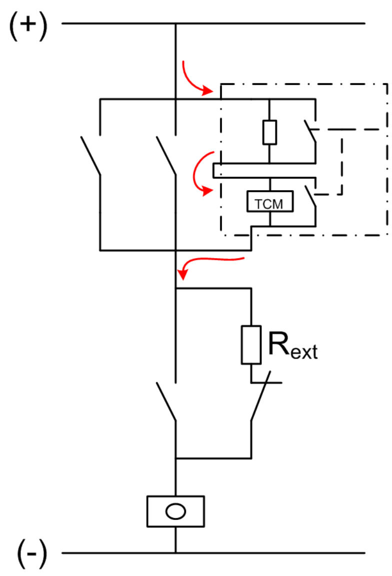


Figure 293: Constant test current flow in parallel trip contacts and trip circuit supervision

In case of parallel trip contacts, the recommended way to do the wiring is that the TCM test current flows through all wires and joints.

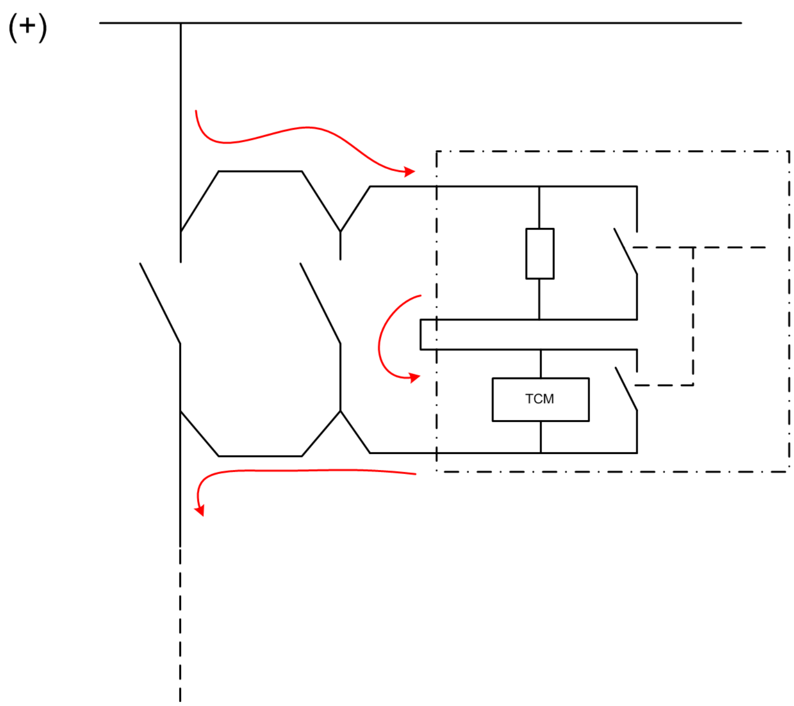


Figure 294: Improved connection for parallel trip contacts where the test current flows through all wires and joints

Several trip circuit supervision functions parallel in circuit

Not only the trip circuit often have parallel trip contacts, it is also possible that the circuit has multiple TCM circuits in parallel. Each TCM circuit causes its own supervising current to flow through the monitored coil and the actual coil current is a sum of all TCM currents. This must be taken into consideration when determining the resistance of R_{ext}.

Setting the TCM function in a protection relay not-in-use does not typically affect the supervising current injection.

Trip circuit supervision with auxiliary relays

Many retrofit projects are carried out partially, that is, the old electromechanical relays are replaced with new ones but the circuit breaker is not replaced. This creates a problem that the coil current of an old type circuit breaker can be too high for the protection relay trip contact to break.

The circuit breaker coil current is normally cut by an internal contact of the circuit breaker. In case of a circuit breaker failure, there is a risk that the protection relay trip contact is destroyed since the contact is obliged to disconnect high level of electromagnetic energy accumulated in the trip coil.

An auxiliary relay can be used between the protection relay trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCM circuit in the protection relay monitors the healthy auxiliary relay coil, not the circuit breaker coil. The separate trip circuit supervision relay is applicable for this to supervise the trip coil of the circuit breaker.

Dimensioning of the external resistor

Under normal operating conditions, the applied external voltage is divided between the relay's internal circuit and the external trip circuit so that at the minimum 20 V (15...20 V) remains over the relay's internal circuit. Should the external circuit's resistance be too high or the internal circuit's too low, for example due to welded relay contacts, a fault is detected.

Mathematically, the operation condition can be expressed as:

$$V_C - (R_{ext} + R_{int} + R_s) \times I_c \geq 20V \quad AC/DC$$

(Equation 89)

V_c	Operating voltage over the supervised trip circuit
I_c	Measuring current through the trip circuit, appr. 1.5 mA (0.99...1.72 mA)
R_{ext}	external shunt resistance
R_{int}	internal shunt resistance, 1 kΩ
R_s	trip coil resistance

If the external shunt resistance is used, it has to be calculated not to interfere with the functionality of the supervision or the trip coil. Too high a resistance causes too high a voltage drop, jeopardizing the requirement of at least 20 V over the internal circuit, while a resistance too low can enable false operations of the trip coil.

Table 423: Values recommended for the external resistor R_{ext}

Operating voltage U_c	Shunt resistor R_{ext}
48 V AC/DC	1.2 kΩ, 5 W
60 V AC/DC	5.6 kΩ, 5 W
110 V AC/DC	22 kΩ, 5 W
220 V AC/DC	33 kΩ, 5 W

Due to the requirement that the voltage over the TCM contact must be 20 V or higher, the correct operation is not guaranteed with auxiliary operating voltages lower than 48 V DC because of the voltage drop in the R_{ext} and operating coil or even voltage drop of the feeding auxiliary voltage system which can cause too low voltage values over the TCM contact. In this case, erroneous alarming can occur.

At lower (<48 V DC) auxiliary circuit operating voltages, it is recommended to use the circuit breaker position to block unintentional operation of TCM. The use of the position indication is described earlier in this chapter.

Using power output contacts without trip circuit supervision

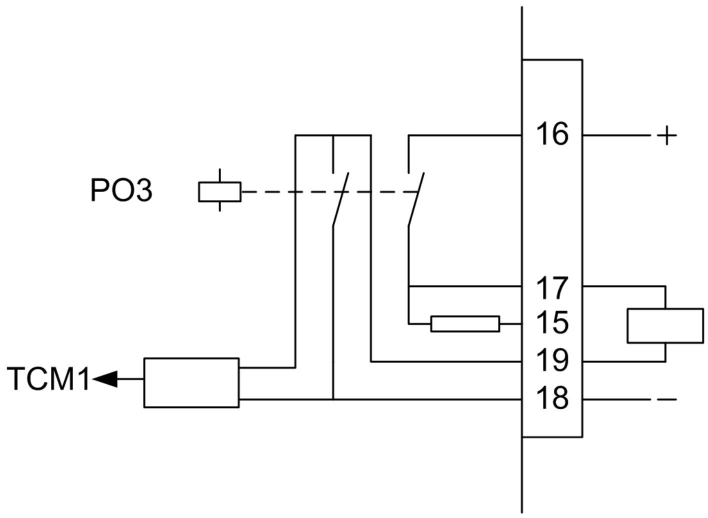


Figure 295: Connection of a power output in a case when TCM is not used and the internal resistor is disconnected

Incorrect connections and use of trip circuit supervision

Although the TCM circuit consists of two separate contacts, it must be noted that those are designed to be used as series connected to guarantee the breaking capacity given in the technical manual of the protection relay. In addition to the weak breaking capacity, the internal resistor is not dimensioned to withstand current without a TCM circuit. As a result, this kind of incorrect connection causes immediate burning of the internal resistor when the circuit breaker is in the close position and the voltage is applied to the trip circuit. The following figure shows incorrect usage of a TCM circuit when only one of the contacts is used.

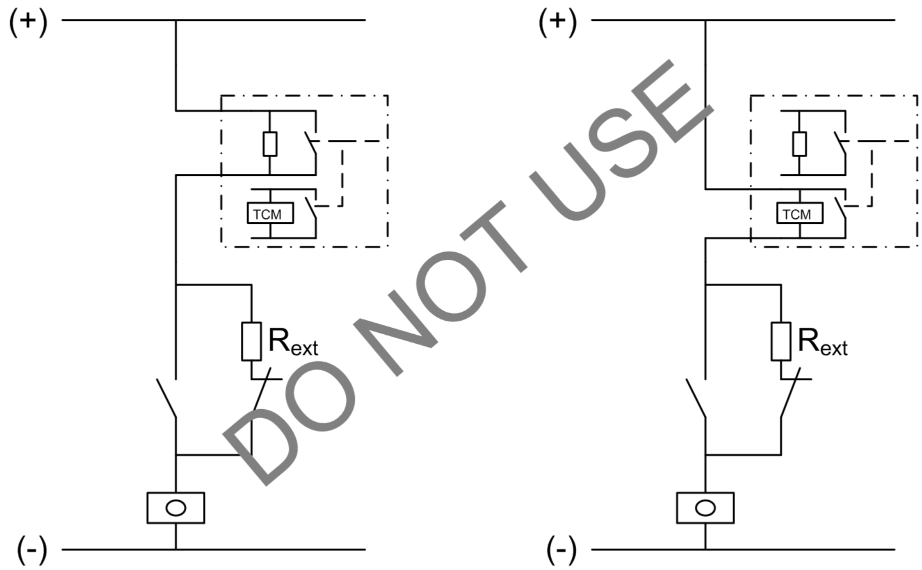


Figure 296: Incorrect connection of trip-circuit supervision

A connection of three protection relays with a double pole trip circuit is shown in the following figure. Only the protection relay R3 has an internal TCM circuit. In order to test the operation of the protection relay R2, but not to trip the circuit breaker, the upper trip contact of the protection relay R2 is disconnected, as shown in the figure, while the lower contact is still connected. When the protection relay R2 operates, the coil current starts to flow through the internal resistor of the protection relay R3 and the resistor burns immediately. As proven with the previous examples, both trip contacts must operate together. Attention should also be paid for correct usage of the trip circuit supervision while, for example, testing the protection relay.

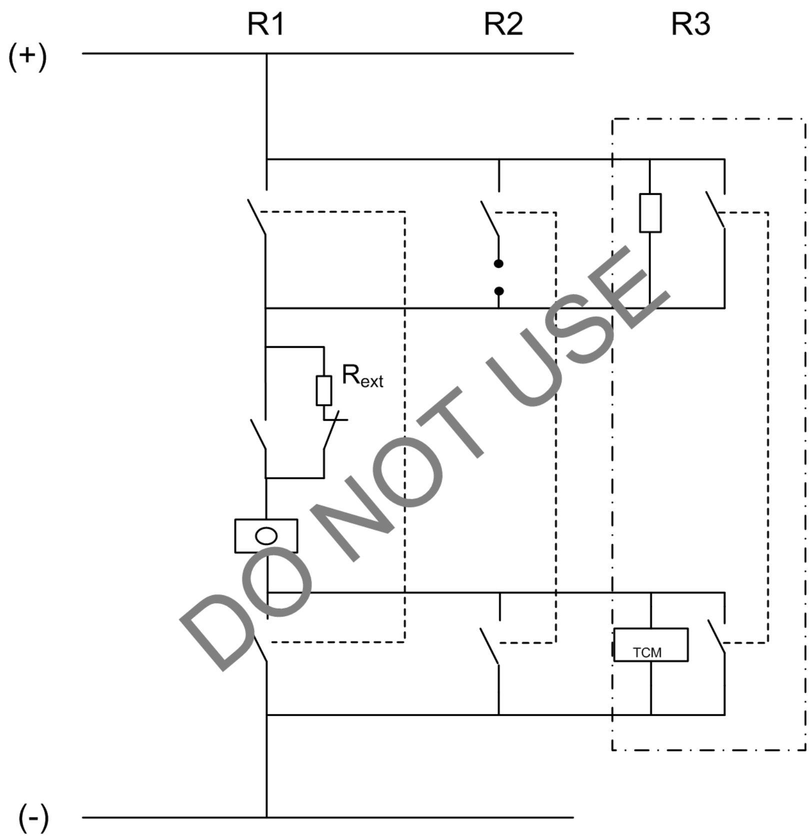


Figure 297: Incorrect testing of protection relays

6.2.6 Signals

Table 424: TCM Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status

Table 425: TCM Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.2.7 Settings

Table 426: TCM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Trip delay time	20...300000	ms	1	3000	Trip delay time
Reset delay time	20...60000	ms	1	1000	Reset delay time

6.2.8 Monitored data

Table 427: TCM Monitored data

Name	Type	Values (Range)	Unit	Description
TCM	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.3 Current circuit supervision CCM

6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision	CCRDIF	MCS 3I	CCM

6.3.2 Function block

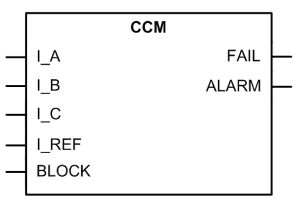


Figure 298: Function block

6.3.3 Functionality

The current circuit supervision function CCM is used for monitoring current transformers.

CCM calculates internally the sum of phase currents (I_A, I_B and I_C) and compares the sum against the measured single reference current (I_REF). The reference current must originate from other three-phase CT cores than the phase currents (I_A, I_B and I_C) and it is to be externally summated, that is, outside the protection relay.

CCM detects a fault in the measurement circuit and issues an alarm or blocks the protection functions to avoid unwanted tripping.

It must be remembered that the blocking of protection functions at an occurring open CT circuit means that the situation remains unchanged and extremely high voltages stress the secondary circuit.

6.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of current circuit supervision can be described with a module diagram. All the modules in the diagram are explained in the next sections.

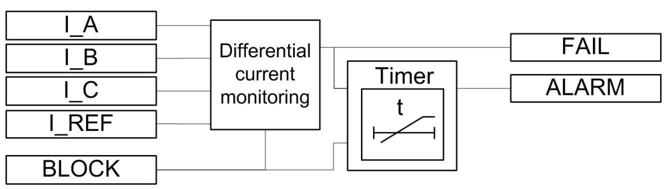


Figure 299: Functional module diagram

Differential current monitoring

Differential current monitoring supervises the difference between the summed phase currents I_A, I_B and I_C and the reference current I_REF.

The current operating characteristics can be selected with the *Pickup value* setting. When the highest phase current is less than 1.0 × In, the differential current limit is defined with *Pickup value*. When the highest phase current is more than 1.0 × In, the differential current limit is calculated with the equation.

$$MAX(I\_A, I\_B, I\_C) \times Pickup\ value$$

(Equation 90)

The differential current is limited to 1.0 × In.

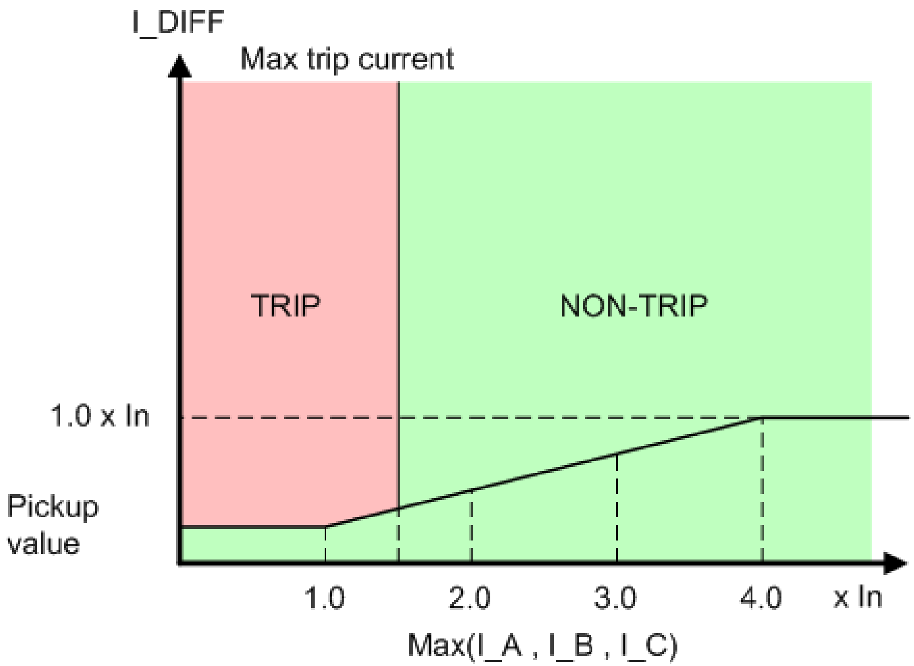


Figure 300: CCM operating characteristics

When the differential current I_DIFF is in the operating region, the FAIL output is activated.

The function is internally blocked if any phase current is higher than the set *Max trip current*. When the internal blocking activates, the FAIL output is deactivated immediately. The internal blocking is used for avoiding false operation during a fault situation when the current transformers are saturated due to high fault currents.

The value of the differential current is available in the monitored data view on the LHMI or through other communication tools. The value is calculated with the equation.

$$I\_DIFF = \left|\overline{I\_A} + \overline{I\_B} + \overline{I\_C}\right| - \left|\overline{I\_REF}\right|$$

(Equation 91)

The *Start value* setting is given in units of ×In of the phase current transformer. The possible difference in the phase and reference current transformer ratios is internally compensated by scaling I_REF with the value derived from the *Primary current* setting values. These setting parameters can be found in the Basic functions section.

The activation of the BLOCK input deactivates the FAIL output immediately.

Timer

The timer is activated with the FAIL signal. The ALARM output is activated after a fixed 200 ms delay. FAIL needs to be active during the delay.

When the internal blocking is activated, the FAIL output is deactivated immediately. The ALARM output is deactivated after a fixed 3 s delay, and the FAIL is deactivated.

The deactivation happens only when the highest phase current is more than 5 percent of the nominal current (0.05 xIn).

When the line is de-energized, the deactivation of the ALARM output is prevented.

The activation of the BLOCK input deactivates the ALARM output.

6.3.5 Application

Open or short-circuited current transformer cores can cause unwanted operation in many protection functions such as differential, ground-fault current and negative-sequence current functions. When currents from two independent three-phase sets of CTs or CT cores measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. When an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of high currents, the unequal transient saturation of CT cores with a different remanence or saturation factor can result in differences in the secondary currents from the two CT cores. An unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short trip time to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits create extremely high voltages in the circuits, which may damage the insulation and cause further problems. This must be taken into consideration especially when the protection functions are blocked.

When the reference current is not connected to the protection relay, the function should be turned off. Otherwise, the FAIL output is activated when unbalance occurs in the phase currents even if there was nothing wrong with the measurement circuit.

Reference current measured with core-balanced current transformer

CCM compares the sum of phase currents to the current measured with the core-balanced CT.

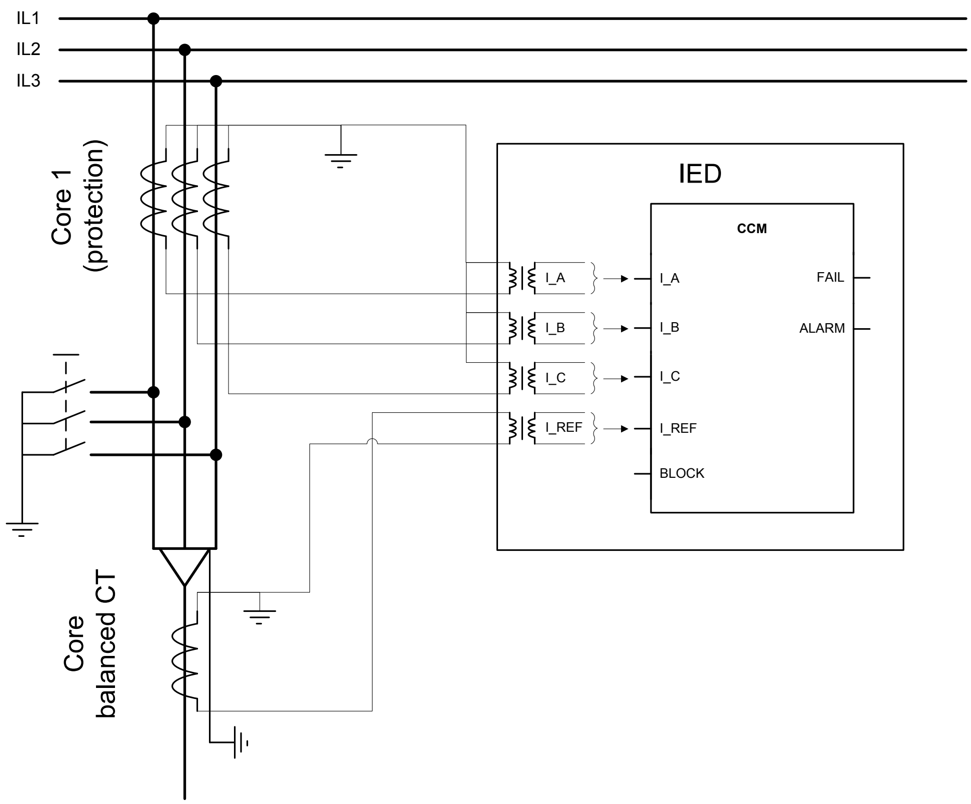


Figure 301: Connection diagram for reference current measurement with core-balanced current transformer

Current measurement with two independent three-phase sets of CT cores

Figure 302 and Figure 303 show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores.

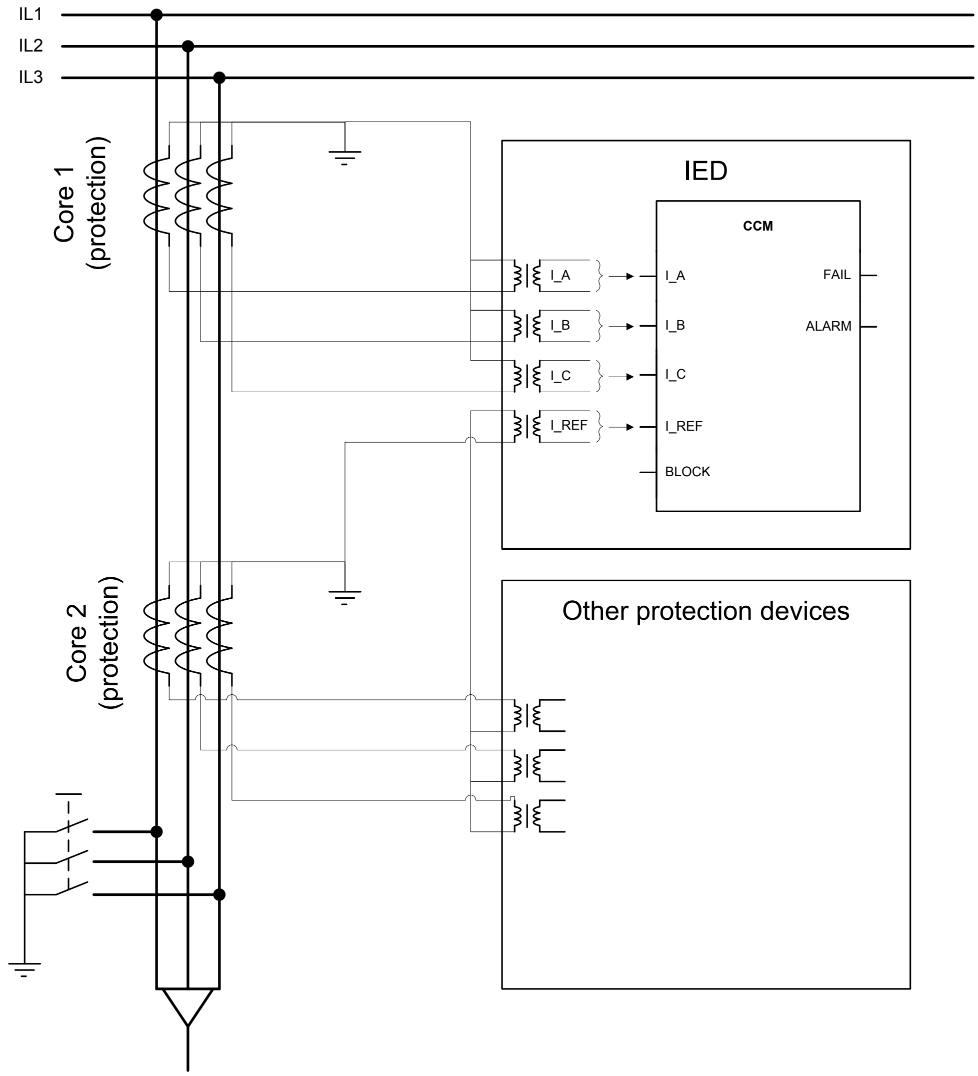


Figure 302: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores

When using the measurement core for reference current measurement, it should be noted that the saturation level of the measurement core is much lower than with the protection core. This should be taken into account when setting the current circuit supervision function.

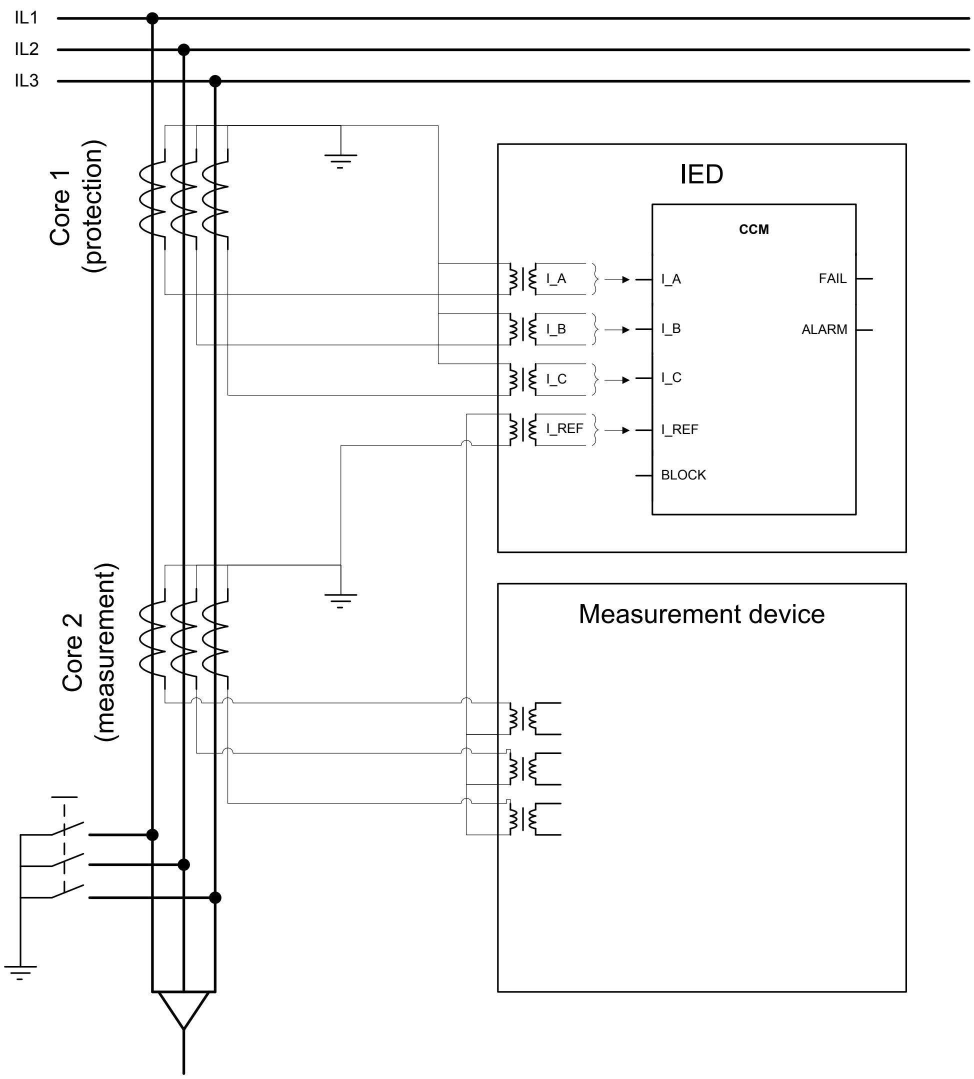


Figure 303: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)

Example of incorrect connection

The currents must be measured with two independent cores, that is, the phase currents must be measured with a different core than the reference current. A connection diagram shows an example of a case where the phase currents and the reference currents are measured from the same core.

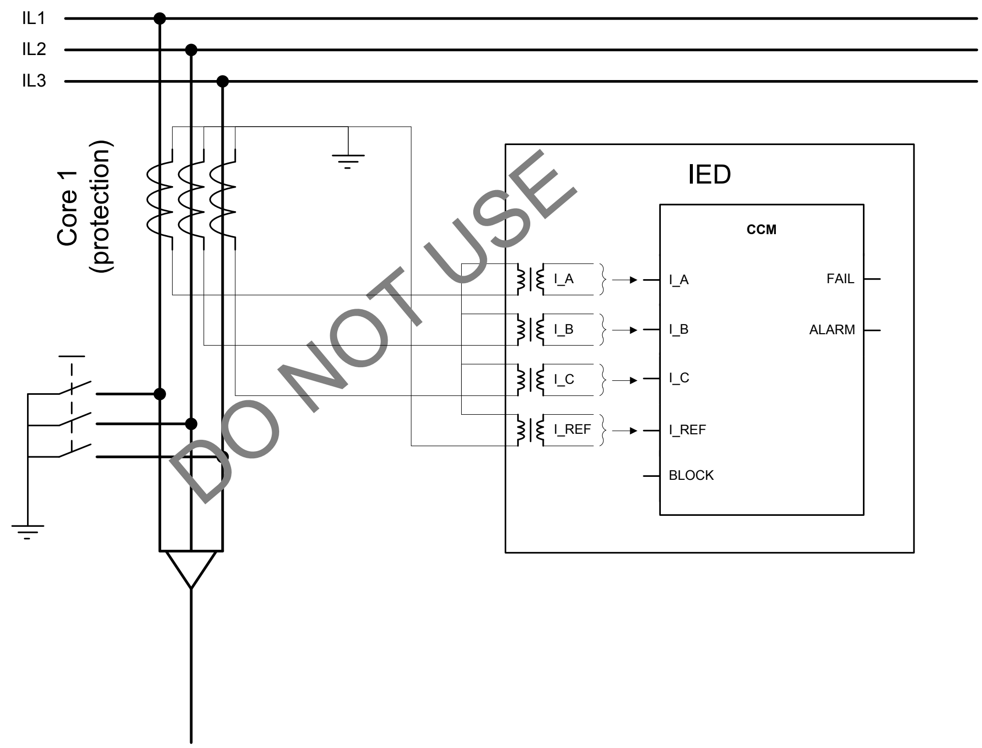


Figure 304: Example of incorrect reference current connection

6.3.6 Signals

Table 428: CCM Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_REF	SIGNAL	0	Reference current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 429: CCM Output signals

Name	Type	Description
FAIL	BOOLEAN	Fail output
ALARM	BOOLEAN	Alarm output

6.3.7 Settings

Table 430: CCM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Enable / Disable
Pickup value	0.05...0.20	xIn	0.01	0.05	Minimum trip current differential level
Max alarm current	1.00...5.00	xIn	0.01	1.50	Block of the function at high phase current

6.3.8 Monitored data

Table 431: CCM Monitored data

Name	Type	Values (Range)	Unit	Description
I_DIFF	FLOAT32	0.00...40.00	xIn	Differential current
CCM	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.3.9 Technical data

Table 432: CCM Technical data

Characteristic	Value
Trip time [1)]	<30 ms

1) Including the delay of the output contact

6.4 Advanced current circuit supervision for transformers MCS 3I, I2

6.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Advanced current circuit supervision for transformers	CTSRCTF	MCS 3I, I2	MCS 3I, I2

6.4.2 Function block

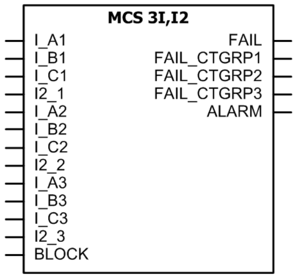


Figure 305: Function block

6.4.3 Functionality

The CT secondary circuit supervision function MCS 3I, I2 is used for monitoring the current transformer secondary circuit where a separate reference current transformer input for comparison is not available or where a separate voltage channel for calculating or measuring the zero-sequence voltage is not available. MCS 3I, I2 can be used for detecting the single-phase failure on the current transformer secondary for protection application involving two or three sets of the three-phase current transformers.

MCS 3I, I2 detects a fault in the measurement circuit and issues an alarm which can be used for blocking the protection functions, for example, differential protection, to avoid unwanted tripping.

MCS 3I, I2 is internally blocked in case of a transformer under no-load condition or if a current in any one phase exceeds the set maximum limit.

6.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the CT secondary circuit supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

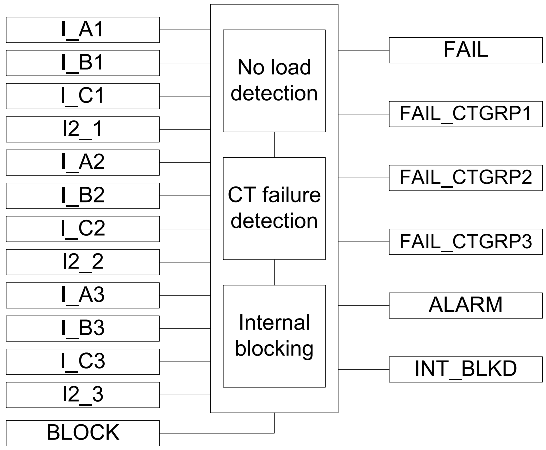


Figure 306: Functional module diagram

No-load detection

No-load detection module detects the loading condition. If all the three-phase currents of any two sets of current transformer are zero, the protected equipment is considered to be in the no-load condition and the function is internally blocked by activating the `INT_BLKD` output.

To avoid any false operation, the function is also internally blocked if any two-phase currents of any set of current transformers are below *Min operate current*. This activates `INT_BLKD`. The value of the *Min operate current* setting depends on the type of equipment to be protected. For example, in case of transformer protection, *Min operate current* depends on the no-load current rating. Typically, it can be set equal to the transformer no-load current rating.

CT failure detection

This module detects the CT secondary failure in any sets of current transformers. The module continuously scans the value of all the three-phase currents in all groups of current transformers to detect any sudden drop in the current value to zero. The detection of a zero current should not be the only criterion for considering a fault in the current transformer secondary. Two other criteria are evaluated to confirm the CT failure:

- A zero current due to the CT failure does not result in a negative-sequence current on healthy CT sets.

  On the detection of a zero current in any phase on either group of CT, the negative-sequence current I_2 is further evaluated. For a genuine CT secondary failure, the magnitude of I_2 changes only on the side where zero current has been detected. The change in the magnitude of I_2 (ΔI_2) on the other sets of the current transformer (other than where zero current is detected) is calculated. If the change is detected on the healthy sets of CT, it is an indication of system failure.

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- A zero current due to the CT failure does not result in a phase angle difference between the healthy phases.

  If a system faults happens on the phase A, it results in a change in the phase angle difference between phase B and phase C. This change in the phase angle difference between the healthy phases is evaluated in all three sets of current transformer, and if the change is detected in any set of CT, it is an indication of the system failure.

If both conditions are satisfied at zero current, the `FAIL` output is activated immediately. The `ALARM` output is activated after a fixed 200 ms delay. `FAIL` needs to be active during the delay. The outputs `FAIL`, `CTGRP1`, `FAIL_CTGRP2` and `FAIL_CTGRP3` are activated according to the CT group where the secondary failure is detected.

Activation of the `BLOCK` input deactivates the `FAIL` and `ALARM` outputs.

It is not possible to detect the CT secondary failure happening simultaneously with the system faults or failures or two simultaneous failures in the secondary circuit. The function resets if the zero current does not exist longer than 200 ms.

Internal blocking

This module blocks the function internally under specific condition to avoid any false operation during a system fault situation. When any of the following condition is satisfied, the function is internally blocked and the `FAIL` output is deactivated immediately.

- Magnitude of any phase current for any group of current transformers exceeds the *Max operate current* setting. The magnitude of phase current is calculated from the peak-to-peak value.
- Magnitude of the negative-sequence current I_2 on the healthy set of current transformer exceeds the *Max Nq Seq current* setting.

The `INT_BLKD` output is activated when `FAIL` is deactivated if any of the above conditions is satisfied. The `ALARM` output is also deactivated after a fixed three-second delay after the `FAIL` output is deactivated.

6.4.5 Application

Open or short-circuited current transformer secondary can cause unwanted operation in many protection functions, such as earth-fault current and differential. The simplest method for detecting the current transformer secondary failure is by comparing currents from two independent three-phase sets of CTs or the CT cores measuring the same primary currents. Another widely used method is the detection of a zero-sequence current and zero-sequence voltage. The detection of a zero-sequence current in the absence of a zero-sequence voltage is an indication of the current transformer secondary failure. However, both methods have disadvantages as they require an additional set of current transformer, or a voltage channel is needed for detecting a zero-sequence voltage.

The methods may not be applicable where additional current channels or voltage channels are not available. This CT secondary circuit supervision presents an algorithm that can be used as an example for detecting the CT secondary failure used for the unit protection of a two-winding or three-winding transformer. However, the function has a limitation that it cannot detect failure in case of equipment under protection in no-load condition or when two simultaneous secondary CT failures occur.

The detection of a zero current in any one phase is a partial indication of failure in the current transformer secondary. Furthermore, if this current zero is due to the failure in the current transformer secondary, it results in a change in the magnitude of the negative-sequence current in the group only where current zero has been detected. However, changes in the negative-sequence current in other groups of three-phase current transformers at the instance of zero-current detection is an indication of a system problem. Also, it may happen that after the detection of a failure in the current transformer secondary, a fault may occur in the system. During such condition, functions are internally blocked.

Phase discontinuity

A zero current detected due to the phase discontinuity results in an asymmetry in all the sets of the current transformer, which then results in a change in the negative-sequence current (ΔI_2) in the healthy set. This change in the negative-sequence current on the healthy sides, that is, other than where a zero current has been detected, blocks the function.

In case of a lightly loaded transformer (up to 30%) the change in the negative-sequence current may be very negligible. However, a phase discontinuity results in a change in the phase angle difference between two healthy phases in the set of CTs where a zero current has been detected as well as on the primary side of the transformer. This change in the value of the angle blocks the function internally.

Overload / System short circuit condition

It is required that any overload or short circuit conditions after a CT failure should block the function. During overload or short circuit condition, the phase current increases beyond its rated value; if any phase current on any set of current transformer exceeds the set limit, the function is blocked internally. Also in case of an unsymmetrical fault, the negative-sequence current increases. If the negative-sequence current increases beyond the set limit, the function is blocked internally. The overcurrent and negative-sequence current setting both can be set equal to the overcurrent and negative-sequence protection function pickup value.

The internal blocking is thus useful for avoiding false operation during a fault situation.

6.4.6 Signals

Table 433: MCS 3I,I2 Input signals

Name	Type	Default	Description
I_A1	SIGNAL	0	Current ID for getting current values for phase A, winding 1
I_B1	SIGNAL	0	Current ID for getting current values for phase B, winding 1
I_C1	SIGNAL	0	Current ID for getting current values for phase C, winding 1
I2_1	SIGNAL	0	Negative-sequence current from set 1
I_A2	SIGNAL	0	Current ID for getting current values for phase A, winding 2
I_B2	SIGNAL	0	Current ID for getting current values for phase B, winding 2
I_C2	SIGNAL	0	Current ID for getting current values for phase C, winding 2
I_A3	SIGNAL	0	Current ID for getting current values for phase 1, tertiary side or LV restraint
I_B3	SIGNAL	0	Current ID for getting current values for phase 2, tertiary side or LV restraint
I_C3	SIGNAL	0	Current ID for getting current values for phase 3, tertiary side or LV restraint
I2_3	SIGNAL	0	Negative-sequence current from set 3
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 434: MCS 3I,I2 Output signals

Name	Type	Description
FAIL	BOOLEAN	CT secondary failure
FAIL_CTGRP1	BOOLEAN	CT secondary failure group 1
FAIL_CTGRP2	BOOLEAN	CT secondary failure group 2
FAIL_CTGRP3	BOOLEAN	CT secondary failure group 3
ALARM	BOOLEAN	Alarm

6.4.7 Settings

Table 435: MCS 3I,I2 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Min alarm current	0.01...0.50	xIn	0.01	0.02	Minimum alarm current
Max alarm current	1.00...5.00	xIn	0.01	1.30	Maximum alarm current
Max Ng Seq current	0.01...1.00	xIn	0.01	0.10	Maximum I2 current in healthy set

6.4.8 Monitored data

Table 436: MCS 3I,I2 Monitored data

Name	Type	Values (Range)	Unit	Description
INT_BLKD	BOOLEAN	0=False 1=True		Function blocked internally
MCS 3I,I2	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.5 Fuse failure supervision 60

6.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	SEQRFUF	FUSEF	60

6.5.2 Function block

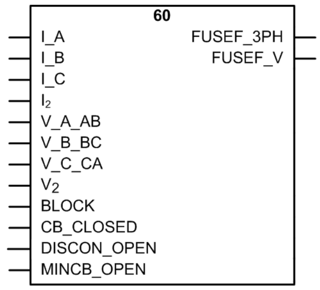


Figure 307: Function block

6.5.3 Functionality

The fuse failure supervision function 60 is used to block the voltage-measuring functions when failure occurs in the secondary circuits between the voltage transformer and protection relay to avoid misoperations of the voltage protection functions.

60 has two algorithms, a negative sequence-based algorithm and a delta current and delta voltage algorithm.

A criterion based on the delta current and the delta voltage measurements can be activated to detect three-phase fuse failures which usually are more associated with the voltage transformer switching during station operations.

6.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the fuse failure supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

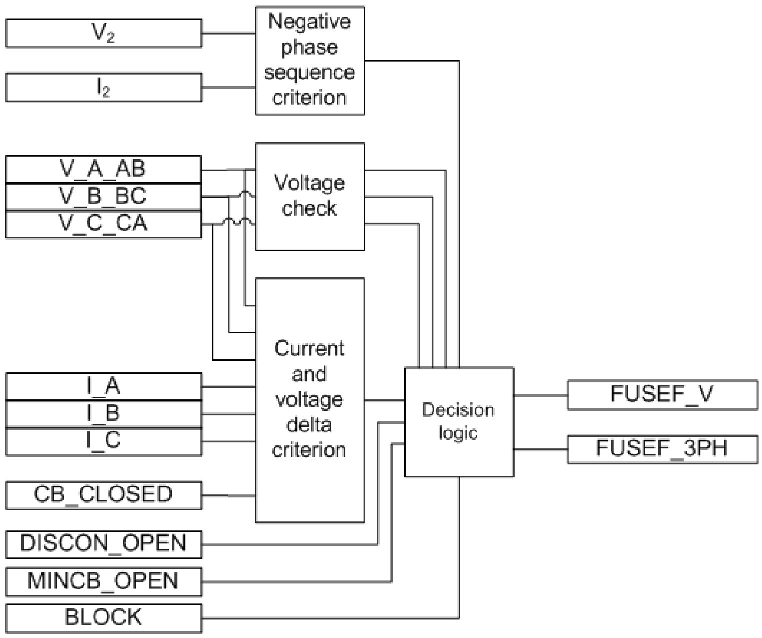


Figure 308: Functional module diagram

Negative phase-sequence criterion

A fuse failure based on the negative-sequence criterion is detected if the measured negative-sequence voltage exceeds the set *Neg Seq voltage Lev* value and the measured negative-sequence current is below the set *Neg Seq current Lev* value. The detected fuse failure is reported to the decision logic module.

Voltage check

The phase voltage magnitude is checked when deciding whether the fuse failure is a three, two or a single-phase fault.

The module makes a phase-specific comparison between each voltage input and the *Seal in voltage* setting. If the input voltage is lower than the setting, the corresponding phase is reported to the decision logic module.

Current and voltage delta criterion

The delta function can be activated by setting the *Change rate enable* parameter to "True". Once the function is activated, it operates in parallel with the negative sequence-based algorithm. The current and voltage are continuously measured in all three phases to calculate:

- Change of voltage dV/dt
- Change of current dI/dt

The calculated delta quantities are compared to the respective set values of the *Current change rate* and *Voltage change rate* settings.

The delta current and delta voltage algorithms detect a fuse failure if there is a sufficient negative change in the voltage amplitude without a sufficient change in the current amplitude in each phase separately. This is performed when the circuit breaker is closed. Information about the circuit breaker position is connected to the `CB_CLOSED` input.

There are two conditions for activating the current and voltage delta function.

- The magnitude of dV/dt exceeds the corresponding value of the *Voltage change rate* setting and magnitude of dI/dt is below the value of the *Current change rate* setting in any phase at the same time due to the closure of the circuit breaker (`CB_CLOSED` = TRUE).
- The magnitude of dV/dt exceeds the value of the *Voltage change rate* setting and the magnitude of dI/dt is below the Current change rate setting in any phase at the same time and the magnitude of the phase current in the same phase exceeds the *Min Op current delta* setting.

The first condition requires the delta criterion to be fulfilled in any phase at the same time as the circuit breaker is closed. Opening the circuit breaker at one end and energizing the line from the other end onto a fault could lead to an improper operation of the fuse failure supervision with an open breaker. If this is considered to be an important disadvantage, the `CB_CLOSED` input is to be connected to FALSE. In this way only the second criterion can activate the delta function.

The second condition requires the delta criterion to be fulfilled in one phase together with a high current for the same phase. The measured phase current is used to reduce the risk of a false fuse failure detection. If the current on the protected line is low, a voltage drop in the system (not caused by the fuse failure) is not followed by a current change and a false fuse failure can occur. To prevent this, the minimum phase current criterion is checked.

The fuse failure detection is active until the voltages return above the *Min Op voltage delta* setting. If a voltage in a phase is below the *Min Op voltage delta* setting, a new fuse failure detection for that phase is not possible until the voltage returns above the setting value.

Decision logic

The fuse failure detection outputs `FUSEF_V` and `FUSEF_3PH` are controlled according to the detection criteria or external signals.

Table 437: Fuse failure output control

Fuse failure detection criterion	Conditions and function response
Negative-sequence criterion	If a fuse failure is detected based on the negative sequence criterion, the FUSEF_V output is activated.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.
	The FUSEF_V output signal is also activated if all the phase voltages are above the *Seal in voltage* setting for more than 60 seconds and at the same time the negative sequence voltage is above *Neg Seq voltage Lev* for more than 5 seconds, all the phase currents are below the *Current dead Lin Val* setting and the circuit breaker is closed, that is CB_CLOSED is TRUE.
Current and voltage delta function criterion	If the current and voltage delta criterion detects a fuse failure condition, but all the voltages are not below the *Seal in voltage* setting, only the FUSEF_V output is activated.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.
External fuse failure detection	The MINCB_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit.The MINCB_OPEN signal sets the FUSEF_V output signal to block all the voltage-related functions when MCB is in the open state.
	The DISCON_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the line disconnector. The DISCON_OPEN signal sets the FUSEF_V output signal to block the voltage-related functions when the line disconnector is in the open state.

It is recommended to always set *Enable seal in* to "True". This secures that the blocked protection functions remain blocked until normal voltage conditions are restored if the fuse failure has been active for 5 seconds, that is, the fuse failure outputs are deactivated when the normal voltage conditions are restored.

The activation of the BLOCK input deactivates both FUSEF_V and FUSEF_3PH outputs.

6.5.5 Application

Some protection functions operate on the basis of the measured voltage value in the protection relay point. These functions can fail if there is a fault in the measuring circuits between the voltage transformers and protection relay.

A fault in the voltage-measuring circuit is called a fuse failure. This term is misleading since a blown fuse is just one of the many possible reasons for a broken circuit. Since incorrectly measured voltage can result in a misoperation of some of the protection functions, fast failure detection is one of the means to block voltage-based functions before they operate.

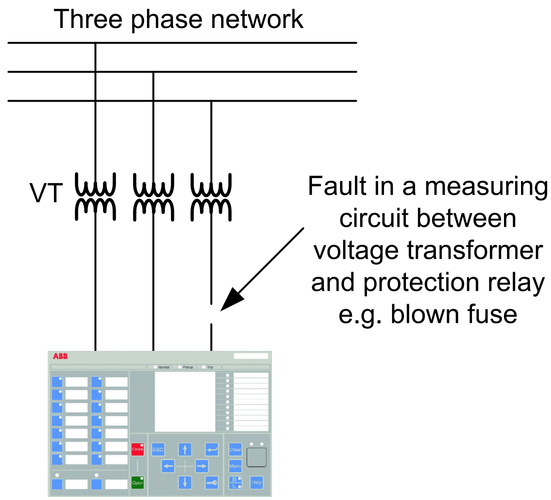


Figure 309: Fault in a circuit from the voltage transformer to the protection relay

A fuse failure occurs due to blown fuses, broken wires or intended substation operations. The negative sequence component-based function can be used to detect different types of single-phase or two-phase fuse failures. However, at least one of the three circuits from the voltage transformers must be intact. The supporting delta-based function can also detect a fuse failure due to three-phase interruptions.

In the negative sequence component-based part of the function, a fuse failure is detected by comparing the calculated value of the negative sequence component voltage to the negative sequence component current. The sequence entities are calculated from the measured current and voltage data for all three phases. The purpose of this function is to block voltage-dependent functions when a fuse failure is detected. Since the voltage dependence differs between these functions, 60 has two outputs for this purpose.

6.5.6 Signals

Table 438: 60 Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative sequence current
V_A_AB	SIGNAL	0	Phase A voltage
V_B_BC	SIGNAL	0	Phase B voltage
V_C_CA	SIGNAL	0	Phase C voltage
V_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block of function
CB_CLOSED	BOOLEAN	0=False	Active when circuit breaker is closed
DISCON_OPEN	BOOLEAN	0=False	Active when line disconnector is open
MINCB_OPEN	BOOLEAN	0=False	Active when external MCB opens protected voltage circuit

Table 439: 60 Output signals

Name	Type	Description
FUSEF_3PH	BOOLEAN	Three-phase pickup of function
FUSEF_V	BOOLEAN	General pickup of function

6.5.7 Settings

Table 440: 60 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Neg Seq current Lev	0.03...0.20	xIn	0.01	0.03	Trip level of neg seq undercurrent element
Neg Seq voltage Lev	0.03...0.20	xVn	0.01	0.10	Trip level of neg seq overvoltage element
Current change rate	0.01...0.50	xIn	0.01	0.15	Trip level of change in phase current
Voltage change rate	0.50...0.90	xVn	0.01	0.60	Trip level of change in phase voltage
Change rate enable	0=False 1=True			0=False	Enabling operation of change based function
Min Op voltage delta	0.01...1.00	xVn	0.01	0.70	Minimum trip level of phase voltage for delta calculation
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Min Op current delta	0.01...1.00	xIn	0.01	0.10	Minimum trip level of phase current for delta calculation
Seal in voltage	0.01...1.00	xVn	0.01	0.70	Trip level of seal-in phase voltage
Enable seal in	0=False 1=True			0=False	Enabling seal in functionality
Current dead Lin Val	0.05...1.00	xIn	0.01	0.05	Trip level for open phase current detection

6.5.8 Monitored data

Table 441: 60 Monitored data

Name	Type	Values (Range)	Unit	Description
60	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.5.9 Technical data

Table 442: 60 Technical data

Characteristic		Value	
Trip time[1)]	NPS function	V_{Fault} = 1.1 × set *Neg Seq voltage Lev*	<33 ms
		V_{Fault} = 5.0 × set *Neg Seq voltage Lev*	<18 ms
	Delta function	ΔV = 1.1 × set *Voltage change rate*	<30 ms
		ΔV = 2.0 × set *Voltage change rate*	<24 ms

1) Includes the delay of the signal output contact, f_n = 60 Hz, fault voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

6.6 Motor start-up supervision 66/51LRS

6.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor start-up supervision	STTPMSU	Is2t n<	66/51LRS

6.6.2 Function block

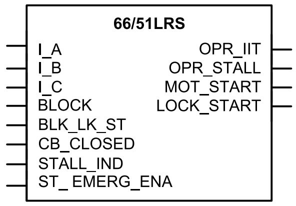


Figure 310: Function block

6.6.3 Functionality

The motor start-up supervision function 66/51LRS is designed for protection against excessive starting time and locked rotor conditions of the motor during starting. For the reliable operation of the motor, the thermal stress during the motor starting is maintained within the allowed limits.

The starting of the motor is supervised by monitoring the TRMS magnitude of all the phase currents or by monitoring the status of the circuit breaker connected to the motor.

During the start-up period of the motor, 66/51LRS calculates the integral of the I^2t value. If the calculated value exceeds the set value, the trip signal is activated.

66/51LRS has the provision to check the locked rotor condition of the motor using the speed switch, which means checking if the rotor is able to rotate or not. This feature trips after a predefined operating time.

66/51LRS also protects the motor from an excessive number of start-ups. Upon exceeding the specified number of start-ups within certain duration, 66/51LRS blocks further pickups. The restart of the motor is also inhibited after each start and continues to be inhibited for a set duration. When the lock of pickup of motor is enabled, 66/51LRS gives the time remaining until the restart of the motor.

66/51LRS contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

6.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the motor start-up supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

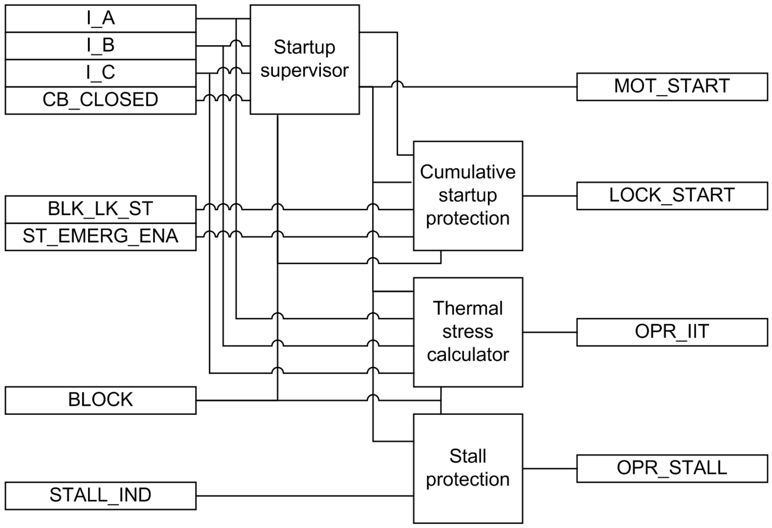


Figure 311: Functional module diagram

Startup supervisor

This module detects the starting of the motor. The starting and stalling motor conditions are detected in four different modes of operation. This is done through the *Operation mode* setting.

When the *Operation mode* setting is operated in the "IIt" mode, the function calculates the value of the thermal stress of the motor during the start-up condition. In this mode, the start-up condition is detected by monitoring the TRMS currents.

The *Operation mode* setting in the "IIt, CB" mode enables the function to calculate the value of the thermal stress when a start-up is monitored in addition to the `CB_CLOSED` input.

In the "IIt & stall" mode, the function calculates the thermal stress of the motor during the start-up condition. The start-up condition is detected by monitoring the TRMS currents.

In the "IIt & stall, CB" mode, the function calculates the thermal stress of the motor during the start-up condition but the start-up condition is detected by monitoring the TRMS current as well as the circuit breaker status.

In both the "IIt & stall" and "IIt & stall, CB" mode, the function also checks for motor stalling by monitoring the speed switch.

When the measured current value is used for start-up supervision in the "IIt" and "IIt & stall" modes, the module initially recognizes the de-energized condition of the motor when the values of all three phase currents are less than *Motor standstill A* for longer than 100 milliseconds. If any of the phase currents of the de-energized condition rises to a value equal to or greater than *Motor standstill A*, the MOT_START output signal is activated indicating that the motor start-up is in progress. The MOT_START output remains active until the values of all three phase currents drop below 90 percent of the set value of *Start detection A* and remain below that level for a time of *Str over delay time*, that is, until the start-up situation is over.

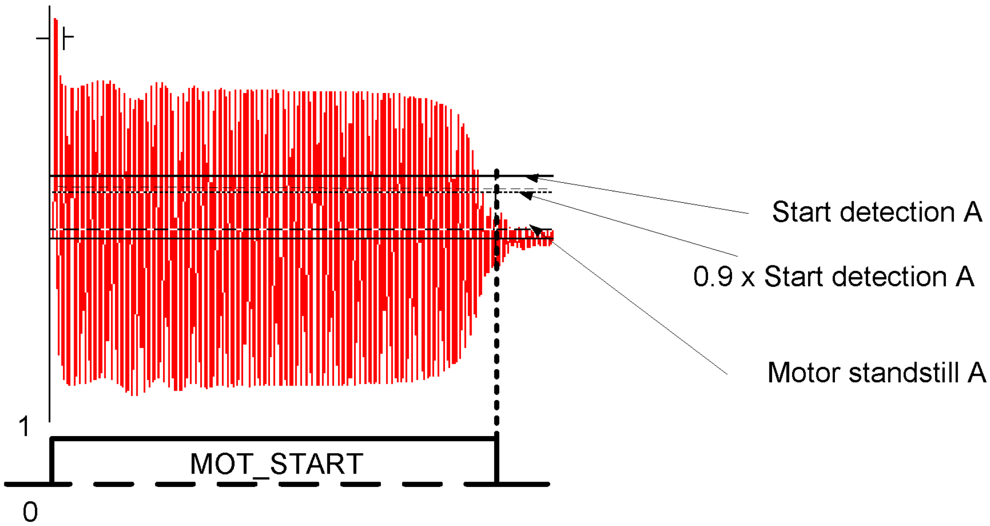


Figure 312: Functionality of start-up supervision in the "IIt and IIt&stall" mode

In case of the "IIt, CB" or "IIt & stall, CB" modes, the function initially recognizes the de-energized condition of the motor when the value of all three phase currents is below the value of the *Motor standstill A* setting for 100 milliseconds. The beginning of the motor start-up is recognized when CB is closed, that is, when the CB_CLOSED input is activated and at least one phase current value exceeds the *Motor standstill A* setting.

These two events do not take place at the same instant, that is, the CB main contact is closed first, in which case the phase current value rises above 0.1 pu and after some delay the CB auxiliary contact gives the information of the CB_CLOSED input. In some cases, the CB_CLOSED input can be active but the value of current may not be greater than the value of the *Motor standstill A* setting. To allow both possibilities, a time slot of 200 milliseconds is provided for current and the CB_CLOSED input. If both events occur during this time, the motor start-up is recognized.

The motor start-up ends either within the value of the *Str over delay time* setting from the beginning of the start-up or the opening of CB or when the CB_CLOSED input is deactivated. The operation of the MOT_START output signal in this operation mode is as illustrated in Figure 313.

This CB mode can be used in soft-started or slip ring motors for protection against a large starting current, that is, a problem in starting and so on.

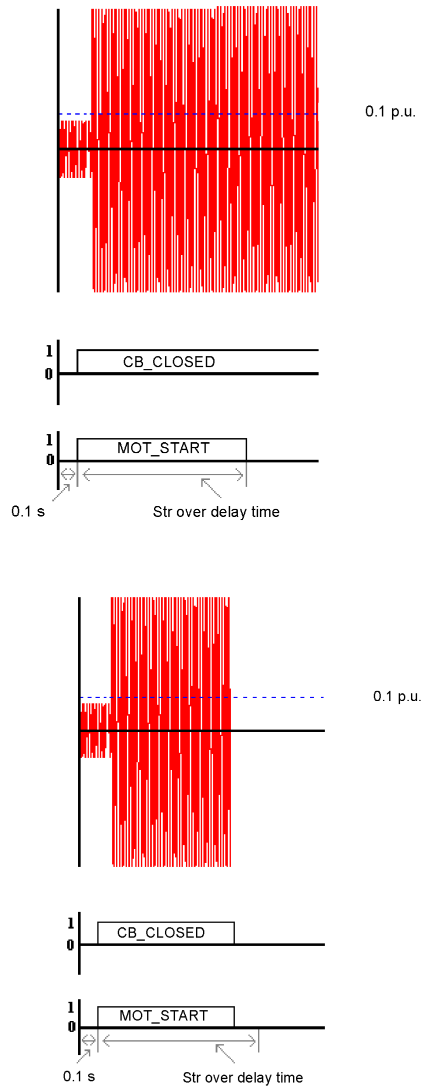


Figure 313: Functionality of start-up supervision in the "IIt, CB" mode and the "IIt and stall, CB" mode

The *Str over delay time* setting has different purposes in different modes of operation.

- In the "IIt" or "IIt & stall" modes, the aim of this setting is to check for the completion of the motor start-up period. The purpose of this time delay setting is to allow for short interruptions in the current without changing the state of the MOT_START output. In this mode of operation, the value of the setting is in the range of around 100 milliseconds.

- In the “IIt, CB” or “IIt & stall, CB” modes, the purpose of this setting is to check for the life of the protection scheme after the CB_CLOSED input has been activated. Based on the values of the phase currents, the completion of the start-up period cannot be judged. So in this mode of operation, the value of the time delay setting can even be as high as within the range of seconds, for example around 30 seconds.

The activation of the BLOCK input signal deactivates the MOT_START output.

Thermal stress calculator

Because of the high current surges during the start-up period, a thermal stress is imposed on the rotor. With less air circulation in the ventilation of the rotor before it reaches its full speed, the situation becomes even worse. Consequently, a long start-up causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during start-up. The heat developed during the starting can be calculated with the equation.

$$W = R_s \int_0^t i_s^2(t)\,dt$$

(Equation 92)

R_s combined rotor and stator resistance

i_s starting current of the motor

t starting time of the motor

This equation is normally represented as the integral of I²t. It is a commonly used method in protective protection relays to protect the motor from thermal stress during starting. The advantage of this method over the traditional definite time overcurrent protection is that when the motor is started with a reduced voltage as in the star-delta starting method, the starting current is lower. This allows more starting time for the motor since the module is monitoring the integral of I²t.

The module calculates the accumulated heat continuously and compares it to the limiting value obtained from the product of the square of the values of the *Motor start-up A* and *Motor start-up time* settings. When the calculated value of the thermal stress exceeds this limit, the OPR_IIT output is activated.

The module also measures the time START_TIME required by the motor to attain the rated speed and the relative thermal stress IIT_RL. The values are available in the Monitored data view.

The activation of the BLOCK input signal resets the thermal stress calculator and deactivates the OPR_IIT output.

Stall protection

This module is activated only when the selected *Operation mode* setting value is "IIt & stall" or "IIt & stall, CB".

The start-up current is specific to each motor and depends on the start-up method used, such as direct online, autotransformer and rotor resistance insertion. The start-up time is dependent on the load connected to the motor.

Based on the motor characteristics supplied by the manufacturer, this module is required if the stalling time is shorter than or too close to the starting time. In such cases, a speed switch must be used to indicate whether a motor is accelerating during start-up or not.

At motor standstill, the STALL_IND input is active. It indicates that the rotor is not rotating. When the motor is started, at certain revolution the deactivation of the STALL_IND by the speed switch indicates that the rotor is rotating. If the input is not deactivated within *Lock rotor time*, the OPR_STALL output is activated.

The module calculates the duration of the motor in stalling condition, the STALL_RL output indicating the percent ratio of the start situation and the set value of *Lock rotor time*. The value is available in the Monitored data view.

The activation of the BLOCK input signal resets the operation time and deactivates the OPR_STALL output.

Cumulative start-up protection

This module protects the motor from an excessive number of start-ups.

Whenever the motor is started, the latest value of START_TIME is added to the existing value of T_ST_CNT and the updated cumulative start-up time is available at T_ST_CNT. If the value of T_ST_CNT is greater than the value of *Cumulative time Lim*, the LOCK_START output is activated and motor restarting is inhibited during the time the output is active. The LOCK_START output remains high until the T_ST_CNT value reduces to a value less than the value of *Cumulative time Lim*. The start time counter reduces at the rate of the value of *Counter Red rate*.

The LOCK_START output becomes activated at the start of MOT_START. The output remains active for a period of *Restart inhibit time*.

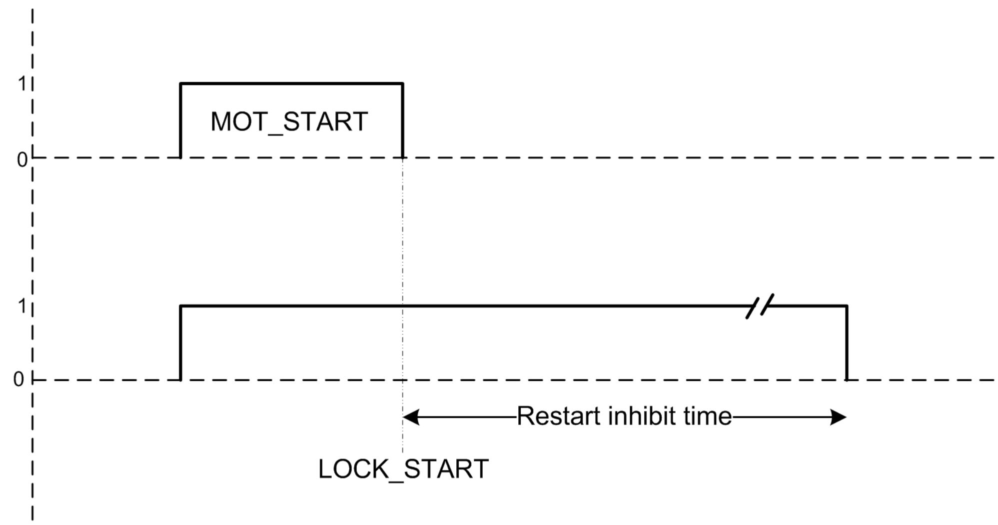


Figure 314: Time delay for cumulative start

This module also protects the motor from consecutive start-ups. When the LOCK_START output is active, T_RST_ENA shows the possible time for next restart. The value of T_RST_ENA is calculated by the difference of *Restart inhibit time* and the elapsed time from the instant LOCK_START is enabled.

When the ST_EMERG_ENA emergency start is set high, the value of the cumulative start-up time counter is set to *Cumulative time Lim* - 60s · *Emg start Red rate*. This disables LOCK_START and in turn makes the restart of the motor possible.

This module also calculates the total number of start-ups occurred, START_CNT. The value can be reset from the Clear menu.

The calculated values of T_RST_ENA, T_ST_CNT and START_CNT are available in the Monitored data view.

The activation of the BLK_LK_ST input signal deactivates the LOCK_START output. The activation of the BLOCK input signal resets the cumulative start-up counter module.

6.6.5 Application

When a motor is started, it draws a current well in excess of the motor's full-load rating throughout the period it takes for the motor to run up to the rated speed. The motor starting current decreases as the motor speed increases and the value of current remains close to the rotor-locked value for most of the acceleration period.

The full-voltage starting or the direct-on-line starting method is used out of the many methods used for starting the induction motor. If there is either an electrical or mechanical constraint, this starting method is not suitable. The full-voltage starting produces the highest starting torque. A high starting torque is generally required to start a high-inertia load to limit the acceleration time. In this method, full voltage is applied to the motor when the switch is in the "On" position. This method of starting results in a large initial current surge, which is typically four to eight times that of the full-load current drawn by the motor. If a star-delta starter is used, the value of the line current will only be about one-third of the direct-on-line starting current.

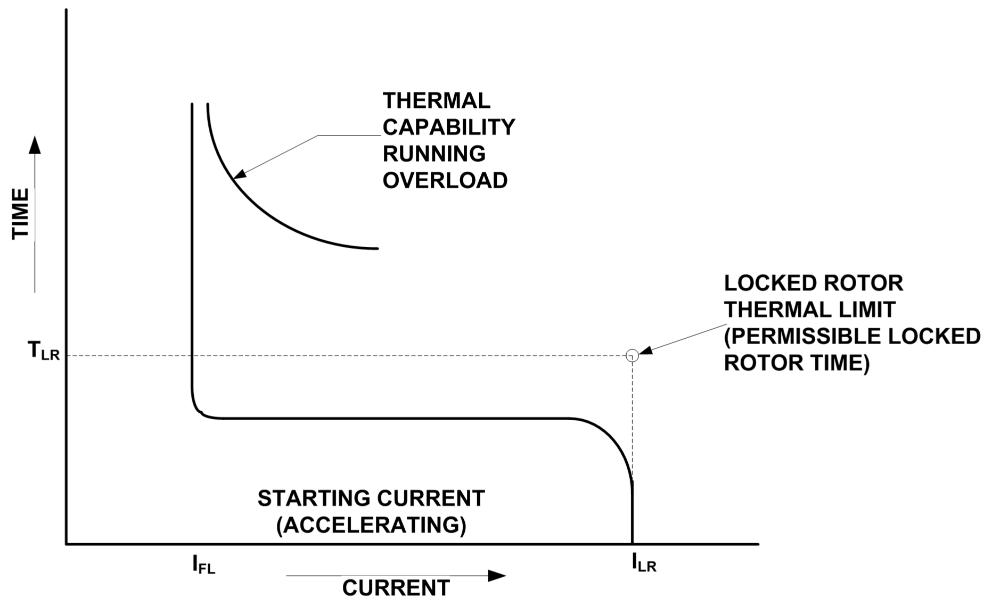


Figure 315: Typical motor starting and capability curves

The start-up supervision of a motor is an important function because of the higher thermal stress developed during starting. During the start-up, the current surge imposes a thermal strain on the rotor. This is exaggerated as the air flow for cooling is less because the fans do not rotate in their full speed. Moreover, the difference of speed between the rotating magnetic field and the rotor during the start-up time induces a high magnitude of slip current in the rotor at frequencies higher than when the motor is at full speed. The skin effect is stronger at higher frequencies and all these factors increase the losses and the generated heat. This is worse when the rotor is locked.

The starting current for slip-ring motors is less than the full load current and therefore it is advisable to use the circuit breaker in the closed position to indicate the starting for such type of motors.

The starting times vary depending on motor design and load torque characteristics. The time taken may vary from less than two seconds to more than 60 seconds. The starting time is determined for each application.

When the permissible stall time is less than the starting time of the motor, the stalling protection is used and the value of the time delay setting should be set slightly less than the permissible stall time. The speed switch on the motor shaft must be used for detecting whether the motor begins to accelerate or not. However, if the safe stall time is longer than the start-up time of the motor, the speed switch is not required.

The failure of a motor to accelerate or to reach its full nominal speed in an acceptable time when the stator is energized is caused by several types of abnormal conditions, including a mechanical failure of the motor or load bearings, low supply voltage, open circuit in one phase of a three-phase voltage supply or too high starting voltage. All these abnormal conditions result in overheating.

Repeated starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor manufacturers have restrictions on how many starts are allowed in a defined time interval. This function does not allow starting of the motor if the number of starts exceeds the set level in the register that calculates them. This insures that the thermal effects on the motor for consecutive starts stay within permissible levels.

For example, the motor manufacturer may state that three starts at the maximum are allowed within 4 hours and the start-up situation time is 60 seconds. By initiating three successive starts we reach the situation as illustrated. As a result, the value of the register adds up to a total of 180 seconds. Right after the third start has been initiated, the output lock of start of motor is activated and the fourth start will not be allowed, provided the time limit has been set to 121 seconds.

Furthermore, a maximum of three starts in 4 hours means that the value of the register should reach the set start time counter limit within 4 hours to allow a new start. Accordingly, the start time counter reduction should be 60 seconds in 4 hours and should thus be set to 60 s / 4 h = 15 s / h.

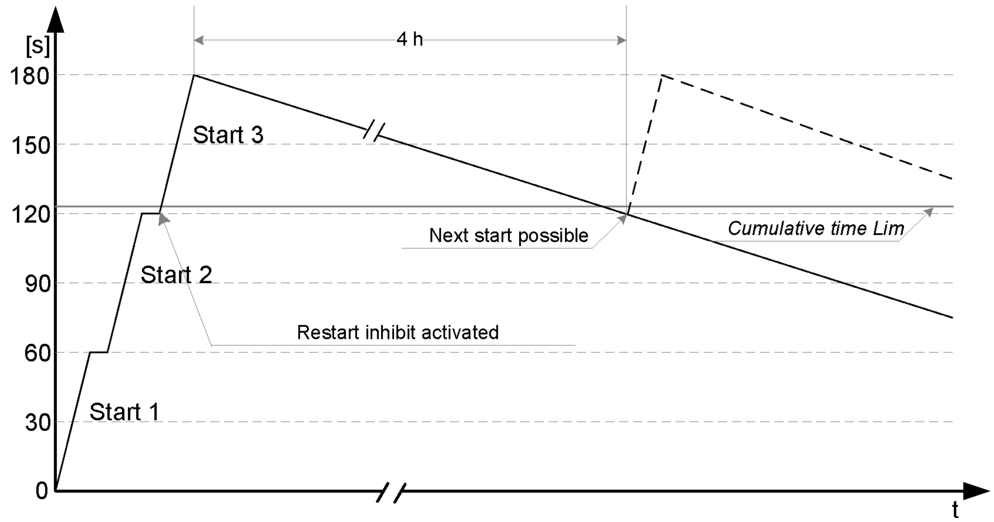


Figure 316: Typical motor-starting and capability curves

Setting of *Cumulative time Lim*

Cumulative time Lim is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

(Equation 93)

n	specified maximum allowed number of motor start-ups
t	start-up time of the motor (in seconds)
margin	safety margin (~10...20 percent)

Setting of *Counter Red rate*

Counter Red rate is calculated by

$$\Delta \sum t_s = \frac{t}{t_{reset}}$$

(Equation 94)

t	specified start time of the motor in seconds
t_{reset}	duration during which the maximum number of motor start-ups stated by the manufacturer can be made; time in hours

6.6.6 Signals

Table 443: 66/51LRS Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block of function
BLK_LK_ST	BOOLEAN	0=False	Blocks lock out condition for restart of motor
CB_CLOSED	BOOLEAN	0=False	Input showing the status of motor circuit breaker
STALL_IND	BOOLEAN	0=False	Input signal for showing the motor is not stalling
ST_EMERG_ENA	BOOLEAN	0=False	Enable emergency start to disable lock of start of motor

Table 444: 66/51LRS Output signals

Name	Type	Description
OPR_IIT	BOOLEAN	Trip signal for thermal stress.
OPR_STALL	BOOLEAN	Trip signal for stalling protection.
MOT_START	BOOLEAN	Signal to show that motor startup is in progress
LOCK_START	BOOLEAN	Lock out condition for restart of motor.

6.6.7 Settings

Table 445: 66/51LRS Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pickup detection A	0.1...10.0	xIn	0.1	1.5	Current value for detecting starting of motor.
Motor start-up A	1.0...10.0	xIn	0.1	6	Motor starting current
Motor start-up time	1...80	s	1	10	Motor starting time
Lock rotor time	2...120	s	1	10	Permitted stalling time
Str over delay time	0...60000	ms	1	100	Time delay to check for completion of motor startup period

Table 446: 66/51LRS Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Operation mode	1=IIt 2=IIt, CB 3=IIt + stall 4=IIt + stall, CB			1=IIt	Motor start-up operation mode
Counter Red rate	2.0...250.0	s/h	0.1	60.0	Start time counter reduction rate
Cumulative time Lim	1...500	s	1	10	Cumulative time based restart inhibit limit
Emg start Red rate	0.00...100.00	%	0.01	20.00	Start time reduction factor when emergency start is On
Restart inhibit time	0...250	min	1	30	Time delay between consecutive startups
Motor standstill A	0.05...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

6.6.8 Monitored data

Table 447: 66/51LRS Monitored data

Name	Type	Values (Range)	Unit	Description
START_CNT	INT32	0...999999		Number of motor start-ups occurred
START_TIME	FLOAT32	0.0...999.9	s	Measured motor latest startup time in sec
T_ST_CNT	FLOAT32	0.0...99999.9	s	Cumulated start-up time in sec
T_RST_ENA	INT32	0...999	min	Time left for restart when lockstart is enabled in minutes
IIT_RL	FLOAT32	0.00...100.00	%	Thermal stress relative to set maximum thermal stress
STALL_RL	FLOAT32	0.00...100.00	%	Pickup time relative to the trip time for stall condition
66/51LRS	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.6.9 Technical data

Table 448: 66/51LRS Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Pickup time[1)2)]		Minimum	Typical	Maximum
	I_{Fault} = 1.1 × set *Pickup detection A*	29 ms	31 ms	34 ms
Trip time accuracy		±1.0% of the set value or ±20 ms		
Reset ratio		Typically 0.90		

1) Current before = 0.0 × I_n, f_n = 60 Hz, overcurrent in one phase, results based on statistical distribution of 1000 measurements
2) Includes the delay of the signal output contact

6.7 Cable fault detection CFD

6.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Cable fault detection	RCFD	CFD	CFD

6.7.2 Function block

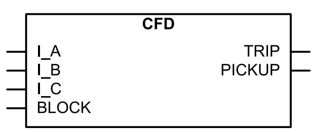


Figure 317: Function block

6.7.3 Functionality

The self-clearing fault detection function CFD calculates the half-cycle DFT of the current signal for all three phases and uses it to detect a self-clearing fault pronounced primarily in underground circuits.

The phase discontinuity protection function provides individual counter values for the number of times a self-clearing fault is observed in each phase. The phase discontinuity protection function also determines whether the self-clearing fault is observed in all three phases or not.

This phase discontinuity protection contains a blocking functionality. It is possible to block the function outputs or the function itself if desired.

6.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the phase discontinuity protection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

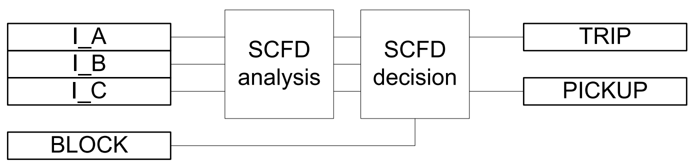


Figure 318: Functional module diagram.

SCFD analysis

The self-clearing fault detection SCFD analysis module detects the self-clearing fault in each phase by comparing the corresponding phase current magnitude to the set value *PhPu*.

If the phase current I_A magnitude goes above double the set value *PhPu*, the module calculates the time duration for which the current I_A continuously stays above double the set value *PhPu*. If the calculated time duration is greater than 1/4 cycles and less than the number of cycles set by *CyMulit*, it regards that the self-clearing fault is observed in phase A and `DetectfaultPhA` in the monitored data is set to "True". If the time duration criterion fails, `PickUpNoTripA` in the monitored data is set to "True". Once the self-clearing fault is detected in phase A, function increments the count `SCA` in the monitored data, which keeps record of the number of times the fault has been detected.

Self-clearing faults in phase B and phase C are detected similarly as explained for phase A, that is, by comparing I_B and I_C magnitudes to the set value *PhPu* and by checking the time duration. If the fault is detected in phase B or phase C, `DetectfaultPhB` or respectively `DetectfaultPhC` in the monitored data is set to "True". If the time duration criterion fails for phase B or phase C, the corresponding `PickUpNoTripB` or

PickUpNoTripC in the monitored data is set to "True". Once the fault is detected in phase B or phase C, the corresponding fault count SCB or SCC is incremented.

If the *AdapPhPu* setting is set to "True", the threshold setting value *PhPu* is adaptively calculated for each phase separately. The adaptive threshold value set equal to the average of the phase current over the 2^{nd} and 3^{rd} cycle after the *AdapPhPu* setting is set to "True". Until the 3^{rd} cycle, the set value *PhPu* is used for detecting the self-clearing fault. After the 3^{rd} cycle, the adaptively calculated threshold value for each phase is used for detecting the self-clearing fault.

This adaptive threshold implementation for each phase is considered only if the average of the phase current over the 2^{nd} and 3^{rd} cycle is greater than setting *AbsMinLoad*. Otherwise, the set value *PhPu* is considered for the corresponding phase fault detection.

SCFD decision

If the self-clearing fault is detected in at least one phase, the PICKUP and TRIP outputs are set to "True". Also SCDetect in the monitored data is set to "True".

When one phase detects a fault, the algorithm waits for one cycle time and during this period if the other two phases have detected a fault, the event is considered a three-phase event and the Event3Ph in the monitored data is set to "True".

Activation of the BLOCK input deactivates all the binary outputs.

6.7.5 Signals

Table 449: CFD Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block overall functions

Table 450: CFD Output signals

Name	Type	Description
TRIP	BOOLEAN	Trip
PICKUP	BOOLEAN	Pickup

6.7.6 Settings

Table 451: CFD Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
PhPu	0...100000		10	500	Fault Pickup parameter Threshold
CyMulit	1...20		1	5	Fault detect threshold parameter
AbsMinLoad	0...300		10	100	Absolute min loading on the feeder
AdapPhPu	0=False 1=True			0=False	Adaptive phase pickup

Table 452: CFD Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable

6.7.7 Monitored data

Table 453: CFD Monitored data

Name	Type	Values (Range)	Unit	Description
SCDetect	BOOLEAN	0=False 1=True		SC Fault Detect
Event3Ph	BOOLEAN	0=False 1=True		Three Phase Event
PickUpNoTripA	BOOLEAN	0=False 1=True		Pick up no trip Phase A
PickUpNoTripB	BOOLEAN	0=False 1=True		Pick up no trip Phase B
PickUpNoTripC	BOOLEAN	0=False 1=True		Pick up no trip Phase C
SCA	INT32	0...10000		Number of faults in Phase A
SCB	INT32	0...10000		Number of faults in Phase B
SCC	INT32	0...10000		Number of faults in Phase C
DetectfaultPhA	BOOLEAN	0=False 1=True		Fault detected in Phase A
DetectfaultPhB	BOOLEAN	0=False 1=True		Fault detected in Phase B
DetectfaultPhC	BOOLEAN	0=False 1=True		Fault detected in Phase C
CFD	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

6.8 Runtime counter for machines and devices OPTM

6.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM

6.8.2 Function block

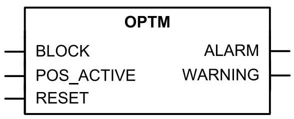


Figure 319: Function block

6.8.3 Functionality

The generic operation time counter function OPTM calculates and presents the accumulated operation time of a machine or device as the output. The unit of time for accumulation is hour. The function generates a warning and an alarm when the accumulated operation time exceeds the set limits. It utilizes a binary input to indicate the active operation condition.

The accumulated operation time is one of the parameters for scheduling a service on the equipment like motors. It indicates the use of the machine and hence the mechanical wear and tear. Generally, the equipment manufacturers provide a maintenance schedule based on the number of hours of service.

6.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the generic runtime counter for machines and devices can be described using a module diagram. All the modules in the diagram are explained in the next sections.

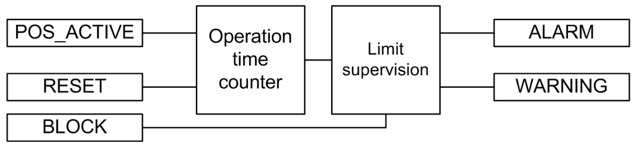


Figure 320: Functional module diagram

Operation time counter

This module counts the operation time. When POS_ACTIVE is active, the count is continuously added to the time duration until it is deactivated. At any time the OPR_TIME output is the total duration for which POS_ACTIVE is active. The unit of time duration count for OPR_TIME is hour. The value is available through the Monitored data view.

The OPR_TIME output is a continuously increasing value and it is stored in a non-volatile memory. When POS_ACTIVE is active, the OPR_TIME count starts increasing from the previous value. The count of OPR_TIME saturates at the final value of 299999, that is, no further increment is possible. The activation of RESET can reset the count to the *Initial value* setting.

Limit Supervision

This module compares the motor run-time count to the set values of *Warning value* and *Alarm value* to generate the WARNING and ALARM outputs respectively when the counts exceed the levels.

The activation of the WARNING and ALARM outputs depends on the *Operating time mode* setting. Both WARNING and ALARM occur immediately after the conditions are met if *Operating time mode* is set to “Immediate”. If *Operating time mode* is set to “Timed Warn”, WARNING is activated within the next 24 hours at the time of the day set using the *Operating time hour* setting. If *Operating time mode* is set to “Timed Warn Alm”, the WARNING and ALARM outputs are activated at the time of day set using *Operating time hour*.

The *Operating time hour* setting is used to set the hour of day in Coordinated Universal Time (UTC). The setting has to be adjusted according to the local time and local daylight-saving time.

The function contains a blocking functionality. Activation of the BLOCK input blocks both WARNING and ALARM.

6.8.5 Application

The machine operating time since commissioning indicates the use of the machine. For example, the mechanical wear and lubrication requirement for the shaft bearing of the motors depend on the use hours.

If some motor is used for long duration runs, it might require frequent servicing, while for a motor that is not used regularly the maintenance and service are scheduled less frequently. The accumulated operating time of a motor together with the appropriate settings for warning can be utilized to trigger the condition based maintenance of the motor.

The operating time counter combined with the subsequent reset of the operating-time count can be used to monitor the motor's run time for a single run.

Both the long term accumulated operating time and the short term single run duration provide valuable information about the condition of the machine and device. The information can be co-related to other process data to provide diagnoses for the process where the machine or device is applied.

6.8.6 Signals

Table 454: OPTM Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status
POS_ACTIVE	BOOLEAN	0=False	When active indicates the equipment is running
RESET	BOOLEAN	0=False	Resets the accumulated operation time to initial value

Table 455: OPTM Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm accumulated operation time exceeds Alarm value
WARNING	BOOLEAN	Warning accumulated operation time exceeds Warning value

6.8.7 Settings

Table 456: OPTM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Warning value	0...299999	h	1	8000	Warning value for operation time supervision
Alarm value	0...299999	h	1	10000	Alarm value for operation time supervision
Initial value	0...299999	h	1	0	Initial value for operation time supervision
Operating time hour	0...23	h	1	0	Time of day when alarm and warning will occur
Operating time mode	1=Immediate 2=Timed Warn 3=Timed Warn Alm			1=Immediate	Operating time mode for warning and alarm

6.8.8 Monitored data

Table 457: OPTM Monitored data

Name	Type	Values (Range)	Unit	Description
OPTM	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status
OPR_TIME	INT32	0...299999	h	Total operation time in hours

6.8.9 Technical data

Table 458: OPTM Technical data

Description	Value
Motor runtime measurement accuracy[1)]	±0.5%

1) Of the reading, for a stand-alone relay, without time synchronization.

Section 7 Measurement functions

7.1 Basic measurements

7.1.1 Functions

The three-phase current measurement function IA, IB, IC is used for monitoring and metering the phase currents of the power system.

The three-phase voltage measurement function VA, VB, VC is used for monitoring and metering the phase-to-phase voltages of the power system. The phase-to-ground voltages are also available in VA, VB, VC.

The ground current measurement function IG is used for monitoring and metering the ground current of the power system.

The ground voltage measurement function VG is used for monitoring and metering the ground voltage of the power system.

The sequence current measurement I1, I2, I0 is used for monitoring and metering the phase sequence currents.

The sequence voltage measurement V1, V2, V0 is used for monitoring and metering the phase sequence voltages.

The frequency measurement F is used for monitoring and metering the power system frequency.

The single-phase power and energy measurement SP, SE and the three-phase power and energy measurement P, E is used for monitoring and metering the active power P, reactive power Q, apparent power S, power factor PF and for calculating the accumulated energy separately as forward active, reverse active, forward reactive and reverse reactive. P, E calculates these quantities with the fundamental frequency phasors, that is, the DFT values of the measured phase current and phase voltage signals.

The information of the measured quantity is available for the operator both locally in LHMI and remotely to a network control center with communication.

If the measured data is within parentheses, there are some problems to express the data.

7.1.2 Measurement functionality

The functions can be enabled or disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

Some of the measurement functions operate on two alternative measurement modes: "DFT" and "RMS". The measurement mode is selected with the *X Measurement mode* setting. Depending on the measuring function if the measurement mode cannot be selected, the measuring mode is "DFT".

Demand value calculation

The demand values are calculated separately for each measurement function and per phase when applicable. The available measurement modes are "Linear" and "Logarithmic". The "Logarithmic" measurement mode is only effective for phase current and residual current demand value calculations. The demand value calculation mode is selected with the setting parameter **Configuration/Measurements/A demand Av mode**. The time interval for all demand value calculations is selected with the setting parameter **Configuration/Measurements/Demand interval**.

If the *Demand interval* setting is set to "15 minutes", for example, the demand values are updated every quarter of an hour. The demand time interval is synchronized to the real-time clock of the protection relay. When the demand time interval or calculation mode is changed, it initializes the demand value calculation. For the very first demand value calculation interval, the values are stated as invalid until the first refresh is available.

The "Linear" calculation mode uses the periodic sliding average calculation of the measured signal over the demand time interval. A new demand value is obtained once in a minute, indicating the analog signal demand over the demand time interval proceeding the update time. The actual rolling demand values are stored in the memory until the value is updated at the end of the next time interval.

The "Logarithmic" calculation mode uses the periodic calculation using a log10 function over the demand time interval to replicate thermal demand ammeters. The logarithmic demand calculates a snapshot of the analog signal every 1/15 x demand time interval.

Each measurement function has its own recorded data values. In protection relay, these are found in **Monitoring/Recorded data/Measurements**. In the technical manual these are listed in the monitored data section of each measurement function. These values are periodically updated with the maximum and minimum demand values. The time stamps are provided for both values.

Value reporting

The measurement functions are capable of reporting new values for network control center (SCADA system) based on the following functions:

- Zero-point clamping
- Deadband supervision
- Limit value supervision

In the three-phase voltage measurement function VA, VB, VC the supervision functions are based on the phase-to-phase voltages. However, the phase-to-ground voltage values are also reported together with the phase-to-phase voltages.

Zero-point clamping

A measured value under the zero-point clamping limit is forced to zero. This allows the noise in the input signal to be ignored. The active clamping function forces both the actual measurement value and the angle value of the measured signal to zero. In the three-phase or sequence measuring functions, each phase or sequence component has a separate zero-point clamping function. The zero-value detection operates so that once the measured value exceeds or falls below the value of the zero-clamping limit, new values are reported.

Table 459: Zero-point clamping limits

Function	Zero-clamping limit
Three-phase current measurement (IA, IB, IC)	1% of nominal (In)
Three-phase voltage measurement (VA, VB, VC)	1% of nominal (Vn)
Ground current measurement (IG)	1% of nominal (In)
Ground voltage measurement (VG)	1% of nominal (Vn)
Phase sequence current measurement (I1, I2, I0)	1% of the nominal (In)
Phase sequence voltage measurement (V1, V2, V0)	1% of the nominal (Vn)
Single-phase power and energy measurement (SP, SE)	1.5% of the nominal (Sn)
Three-phase power and energy measurement (P, E)	1.5% of the nominal (Sn)

When the frequency measurement function F is unable to measure the network frequency in the undervoltage situation, the measured values are set to the nominal and also the quality information of the data set accordingly. The undervoltage limit is fixed to 10 percent of the nominal for the frequency measurement.

Limit value supervision

The limit value supervision function indicates whether the measured value of X_INST exceeds or falls below the set limits. The measured value has the corresponding range information X_RANGE and has a value in the range of 0 to 4:

- 0: "normal"
- 1: "high"
- 2: "low"
- 3: "high-high"
- 4: "low-low"

The range information changes and the new values are reported.

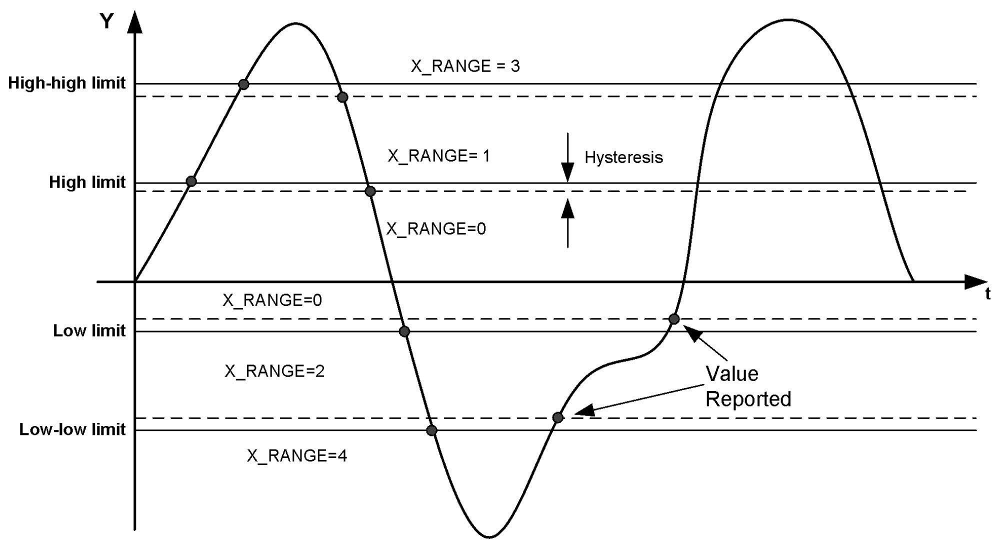


Figure 321: Presentation of operating limits

The range information can also be decoded into boolean output signals on some of the measuring functions and the number of phases required to exceed or undershoot the limit before activating the outputs and can be set with the *Num of phases* setting in the three-phase measurement functions IA, IB, IC and VA, VB, VC. The limit supervision boolean alarm and warning outputs can be blocked.

Table 460: Settings for limit value supervision

Function	Settings for limit value supervision	
Three-phase current measurement (IA, IB, IC)	High limit	*A high limit*
	Low limit	*A low limit*
	High-high limit	*A high high limit*
	Low-low limit	*A low low limit*
Three-phase voltage measurement (VA, VB, VC)	High limit	*V high limit*
	Low limit	*V low limit*
	High-high limit	*V high high limit*
	Low-low limit	*V low low limit*
Ground current measurement (IG)	High limit	*A high limit res*
	Low limit	-
	High-high limit	*A Hi high limit res*
	Low-low limit	-
Frequency measurement (F)	High limit	*F high limit*
	Low limit	*F low limit*
	High-high limit	*F high high limit*
	Low-low limit	*F low low limit*
Ground voltage measurement (VG)	High limit	*V high limit res*
	Low limit	-
	High-high limit	*V Hi high limit res*
	Low-low limit	-
Phase sequence current measurement (I1, I2, I0)	High limit	*Ps Seq A high limit*, *Ng Seq A high limit*, *Zro A high limit*
	Low limit	*Ps Seq A low limit*, *Ng Seq A low limit*, *Zro A low limit*
	High-high limit	*Ps Seq A Hi high Lim*, *Ng Seq A Hi high Lim*, *Zro A Hi high Lim*
	Low-low limit	*Ps Seq A low low Lim*, *Ng Seq A low low Lim*, *Zro A low low Lim*
Phase sequence voltage measurement (V1, V2, V0)	High limit	*Ps Seq V high limit*, *Ng Seq V high limit*, *Zro V high limit*
	Low limit	*Ps Seq V low limit*, *Ng Seq V low limit*, *Zro V low limit*
	High-high limit	*Ps Seq V Hi high Lim*, *Ng Seq V Hi high Lim*, *Zro V Hi high Lim*
	Low-low limit	*Ps Seq V low low Lim*, *Ng Seq V low low Lim*,

Table continues on next page

Function	Settings for limit value supervision	
Three-phase power and energy measurement (SP, SE)	High limit	-
	Low limit	-
	High-high limit	-
	Low-low limit	-
Three-phase power and energy measurement (P, E)	High limit	-
	Low limit	-
	High-high limit	-
	Low-low limit	-

Deadband supervision

The deadband supervision function reports the measured value according to integrated changes over a time period.

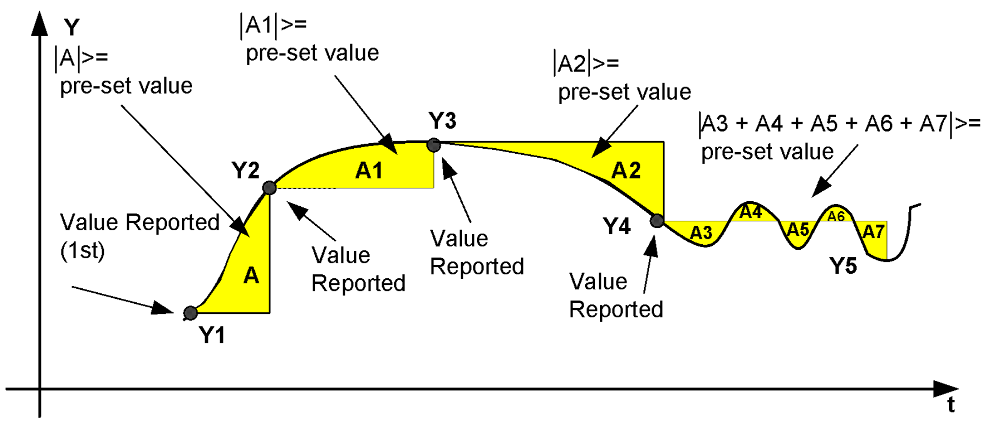


Figure 322: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *X deadband* setting. The value represents the percentage of the difference between the maximum and minimum limit in the units of 0.001 percent x seconds.

The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(\max - \min) \times deadband / 1000}{|\Delta Y| \times 100\%}$$

(Equation 95)

Example for IA, IB, IC:

A deadband = 2500 (2.5% of the total measuring range of 40)

I_INST_A = I_DB_A = 0.30

If I_INST_A changes to 0.40, the reporting delay is:

$$t(s) = \frac{(40-0)\times 2500/1000}{|0.40-0.30|\times 100\%} = 10s$$

Table 461: Parameters for deadband calculation

Function	Settings	Maximum/minimum (=range)
Three-phase current measurement (IA, IB, IC)	*A deadband*	*40 / 0 (=40xIn)*
Three-phase voltage measurement (VA, VB, VC)	*V Deadband*	*4 / 0 (=4xVn)*
Ground current measurement (IG)	*A deadband res*	*40 / 0 (=40xIn)*
Ground voltage measurement (VG)	*V deadband res*	*4 / 0 (=4xVn)*
Frequency measurement (F)	*F deadband*	*75 / 35 (=40Hz)*
Phase sequence current measurement (I1, I2, I0)	*Ps Seq A deadband, Ng Seq A deadband, Zro A deadband*	*40 / 0 (=40xIn)*
Phase sequence voltage measurement (V1, V2, V0)	*Ps Seq V deadband, Ng Seq V deadband, Zro V deadband*	*4/0 (=4xVn)*
Single-phase power and energy measurement (SP, SE)	-	
Three-phase power and energy measurement (P, E)	-	

In the power and energy measurement functions P, E and SP, SE, the deadband supervision is done separately for apparent power S, with the preset value of fixed 10 percent of the Sn and the power factor PF, with the preset values fixed at 0.10. All the power measurement-related values P, Q, S and PF are reported simultaneously when either one of the S or PF values exceeds the preset limit.

Power and energy calculation

The single-phase and three-phase power is calculated from the phase-to-ground voltages and phase-to-ground currents. The power measurement function is capable of calculating a complex power based on the fundamental frequency component phasors (DFT).

$$\overline{S} = (\overline{V}_A \cdot \overline{I}_A^* + \overline{V}_B \cdot \overline{I}_B^* + \overline{V}_C \cdot \overline{I}_C^*)$$

(Equation 96)

Once the complex apparent power is calculated, P, Q, S and PF are calculated with the equations:

$$P = \mathrm{Re}(\overline{S})$$

(Equation 97)

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 98)

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2}$$

(Equation 99)

$$Cos\varphi = \frac{P}{S}$$

(Equation 100)

Depending on the unit multiplier selected with *Power unit Mult*, the calculated power values are presented in units of kVA/kW/kVAr or in units of MVA/MW/MVAr.

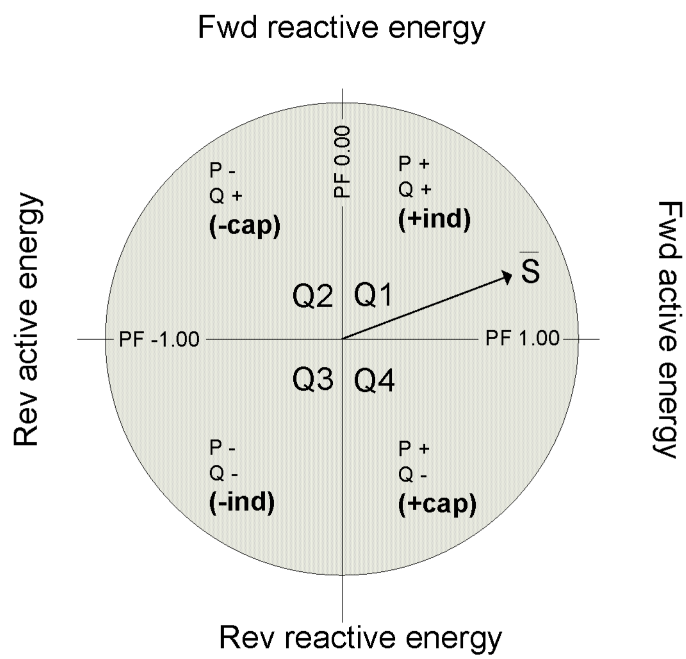


Figure 323: Complex power and power quadrants

Table 462: Power quadrants

Quadrant	Current	P	Q	PF	Power
Q1	Lagging	+	+	0…+1.00	+ind
Q2	Lagging	-	+	0…-1.00	-cap
Q3	Leading	-	-	0…-1.00	-ind
Q4	Leading	+	-	0…+1.00	+cap

The active power P direction can be selected between forward and reverse with *Active power Dir* and correspondingly the reactive power Q direction can be selected with *Reactive power Dir*. This affects also the accumulated energy directions.

The accumulated energy is calculated separately as forward active (EA_FWD_ACM), reverse active (EA_RV_ACM), forward reactive (ER_FWD_ACM) and reverse reactive (ER_RV_ACM). Depending on the value of the unit multiplier selected with *Energy unit Mult*, the calculated power values are presented in units of kWh/kVArh or in units of MWh/MVArh.

When the energy counter reaches its defined maximum value, the counter value is reset and restarted from zero. Changing the value of the *Energy unit Mult* setting resets the accumulated energy values to the initial values, that is, EA_FWD_ACM to *Forward Wh Initial*, EA_RV_ACM to *Reverse Wh Initial*, ER_FWD_ACM to *Forward WArh Initial* and ER_RV_ACM to *Reverse WArh Initial*. It is also possible to reset the accumulated energy to initial values through a parameter or with the RSTACM input.

Sequence components

The phase-sequence components are calculated using the phase currents and phase voltages. More information on calculating the phase-sequence components can be found in Calculated measurements in this manual.

7.1.3 Measurement function applications

The measurement functions are used for power system measurement, supervision and reporting to LHMI, a monitoring tool within PCM600, or to the station level, for example, with IEC 61850. The possibility to continuously monitor the measured values of active power, reactive power, currents, voltages, power factors and so on, is vital for efficient production, transmission, and distribution of electrical energy. It provides a fast and easy overview of the present status of the power system to the system operator. Additionally, it can be used during testing and commissioning of protection and control protection relays to verify the proper operation and connection of instrument transformers, that is, the current transformers (CTs) and voltage transformers (VTs). The proper operation of the protection relay analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the protection relay to other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and, hence, prevent the noise to be shown in the user display. The zero clamping is done for the measured analog signals and angle values.

The demand values are used to neglect sudden changes in the measured analog signals when monitoring long time values for the input signal. The demand values are linear average values of the measured signal over a settable demand interval. The demand values are calculated for the measured analog three-phase current signals.

The limit supervision indicates, if the measured signal exceeds or goes below the set limits. Depending on the measured signal type, up to two high limits and up to two low limits can be set for the limit supervision.

The deadband supervision reports a new measurement value if the input signal has gone out of the deadband state. The deadband supervision can be used in value reporting between the measurement point and operation control. When the deadband supervision is properly configured, it helps in keeping the communication load in minimum and yet measurement values are reported frequently enough.

7.1.4 Three-phase current measurement IA, IB, IC

7.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase current measurement	CMMXU	3I	IA,IB,IC

7.1.4.2 Function block

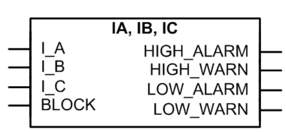


Figure 324: Function block

7.1.4.3 Signals

Table 463: IA,IB,IC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 464: IA,IB,IC Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm

7.1.4.4 Settings

Table 465: IA,IB,IC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
A high high limit	0.00...40.00	xIn		2	High alarm current limit
A high limit	0.00...40.00	xIn		2	High warning current limit
A low limit	0.00...40.00	xIn		0.00	Low warning current limit
A low low limit	0.00...40.00	xIn		0.00	Low alarm current limit
A deadband	100...100000			2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.4.5 Monitored data

Table 466: IA,IB,IC Monitored data

Name	Type	Values (Range)	Unit	Description
IA-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase A
IB-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase B
IC-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase C
Max demand IA	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase A
Max demand IB	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase B
Max demand IC	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase C
Min demand IA	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase A
Min demand IB	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase B
Min demand IC	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase C
Time max demand IA	Timestamp			Time of maximum demand phase A
Time max demand IB	Timestamp			Time of maximum demand phase B
Time max demand IC	Timestamp			Time of maximum demand phase C
Time min demand IA	Timestamp			Time of minimum demand phase A
Time min demand IB	Timestamp			Time of minimum demand phase B
Time min demand IC	Timestamp			Time of minimum demand phase C

7.1.4.6 Technical data

Table 467: IA, IB, IC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz at currents in the range of 0.01...4.00 × I_n
	Current: ±0.5% or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n) Phase angle: ±2.5°
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

7.1.5 Three-phase voltage measurement VA, VB, VC

7.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage measurement	VMMXU	3U	VA, VB, VC

7.1.5.2 Function block

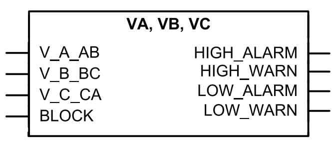


Figure 325: Function block

7.1.5.3 Signals

Table 468: VA, VB, VC Input signals

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase A voltage
V_B_BC	SIGNAL	0	Phase B voltage
V_C_CA	SIGNAL	0	Phase C voltage
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 469: VA, VB, VC Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm

7.1.5.4 Settings

Table 470: VA, VB, VC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
V high high limit	0.00...4.00	xVn		2	High alarm voltage limit
V high limit	0.00...4.00	xVn		2	High warning voltage limit
V low limit	0.00...4.00	xVn		0.00	Low warning voltage limit
V low low limit	0.00...4.00	xVn		0.00	Low alarm voltage limit
V deadband	100...100000			10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.5.5 Monitored data

Table 471: VA, VB, VC Monitored data

Name	Type	Values (Range)	Unit	Description
VAB-kV	FLOAT32	0.00...4.00	xVn	Measured phase to phase voltage amplitude phase AB
VBC-kV	FLOAT32	0.00...4.00	xVn	Measured phase to phase voltage amplitude phase BC
VCA-kV	FLOAT32	0.00...4.00	xVn	Measured phase to phase voltage amplitude phase CA

7.1.5.6 Technical data

Table 472: VA, VB, VC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × V_n
	Voltage:±0.5% or ±0.002 × V_n Phase angle:±2.5°
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

7.1.6 Residual current measurement IG

7.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current measurement	RESCMMXU	Io	IG

7.1.6.2 Function block

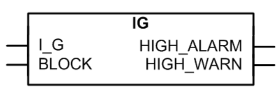


Figure 326: Function block

7.1.6.3 Signals

Table 473: IG Input signals

Name	Type	Default	Description
IG	SIGNAL	0	Ground current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 474: IG Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

7.1.6.4 Settings

Table 475: IG Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
A Hi high limit res	0.00...40.00	xIn		2	High alarm current limit
A high limit res	0.00...40.00	xIn		2	High warning current limit
A deadband res	100...100000			2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.6.5 Monitored data

Table 476: IG Monitored data

Name	Type	Values (Range)	Unit	Description
IG-A	FLOAT32	0.00...40.00	xIn	Measured residual current
Max demand IG	FLOAT32	0.00...40.00	xIn	Maximum demand for residual current
Min demand IG	FLOAT32	0.00...40.00	xIn	Minimum demand for residual current
Time max demand IG	Timestamp			Time of maximum demand residual current
Time min demand IG	Timestamp			Time of minimum demand residual current

7.1.6.6 Technical data

Table 477: IG Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5% or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

7.1.7 Residual voltage measurement VG

7.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual voltage measurement	RESVMMXU	Uo	VG

7.1.7.2 Function block

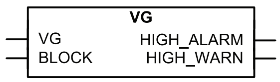


Figure 327: Function block

7.1.7.3 Signals

Table 478: VG Input signals

Name	Type	Default	Description
VG	SIGNAL	0	Ground voltage
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 479: VG Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

7.1.7.4 Settings

Table 480: VG Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
V Hi high limit res	0.00...4.00	xVn		0.20	High alarm voltage limit
V high limit res	0.00...4.00	xVn		0.05	High warning voltage limit
V deadband res	100...100000			10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.7.5 Monitored data

Table 481: VG Monitored data

Name	Type	Values (Range)	Unit	Description
VG-kV	FLOAT32	0.00...4.00	xVn	Measured residual voltage

7.1.7.6 Technical data

Table 482: VG Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f/f_n = ±2 Hz
	±0.5% or ±0.002 × V_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

7.1.8 Sequence current measurement I1, I2, I0

7.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence current measurement	CSMSQI	I1, I2, I0	I1, I2, I0

7.1.8.2 Function block

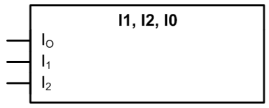


Figure 328: Function block

7.1.8.3 Signals

Table 483: I1, I2, I0 Input signals

Name	Type	Default	Description
I_0	SIGNAL	0	Zero sequence current
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current

7.1.8.4 Settings

Table 484: I1, I2, I0 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Ps Seq A Hi high Lim	0.00...40.00	xIn		2	High alarm current limit for positive sequence current
Ps Seq A high limit	0.00...40.00	xIn		2	High warning current limit for positive sequence current
Ps Seq A low limit	0.00...40.00	xIn		0.00	Low warning current limit for positive sequence current
Ps Seq A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for positive sequence current
Ps Seq A deadband	100...100000			2500	Deadband configuration value for positive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq A Hi high Lim	0.00...40.00	xIn		2	High alarm current limit for negative sequence current
Ng Seq A High limit	0.00...40.00	xIn		2	High warning current limit for negative sequence current
Ng Seq A low limit	0.00...40.00	xIn		0.00	Low warning current limit for negative sequence current

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Ng Seq A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for negative sequence current
Ng Seq A deadband	100...100000			2500	Deadband configuration value for negative sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro A Hi high Lim	0.00...40.00	xIn		2	High alarm current limit for zero sequence current
Zro A High limit	0.00...40.00	xIn		2	High warning current limit for zero sequence current
Zro A low limit	0.00...40.00	xIn		0.00	Low warning current limit for zero sequence current
Zro A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for zero sequence current
Zro A deadband	100...100000			2500	Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.8.5 Monitored data

Table 485: I1, I2, I0 Monitored data

Name	Type	Values (Range)	Unit	Description
I2-A	FLOAT32	0.00...40.00	xIn	Measured negative sequence current
I1-A	FLOAT32	0.00...40.00	xIn	Measured positive sequence current
I0-A	FLOAT32	0.00...40.00	xIn	Measured zero sequence current

7.1.8.6 Technical data

Table 486: I1, I2, I0 Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: $f/f_n = \pm 2$ Hz
	±1.0% or ±0.002 × I_n at currents in the range of 0.01...4.00 × I_n
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

7.1.8.7 Technical revision history

Table 487: I1, I2, I0 Technical revision history

Technical revision	Change
A	-
B	Sequence current angle values added to the Monitored data view.
C	Internal improvement.

7.1.9 Sequence voltage measurement V1, V2, V0

7.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence voltage measurement	VSMSQI	U1, U2, U0	V1, V2, V0

7.1.9.2 Function block

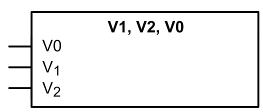


Figure 329: Function block

7.1.9.3 Signals

Table 488: V1, V2, V0 Input signals

Name	Type	Default	Description
V_0	SIGNAL	0	Zero sequence voltage
V_1	SIGNAL	0	Positive phase sequence voltage
V_2	SIGNAL	0	Negative phase sequence voltage

7.1.9.4 Settings

Table 489: V1, V2, V0 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Ps Seq V Hi high Lim	0.00...4.00	xVn		2	High alarm voltage limit for positive sequence voltage
Ps Seq V high limit	0.00...4.00	xVn		2	High warning voltage limit for positive sequence voltage
Ps Seq V low limit	0.00...4.00	xVn		0.00	Low warning voltage limit for positive sequence voltage
Ps Seq V low low Lim	0.00...4.00	xVn		0.00	Low alarm voltage limit for positive sequence voltage
Ps Seq V deadband	100...100000			10000	Deadband configuration value for positive sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq V Hi high Lim	0.00...4.00	xVn		2	High alarm voltage limit for negative sequence voltage
Ng Seq V High limit	0.00...4.00	xVn		2	High warning voltage limit for negative sequence voltage
Ng Seq V low limit	0.00...4.00	xVn		0.00	Low warning voltage limit for negative sequence voltage
Ng Seq V low low Lim	0.00...4.00	xVn		0.00	Low alarm voltage limit for negative sequence voltage
Ng Seq V deadband	100...100000			10000	Deadband configuration value for negative sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro V Hi high Lim	0.00...4.00	xVn		2	High alarm voltage limit for zero sequence voltage
Zro V High limit	0.00...4.00	xVn		2	High warning voltage limit for zero sequence voltage
Zro V low limit	0.00...4.00	xVn		0.00	Low warning voltage limit for zero sequence voltage
Zro V low low Lim	0.00...4.00	xVn		0.00	Low alarm voltage limit for zero sequence voltage
Zro V deadband	100...100000			10000	Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.9.5 Monitored data

Table 490: V1, V2, V0 Monitored data

Name	Type	Values (Range)	Unit	Description
V2-kV	FLOAT32	0.00...4.00	xVn	Measured negative sequence voltage
V1-kV	FLOAT32	0.00...4.00	xVn	Measured positive sequence voltage
V0-kV	FLOAT32	0.00...4.00	xVn	Measured zero sequence voltage

7.1.9.6 Technical data

Table 491: V1, V2, V0 Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × V_n
	±1.0% or ±0.002 × V_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

7.1.10 Three-phase power and energy measurement P, E

7.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase power and energy measurement	PEMMXU	P, E	P, E

7.1.10.2 Function block

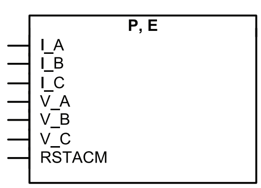


Figure 330: Function block

7.1.10.3 Signals

Table 492: P, E Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
V_A	SIGNAL	0	Phase A voltage
V_B	SIGNAL	0	Phase B voltage
V_C	SIGNAL	0	Phase C voltage
RSTACM	BOOLEAN	0=False	Reset of accumulated energy reading

7.1.10.4 Settings

Table 493: P, E Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Power unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the power related values
Energy unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the energy related values
Active power Dir	1=Forward 2=Reverse			1=Forward	Direction of active power flow: Forward, Reverse
Reactive power Dir	1=Forward 2=Reverse			1=Forward	Direction of reactive power flow: Forward, Reverse
Forward Wh Initial	0...999999999		1	0	Preset Initial value for forward active energy
Reverse Wh Initial	0...999999999		1	0	Preset Initial value for reverse active energy
Forward VArh Initial	0...999999999		1	0	Preset Initial value for forward reactive energy
Reverse VArh Initial	0...999999999		1	0	Preset Initial value for reverse reactive energy

7.1.10.5 Monitored data

Table 494: P, E Monitored data

Name	Type	Values (Range)	Unit	Description
S-kVA	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value
P-kW	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value
Q-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value
PF	FLOAT32	-1.00...1.00		Average Power factor
Max demand S	FLOAT32	-999999.9...999999.9	kVA	Maximum demand value of apparent power
Min demand S	FLOAT32	-999999.9...999999.9	kVA	Minimum demand value of apparent power
Max demand P	FLOAT32	-999999.9...999999.9	kW	Maximum demand value of active power
Min demand P	FLOAT32	-999999.9...999999.9	kW	Minimum demand value of active power
Max demand Q	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand value of reactive power
Min demand Q	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand value of reactive power
Time max dmd S	Timestamp			Time of maximum demand of apparent power
Time min dmd S	Timestamp			Time of minimum demand of apparent power
Time max dmd P	Timestamp			Time of maximum demand of active power
Time min dmd P	Timestamp			Time of minimum demand of active power
Time max dmd Q	Timestamp			Time of maximum demand of reactive power
Time min dmd Q	Timestamp			Time of minimum demand of reactive power

7.1.10.6 Technical data

Table 495: P, E Technical data

Characteristic	Value
Operation accuracy	At all three currents in range 0.10…1.20 × I_n At all three voltages in range 0.50…1.15 × V_n At the frequency f_n ±1 Hz Active power and energy in range |PF| > 0.71 Reactive power and energy in range |PF| < 0.71
	±1.5% for power (S, P and Q) ±0.015 for power factor ±1.5% for energy
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

7.1.11 Single-phase power and energy measurement SP, SE

7.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single-phase power and energy measurement	SPEMMXU	SP, SE	SP, SE

7.1.11.2 Function block

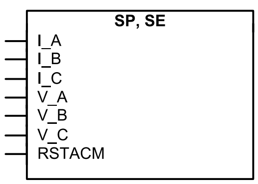


Figure 331: Function block

7.1.11.3 Signals

Table 496: SP, SE Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
Table continues on next page			

Name	Type	Default	Description
V_A	SIGNAL	0	Phase A voltage
V_B	SIGNAL	0	Phase B voltage
V_C	SIGNAL	0	Phase C voltage
RSTACM	BOOLEAN	0=False	Reset of accumulated energy reading

7.1.11.4 Settings

Table 497: SP, SE Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Power unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the power related values
Energy unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the energy related values
Active power Dir	1=Forward 2=Reverse			1=Forward	Direction of active power flow: Forward, Reverse
Reactive power Dir	1=Forward 2=Reverse			1=Forward	Direction of reactive power flow: Forward, Reverse
Forward Wh Initial	0...999999999		1	0	Preset Initial value for forward active energy
Reverse Wh Initial	0...999999999		1	0	Preset Initial value for reverse active energy
Forward VArh Initial	0...999999999		1	0	Preset Initial value for forward reactive energy
Reverse VArh Initial	0...999999999		1	0	Preset Initial value for reverse reactive energy

7.1.11.5 Monitored data

Table 498: SP, SE Monitored data

Name	Type	Values (Range)	Unit	Description
SA-kVA	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value, Phase A
SB-kVA	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value, Phase B
SC-kVA	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value, Phase C
PA-kW	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value, Phase A
PB-kW	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value, Phase B
PC-kW	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value, Phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
QA-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value, Phase A
QB-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value, Phase B
QC-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value, Phase C
PFA	FLOAT32	-1.00...1.00		Power factor, magnitude of instantaneous value, Phase A
PFB	FLOAT32	-1.00...1.00		Power factor, magnitude of instantaneous value, Phase B
PFC	FLOAT32	-1.00...1.00		Power factor, magnitude of instantaneous value, Phase C
Max demand SA	FLOAT32	-999999.9...999999.9	kVA	Maximum demand for Phase SA
Max demand SB	FLOAT32	-999999.9...999999.9	kVA	Maximum demand for Phase SB
Max demand SC	FLOAT32	-999999.9...999999.9	kVA	Maximum demand for Phase SC
Min demand SA	FLOAT32	-999999.9...999999.9	kVA	Minimum demand for Phase SA
Min demand SB	FLOAT32	-999999.9...999999.9	kVA	Minimum demand for Phase SB
Min demand SC	FLOAT32	-999999.9...999999.9	kVA	Minimum demand for Phase SC
Max demand PA	FLOAT32	-999999.9...999999.9	kW	Maximum demand for Phase A
Max demand PB	FLOAT32	-999999.9...999999.9	kW	Maximum demand for Phase B
Max demand PC	FLOAT32	-999999.9...999999.9	kW	Maximum demand for Phase C
Min demand PA	FLOAT32	-999999.9...999999.9	kW	Minimum demand for Phase PA
Min demand PB	FLOAT32	-999999.9...999999.9	kW	Minimum demand for Phase PB
Min demand PC	FLOAT32	-999999.9...999999.9	kW	Minimum demand for Phase PC
Max demand QA	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand for Phase QA
Max demand QB	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand for Phase QB
Max demand QC	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand for Phase QC
Min demand QA	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand for Phase QA

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Min demand QB	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand for Phase QB
Min demand QC	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand for Phase QC
Time max dmd SA	Timestamp			Time of maximum demand phase SA
Time max dmd SB	Timestamp			Time of maximum demand phase SB
Time max dmd SC	Timestamp			Time of maximum demand phase SC
Time max dmd PA	Timestamp			Time of maximum demand phase PA
Time max dmd PB	Timestamp			Time of maximum demand phase PB
Time max dmd PC	Timestamp			Time of maximum demand phase PC
Time max dmd QA	Timestamp			Time of maximum demand phase QA
Time max dmd QB	Timestamp			Time of maximum demand phase QB
Time max dmd QC	Timestamp			Time of maximum demand phase QC
Time min dmd SA	Timestamp			Time of minimum demand phase SA
Time min dmd SB	Timestamp			Time of minimum demand phase SB
Time min dmd SC	Timestamp			Time of minimum demand phase SC
Time min dmd PA	Timestamp			Time of minimum demand phase PA
Time min dmd PB	Timestamp			Time of minimum demand phase PB
Time min dmd PC	Timestamp			Time of minimum demand phase PC
Time min dmd QA	Timestamp			Time of minimum demand phase QA
Time min dmd QB	Timestamp			Time of minimum demand phase QB
Time min dmd QC	Timestamp			Time of minimum demand phase QC

7.1.11.6 Technical data

Table 499: SP, SE Technical data

Characteristic	Value
Operation accuracy	At all three currents in range 0.10…1.20 x I_n At all three voltages in range 0.50…1.15 x V_n At the frequency f_n ±1 Hz Active power and energy in range |PF| > 0.71 Reactive power and energy in range |PF| < 0.71
	±1.5% for power (S, P and Q) ±0.015 for power factor ±1.5% for energy
Suppression of harmonics	DFT: -50 dB at f = n x f_n, where n = 2, 3, 4, 5,…

7.1.12 Frequency measurement f

7.1.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency measurement	FMMXU	f	f

7.1.12.2 Function block

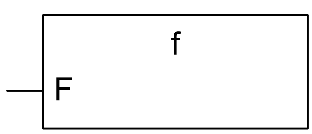


Figure 332: Function block

7.1.12.3 Signals

Table 500: f Input signals

Name	Type	Default	Description
F	SIGNAL	—	Measured system frequency

7.1.12.4 Settings

Table 501: f Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
F high high limit	35.00...75.00	Hz		70	High alarm frequency limit
F high limit	35.00...75.00	Hz		65	High warning frequency limit
F low limit	35.00...75.00	Hz		55	Low warning frequency limit
F low low limit	35.00...75.00	Hz		50	Low alarm frequency limit
F deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

7.1.12.5 Monitored data

Table 502: f Monitored data

Name	Type	Values (Range)	Unit	Description
f-Hz	FLOAT32	35.00...75.00	Hz	Measured frequency

7.1.12.6 Technical data

Table 503: f Technical data

Characteristic	Value
Operation accuracy	±10 mHz (in measurement range 35...75 Hz)

7.2 Tap changer position indication 84T

7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer position indication	TPOSSLTC	TPOSM	84T

7.2.2 Function block

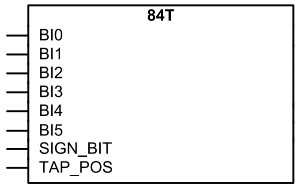


Figure 333: Function block

7.2.3 Functionality

The binary converter function 84T is used for converting binary-coded tap position inputs to their decimal equivalent when a tap position indication is received from the I/O board with the help of the coded binary inputs.

There are three user-selectable conversion modes available for the 7-bit binary inputs where MSB is used as the SIGN bit: the natural binary-coded boolean input to the signed integer output, binary coded decimal BCD input to the signed integer output and binary reflected GRAY coded input to the signed integer output.

7.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”. When the function is disabled, the tap position quality information is changed accordingly. When the tap position information is not available, it is recommended to disable this function with the *Operation* setting.

The operation of the tap changer position indication function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

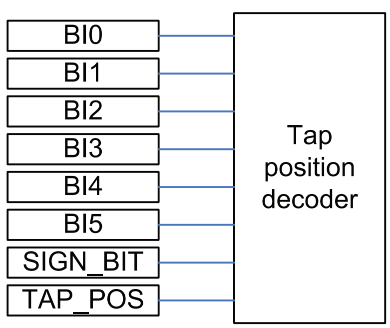


Figure 334: Functional module diagram

Tap position decoder

When there is a wired connection to the TAP_POS input connector, the corresponding tap changer position is decoded from the mA or RTD input. When there is no wired connection to the TAP_POS connector, the binary inputs are expected to be used for the tap changer position information. The tap changer position value and quality are internally shared to other functions. The value is available through the Monitored data view.

The function has three alternative user selectable operation modes: "NAT2INT", "BCD2INT" and "GRAY2INT". The operation mode is selected with the *Operation mode* setting. Each operation mode can be used to convert a maximum of 6–bit coded input to an 8–bit signed short integer output. For less than 6–bit input, for example 19 positions with 5 bits when the BCD coding is used, the rest of the bits can be set to FALSE (0).

The operation mode "NAT2INT" is selected when the natural binary coding is used for showing the position of the transformer tap changer. The basic principle of the natural binary coding is to calculate the sum of the bits set to TRUE (1). The LSB has the factor 1. Each following bit has the previous factor multiplied by 2. This is also called dual coding.

The operation mode "BCD2INT" is selected when the binary-coded decimal coding is used for showing the position of the transformer tap changer. The basic principle with the binary-coded decimal coding is to calculate the sum of the bits set to TRUE (1). The four bits nibble (BI3...BI0) have a typical factor to the natural binary coding. The sum of the values should not be more than 9. If the nibble sum is greater than 9, the tap position output validity is regarded as bad.

The operation mode “GRAY2INT” is selected when the binary-reflected Gray coding is used for showing the position of the transformer tap changer. The basic principle of the Gray coding is that only one actual bit changes value with consecutive positions. This function is based on the common binary-reflected Gray code which is used with some tap changers. Changing the bit closest to the right side bit gives a new pattern.

An additional separate input, SIGN_BIT, can be used for negative values. If the values are positive, the input is set to FALSE (0). If the SIGN_BIT is set to TRUE (1) making the number negative, the remaining bits are identical to those of the coded positive number.

The tap position validity is set to good in all valid cases. The quality is set to bad in invalid combinations in the binary inputs. For example, when the “BCD2INT” mode is selected and the input binary combination is “0001101”, the quality is set to bad. For negative values, when the SIGN_BIT is set to TRUE (1) and the input binary combination is “1011011”, the quality is set to bad.

Table 504: Truth table of the decoding modes

Inputs							TAP_POS outputs		
SIGN_BIT	BI5	BI4	BI3	BI2	BI1	BI0	NAT2INT	BCD2INT	GRAY2INT
...		...		...		...	...	...	...
1	0	0	0	0	1	1	—3	—3	—2
1	0	0	0	0	1	0	—2	—2	—3
1	0	0	0	0	0	1	—1	—1	—1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	1
0	0	0	0	0	1	0	2	2	3
0	0	0	0	0	1	1	3	3	2
0	0	0	0	1	0	0	4	4	7
0	0	0	0	1	0	1	5	5	6
0	0	0	0	1	1	0	6	6	4
0	0	0	0	1	1	1	7	7	5
0	0	0	1	0	0	0	8	8	15
0	0	0	1	0	0	1	9	9	14
0	0	0	1	0	1	0	10	9	12
0	0	0	1	0	1	1	11	9	13
0	0	0	1	1	0	0	12	9	8
0	0	0	1	1	0	1	13	9	9
0	0	0	1	1	1	0	14	9	11
0	0	0	1	1	1	1	15	9	10
0	0	1	0	0	0	0	16	10	31
0	0	1	0	0	0	1	17	11	30
0	0	1	0	0	1	0	18	12	28
0	0	1	0	0	1	1	19	13	29
0	0	1	0	1	0	0	20	14	24
0	0	1	0	1	0	1	21	15	25
0	0	1	0	1	1	0	22	16	27
0	0	1	0	1	1	1	23	17	26
0	0	1	1	0	0	0	24	18	16
0	0	1	1	0	0	1	25	19	17
0	0	1	1	0	1	0	26	19	19
0	0	1	1	0	1	1	27	19	18
0	0	1	1	1	0	0	28	19	23

Table continues on next page

Inputs							TAP_POS outputs		
0	0	1	1	1	0	1	29	19	22
0	0	1	1	1	1	0	30	19	20
0	0	1	1	1	1	1	31	19	21
0	1	0	0	0	0	0	32	20	63
0	1	0	0	0	0	1	33	21	62
0	1	0	0	0	1	0	34	22	60
0	1	0	0	0	1	1	35	23	61
0	1	0	0	1	0	0	36	24	56
...		...		...		...	...	...	...

7.2.5 Application

84T provides tap position information for other functions as a signed integer value that can be fed to the tap position input.

The position information of the tap changer can be coded in various methods for many applications, for example, the differential protection algorithms. In this function, the binary inputs in the transformer terminal connector are used as inputs to the function. The coding method can be chosen by setting the mode parameter. The available coding methods are BCD, Gray and Natural binary coding. Since the number of binary inputs are limited to seven, the coding functions are limited to seven bits including the sign bit and thus the six bits are used in the coding functions. The position limits for the tap positions at BCD, Gray and Natural binary coding are ±39, ±63 and ±63 respectively.

In this example, the transformer tap changer position indication is wired as a mA signal from the corresponding measuring transducer. The position indication is connected to input 1 (`AI_VAL1`) of the X130 (RTD) card. The tap changer operating range from the minimum to maximum turns of the tap and a corresponding mA signal for the tap position are set in XRGGIO130. Since the values of the XRGGIO130 outputs are floating point numbers, the float to integer (T_F32_INT8) conversion is needed before the tap position information can be fed to 84T. When there is a wired connection to the `TAP_POS` connector, the validated tap changer position is presented in the `TAP_POS` output that is connected to other functions. When there is no wired connection to the `TAP_POS` connector, the binary inputs are expected to be used for the tap changer position information.

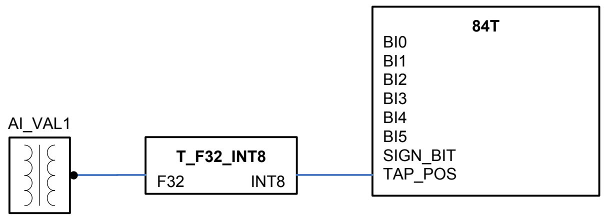


Figure 335: RTD/analog input configuration example

7.2.6 Signals

Table 505: 84T Input signals

Name	Type	Default	Description
BI0	BOOLEAN	0=False	Binary input 1
BI1	BOOLEAN	0=False	Binary input 2
BI2	BOOLEAN	0=False	Binary input 3
BI3	BOOLEAN	0=False	Binary input 4
BI4	BOOLEAN	0=False	Binary input 5
BI5	BOOLEAN	0=False	Binary input 6
SIGN_BIT	BOOLEAN	0=False	Binary input sign bit
TAP_POS	INT8	0	Tap position indication

7.2.7 Settings

Table 506: 84T Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Operation mode	1=NAT2INT 2=BCD2INT 3=GRAY2INT			2=BCD2INT	Operation mode selection

7.2.8 Monitored data

7.2.9 Technical data

Table 507: 84T Technical data

Descrpition	Value
Response time for binary inputs	Typical 100 ms

Section 8 Power quality measurement functions

8.1 Current total demand distortion PQI

8.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current total demand distortion	CMHAI	PQM3I	PQI

8.1.2 Function block

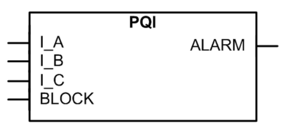


Figure 336: Function block

8.1.3 Functionality

The current total demand distortion PQI is used for monitoring the current total demand distortion TDD.

8.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the current distortion monitoring function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

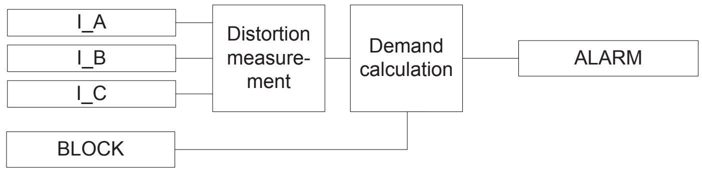


Figure 337: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total demand distortion TDD is calculated from the measured harmonic components with the formula

$$TDD = \frac{\sqrt{\sum_{k=2}^{N} I_k^2}}{I_{max\_demand}}$$

(Equation 101)

I_k	k^{th} harmonic component
I_{max_demand}	The maximum demand current measured by IA, IB, IC

If IA, IB, IC are not available in the configuration or the measured maximum demand current is less than the *Initial Dmd current* setting, *Initial Dmd current* is used for I_{max_demand}.

Demand calculation

The demand value for TDD is calculated separately for each phase. If any of the calculated total demand distortion values is above the set alarm limit *TDD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

8.1.5 Application

In standards, the power quality is defined through the characteristics of the supply voltage. Transients, short-duration and long-duration voltage variations, unbalance and waveform distortions are the key characteristics describing power quality. Power quality is, however, a customer-driven issue. It could be said that any power problem concerning voltage or current that results in a failure or misoperation of customer equipment is a power quality problem.

Harmonic distortion in a power system is caused by nonlinear devices. Electronic power converter loads constitute the most important class of nonlinear loads in a power system. The switch mode power supplies in a number of single-phase electronic equipment, such as personal computers, printers and copiers, have a very high third-harmonic content in the current. Three-phase electronic power converters, that is, dc/ac drives, however, do not generate third-harmonic currents. Still, they can be significant sources of harmonics.

Power quality monitoring is an essential service that utilities can provide for their industrial and key customers. Not only can a monitoring system provide information about system disturbances and their possible causes, it can also detect problem conditions throughout the system before they cause customer complaints, equipment malfunctions and even equipment damage or failure. Power quality problems are not limited to the utility side of the system. In fact, the majority of power quality problems are localized within customer facilities. Thus, power quality monitoring is not only an effective customer service strategy but also a way to protect a utility's reputation for quality power and service.

PQI provides a method for monitoring the power quality by means of the current waveform distortion. PQI provides a short-term 3-second average and a long-term demand for TDD.

8.1.6 Signals

Table 508: PQI Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 509: PQI Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for TDD

8.1.7 Settings

Table 510: PQI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			2=10 minutes	Time interval for demand calculation
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
TDD alarm limit	1.0...100.0	%	0.1	50.0	TDD alarm limit
Initial Dmd current	0.10...1.00	xIn	0.01	1.00	Initial demand current

8.1.8 Monitored data

Table 511: PQI Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand TDD IA	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase A
Max demand TDD IB	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase B
Max demand TDD IC	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase C
Time max dmd TDD IA	Timestamp			Time of maximum demand TDD phase A
Time max dmd TDD IB	Timestamp			Time of maximum demand TDD phase B
Time max dmd TDD IC	Timestamp			Time of maximum demand TDD phase C
3SMHTDD_A	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase A
DMD_TDD_A	FLOAT32	0.00...500.00	%	Demand value for TDD for phase A
3SMHTDD_B	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase B
DMD_TDD_B	FLOAT32	0.00...500.00	%	Demand value for TDD for phase B
3SMHTDD_C	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase C
DMD_TDD_C	FLOAT32	0.00...500.00	%	Demand value for TDD for phase C

8.2 Voltage total harmonic distortion PQVPH

8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage total harmonic distortion	VMHAI	PQM3U	PQVPH

8.2.2 Function block

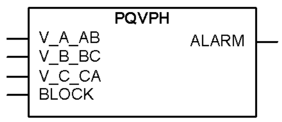


Figure 338: Function block

8.2.3 Functionality

The voltage total harmonic distortion function PQVPH is used for monitoring the voltage total harmonic distortion THD.

8.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the voltage distortion monitoring function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

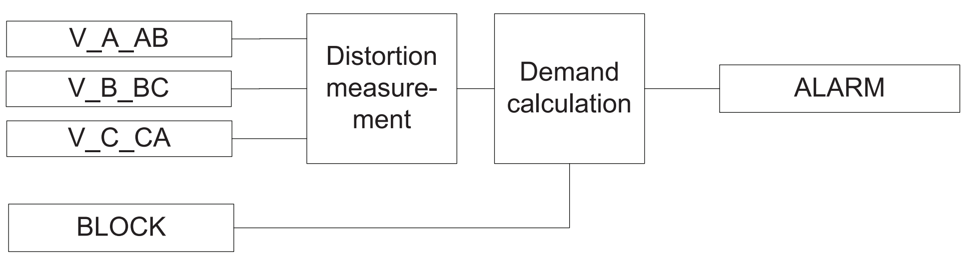


Figure 339: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total harmonic distortion THD for voltage is calculated from the measured harmonic components with the formula

$$THD = \frac{\sqrt{\sum_{k=2}^{N} V_k^2}}{V_1}$$

(Equation 102)

V_k k^{th} harmonic component

V_1 the voltage fundamental component amplitude

Demand calculation

The demand value for THD is calculated separately for each phase. If any of the calculated demand THD values is above the set alarm limit *THD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

8.2.5 Application

PQVPH provides a method for monitoring the power quality by means of the voltage waveform distortion. PQVPH provides a short-term three-second average and long-term demand for THD.

8.2.6 Signals

Table 512: PQVPH Input signals

Name	Type	Default	Description
V_A_AB	SIGNAL	0	Phase A voltage
V_B_BC	SIGNAL	0	Phase B voltage
V_C_CA	SIGNAL	0	Phase C voltage
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 513: PQVPH Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for THD

8.2.7 Settings

Table 514: PQVPH Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			2=10 minutes	Time interval for demand calculation
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
THD alarm limit	1.0...100.0	%	0.1	50.0	THD alarm limit

8.2.8 Monitored data

Table 515: PQVPH Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand THD VA	FLOAT32	0.00...500.00	%	Maximum demand THD for phase A
Max demand THD VB	FLOAT32	0.00...500.00	%	Maximum demand THD for phase B
Max demand THD VC	FLOAT32	0.00...500.00	%	Maximum demand THD for phase C
Time max dmd THD VA	Timestamp			Time of maximum demand THD phase A
Time max dmd THD VB	Timestamp			Time of maximum demand THD phase B
Time max dmd THD VC	Timestamp			Time of maximum demand THD phase C
3SMHTHD_A	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase A
DMD_THD_A	FLOAT32	0.00...500.00	%	Demand value for THD for phase A
3SMHTHD_B	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase B

Table continues on next page

Name	Type	Values (Range)	Unit	Description
DMD_THD_B	FLOAT32	0.00...500.00	%	Demand value for THD for phase B
3SMHTHD_C	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase C
DMD_THD_C	FLOAT32	0.00...500.00	%	Demand value for THD for phase C

8.3 Voltage variation PQSS

8.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage variation	PHQVVR	PQ 3U<>	PQSS

8.3.2 Function block

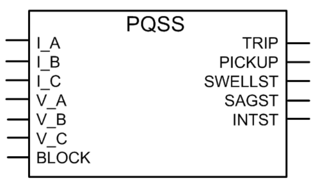


Figure 340: Function block

8.3.3 Functionality

The voltage variation measurement function PQSS is used for measuring the short-duration voltage variations in distribution networks.

Power quality in the voltage waveform is evaluated by measuring voltage swells, dips and interruptions. PQSS includes single-phase and three-phase voltage variation modes.

Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute. The maximum magnitude (in the case of a voltage swell) or depth (in the case of a voltage dip or interruption) and the duration of the variation can be obtained by measuring the RMS value of the voltage for each phase. International standard 61000-4-30 defines the voltage variation to be implemented using the RMS value of the voltage. IEEE standard 1159-1995 provides recommendations for monitoring the electric power quality of the single-phase and polyphase ac power systems.

PQSS contains a blocking functionality. It is possible to block a set of function outputs or the function itself, if desired.

8.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the voltage variation detection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

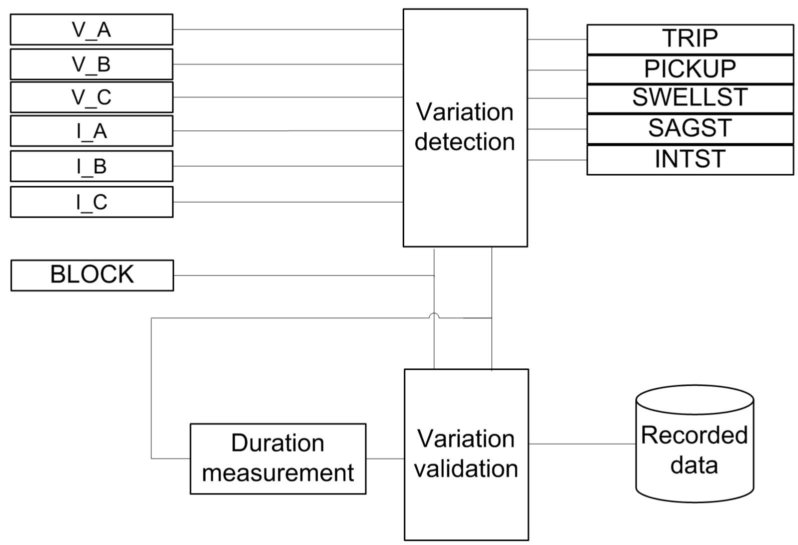


Figure 341: Functional module diagram

8.3.4.1 Phase mode setting

PQSS is designed for both single-phase and polyphase ac power systems, and selection can be made with the *Phase mode* setting, which can be set either to the "Single Phase" or "Three Phase" mode. The default setting is "Single Phase".

The basic difference between these alternatives depends on how many phases are needed to have the voltage variation activated. When the *Phase mode* setting is "Single Phase", the activation is straightforward. There is no dependence between the phases for variation pickup. The `PICKUP` output and the corresponding phase pickup are activated when the limit is exceeded or undershot. The corresponding phase pickup deactivation takes place when the limit (includes small hysteresis) is undershot or exceeded. The `PICKUP` output is deactivated when there are no more active phases.

However, when *Phase mode* is "Three Phase", all the monitored phase signal magnitudes, defined with *Phase supervision*, have to fall below or rise above the limit setting to activate the PICKUP output and the corresponding phase output, that is, all the monitored phases have to be activated. Accordingly, the deactivation occurs when the activation requirement is not fulfilled, that is, one or more monitored phase signal magnitudes return beyond their limits. Phases do not need to be activated by the same variation type to activate the PICKUP output. Another consequence is that if only one or two phases are monitored, it is sufficient that these monitored phases activate the PICKUP output.

8.3.4.2 Variation detection

The module compares the measured voltage against the limit settings. If there is a permanent undervoltage or overvoltage, the *Reference voltage* setting can be set to this voltage level to avoid the undesired voltage dip or swell indications. This is accomplished by converting the variation limits with the *Reference voltage* setting in the variation detection module, that is, when there is a voltage different from the nominal voltage, the *Reference voltage* setting is set to this voltage.

The *Variation enable* setting is used for enabling or disabling the variation types. By default, the setting value is "Swell+dip+Int" and all the alternative variation types are indicated. For example, for setting "Swell+dip", the interruption detection is not active and only swell or dip events are indicated.

In a case where *Phase mode* is "Single Phase" and the dip functionality is available, the output DIPST is activated when the measured TRMS value drops below the *Voltage dip set 3* setting in one phase and also remains above the *Voltage Int set* setting. If the voltage drops below the *Voltage Int set* setting, the output INTST is activated. INTST is deactivated when the voltage value rises above the setting *Voltage Int set*. When the same measured TRMS magnitude rises above the setting *Voltage swell set 3*, the SWELLST output is activated.

There are three setting value limits for dip (*Voltage dip set 1..3*) and swell activation (*Voltage swell set 1..3*) and one setting value limit for interruption.

If *Phase mode* is "Three Phase", the DIPST and INTST outputs are activated when the voltage levels of all monitored phases, defined with the parameter *Phase supervision*, drop below the *Voltage Int set* setting value. An example for the detection principle of voltage interruption for "Three Phase" when *Phase supervision* is "Ph A + B + C", and also the corresponding pickup signals when *Phase mode* is "Single Phase", are as shown in the example for the detection of a three-phase interruption.

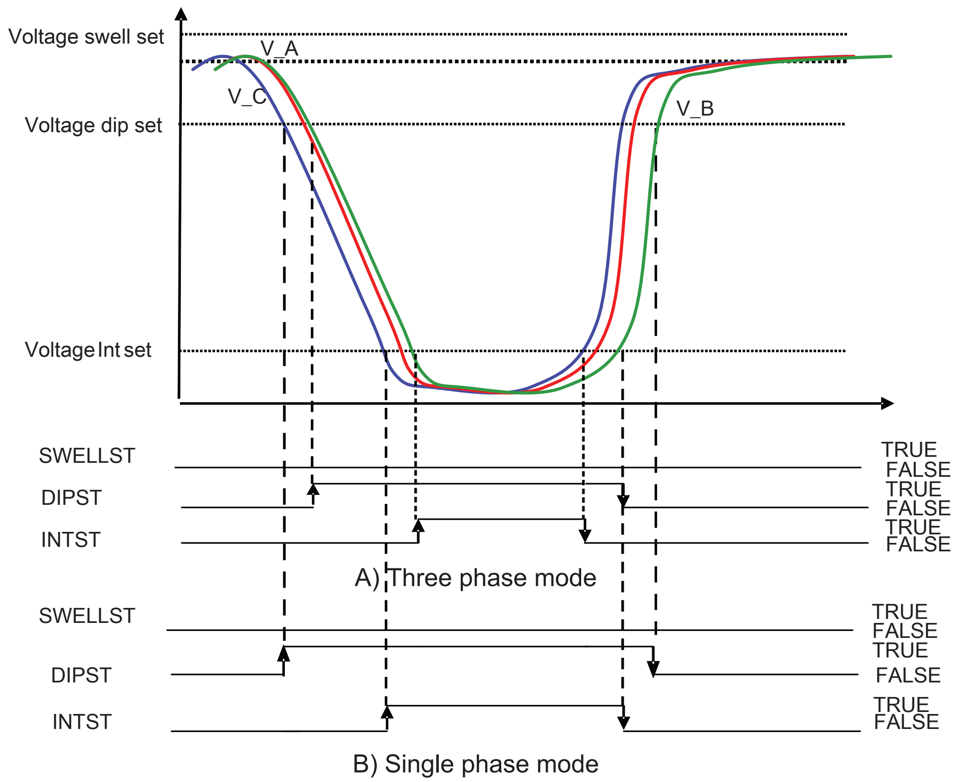


Figure 342: Detection of three-phase voltage interruption

The module measures voltage variation magnitude on each phase separately, that is, phase-segregated status for voltage variation indication is available in monitored data (PICKUP_A, PICKUP_B and PICKUP_C). The configuration parameter *Phase supervision* defines which voltage phase or phases are monitored. If a voltage phase is selected to be monitored, the function assumes it to be connected to a voltage measurement channel. In other words, if an unconnected phase is monitored, the function falsely detects a voltage interruption in that phase.

The maximum magnitude and depth are defined as percentage values calculated from the difference between the reference and the measured voltage. For example, a dip to 70 percent means that the minimum voltage dip magnitude variation is 70 percent of the reference dip voltage amplitude.

The activation of the `BLOCK` input resets the function and outputs.

8.3.4.3 Variation validation

The validation criterion for voltage variation is that the measured total variation duration is between the set minimum and maximum durations (Either one of *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, depending on the variation type, and *VVa Dur Max*). The maximum variation duration setting is the same for all variation types.

Figure 343 shows voltage dip operational regions. In Figure 342, only one voltage dip/swell/Int set is drawn, whereas in this figure there are three sub-limits for the dip operation. When *Voltage dip set 3* is undershot, the corresponding `PICKUP_x` and also the `DIPST` outputs are activated. When the TRMS voltage magnitude remains between *Voltage dip set 2* and *Voltage dip set 1* for a period longer than *VVa dip time 2* (shorter time than *VVa dip time 3*), a momentary dip event is detected. Furthermore, if the signal magnitude stays between the limits longer than *VVa dip time 3* (shorter time than *VVa Dur max*), a temporary dip event is detected. If the voltage remains below *Voltage dip set 1* for a period longer than *VVa dip time 1* but a shorter time than *VVa dip time 2*, an instantaneous dip event is detected.

For an event detection, the `TRIP` output is always activated for one task cycle. The corresponding counter and only one of them (INSTDIPCNT, MOMDIPCNT or TEMPDIPCNT) is increased by one. If the dip limit undershooting duration is shorter than *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, the event is not detected at all, and if the duration is longer than *VVa Dur Max*, MAXDURDIPCNT is increased by one but no event detection resulting in the activation of the `TRIP` output and recording data update takes place. These counters are available through the monitored data view on the LHMI or through tools via communications. There are no phase-segregated counters but all the variation detections are registered to a common time/magnitude-classified counter type. Consequently, a simultaneous multiphase event, that is, the variation-type event detection time moment is exactly the same for two or more phases, is counted only once also for single-phase power systems.

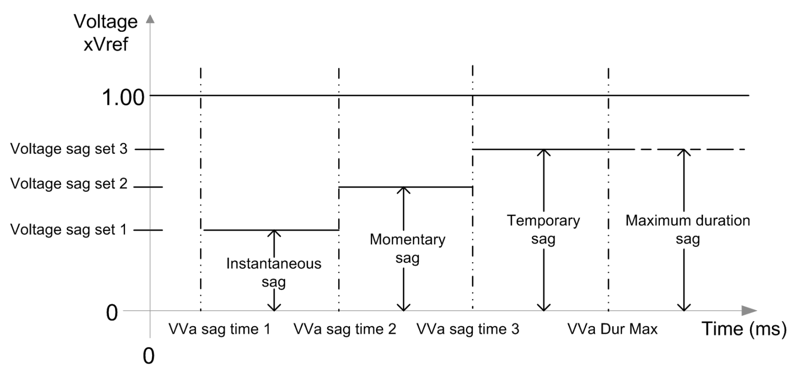


Figure 343: Voltage dip operational regions

In Figure 344, the corresponding limits regarding the swell operation are provided with the inherent magnitude limit order difference. The swell functionality principle is the same as for dips, but the different limits for the signal magnitude and times and the inherent operating zone change (here, *Voltage swell set x* > 1.0 xVn) are applied.

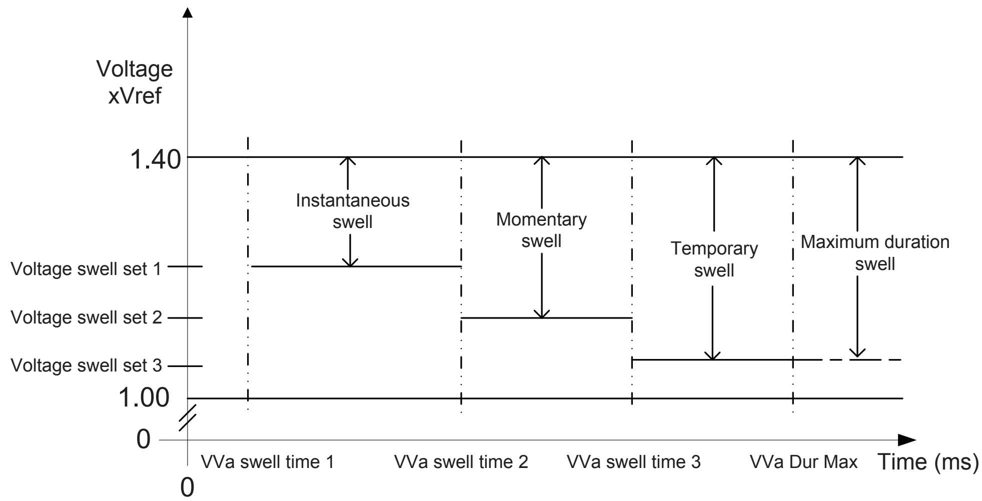


Figure 344: Voltage swell operational regions

For interruption, as shown in Figure 345, there is only one magnitude limit but four duration limits for interruption classification. Now the event and counter type depends only on variation duration time.

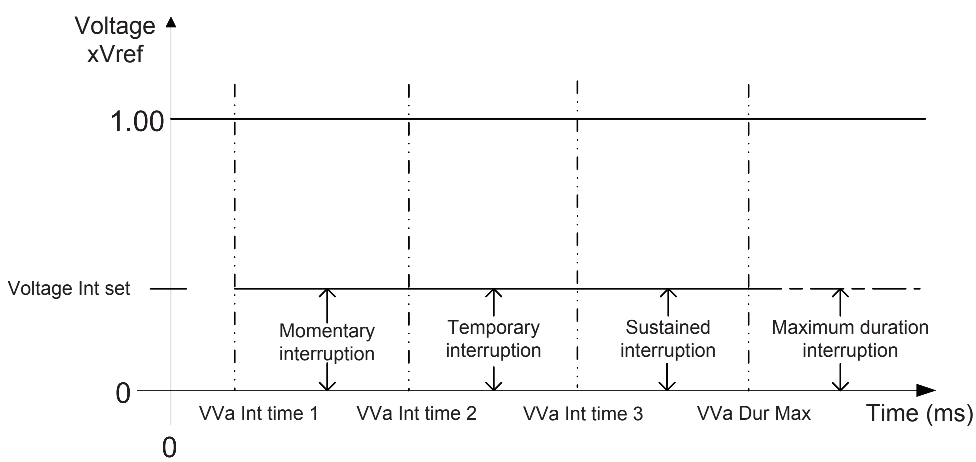


Figure 345: Interruption operating regions

Generally, no event detection is done if both the magnitude and duration requirements are not fulfilled. For example, the dip event does not indicate if the TRMS voltage magnitude remains between *Voltage dip set 3* and *Voltage dip set 2* for a period shorter than *VVa dip time 3* before rising back above *Voltage dip set 3*.

The event indication ends and possible detection is done when the TRMS voltage returns above (for dip and interruption) or below (for swell) the activation pickup limit. For example, after an instantaneous dip, the event indication when the voltage magnitude exceeds *Voltage dip set 1* is not detected (and recorded) immediately but only if no longer dip indication for the same dip variation takes place and the maximum duration time for dip variation is not exceeded before the signal magnitude rises above *Voltage dip set 3*. There is a small hysteresis for all these limits to avoid the oscillation of the output activation. No drop-off approach is applied here due to this hysteresis.

Consequently, only one event detection and recording of the same variation type can take place for one voltage variation, so the longest indicated variation of each variation type is detected. Furthermore, it is possible that another instantaneous dip event replaces the one already indicated if the magnitude again undershoots *Voltage dip set 1* for the set time after the first detection and the signal magnitude or time requirement is again fulfilled. Another possibility is that if the time condition is not fulfilled for an instantaneous dip detection but the signal rises above *Voltage dip set 1*, the already elapsed time is included in the momentary dip timer. Especially the interruption time is included in the dip time. If the signal does not exceed *Voltage dip set 2* before the timer *VVa dip time 2* has elapsed when the momentary dip timer is also started after the magnitude undershooting *Voltage dip set 2*, the momentary dip event instead is detected. Consequently, the same dip occurrence with a changing variation depth can result in several dip event indications but only one detection. For example, if the magnitude has undershot *Voltage dip set 1* but remained above *Voltage Intr set* for a shorter time than the value of *VVa dip time 1* but the signal rises between *Voltage dip set 1* and *Voltage dip set 2* so that the total duration of the dip activation is longer than *VVa dip time 2* and the maximum time is not overshot, this is detected as a momentary dip even though a short instantaneous dip period has been included. In text, the terms "deeper" and "higher" are used for referring to dip or interruption.

Although examples are given for dip events, the same rules can be applied to the swell and interruption functionality too. For swell indication, "deeper" means that the signal rises even more and "higher" means that the signal magnitude becomes lower respectively.

The adjustable voltage thresholds adhere to the relationships:

VVa dip time 1 ≤ *VVa dip time 2* ≤ *VVa dip time 3*.

VVa swell time 1 ≤ *VVa swell time 2* ≤ *VVa swell time 3*.

VVa Int time 1 ≤ *VVa Int time 2* ≤ *VVa Int time 3*.

There is a validation functionality built-in function that checks the relationship adherence so that if *VVa x time 1* is set higher than *VVa x time 2* or *VVa x time 3*, *VVa x time 2* and *VVa x time 3* are set equal to the new *VVa x time 1*. If *VVa x time 2* is set higher than *VVa x time 3*, *VVa x time 3* is set to the new *VVa x time 2*. If *VVa x time 2* is set lower than *VVa x time 1*, the entered *VVa x time 2* is rejected. If *VVa x time 3* is set lower than *VVa x time 2*, the entered *VVa x time 3* is rejected.

8.3.4.4 Duration measurement

The duration of each voltage phase corresponds to the period during which the measured TRMS values remain above (swell) or below (dip, interruption) the corresponding limit.

Besides the three limit settings for the variation types dip and swell, there is also a specific duration setting for each limit setting. For interruption, there is only one limit setting common for the three duration settings. The maximum duration setting is common for all variation types.

The duration measurement module measures the voltage variation duration of each phase voltage separately when the *Phase mode* setting is "Single Phase". The phase variation durations are independent. However, when the *Phase mode* setting is "Three Phase", voltage variation may pick up only when all the monitored phases are active. An example of variation duration when *Phase mode* is "Single Phase" can be seen in Figure 346. The voltage variation in the example is detected as an interruption for the phase B and a dip for the phase A, and also the variation durations are interpreted as independent `V_B` and `V_A` durations. In case of single-phase interruption, the `DIPST` output is active when either `PICKUP_A` or `PICKUP_B` is active. The measured variation durations are the times measured between the activation of the `PICKUP_A` or `PICKUP_B` outputs and deactivation of the `PICKUP_A` or `PICKUP_B` outputs. When the *Phase mode* setting is "Three Phase", the example case does not result in any activation.

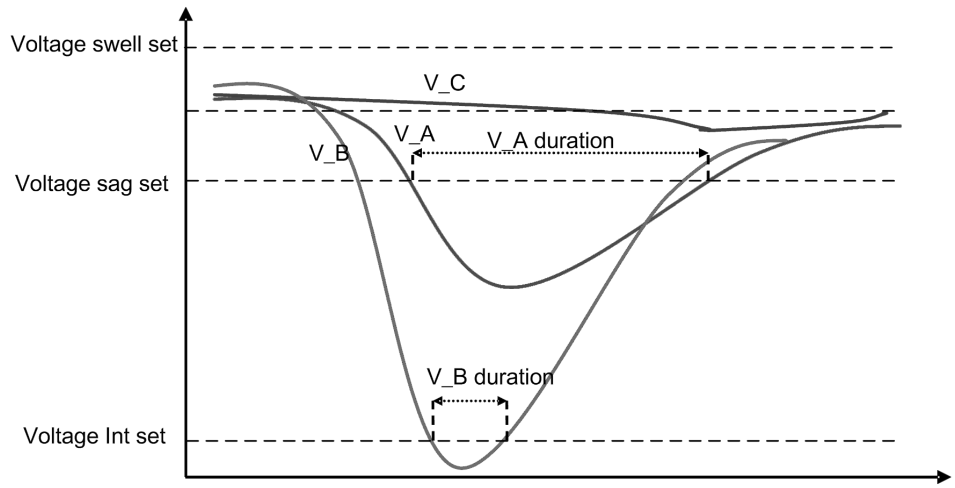


Figure 346: Single-phase interruption for the Phase mode value "Single Phase"

8.3.4.5 Three/single-phase selection variation examples

The provided rules always apply for single-phase (*Phase Mode* is "Single Phase") power systems. However, for three-phase power systems (where *Phase Mode* is "Three Phase"), it is required that all the phases have to be activated before the activation of the PICKUP output. Interruption event indication requires all three phases to undershoot *Voltage Int set* simultaneously, as shown in Figure 342. When the requirement for interruption for "Three Phase" is no longer fulfilled, variation is indicated as a dip as long as all phases are active.

In case of a single-phase interruption of Figure 346, when there is a dip indicated in another phase but the third phase is not active, there is no variation indication pickup when *Phase Mode* is "Three Phase". In this case, only the *Phase Mode* value "Single Phase" results in the PICKUP_B interruption and the PICKUP_A dip.

It is also possible that there are simultaneously a dip in one phase and a swell in other phases. The functionality of the corresponding event indication with one inactive phase is shown in Figure 347. Here, the "Swell + dip" variation type of *Phase mode* is "Single Phase". For the selection "Three Phase" of *Phase mode*, no event indication or any activation takes place due to a non-active phase.

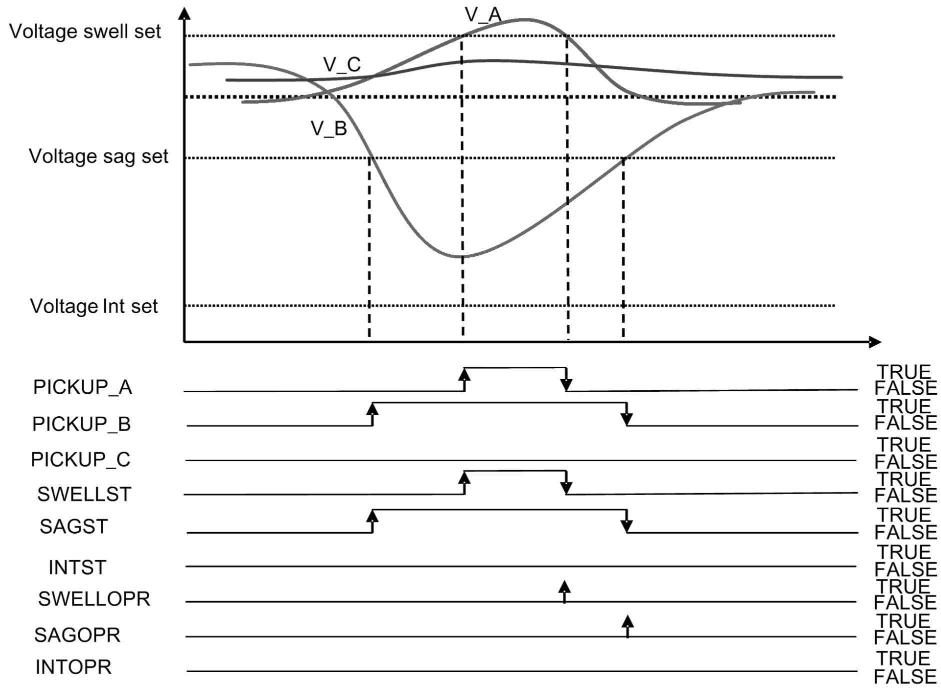


Figure 347: Concurrent dip and swell when Phase mode is "Single Phase"

In Figure 348, one phase is in dip and two phases have a swell indication. For the *Phase Mode Dip* value "Three Phase", the activation occurs only when all the phases are active. Furthermore, both swell and dip variation event detections take place simultaneously. In case of a concurrent voltage dip and voltage swell, both SWELLCNT and DIPCNT are incremented by one.

Also Figure 348 shows that for the *Phase Mode* value "Three Phase", two different time moment variation event swell detections take place and, consequently, DIPCNT is incremented by one but SWELLCNT is totally incremented by two. Both in Figure 347 and Figure 348 it is assumed that variation durations are sufficient for detections to take place.

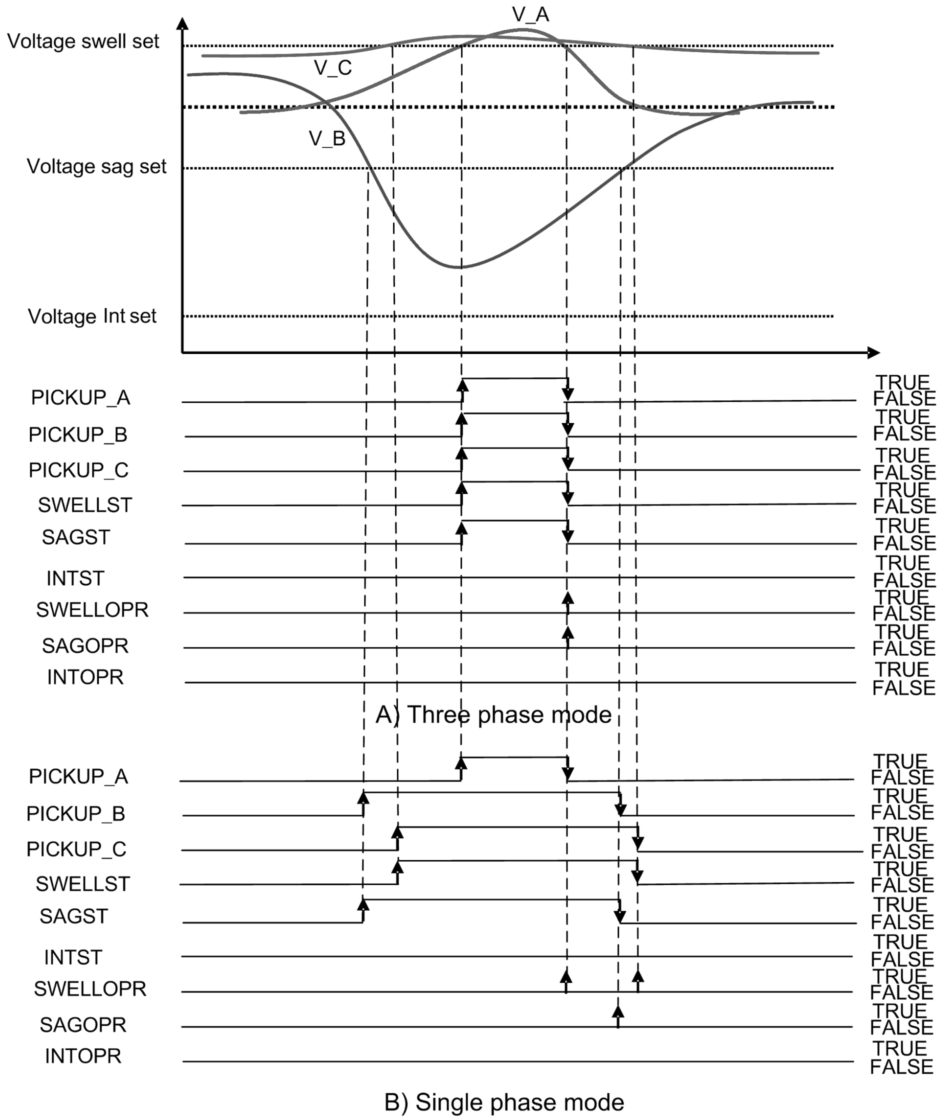


Figure 348: Concurrent dip and two-phase swell

8.3.5 Recorded data

Besides counter increments, the information required for a later fault analysis is stored after a valid voltage variation is detected.

Recorded data information

When voltage variation starts, the phase current magnitudes preceding the activation moment are stored. Also, the initial voltage magnitudes are temporarily stored at the variation pickup moment. If the variation is, for example, a two-phase voltage dip, the voltage magnitude of the non-active phase is stored from this same moment, as shown in Figure 349. The function tracks each variation-active voltage phase, and the minimum or maximum magnitude corresponding to swell or dip/interruption during variation is temporarily stored. If the minimum or maximum is found in tracking and a new magnitude is stored, also the inactive phase voltages are stored at the same moment, that is, the inactive phases are not magnitude-tracked. The time instant (time stamp) at which the minimum or maximum magnitude is measured is also temporarily stored for each voltage phase where variation is active. Finally, variation detection triggers the recorded data update when the variation activation ends and the maximum duration time is not exceeded.

The data objects to be recorded for PQSS are given in Table 516. There are totally three data banks, and the information given in the table refers to one data bank content.

The three sets of recorded data available are saved in data banks 1-3. The data bank 1 holds always the most recent recorded data, and the older data sets are moved to the next banks (1→2 and 2→3) when a valid voltage variation is detected. When all three banks have data and a new variation is detected, the newest data are placed into bank 1 and the data in bank 3 are overwritten by the data from bank 2.

Figure 349 shows a valid recorded voltage interruption and two dips for the *Phase mode* value "Single Phase". The first dip event duration is based on the `V_A` duration, while the second dip is based on the time difference between the dip stop and start times. The first detected event is an interruption based on the `V_B` duration given in Figure 349. It is shown also with dotted arrows how voltage time stamps are taken before the final time stamp for recording, which is shown as a solid arrow. Here, the `V_B` timestamp is not taken when the `V_A` activation starts.

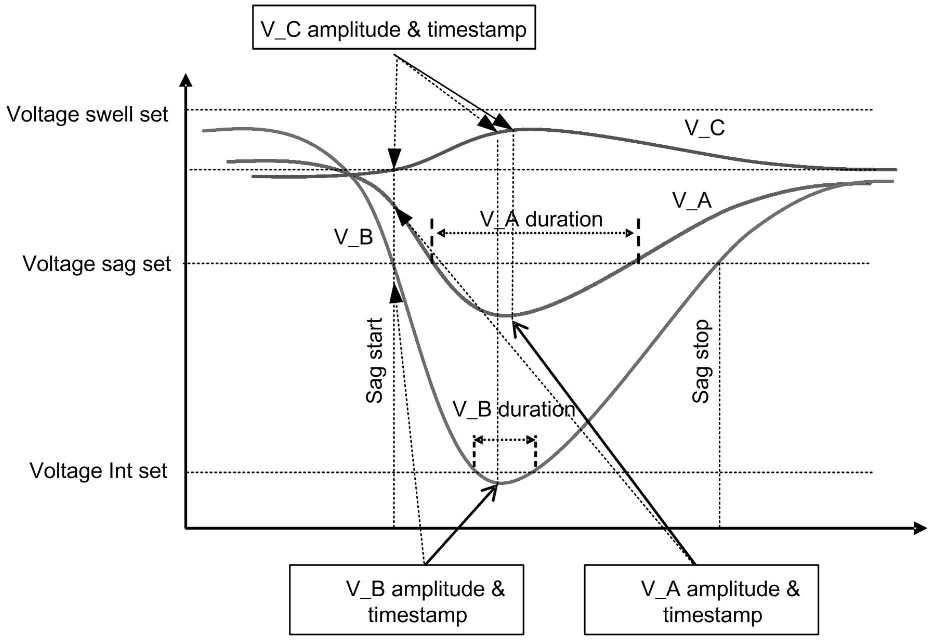


Figure 349: Valid recorded voltage interruption and two dips

Table 516: PQSS recording data bank parameters

Parameter description	Parameter name
Event detection triggering time stamp	Time
Variation type	Variation type
Variation magnitude Ph A	Variation Ph A
Variation magnitude Ph A time stamp (maximum/ minimum magnitude measuring time moment during variation)	Var Ph A rec time
Variation magnitude Ph B	Variation Ph B
Variation magnitude Ph B time stamp (maximum/ minimum magnitude measuring time moment during variation)	Var Ph B rec time
Variation magnitude Ph C	Variation Ph C
Variation magnitude Ph C time stamp (maximum/ minimum magnitude measuring time moment during variation)	Var Ph C rec time
Variation duration Ph A	Variation Dur Ph A
Variation Ph A start time stamp (phase A variation start time moment)	Var Dur Ph A time
Variation duration Ph B	Variation Dur Ph B

Table continues on next page

Parameter description	Parameter name
Variation Ph B start time stamp (phase B variation start time moment)	Var Dur Ph B time
Variation duration Ph C	Variation Dur Ph C
Variation Ph C start time stamp (phase C variation start time moment)	Var Dur Ph C time
Current magnitude Ph A preceding variation	Var current Ph A
Current magnitude Ph B preceding variation	Var current Ph B
Current magnitude Ph C preceding variation	Var current Ph C

Table 517: Enumeration values for the recorded data parameters

Setting name	Enum name	Value
Variation type	Swell	1
Variation type	Dip	2
Variation type	Swell + dip	3
Variation type	Interruption	4
Variation type	Swell + Int	5
Variation type	Dip + Int	6
Variation type	Swell+dip+Int	7

8.3.6 Application

Voltage variations are the most typical power quality variations on the public electric network. Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute (European Standard EN 50160 and IEEE Std 1159-1995).

These short-duration voltage variations are almost always caused by a fault condition. Depending on where the fault is located, it can cause either a temporary voltage rise (swell) or voltage drop (dip). A special case of voltage drop is the complete loss of voltage (interruption).

PQSS is used for measuring short-duration voltage variations in distribution networks. The power quality is evaluated in the voltage waveform by measuring the voltage swells, dips and interruptions.

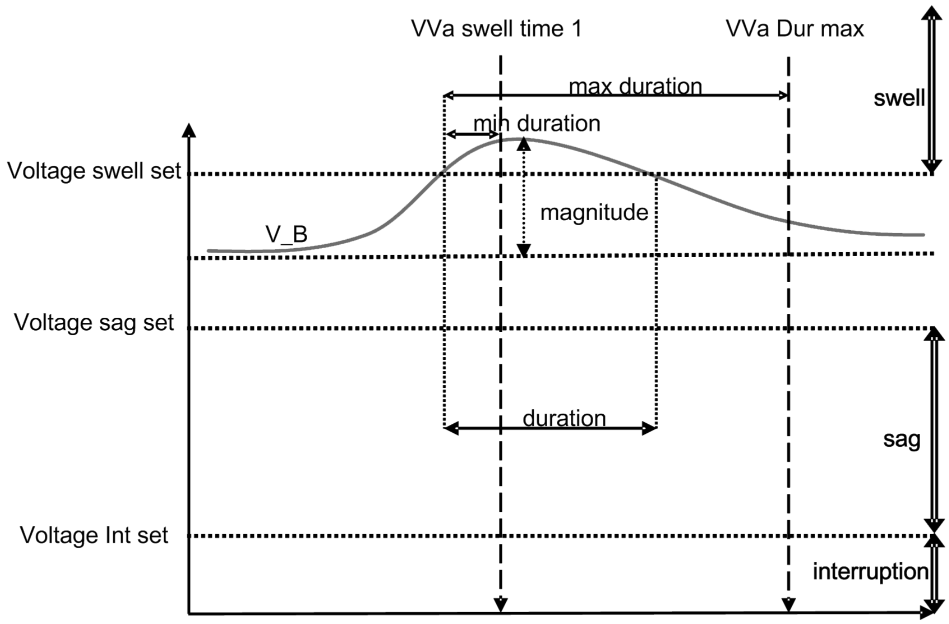


Figure 350: Duration and voltage magnitude limits for swell, dip and interruption measurement

Voltage dips disturb the sensitive equipment such as computers connected to the power system and may result in the failure of the equipment. Voltage dips are typically caused by faults occurring in the power distribution system. Typical reasons for the faults are lightning strikes and tree contacts. In addition to fault situations, the switching of heavy loads and starting of large motors also cause dips.

Voltage swells cause extra stress for the network components and the devices connected to the power system. Voltage swells are typically caused by the earth faults that occur in the power distribution system.

Voltage interruptions are typically associated with the switchgear operation related to the occurrence and termination of short circuits. The operation of a circuit breaker disconnects a part of the system from the source of energy. In the case of overhead networks, automatic reclosing sequences are often applied to the circuit breakers that interrupt fault currents. All these actions result in a sudden reduction of voltages on all voltage phases.

Due to the nature of voltage variations, the power quality standards do not specify any acceptance limits. There are only indicative values for, for example, voltage dips in the European standard EN 50160. However, the power quality standards like the international standard IEC 61000-4-30 specify that the voltage variation event is characterized by its duration and magnitude. Furthermore, IEEE Std 1159-1995 gives the recommended practice for monitoring the electric power quality.

Voltage variation measurement can be done to the phase-to-earth and phase-to-phase voltages. The power quality standards do not specify whether the measurement should be done to phase or phase-to-phase voltages. However, in some cases it is preferable to use phase-to-earth voltages for measurement. The measurement mode is always TRMS.

8.3.7 Signals

Table 518: PQSS Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
V_A	SIGNAL	0	Phase A voltage
V_B	SIGNAL	0	Phase B voltage
V_C	SIGNAL	0	Phase C voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 519: PQSS Output signals

Name	Type	Description
TRIP	BOOLEAN	Voltage variation detected
PICKUP	BOOLEAN	Voltage variation present
SWELLST	BOOLEAN	Voltage swell active
DIPST	BOOLEAN	Voltage dip active
INTST	BOOLEAN	Voltage interruption active

8.3.8 Settings

Table 520: PQSS Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Reference voltage	10.0...200.0	%Un	0.1	57.7	Reference supply voltage in %
Voltage dip set 1	10.0...100.0	%	0.1	80.0	Dip limit 1 in % of reference voltage
VVa dip time 1	0.5...54.0	cycles	0.1	3.0	Voltage variation dip duration 1
Voltage dip set 2	10.0...100.0	%	0.1	80.0	Dip limit 2 in % of reference voltage
VVa dip time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation dip duration 2
Voltage dip set 3	10.0...100.0	%	0.1	80.0	Dip limit 3 in % of reference voltage
VVa dip time 3	2000...60000	ms	10	3000	Voltage variation dip duration 3
Voltage swell set 1	100.0...140.0	%	0.1	120.0	Swell limit 1 in % of reference voltage
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
VVa swell time 1	0.5...54.0	cycles	0.1	0.5	Voltage variation swell duration 1
Voltage swell set 2	100.0...140.0	%	0.1	120.0	Swell limit 2 in % of reference voltage
VVa swell time 2	10.0...80.0	cycles	0.1	10.0	Voltage variation swell duration 2
Voltage swell set 3	100.0...140.0	%	0.1	120.0	Swell limit 3 in % of reference voltage
VVa swell time 3	2000...60000	ms	10	2000	Voltage variation swell duration 3
Voltage Int set	0.0...100.0	%	0.1	10.0	Interruption limit in % of reference voltage
VVa Int time 1	0.5...30.0	cycles	0.1	3.0	Voltage variation Int duration 1
VVa Int time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation Int duration 2
VVa Int time 3	2000...60000	ms	10	3000	Voltage variation interruption duration 3
VVa Dur Max	100...3600000	ms	100	60000	Maximum voltage variation duration

Table 521: PQSS Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Phase supervision	1=Ph A 2=Ph B 3=Ph A + B 4=Ph C 5=Ph A + C 6=Ph B + C 7=Ph A + B + C			7=Ph A + B + C	Monitored voltage phase
Phase mode	1=Three Phase 2=Single Phase			2=Single Phase	Three/Single phase mode
Variation enable	1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int			7=Swell+dip+Int	Enable variation type

8.3.9 Monitored data

Table 522: PQSS Monitored data

Name	Type	Values (Range)	Unit	Description
ST_A	BOOLEAN	0=False 1=True		Pickup Phase A (Voltage Variation Event in progress)
ST_B	BOOLEAN	0=False 1=True		Pickup Phase B (Voltage Variation Event in progress)
ST_C	BOOLEAN	0=False 1=True		Pickup Phase C (Voltage Variation Event in progress)

Table continues on next page

Name	Type	Values (Range)	Unit	Description
INSTSWELLCNT	INT32	0...2147483647		Instantaneous swell operation counter
MOMSWELLCNT	INT32	0...2147483647		Momentary swell operation counter
TEMPSWELLCNT	INT32	0...2147483647		Temporary swell operation counter
MAXDURSWELLCNT	INT32	0...2147483647		Maximum duration swell operation counter
INSTDIPCNT	INT32	0...2147483647		Instantaneous dip operation counter
MOMDIPCNT	INT32	0...2147483647		Momentary dip operation counter
TEMPDIPCNT	INT32	0...2147483647		Temporary dip operation counter
MAXDURDIPCNT	INT32	0...2147483647		Maximum duration dip operation counter
MOMINTCNT	INT32	0...2147483647		Momentary interruption operation counter
TEMPINTCNT	INT32	0...2147483647		Temporary interruption operation counter
SUSTINTCNT	INT32	0...2147483647		Sustained interruption operation counter
MAXDURINTCNT	INT32	0...2147483647		Maximum duration interruption operation counter
PQSS	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase C

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xVn	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation

8.4 Voltage unbalance PQVUB

8.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage unbalance	VSQVUB	PQMUBU	PQVUB

8.4.2 Function block

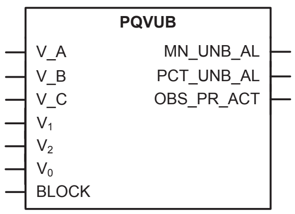


Figure 351: Function block

8.4.3 Functionality

The voltage unbalance power quality function PQVUB monitors voltage unbalance conditions in power transmission and distribution networks. It can be applied to identify a network and load unbalance that can cause sustained voltage unbalance. PQVUB is also used to monitor the commitment of the power supply utility of providing a high-quality, that is, a balanced voltage supply on a continuous basis.

PQVUB uses five different methods for calculating voltage unbalance. The methods are the negative-sequence voltage magnitude, zero-sequence voltage magnitude, ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude, ratio of the zero-sequence voltage magnitude to the positive-sequence voltage magnitude or ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude.

PQVUB provides statistics which can be used to verify the compliance of the power quality with the European standard EN 50160 (2000). The statistics over selected period include freely selectable percentile for unbalance. PQVUB also includes an alarm functionality providing a maximum unbalance value and the date and time of occurrence.

PQVUB contains a blocking functionality. It is possible to block function outputs, if desired.

8.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the voltage unbalance power quality function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

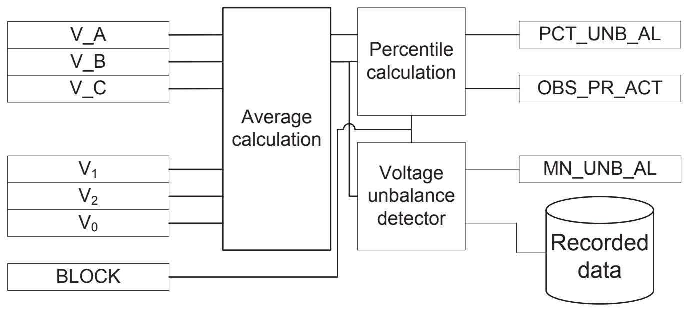


Figure 352: Functional module diagram

Average calculation

PQVUB calculates two sets of measured voltage unbalance values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring. The ten-minute average is used for percentile calculation for a longer period.

The Average calculation module uses five different methods for the average calculation. The required method can be selected with the *Unb detection method* parameter.

When the "Neg Seq" mode is selected with *Unb detection method*, the voltage unbalance is calculated based on the negative-sequence voltage magnitude. Similarly, when the "Zero Seq" mode is selected, the voltage unbalance is calculated based on the zero-sequence voltage magnitude. When the "Neg to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the negative-sequence voltage magnitude to the positive-sequence magnitude. When the "Zero to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the zero-sequence voltage magnitude to the positive-sequence magnitude. When the "Ph vectors Comp" mode is selected, the ratio of the maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude is used for voltage unbalance calculation.

The calculated three-second value and ten-minute value are available in the Monitored data view through the outputs `3S_MN_UNB` and `10MN_MN_UNB`.

Voltage unbalance detector

The three-second average value is calculated and compared to the set value *Unbalance start val*. If the voltage unbalance exceeds this limit, the MN_UNB_AL output is activated.

The activation of the BLOCK input blocks MN_UNB_AL output.

Percentile calculation

The Percentile calculation module performs the statistics calculation for the level of voltage unbalance value for a settable duration. The operation of the Percentile calculation module can be described with a module diagram.

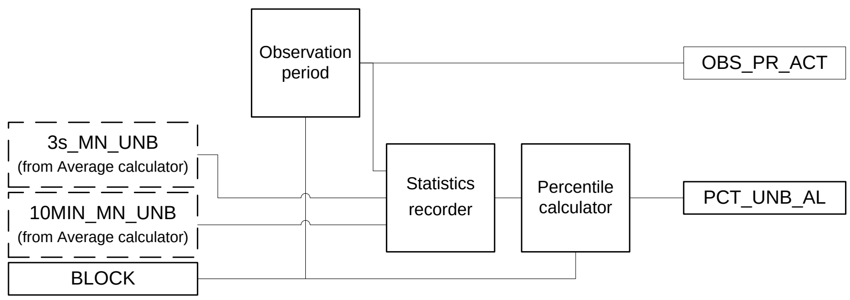


Figure 353: Percentile calculation

Observation period

The Observation period module calculates the length of the observation time for the Statistics recorder sub-module as well as determines the possible start of a new one. A new period can be started by timed activation using settings *Obs period Str time*.

A preferable way of continuous statistics recordings can be selected over a longer period (months, years). With the *Trigger mode* setting, the way the next possible observation time is activated after the former one has finished can be selected. When the trigger mode is selected "Single", it is the single triggering mode, when the trigger mode is selected "Periodic", it is the periodic triggering mode and when the trigger mode is selected "Continuous", it is the continuous triggering mode.

In the single triggering mode, only one period of observation time is activated. In the periodic triggering mode, the time gap between the two trigger signals is seven days. In the continuous triggering mode, the next period starts right after the former observation period is completed.

The length of the period is determined by the settings *Obs period selection* and *User Def Obs period*. The OBS_PR_ACT output is an indication signal which exhibits rising edge (TRUE) when the observation period starts and falling edge (FALSE) when the observation period ends.

If the *Percentile unbalance*, *Trigger mode* or *Obs period duration* settings change when OBS_PR_ACT is active, OBS_PR_ACT deactivates immediately.

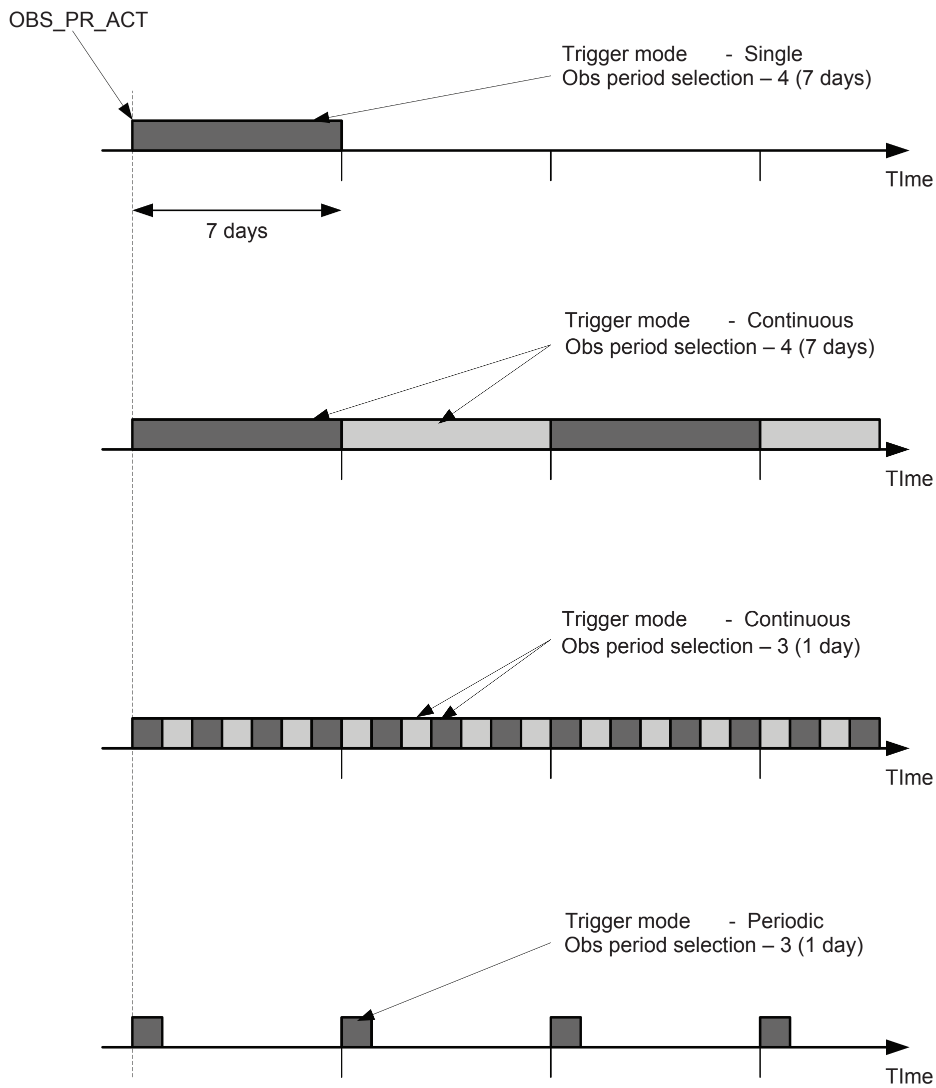


Figure 354: Periods for statistics recorder with different trigger modes and period settings

The BLOCK input blocks the OBS_PR_ACT output, which then disables the maximum value calculation of the Statistics recorder module. If the trigger mode is selected "Periodic" or "Continuous" and the blocking is deactivated before the next observation period is due to start, the scheduled period starts normally.

Statistics recorder

The Statistics recorder module provides readily calculated three-second or ten-minute values of the selected phase to the percentile calculator module based on the length of the active observation period. If the observation period is less than one day, the three-second average values are used. If the observation period is one day or longer, the ten-minute average values are used.

The maximum three-second or ten-minute mean voltage unbalance is recorded during the active observation period. The observation period start time *PR_STR_TIME*, observation period end time *PR_END_TIME*, maximum voltage unbalance value during observation period active, *MAX_UNB_VAL* and time of occurrence *MAX_UNB_TIME* are available through the Monitored data view. These outputs are updated once `OBS_PR_ACT` deactivates.

Percentile calculator

The purpose of the Percentile calculator module is to find the voltage unbalance level so that during the observation time 95 percent (default value of the *Percentile unbalance* setting) of all the measured voltage unbalance amplitudes are less than or equal to the calculated percentile.

The computed output value `PCT_UNB_VAL`, below which the percentile of the values lies, is available in the Monitored data view. The `PCT_UNB_VAL` output value is updated at the end of the observation period.

If the output `PCT_UNB_VAL` is higher than the defined setting *Unbalance start val* at the end of the observation period, an alarm output `PCT_UNB_AL` is activated. The `PCT_UNB_AL` output remains active for the whole period before the next period completes.

The `BLOCK` input blocks the output `PCT_UNB_VAL`.

Recorded data

The information required for a later fault analysis is stored when the Recorded data module is triggered. This happens when a voltage unbalance is detected by the Voltage unbalance detector module.

Three sets of recorded data are available in total. The sets are saved in data banks 1...3. The data bank 1 holds the most recent recorded data. Older data are moved to the subsequent banks (1 to 2 and 2 to 3) when a voltage unbalance is detected. When all three banks have data and a new variation is detected, the latest data set is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

The recorded data can be reset with the RESET binary input signal by navigating to the HMI reset (**Main menu/Clear/Reset recorded data/PQVUBx**) or through tools via communications.

When voltage unbalance is detected in the system, PQVUB responds with the MN_UNB_AL alarm signal. During the alarm situation, PQVUB stores the maximum magnitude and the time of occurrence and the duration of alarm MN_UNB_AL. The recorded data is stored when MN_UNB_AL is deactivated.

Table 523: Recorded data

Parameter	Description
Alarm high mean Dur	Time duration for alarm high mean unbalance
Max unbalance Volt	Maximum three-second voltage
Time Max Unb Volt	Time stamp of voltage unbalance

8.4.5 Application

Voltage unbalance is one of the basic power quality parameters.

Ideally, in a three-phase or multiphase power system, the frequency and voltage magnitude of all the phases are equal and the phase displacement between any two consecutive phases is also equal. This is called a balanced source. Apart from the balanced source, usually the power system network and loads are also balanced, implying that network impedance and load impedance in each phase are equal. In some cases, the condition of a balance network and load is not met completely, which leads to a current and voltage unbalance in the system. Providing unbalanced supply voltage has a detrimental effect on load operation. For example, a small magnitude of a negative-sequence voltage applied to an induction motor results in a significant heating of the motor.

A balanced supply, balanced network and balanced load lead to a better power quality. When one of these conditions is disturbed, the power quality is deteriorated. PQVUB monitors such voltage unbalance conditions in power transmission and distribution networks. PQVUB calculates two sets of measured values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring while the ten-minute average value is used for percentile calculation for a longer period of time. It can be applied to identify the network and load unbalance that may cause sustained voltage unbalance. A single-phase or phase-to-phase fault in the network or load side can create voltage unbalance but, as faults are usually isolated in a short period of time, the voltage unbalance is not a sustained one. Therefore, the voltage unbalance may not be covered by PQVUB.

Another major application is the long-term power quality monitoring. This can be used to confirm a compliance to the standard power supply quality norms. The function provides a voltage unbalance level which corresponds to the 95th percentile of the ten minutes' average values of voltage unbalance recorded over a period of up to one week. It means that for 95 percent of time during the observation period the voltage unbalance was less than or equal to the calculated percentile. An alarm can be obtained if this value exceeds the value that can be set.

The function uses five different methods for calculating voltage unbalance.

- Negative-sequence voltage magnitude
- Zero-sequence voltage magnitude
- Ratio of negative-sequence to positive-sequence voltage magnitude
- Ratio of zero-sequence to positive-sequence voltage magnitude
- Ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of phase voltage magnitude.

Usually, the ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude is selected for monitoring the voltage unbalance. However, other methods may also be used if required.

8.4.6 Signals

Table 524: PQVUB Input signals

Name	Type	Default	Description
V_A	SIGNAL	0	Phase A voltage
V_B	SIGNAL	0	Phase B voltage
V_C	SIGNAL	0	Phase C voltage
V_1	SIGNAL	0	Positive phase sequence voltage
V_2	SIGNAL	0	Negative phase sequence voltage
V_0	SIGNAL	0	Zero sequence voltage
BLOCK	BOOLEAN	0=False	Block all outputs except measured values

Table 525: PQVUB Output signals

Name	Type	Description
MN_UNB_AL	BOOLEAN	Alarm active when 3 sec voltage unbalance exceeds the limit
PCT_UNB_AL	BOOLEAN	Alarm active when percentile unbalance exceeds the limit
OBS_PR_ACT	BOOLEAN	Observation period is active

8.4.7 Settings

Table 526: PQVUB Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Opeartion	1=enable 5=disable			5=disable	Opeartion Enable/Disable
Unb detection method	1=Neg Seq 2=Zero Seq 3=Neg to Pos Seq 4=Zero to Pos Seq 5=Ph vectors Comp			3=Neg to Pos Seq	Set the operation mode for voltage unbalance calculation
Unbalance pickup Val	1...100	%	1	1	Voltage unbalance pickup value
Trigger mode	1=Single 2=Periodic 3=Continuous			3=Continuous	Specifies the observation period triggering mode
Percentile unbalance	1...100	%	1	95	The percent to which percentile value PCT_UNB_VAL is calculated
Obs period selection	1=1 Hour 2=12 Hours 3=1 Day 4=7 Days 5=User defined			5=User defined	Observation period for unbalance calculation
User Def Obs period	1...168	h	1	168	User define observation period for statistic calculation
Obs period Str time	2008010100...2076010100		1	2011010101	Calendar time for observation period start given as YYYYMMDDhh

8.4.8 Monitored data

Table 527: PQVUB Monitored data

Name	Type	Values (Range)	Unit	Description
3S_MN_UNB	FLOAT32	0.00...100.00	%	Non sliding 3 second mean value of voltage unbalance
10MIN_MN_UNB	FLOAT32	0.00...100.00	%	Sliding 10 minutes mean value of voltage unbalance
PCT_UNB_VAL	FLOAT32	0.00...100.00	%	Limit below which percentile unbalance of the values lie
MAX_UNB_VAL	FLOAT32	0.00...100.00	%	Maximum voltage unbalance measured in the observation period
MAX_UNB_TIME	Timestamp			Time stamp at which maximum voltage unbalance measured in the observation period
PR_STR_TIME	Timestamp			Time stamp of starting of the previous observation period

Table continues on next page

Name	Type	Values (Range)	Unit	Description
PR_END_TIME	Timestamp			Time stamp of end of previous observation period
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...100.00	%	Maximum 3 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of voltage unbalance
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...100.00	%	Maximum 3 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of voltage unbalance
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...100.00	%	Maximum 3 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of voltage unbalance
PQMUBV	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

8.4.9 Technical data

Table 528: PQVUB Technical data

Characteristic	Value
Operation accuracy	±1.5% of the set value or ±0.002 × U_n
Reset ratio	Typically 0.96

Section 9 Control functions

9.1 Circuit-breaker control 52

9.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit-breaker control	CBXCBR	I<->O CB	52

9.1.2 Function block

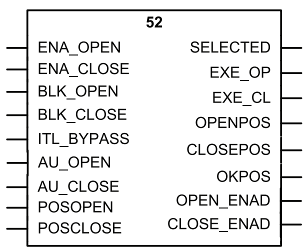


Figure 355: Function block

9.1.3 Functionality

The circuit breaker control function 52 is intended for circuit breaker control and status information purposes. This function executes commands and evaluates block conditions and different time supervision conditions. The function performs an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the function indicates an appropriate cause value. The function is designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XCBR.

The circuit breaker, disconnector and earthing switch control functions have an operation counter for closing and opening cycles. The counter value can be read and written remotely from the place of operation or via LHMI.

9.1.4 Operation principle

Status indication and validity check

The object state is defined by two digital inputs, POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS information. The debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of the digital inputs that indicate the object state is used as additional information in indications and event logging. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting, assuming that the circuit breaker is still in a corresponding state.

Table 529: Status indication

Status (POSITION)	POSOPEN/OPENPOS	POSCLOSE/ CLOSEPOS	OKPOS
1=Open	1=True	0=False	1=True
2=Closed	0=False	1=True	1=True
3=Faulty/Bad (11)	1=True	1=True	0=False
0=Intermediate (00)	0=False	0=False	0=False

Blocking

52 has a blocking functionality to prevent human errors that can cause serious injuries for the operator and damages for the system components.

The basic principle for all blocking signals is that they affect the commands of other clients: the operator place and protection and autoreclosing functions, for example. There are two blocking principles.

- Enabling the opening command: the function is used to block the operation of the opening command. This block signal also affects the OPEN input of immediate command.
- Enabling the closing command: the function is used to block the operation of the closing command. This block signal also affects the CLOSE input of immediate command.

The ITL_BYPASS input is used if the interlocking functionality needs to be bypassed. When INT_BYPASS is TRUE, the apparatus control is made possible by discarding the ENA_OPEN and ENA_CLOSE input states. However, the BLK_OPEN and BLK_CLOSE input signals are not bypassed with the interlocking bypass functionality since they always have the higher priority.

Table 530: Interlocking conditions for enabling the closing (opening) command

Inputs			Outputs
INT_BYPASS	ENA_CLOSE (ENA_OPEN)	BLK_CLOSE (BLK_OPEN)	CLOSE_ENAD (OPEN_ENAD)
0 = False	0 = False	0 = False	0 = False
0 = False	0 = False	1 = True	0 = False
0 = False	1 = True	0 = False	1 = True
0 = False	1 = True	1 = True	0 = False
1 = True	0 = False	0 = False	1 = True
1 = True	0 = False	1 = True	0 = False
1 = True	1 = True	0 = False	1 = True
1 = True	1 = True	1 = True	0 = False

Opening and closing operations

The opening and closing operations are available via communication, binary inputs or LHMI commands. As a prerequisite for control commands, there are enabling and blocking functionalities for both opening and closing commands (`CLOSE_ENAD` and `OPEN_ENAD` signals). If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, 52 generates an error message.

Opening and closing pulse widths

The pulse width type can be defined with the *Adaptive pulse* setting. The function provides two modes to characterize the opening and closing pulse widths. When the *Adaptive pulse* is set to “TRUE”, it causes a variable pulse width, which means that the output pulse is deactivated when the object state shows that the apparatus has entered the correct state. When the *Adaptive pulse* is set to “FALSE”, the functions always use the maximum pulse width, defined by the user-configurable *Pulse length* setting. The *Pulse length* setting is the same for both the opening and closing commands. When the apparatus already is in the right position, the maximum pulse length is given.

The *Pulse length* setting does not affect the length of the trip pulse.

Control methods

The command execution mode can be set with the *Control model* setting. The alternatives for command execution are direct control and secured object control, which can be used to secure controlling.

The secured object control SBO is an important feature of the communication protocols that support horizontal communication, because the command reservation and interlocking signals can be transferred with a bus. All secured control operations require two-step commands: a selection step and an execution step. The secured object control is responsible for the several tasks.

- Command authority: ensures that the command source is authorized to operate the object
- Mutual exclusion: ensures that only one command source at a time can control the object
- Interlocking: allows only safe commands
- Execution: supervises the command execution
- Command canceling: cancels the controlling of a selected object.

In direct operation, a single message is used to initiate the control action of a physical device. The direct operation method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

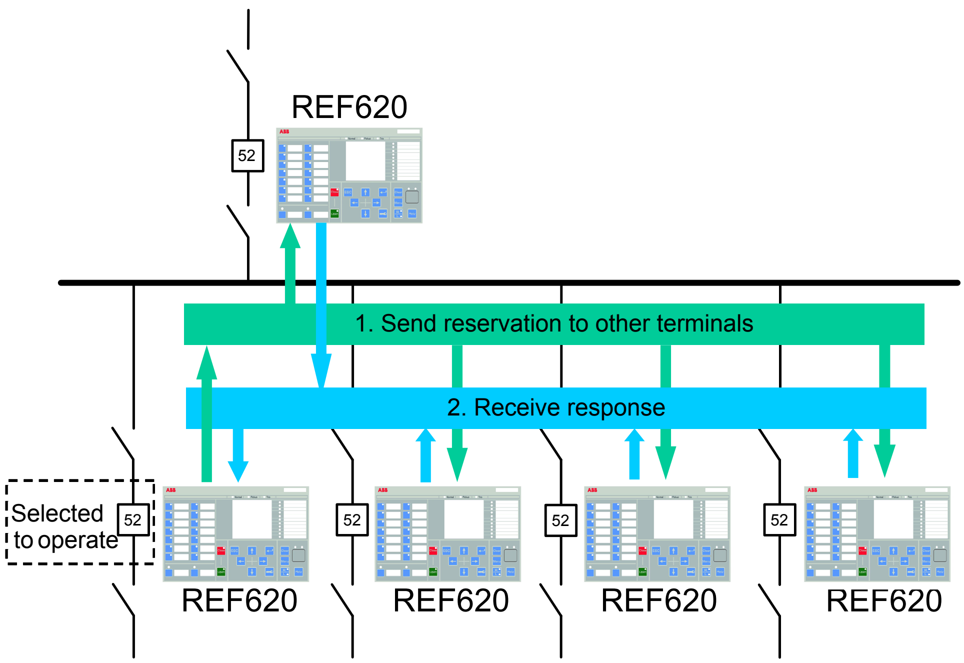


Figure 356: Control procedure in SBO method

9.1.5 Application

In the field of distribution and sub-transmission automation, reliable control and status indication of primary switching components both locally and remotely is in a significant role. They are needed especially in modern remotely controlled substations.

Control and status indication facilities are implemented in the same package with 52. When primary components are controlled in the energizing phase, for example, it must be ensured that the control commands are executed in a correct sequence. This can be achieved, for example, with interlocking based on the status indication of the related primary components. The interlocking on substation level can be applied using the IEC61850 GOOSE messages between feeders.

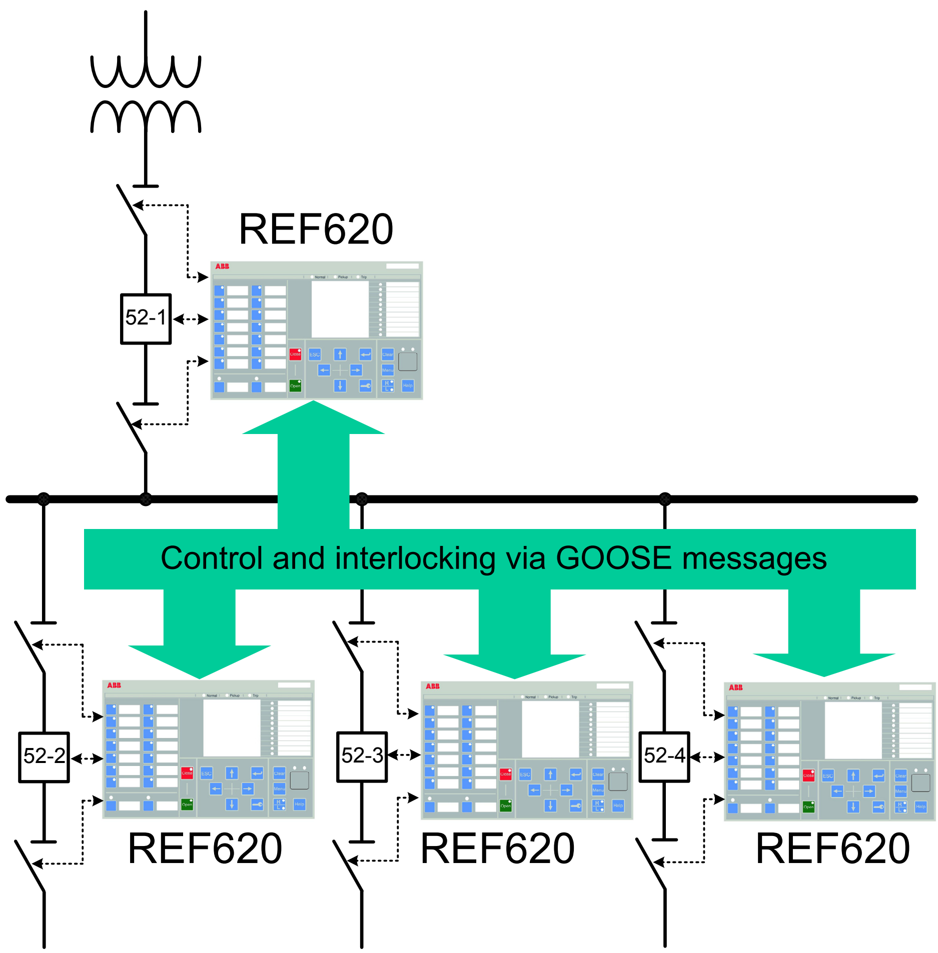


Figure 357: Status indication-based interlocking via the GOOSE messaging

9.1.6 Signals

Table 531: 52 Input signals

Name	Type	Default	Description
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE
AU_OPEN	BOOLEAN	0=False	Input signal used to open the breaker[1)]
AU_CLOSE	BOOLEAN	0=False	Input signal used to close the breaker[1)]
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O[1)]
POSCLOSE	BOOLEAN	0=False	Signal for closed position of apparatus from I/O[1)]

1) Not available for monitoring

Table 532: 52 Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status

9.1.7 Settings

Table 533: 52 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation mode disable / disable
Select timeout	10000...300000	ms	10000	60000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Operation counter	0...10000			0	Breaker operation cycles
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...10000	ms	1	100	Event delay of the intermediate position
Operation timeout	10...60000	ms		500	Timeout for negative termination

9.1.8 Monitored data

Table 534: 52 Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.2 Autoreclosing 79

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autoreclosing	DARREC	O -> I	79

9.2.2 Function block

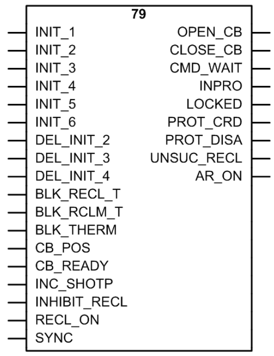


Figure 358: Function block

9.2.3 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The autoreclosing function can be used with any circuit breaker suitable for autoreclosing. The function provides five programmable autoreclosing shots which can perform one to five successive autoreclosing of desired type and duration, for instance one high-speed and one delayed autoreclosing.

When the reclosing is initiated with pickup of the protection function, the autoreclosing function can execute the final trip of the circuit breaker in a short trip time, provided that the fault still persists when the last selected reclosing has been carried out.

9.2.3.1 Protection signal definition

The *Control line* setting defines which of the initiation signals are protection pickup and trip signals and which are not. With this setting, the user can distinguish the blocking signals from the protection signals. The *Control line* setting is a bit mask, that is, the lowest bit controls the `INIT_1` line and the highest bit the `INIT_6` line. Some example combinations of the *Control line* setting are as follows:

Table 535: Control line setting definition

Control line setting	INIT_1	INIT_2 DEL_INIT_2	INIT_3 DEL_INIT_3	INIT_4 DEL_INIT_4	INIT_5	INIT_6
0	other	other	other	other	other	other
1	prot	other	other	other	other	other
2	other	prot	other	other	other	other
3	prot	prot	other	other	other	other
4	other	other	prot	other	other	other
5	prot	other	prot	other	other	other
...63	prot	prot	prot	prot	prot	prot

prot = protection signal

other = non-protection signal

When the corresponding bit or bits in both the *Control line* setting and the INIT_X line are TRUE:

- The CLOSE_CB output is blocked until the protection is reset
- If the INIT_X line defined as the protection signal is activated during the discrimination time, the AR function goes to lockout
- If the INIT_X line defined as the protection signal stays active longer than the time set by the *Max trip time* setting, the AR function goes to lockout (long trip)
- The UNSUC_RECL output is activated after a pre-defined two minutes (alarming ground-fault).

9.2.3.2 Zone coordination

Zone coordination is used in the zone sequence between local protection units and downstream devices. At the falling edge of the INC_SHOTP line, the value of the shot pointer is increased by one, unless a shot is in progress or the shot pointer already has the maximum value.

The falling edge of the INC_SHOTP line is not accepted if any of the shots are in progress.

9.2.3.3 Master and slave scheme

With the cooperation between the AR units in the same protection relay or between protection relays, sequential reclosings of two breakers at a line end in a 1½-breaker, double breaker or ring-bus arrangement can be achieved. One unit is defined as a master and it executes the reclosing first. If the reclosing is successful and no trip takes place, the second unit, that is the slave, is released to complete the reclose shot. With persistent faults, the breaker reclosing is limited to the first breaker.

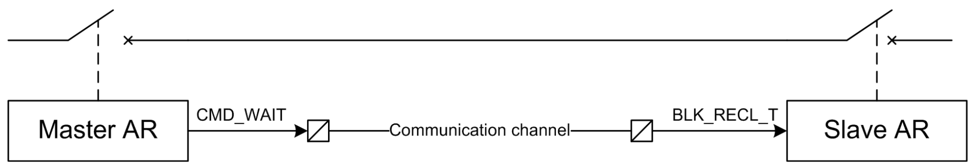


Figure 359: Master and slave scheme

If the AR unit is defined as a master by setting its terminal priority to high:

- The unit activates the `CMD_WAIT` output to the low priority slave unit whenever a shot is in progress, a reclosing is unsuccessful or the `BLK_RCLM_T` input is active
- The `CMD_WAIT` output is reset one second after the reclose command is given or if the sequence is unsuccessful when the reclaim time elapses.

If the AR unit is defined as a slave by setting its terminal priority to low:

- The unit waits until the master releases the `BLK_RECL_T` input (the `CMD_WAIT` output in the master). Only after this signal has been deactivated, the reclose time for the slave unit can be started.
- The slave unit is set to a lockout state if the `BLK_RECL_T` input is not released within the time defined by the *Max wait time* setting , which follows the initiation of an autoreclosing shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

9.2.3.4 Thermal overload blocking

An alarm or pickup signal from the thermal overload protection 49F can be routed to the input `BLK_THERM` to block and hold the reclose sequence. The `BLK_THERM` signal does not affect the starting of the sequence. When the reclose time has elapsed and the `BLK_THERM` input is active, the shot is not ready until the `BLK_THERM` input deactivates. Should the `BLK_THERM` input remain active longer than the time set by the setting *Max block time*, the AR function goes to lockout.

If the `BLK_THERM` input is activated when the auto wait timer is running, the auto wait timer is reset and the timer restarted when the `BLK_THERM` input deactivates.

9.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The reclosing operation can be enabled and disabled with the *Reclosing operation* setting. This setting does not disable the function, only the reclosing functionality. The setting has three parameter values: “Enable”, “External Ctl” and ”Disable”. When the setting value “External Ctl” is selected, the reclosing operation is controlled with the RECL_ON input.

The operation of the autoreclosing function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

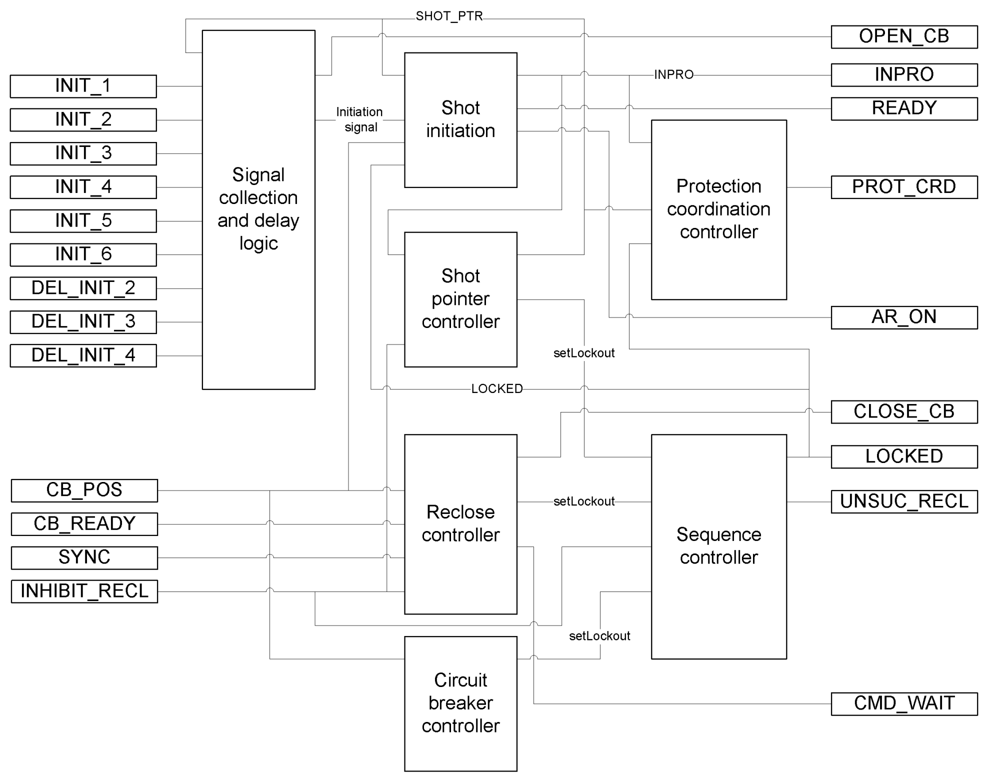


Figure 360: Functional module diagram

9.2.4.1 Signal collection and delay logic

When the protection trips, the initiation of autoreclosing shots is in most applications executed with the INIT_1...6 inputs. The DEL_INIT2...4 inputs are not used. In some situations, pickup of the protection stage is also used for the shot initiation. This is the only time when the DEL_INIT inputs are used.

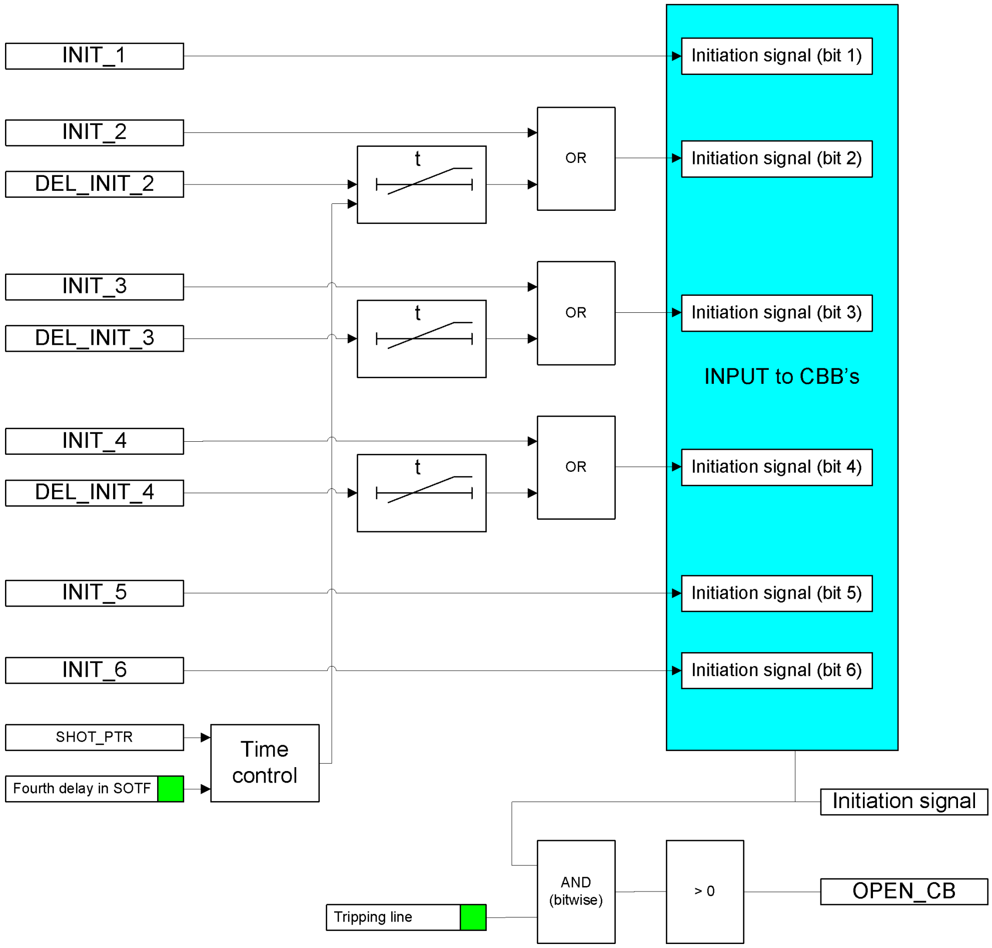


Figure 361: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the autoreclosing shots. These lines are divided into two types of channels. In three of these channels, the signal to the AR function can be delayed, whereas the other three channels do not have any delaying capability.

Each channel that is capable of delaying a pickup signal has four time delays. The time delay is selected based on the shot pointer in the AR function. For the first reclose attempt, the first time delay is selected; for the second attempt, the second time delay and so on. For the fourth and fifth attempts, the time delays are the same.

Time delay settings for the `DEL_INIT_2` signal

- *Str 2 delay shot 1*
- *Str 2 delay shot 2*
- *Str 2 delay shot 3*
- *Str 2 delay shot 4*

Time delay settings for the `DEL_INIT_3` signal

- *Str 3 delay shot 1*
- *Str 3 delay shot 2*
- *Str 3 delay shot 3*
- *Str 3 delay shot 4*

Time delay settings for the `DEL_INIT_4` signal

- *Str 4 delay shot 1*
- *Str 4 delay shot 2*
- *Str 4 delay shot 3*
- *Str 4 delay shot 4*

Normally, only two or three reclosing attempts are made. The third and fourth attempts are used to provide the so-called fast final trip to lockout.

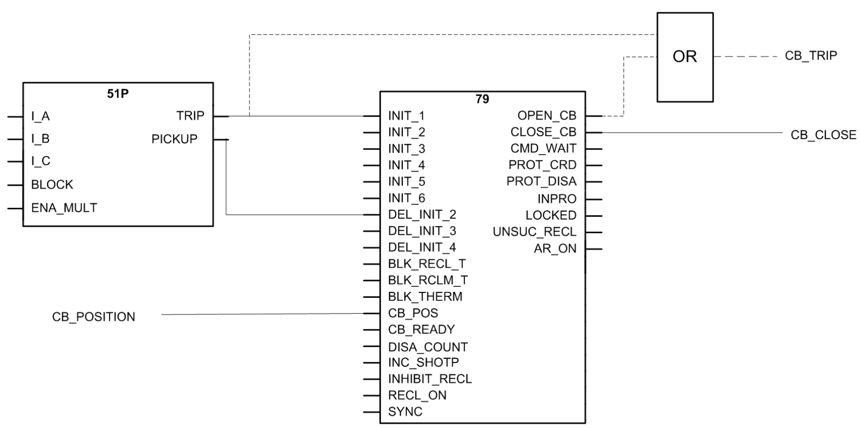


Figure 362: Autoreclosing configuration example

Delayed `DEL_INIT_2...4` signals are used only when the autoreclosing shot is initiated with the pickup signal of a protection stage. After a pickup delay, the AR function opens the circuit breaker and an autoreclosing shot is initiated. When the shot is initiated with the trip signal of the protection, the protection function trips the circuit breaker and simultaneously initiates the autoreclosing shot.

If the circuit breaker is manually closed against the fault, that is, if SOTF is used, the fourth time delay can automatically be taken into use. This is controlled with the internal logic of the AR function and the *Fourth delay in SOTF* parameter.

A typical autoreclose situation is where one autoreclosing shot has been performed after the fault was detected. There are two types of such cases: operation initiated with protection pickup signal and operation initiated with protection trip signal. In both cases, the autoreclosing sequence is successful: the reclaim time elapses and no new sequence is picked up.

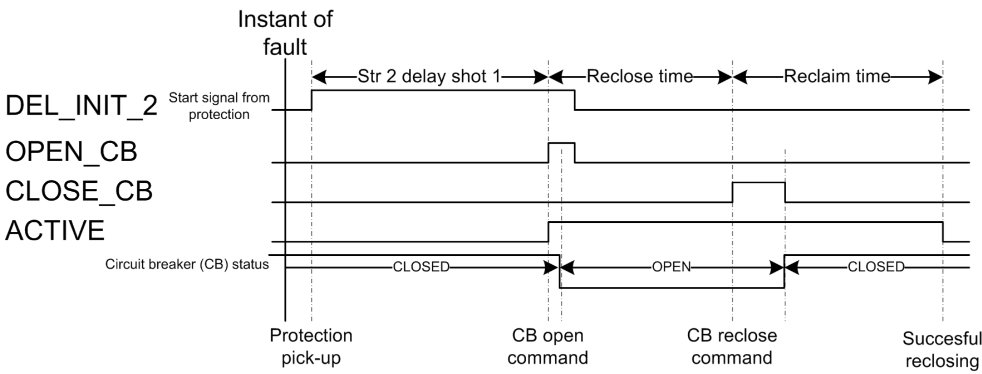


Figure 363: Signal scheme of autoreclosing operation initiated with protection pickup signal

The autoreclosing shot is initiated with a trip signal of the protection function after the pickup delay time has elapsed. The autoreclosing picks up when the *Str 2 delay shot 1* setting elapses.

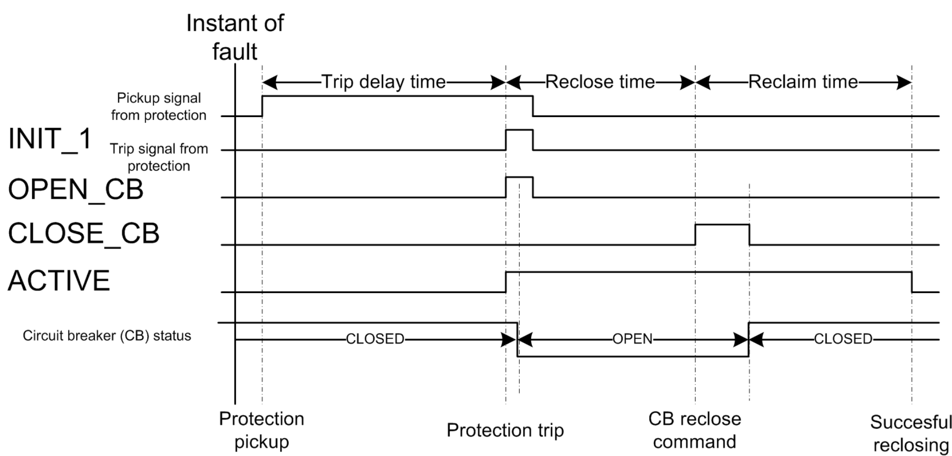


Figure 364: Signal scheme of autoreclosing operation initiated with protection trip signal

The autoreclosing shot is initiated with a trip signal of the protection function. The autoreclosing picks up when the protection trip delay time elapses.

Normally, all trip and pickup signals are used to initiate an autoreclosing shot and trip the circuit breaker. If any of the input signals INIT_X or DEL_INIT_X are used for blocking, the corresponding bit in the *Tripping line* setting must be FALSE. This is to ensure that the circuit breaker does not trip from that signal, that is, the signal does not activate the OPEN_CB output. The default value for the setting is "63", which means that all initiation signals activate the OPEN_CB output. The lowest bit in the *Tripping line* setting corresponds to the INIT_1 input, the highest bit to the INIT_6 line.

9.2.4.2 Shot initiation

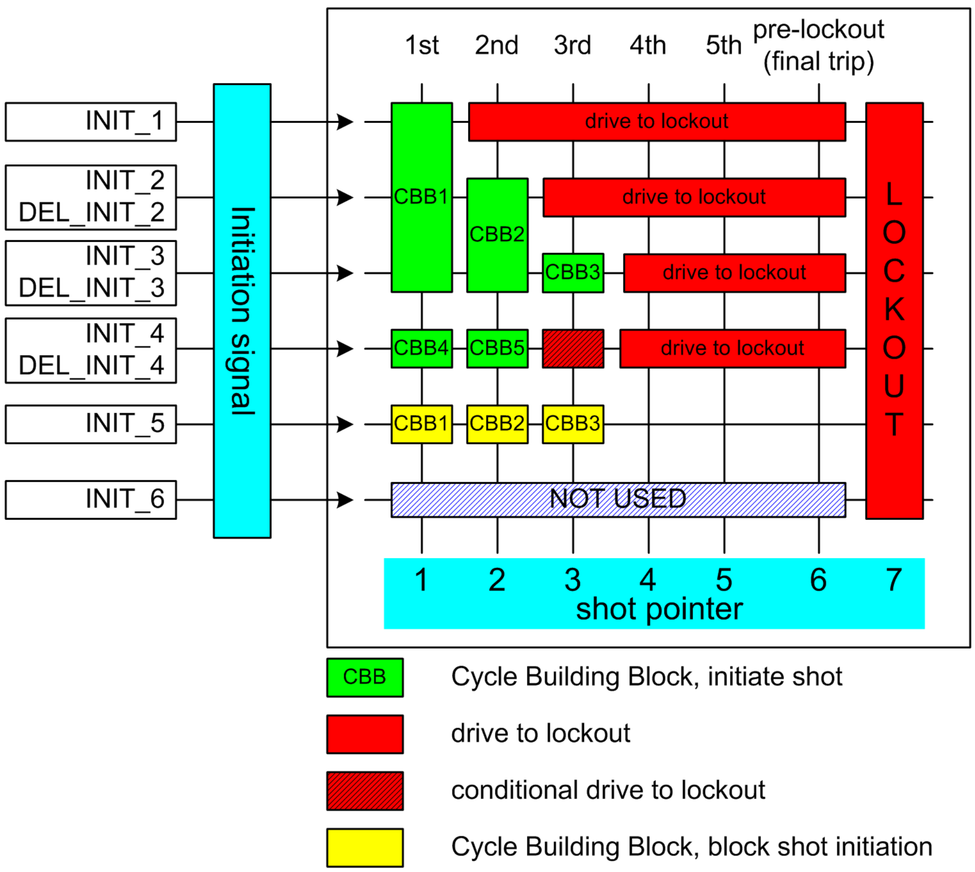


Figure 365: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 000111 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 000110 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 000100 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 001000 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the INIT_4 line leads to a lockout after two shots. In a situation where the initiation is made from both the INIT_3 and INIT_4 lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the INIT_2 and INIT_3 lines, an immediate lockout occurs.

The INIT_5 line is used for blocking purposes. If the INIT_5 line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the INIT_2 and INIT_4 lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a CLOSE_CB command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the autoreclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

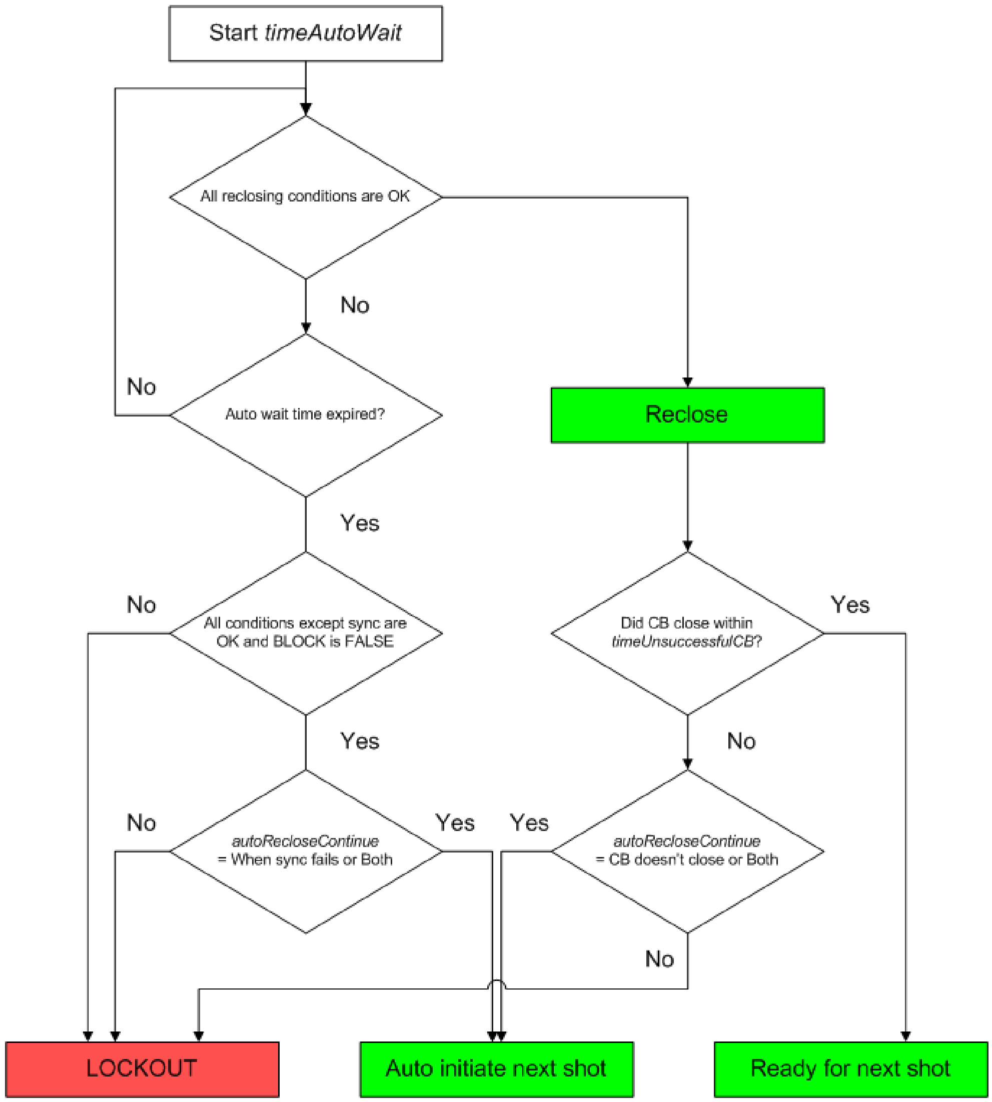


Figure 366: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.

The *Auto init* parameter defines which INIT_X lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

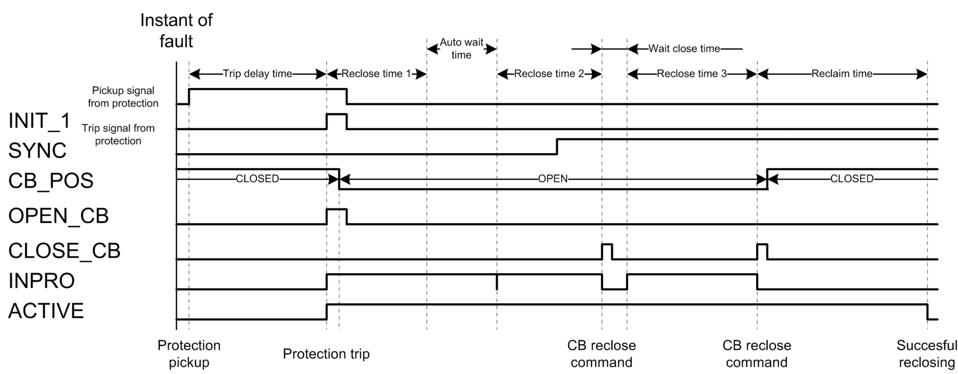


Figure 367: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (SYNC is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

9.2.4.3 Shot pointer controller

The execution of a reclose sequence is controlled by a shot pointer. It can be adjusted with the SHOT_PTR monitored data.

The shot pointer starts from an initial value "1" and determines according to the settings whether or not a certain shot is allowed to be initiated. After every shot, the shot pointer value increases. This is carried out until a successful reclosing or lockout takes place after a complete shot sequence containing a total of five shots.

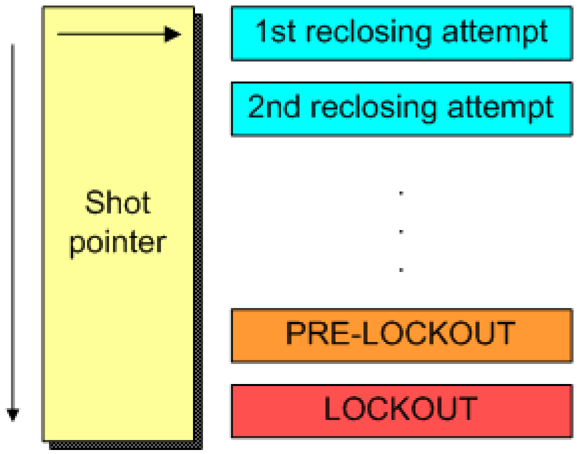


Figure 368: Shot pointer function

Every time the shot pointer increases, the reclaim time starts. When the reclaim time ends, the shot pointer sets to its initial value, unless no new shot is initiated. The shot pointer increases when the reclose time elapses or at the falling edge of the `INC_SHOTP` signal.

When `SHOT_PTR` has the value six, the AR function is in a so called pre-lockout state. If a new initiation occurs during the pre-lockout state, the AR function goes to lockout. Therefore, a new sequence initiation during the pre-lockout state is not possible.

The AR function goes to the pre-lockout state in the following cases:

- During SOTF
- When the AR function is active, it stays in a pre-lockout state for the time defined by the reclaim time
- When all five shots have been executed
- When the frequent operation counter limit is reached. A new sequence initiation forces the AR function to lockout.

9.2.4.4 Reclose controller

The reclose controller calculates the reclose, discrimination and reclaim times. The reclose time is started when the `INPRO` signal is activated, that is, when the sequence starts and the activated CBB defines the reclose time.

When the reclose time has elapsed, the CLOSE_CB output is not activated until the following conditions are fulfilled:

- The SYNC input must be TRUE if the particular CBB requires information about the synchronism
- All AR initiation inputs that are defined protection lines (using the *Control line* setting) are inactive
- The circuit breaker is open
- The circuit breaker is ready for the close command, that is, the CB_READY input is TRUE.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the autoreclose sequence is locked.

The synchronism requirement for the CBBs can be defined with the *Synchronisation set* setting, which is a bit mask. The lowest bit in the *Synchronisation set* setting is related to CBB1 and the highest bit to CBB7. For example, if the setting is set to "1", only CBB1 requires synchronism. If the setting is it set to "7", CBB1, CBB2 and CBB3 require the SYNC input to be TRUE before the reclosing command can be given.

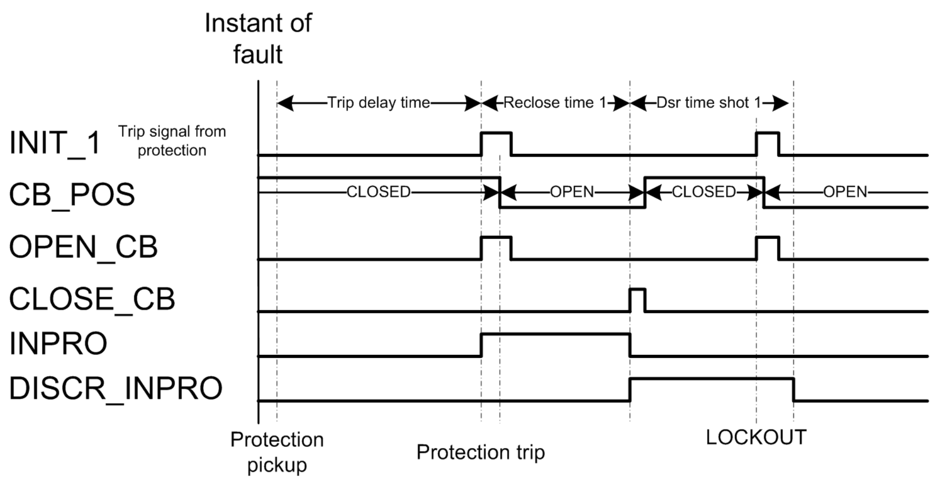


Figure 369: Initiation during discrimination time - AR function goes to lockout

The discrimination time starts when the close command CLOSE_CB has been given. If a pickup input is activated before the discrimination time has elapsed, the AR function goes to lockout. The default value for each discrimination time is zero. The discrimination time can be adjusted with the *Dsr time shot 1...4* parameter.

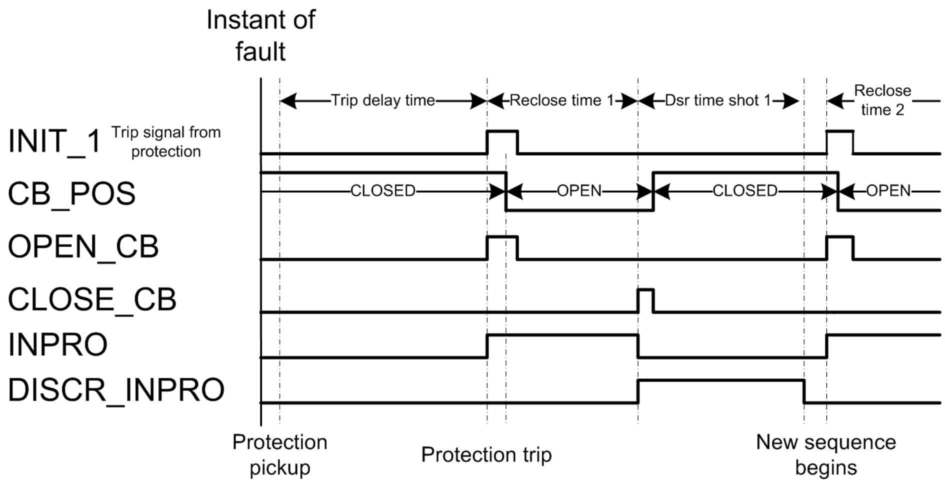


Figure 370: Initiation after elapsed discrimination time - new shot begins

9.2.4.5 Sequence controller

When the LOCKED output is active, the AR function is in lockout. This means that new sequences cannot be initialized, because AR is insensitive to initiation commands. It can be released from the lockout state in the following ways.

- The function is reset through communication with the *RsRec* parameter.
- The lockout is automatically reset after the reclaim time, if the *Auto lockout reset* setting is in use.

If the *Auto lockout reset* setting is not in use, the lockout can be released only with the *RsRec* parameter.

The AR function can go to lockout for many reasons.

- The INHIBIT_RECL input is active.
- All shots have been executed and a new initiation is made (final trip).
- The time set with the *Auto wait time* parameter expires and the automatic sequence initiation is not allowed because of a synchronization failure.
- The time set with the *Wait close time* parameter expires, that is, the circuit breaker does not close or the automatic sequence initiation is not allowed due to a closing failure of the circuit breaker.
- A new shot is initiated during the discrimination time.
- The time set with the *Max wait time* parameter expires, that is, the master unit does not release the slave unit.

- The frequent operation counter limit is reached and new sequence is initiated. The lockout is released when the recovery timer elapses.
- The protection trip signal has been active longer than the time set with the *Max wait time* parameter since the shot initiation.
- The circuit breaker is closed manually during an autoreclosing sequence and the manual close mode is FALSE.

9.2.4.6 Protection coordination controller

The PROT_CRD output is used for controlling the protection functions. In several applications, such as fuse-saving applications involving down-stream fuses, tripping and initiation of shot 1 should be fast (instantaneous or short-time delayed). The tripping and initiation of shots 2, 3 and definite tripping time should be delayed.

In this example, two overcurrent elements 51P and 50P-2 are used. 50P-2 is given an instantaneous characteristic and 51P is given a time delay.

The PROT_CRD output is activated, if the SHOT_PTR value is higher than the value defined with the *Protection crd limit* setting and all initialization signals have been reset. The PROT_CRD output is reset under the following conditions:

- If the cut-out time elapses
- If the reclaim time elapses and the AR function is ready for a new sequence
- If the AR function is in lockout or disabled, that is, if the value of the *Protection crd mode* setting is "AR inoperative" or "AR inop, CB man".

The PROT_CRD output can also be controlled with the *Protection crd mode* setting. The setting has the following modes:

- "no condition": the PROT_CRD output is controlled only with the *Protection crd limit* setting
- "AR inoperative": the PROT_CRD output is active, if the AR function is disabled or in the lockout state, or if the INHIBIT_RECL input is active
- "CB close manual": the PROT_CRD output is active for the reclaim time if the circuit breaker has been manually closed, that is, the AR function has not issued a close command
- "AR inop, CB man": both the modes "AR inoperative" and "CB close manual" are effective
- "always": the PROT_CRD output is constantly active

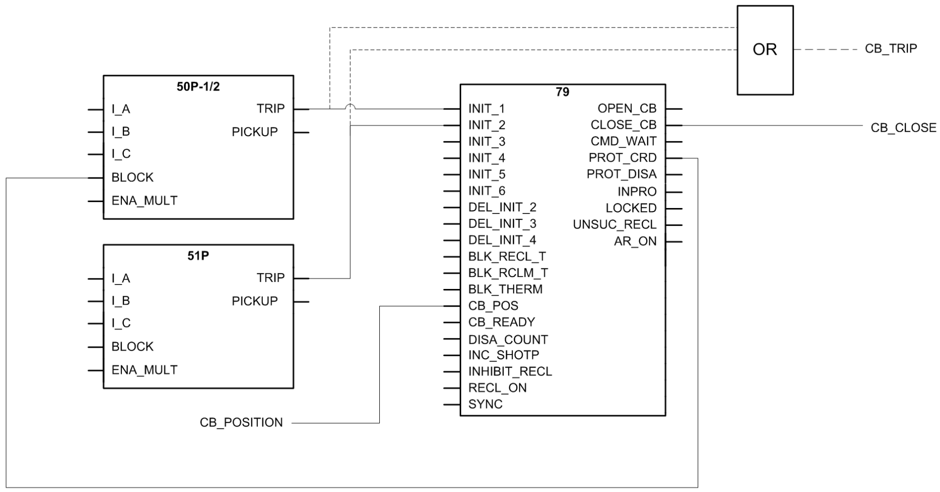


Figure 371: Configuration example of using the `PROT_CRD` output for protection blocking

If the *Protection crd limit* setting has the value "1", the instantaneous three-phase overcurrent protection function 50P-3 is disabled or blocked after the first shot.

9.2.4.7 Circuit breaker controller

Circuit breaker controller contains two features: SOTF and frequent-operation counter. SOTF protects the AR function in permanent faults.

The circuit breaker position information is controlled with the *CB closed Pos status* setting. The setting value "TRUE” means that when the circuit breaker is closed, the `CB_POS` input is TRUE. When the setting value is “FALSE”, the `CB_POS` input is FALSE, provided that the circuit breaker is closed. The reclose command pulse time can be controlled with the *Close pulse time* setting: the `CLOSE_CB` output is active for the time set with the *Close pulse time* setting. The `CLOSE_CB` output is deactivated also when the circuit breaker is detected to be closed, that is, when the `CB_POS` input changes from open state to closed state. The *Wait close time* setting defines the time after the `CLOSE_CB` command activation, during which the circuit breaker should be closed. If the closing of circuit breaker does not happen during this time, the autoreclosing function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for autoreclosing to begin with is the assumption that the fault is temporary by nature, and that a momentary de-energizing of the power line and an automatic reclosing restores the power supply. However, when the power line is manually energized and an immediate protection trip is detected, it is very likely that the fault is of a permanent type. An example of a permanent fault is, for example, energizing a power line into a forgotten grounding after a maintenance work along the power line. In such cases, SOTF is activated, but only for the reclaim time after energizing the power line and only when the circuit breaker is closed manually and not by the AR function.

SOTF disables any initiation of an autoreclosing shot. The energizing of the power line is detected from the `CB_POS` information.

SOTF is activated when the AR function is enabled or when the AR function is started and the SOTF should remain active for the reclaim time.

When SOTF is detected, the parameter *SOTF* is active.

If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an autoreclosing shot, the AR unit goes to an immediate lockout.

If the *Manual close mode* setting is set to TRUE and the circuit breaker has been manually closed during an autoreclosing shot (the `INPRO` is active), the shot is considered as completed.

When SOTF starts, reclaim time is restarted, provided that it is running.

The frequent-operation counter is intended for blocking the autoreclosing function in cases where the fault causes repetitive autoreclosing sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are autoreclosing shots within a few minutes interval during a stormy night. These types of faults can easily damage the circuit breaker if the AR function is not locked by a frequent-operation counter.

The frequent-operation counter has three settings:

- *Frq Op counter limit*
- *Frq Op counter time*
- *Frq Op recovery time*

The *Frq Op counter limit* setting defines the number of reclose attempts that are allowed during the time defined with the *Frq Op counter time* setting. If the set value is reached within a pre-defined period defined with the *Frq Op counter time* setting, the AR function goes to lockout when a new shot begins, provided that the counter is still above the set limit. The lockout is released after the recovery time has elapsed. The recovery time can be defined with the *Frq Op recovery time* setting .

If the circuit breaker is manually closed during the recovery time, the reclaim time is activated after the recovery timer has elapsed.

9.2.5 Counters

The AR function contains six counters. Their values are stored in a semi-retain memory. The counters are increased at the rising edge of the reclosing command. The counters count the following situations.

- `COUNTER`: counts every reclosing command activation
- `CNT_SHOT1`: counts reclosing commands that are executed from shot 1
- `CNT_SHOT2`: counts reclosing commands that are executed from shot 2
- `CNT_SHOT3`: counts reclosing commands that are executed from shot 3
- `CNT_SHOT4`: counts reclosing commands that are executed from shot 4
- `CNT_SHOT5`: counts reclosing commands that are executed from shot 5

The counters are disabled through communication with the *DsaCnt* parameter. When the counters are disabled, the values are not updated.

The counters are reset through communication with the *RsCnt* parameter.

9.2.6 Application

Modern electric power systems can deliver energy to users very reliably. However, different kind of faults can occur. Protection relays play an important role in detecting failures or abnormalities in the system. They detect faults and give commands for corresponding circuit breakers to isolate the defective element before excessive damage or a possible power system collapse occurs. A fast isolation also limits the disturbances caused for the healthy parts of the power system.

The faults can be transient, semi-transient or permanent. For example, a permanent fault in power cables means that there is a physical damage in the fault location that must first be located and repaired before the network voltage can be restored.

In overhead lines, the insulating material between phase conductors is air. The majority of the faults are flash-over arcing faults caused by lightning, for example. Only a short interruption is needed for extinguishing the arc. These faults are transient by nature.

A semi-transient fault can be caused for example by a bird or a tree branch falling on the overhead line. The fault disappears on its own if the fault current burns the branch or the wind blows it away.

Transient and semi-transient faults can be cleared by momentarily de-energizing the power line. Using the autoreclose function minimizes interruptions in the power system service and brings the power back on-line quickly and effortlessly.

The basic idea of the autoreclose function is simple. In overhead lines, where the possibility of self-clearing faults is high, the autoreclose function tries to restore the power by reclosing the breaker. This is a method to get the power system back into normal operation by removing the transient or semi-transient faults. Several trials, that is, autoreclose shots are allowed. If none of the trials is successful and the fault persists, definite final tripping follows.

The autoreclose function can be used with every circuit breaker that has the ability for a reclosing sequence. In 79 autoreclose function the implementing method of autoreclose sequences is patented by ABB

Table 536: Important definitions related to autoreclosing

autoreclose shot	an operation where after a preset time the breaker is closed from the breaker tripping caused by protection
autoreclose sequence	a predefined method to do reclose attempts (shots) to restore the power system
SOTF	If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten grounding after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited.
final trip	Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed autoreclose operations. Since no autoreclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

9.2.6.1 Shot initiation

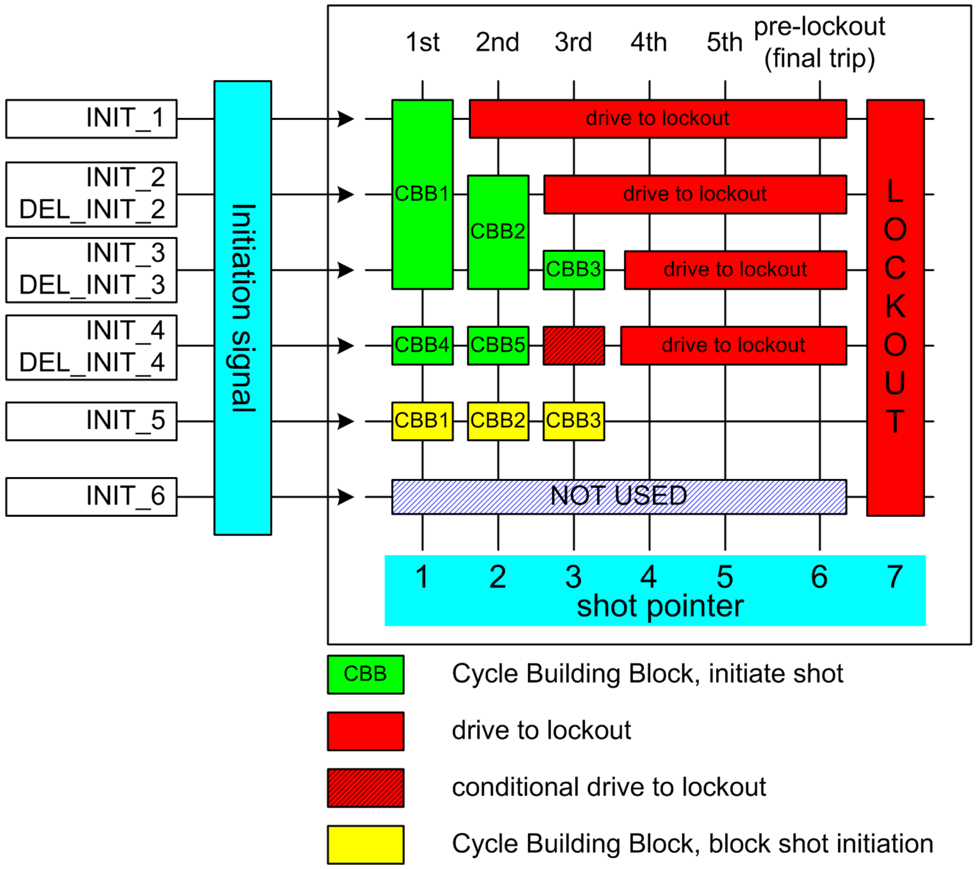


Figure 372: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 000111 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 000110 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 000100 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 010000 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 001000 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the

INIT_2 and INIT_4 lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a CLOSE_CB command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the autoreclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

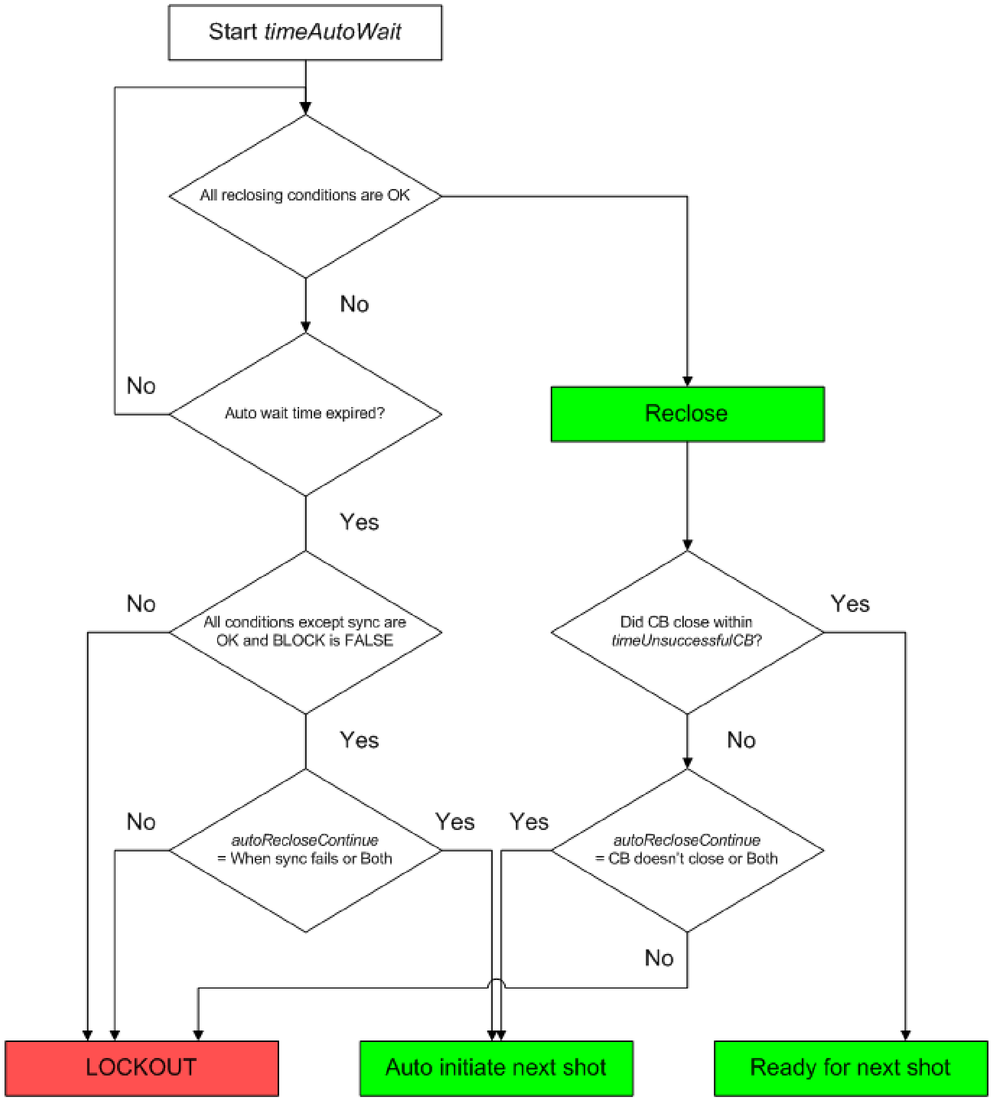


Figure 373: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.

The *Auto init* parameter defines which INIT_X lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

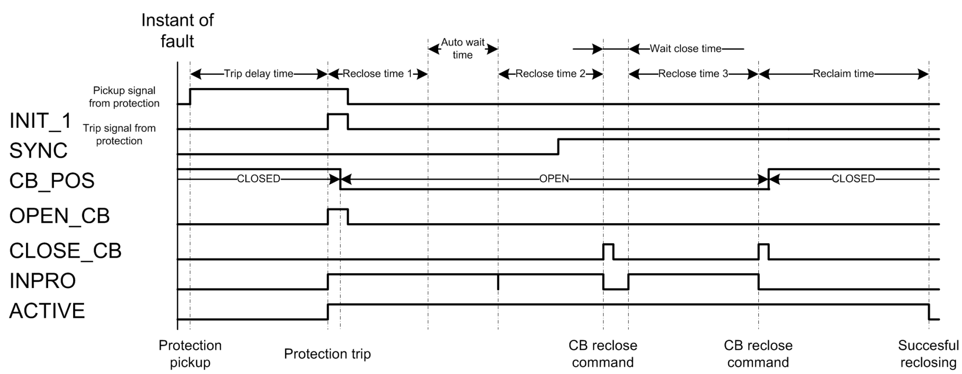


Figure 374: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (SYNC is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

9.2.6.2 Sequence

The autoreclose sequence is implemented by using up to seven CBBs. For example, if the user wants a sequence of three shots then only the first three CBBs are needed. Using building blocks instead of fixed shots gives enhanced flexibility, allowing multiple and adaptive sequences.

Each CBB is identical. The *Shot number CBB_* setting defines at which point in the autoreclose sequence the CBB should be performed, that is, whether the particular CBB is going to be the first, second, third, fourth or fifth shot.

During the initiation of a CBB, the conditions of initiation and blocking are checked. This is done for all CBBs simultaneously. Each CBB that fulfils the initiation conditions requests an execution.

The function also keeps track of shots already performed. That is, at which point the autoreclose sequence is from shot 1 to lockout. For example, if shots 1 and 2 have already been performed, only shots 3 to 5 are allowed.

Additionally, the *Enable shot jump* setting gives two possibilities:

- Only such CBBs that are set for the next shot in the sequence can be accepted for execution. For example, if the next shot in the sequence should be shot 2, a request from CBB set for shot 3 is rejected.
- Any CBB that is set for the next shot or any of the following shots can be accepted for execution. For example, if the next shot in the sequence should be shot 2, also CBBs that are set for shots 3, 4 and 5 are accepted. In other words, shot 2 can be ignored.

In case there are multiple CBBs allowed for execution, the CBB with the smallest number is chosen. For example, if CBB2 and CBB4 request an execution, CBB2 is allowed to execute the shot.

The autoreclose function can perform up to five autoreclose shots or cycles.

9.2.6.3 Configuration examples

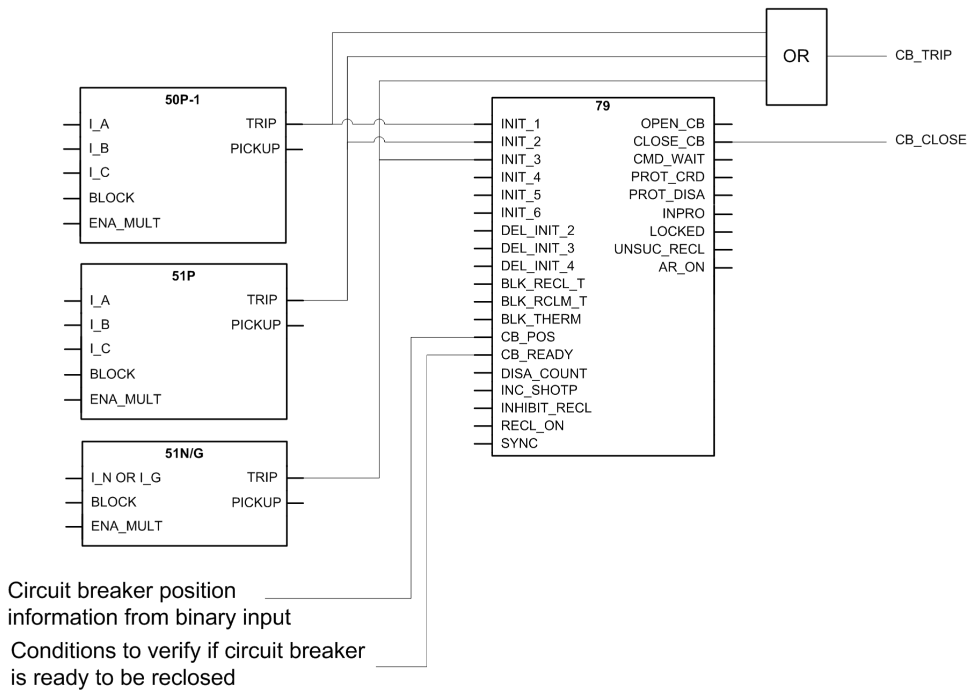


Figure 375: Example connection between protection and autoreclosing functions in protection relay configuration

It is possible to create several sequences for a configuration.

Autoreclose sequences for overcurrent and non-directional ground-fault protection applications where high speed and delayed autoreclosings are needed can be as follows:

Example 1.

The sequence is implemented by two shots which have the same reclose time for all protection functions, namely 50P-1, 51P and 51N/G. The initiation of the shots is done by activating the trip signals of the protection functions.

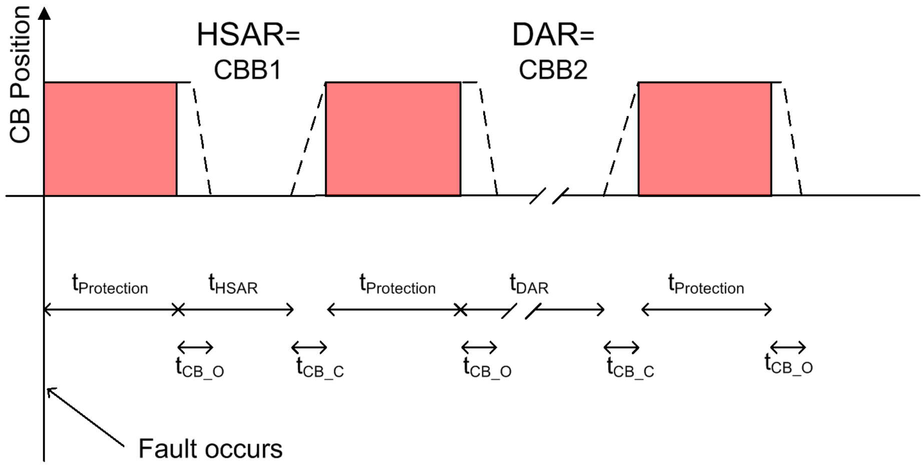


Figure 376: Autoreclosing sequence with two shots

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{Protection}$	Operating time for the protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the sequence needs two CBBs. The reclosing times for shot 1 and shot 2 are different, but each protection function initiates the same sequence. The CBB sequence is described in Table 537 as follows:

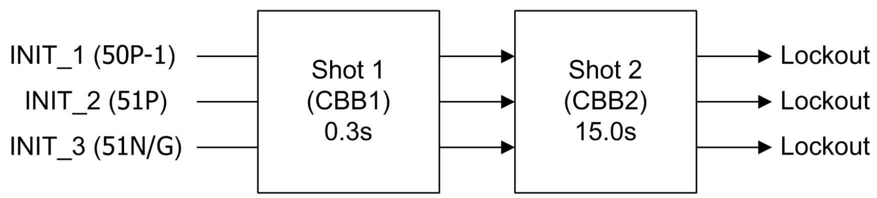


Figure 377: Two shots with three initiation lines

Table 537: Settings for configuration example 1

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	7 (lines 1, 2 and 3 = 1+2+4 = 7)
First reclose time	0.3s (an example)
Shot number CBB2	2
Init signals CBB2	7 (lines 1, 2 and 3 = 1+2+4 = 7)
Second reclose time	15.0s (an example)

Example 2

There are two separate sequences implemented with three shots. Shot 1 is implemented by CBB1 and it is initiated with the high stage of the overcurrent protection (50P-1). Shot 1 is set as a high-speed autoreclosing with a short time delay. Shot 2 is implemented with CBB2 and meant to be the first shot of the autoreclose sequence initiated by the low stage of the overcurrent protection (51P) and the low stage of the non-directional ground-fault protection (51N/G). It has the same reclose time in both situations. It is set as a high-speed autoreclosing for corresponding faults. The third shot, which is the second shot in the autoreclose sequence initiated by 51P or 51N/G, is set as a delayed autoreclosing and executed after an unsuccessful high-speed autoreclosing of a corresponding sequence.

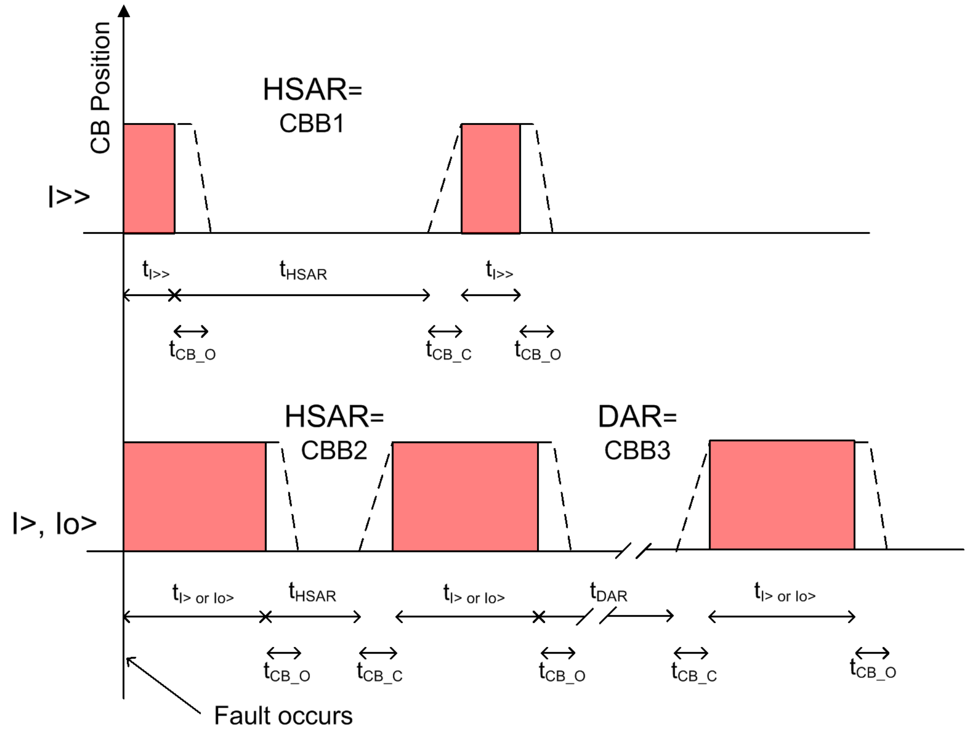


Figure 378: Autoreclosing sequence with two shots with different shot settings according to initiation signal

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{I>>}$	Operating time for the 50P-1 protection stage to clear the fault
$t_{I>}$ or $_{Io>}$	Operating time for the 51P or 51N/G protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the number of needed CBBs is three, that is, the first shot's reclosing time depends on the initiation signal.

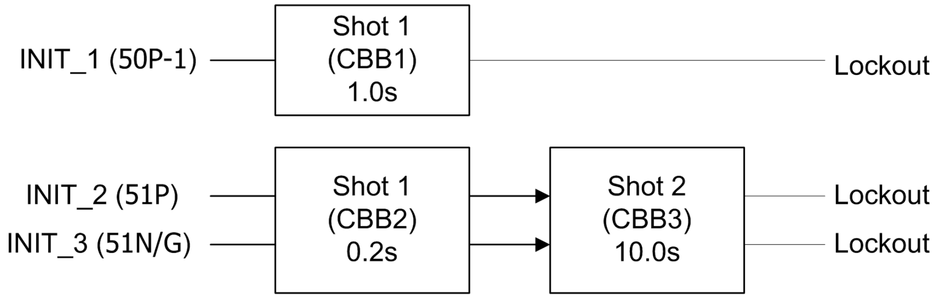


Figure 379: Three shots with three initiation lines

If the sequence is initiated from the `INIT_1` line, that is, the overcurrent protection high stage, the sequence is one shot long. If the sequence is initiated from the `INIT_2` or `INIT_3` lines, the sequence is two shots long.

Table 538: Settings for configuration example 2

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	1 (line 1)
First reclose time	0.0s (an example)
Shot number CBB2	1
Init signals CBB2	6 (lines 2 and 3 = 2+4 = 6)
Second reclose time	0.2s (an example)
Shot number CBB3	2
Init signals CBB3	6 (lines 2 and 3 = 2+4 = 6)
Third reclose time	10.0s

9.2.6.4 Delayed initiation lines

The autoreclose function consists of six individual autoreclose initiation lines `INIT_1...INIT 6` and three delayed initiation lines:

- `DEL_INIT_2`
- `DEL_INIT_3`
- `DEL_INIT_4`

`DEL_INIT_2` and `INIT_2` are connected together with an OR-gate, as are inputs 3 and 4. Inputs 1, 5 and 6 do not have any delayed input. From the autoreclosing point of view, it does not matter whether `INIT_x` or `DEL_INIT_x` line is used for shot initiation or blocking.

The autoreclose function can also open the circuit breaker from any of the initiation lines. It is selected with the *Tripping line* setting. As a default, all initiation lines activate the `OPEN_CB` output.

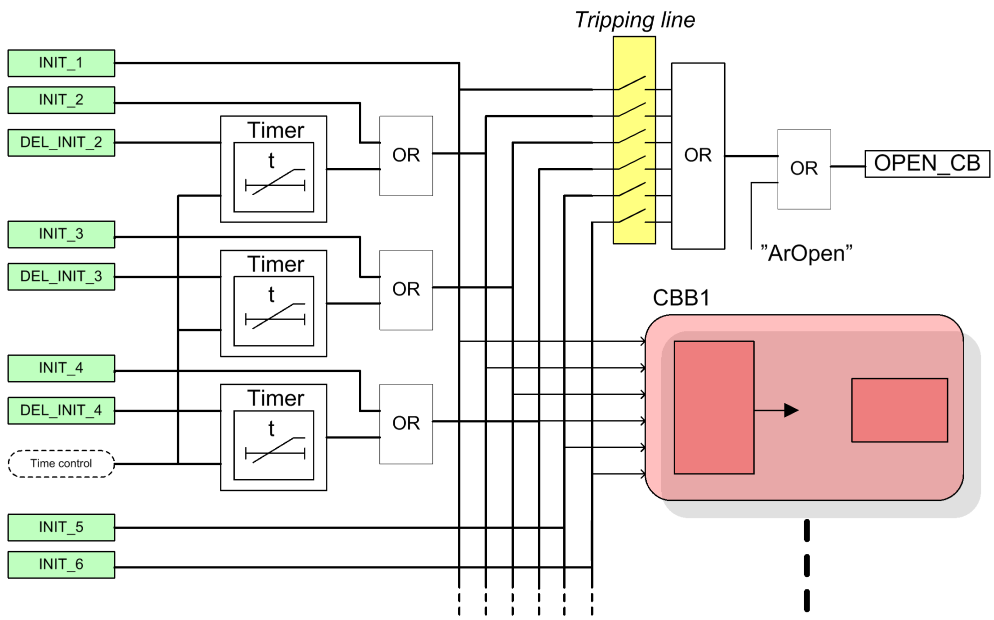


Figure 380: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 539: Settings for delayed initiation lines

Setting name	Description and purpose
Str x delay shot 1	Time delay for the `DEL_INIT_x` line, where x is the number of the line 2, 3 or 4. Used for shot 1.
Str x delay shot 2	Time delay for the `DEL_INIT_x` line, used for shot 2.
Str x delay shot 3	Time delay for the `DEL_INIT_x` line, used for shot 3.
Str x delay shot 4	Time delay for the `DEL_INIT_x` line, used for shots 4 and 5. Optionally, can also be used with SOTF.

9.2.6.5 Shot initiation from protection pickup signal

All autoreclose shots are initiated by protection trips. As a result, all trip times in the sequence are the same. This is why using protection trips may not be the optimal solution. Using protection pickup signals instead of protection trips for initiating shots shortens the trip times.

Example 1

When a two-shot-sequence is used, the pickup information from the protection function is routed to the `DEL_INIT 2` input and the trip information to the `INIT_2` input. The following conditions have to apply:

- protection trip time = 0.5s
- *Str 2 delay shot 1* = 0.05s
- *Str 2 delay shot 2* = 60s
- *Str 2 delay shot 3* = 60s

Operation in a permanent fault:

1. Protection picks up and activates the `DEL_INIT 2` input.
2. After 0.05 seconds, the first autoreclose shot is initiated. The function opens the circuit breaker: the `OPEN_CB` output activates. The total trip time is the protection pickup delay + 0.05 seconds + the time it takes to open the circuit breaker.
3. After the first shot, the circuit breaker is reclosed and the protection picks up again.
4. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time, activating the `INIT 2` input. The second shot is initiated.
5. After the second shot, the circuit breaker is reclosed and the protection picks up again.
6. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time. No further shots are programmed after the final trip. The function is in lockout and the sequence is considered unsuccessful.

Example 2

The delays can be used also for fast final trip. The conditions are the same as in Example 1, with the exception of *Str 2 delay shot 3* = 0.10 seconds.

The operation in a permanent fault is the same as in Example 1, except that after the second shot when the protection picks up again, *Str 2 delay shot 3* elapses before the protection trip time and the final trip follows. The total trip time is the protection pickup delay + 0.10 seconds + the time it takes to open the circuit breaker.

9.2.6.6 Fast trip in Switch on to fault

The *Str _ delay shot 4* parameter delays can also be used to achieve a fast and accelerated trip with SOTF. This is done by setting the *Fourth delay in SOTF* parameter to "1" and connecting the protection pickup information to the corresponding `DEL_INIT_` input.

When the function detects a closing of the circuit breaker, that is, any other closing except the reclosing done by the function itself, it always prohibits shot initiation for the time set with the *Reclaim time* parameter. Furthermore, if the *Fourth delay in SOTF* parameter is "1", the *Str _ delay shot 4* parameter delays are also activated.

Example 1

The protection operation time is 0.5 seconds, the *Fourth delay in SOTF* parameter is set to "1" and the *Str 2 delay shot 4* parameter is 0.05 seconds. The protection pickup signal is connected to the DEL_INIT_2 input.

If the protection picks up after the circuit breaker closes, the fast trip follows after the set 0.05 seconds. The total trip time is the protection pickup delay + 0.05 seconds + the time it takes to open the circuit breaker.

9.2.7 Signals

Table 540: 79 Input signals

Name	Type	Default	Description
INIT_1	BOOLEAN	0=False	AR initialization / blocking signal 1
INIT_2	BOOLEAN	0=False	AR initialization / blocking signal 2
INIT_3	BOOLEAN	0=False	AR initialization / blocking signal 3
INIT_4	BOOLEAN	0=False	AR initialization / blocking signal 4
INIT_5	BOOLEAN	0=False	AR initialization / blocking signal 5
INIT_6	BOOLEAN	0=False	AR initialization / blocking signal 6
DEL_INIT_2	BOOLEAN	0=False	Delayed AR initialization / blocking signal 2
DEL_INIT_3	BOOLEAN	0=False	Delayed AR initialization / blocking signal 3
DEL_INIT_4	BOOLEAN	0=False	Delayed AR initialization / blocking signal 4
BLK_RECL_T	BOOLEAN	0=False	Blocks and resets reclose time
BLK_RCLM_T	BOOLEAN	0=False	Blocks and resets reclaim time
BLK_THERM	BOOLEAN	0=False	Blocks and holds the reclose shot from the thermal overload
CB_POS	BOOLEAN	0=False	Circuit breaker position input
CB_READY	BOOLEAN	1=True	Circuit breaker status signal
INC_SHOTP	BOOLEAN	0=False	A zone sequence coordination signal
INHIBIT_RECL	BOOLEAN	0=False	Interrupts and inhibits reclosing sequence
RECL_ON	BOOLEAN	0=False	Level sensitive signal for allowing (high) / not allowing (low) reclosing
SYNC	BOOLEAN	0=False	Synchronizing check fulfilled

Table 541: 79 Output signals

Name	Type	Description
OPEN_CB	BOOLEAN	Open command for circuit breaker
CLOSE_CB	BOOLEAN	Close (reclose) command for circuit breaker
CMD_WAIT	BOOLEAN	Wait for master command
INPRO	BOOLEAN	Reclosing shot in progress, activated during dead time
LOCKED	BOOLEAN	Signal indicating that AR is locked out
PROT_CRD	BOOLEAN	A signal for coordination between the AR and the protection
UNSUC_RECL	BOOLEAN	Indicates an unsuccessful reclosing sequence
AR_ON	BOOLEAN	Autoreclosing allowed
READY	BOOLEAN	Indicates that the AR is ready for a new sequence

9.2.8 Settings

Table 542: 79 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable/ Enable
Reclosing operation	1=Off 2=External Ctl 3=On			1=Off	Reclosing operation (Off, External Ctl / On)
Manual close mode	0=False 1=True			0=False	Manual close mode
Wait close time	50...10000	ms	50	250	Allowed CB closing time after reclose command
Max wait time	100...1800000	ms	100	10000	Maximum wait time for haltDeadTime release
Max trip time	100...10000	ms	100	10000	Maximum wait time for deactivation of protection signals
Close pulse time	10...10000	ms	10	300	CB close pulse time
Max Thm block time	100...1800000	ms	100	10000	Maximum wait time for thermal blocking signal deactivation
Cut-out time	0...1800000	ms	100	10000	Cutout time for protection coordination
Reclaim time	100...1800000	ms	100	10000	Reclaim time
Dsr time shot 1	0...10000	ms	100	0	Discrimination time for first reclosing

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Dsr time shot 2	0...10000	ms	100	0	Discrimination time for second reclosing
Dsr time shot 3	0...10000	ms	100	0	Discrimination time for third reclosing
Dsr time shot 4	0...10000	ms	100	0	Discrimination time for fourth reclosing
Terminal priority	1=None 2=Low (follower) 3=High (master)			1=None	Terminal priority
Synchronisation set	0...127			0	Selection for synchronizing requirement for reclosing
Auto wait time	0...60000	ms	10	2000	Wait time for reclosing condition fullfilling
Auto lockout reset	0=False 1=True			0=False	Automatic lockout reset
Protection crd limit	1...5			2	Protection coordination shot limit
Protection crd mode	1=No condition 2=AR inoperative 3=CB close manual 4=AR inop, CB man 5=Always			1=No condition	Protection coordination mode
Auto initiation cnd	1=Not allowed 2=When sync fails 3=CB doesn't close 4=Both			2=When sync fails	Auto initiation condition
Tripping line	0...63			19	Tripping line, defines INIT inputs which cause OPEN_CB activation
Control line	0...63			19	Control line, defines INIT inputs which are protection signals
Enable shot jump	0=False 1=True			0=False	Enable shot jumping
CB closed Pos status	0=False 1=True			0=False	Circuit breaker closed position status
Fourth delay in SOTF	0=False 1=True			0=False	Sets 4th delay into use for all DEL_INIT signals during SOTF
First reclose time	0...300000	ms	10	500	Dead time for CBB1
Second reclose time	0...300000	ms	10	1000	Dead time for CBB2
Third reclose time	0...300000	ms	10	2000	Dead time for CBB3

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Fourth reclose time	0...300000	ms	10	5000	Dead time for CBB4
Fifth reclose time	0...300000	ms	10	5000	Dead time for CBB5
Sixth reclose time	0...300000	ms	10	5000	Dead time for CBB6
Seventh reclose time	0...300000	ms	10	5000	Dead time for CBB7
Init signals CBB1	0...63			3	Initiation lines for CBB1
Init signals CBB2	0...63			3	Initiation lines for CBB2
Init signals CBB3	0...63			2	Initiation lines for CBB3
Init signals CBB4	0...63			2	Initiation lines for CBB4
Init signals CBB5	0...63			0	Initiation lines for CBB5
Init signals CBB6	0...63			0	Initiation lines for CBB6
Init signals CBB7	0...63			0	Initiation lines for CBB7
Blk signals CBB1	0...63			16	Blocking lines for CBB1
Blk signals CBB2	0...63			16	Blocking lines for CBB2
Blk signals CBB3	0...63			16	Blocking lines for CBB3
Blk signals CBB4	0...63			16	Blocking lines for CBB4
Blk signals CBB5	0...63			0	Blocking lines for CBB5
Blk signals CBB6	0...63			0	Blocking lines for CBB6
Blk signals CBB7	0...63			0	Blocking lines for CBB7
Shot number CBB1	0...5			1	Shot number for CBB1
Shot number CBB2	0...5			2	Shot number for CBB2
Shot number CBB3	0...5			3	Shot number for CBB3
Shot number CBB4	0...5			4	Shot number for CBB4
Shot number CBB5	0...5			0	Shot number for CBB5
Shot number CBB6	0...5			0	Shot number for CBB6

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Shot number CBB7	0...5			0	Shot number for CBB7
Str 2 delay shot 1	0...300000	ms	10	0	Delay time for start2, 1st reclose
Str 2 delay shot 2	0...300000	ms	10	0	Delay time for start2 2nd reclose
Str 2 delay shot 3	0...300000	ms	10	0	Delay time for start2 3rd reclose
Str 2 delay shot 4	0...300000	ms	10	0	Delay time for start2, 4th reclose
Str 3 delay shot 1	0...300000	ms	10	0	Delay time for start3, 1st reclose
Str 3 delay shot 2	0...300000	ms	10	0	Delay time for start3 2nd reclose
Str 3 delay shot 3	0...300000	ms	10	0	Delay time for start3 3rd reclose
Str 3 delay shot 4	0...300000	ms	10	0	Delay time for start3, 4th reclose
Str 4 delay shot 1	0...300000	ms	10	0	Delay time for start4, 1st reclose
Str 4 delay shot 2	0...300000	ms	10	0	Delay time for start4 2nd reclose
Str 4 delay shot 3	0...300000	ms	10	0	Delay time for start4 3rd reclose
Str 4 delay shot 4	0...300000	ms	10	0	Delay time for start4, 4th reclose
Frq Op counter limit	0...250			250	Frequent operation counter lockout limit
Frq Op counter time	1...250	min		1	Frequent operation counter time
Frq Op recovery time	1...250	min		1	Frequent operation counter recovery time
Auto init	0...63			1	Defines INIT lines that are activated at auto initiation

9.2.9 Monitored data

Table 543: 79 Monitored data

Name	Type	Values (Range)	Unit	Description
DISA_COUNT	BOOLEAN	0=False 1=True		Signal for counter disabling
FRQ_OPR_CNT	INT32	0...2147483647		Frequent operation counter
FRQ_OPR_AL	BOOLEAN	0=False 1=True		Frequent operation counter alarm
STATUS	Enum	-2=Unsuccessful -1=Not defined 1=Ready 2=In progress 3=Successful		AR status signal for IEC61850
ACTIVE	BOOLEAN	0=False 1=True		Reclosing sequence is in progress
INPRO_1	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 1
INPRO_2	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 2
INPRO_3	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 3
INPRO_4	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 4
INPRO_5	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 5
DISCR_INPRO	BOOLEAN	0=False 1=True		Signal indicating that discrimination time is in progress
CUTOUT_INPRO	BOOLEAN	0=False 1=True		Signal indicating that cut-out time is in progress
SUC_RECL	BOOLEAN	0=False 1=True		Indicates a successful reclosing sequence
UNSUC_CB	BOOLEAN	0=False 1=True		Indicates an unsuccessful CB closing
CNT_SHOT1	INT32	0...2147483647		Resetable operation counter, shot 1
CNT_SHOT2	INT32	0...2147483647		Resetable operation counter, shot 2
CNT_SHOT3	INT32	0...2147483647		Resetable operation counter, shot 3
CNT_SHOT4	INT32	0...2147483647		Resetable operation counter, shot 4
CNT_SHOT5	INT32	0...2147483647		Resetable operation counter, shot 5

Table continues on next page

Name	Type	Values (Range)	Unit	Description
COUNTER	INT32	0...2147483647		Resetable operation counter, all shots
SHOT_PTR	INT32	0...7		Shot pointer value
MAN_CB_CL	BOOLEAN	0=False 1=True		Indicates CB manual closing during reclosing sequence
SOTF	BOOLEAN	0=False 1=True		Switch-onto-fault
79	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

9.2.10 Technical data

Table 544: 79 Technical data

Characteristic	Value
Trip time accuracy	±1.0% of the set value or ±20 ms

9.3 Synchronism and energizing check 25

9.3.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Synchronism and energizing check	SECRSYN	SYNC	25

9.3.2 Function block

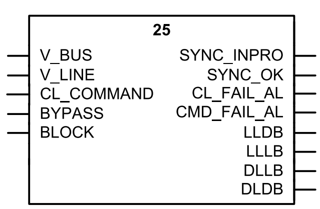


Figure 381: Function block

9.3.3 Functionality

The synchrocheck function 25 checks the condition across the circuit breaker from separate power system parts and gives the permission to close the circuit breaker. 25 includes the functionality of synchrocheck and energizing check.

Asynchronous operation mode is provided for asynchronously running systems. The main purpose of the asynchronous operation mode is to provide a controlled closing of circuit breakers when two asynchronous systems are connected.

The synchrocheck operation mode checks that the voltages on both sides of the circuit breaker are perfectly synchronized. It is used to perform a controlled reconnection of two systems which are divided after islanding and it is also used to perform a controlled reconnection of the system after reclosing.

The energizing check function checks that at least one side is dead to ensure that closing can be done safely.

The function contains a blocking functionality. It is possible to block function outputs and timers if desired.

9.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

SECRSYN has two parallel functionalities, the synchro check and energizing check functionality. The operation of the synchronism and energizing check functionality can be described using a module diagram. All the modules in the diagram are explained in the next sections.

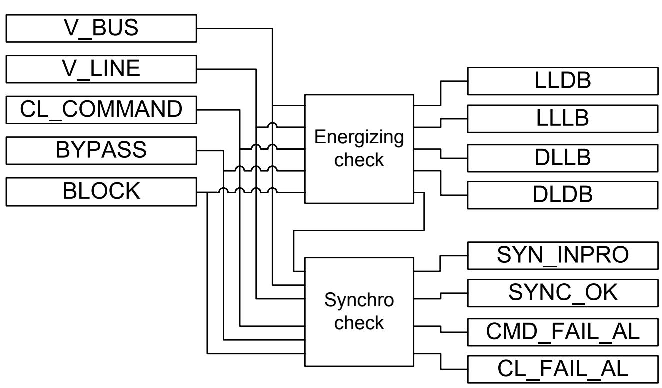


Figure 382: Functional module diagram

The Synchro check function can operate either with the V_AB or V_A voltages. The selection of used voltages is defined with the *VT connection* setting of the line voltage general parameters.

Energizing check

The Energizing check function checks the energizing direction. Energizing is defined as a situation where a dead network part is connected to an energized section of the network. The conditions of the network sections to be controlled by the circuit breaker, that is, which side has to be live and which side dead, are determined by the setting. A situation where both sides are dead is possible as well. The actual value for defining the dead line or bus is given with the *Dead bus value* and *Dead line value* settings. Similarly, the actual values of live line or bus are defined with the *Live bus value* and *Live line value* settings.

Table 545: Live dead mode of operation under which switching can be carried out

Live dead mode	Description
Both Dead	Both line and bus de-energized
Live L, Dead B	Bus de-energized and line energized
Dead L, Live B	Line de-energized and bus energized
Dead Bus, L Any	Both line and bus de-energized or bus de-energized and line energized
Dead L, Bus Any	Both line and bus de-energized or line de-energized and bus energized
One Live, Dead	Bus de-energized and line energized or line de-energized and bus energized
Not Both Live	Both line and bus de-energized or bus de-energized and line energized or line de-energized and bus energized

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the circuit breaker closing is permitted. The purpose of this time delay is to ensure that the dead side remains de-energized and also that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operation time, the timer is reset and the procedure is restarted when the conditions allow. The circuit breaker closing is not permitted if the measured voltage on the live side is greater than the set value of *Max energizing V*.

The measured energized state is available as a monitored data value ENERG_STATE and as four function outputs `LLDB` (live line / dead bus), `LLLB` (live line / live bus), `DLLB` (dead line / live bus) and `DLDB` (dead line / dead bus), of which only one can be active at a time. It is also possible that the measured energized state indicates “Unknown” if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

Synchro check

The Synchro check function measures the difference between the line voltage and bus voltage. The function trips and issues a closing command to the circuit breaker when the calculated closing angle is equal to the measured phase angle and if the conditions are simultaneously fulfilled.

- The measured line and bus voltages are higher than the set values of *Live bus value* and *Live line value* (ENERG_STATE equals to "Both Live").
- The measured bus and line frequency are both within the range of 95 to 105 percent of the value of f_n.
- The measured voltages for the line and bus are less than the set value of *Max energizing V*.

In case *Syncro check mode* is set to "Syncronous", the additional conditions must be fulfilled.

- In the synchronous mode, the closing is attempted so that the phase difference at closing is close to zero.
- The synchronous mode is only possible when the frequency slip is below 0.1 percent of the value of f_n.
- The voltage difference must not exceed the 1 percent of the value of V_n.

In case *Syncro check mode* is set to “Asyncronous”, the additional conditions must be fulfilled.

- The measured difference of the voltages is less than the set value of *Difference voltage*.
- The measured difference of the phase angles is less than the set value of *Difference angle*.
- The measured difference in frequency is less than the set value of *Frequency difference*.
- The estimated breaker closing angle is decided to be less than the set value of *Difference angle*.

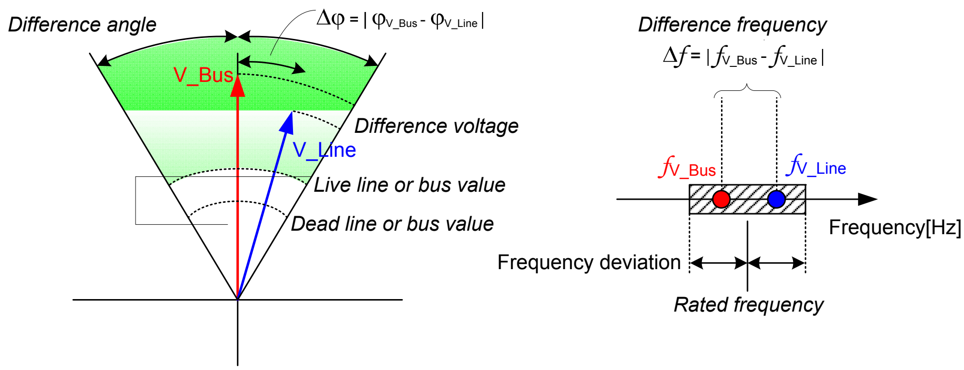


Figure 383: Conditions to be fulfilled when detecting synchronism between systems

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked so as to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the circuit breaker and the closing system, the delay from the moment the closing signal is given until the circuit breaker finally closes is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The Synchro check function compensates for the measured slip frequency and the circuit breaker closing delay. The phase angle advance is calculated continuously with the formula.

$$Closing\ angle = \left|(\angle V_{Bus} - \angle V_{Line})° + ((f_{Bus} - f_{line}) \times (T_{CB} + T_{PL}) \times 360°)\right|$$

(Equation 103)

$\angle V_{Bus}$	Measured bus voltage phase angle
$\angle V_{Line}$	Measured line voltage phase angle
f_{Bus}	Measured bus frequency
f_{line}	Measured line frequency
T_{CB}	Total circuit breaker closing delay, including the delay of the protection relay output contacts defined with the *Closing time of CB* setting parameter value

The closing angle is the estimated angle difference after the breaker closing delay.

The *Minimum Syn time* setting time can be set, if required, to demand the minimum time within which conditions must be simultaneously fulfilled before the SYNC_OK output is activated.

The measured voltage, frequency and phase angle difference values between the two sides of the circuit breaker are available as monitored data values V_DIFF_MEAS, FR_DIFF_MEAS and PH_DIFF_MEAS. Also, the indications of the conditions that are not fulfilled and thus preventing the breaker closing permission are available as monitored data values V_DIFF_SYNC, PH_DIF_SYNC and FR_DIFF_SYNC. These monitored data values are updated only when the Synchro check enabled with the *Synchro check mode* setting and the measured ENERG_STATE is "Both Live".

Continuous mode

The continuous mode is activated by setting the parameter *Control mode* to "Continuous". In the continuous control mode, Synchro check is continuously checking the synchronism. When synchronism is detected (according to the settings), the `SYNC_OK` output is set to TRUE (logic '1') and it stays TRUE as long as the conditions are fulfilled. The command input is ignored in the continuous control mode. The mode is used for situations where Synchro check only gives the permission to the control block that executes the CB closing.

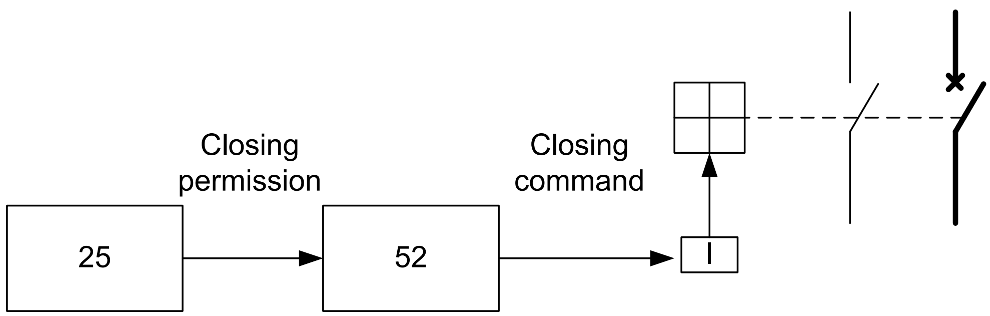


Figure 384: A simplified block diagram of the Synchro check function in the continuous mode operation

Command mode

If *Control mode* is set to "Command", the purpose of the Synchro check functionality in the command mode is to find the instant when the voltages on both sides of the circuit breaker are in synchronism. The conditions for synchronism are met when the voltages on both sides of the circuit breaker have the same frequency and are in phase with a magnitude that makes the concerned busbars or lines such that they can be regarded as live.

In the command mode operation, an external command signal `CL_COMMAND`, besides the normal closing conditions, is needed for delivering the closing signal. In the command control mode operation, the Synchro check function itself closes the breaker via the `SYNC_OK` output when the conditions are fulfilled. In this case, the control function block delivers the command signal to close the Synchro check function for the releasing of a closing-signal pulse to the circuit breaker. If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, the Synchro check function delivers a closing signal to the circuit breaker after the command signal is delivered for closing.

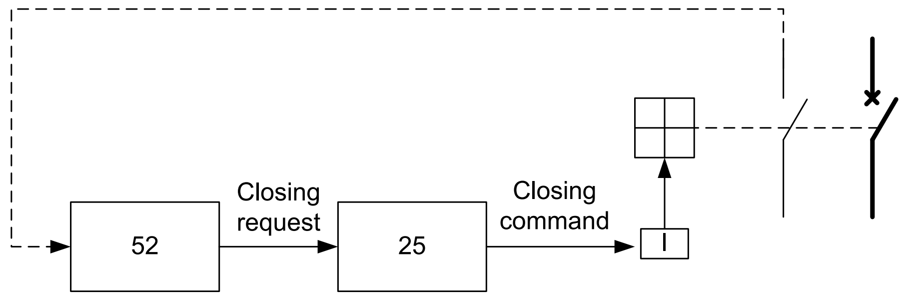


Figure 385: A simplified block diagram of SECRSYN in the command mode operation

The closing signal is delivered only once for each activated external closing command signal. The pulse length of the delivered closing is set with the *Close pulse* setting.

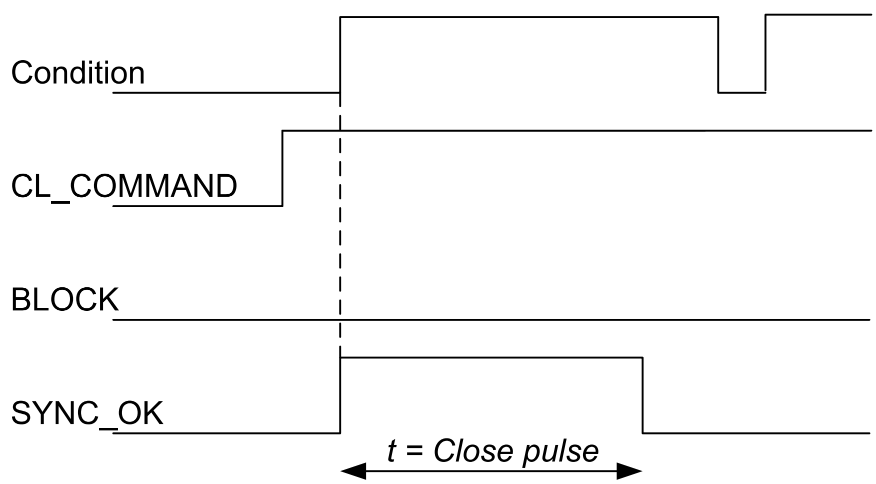


Figure 386: Determination of the pulse length of the closing signal

In the command control mode operation, there are alarms for a failed closing attempt (CL_FAIL_AL) and for a command signal that remains active too long (CMD_FAIL_AL).

If the conditions for closing are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The CL_FAIL_AL alarm output signal is pulse-shaped and the pulse length is 500 ms. If the external command signal is removed too early, that is, before conditions are fulfilled and the closing pulse is given, the alarm timer is reset.

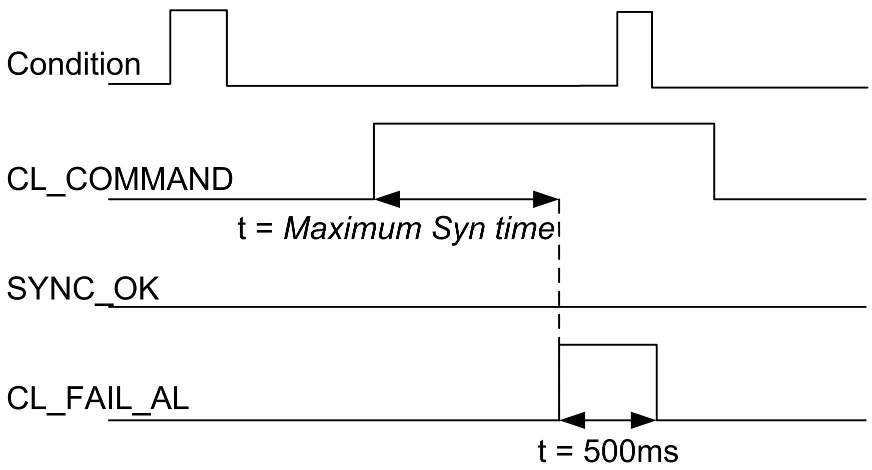


Figure 387: Determination of the checking time for closing

The control module receives information about the circuit breaker status and thus is able to adjust the command signal to be delivered to the Synchro check function. If the external command signal CL_COMMAND is kept active longer than necessary, the `CMD_FAIL_AL` alarm output is activated. The alarm indicates that the control module has not removed the external command signal after the closing operation. To avoid unnecessary alarms, the duration of the command signal should be set in such a way that the maximum length of the signal is always below *Maximum Syn time* + 5s.

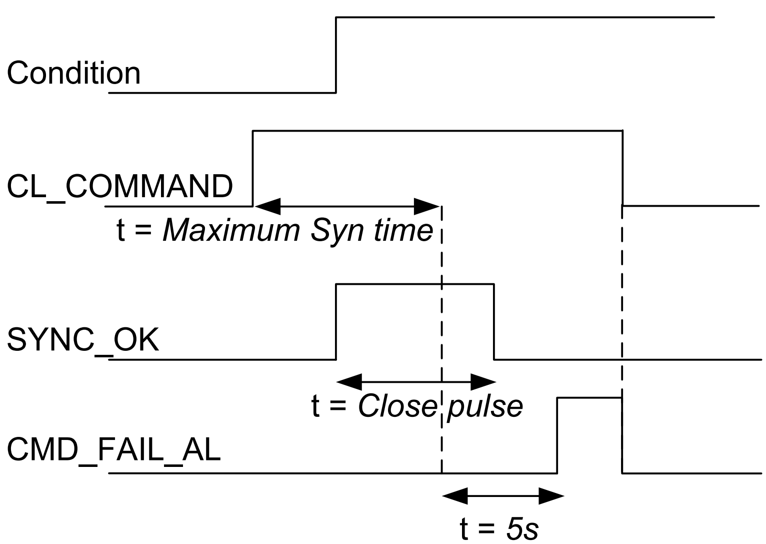


Figure 388: Determination of the alarm limit for a still-active command signal

Closing is permitted during *Maximum Syn time*, starting from the moment the external command signal CL_COMMAND is activated. The CL_COMMAND input must be kept active for the whole time that the closing conditions are waited to be fulfilled. Otherwise, the procedure is cancelled. If the closing-command conditions are fulfilled during *Maximum Syn time*, a closing pulse is delivered to the circuit breaker. If the closing conditions are not fulfilled during the checking time, the alarm CL_FAIL_AL is activated as an indication of a failed closing attempt. The closing pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated external command signal, and a new closing-command sequence cannot be started until the external command signal is reset and reactivated. The SYNC_INPRO output is active when the closing-command sequence is in progress and it is reset when the CL_COMMAND input is reset or *Maximum Syn time* has elapsed.

Bypass mode

25 can be set to the bypass mode by setting the parameters *Synchro check mode* and *Energizing check mode* to "Off" or alternatively by activating the BYPASS input.

In the bypass mode, the closing conditions are always considered to be fulfilled by 25. Otherwise, the operation is similar to the normal mode.

Voltage angle difference adjustment

In application where the power transformer is located between the voltage measurement and the vector group connection gives phase difference to the voltages between the high- and low-voltage sides, the angle adjustment can be used to meet synchronism.

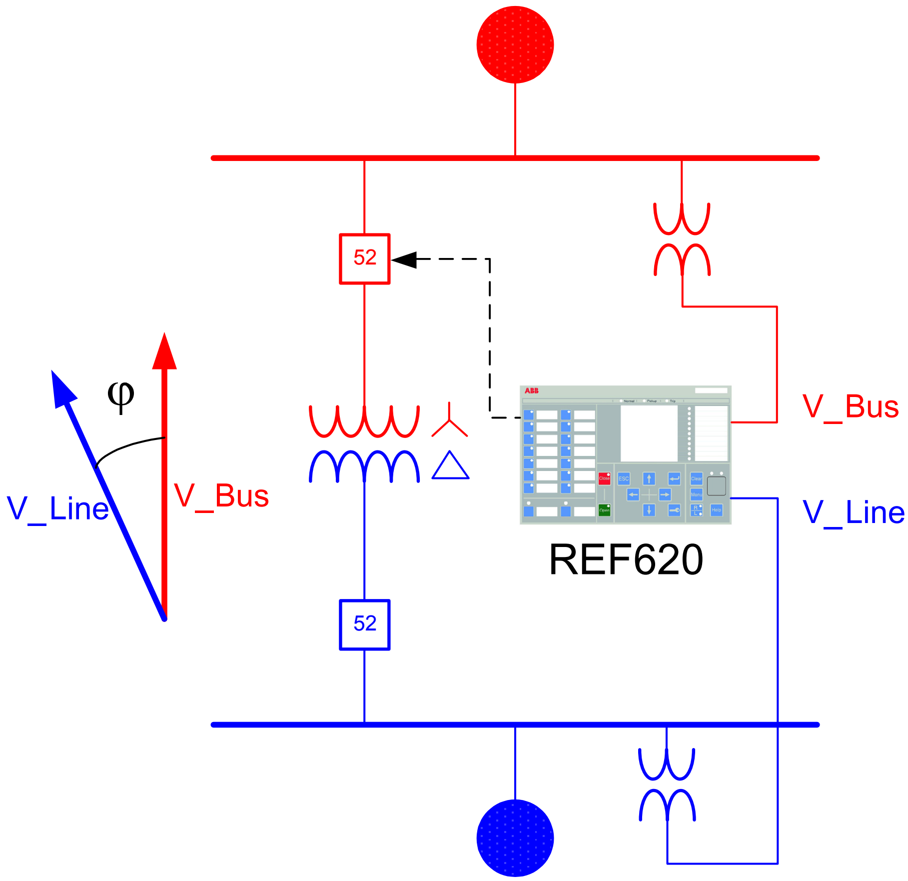


Figure 389: Angle difference when power transformer is in sychrocheck zone

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage-side phasor and the high-voltage-side phasor is always fixed to the clock number 12, which is same as zero. The angle between clock numbers is 30 degrees. When comparing phase angles, the `V_BUS` input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage-side voltage phasor leads by 30 degrees or lags by 330 degrees the high-voltage-side phasor. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage-side phasor lags the high-voltage-side phasor by clock number * 30º. This is called angle difference adjustment and can be set for SECRSYN with the *Phase shift* setting.

9.3.5 Application

The main purpose of the synchrocheck function is to provide control over the closing of the circuit breakers in power networks to prevent the closing if the conditions for synchronism are not detected. This function is also used to prevent the reconnection of two systems which are divided after islanding and a three-pole reclosing.

The Synchro check function block includes both the synchronism check function and the energizing function to allow closing when one side of the breaker is dead.

Network and the generator running in parallel with the network are connected through the line AB. When a fault occurs between A and B, the protection relay protection opens the circuit breakers A and B, thus isolating the faulty section from the network and making the arc that caused the fault extinguish. The first attempt to recover is a delayed autoreclosure made a few seconds later. Then, the autoreclose function 79 gives a command signal to the synchrocheck function to close the circuit breaker A. 25 performs an energizing check, as the line AB is de-energized (`V_BUS`> *Live bus value*, `V_LINE`< *Dead line value*). After verifying the line AB is dead and the energizing direction is correct, the protection relay energizes the line (`V_BUS` -> `V_LINE`) by closing the circuit breaker A. The PLC of the power plant discovers that the line has been energized and sends a signal to the other synchrocheck function to close the circuit breaker B. Since both sides of the circuit breaker B are live (`V_BUS` > *Live bus value*, `V_LINE` > *Live bus value*), the synchrocheck function controlling the circuit breaker B performs a synchrocheck and, if the network and the generator are in synchronism, closes the circuit breaker.

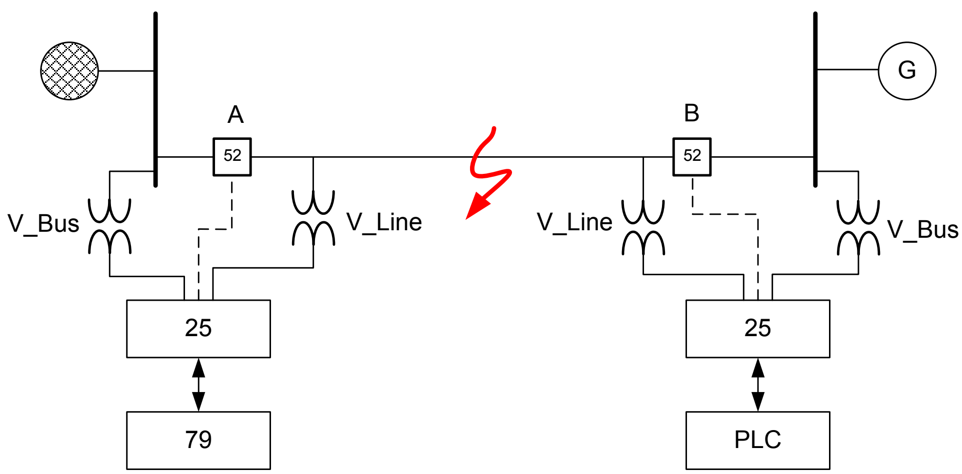


Figure 390: Synchrocheck function 79 checking energizing conditions and synchronism

Connections

A special attention is paid to the connection of the protection relay. Furthermore it is checked that the primary side wiring is correct.

A faulty wiring of the voltage inputs of the protection relay causes a malfunction in the synchrocheck function. If the wires of an energizing input have changed places, the polarity of the input voltage is reversed (180°). In this case, the protection relay permits the circuit breaker closing in a situation where the voltages are in opposite phases. This can damage the electrical devices in the primary circuit. Therefore, it is extremely important that the wiring from the voltage transformers to the terminals on the rear of the protection relay is consistent regarding the energizing inputs `V_BUS` (bus voltage) and `V_LINE` (line voltage).

The wiring should be verified by checking the reading of the phase difference measured between the `V_BUS` and `V_LINE` voltages. The phase difference measured by the protection relay has to be close to zero within the permitted accuracy tolerances. The measured phase differences are indicated in the LHMI. At the same time, it is recommended to check the voltage difference and the frequency differences presented in the monitored data view. These values should be within the permitted tolerances, that is, close to zero.

Figure 391 shows an example where the synchrocheck is used for the circuit breaker closing between a busbar and a line. The phase-to-phase voltages are measured from the busbar and also one phase-to-phase voltage from the line is measured.

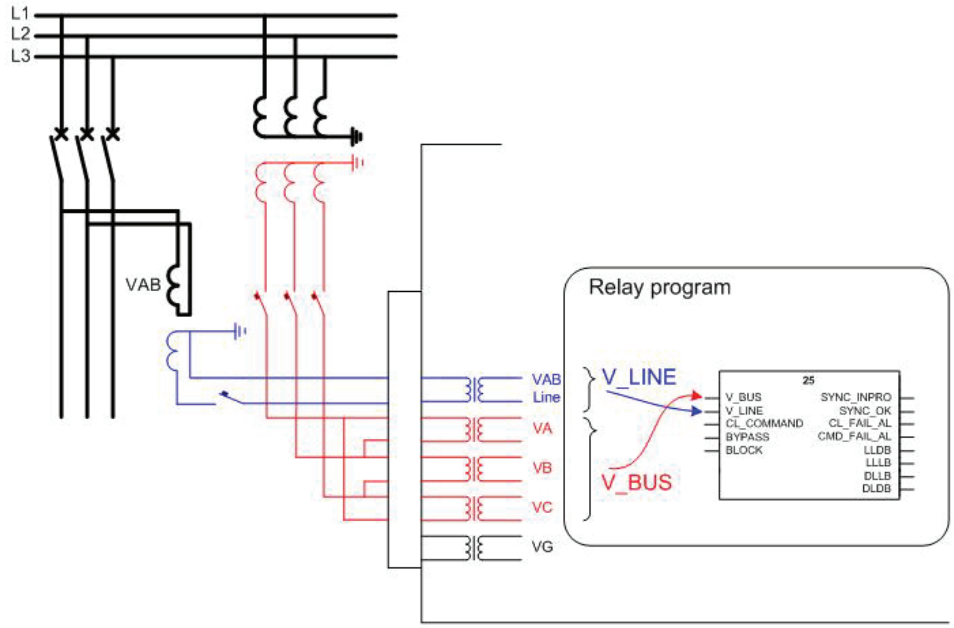


Figure 391: Connection of voltages for the protection relay and signals used in synchrocheck

9.3.6 Signals

Table 546: 25 Input signals

Name	Type	Default	Description
V_BUS	SIGNAL	0=False	Busbar Voltage
V_LINE	SIGNAL	0=False	Line Voltage
CL_COMMAND	BOOLEAN	0=False	External closing request
BYPASS	BOOLEAN	0=False	Request to bypass synchronism check and voltage check
BLOCK	BOOLEAN	0=False	Blocking signal of the synchro check and voltage check function

Table 547: 25 Output signals

Name	Type	Description
SYNC_INPRO	BOOLEAN	Synchronizing in progress
SYNC_OK	BOOLEAN	Systems in synchronism
CL_FAIL_AL	BOOLEAN	CB closing failed
Table continues on next page		

Name	Type	Description
CMD_FAIL_AL	BOOLEAN	CB closing request failed
LLDB	BOOLEAN	Live Line, Dead Bus
LLLB	BOOLEAN	Live Line, Live Bus
DLLB	BOOLEAN	Dead Line, Live Bus
DLDB	BOOLEAN	Dead Line, Dead Bus

9.3.7 Settings

Table 548: 25 Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Live dead mode	-1=Off 1=Both Dead 2=Live L, Dead B 3=Dead L, Live B 4=Dead Bus, L Any 5=Dead L, Bus Any 6=One Live, Dead 7=Not Both Live			1=Both Dead	Energizing check mode
Difference voltage	0.01...0.50	xVn	0.01	0.05	Maximum voltage difference limit
Difference frequency	0.001...0.100	xFn	0.001	0.001	Maximum frequency difference limit
Difference angle	5...90	deg	1	5	Maximum angle difference limit

Table 549: 25 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Synchro check mode	1=Off 2=Synchronous 3=Asynchronous			2=Synchronous	Synchro check operation mode
Control mode	1=Continuous 2=Command			1=Continuous	Selection of synchro check command or Continuous control mode
Dead line value	0.1...0.8	xVn	0.1	0.2	Voltage low limit line for energizing check
Live line value	0.2...1.0	xVn	0.1	0.5	Voltage high limit line for energizing check
Dead bus value	0.1...0.8	xVn	0.1	0.2	Voltage low limit bus for energizing check
Live bus value	0.2...1.0	xVn	0.1	0.5	Voltage high limit bus for energizing check
Close pulse	200...60000	ms	10	200	Breaker closing pulse duration
Max energizing V	0.50...1.15	xVn	0.01	1.05	Maximum voltage for energizing
Phase shift	-180...180	deg	1	180	Correction of phase difference between measured U_BUS and U_LINE
Minimum Syn time	0...60000	ms	10	0	Minimum time to accept synchronizing

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Maximum Syn time	100...6000000	ms	10	2000	Maximum time to accept synchronizing
Energizing time	100...60000	ms	10	100	Time delay for energizing check
Closing time of CB	40...250	ms	10	60	Closing time of the breaker

9.3.8 Monitored data

Table 550: 25 Monitored data

Name	Type	Values (Range)	Unit	Description
ENERG_STATE	Enum	0=Unknown 1=Both Live 2=Live L, Dead B 3=Dead L, Live B 4=Both Dead		Energization state of Line and Bus
V_DIFF_MEAS	FLOAT32	0.00...1.00	xVn	Calculated voltage amplitude difference
FR_DIFF_MEAS	FLOAT32	0.000...0.100	xFn	Calculated voltage frequency difference
PH_DIFF_MEAS	FLOAT32	0.00...180.00	deg	Calculated voltage phase angle difference
V_DIFF_SYNC	BOOLEAN	0=False 1=True		Voltage difference out of limit for synchronizing
PH_DIF_SYNC	BOOLEAN	0=False 1=True		Phase angle difference out of limit for synchronizing
FR_DIFF_SYNC	BOOLEAN	0=False 1=True		Frequency difference out of limit for synchronizing
25	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

9.3.9 Technical data

Table 551: 25 Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±1 Hz
	Voltage: ±3.0% of the set value or ±0.01 × U_n Frequency: ±10 mHz Phase angle: ±3°
Reset time	<50 ms
Reset ratio	Typically 0.96
Trip time accuracy in definite time mode	±1.0% of the set value or ±20 ms

9.4 Generic up-down counters CTR

9.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Generic up-down counters	UDFCNT	CTR	CTR

9.4.2 Function block

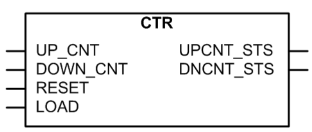


Figure 392: Function block

9.4.3 Functionality

The multipurpose generic up-down counter function CTR counts up or down for each positive edge of the corresponding inputs. The counter value output can be reset to zero or preset to some other value if required.

The function provides up-count and down-count status outputs, which specify the relation of the counter value to a loaded preset value and to zero respectively.

9.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the multipurpose generic up-down counter can be described with a module diagram. All the modules in the diagram are explained in the next sections.

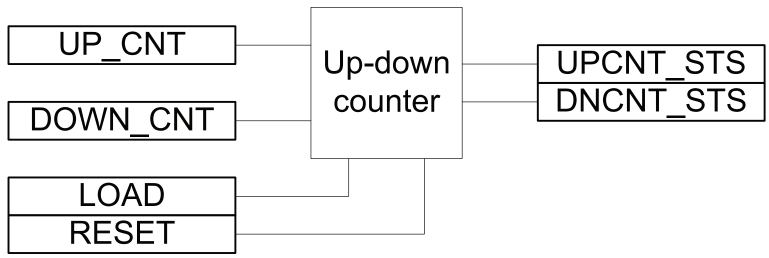


Figure 393: Functional module diagram

Up-down counter

Each rising edge of the UP_CNT input increments the counter value CNT_VAL by one and each rising edge of the DOWN_CNT input decrements the CNT_VAL by one. If there is a rising edge at both the inputs UP_CNT and DOWN_CNT, the counter value CNT_VAL is unchanged. The CNT_VAL is available in the monitored data view.

The counter value CNT_VAL is stored in a nonvolatile memory. The range of the counter is 0...+2147483647. The count of CNT_VAL saturates at the final value of 2147483647, that is, no further increment is possible.

The value of the setting *Counter load value* is loaded into counter value CNT_VAL either when the LOAD input is set to "True" or when the *Load Counter* is set to "Load" in the LHMI. Until the LOAD input is "True", it prevents all further counting.

The function also provides status outputs UPCNT_STS and DNCNT_STS. The UPCNT_STS is set to "True" when the CNT_VAL is greater than or equal to the setting *Counter load value*. DNCNT_STS is set to "True" when the CNT_VAL is zero.

The RESET input is used for resetting the function. When this input is set to "True" or when *Reset counter* is set to "reset", the CNT_VAL is forced to zero.

9.4.5 Signals

Table 552: CTR Input signals

Name	Type	Default	Description
UP_CNT	BOOLEAN	0=False	Input for up counting
DOWN_CNT	BOOLEAN	0=False	Input for down counting
RESET	BOOLEAN	0=False	Reset input for counter
LOAD	BOOLEAN	0=False	Load input for counter

Table 553: CTR Output signals

Name	Type	Description
UPCNT_STS	BOOLEAN	Status of the up counting
DNCNT_STS	BOOLEAN	Status of the down counting

9.4.6 Settings

Table 554: CTR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable
Counter load value	0...2147483647		1	10000	Preset counter value
Reset counter	0=Cancel 1=Reset			0=Cancel	Resets counter value
Load counter	0=Cancel 1=Load			0=Cancel	Loads the counter to preset value

9.4.7 Monitored data

Table 555: CTR Monitored data

Name	Type	Values (Range)	Unit	Description
CNT_VAL	INT128	0...2147483647		Output counter value

9.5 Emergency start-up 62EST

9.5.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Emergency start-up	ESMGAPC	ESTART	62EST

9.5.2 Function block

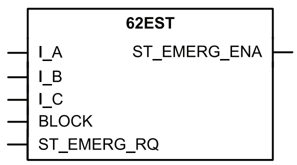


Figure 394: Function block

9.5.3 Functionality

An emergency condition can arise in cases where the motor needs to be started despite knowing that this can increase the temperature above limits or cause a thermal overload that can damage the motor. The emergency start-up function 62EST allows motor start-ups during such emergency conditions. 62EST is only to force the protection relay to allow the restarting of the motor. After the emergency start input is activated, the motor can be started normally. 62EST itself does not actually restart the motor.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself, if desired.

9.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the emergency start-up can be described using a module diagram. All the modules in the diagram are explained in the next sections.

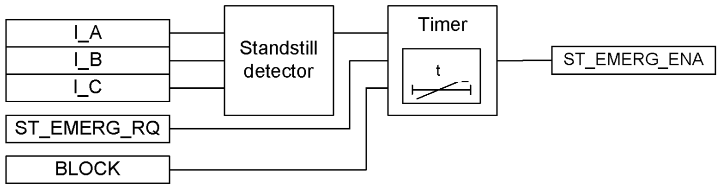


Figure 395: Functional module diagram

Standstill detector

The module detects if the motor is in a standstill condition. The standstill condition can be detected based on the phase current values. If all three phase currents are below the set value of *Motor standstill A*, the motor is considered to be in a standstill condition.

Timer

The timer is a fixed 10-minute timer that is activated when the `ST_EMERG_RQ` input is activated and motor standstill condition is fulfilled. Thus, the activation of the `ST_EMERG_RQ` input activates the `ST_EMERG_ENA` output, provided that the motor is in a standstill condition. The `ST_EMERG_ENA` output remains active for 10 minutes or as long as the `ST_EMERG_RQ` input is high, whichever takes longer.

The activation of the `BLOCK` input blocks and also resets the timer.

The function also provides the `ST_EMERG_ENA` output change date and time, `T_ST_EMERG`. The information is available in the monitored data view.

9.5.5 Application

If the motor needs to be started in an emergency condition at the risk of damaging the motor, all the external restart inhibits are ignored, allowing the motor to be restarted. Furthermore, if the calculated thermal level is higher than the restart inhibit level at an emergency start condition, the calculated thermal level is set slightly below the restart inhibit level. Also, if the register value of the cumulative startup time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor startup.

The activation of the `ST_EMERG_RQ` digital input allows to perform emergency start. The protection relay is forced to a state which allows the restart of motor, and the operator can now restart the motor. A new emergency start cannot be made until the 10 minute time-out has passed or until the emergency start is released, whichever takes longer.

The last change of the emergency start output signal is recorded.

9.5.6 Signals

Table 556: 62EST Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ST_EMERG_RQ	BOOLEAN	0=False	Emergency start input

Table 557: 62EST Output signals

Name	Type	Description
ST_EMERG_ENA	BOOLEAN	Emergency start

9.5.7 Settings

Table 558: 62EST Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Motor standstill A	0.05...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

Table 559: 62EST Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			1=enable	Operation Disable / Enable

9.5.8 Monitored data

Table 560: 62EST Monitored data

Name	Type	Values (Range)	Unit	Description
T_ST_EMERG	Timestamp			Emergency start activation timestamp
62EST	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

9.5.9 Technical data

Table 561: ESMGAPC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5% of the set value or ±0.002 × U_n

Section 10 Recording functions

10.1 Disturbance recorder DFR

10.1.1 Functionality

The relay is provided with a disturbance recorder featuring up to 12 analog and 64 binary signal channels. The analog channels can be set to record either the waveform or the trend of the currents and voltages measured.

The analog channels can be set to trigger the recording function when the measured value falls below or exceeds the set values. The binary signal channels can be set to start a recording either on the rising or the falling edge of the binary signal or on both.

By default, the binary channels are set to record external or internal relay signals, for example, the pickup or trip signals of the relay stages, or external blocking or control signals. Binary relay signals, such as a protection pickup or trip signal, or an external relay control signal via a binary input, can be set to trigger the recording. Recorded information is stored in a non-volatile memory and can be uploaded for subsequent fault analysis.

10.1.1.1 Recorded analog inputs

The user can map any analog signal type of the protection relay to each analog channel of the disturbance recorder by setting the *Channel selection* parameter of the corresponding analog channel. In addition, the user can enable or disable each analog channel of the digital fault recorder by setting the *Operation* parameter of the corresponding analog channel to “Enable” or “Disable”.

All analog channels of the disturbance recorder that are enabled and have a valid signal type mapped are included in the recording.

10.1.1.2 Triggering alternatives

The recording can be triggered by any or several of the following alternatives:

- Triggering according to the state change of any or several of the binary channels of the disturbance recorder. The user can set the level sensitivity with the *Level trigger mode* parameter of the corresponding binary channel.
- Triggering on limit violations of the analog channels of the disturbance recorder (high and low limit)
- Manual triggering via the *Trig recording* parameter (LHMI or communication)
- Periodic triggering.

Regardless of the triggering type, each recording generates events through state changes of the *Recording started*, *Recording made* and *Recording stored* status parameters. The *Recording stored* parameter indicates that the recording has been stored to the non-volatile memory. In addition, every analog channel and binary channel of the disturbance recorder has its own *Channel triggered* parameter. Manual trigger has the *Manual triggering* parameter and periodic trigger has the *Periodic triggering* parameter.

Triggering by binary channels

Input signals for the binary channels of the disturbance recorder can be formed from any of the digital signals that can be dynamically mapped. A change in the status of a monitored signal triggers the recorder according to the configuration and settings. Triggering on the rising edge of a digital input signal means that the recording sequence starts when the input signal is activated. Correspondingly, triggering on the falling edge means that the recording sequence starts when the active input signal resets. It is also possible to trigger from both edges. In addition, if preferred, the monitored signal can be non-triggering. The trigger setting can be set individually for each binary channel of the disturbance recorder with the *Level trigger mode* parameter of the corresponding binary channel.

Triggering by analog channels

The trigger level can be set for triggering in a limit violation situation. The user can set the limit values with the *High trigger level* and *Low trigger level* parameters of the corresponding analog channel. Both high level and low level violation triggering can be active simultaneously for the same analog channel. If the duration of the limit violation condition exceeds the filter time of approximately 50 ms, the recorder triggers. In case of a low level limit violation, if the measured value falls below approximately 0.05 during the filter time, the situation is considered to be a circuit-breaker operation and therefore, the recorder does not trigger. This is useful especially in undervoltage situations. The filter time of approximately 50 ms is common to all the analog channel triggers of the disturbance recorder. The value used for triggering is the calculated peak-to-peak value. Either high or low analog channel trigger can be disabled by setting the corresponding trigger level parameter to zero.

Manual triggering

The recorder can be triggered manually via the LHMI or via communication by setting the *Trig recording* parameter to TRUE.

Periodic triggering

Periodic triggering means that the recorder automatically makes a recording at certain time intervals. The user can adjust the interval with the *Periodic trig time* parameter. If the value of the parameter is changed, the new setting takes effect when the next periodic triggering occurs. Setting the parameter to zero disables the triggering alternative and the setting becomes valid immediately. If a new non-zero setting needs to be valid immediately, the user should first set the *Periodic trig time* parameter to zero and then to the new value. The user can monitor the time remaining to the next triggering with the `Time to trigger` monitored data which counts downwards.

10.1.1.3 Length of recordings

The user can define the length of a recording with the *Record length* parameter. The length is given as the number of fundamental cycles.

According to the memory available and the number of analog channels used, the disturbance recorder automatically calculates the remaining amount of recordings that fit into the available recording memory. The user can see this information with the `Rem. amount of rec` monitored data. The fixed memory size allocated for the recorder can fit in two recordings that are ten seconds long. The recordings contain data from all analog and binary channels of the disturbance recorder, at the sample rate of 32 samples per fundamental cycle.

The user can view the number of recordings currently in memory with the `Number of recordings` monitored data. The currently used memory space can be viewed with the `Rec. memory used` monitored data. It is shown as a percentage value.

The maximum number of recordings is 100.

10.1.1.4 Sampling frequencies

The sampling frequency of the disturbance recorder analog channels depends on the set rated frequency. One fundamental cycle always contains the amount of samples set with the *Storage rate* parameter. Since the states of the binary channels are sampled once per task execution of the disturbance recorder, the sampling frequency of binary channels is 400 Hz at the rated frequency of 50 Hz and 480 Hz at the rated frequency of 60 Hz.

Table 562: Sampling frequencies of the digital fault recorder analog channels

Storage rate (samples per fundamental cycle)	Recording length	Sampling frequency of analog channels, when the rated frequency is 50 Hz	Sampling frequency of binary channels, when the rated frequency is 50 Hz	Sampling frequency of analog channels, when the rated frequency is 60 Hz	Sampling frequency of binary channels, when the rated frequency is 60 Hz
32	1* Record length	1600 Hz	400 Hz	1920 Hz	480 Hz
16	2* Record length	800 Hz	400 Hz	960 Hz	480 Hz
8	4 * Record length	400 Hz	400 Hz	480 Hz	480 Hz

10.1.1.5 Uploading of recordings

The protection relay stores COMTRADE files to the `C:\COMTRADE\` folder. The files can be uploaded with the PCM tool or FTP software that can access the `C:\COMTRADE\` folder.

One complete disturbance recording consists of two COMTRADE file types: the configuration file and the data file. The file name is the same for both file types. The configuration file has .CFG and the data file .DAT as the file extension.

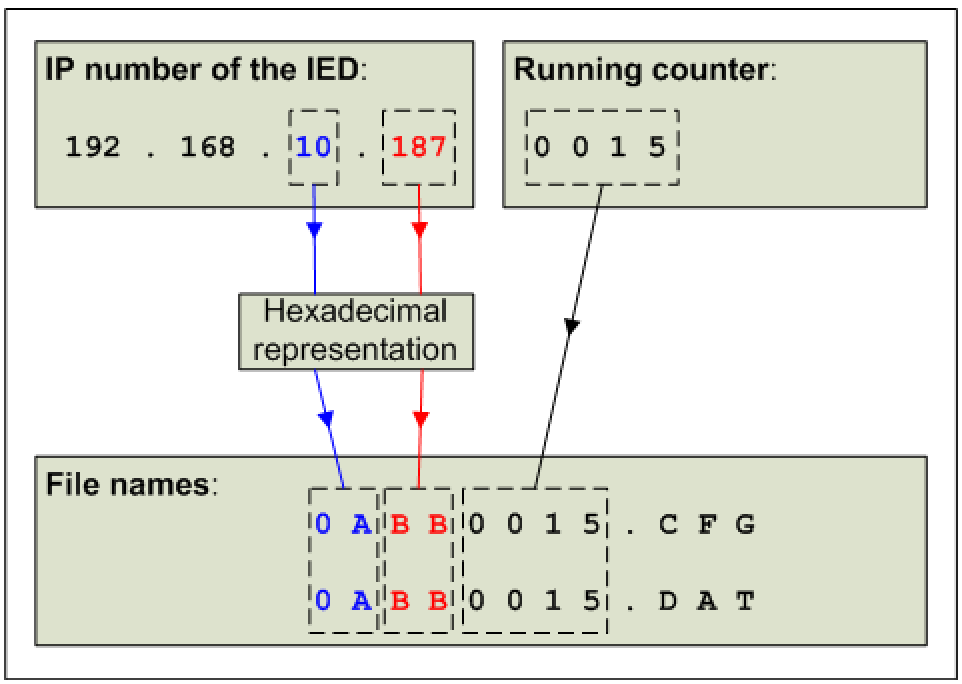


Figure 396: Disturbance recorder file naming

The naming convention of 8+3 characters is used in COMTRADE file naming. The file name is composed of the last two octets of the protection relay's IP number and a running counter, which has a range of 1...9999. A hexadecimal representation is used for the IP number octets. The appropriate file extension is added to the end of the file name.

10.1.1.6 Deletion of recordings

There are several ways to delete disturbance recordings. The recordings can be deleted individually or all at once.

Individual disturbance recordings can be deleted with PCM600 or any appropriate computer software, which can access the protection relay's `C:\COMTRADE` folder. The disturbance recording is not removed from the protection relay's memory until both of the corresponding COMTRADE files, .CFG and .DAT, are deleted. The user may have to delete both of the files types separately, depending on the software used.

Deleting all disturbance recordings at once is done either with PCM600 or any appropriate computer software, or from the LHMI via the **Clear/Digital fault recorder** menu. Deleting all disturbance recordings at once also clears the pre-trigger recording in progress.

10.1.1.7 Storage mode

The disturbance recorder can capture data in two modes: waveform and trend mode. The user can set the storage mode individually for each trigger source with the *Storage mode* parameter of the corresponding analog channel or binary channel, the *Stor. mode manual* parameter for manual trigger and the *Stor. mode periodic* parameter for periodic trigger.

In the waveform mode, the samples are captured according to the *Storage rate* and *Pre-trg length* parameters.

In the trend mode, one RMS value is recorded for each enabled analog channel, once per fundamental cycle. The binary channels of the disturbance recorder are also recorded once per fundamental cycle in the trend mode.

Only post-trigger data is captured in trend mode.

The trend mode enables recording times of 32 * *Record length*.

10.1.1.8 Pre-trigger and post-trigger data

The waveforms of the disturbance recorder analog channels and the states of the disturbance recorder binary channels are constantly recorded into the history memory of the recorder. The user can adjust the percentage of the data duration preceding the triggering, that is, the so-called pre-trigger time, with the *Pre-trg length* parameter. The duration of the data following the triggering, that is, the so-called post-trigger time, is the difference between the recording length and the pre-trigger time. Changing the pre-trigger time resets the history data and the current recording under collection.

10.1.1.9 Operation modes

Disturbance recorder has two operation modes: saturation and overwrite mode. The user can change the operation mode of the disturbance recorder with the *Operation mode* parameter.

Saturation mode

In saturation mode, the captured recordings cannot be overwritten with new recordings. Capturing the data is stopped when the recording memory is full, that is, when the maximum number of recordings is reached. In this case, the event is sent via the state change (TRUE) of the *Memory full* parameter. When there is memory available again, another event is generated via the state change (FALSE) of the *Memory full* parameter.

Overwrite mode

When the operation mode is "Overwrite" and the recording memory is full, the oldest recording is overwritten with the pre-trigger data collected for the next recording. Each time a recording is overwritten, the event is generated via the state change of the *Overwrite of rec.* parameter. The overwrite mode is recommended, if it is more important to have the latest recordings in the memory. The saturation mode is preferred, when the oldest recordings are more important.

New triggerings are blocked in both the saturation and the overwrite mode until the previous recording is completed. On the other hand, a new triggering can be accepted before all pre-trigger samples are collected for the new recording. In such a case, the recording is as much shorter as there were pre-trigger samples lacking.

10.1.1.10 Exclusion mode

Exclusion mode is on, when the value set with the *Exclusion time* parameter is higher than zero. During the exclusion mode, new triggerings are ignored if the triggering reason is the same as in the previous recording. The *Exclusion time* parameter controls how long the exclusion of triggerings of same type is active after a triggering. The exclusion mode only applies to the analog and binary channel triggerings, not to periodic and manual triggerings.

When the value set with the *Exclusion time* parameter is zero, the exclusion mode is disabled and there are no restrictions on the triggering types of the successive recordings.

The exclusion time setting is global for all inputs, but there is an individual counter for each analog and binary channel of the disturbance recorder, counting the remaining exclusion time. The user can monitor the remaining exclusion time with the *Exclusion time rem* parameter of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

10.1.2 Configuration

The disturbance recorder can be configured with PCM600 or any tool supporting the IEC 61850 standard.

The disturbance recorder can be enabled or disabled with the *Operation* parameter under the **Configuration/Digital fault recorder/General** menu.

Analog channels are fixed except channel 4 which is selectable based on the Ground CT option. The name of the analog channel is user-configurable. It can be modified it by writing the new name to the *Channel id text* parameter of the corresponding analog channel.

Any external or internal digital signal of the protection relay which can be dynamically mapped can be connected to the binary channels of the disturbance recorder. These signals can be, for example, the pickup and trip signals from protection function blocks or the external digital inputs of the protection relay. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using, for example, SMT of PCM600. It is also possible to connect several digital signals to one binary channel of the disturbance recorder. In that case, the signals can be combined with logical functions, for example AND and OR. The name of the binary channel can be configured and modified by writing the new name to the *Channel id text* parameter of the corresponding binary channel.

Note that the *Channel id text* parameter is used in COMTRADE configuration files as a channel identifier.

The recording always contains all binary channels of the disturbance recorder. If one of the binary channels is disabled, the recorded state of the channel is continuously FALSE and the state changes of the corresponding channel are not recorded. The corresponding channel name for disabled binary channels in the COMTRADE configuration file is Unused BI.

To enable or disable a binary channel of the disturbance recorder, the *Operation* parameter of the corresponding binary channel is set to “Enable” or “Disable”.

The states of manual triggering and periodic triggering are not included in the recording, but they create a state change to the *Periodic triggering* and *Manual triggering* status parameters, which in turn create events.

The *Recording started* parameter can be used to control the indication LEDs of the protection relay. The output of the *Recording started* parameter is TRUE due to the triggering of the disturbance recorder, until all the data for the corresponding recording is recorded.

The IP number of the protection relay and the content of the *Bay name* parameter are both included in the COMTRADE configuration file for identification purposes.

10.1.3 Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection protection relays and circuit breakers. It can record both analog and binary signal information. The analog inputs are recorded as instantaneous values and converted to primary peak value units when the protection relay converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used in storing disturbance recordings.

The binary channels are sampled once per task execution of the disturbance recorder. The task execution interval for the disturbance recorder is the same as for the protection functions. During the COMTRADE conversion, the digital status values are repeated so that the sampling frequencies of the analog and binary channels correspond to each other. This is required by the COMTRADE standard.

The disturbance recorder follows the 1999 version of the COMTRADE standard and uses the binary data file format.

10.1.4 Settings

Table 563: DFR Non-group general settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=Enable 5=Disable		1	1=Enable	DFR Enabled / Disabled
Record length	10...500	fundamental cycles	1	50	Size of the recording in fundamental cycles
Pre-trg length	5...95	%	1	10	Length of the recording preceding the triggering
Operation mode	1=Saturation 2=Overwrite		1	1	Operation mode of the recorder
Exclusion time	0...1 000 000	ms	1	0	The time during which triggerings of same type are ignored
Storage rate	32, 16, 8	samples per fundamental cycle		32	Storage rate of the waveform recording
Periodic trig time	0...604 800	s	10	0	Time between periodic triggerings
Stor. mode periodic	0=Waveform 1=Trend / cycle		1	0	Storage mode for periodic triggering
Stor. mode manual	0=Waveform 1=Trend / cycle		1	0	Storage mode for manual triggering

Table 564: DFR Non-group channel settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=Enable 5=Disable		1	1=Enable for Channels 1 - 4 5=Disable for channels 5 - 8	Analog channel is enabled or disabled
Channel selection	1)		0	1)	Select the signal to be recorded by this channel. Applicable values for this parameter are product variant dependent. Every product variant includes only the values that are applicable to that particular variant
Channel id text	0 to 64 characters, alphanumeric			DR analog channel X	Identification text for the analog channel used in the COMTRADE format
High trigger level	0.00...60.00	pu	0.01	10.00	High trigger level for the analog channel
Low trigger level	0.00...2.00	pu	0.01	0.00	Low trigger level for the analog channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the analog channel

1) Refer to the application manual for channel allocation for each configuration.

Table 565: DFR Non-group binary channel settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=Enable 5=Disable		1	5=Disable	Binary channel is enabled or disabled
Level trigger mode	1=Positive or Rising 2=Negative or Falling 3=Both 4=Level trigger off		1	1=Rising	Level trigger mode for the binary channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the binary channel
Channel id text	0 to 64 characters, alphanumeric			DR binary channel X	Identification text for the analog channel used in the COMTRADE format

Table 566: DFR Control data

Parameter	Values (Range)	Unit	Step	Default	Description
Trig recording	0=Cancel 1=Trig				Trigger the disturbance recording
Clear recordings	0=Cancel 1=Clear				Clear all recordings currently in memory

10.1.5 Monitored data

Table 567: DFR Monitored data

Parameter	Values (Range)	Unit	Step	Default	Description
Number of recordings	0...100				Number of recordings currently in memory
Rem. amount of rec.	0...100				Remaining amount of recordings that fit into the available recording memory, when current settings are used
Rec. memory used	0...100	%			Storage mode for the binary channel
Time to trigger	0...604 800	s			Time remaining to the next periodic triggering

10.2 Fault location FLO

10.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fault location	DRFLO	DRFLO	FLO

10.2.2 Function block

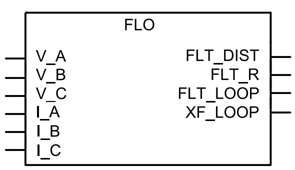


Figure 397: Function block

10.2.3 Functionality

The fault locator function FLO performs the estimation of apparent distance to fault and fault resistance. The calculation is performed by comparing the pre-fault current and voltage phasor by fault current and voltage phasor along with line parameters.

The fault loop is determined and the respective voltage and current phasor are selected for the fault location algorithm. The pre-fault current and voltage phasor are used to calculate the pre-fault load impedance, and fault current and voltage phasor are used to calculate the apparent impedance during the fault. The load impedance, apparent impedance and line parameters are used to estimate the fault resistance and distance to fault.

10.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

The operation of the fault locator function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

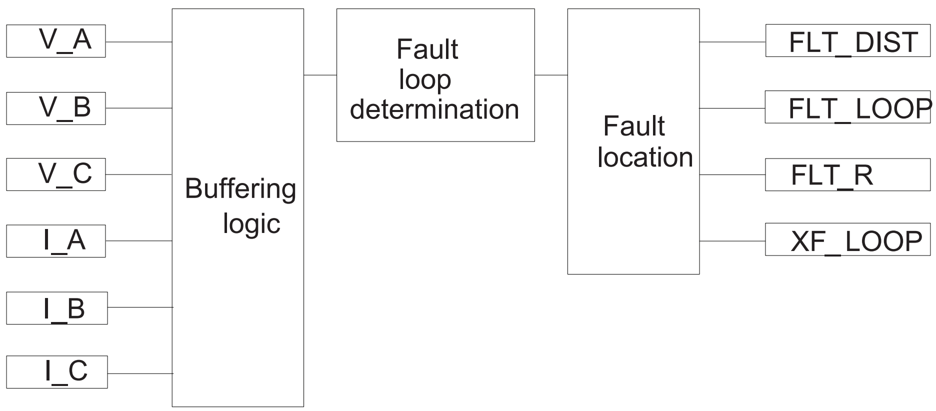


Figure 398: Functional module diagram

Buffering logic

The Buffering logic module buffers the three-phase voltage and current phasor input values (DFT values of V_A, V_B, V_C, I_A, I_B, I_C). Once the phase current magnitude is more than the *Phase Level* setting, the pre-fault buffer freezes and the updating of fault buffer is started. The fault buffer freezes once the buffer is updated fully. The fault location algorithm is started only if the Relay Trip signal is detected.

Fault loop determination

Any fault can be categorized as either a phase-to-phase fault or a phase-to-ground fault.

The fault loop determination algorithm determines whether the fault is a phase-to-ground fault or phase-to-phase fault by comparing the phase currents to the zero-sequence current.

Fault loop determines the fault loop from pre-fault and fault phasor stored in the respective buffers. The fault typing is the procedure to identify the type of fault, and therefore the respective voltage and current phasor can be selected from the pre-fault and fault buffers for the fault location algorithm.

Once the fault has been classified as either a phase-to-ground or phase-to-phase fault, the specific fault loop is determined by comparing all the phase currents to the setting *Phase Level*. Fault loop determination is done in accordance with Table 568.

Table 568: Fault identification

Fault in phase A	Fault in phase B	Fault in phase C	Fault in ground (Io)	FLTLOOP	FLTLOOP
1	0	0	1	AG Fault	1
0	1	0	1	BG Fault	2
0	0	1	1	CG Fault	3
1	1	0	0	AB Fault	4
0	1	1	0	BC Fault	5
1	0	1	0	CA Fault	6
1	1	1	0	ABC Fault	7
1	1	0	1	ABG Fault	-1
0	1	1	1	BCG Fault	-2
1	0	1	1	CAG Fault	-3
1	1	1	1	ABCG Fault	-4
0	0	0	0	No Fault	0

Once the specific fault type is determined, the respective fault loop voltage and current phasor are taken for fault location algorithm.

If the fault is any single phase-to-ground fault, the respective phase current should be ground-compensated.

The procedure for the ground compensation is given below,

For ground fault cases, the current measured at the protection relay is ground-compensated by employing the following formula

$$I^*_{rly} = I_{rly} + k * I_0 * (ZL_{Zero} - ZL_{Pos}) / ZL_{Pos}$$

(Equation 104)

where

$$I_0 = (I\_A + I\_B + I\_C) / 3$$

(Equation 105)

k	1.0 (scaling factor)
ZL_{pos} and ZL_{zero}	refer to positive and zero-sequence line impedances.
ZL_{pos}	RL_{pos} + j*XL_{pos}
ZL_{zero}	RL_{zero} + j*XL_{zero}
RL_{pos}	*PosSeqR * LinLen*
XL_{pos}	*PosSeqX * LinLen*
RL_{zero}	*ZeroSeqR * LinLen*
XL_{zero}	*ZeroSeqX * LinLen*
I^*_{rly}	Ground-compensated phase current
I_{rly}	Non-compensated phase current

R1 is positive-sequence line resistance in ohm/(miles or Kms) and is provided as a setting

X1 is positive-sequence line reactance in ohm/(miles or Kms) and is provided as a setting

R0 is zero-sequence line resistance in ohm/(miles or Kms) and is provided as a setting

X0 is zero-sequence line reactance in ohm/(miles or Kms) and is provided as a setting

Line Length is the length of the line in the units of Km (kilometers) or miles and is provided as a setting.

If *R1*, *X1*, *R0*, *X0* are given in ohm/mile, the length of the line *Line Length* should be given in the unit of miles

If *R1*, *X1*, *R0*, *X0* are given in ohm/Km, the length of the line*Line Length* should be given in the unit of Km.

Table 569 describes what are the voltage phasor and current phasor under different fault types.

Table 569: protection relay voltage and current phasor identification

FLTLOOP	Current phasor	Voltage phasor
AG Fault	I_A[1)]	V_A
BG Faul	I_B[1)]	V_B
CG Fault	I_C[1)]	V_C
ABG Fault	(I_A - I_B)	(V_A - V_B)
BCG Fault	(I_B - I_C)	(V_B - V_C)
CAG Fault	(I_C - I_A)	(V_C - V_A)
ABCG Fault	I_A	V_A
AB Fault	(I_A - I_B)	(V_A - V_B)
BC Fault	(I_B - I_C)	(V_B - V_C)
CA Fault	(I_C - I_A)	(V_C - V_A)
ABC Fault	I_A	V_A

1) indicates the respective current is ground-compensated

Fault location

Fault location calculates the distance to fault and fault resistance from the voltage phasor and current phasor selected based on the type of the fault Table 569.

The algorithm uses the fundamental frequency phasor voltages and currents measured at the protection relay terminal before and during the fault.

The algorithm basically is an iterative technique that performs a comparison of the pre-fault load impedance and apparent impedance during the fault to estimate the distance to fault.

Estimated values of fault resistance, pre-fault load impedance and line impedance are modified using the correction factors. The corrected values are used to estimate the final `FLT_DIST` and `FLT_R`.

During the autoreclosure sequences, the fault location is done with initial fault conditions.

10.2.5 Application

Electrical power system has grown rapidly over the last few decades. This resulted in a large increase of the number of lines in operation and their total length. These lines experience faults caused by storms, lightning, snow, freezing rain, insulation breakdown and short circuits caused by birds and other external objects. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service. The restoration can be expedited if the location of the fault is either known or can be expedited with reasonable accuracy.

The fault location algorithm is most applicable for radial feeder. The algorithm is based on the system model shown in Figure 399. The algorithm was designed to be used on a homogeneous radial distribution line. Therefore, the unit is not intended to be used on a distribution line with many different types of conductors because the algorithm is not as accurate. Fault location algorithm may not be accurate for the switch-onto-fault condition.

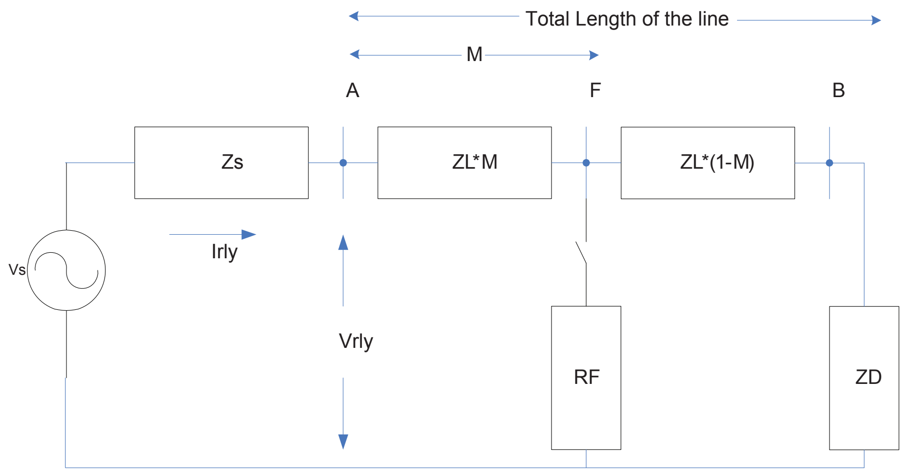


Figure 399: System model considered for fault location

where:

V_s	Source voltage
V_{rly}	Voltage at the protection relay location
I_{rly}	Current in the transmission line at the protection relay location
Z_s	Source impedance
ZL	Transmission line impedance in ohm/unit length
ZD	Load impedance
RF	Fault resistance
M	Distance to point of fault from relay location

10.2.6 Settings

Table 570: FLO Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Phase level	0.05...5.00	xIn	0.01	0.10	Phase Level

Table 571: FLO Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=enable 5=disable			5=disable	Operation Disable / Enable
Line length	0.0...300.0		0.1	100.0	Length of the Line in miles or Km
R1	0.000...20.000	ohm	0.001	1.000	Pos Seq Resistance in ohms/(miles or Km)
X1	0.000...30.000	ohm	0.001	2.000	Pos seq reactance in ohms/(miles or Km)
R0	0.000...20.000	ohm	0.001	0.010	Pos Seq Resistance in ohms/(miles or Km)
X0	0.000...30.000	ohm	0.001	1.000	Zero Seq Reactance in ohms/(miles or Km)

10.2.7 Monitored data

Table 572: FLO Monitored data

Name	Type	Values (Range)	Unit	Description
FLT_DIST	FLOAT32	0.00...9999.00		Fault Distance
FLT_LOOP	Enum	1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -1=ABG Fault -2=BCG Fault -3=CAG Fault -4=ABCG Fault 0=No fault		Fault Loop
FLT_R	FLOAT32	0.00...999.00	ohm	FaultResistance
XF_LOOP	FLOAT32	0.00...9999.00	ohm	Loop Reactance
TIME_FLT_LOC	Timestamp			Time stamp
FLO	Enum	1=Enabled 2=blocked 3=test 4=test/blocked 5=Disabled		Status

Section 11 Other functions

11.1 Minimum pulse timer

11.1.1 Minimum pulse timer TP

11.1.1.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum pulse timer (2 pcs)	TPGAPC	TP	TP

11.1.1.2 Function block

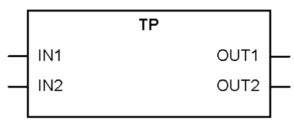


Figure 400: Function block

11.1.1.3 Functionality

The Minimum pulse timer function TP contains two independent timers running in milliseconds. The function has a settable pulse length (in milliseconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated the function gives out a pulse (*Pulse time* setting). But if the input remains active longer than the set *Pulse time*, also the output remains active until the input is deactivated.

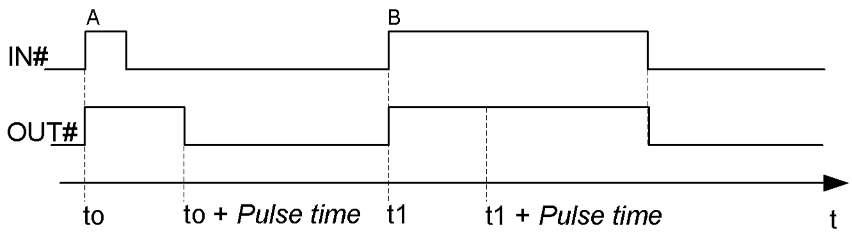


Figure 401: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

11.1.1.4 Signals

Table 573: TPGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status

Table 574: TP Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

11.1.1.5 Settings

Table 575: TP Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...60000	ms	1	150	Minimum pulse time

11.1.2 Minimum second pulse timer TPS

11.1.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum second pulse timer (2 pcs)	TPSGAPC	TPS	62-CLD TPS

11.1.2.2 Function block

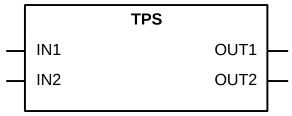


Figure 402: Function block

11.1.2.3 Functionality

The minimum second pulse timer function TPS-1 contains two independent timers. The function has a settable pulse length (in seconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated the function gives out a pulse (*Cold load time* setting). But if the input remains active longer than the set *Cold load time*, also the output remains active until the input is deactivated.

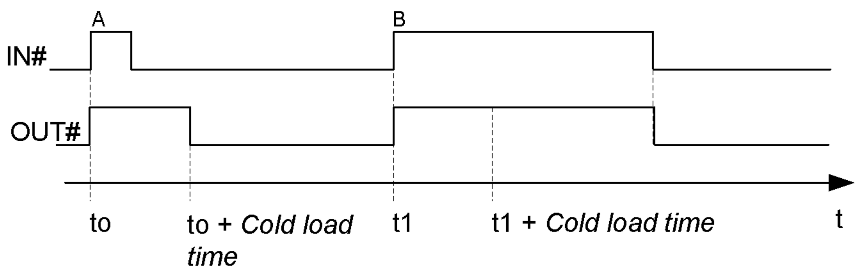


Figure 403: A = Trip pulse is shorter than Cold load time setting, B = Trip pulse is longer than Cold load time setting

11.1.2.4 Signals

Table 576: TPS Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

11.1.2.5 Settings

Table 577: TPS Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Cold load time	0...300	s	1	0	Cold load time

11.1.3 Minimum minute pulse timer TPM

11.1.3.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum minute pulse timer (2 pcs)	TPMGAPC	TPM	62-CLD TPM

11.1.3.2 Function block

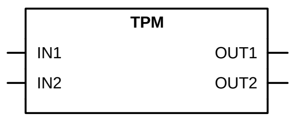


Figure 404: Function block

11.1.3.3 Functionality

The minimum minute pulse timer function TPM contains two independent timers. The function has a settable pulse length (in minutes). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated the function gives out a pulse (*Cold load time* setting). But if the input remains active longer than the set *Cold load time*, also the output remains active until the input is deactivated.

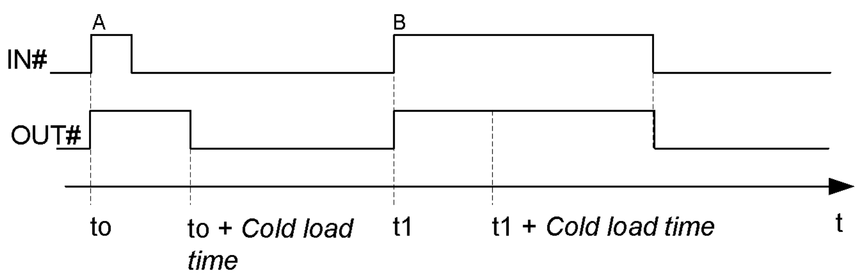


Figure 405: A = Trip pulse is shorter than Cold load time setting, B = Trip pulse is longer than Cold load time setting

11.1.3.4 Signals

Table 578: TPM Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

11.1.3.5 Settings

Table 579: TPM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Cold load time	0...300	min	1	0	Cold load time

11.2 Programmable buttons FKEY

11.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Programmable buttons (16 buttons)	FKEYGGIO	FKEY	FKEY

11.2.2 Function block

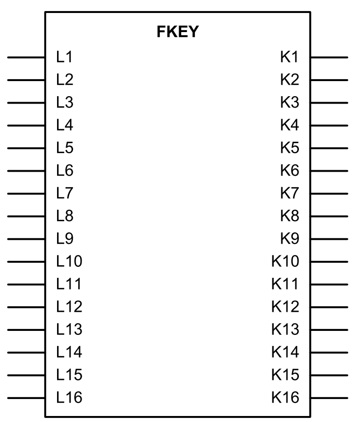


Figure 406: Function block

11.2.3 Functionality

The programmable function block FKEY is a simple interface between the panel and the application. The user input from the buttons available on the front panel is transferred to the assigned functionality and the corresponding LED is Enabled or Disabled for indication. The behavior of each function key in the specific application is configured by connection with other application functions. This gives the maximum flexibility.

11.2.4 Operation principle

Inputs `L1..L16` represent the LEDs on the protection relay's LHMI. When an input is set to TRUE, the corresponding LED is lit. When a function key on LHMI is pressed, the corresponding output `K1..K16` is set to TRUE.

11.2.5 Signals

Table 580: FKEY Input signals

Name	Type	Default	Description
L1	BOOLEAN	0=False	LED 1
L2	BOOLEAN	0=False	LED 2
L3	BOOLEAN	0=False	LED 3
L4	BOOLEAN	0=False	LED 4
L5	BOOLEAN	0=False	LED 5
L6	BOOLEAN	0=False	LED 6
L7	BOOLEAN	0=False	LED 7
L8	BOOLEAN	0=False	LED 8
L9	BOOLEAN	0=False	LED 9
L10	BOOLEAN	0=False	LED 10
L11	BOOLEAN	0=False	LED 11
L12	BOOLEAN	0=False	LED 12
L13	BOOLEAN	0=False	LED 13
L14	BOOLEAN	0=False	LED 14
L15	BOOLEAN	0=False	LED 15
L16	BOOLEAN	0=False	LED 16

Table 581: FKEY Output signals

Name	Type	Description
K1	BOOLEAN	KEY 1
K2	BOOLEAN	KEY 2
K3	BOOLEAN	KEY 3
K4	BOOLEAN	KEY 4
K5	BOOLEAN	KEY 5
K6	BOOLEAN	KEY 6
K7	BOOLEAN	KEY 7
K8	BOOLEAN	KEY 8
K9	BOOLEAN	KEY 9
K10	BOOLEAN	KEY 10
K11	BOOLEAN	KEY 11
K12	BOOLEAN	KEY 12
K13	BOOLEAN	KEY 13
K14	BOOLEAN	KEY 14
K15	BOOLEAN	KEY 15
K16	BOOLEAN	KEY 16

11.3 Move MV

11.3.1 Function block

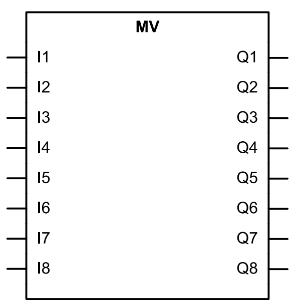


Figure 407: Function block

11.3.2 Functionality

Move (8 pcs) MV is used for user logic bits. Each input state is directly copied to the output state. This allows the creating of events from advanced logic combinations.

11.3.3 Signals

Table 582: MV Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

11.3.4 Settings

Table 583: MV Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Description				MVGAPC1 Q1	Output description
Description				MVGAPC1 Q2	Output description
Description				MVGAPC1 Q3	Output description
Description				MVGAPC1 Q4	Output description
Description				MVGAPC1 Q5	Output description
Description				MVGAPC1 Q6	Output description
Description				MVGAPC1 Q7	Output description
Description				MVGAPC1 Q8	Output description

11.4 Pulse timer PT

11.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Pulse timer (8 pcs)	PTGAPC	PT	PT

11.4.2 Function block

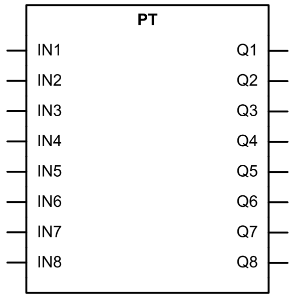


Figure 408: Function block

11.4.3 Functionality

The pulse timer function block PT contains eight independent timers. The function has a settable pulse length. Once the input is activated, the output is set for a specific duration using the *Pulse delay time* setting.

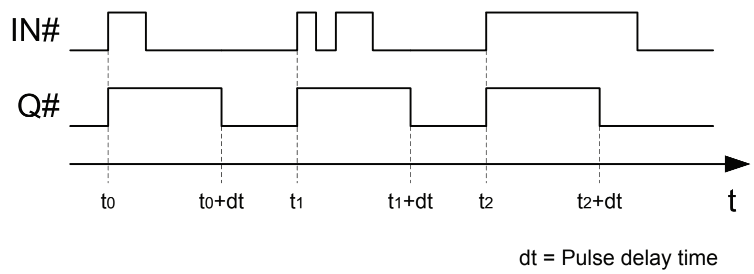


Figure 409: Timer operation

11.4.4 Signals

Table 584: PT Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status

Table continues on next page

Name	Type	Default	Description
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 585: PT Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

11.4.5 Settings

Table 586: PT Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse delay time 1	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 2	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 3	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 4	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 5	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 6	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 7	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 8	0...3600000	ms	10	0	Pulse delay time

11.4.6 Technical data

Table 587: PT Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

11.5 Generic control points CNTRL

11.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/ IEEEidentification
Generic control points	SPCGGIO	SPC	CNTRL

11.5.2 Function block

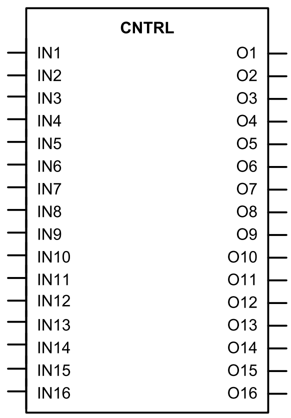


Figure 410: Function block

11.5.3 Functionality

The generic control points function block CNTRL can be used in combination with other function blocks such as FKEYGGIO. SPC offers the capability to activate its outputs through a local or remote control. The local control is provided through the buttons in the front panel and the remote control is provided through communications. CNTRL has two modes of operation. In the "Toggle" mode, the block toggles the output signal for every input pulse received. In the "Pulsed" mode, the block generates an output pulse of a preset duration.

11.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

CNTRL has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. CNTRL also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the protection relay is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or CNTRL can be accessed locally or remotely through communication or the LHMI control. CNTRL follows the local or remote (L/R) state if the *Loc Rem restriction* setting is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The `BLOCK` input can be used for blocking the output functionality. The `BLOCK` input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input `BLOCK` is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the `BLOCK` input resets the output to the FALSE state.

From the remote communication point of view, SPCGGIO toggled operation mode is always working as persistent mode. The output `O#` follows the value written to the input `IN#`.

11.5.5 Signals

Table 588: CNTRL Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
Table continues on next page			

Name	Type	Default	Description
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status
IN9	BOOLEAN	0=False	Input 9 status
IN10	BOOLEAN	0=False	Input 10 status
IN11	BOOLEAN	0=False	Input 11 status
IN12	BOOLEAN	0=False	Input 12 status
IN13	BOOLEAN	0=False	Input 13 status
IN14	BOOLEAN	0=False	Input 14 status
IN15	BOOLEAN	0=False	Input 15 status
IN16	BOOLEAN	0=False	Input 16 status

Table 589: CNTRL Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

11.5.6 Settings

Table 590: CNTRL Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 7	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 14	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 16	Generic control point description

11.6 Remote generic control points RCNTRL

11.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/ IEEEidentification
Remote generic control points	SPCRGGIO	SPCR	RCNTRL

11.6.2 Function block

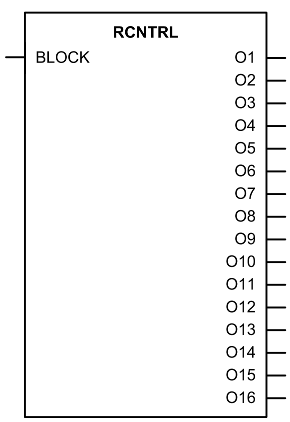


Figure 411: Function block

11.6.3 Functionality

The remote control function block RCNTRL is dedicated only for remote controlling, that is, RCNTRL cannot be controlled locally. The remote control is provided through communications.

11.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

RCNTRL has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. RCNTRL also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the protection relay is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or RCNTRL can only be accessed remotely through communication. RCNTRL follows the local or remote (L/R) state if the setting *Loc Rem restriction* is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The `BLOCK` input can be used for blocking the output functionality. The `BLOCK` input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input `BLOCK` is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the `BLOCK` input resets the output to the FALSE state.

From the remote communication point of view, SPCGGIO toggled operation mode is always working as persistent mode. The output `O#` follows the value written to the input `IN#`.

11.6.5 Signals

Table 591: RCNTRL Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 592: RCNTRL Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

11.6.6 Settings

Table 593: RCNTRL Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 1	Generic control point description
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 7	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 16	Generic control point description

11.7 Local generic control points LCNTRL

11.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/ IEEEidentification
Local generic control points	SPCLGGIO	SPCL	LCNTRL

11.7.2 Function block

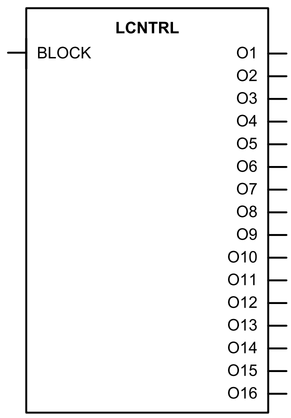


Figure 412: Function block

11.7.3 Functionality

The local control function block LCNTRL is dedicated only for local controlling, that is, LCNTRL cannot be controlled remotely. The local control is done through the buttons in the front panel.

11.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “Enable” and “Disable”.

LCNTRL has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. LCNTRL also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the protection relay is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or LCNTRL can only be accessed through the LHMI control. LCNTRL follows the local or remote (L/R) state if the *Loc Rem restriction* setting is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The BLOCK input can be used for blocking the output functionality. The BLOCK input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input BLOCK is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the BLOCK input resets the output to the FALSE state.

From the remote communication point of view, SPCGGIO toggled operation mode is always working as persistent mode. The output O# follows the value written to the input IN#.

11.7.5 Signals

Table 594: LCNTRL Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 595: LCNTRL Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
Table continues on next page		

Name	Type	Description
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

11.7.6 Settings

Table 596: LCNTRL Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Operation mode	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Description				SPCLGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 7	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 11	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 16	Generic control point description

11.8 Set reset SR

11.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Set reset (8 pcs)	SRGAPC	SR	SR

11.8.2 Function block

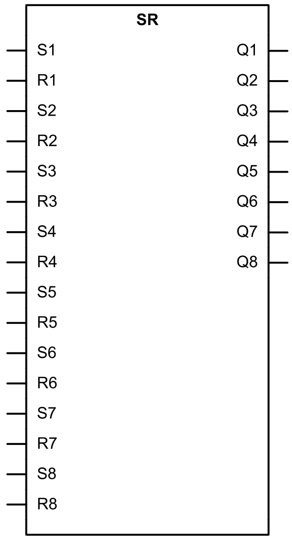


Figure 413: Function block

11.8.3 Functionality

The set-reset (8 pcs) SR function block is a simple SR flip-flop with a memory that can be set or that can reset an output from the `S#` or `R#` inputs, respectively. The function contains eight independent set-reset flip-flop latches where the `SET` input has the higher priority over the `RESET` input. The status of each `Q#` output is retained in the nonvolatile memory. The individual reset for each `Q#` output is available on the LHMI or through tool via communication.

Table 597: Truth table for SRGAPC

S#	R#	Q#
0	0	0 1)
0	1	0
1	0	1
1	1	1

1) Keep state/no change

11.8.4 Signals

Table 598: SR Input signals

Name	Type	Default	Description
S1	BOOLEAN	0=False	Set Q1 output when set
R1	BOOLEAN	0=False	Resets Q1 output when set
S2	BOOLEAN	0=False	Set Q2 output when set
R2	BOOLEAN	0=False	Resets Q2 output when set
S3	BOOLEAN	0=False	Set Q3 output when set
R3	BOOLEAN	0=False	Resets Q3 output when set
S4	BOOLEAN	0=False	Set Q4 output when set
R4	BOOLEAN	0=False	Resets Q4 output when set
S5	BOOLEAN	0=False	Set Q5 output when set
R5	BOOLEAN	0=False	Resets Q5 output when set
S6	BOOLEAN	0=False	Set Q6 output when set
R6	BOOLEAN	0=False	Resets Q6 output when set
S7	BOOLEAN	0=False	Set Q7 output when set
R7	BOOLEAN	0=False	Resets Q7 output when set
S8	BOOLEAN	0=False	Set Q8 output when set
R8	BOOLEAN	0=False	Resets Q8 output when set

Table 599: SR Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

11.8.5 Settings

Table 600: SR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Reset Q1	0=Cancel 1=Reset			0=Cancel	Resets Q1 output when set
Reset Q2	0=Cancel 1=Reset			0=Cancel	Resets Q2 output when set
Reset Q3	0=Cancel 1=Reset			0=Cancel	Resets Q3 output when set
Reset Q4	0=Cancel 1=Reset			0=Cancel	Resets Q4 output when set
Reset Q5	0=Cancel 1=Reset			0=Cancel	Resets Q5 output when set
Reset Q6	0=Cancel 1=Reset			0=Cancel	Resets Q6 output when set
Reset Q7	0=Cancel 1=Reset			0=Cancel	Resets Q7 output when set
Reset Q8	0=Cancel 1=Reset			0=Cancel	Resets Q8 output when set

11.9 Time delay off TOF

11.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Time delay off (8 pcs)	TOFGAPC	TOF	TOF

11.9.2 Function block

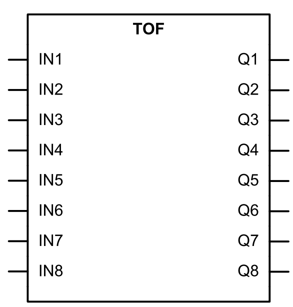


Figure 414: Function block

11.9.3 Functionality

Time delay off (8 pcs) TOF can be used, for example, for a drop-off-delayed output related to the input signal. The function contains eight independent timers. There is a settable delay in the timer. Once the input is activated, the output is set immediately. When the input is cleared, the output stays on until the time set with the *Off delay time* setting has elapsed.

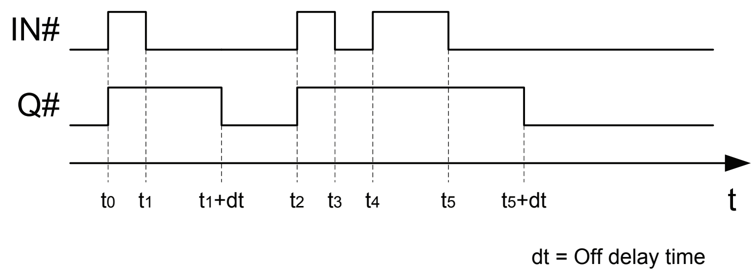


Figure 415: Timer operation

11.9.4 Signals

Table 601: TOF Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 602: TOF Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status

Table continues on next page

Name	Type	Description
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

11.9.5 Settings

Table 603: TOF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Off delay time 1	0...3600000	ms	10	0	Off delay time
Off delay time 2	0...3600000	ms	10	0	Off delay time
Off delay time 3	0...3600000	ms	10	0	Off delay time
Off delay time 4	0...3600000	ms	10	0	Off delay time
Off delay time 5	0...3600000	ms	10	0	Off delay time
Off delay time 6	0...3600000	ms	10	0	Off delay time
Off delay time 7	0...3600000	ms	10	0	Off delay time
Off delay time 8	0...3600000	ms	10	0	Off delay time

11.9.6 Technical data

Table 604: TOF Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

11.10 Time delay on TON

11.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Time delay on (8 pcs)	TONGAPC	TON	TON

11.10.2 Function block

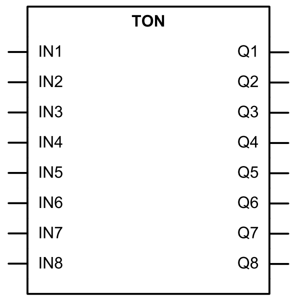


Figure 416: Function block

11.10.3 Functionality

Time delay on (8 pcs) TON can be used, for example, for time-delaying the output related to the input signal. TON contains eight independent timers. The timer has a settable time delay. Once the input is activated, the output is set after the time set by the *On delay time* setting has elapsed.

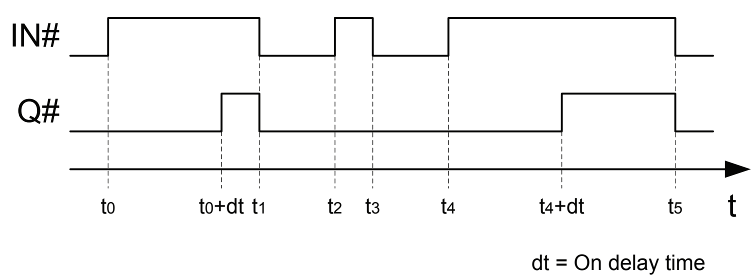


Figure 417: Timer operation

11.10.4 Signals

Table 605: TON Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2
IN3	BOOLEAN	0=False	Input 3
IN4	BOOLEAN	0=False	Input 4

Table continues on next page

Name	Type	Default	Description
IN5	BOOLEAN	0=False	Input 5
IN6	BOOLEAN	0=False	Input 6
IN7	BOOLEAN	0=False	Input 7
IN8	BOOLEAN	0=False	Input 8

Table 606: TON Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1
Q2	BOOLEAN	Output 2
Q3	BOOLEAN	Output 3
Q4	BOOLEAN	Output 4
Q5	BOOLEAN	Output 5
Q6	BOOLEAN	Output 6
Q7	BOOLEAN	Output 7
Q8	BOOLEAN	Output 8

11.10.5 Settings

Table 607: TON Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
On delay time 1	0...3600000	ms	10	0	On delay time
On delay time 2	0...3600000	ms	10	0	On delay time
On delay time 3	0...3600000	ms	10	0	On delay time
On delay time 4	0...3600000	ms	10	0	On delay time
On delay time 5	0...3600000	ms	10	0	On delay time
On delay time 6	0...3600000	ms	10	0	On delay time
On delay time 7	0...3600000	ms	10	0	On delay time
On delay time 8	0...3600000	ms	10	0	On delay time

11.10.6 Technical data

Table 608: TON Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

11.11 Three-phase measurement switching VSWI

11.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Switch-controlled voltage	VMSWI	VSWI	VSWI

11.11.2 Function block

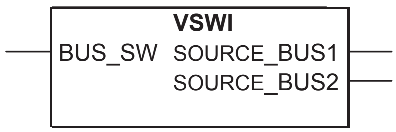


Figure 418: Function block

11.11.3 Functionality

Switching function modeled with extensional logical node VSWI represents the switch-controlled voltage triplet as:

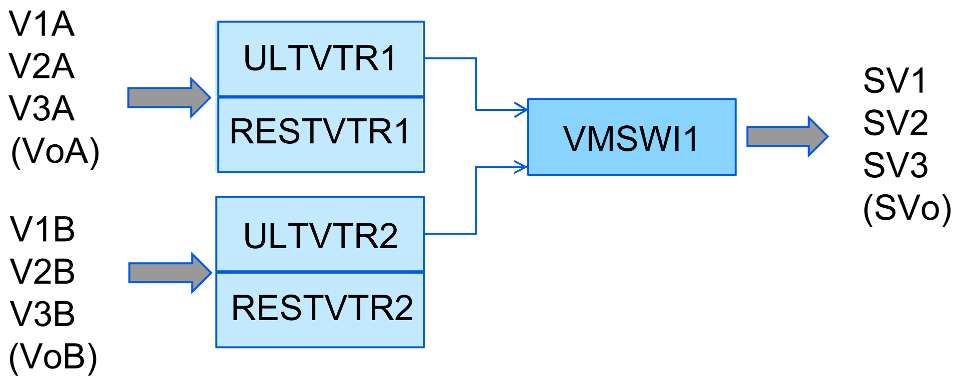


Figure 419: Representation of switch-controlled voltage triplet

VSWI performs the switching function between two voltage groups (Bus 1 and Bus 2).

Residual voltage input can be optional and it depends on the HV configuration. The switching operation can also be performed on the residual voltage.

The calculated components V_1, V_2 and V_0 and the calculated phase-to-phase and phase-to-ground, depending on the wye/delta mode, are switch-controlled too.

11.11.4 Signals

Table 609: VSWI Input signals

Name	Type	Default	Description
BUS_SW	BOOLEAN	0=False	Bus voltage selection

Table 610: VSWI Output signals

Name	Type	Description
SOURCE_BUS1	BOOLEAN	Selected voltage source is bus 1
SOURCE_BUS2	BOOLEAN	Selected voltage source is bus 2

11.11.5 Monitored data

Table 611: VSWI Monitored data

Name	Type	Values (Range)	Unit	Description
BUS_SW_POS	Enum	1=Bus 1 2=Bus 2		Bus switch position

Section 12 General function block features

12.1 Definite time characteristics

12.1.1 Definite time operation

The DT mode is enabled when the *Operating curve type* setting is selected either as "ANSI Def. Time" or "IEC Def. Time". In the DT mode, the `TRIP` output of the function is activated when the time calculation exceeds the set *Trip delay time*.

The user can determine the reset in the DT mode with the *Reset delay time* setting, which provides the delayed reset property when needed.

The *Type of reset curve* setting has no effect on the reset method when the DT mode is selected, but the reset is determined solely with the *Reset delay time* setting.

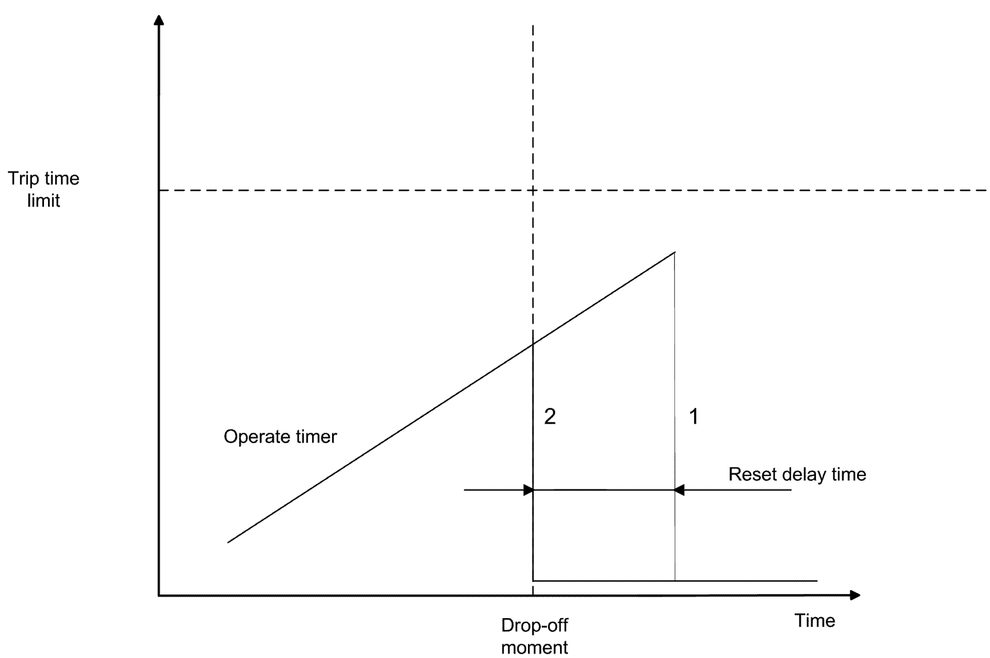


Figure 420: Operation of the counter in drop-off

In case 1, the reset is delayed with the *Reset delay time* setting and in case 2, the counter is reset immediately, because the *Reset delay time* setting is set to zero.

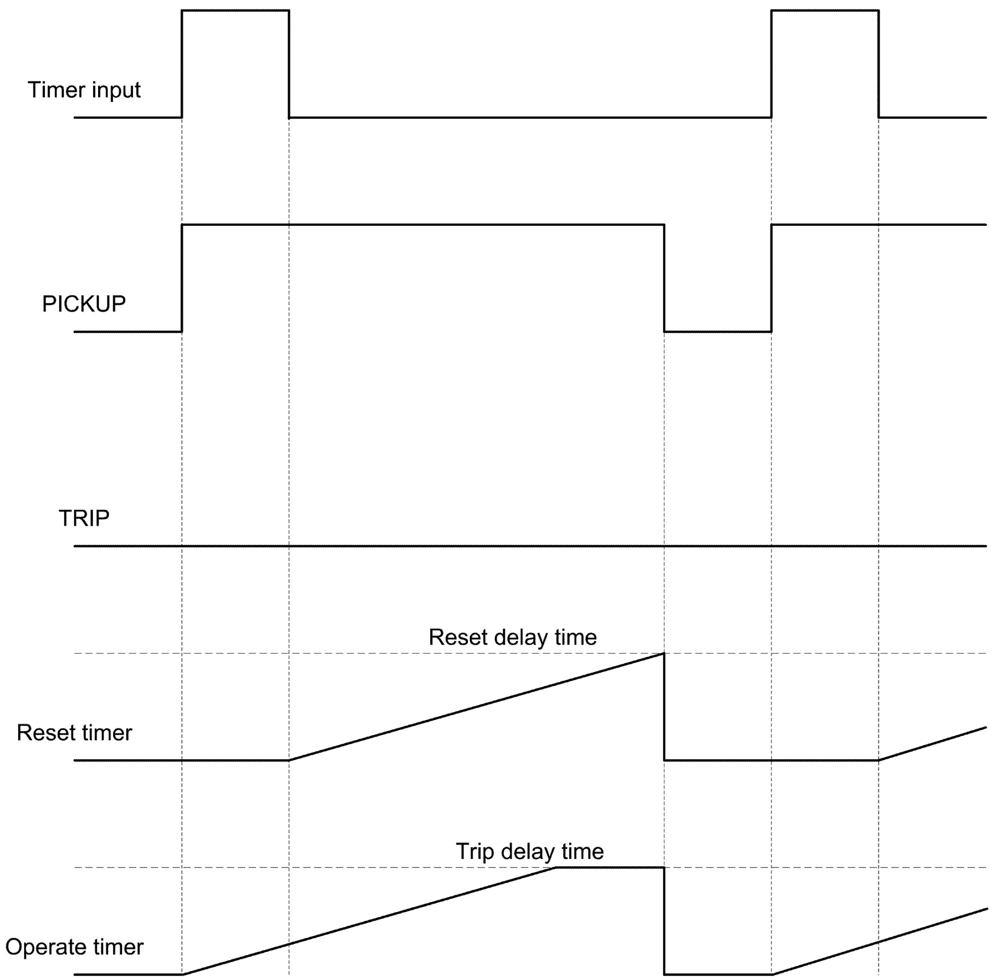


Figure 421: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in Figure 421, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Pickup value*. The input signal is inactive when the current is below the set *Pickup value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the `PICKUP` output and the trip timer starts elapsing. The reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. When the reset (drop-off) timer elapses, the trip timer is reset. Since this happens before another pickup occurs, the `TRIP` output is not activated.

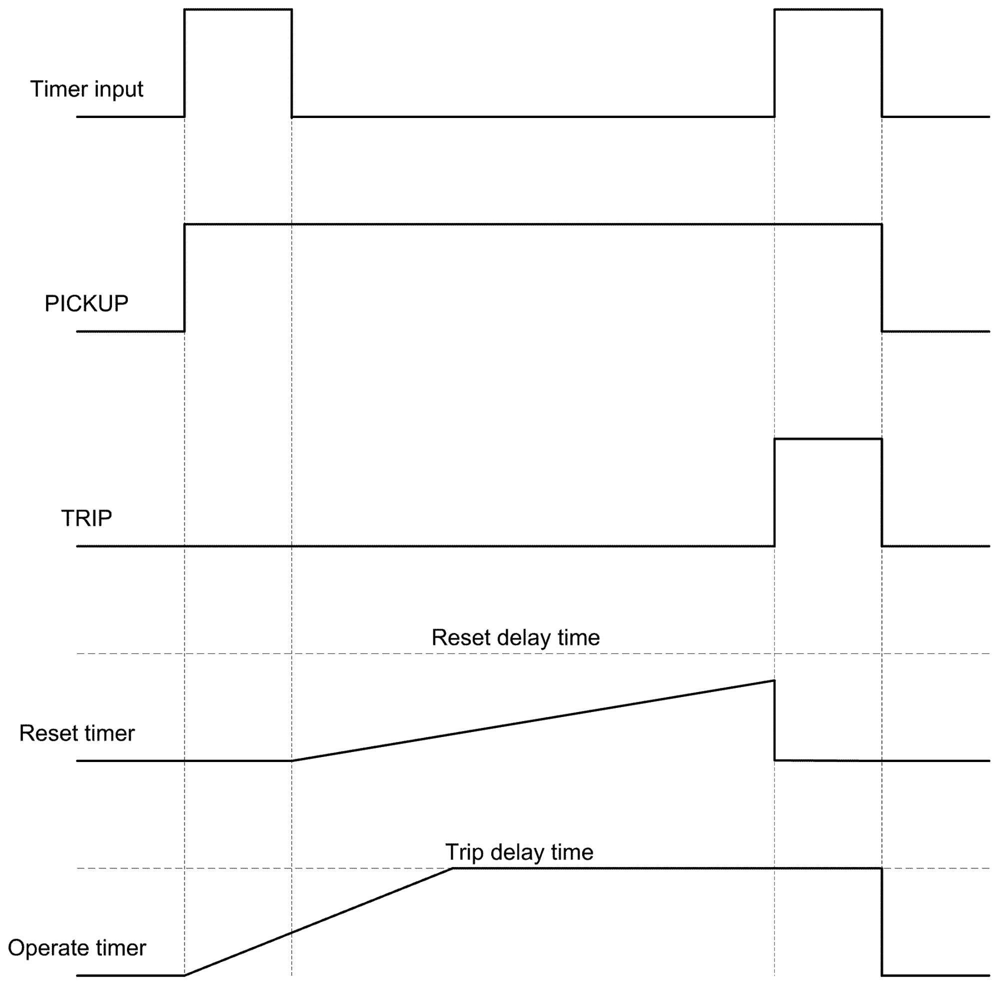


Figure 422: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in Figure 422, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Pickup value*. The input signal is inactive when the current is below the set *Pickup value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the `PICKUP` output and the trip timer starts elapsing. The reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. Another fault situation occurs before the reset (drop-off) timer has elapsed. This causes the activation of the `TRIP` output, since the trip timer already has elapsed.

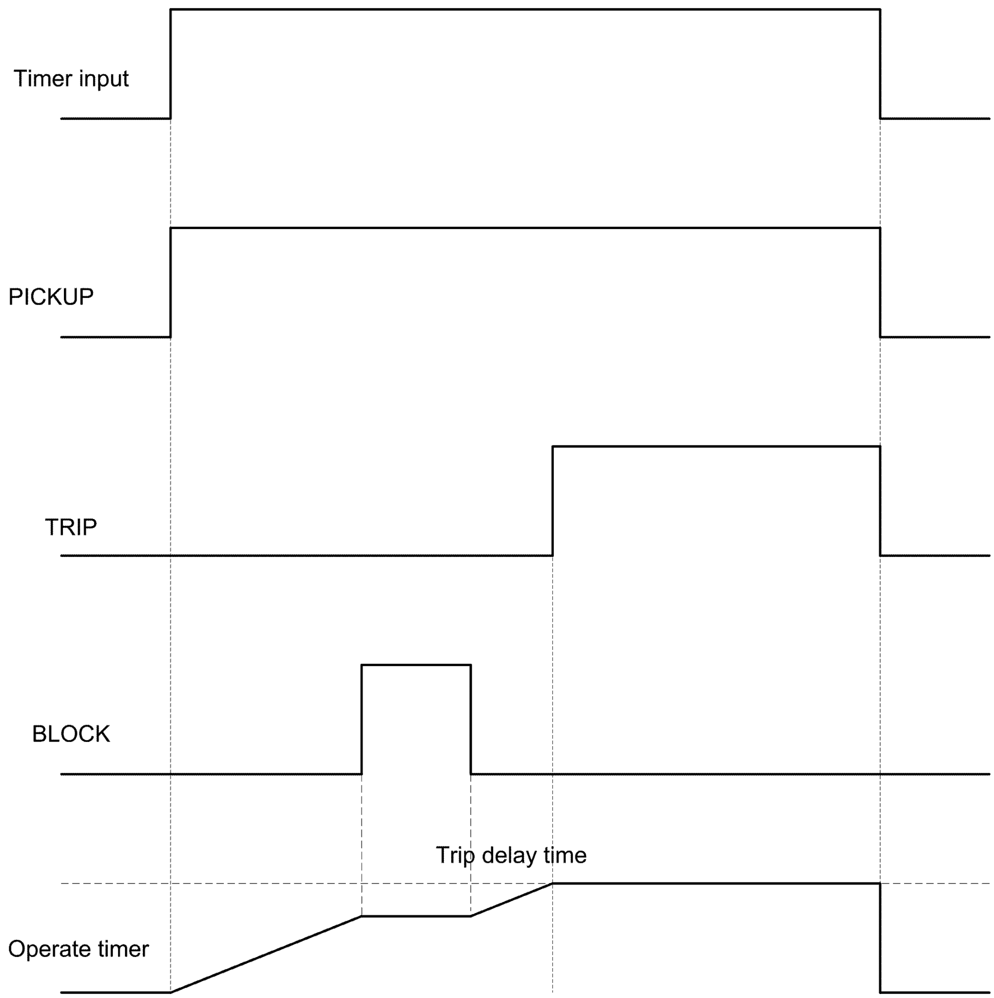


Figure 423: Operating effect of the `BLOCK` input when the selected blocking mode is "Freeze timer"

If the `BLOCK` input is activated when the trip timer is running, as described in Figure 423, the timer is frozen during the time `BLOCK` remains active. If the timer input is not active longer than specified by the *Reset delay time* setting, the trip timer is reset in the same way as described in Figure 421, regardless of the `BLOCK` input.

The selected blocking mode is "Freeze timer".

12.2 Current based inverse definite minimum time characteristics

12.2.1 IDMT curves for overcurrent protection

In inverse-time modes, the trip time depends on the momentary value of the current: the higher the current, the faster the trip time. The trip time calculation or integration starts immediately when the current exceeds the set *Pickup value* and the `PICKUP` output is activated.

The `TRIP` output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The curve scaling is determined with the *Time multiplier* setting.

There are two methods to level out the inverse-time characteristic.

- The *Minimum operate time* setting defines the minimum operating time for the IDMT curve, that is, the operation time is always at least the *Minimum operate time* setting.
- Alternatively, the *IDMT Sat point* is used for giving the leveling-out point as a multiple of the *Start value* setting. (Global setting: **Configuration/System/*IDMT Sat point***). The default parameter value is 50. This setting affects only the overcurrent and earth-fault IDMT timers.

IDMT operation time at currents over 50 x In is not guaranteed.

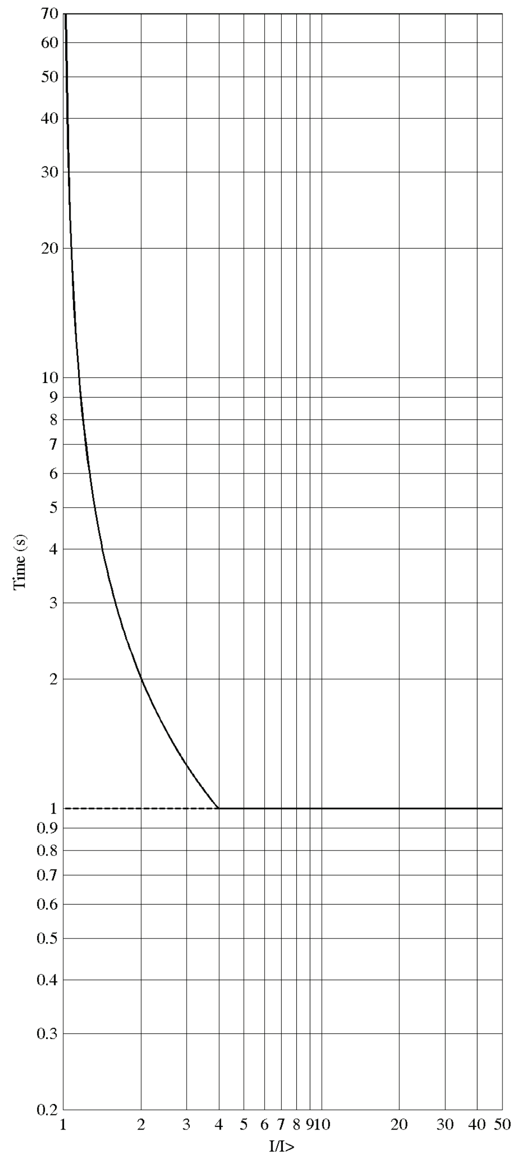


Figure 424: Operation time curve based on the IDMT characteristic leveled out with the Minimum operate time setting is set to 1000 milliseconds (the IDMT Sat point setting is set to maximum).

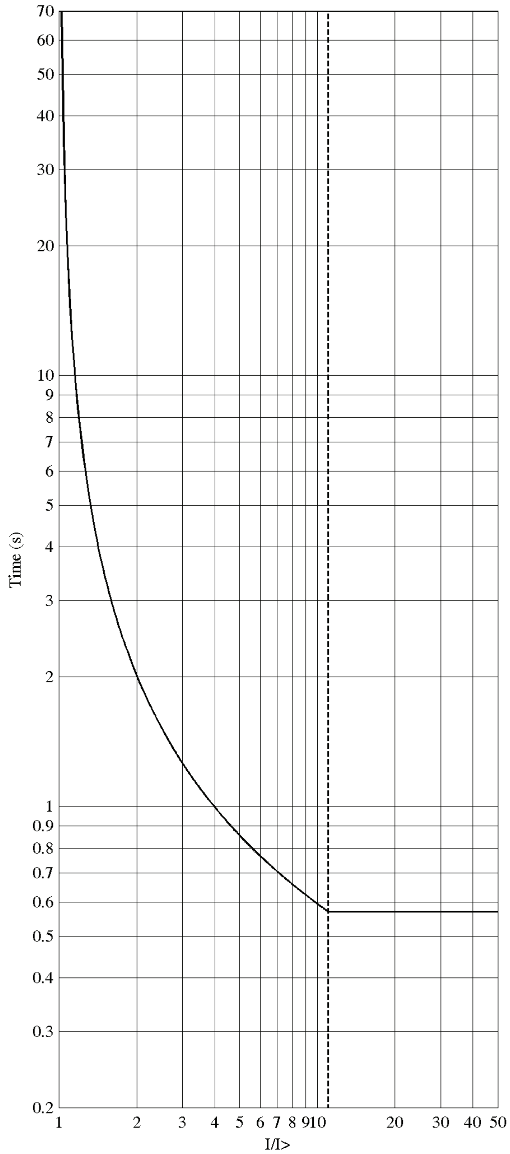


Figure 425: Operation time curve based on the IDMT characteristic leveled out with IDMT Sat point setting value “11” (the Minimum operate time setting is set to minimum).

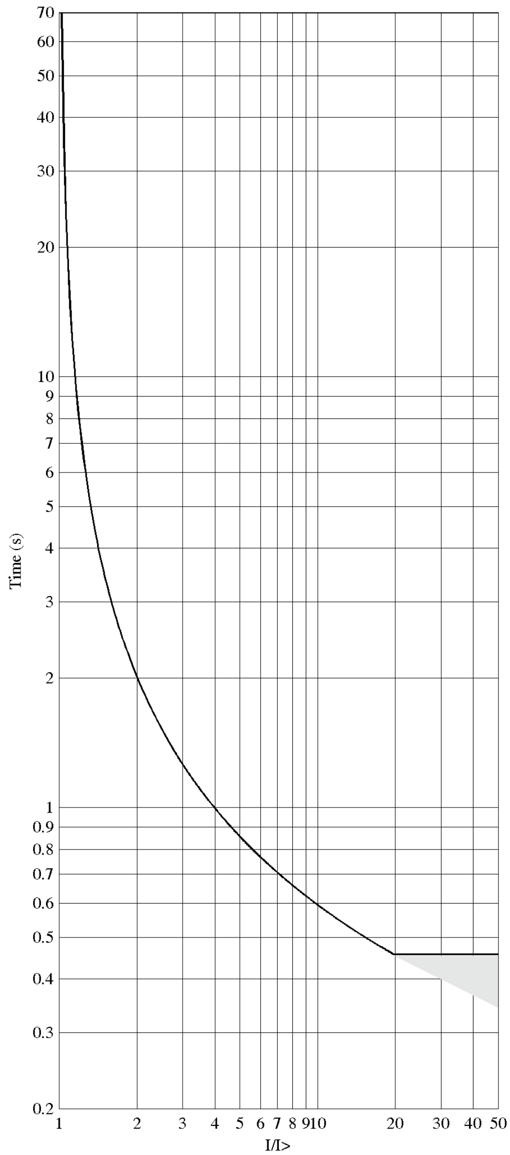


Figure 426: Example of how the inverse time characteristic is leveled out with currents over 50 x In and the Setting Start value setting "2.5 x In". (the IDMT Sat point setting is set to maximum and the Minimum operate time setting is set to minimum).

The grey zone in Figure 426 shows the behavior of the curve in case the measured current is outside the guaranteed measuring range. Also, the maximum measured current of 50 x In gives the leveling-out point 50/2.5 = 20 x I/I>.

The *Minimum trip time* setting defines the minimum trip time for the IDMT mode, that is, it is possible to limit the IDMT based trip time for not becoming too short. For example:

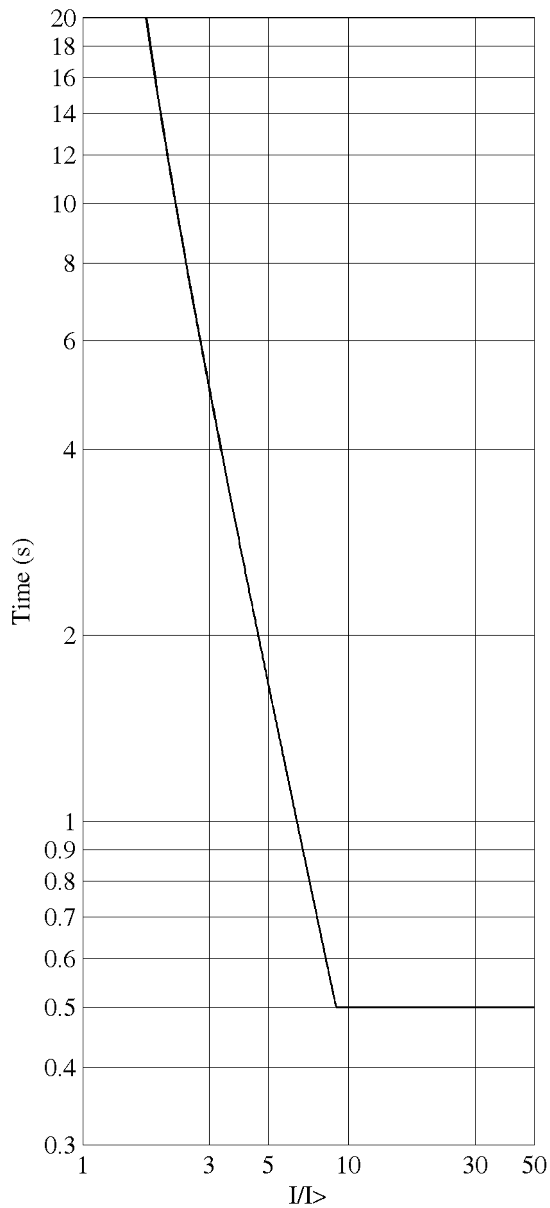


Figure 427: Trip time curves based on IDMT characteristic with the value of the Minimum trip time setting = 0.5 second

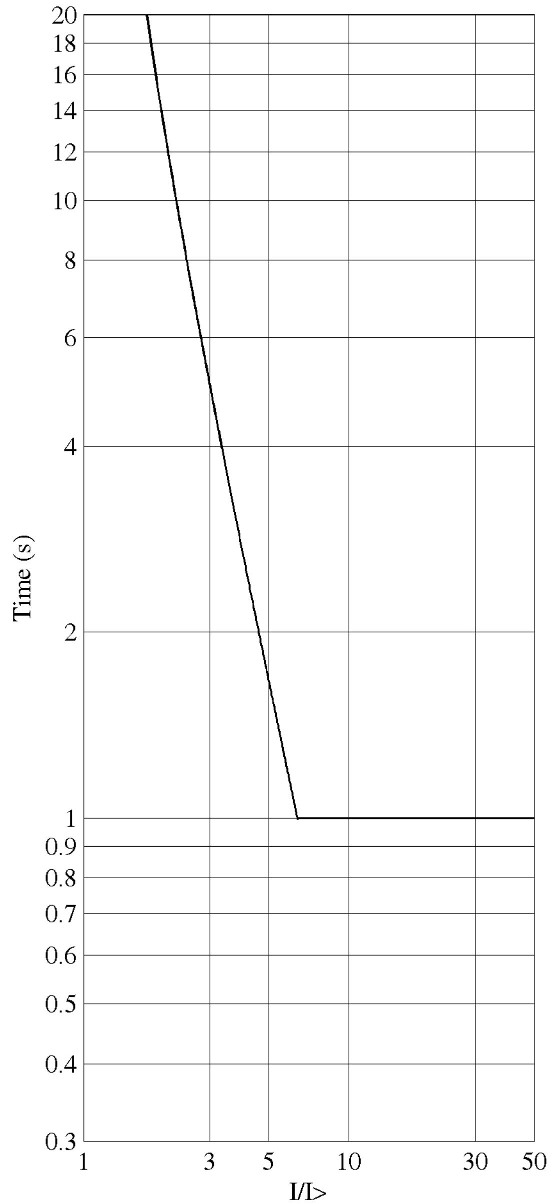


Figure 428: Trip time curves based on IDMT characteristic with the value of the Minimum trip time setting = 1 second

12.2.1.1 Standard inverse-time characteristics

For inverse-time operation, both IEC and ANSI/IEEE standardized inverse-time characteristics are supported.

The trip times for the ANSI and IEC IDMT curves are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>} \right)^{c} - 1} + B \right) \cdot k$$

(Equation 106)

t[s]	t[s] = Trip time in seconds
I	measured current
I>	set *Pickup value*
k	set *Time multiplier*

Table 612: Curve parameters for ANSI and IEC IDMT curves

Curve name	A	B	C
(1) ANSI Extremely Inverse	28.2	0.1217	2.0
(2) ANSI Very Inverse	19.61	0.491	2.0
(3) ANSI Normal Inverse	0.0086	0.0185	0.02
(4) ANSI Moderately Inverse	0.0515	0.1140	0.02
(6) Long Time Extremely Inverse	64.07	0.250	2.0
(7) Long Time Very Inverse	28.55	0.712	2.0
(8) Long Time Inverse	0.086	0.185	0.02
(9) IEC Normal Inverse	0.14	0.0	0.02
(10) IEC Very Inverse	13.5	0.0	1.0
(11) IEC Inverse	0.14	0.0	0.02
(12) IEC Extremely Inverse	80.0	0.0	2.0
(13) IEC Short Time Inverse	0.05	0.0	0.04
(14) IEC Long Time Inverse	120	0.0	1.0

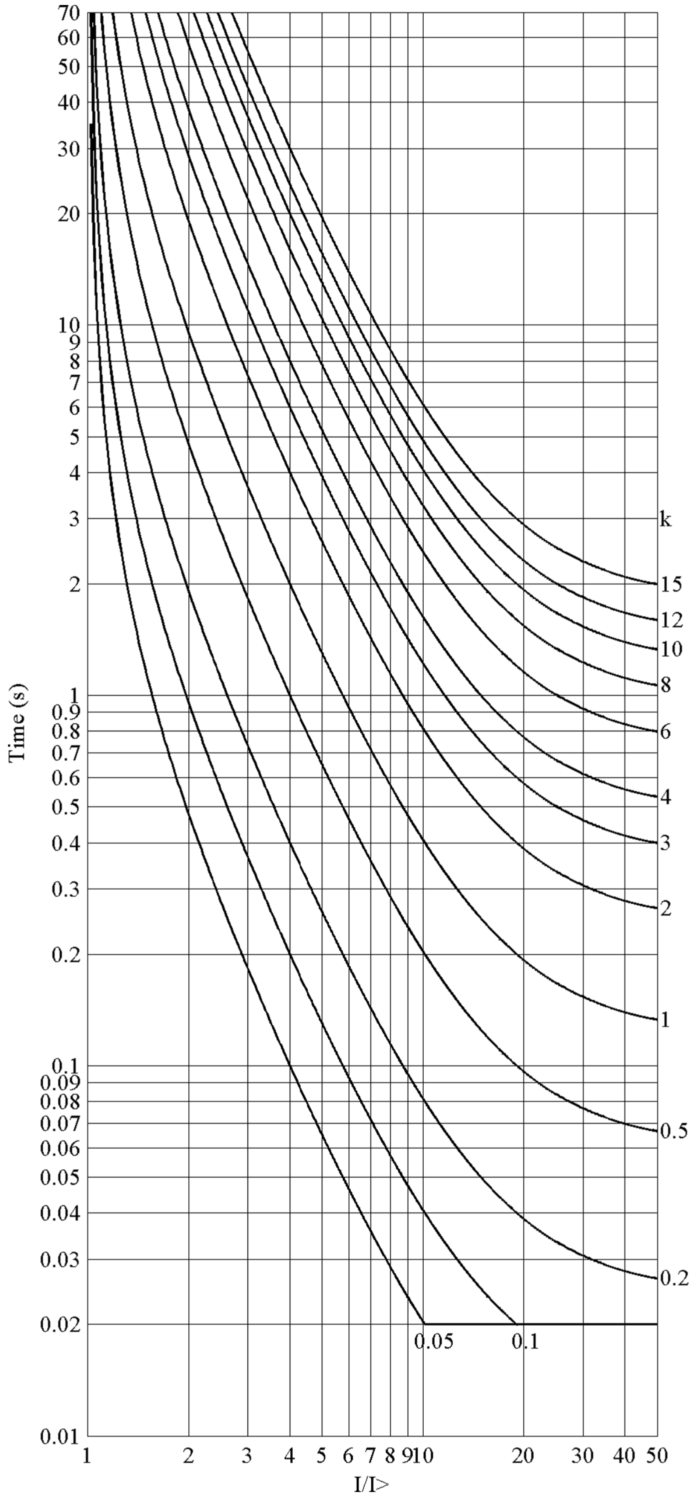


Figure 429: ANSI extremely inverse-time characteristics

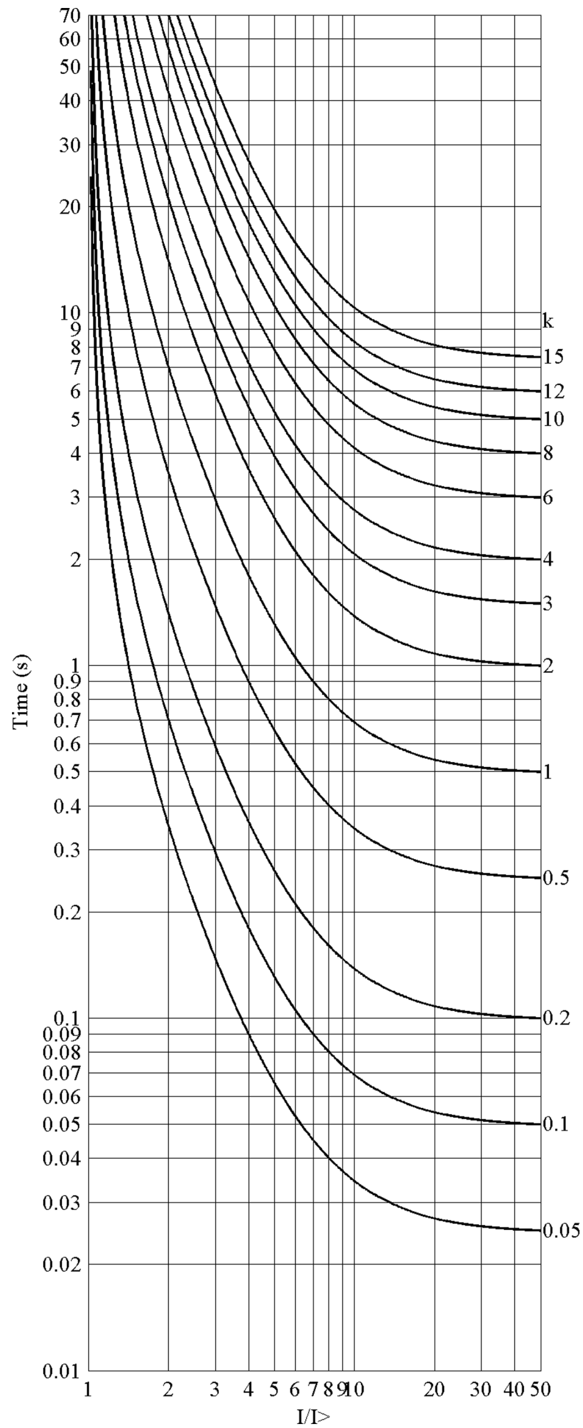


Figure 430: ANSI very inverse-time characteristics

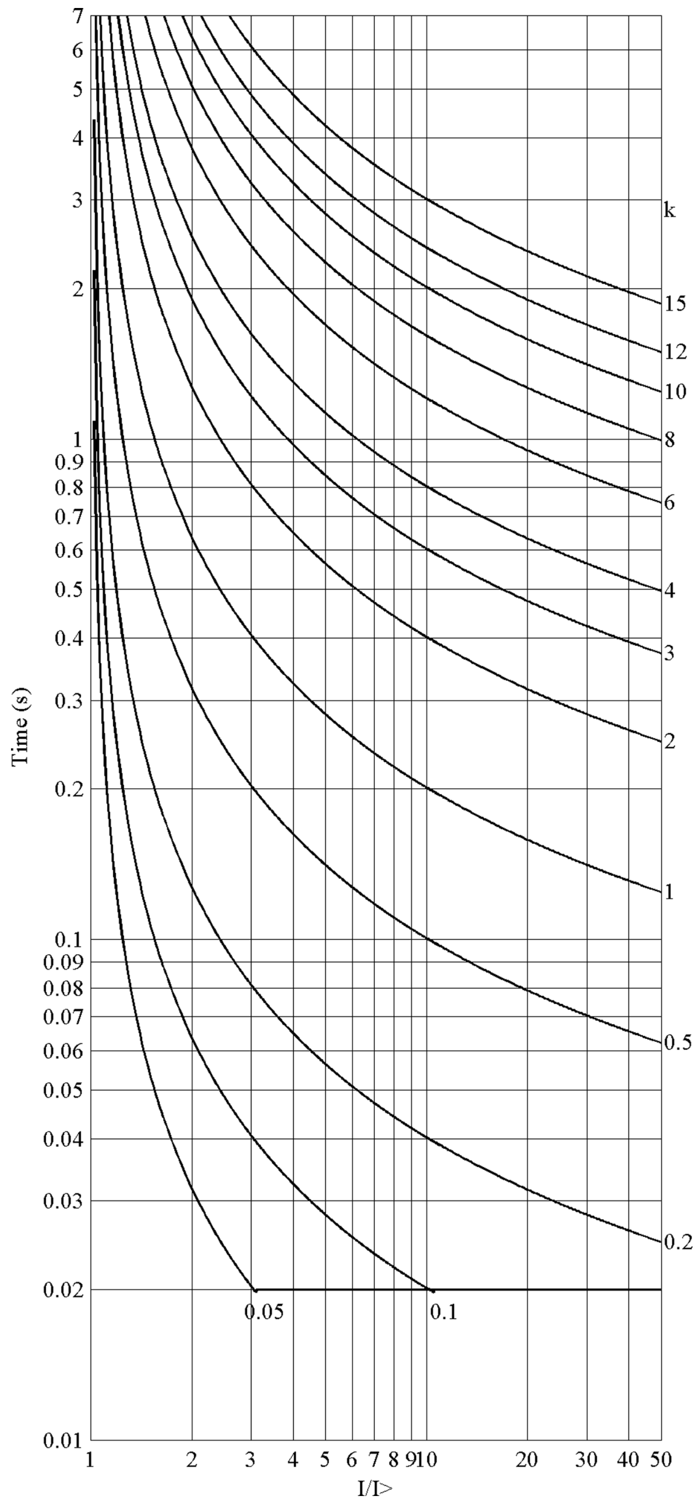


Figure 431: ANSI normal inverse-time characteristics

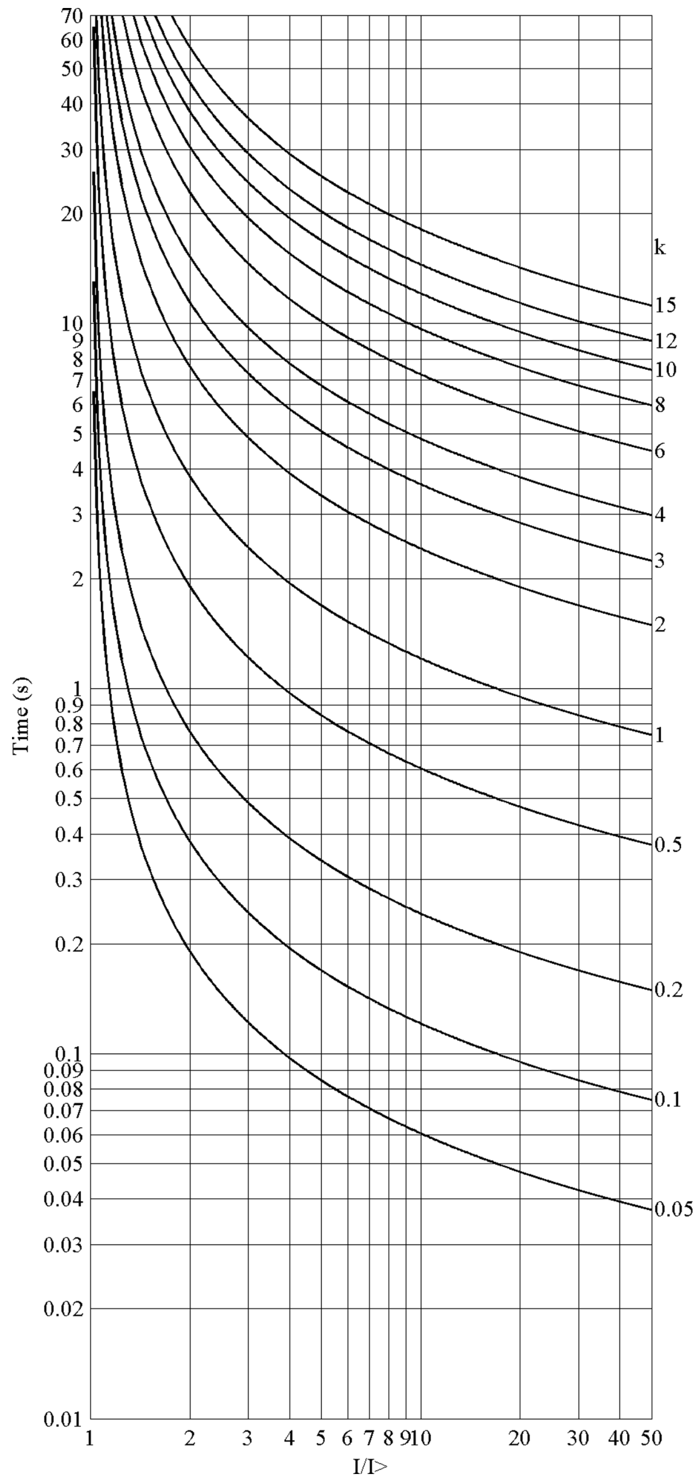


Figure 432: ANSI moderately inverse-time characteristics

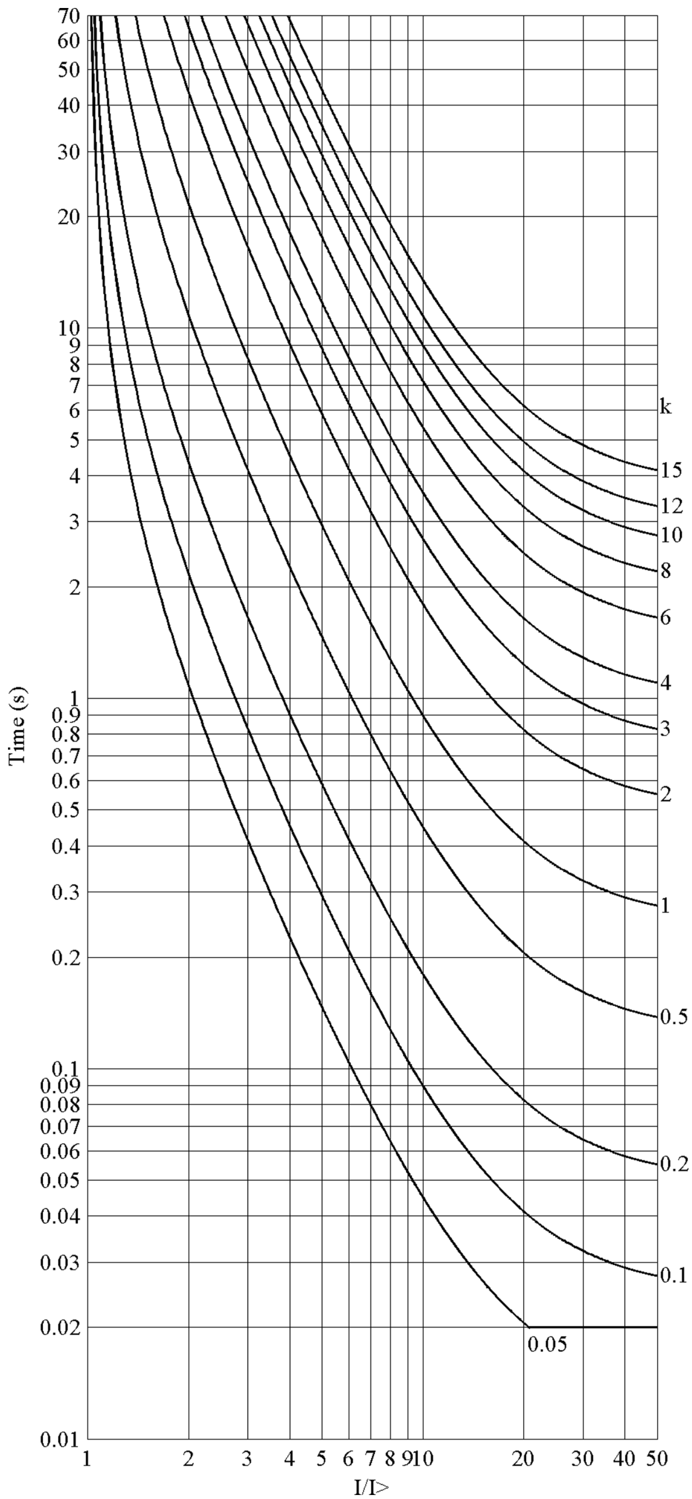


Figure 433: ANSI long-time extremely inverse-time characteristics

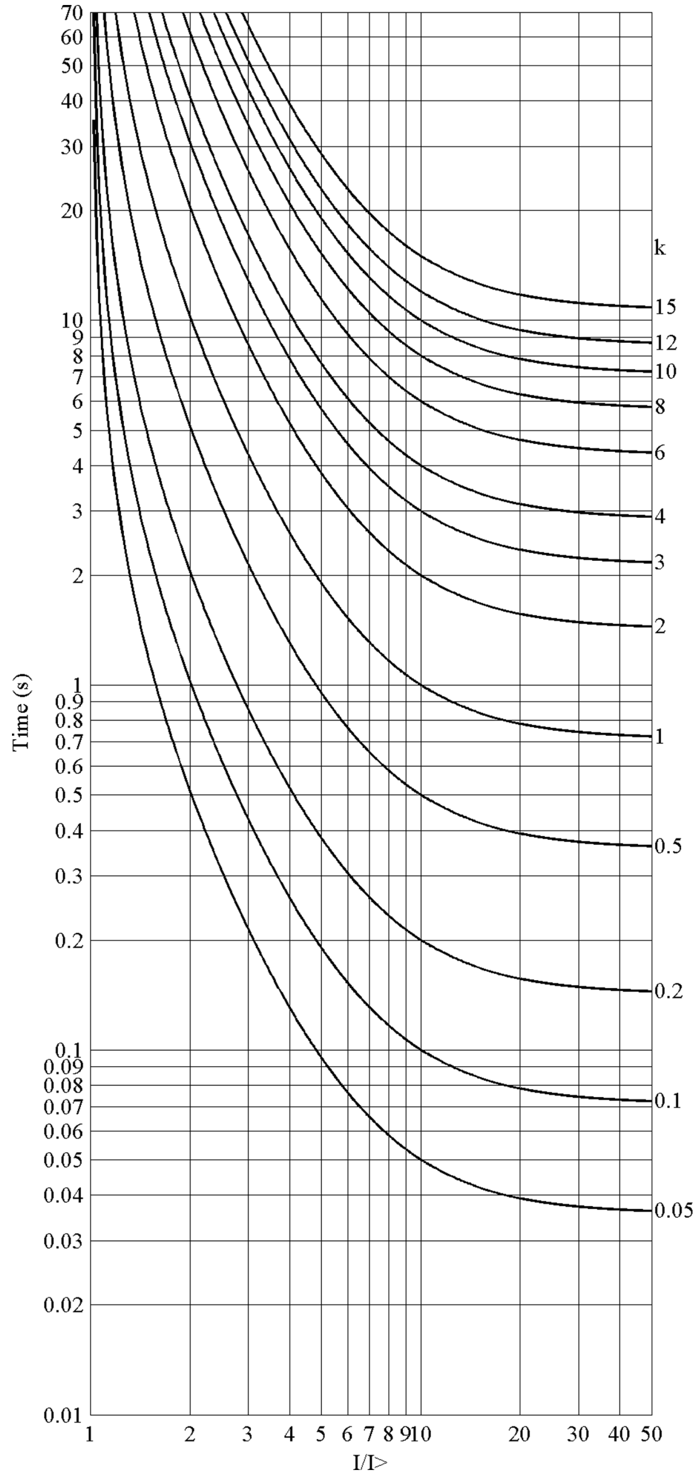


Figure 434: ANSI long-time very inverse-time characteristics

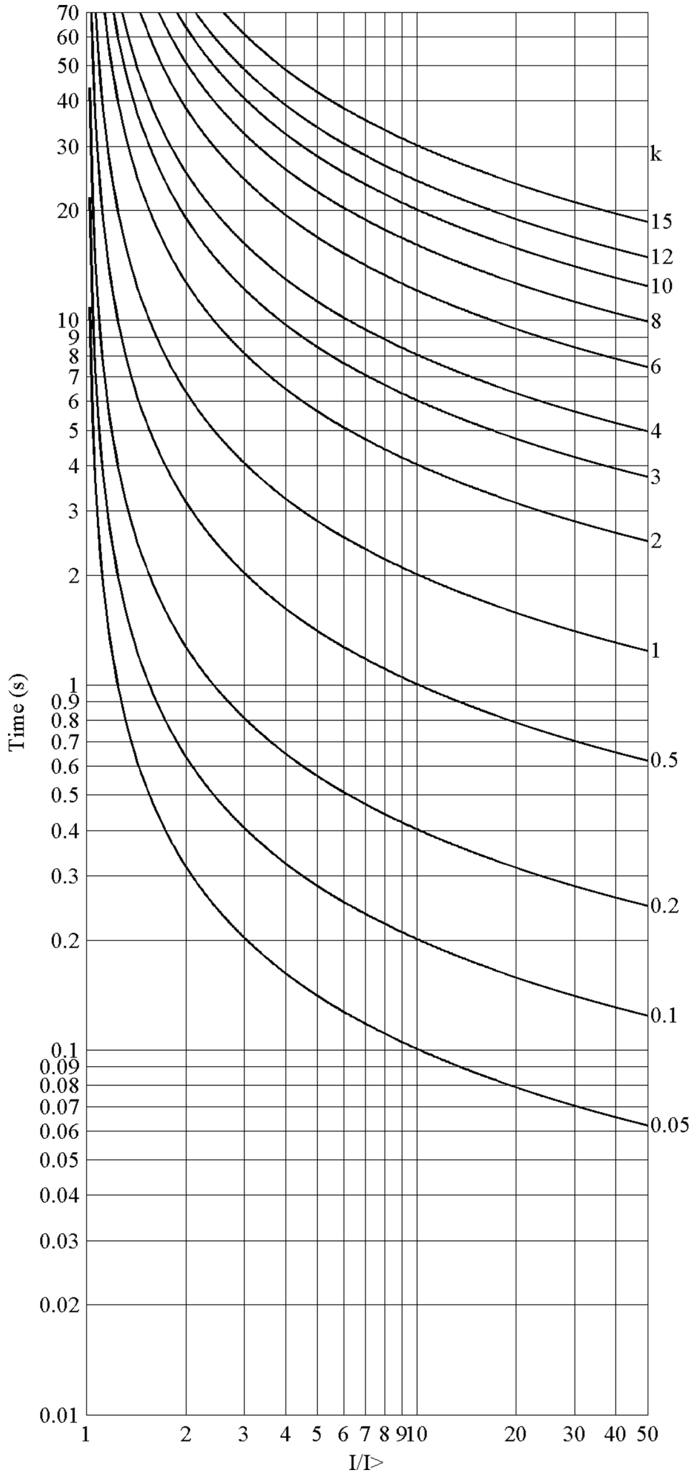


Figure 435: ANSI long-time inverse-time characteristics

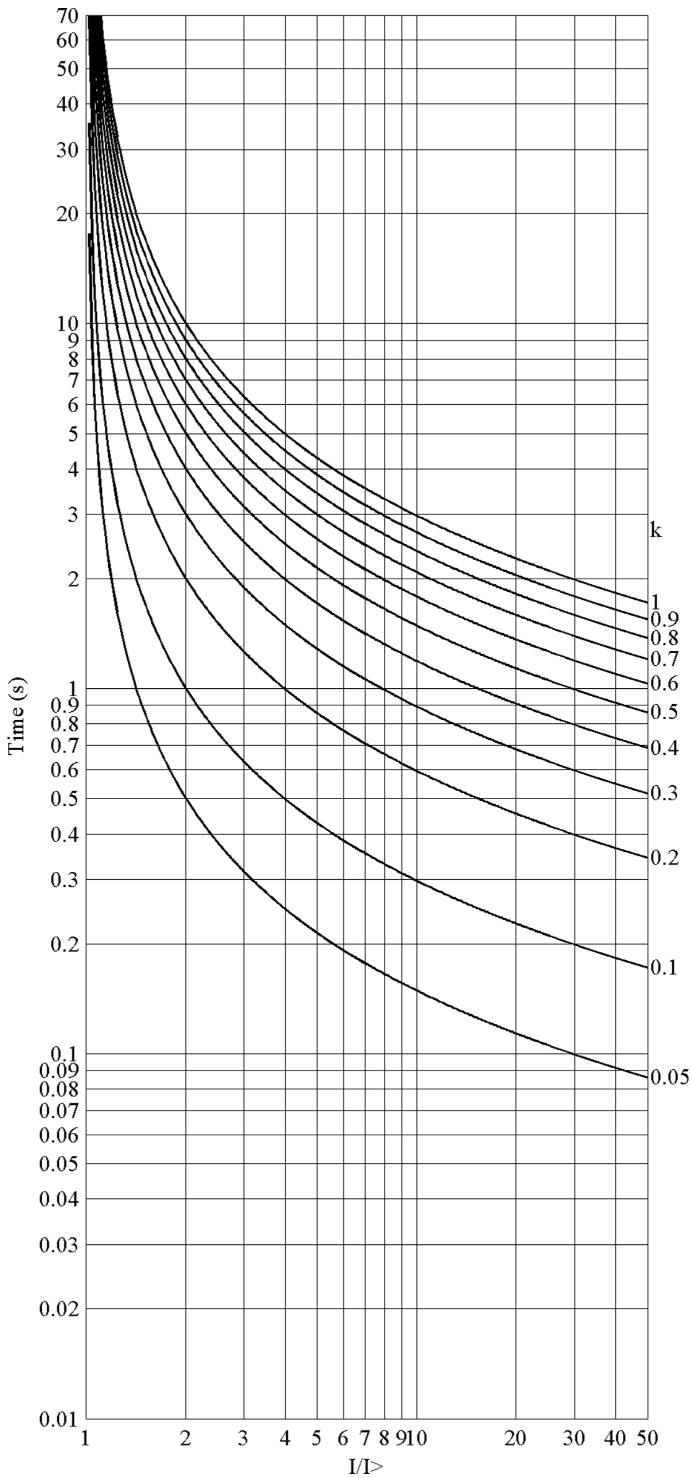


Figure 436: IEC normal inverse-time characteristics

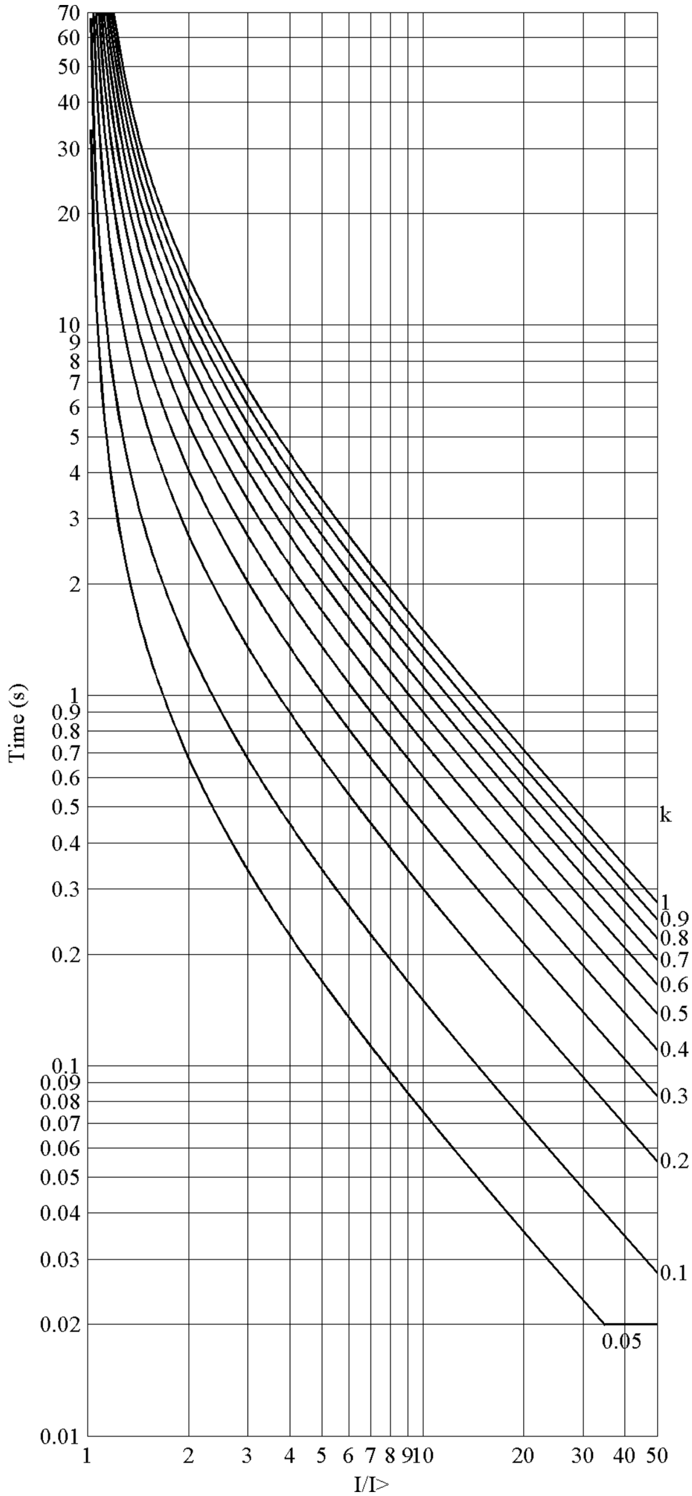


Figure 437: IEC very inverse-time characteristics

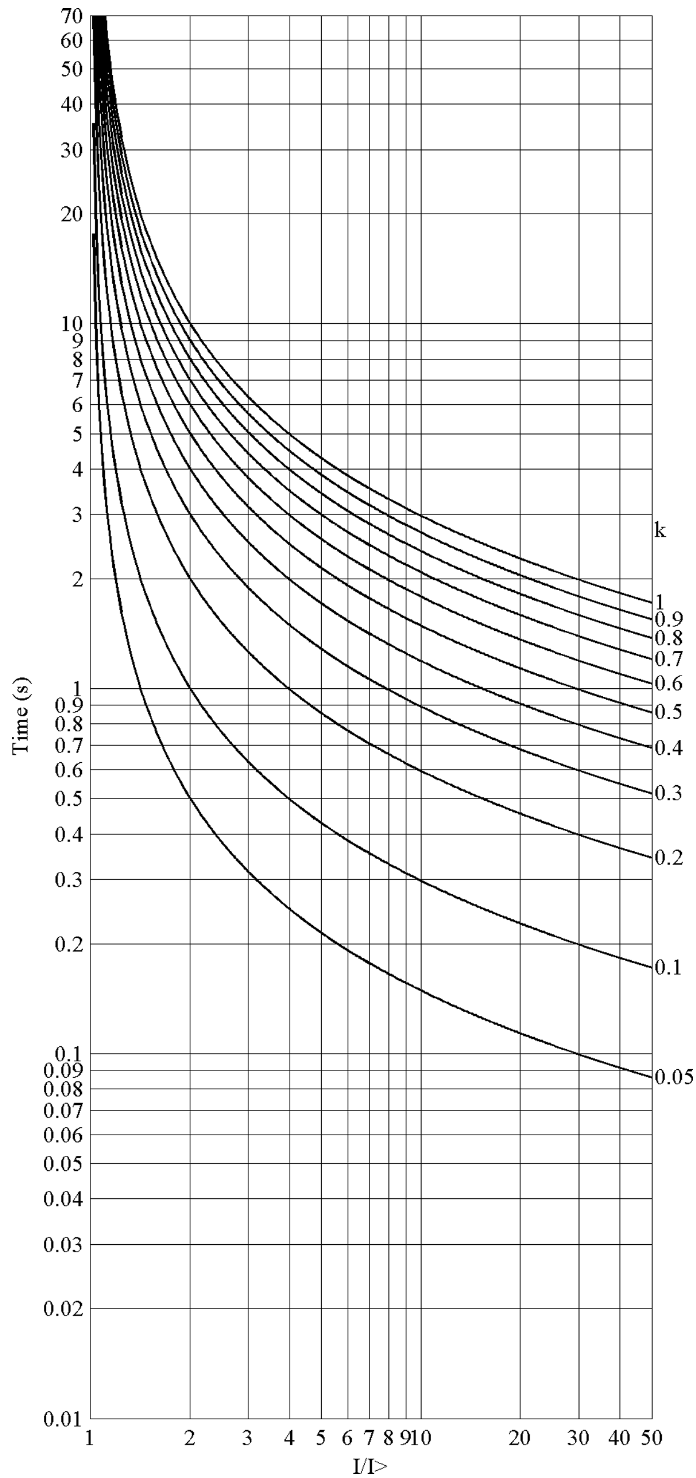


Figure 438: IEC inverse-time characteristics

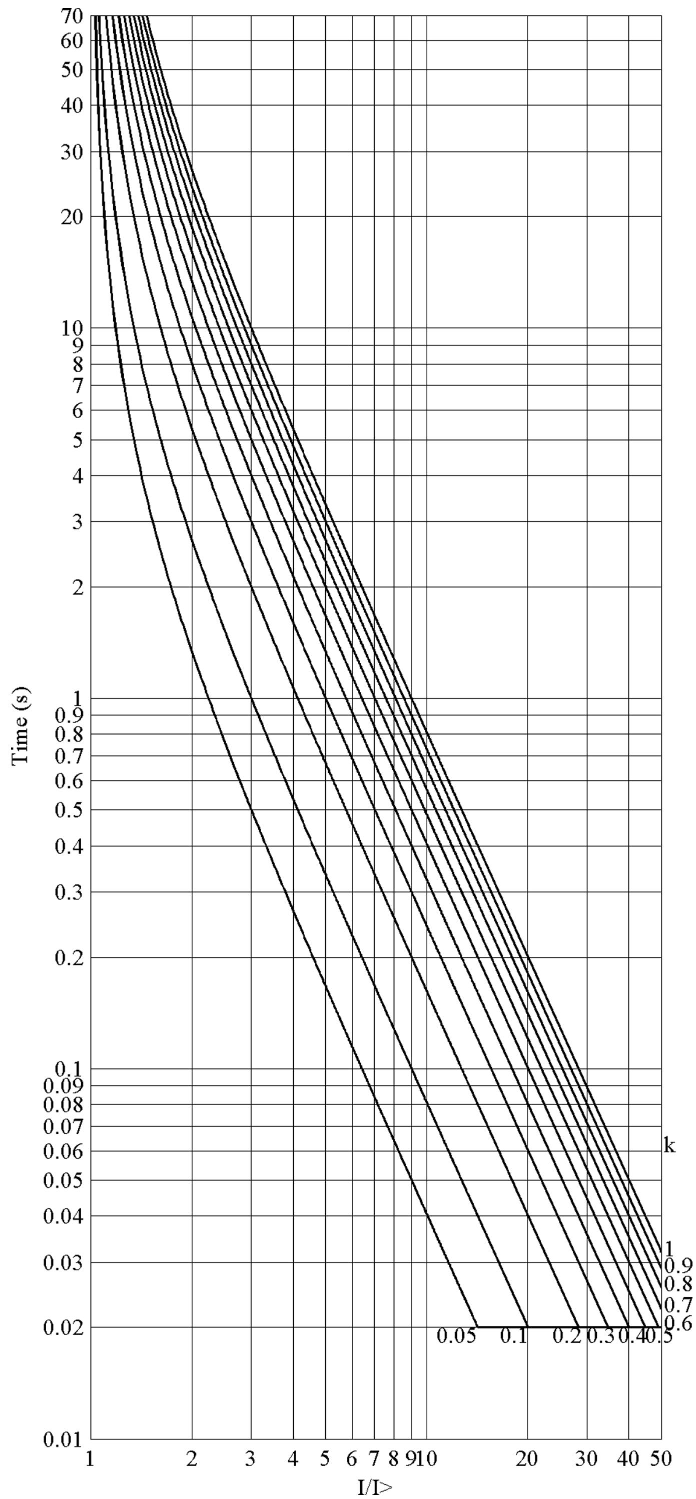


Figure 439: IEC extremely inverse-time characteristics

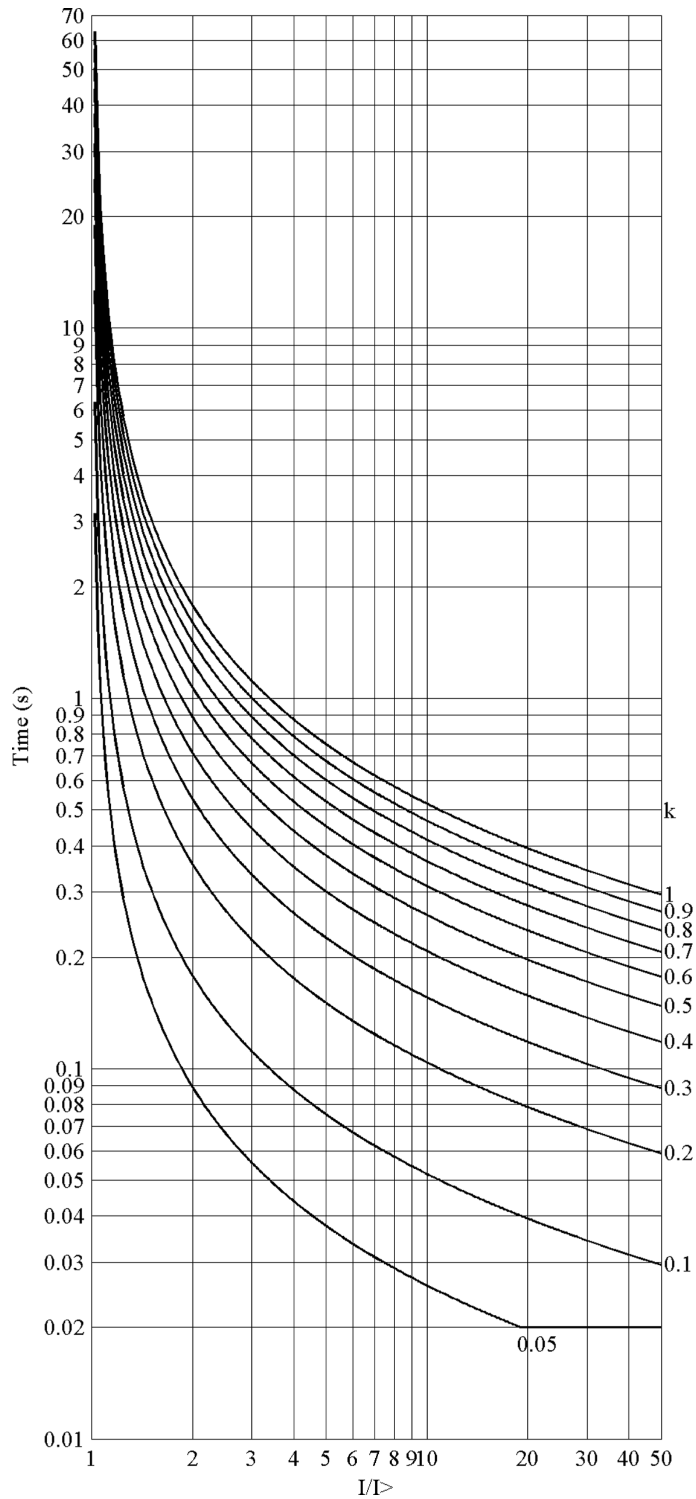


Figure 440: IEC short-time inverse-time characteristics

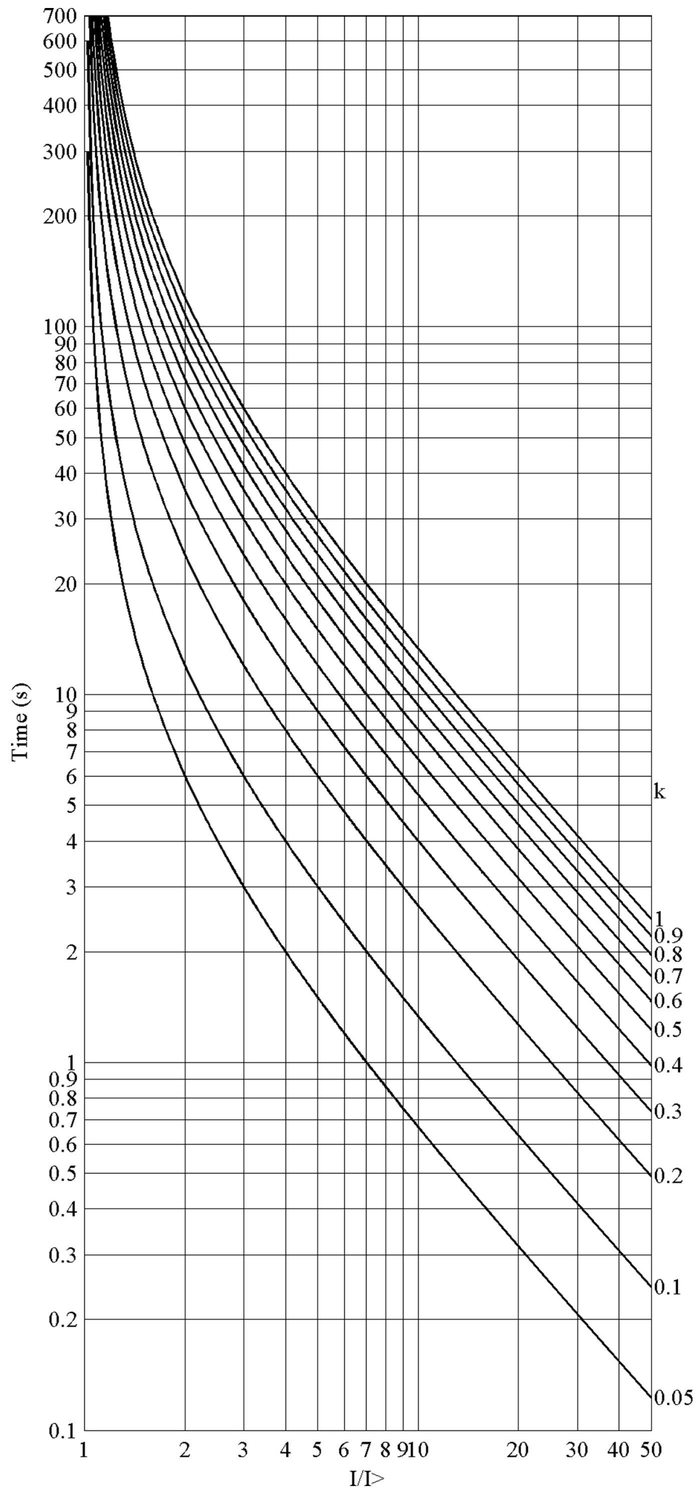


Figure 441: IEC long-time inverse-time characteristics

12.2.1.2 User-programmable inverse-time characteristics

The user can define curves by entering parameters into the following standard formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>}\right)^{c} - E} + B \right) \cdot k$$

(Equation 107)

t[s]	Trip time (in seconds)
A	set *Curve parameter A*
B	set *Curve parameter B*
C	set *Curve parameter C*
E	set *Curve parameter E*
I	Measured current
I>	set *Pickup value*
k	set *Time multiplier*

12.2.1.3 RI and RD-type inverse-time characteristics

The RI-type simulates the behavior of electromechanical relays. The RD-type is a ground-fault specific characteristic.

The RI-type is calculated using the formula

$$t[s] = \left(\frac{k}{0.339 - 0.236 \times \frac{I>}{I}} \right)$$

(Equation 108)

The RD-type is calculated using the formula

$$t[s] = 5.8 - 1.35 \times \text{In}\left(\frac{I}{k \times I>} \right)$$

(Equation 109)

t[s] Trip time (in seconds)

k set *Time multiplier*

I Measured current

I> set *Pickup value*

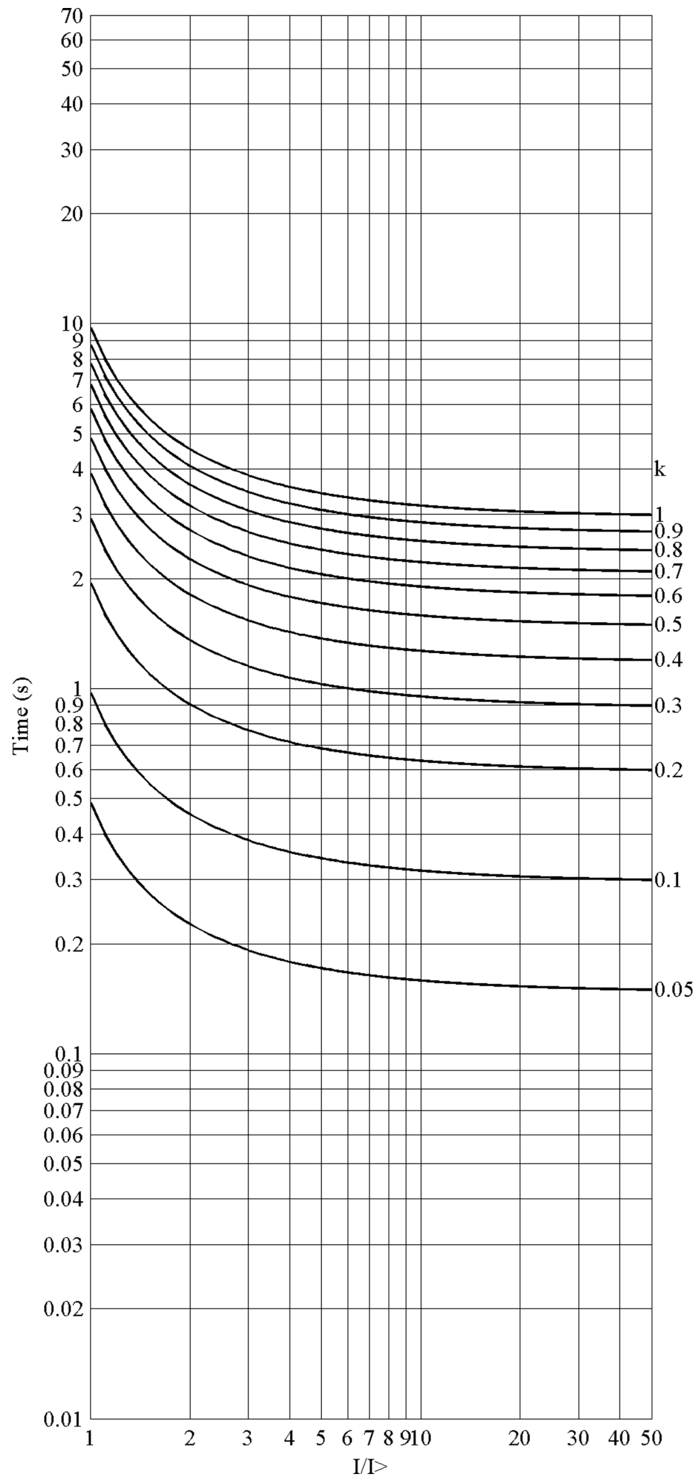


Figure 442: RI-type inverse-time characteristics

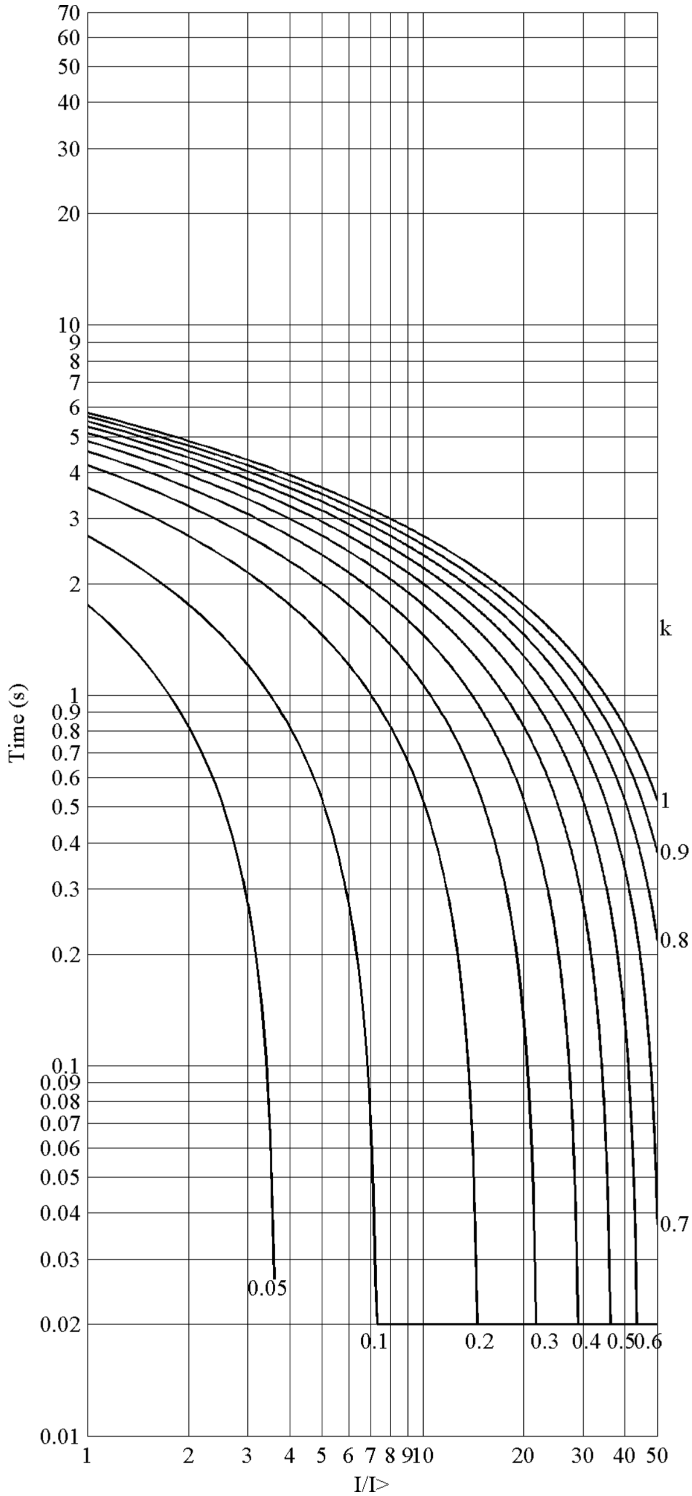


Figure 443: RD-type inverse-time characteristics

12.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

Table 613: Values for reset mode

Setting name	Possible values
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset

Immediate reset

If the *Type of reset curve* setting in a drop-off case is selected as "Immediate", the inverse timer resets immediately.

Definite time reset

The definite type of reset in the inverse-time mode can be achieved by setting the *Type of reset curve* parameter to “Def time reset”. As a result, the trip inverse-time counter is frozen for the time determined with the *Reset delay time* setting after the current drops below the set *Pickup value*, including hysteresis.The integral sum of the inverse-time counter is reset, if another pickup does not occur during the reset delay.

If the *Type of reset curve* setting is selected as “Def time reset”, the current level has no influence on the reset characteristic.

Inverse reset

Inverse reset curves are available only for ANSI and user-programmable curves. If you use other curve types, immediate reset occurs.

Standard delayed inverse reset

The reset characteristic required in ANSI (IEEE) inverse-time modes is provided by setting the *Type of reset curve* parameter to “Inverse reset”. In this mode, the time delay for reset is given with the following formula using the coefficient D, which has its values defined in the table below.

$$t[s] = \left(\frac{D}{\left(\frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

(Equation 110)

t[s] Reset time (in seconds)

k set *Time multiplier*

I Measured current

I> set *Pickup value*

Table 614: Coefficients for ANSI delayed inverse reset curves

Curve name	D
(1) ANSI Extremely Inverse	29.1
(2) ANSI Very Inverse	21.6
(3) ANSI Normal Inverse	0.46
(4) ANSI Moderately Inverse	4.85
(6) Long Time Extremely Inverse	30
(7) Long Time Very Inverse	13.46
(8) Long Time Inverse	4.6

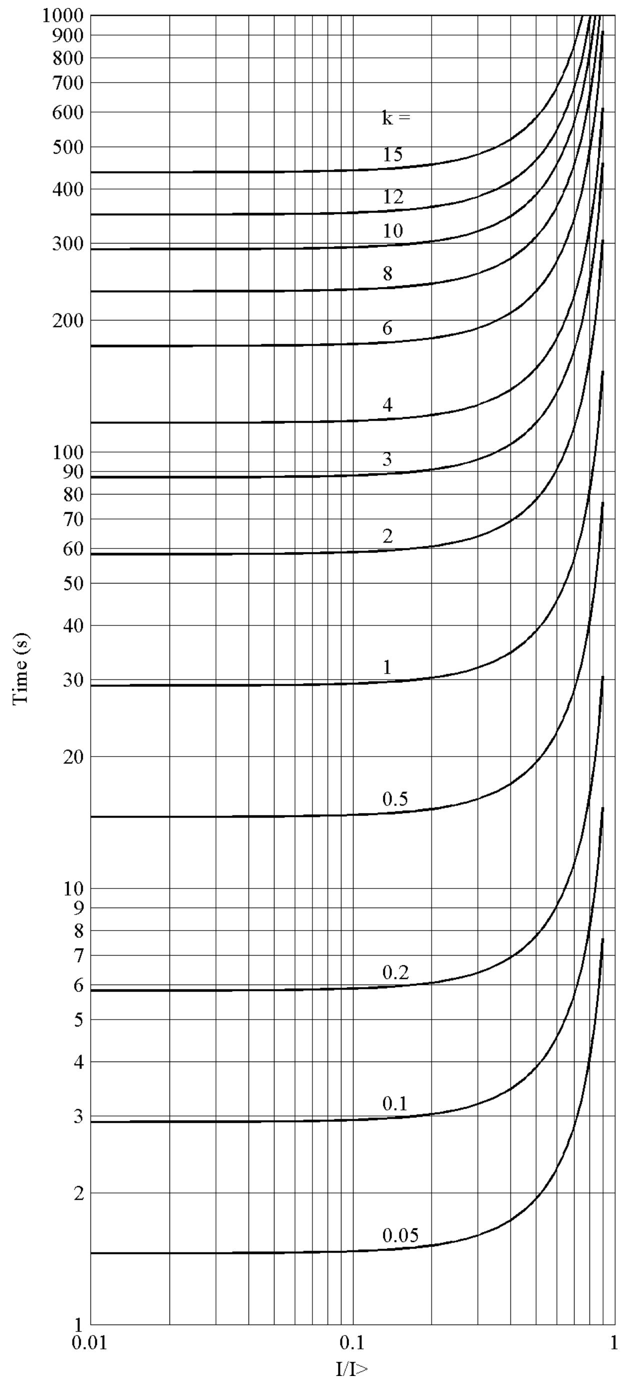


Figure 444: ANSI extremely inverse reset time characteristics

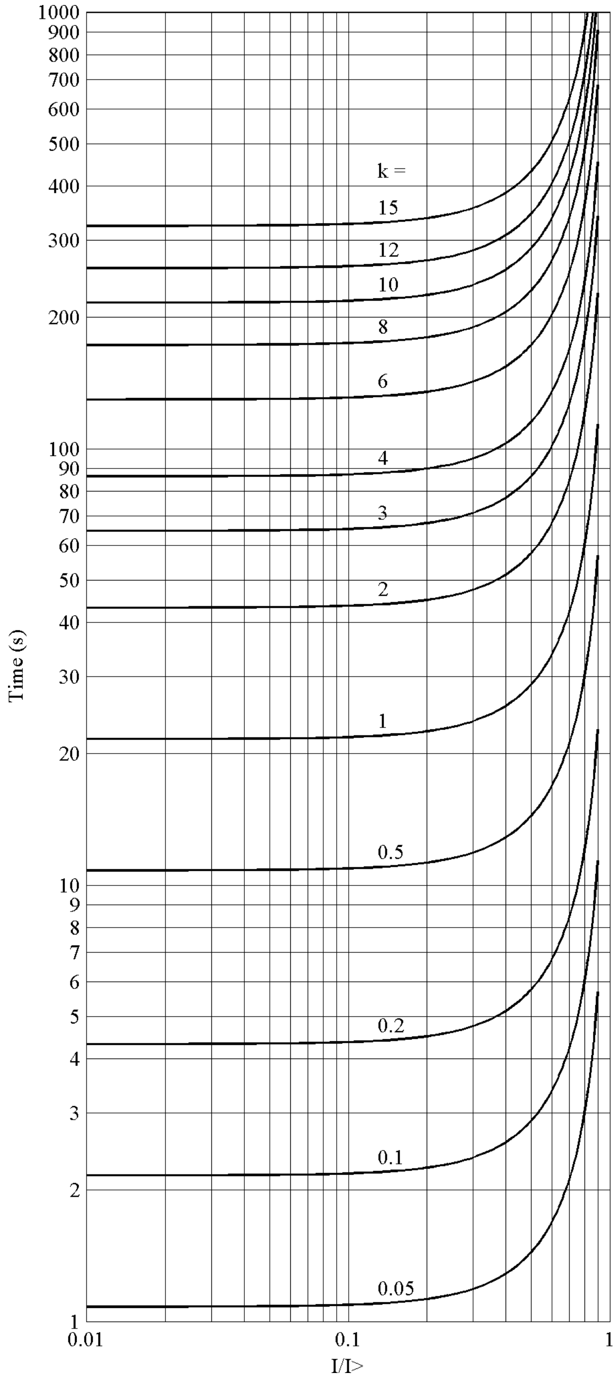


Figure 445: ANSI very inverse reset time characteristics

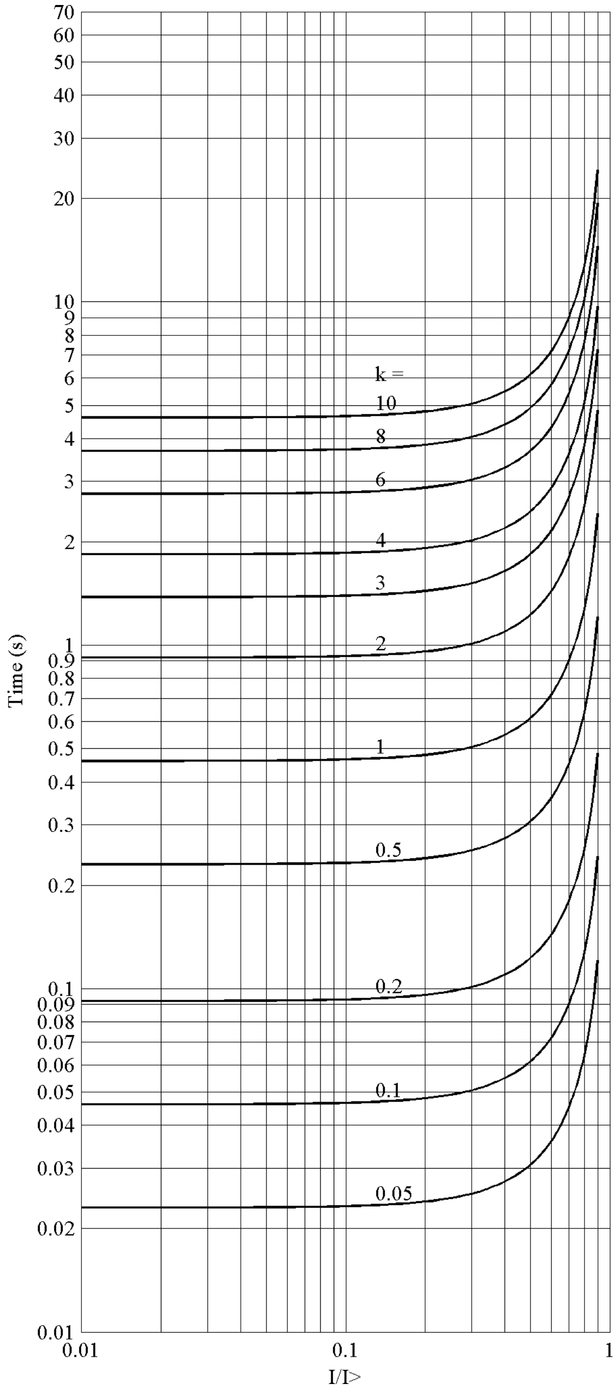


Figure 446: ANSI normal inverse reset time characteristics

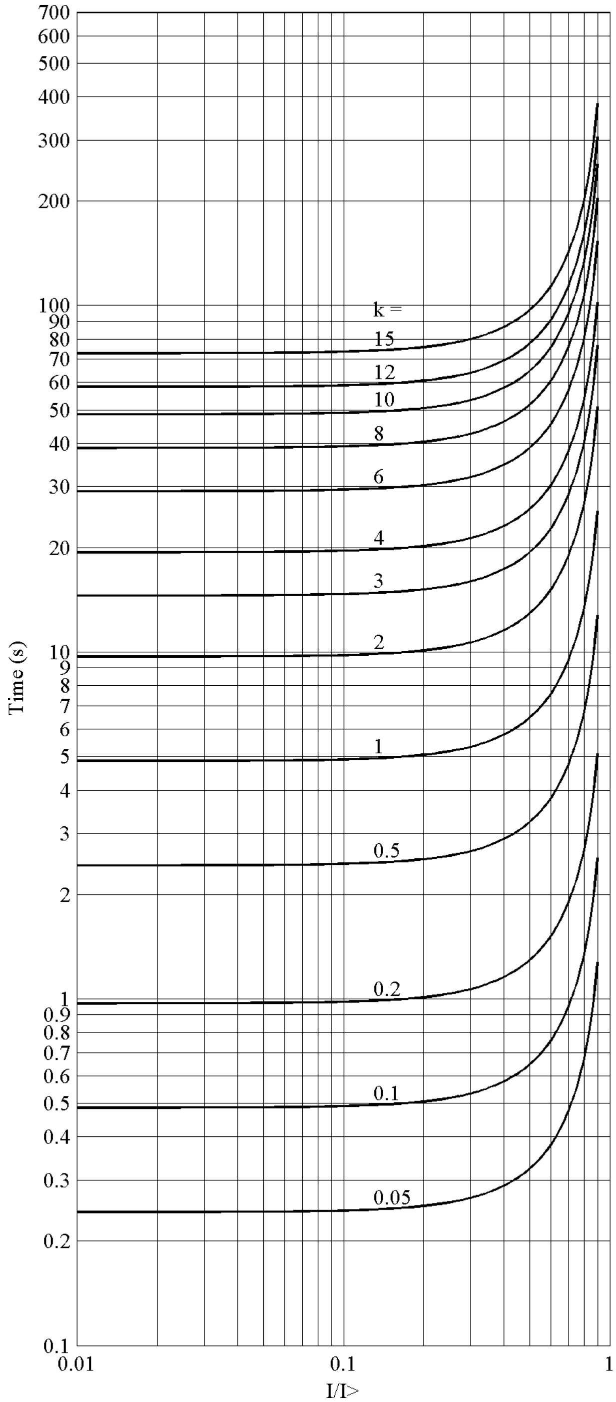


Figure 447: ANSI moderately inverse reset time characteristics

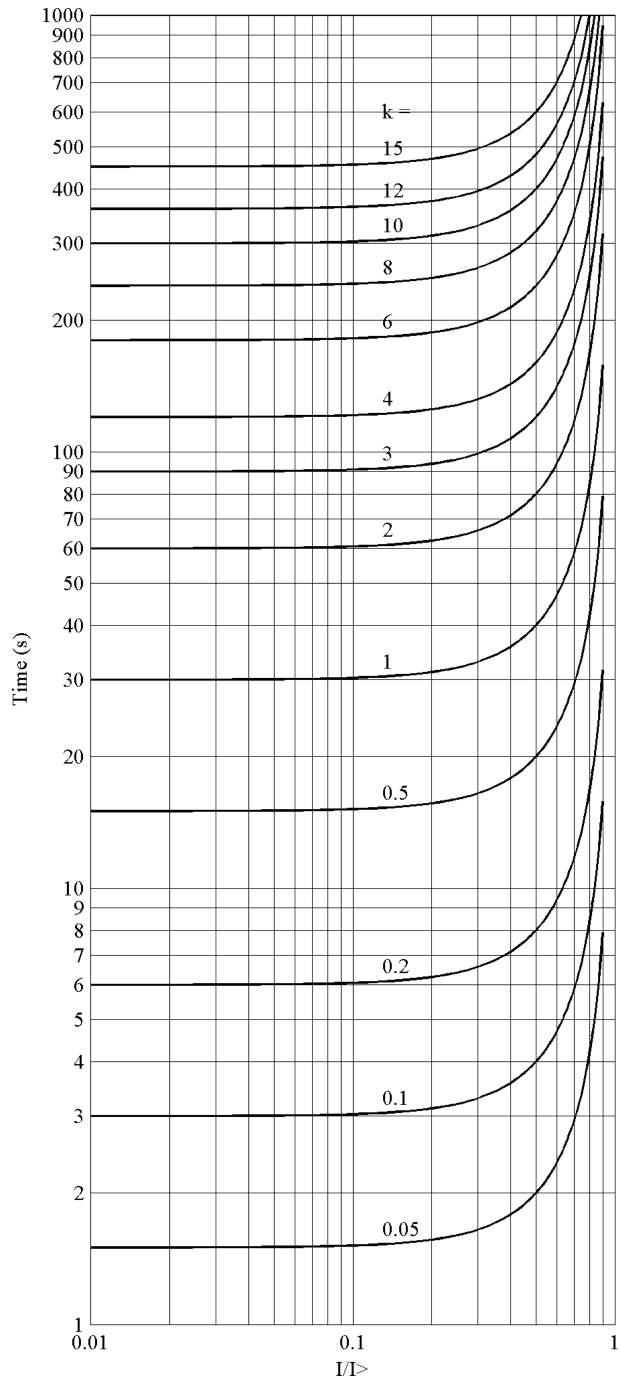


Figure 448: ANSI long-time extremely inverse reset time characteristics

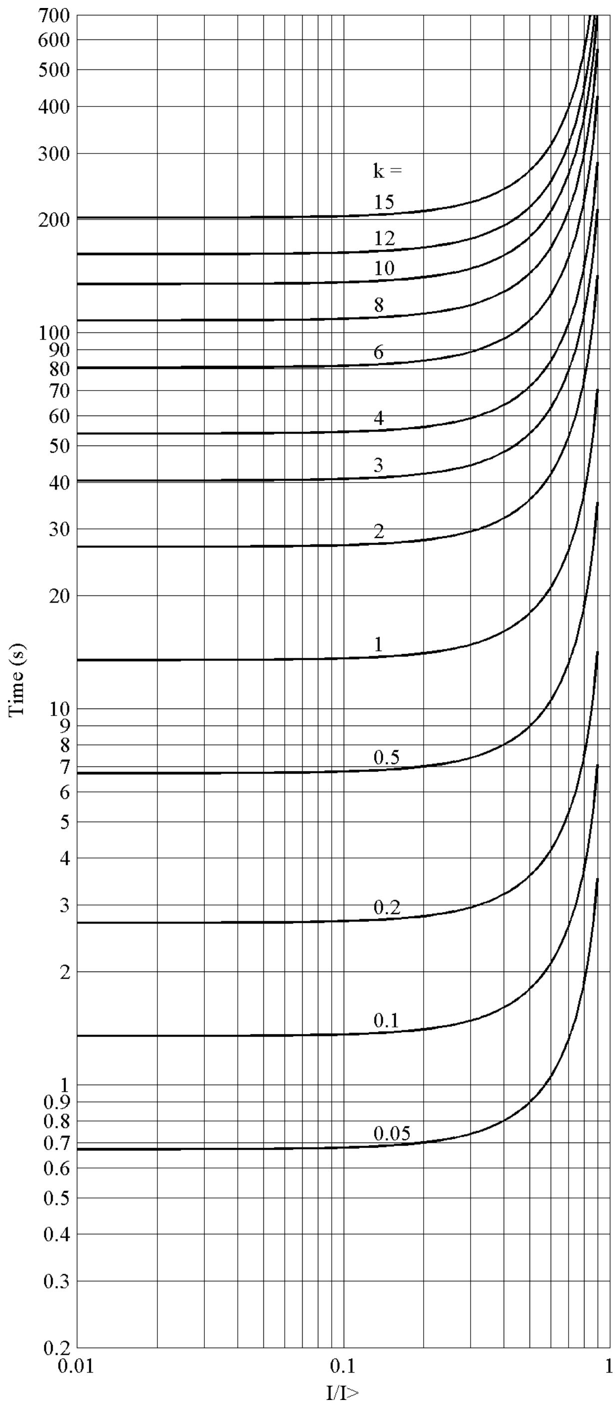


Figure 449: ANSI long-time very inverse reset time characteristics

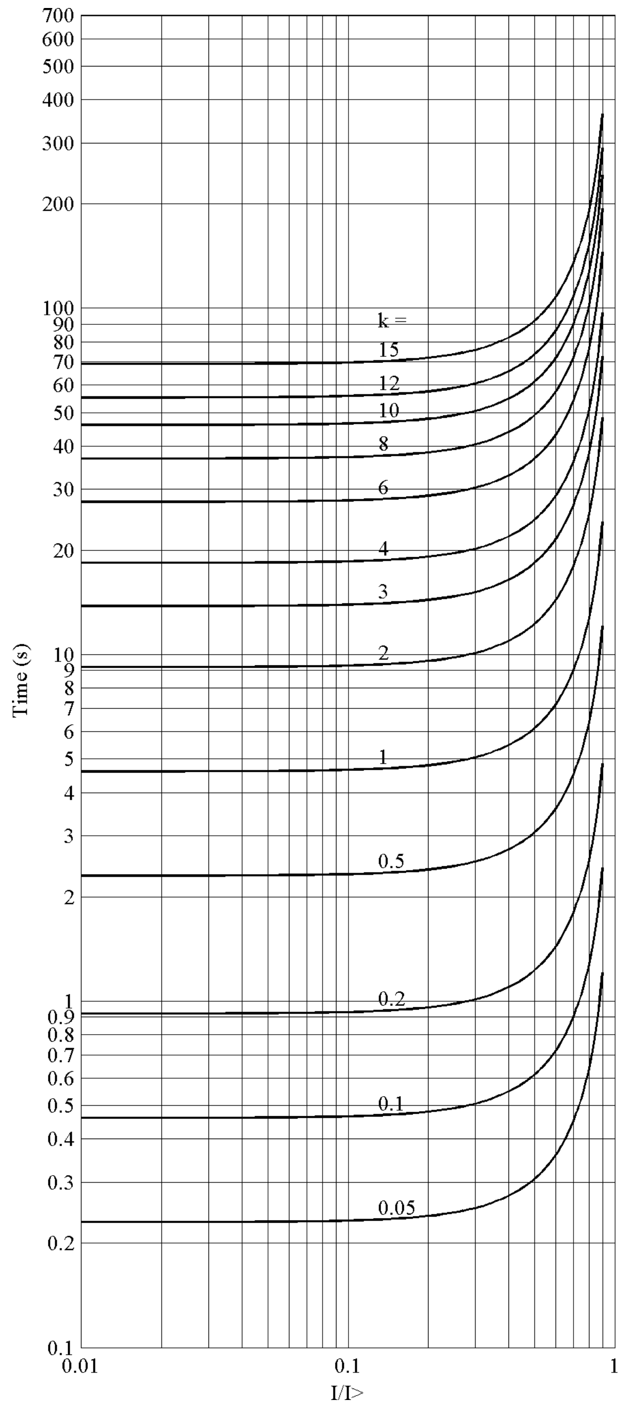


Figure 450: ANSI long-time inverse reset time characteristics

The delayed inverse-time reset is not available for IEC-type inverse time curves.

User-programmable delayed inverse reset

The user can define the delayed inverse reset time characteristics with the following formula using the set *Curve parameter D*.

$$t[s] = \left(\frac{D}{\left(\frac{I}{I>} \right)^2 - 1} \right) \cdot k$$

(Equation 111)

t[s]	Reset time (in seconds)
k	set *Time multiplier*
D	set *Curve parameter D*
I	Measured current
I>	set *Pickup value*

12.2.3 Inverse-timer freezing

When the BLOCK input is active, the internal value of the time counter is frozen at the value of the moment just before the freezing. Freezing of the counter value is chosen when the user does not wish the counter value to count upwards or to be reset. This may be the case, for example, when the inverse-time function of a protection relay needs to be blocked to enable the definite-time operation of another protection relay for selectivity reasons, especially if different relaying techniques (old and modern relays) are applied.

The selected blocking mode is "Freeze timer".

The activation of the BLOCK input also lengthens the minimum delay value of the timer.

Activating the BLOCK input alone does not affect the operation of the PICKUP output. It still becomes active when the current exceeds the set *Pickup value*, and inactive when the current falls below the set *Pickup value* and the set *Reset delay time* has expired.

12.3 Voltage based inverse definite minimum time characteristics

12.3.1 IDMT curves for overvoltage protection

In inverse-time modes, the trip time depends on the momentary value of the voltage, the higher the voltage, the faster the trip time. The trip time calculation or integration starts immediately when the voltage exceeds the set value of the *Pickup value* setting and the PICKUP output is activated.

The TRIP output of the component is activated when the cumulative sum of the integrator calculating the overvoltage situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum trip time* setting defines the minimum trip time for the IDMT mode, that is, it is possible to limit the IDMT based trip time for not becoming too short. For example:

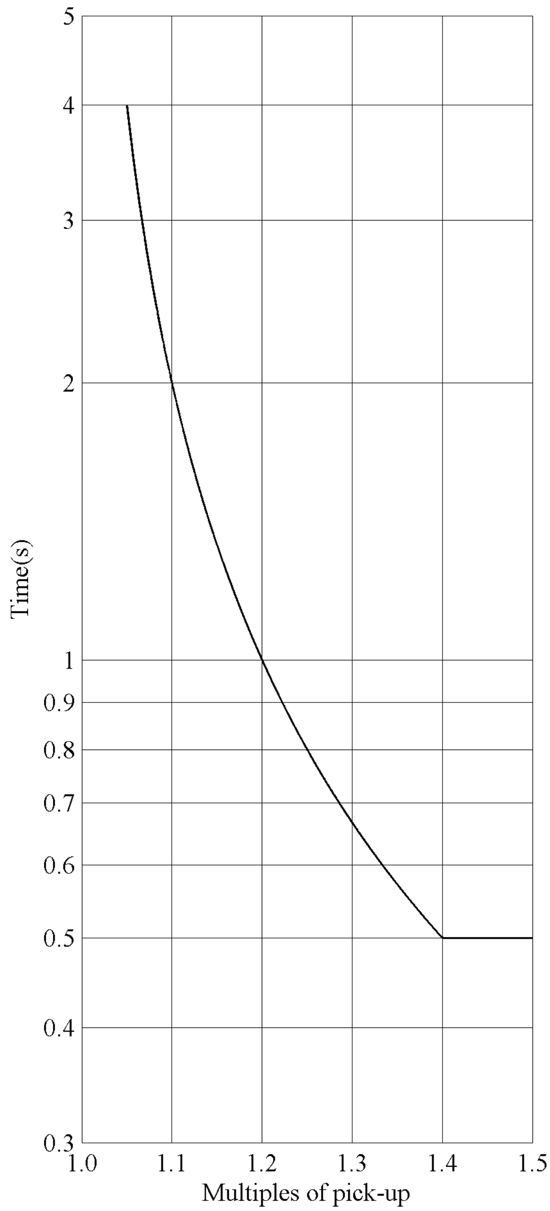


Figure 451: Trip time curve based on IDMT characteristic with Minimum trip time set to 0.5 second

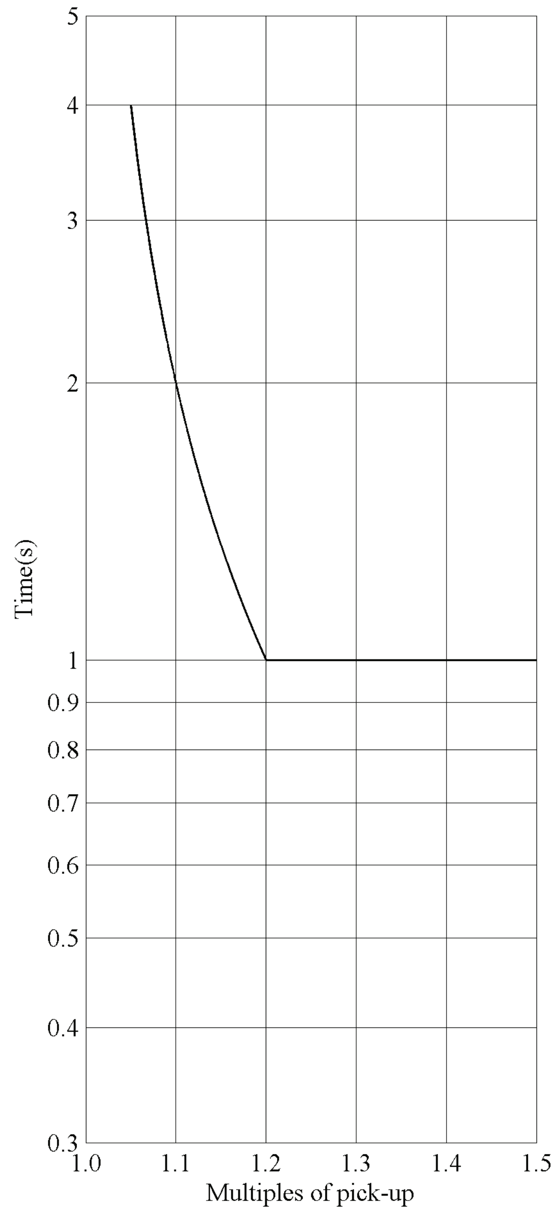


Figure 452: Trip time curve based on IDMT characteristic with Minimum trip time set to 1 second

12.3.1.1 Standard inverse-time characteristics for overvoltage protection

The trip times for the standard overvoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse trip time can be calculated with the formula:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{V-V>}{V>}-C\right)^{E}}+D$$

(Equation 112)

t [s] trip time in seconds

V measured voltage

V> the set value of *Pickup value*

k the set value of *Time multiplier*

Table 615: Curve coefficients for the standard overvoltage IDMT curves

Curve name	A	B	C	D	E
(17) Inverse Curve A	1	1	0	0	1
(18) Inverse Curve B	480	32	0.5	0.035	2
(19) Inverse Curve C	480	32	0.5	0.035	3

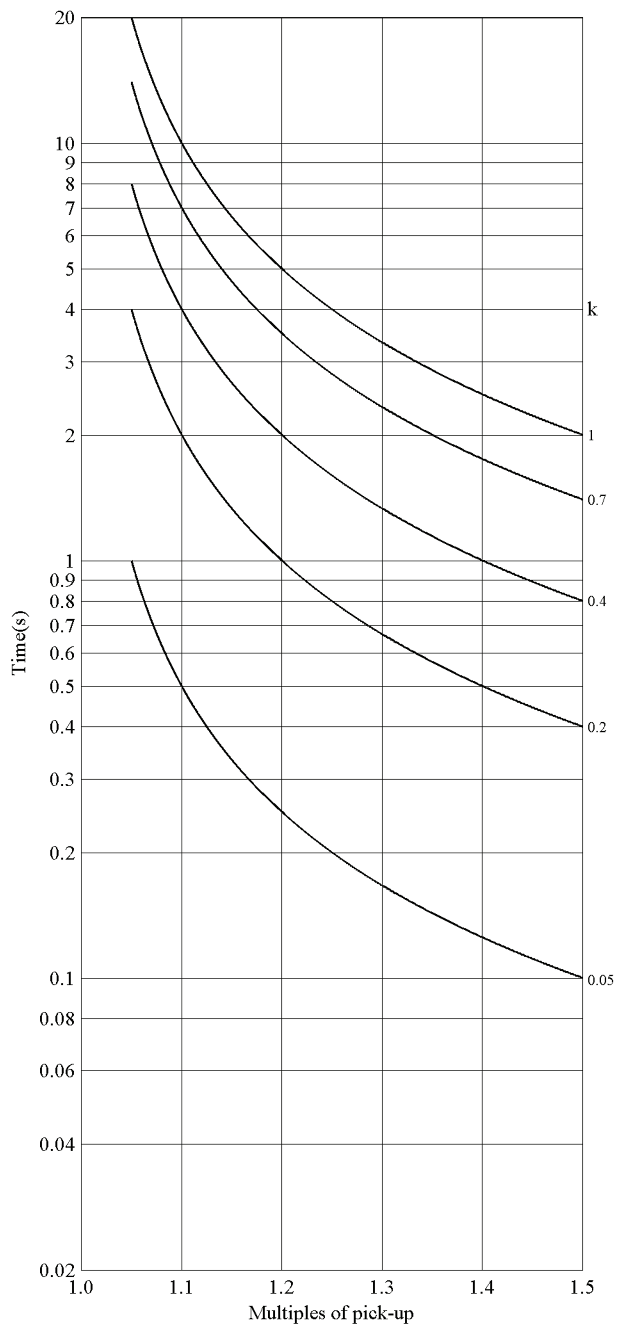


Figure 453: Inverse curve A characteristic of overvoltage protection

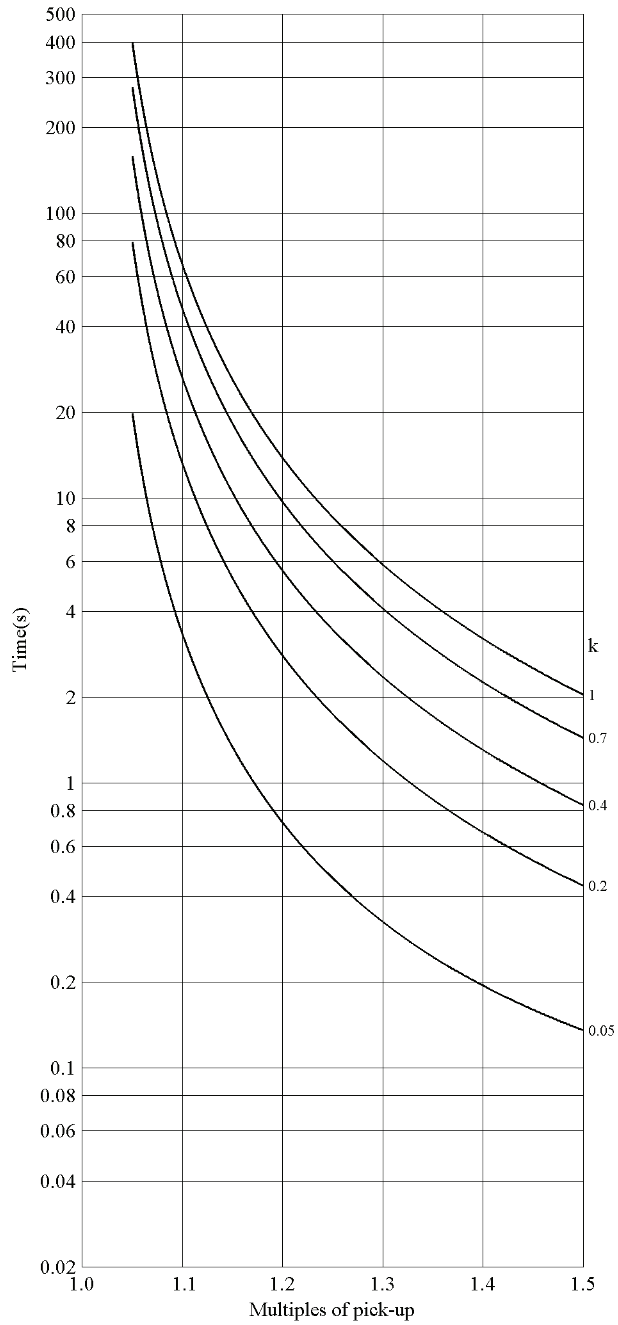


Figure 454: Inverse curve B characteristic of overvoltage protection

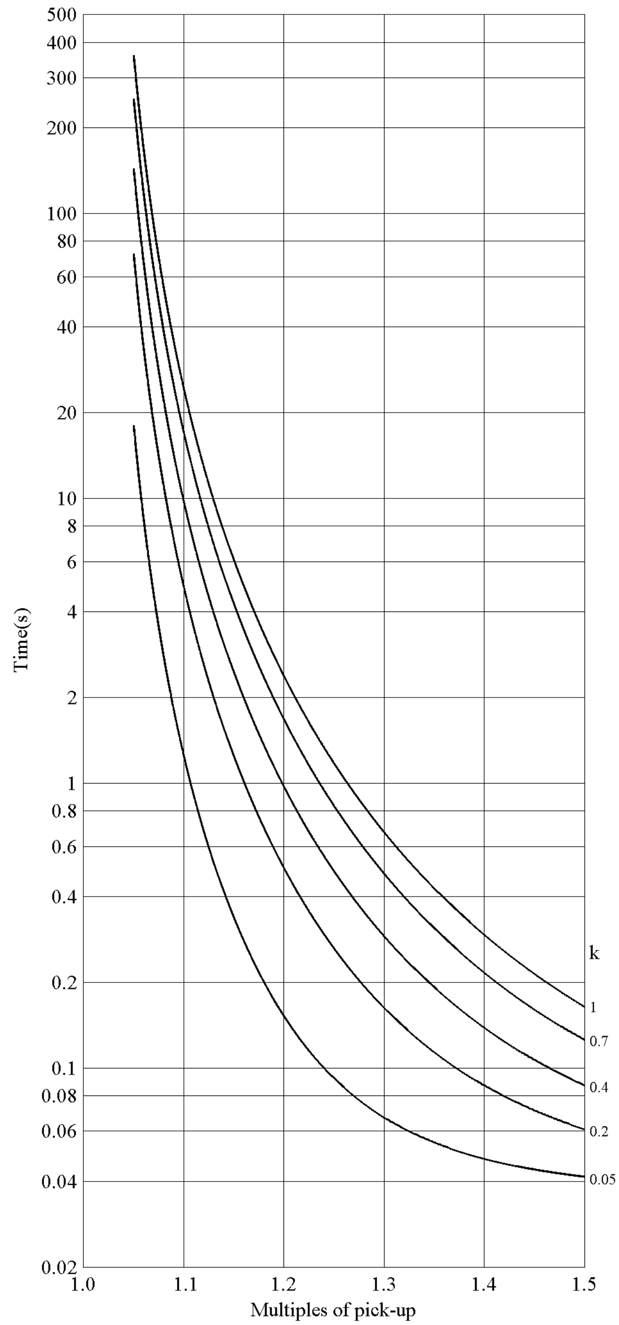


Figure 455: Inverse curve C characteristic of overvoltage protection

12.3.1.2 User programmable inverse-time characteristics for overvoltage protection

The user can define the curves by entering the parameters using the standard formula:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{V-V>}{V>}-C\right)^{E}}+D$$

(Equation 113)

t[s]	trip time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
V	measured voltage
V>	the set value of *Pickup value*
k	the set value of *Time multiplier*

12.3.1.3 IDMT curve saturation of overvoltage protection

For the overvoltage IDMT mode of operation, the integration of the trip time does not start until the voltage exceeds the value of *Pickup value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared to *Pickup value*. For example, due to the curve equation B and C, the characteristics equation output is saturated in such a way that when the input voltages are in the range of *Pickup value* to *Curve Sat Relative* in percent over *Pickup value*, the equation uses *Pickup value* * (1.0 + *Curve Sat Relative* / 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio V/V> exceeds the unity, *Curve Sat Relative* is also set for it. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning the discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum trip time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

12.3.2 IDMT curves for undervoltage protection

In the inverse-time modes, the trip time depends on the momentary value of the voltage, the lower the voltage, the faster the trip time. The trip time calculation or integration starts immediately when the voltage goes below the set value of the *Pickup value* setting and the PICKUP output is activated.

The TRIP output of the component is activated when the cumulative sum of the integrator calculating the undervoltage situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum trip time* setting defines the minimum trip time possible for the IDMT mode. For setting a value for this parameter, the user should carefully study the particular IDMT curve.

12.3.2.1 Standard inverse-time characteristics for undervoltage protection

The trip times for the standard undervoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse trip time can be calculated with the formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{V< - V}{V<} - C\right)^{E}} + D$$

(Equation 114)

t [s]	trip time in seconds
V	measured voltage
V<	the set value of the *Pickup value* setting
k	the set value of the *Time multiplier* setting

Table 616: Curve coefficients for standard undervoltage IDMT curves

Curve name	A	B	C	D	E
(21) Inverse Curve A	1	1	0	0	1
(22) Inverse Curve B	480	32	0.5	0.055	2

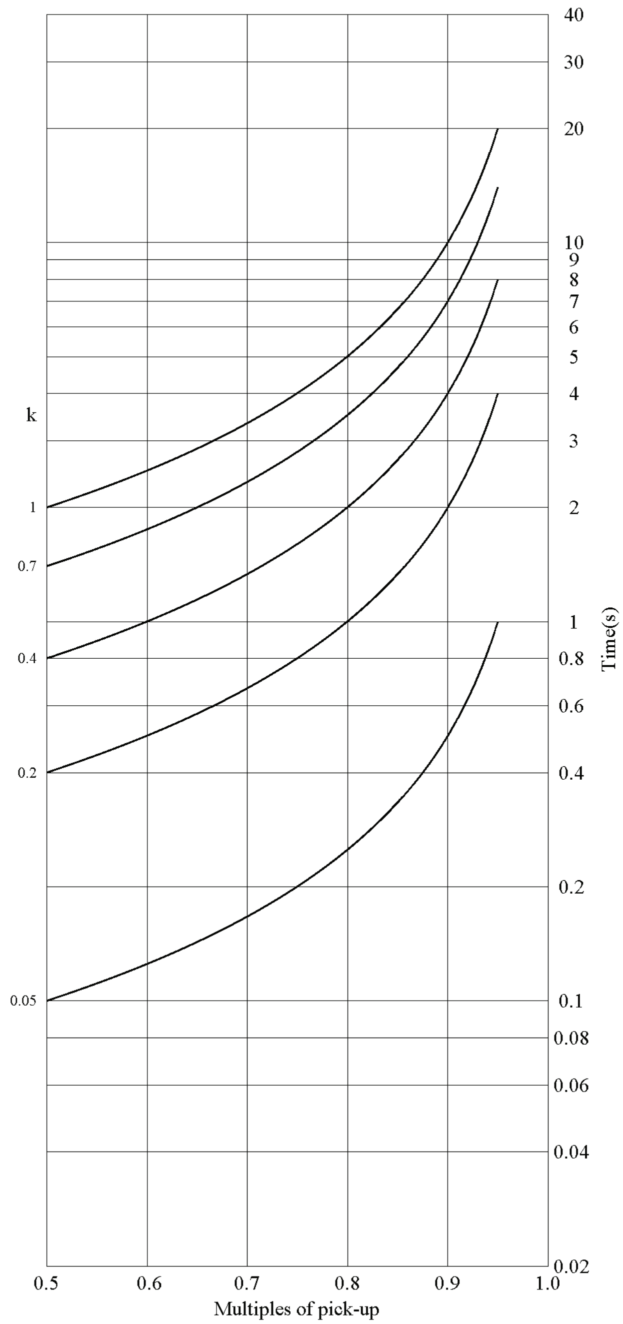


Figure 456: : Inverse curve A characteristic of undervoltage protection

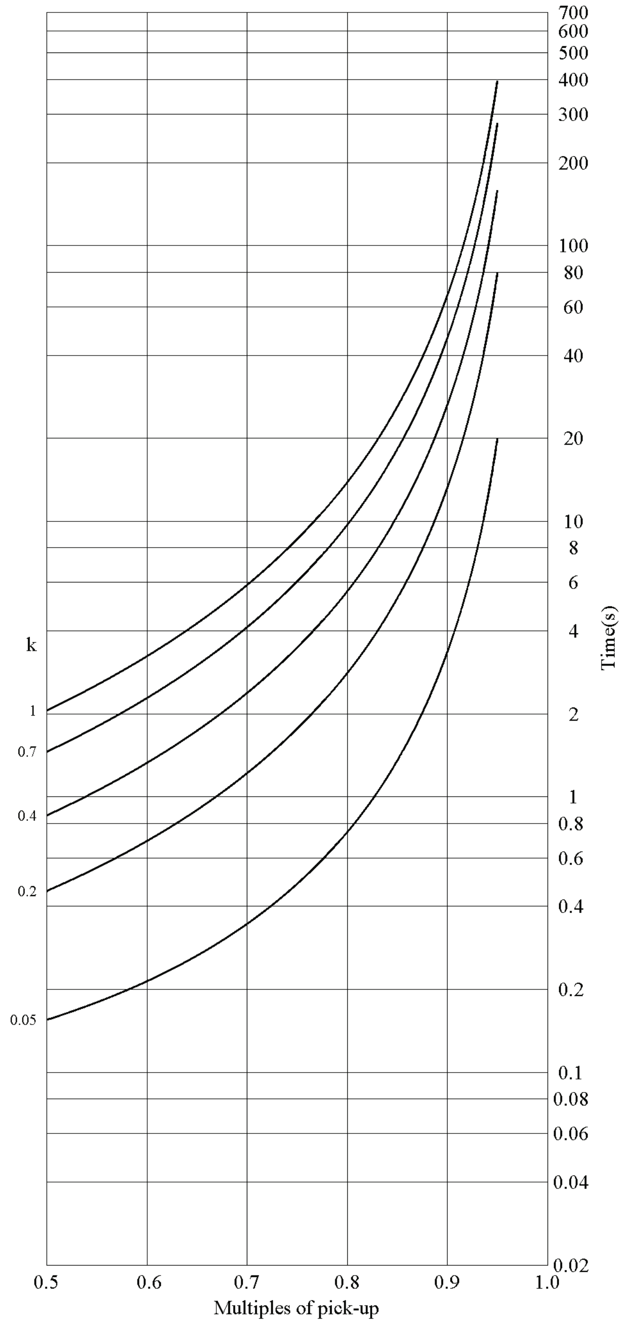


Figure 457: Inverse curve B characteristic of undervoltage protection

12.3.2.2 User-programmable inverse-time characteristics for undervoltage protection

The user can define curves by entering parameters into the standard formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{V< - V}{V<} - C\right)^{E}} + D$$

(Equation 115)

t[s]	trip time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
V	measured voltage
V<	the set value of *Pickup value*
k	the set value of *Time multiplier*

12.3.2.3 IDMT curve saturation of undervoltage protection

For the undervoltage IDMT mode of operation, the integration of the trip time does not start until the voltage falls below the value of *Pickup value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared with *Pickup value*. For example, due to the curve equation B, the characteristics equation output is saturated in such a way that when input voltages are in the range from *Pickup value* to *Curve Sat Relative* in percents under *Pickup value*, the equation uses *Pickup value* * (1.0 - *Curve Sat Relative* / 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio V/V> exceeds the unity, *Curve Sat Relative* is set for it as well. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning also discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum trip time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

12.4 Frequency measurement and protection

All the function blocks that use frequency quantity as their input signal share the common features related to the frequency measurement algorithm. The frequency estimation is done from one phase (phase-to-phase or phase voltage) or from the positive phase sequence (PPS). The voltage groups with three-phase inputs use PPS as the source. The frequency measurement range is 0.6...1.5 xF_n. When the frequency exceeds these limits, it is regarded as out of range and a minimum or maximum value is held as the measured value respectively with appropriate quality information. The frequency estimation requires 160 ms to stabilize after a bad quality signal. Therefore, a delay of 160 ms is added to the transition from the bad quality. The bad quality of the signal can be due to restrictions like:

- The source voltage is below 0.02 xVn at f_n.
- The source voltage waveform is discontinuous.
- The source voltage frequency rate of change exceeds 15 Hz/s (including stepwise frequency changes).

When the bad signal quality is obtained, the nominal frequency value is shown with appropriate quality information in the measurement view. The frequency protection functions are blocked when the quality is bad, thus the timers and the function outputs are reset. When the frequency is out of the function block's setting range but within the measurement range, the protection blocks are running. However, the `TRIP` outputs are blocked until the frequency restores to a valid range.

12.5 Measurement modes

In many current or voltage dependent function blocks, there are various alternative measuring principles.

- RMS
- DFT which is a numerically calculated fundamental component of the signal
- Peak-to-peak
- Peak-to-peak with peak backup

Consequently, the measurement mode can be selected according to the application.

In extreme cases, for example with high overcurrent or harmonic content, the measurement modes function in a slightly different way. The operation accuracy is defined with the frequency range of f/fn=0.95...1.05. In peak-to-peak and RMS measurement modes, the harmonics of the phase currents are not suppressed, whereas in the fundamental frequency measurement the suppression of harmonics is at least -50 dB at the frequency range of f= n x fn, where n = 2, 3, 4, 5,...

RMS

The RMS measurement principle is selected with the *Measurement mode* setting using the value "RMS". RMS consists of both AC and DC components. The AC component is the effective mean value of the positive and negative peak values. RMS is used in applications where the effect of the DC component must be taken into account.

RMS is calculated according to the formula:

$$I_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} I_i^2}$$

(Equation 116)

n The number of samples in a calculation cycle

I_i The current sample value

DFT

The DFT measurement principle is selected with the *Measurement mode* setting using the value "DFT". In the DFT mode, the fundamental frequency component of the measured signal is numerically calculated from the samples. In some applications, for example, it can be difficult to accomplish sufficiently sensitive settings and accurate operation of the low stage, which may be due to a considerable amount of harmonics on the primary side currents. In such a case, the operation can be based solely on the fundamental frequency component of the current. In addition, the DFT mode has slightly higher CT requirements than the peak-to-peak mode, if used with high and instantaneous stages.

Peak-to-peak

The peak-to-peak measurement principle is selected with the *Measurement mode* setting using the value "Peak-to-Peak". It is the fastest measurement mode, in which the measurement quantity is made by calculating the average from the positive and negative peak values. The DC component is not included. The retardation time is short. The damping of the harmonics is quite low and practically determined by the characteristics of the anti-aliasing filter of the protection relay inputs. Consequently, this mode is usually used in conjunction with high and instantaneous stages, where the suppression of harmonics is not so important. In addition, the peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.

Peak-to-peak with peak backup

The peak-to-peak with peak backup measurement principle is selected with the *Measurement mode* setting using the value "P-to-P+backup". It is similar to the peak-to-peak mode, with the exception that it has been enhanced with the peak backup. In the peak-to-peak with peak backup mode, the function starts with two conditions: the peak-to-peak value is above the set pickup current or the peak value is above two times the set *Pickup value*. The peak backup is enabled only when the function is used in the DT mode in high and instantaneous stages for faster operation.

12.6 Calculated measurements

Calculated residual current and voltage

The residual current is calculated from the phase currents according to equation:

$$\overline{Io} = -(\bar{I}_A + \bar{I}_B + \bar{I}_C)$$

(Equation 117)

The residual voltage is calculated from the phase-to-ground voltages when the VT connection is selected as “Wye” with the equation:

$$\overline{Vo} = (\bar{V}_A + \bar{V}_B + \bar{V}_C)$$

(Equation 118)

Sequence components

The phase-sequence current components are calculated from the phase currents according to:

$$\bar{I}_0 = (\bar{I}_A + \bar{I}_B + \bar{I}_C)/3$$

(Equation 119)

$$\bar{I}_1 = (\bar{I}_A + a \cdot \bar{I}_B + a^2 \cdot \bar{I}_C)/3$$

(Equation 120)

$$\bar{I}_2 = (\bar{I}_A + a^2 \cdot \bar{I}_B + a \cdot \bar{I}_C)/3$$

(Equation 121)

The phase-sequence voltage components are calculated from the phase-to-ground voltages when *VT connection* is selected as “Wye” with the formulae:

$$\bar{V}_0 = (\bar{V}_A + \bar{V}_B + \bar{V}_C)/3$$

(Equation 122)

$$\overline{V}_1 = (\overline{V}_A + a \cdot \overline{V}_B + a^2 \cdot \overline{V}_C)/3$$

(Equation 123)

$$\overline{V}_2 = (\overline{V}_A + a^2 \cdot \overline{V}_B + a \cdot \overline{V}_C)/3$$

(Equation 124)

When *VT connection* is selected as “Delta”, the positive and negative phase sequence voltage components are calculated from the phase-to-phase voltages according to the equations:

$$\overline{V}_1 = (\overline{V}_{AB} - a^2 \cdot \overline{V}_{BC})/3$$

(Equation 125)

$$\overline{V}_2 = (\overline{V}_{AB} - a \cdot \overline{V}_{BC})/3$$

(Equation 126)

The phase-to-ground voltages are calculated from the phase-to-phase voltages when *VT connection* is selected as "Delta" according to the equations.

$$\overline{V}_A = \overline{V}_0 + \left(\overline{V}_{AB} - \overline{V}_{CA}\right)/3$$

(Equation 127)

$$\overline{V}_B = \overline{V}_0 + \left(\overline{V}_{BC} - \overline{V}_{AB}\right)/3$$

(Equation 128)

$$\overline{V}_C = \overline{V}_0 + \left(\overline{V}_{CA} - \overline{V}_{BC}\right)/3$$

(Equation 129)

If the $\overline{V}o$ channel is not valid, it is assumed to be zero.

The phase-to-phase voltages are calculated from the phase-to-ground voltages when *VT connection* is selected as "Wye" according to the equations.

$$\overline{V}_{AB} = \overline{V}_A - \overline{V}_B$$

(Equation 130)

$$\overline{V}_{BC} = \overline{V}_B - \overline{V}_C$$

(Equation 131)

$$\overline{V}_{CA} = \overline{V}_C - \overline{V}_A$$

(Equation 132)

Section 13 Requirements for measurement transformers

13.1 Current transformers

13.1.1 Current transformer requirements for non-directional overcurrent protection

For reliable and correct operation of the overcurrent protection, the CT has to be chosen carefully. The distortion of the secondary current of a saturated CT may endanger the operation, selectivity, and co-ordination of protection. However, when the CT is correctly selected, a fast and reliable short circuit protection can be enabled.

The selection of a CT depends not only on the CT specifications but also on the network fault current magnitude, desired protection objectives, and the actual CT burden. The protection settings of the protection relay should be defined in accordance with the CT performance as well as other factors.

Appropriate 'C' class CT should be used based on the total resistances of the CT secondary circuit. If other accuracy class CTs are used then refer the following discussions.

13.1.1.1 Current transformer accuracy class and accuracy limit factor

The rated accuracy limit factor (F_n) is the ratio of the rated accuracy limit primary current to the rated primary current. For example, a protective current transformer of type 5P10 has the accuracy class 5P and the accuracy limit factor 10. For protective current transformers, the accuracy class is designed by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter "P" (meaning protection).

Table 617: Limits of errors according to IEC 60044-1 for protective current transformers

Accuracy class	Current error at rated primary current (%)	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current (%)
		minutes	centiradians	
5P	±1	±60	±1.8	5
10P	±3	-	-	10

The accuracy classes 5P and 10P are both suitable for non-directional overcurrent protection. The 5P class provides a better accuracy. This should be noted also if there are accuracy requirements for the metering functions (current metering, power metering, and so on) of the protection relay.

The CT accuracy primary limit current describes the highest fault current magnitude at which the CT fulfils the specified accuracy. Beyond this level, the secondary current of the CT is distorted and it might have severe effects on the performance of the protection relay.

In practise, the actual accuracy limit factor (F_a) differs from the rated accuracy limit factor (F_n) and is proportional to the ratio of the rated CT burden and the actual CT burden.

The actual accuracy limit factor is calculated using the formula:

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S|}$$

F_n	the accuracy limit factor with the nominal external burden S_n
S_{in}	the internal secondary burden of the CT
S	the actual external burden

13.1.1.2 Non-directional overcurrent protection

The current transformer selection

Non-directional overcurrent protection does not set high requirements on the accuracy class or on the actual accuracy limit factor (F_a) of the CTs. It is, however, recommended to select a CT with F_a of at least 20.

The nominal primary current I_{1n} should be chosen in such a way that the thermal and dynamic strength of the current measuring input of the protection relay is not exceeded. This is always fulfilled when

$I_{1n} > I_{kmax} / 100$,

I_{kmax} is the highest fault current.

The saturation of the CT protects the measuring circuit and the current input of the protection relay. For that reason, in practice, even a few times smaller nominal primary current can be used than given by the formula.

Recommended pickup current settings

If I_{kmin} is the lowest primary current at which the highest set overcurrent stage is to trip, the pickup current should be set using the formula:

Current pickup value < 0.7 x (I_{kmin} / I_{1n})

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection relay inaccuracy, current transformer errors, and imperfections of the short circuit calculations.

The adequate performance of the CT should be checked when the setting of the high set stage overcurrent protection is defined. The trip time delay caused by the CT saturation is typically small enough when the overcurrent setting is noticeably lower than F_a.

When defining the setting values for the low set stages, the saturation of the CT does not need to be taken into account and the pickup current setting is simply according to the formula.

Delay in operation caused by saturation of current transformers

The saturation of CT may cause a delayed protection relay operation. To ensure the time selectivity, the delay must be taken into account when setting the trip times of successive protection relays.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time the constant of the DC component of the fault current, when the current is only slightly higher than the pickup current. This depends on the accuracy limit factor of the CT, on the remanence flux of the core of the CT, and on the trip time setting.

With inverse time mode of operation, the delay should always be considered as being as long as the time constant of the DC component.

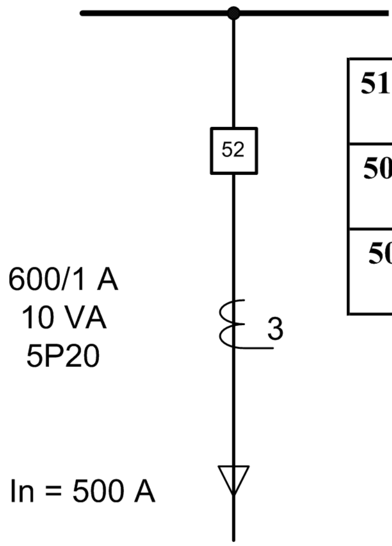
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the pickup current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

F_a > 20**Current pickup value* / I_{1n}

The *Current pickup value* is the primary pickup current setting of the protection relay.

13.1.1.3 Example for non-directional overcurrent protection

The following figure describes a typical medium voltage feeder. The protection is implemented as three-stage definite time non-directional overcurrent protection.



51P	1200 A 0.75 s	2.00 x I_{2n} 0.75 s
50P-1/2	1800A 0.50 s	3.00 x I_{2n} 0.50 s
50P-3	3500 A 0.20 s	5.83 x I_{2n} 0.20 s

Figure 458: Example of three-stage overcurrent protection

The maximum three-phase fault current is 41.7 kA and the minimum three-phase short circuit current is 22.8 kA. The actual accuracy limit factor of the CT is calculated to be 59.

The pickup current setting for low-set stage (51P) is selected to be about twice the nominal current of the cable. The trip time is selected so that it is selective with the next protection relay (not visible in the figure above). The settings for the high-set stage and instantaneous stage are defined also so that grading is ensured with the downstream protection. In addition, the pickup current settings have to be defined so that the protection relay operates with the minimum fault current and it does not trip with the maximum load current. The settings for all three stages are as in the figure above.

For the application point of view, the suitable setting for instantaneous stage (50P-3) in this example is 3 500 A (5.83 x I_{2n}). For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the protection relay setting is considerably below the F_a. In this application, the CT rated burden could have been selected much lower than 10 VA for economical reasons.

13.1.2 Current transformer requirements for differential protections

The sensitivity and the reliability of the protection depends on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all the CTs have an identical constructions, that is, they have an equal burden and characteristics and are of the same type, preferably from the same manufacturing batch. If the CT characteristics and burden values are not equal, calculations for each branch in the scheme should be performed separately and the worst-case results should be used. In Figure 227, the CT winding resistance and the burden of the branches are not equal, and hence, the maximum burden equal to 3.2Ω should be used for calculating the stabilized voltage.

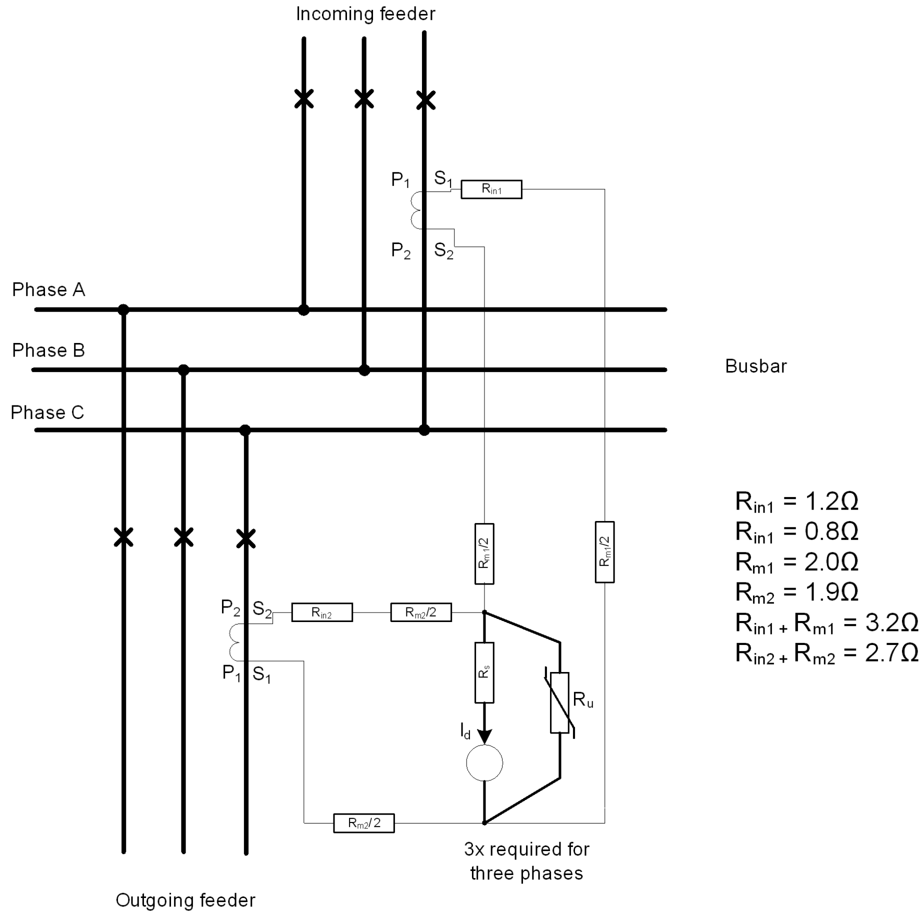


Figure 459: High-impedance busbar differential protection with different CT burden value on each feeder

First, the stabilizing voltage, that is, the voltage appearing across the measuring branch during the out-of-zone fault, is calculated assuming that one of the parallel connected CT is fully saturated. The stabilizing voltage can be calculated with Equation 55.

$$V_s = \frac{I_{k\,max}}{n}\left(R_{in} + R_m\right)$$

(Equation 133)

I_{kmax} the highest through-fault current in primary amps. The highest earth fault or short circuit current during the out-of-zone fault.

n the turns ratio of the CT

R_{in} the secondary internal resistance of the CT in ohms

R_m the resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the protection relay through the differential circuit during a fault condition inside the protection zone. To ensure this, the knee point voltage V_{kn} must be at least two times higher than the stabilizing voltage V_s.

The required knee point voltage V_{kn} of the current transformer is calculated with Equation 56.

$$V_{kn} \geq 2 \cdot V_s$$

(Equation 134)

V_{kn} the knee point voltage

V_s the stabilizing voltage

The factor two is used when a delay in the operating time of the protection is not acceptable. To prevent the knee point voltage from rising too high, CTs with the secondary winding resistance same as the resistance of the measuring loop should be used.

As the impedance of the protection relay is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated with Equation 57.

$$R_s = \frac{V_s}{I_{rs}}$$

(Equation 135)

R_s the resistance of the stabilizing resistor

V_s the stabilizing voltage of the protection relay

I_{rs} the value of the *Operate value* setting in secondary amps.

The stabilizing resistor should be capable to dissipate high energy within a very short time; therefore, a wire wound-type resistor must be used. The minimum rated power should be a few tens of watts because of the possible CT inaccuracy which might cause some current through the stabilizing resistor in a normal load situation.

If V_{kn} is high or V_s is low, a resistor with a higher power rating is needed. The resistor manufacturers often allow 10 times rated power for five seconds. The power of the resistor can be calculated with Equation 58.

$$\frac{V_{kn}^2}{R_s \cdot 10}$$

(Equation 136)

The actual sensitivity of the protection is affected by the protection relay setting, the magnetizing currents of the parallel connected CTs and the shunting effect of the voltage-dependent resistor (VDR). The value of the primary current I_{prim} at which the protection relay operates at a certain setting can be calculated with Equation 59.

$$I_{prim} = n \cdot \left(I_{rs} + I_u + m \cdot I_m \right)$$

(Equation 137)

I_{prim}	the primary current at which the protection is to start
n	the turn ratio of the current transformer
I_{rs}	the value of the *Operate value* setting
I_u	the leakage current flowing through the VDR at the V_s voltage
m	the number of current transformers included in the protection per phase
I_m	the magnetizing current per current transformer at the V_s voltage

The I_e value given in many catalogs is the excitation current at the knee point voltage.

Assuming $V_{kn} \approx 2 \cdot V_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for Equation 59.

The selection of current transformers can be divided into procedures.

1. The rated current I_n of the feeder should be known. The value of I_n also affects the magnitude of I_{kmax}.
2. The rated primary current I_{1n} of the CT must be higher than the rated current of the feeder.

The choice of the CT also specifies R_{in}.

3. The required V_{kn} is calculated with Equation 56. If V_{kn} of the CT is not high enough, another CT has to be selected. The value of the V_{kn} is given by the manufacturer in the case of Class X current transformers or it can be estimated with Equation 60.
4. The sensitivity I_{prim} is calculated with Equation 59. If the achieved sensitivity is sufficient, the present CT is chosen. If a better sensitivity is needed, a CT with a bigger core is chosen.

If other than Class X CTs are used, an estimate for V_{kn} is calculated with Equation 60.

$$V_{kn} = 0.8 \cdot F_n \cdot I_{2n} \cdot \left(R_{in} + \frac{S_n}{I_{2n}^2} \right)$$

(Equation 138)

F_n the rated accuracy limit factor corresponding to the rated burden S_n

I_{2n} the rated secondary current of the CT

R_{in} the secondary internal resistance of the CT

S_n the volt-amp rating of the CT

The equations are based on choosing the CTs according to Equation 56, which results an absolutely stable scheme. In some cases, it is possible to achieve stability with the knee point voltages lower than stated in equations. The conditions in the network, however, must be known well enough to ensure the stability.

1. If $V_k \geq 2 \cdot V_s$, fast protection relay operation is secure.
2. If $V_k \geq 1.5 \cdot V_s$ and $< 2 \cdot V_s$, protection relay operation can be slightly prolonged and must be studied case by case.
   If $V_k < 1.5 \cdot V_s$, the protection relay operation is jeopardized. Another CT has to be chosen.

The need for the VDR depends on certain conditions.

First, voltage V_{max}, ignoring the CT saturation during the fault, is calculated with Equation 61.

$$V_{max} = \frac{I_{k\,max\,in}}{n} \cdot (R_{in} + R_m + R_s) \approx \frac{I_{k\,max\,in}}{n} \cdot R_s$$

(Equation 139)

I_{kmaxin}	the maximum fault current inside the zone, in primary amps
n	the turns ration of the CT
R_{in}	the internal resistance of the CT in ohms
R_m	the resistance of the longest loop of the CT secondary circuit in ohms
R_s	the resistance of the stabilized resistor in ohms

Next, the peak voltage û, which includes the CT saturation, is estimated with Equation 62 (given by P. Mathews, 1955).

$$\breve{u} = 2\sqrt{2V_{kn}(V_{max} - V_{kn})}$$

(Equation 140)

V_{kn} the knee point voltage of the CT

VDR is recommended when the peak voltage û ≥ 2 kV, which is the insulation level for which the protection relay is tested.

The maximum fault current in case of a fault inside the zone is considered to be 12.6 kA in primary, CT is of 1250/5 A (ratio n = 240) and knee-point voltage is 81 V. Stabilizing resistor is 330 Ohms.

$$V_{max} = \frac{12600A}{240} \cdot 330\Omega = 17325V$$

(Equation 141)

$$\breve{u} = 2\sqrt{2 \cdot 81 \cdot (17325 - 81)} \approx 3.34kV$$

(Equation 142)

As the peak voltage û = 3.2 kV, VDR must be used. If the R_s is smaller, VDR can be avoided. The value of R_s depends on the operating current and stabilizing voltage of the operation relay. Therefore, either a higher setting in the protection relay or a lower stabilizing voltage must be used.

Section 14 Protection relay's physical connections

14.1 Connections to the rear panel terminals

All external circuits are connected to the terminals on the rear panel of the protection relay.

- Each signal connector terminal is connected with one 14 or 16 Gauge wire. For CB trip circuit, 12 or 14 Gauge wire is used.
- Each ring-lug terminal for signal connector is connected with one of maximum 14 or 16 Gauge wire.
- Each ring-lug terminal for CTs/VTs is connected with one 12 Gauge wire.

14.2 Protective ground connections

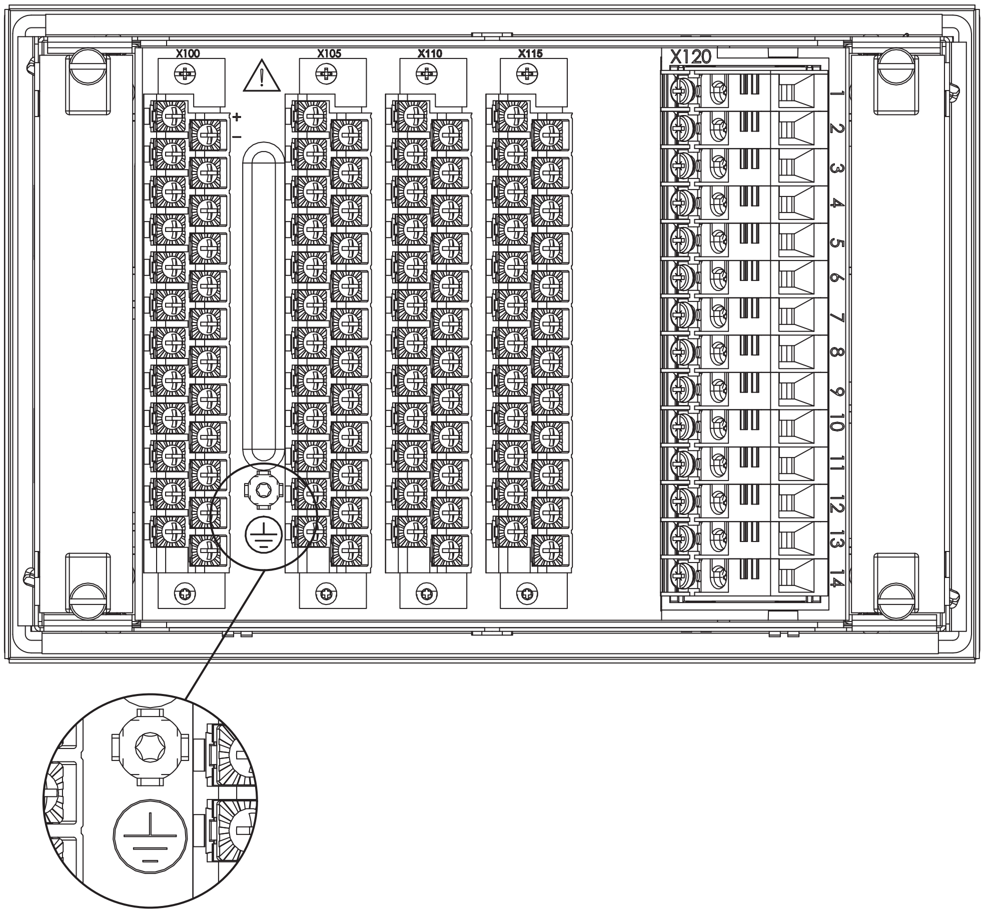


Figure 460: The protective ground screw is located between connectors X100 and X105.

The ground lead must be at least a 10 Gauge wire. If the length of the ground lead is long, the cross section of the wire must be increased.

14.3 Communication connections

The front communication connection is an RJ-45 type connector used mainly for configuration and setting.

Depending on order code, several rear port communication connections are available.

- Galvanic RJ-45 Ethernet connection
- Optical LC Ethernet connection
- ST-type glass fibre serial connection
- EIA-485 serial connection
- EIA-232 serial connection

Fibre optic equipment and cables are very sensitive to dust and dirt. Handle them with care. If the fibre is disconnected from the modem, set the protective hood on the transmitter/receiver. Keep the protective hood on during transportation.

If contaminated, clean optical connectors with a cleaning stick. Recommended cleaning fluids are methyl alcohol, ethyl alcohol, isopropyl alcohol or isobutyl alcohol.

14.3.1 Ethernet RJ-45 front connection

The protection relay is provided with an RJ-45 connector on the LHMI. The connector is mainly for configuration and setting purposes. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside the protection relay for the front interface only.

The events and setting values and all input data such as memorized values and disturbance records can be read via the front communication port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- LHMI
- WHMI

The default IP address of the protection relay through this port is 192.168.0.254.

The front port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the front port.

The speed of the front connector interface is limited to 10 Mbps.

14.3.2 Ethernet rear connections

The Ethernet communication module is provided with either galvanic RJ-45 connection or optical multimode LC type connection depending on the product variant and selected communication interface option. A shielded twisted-pair cable CAT 5e is used with RJ-45, and an optical cable (≤ 2 km) with LC type connections.

In addition, communication modules with multiple Ethernet connectors enable the forwarding of Ethernet traffic. The variants include an internal switch that handles the Ethernet traffic between a protection relay and a station bus. In this case, the used network can be a ring or daisy-chain type of network topology. In loop type topology, a self-healing Ethernet loop is closed by a managed switch supporting rapid spanning tree protocol. In daisy-chain type of topology, the network is bus type and it is either without switches, where the station bus starts from the station client, or with a switch to connect some devices and the 620 series of protection relays chain to the same network.

Communication modules including Ethernet connectors X1, X2, and X3 can utilize the third port for connecting any other device (for example, an SNTP server, that is visible for the whole local subnet) to a station bus.

The protection relay's default IP address through this port is 192.168.2.10 with the TCP/IP protocol. The data transfer rate is 100 Mbps.

14.3.3 EIA-232 serial rear connection

The EIA-232 connection follows the TIA/EIA-232 standard and is intended to be used with a point-to-point connection. The connection supports hardware flow control (RTS, CTS, DTR, DSR), full-duplex and half-duplex communication.

14.3.4 EIA-485 serial rear connection

The EIA-485 communication module follows the TIA/EIA-485 standard and is intended to be used in a daisy-chain bus wiring scheme with 2-wire half-duplex or 4-wire full-duplex, multi-point communication.

The maximum number of devices (nodes) connected to the bus where the protection relay is used is 32, and the maximum length of the bus is 1312 yards (1200 meters).

14.3.5 Optical ST serial rear connection

Serial communication can be used optionally through an optical connection either in loop or star topology. The connection idle state is light on or light off.

14.3.6 Communication interfaces and protocols

The communication protocols supported depend on the optional rear communication module.

Table 618: Supported station communication interfaces and protocols

Interfaces/Protocols	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	EIA-232/EIA-485	Fibre-optic ST
IEC 61850	●	●	-	-
MODBUS RTU/ ASCII	-	-	●	●
MODBUS TCP/IP	●	●	-	-
DNP3 (serial)	-	-	●	●
DNP3 TCP/IP	●	●	-	-
● = Supported				

14.3.7 Rear communication modules

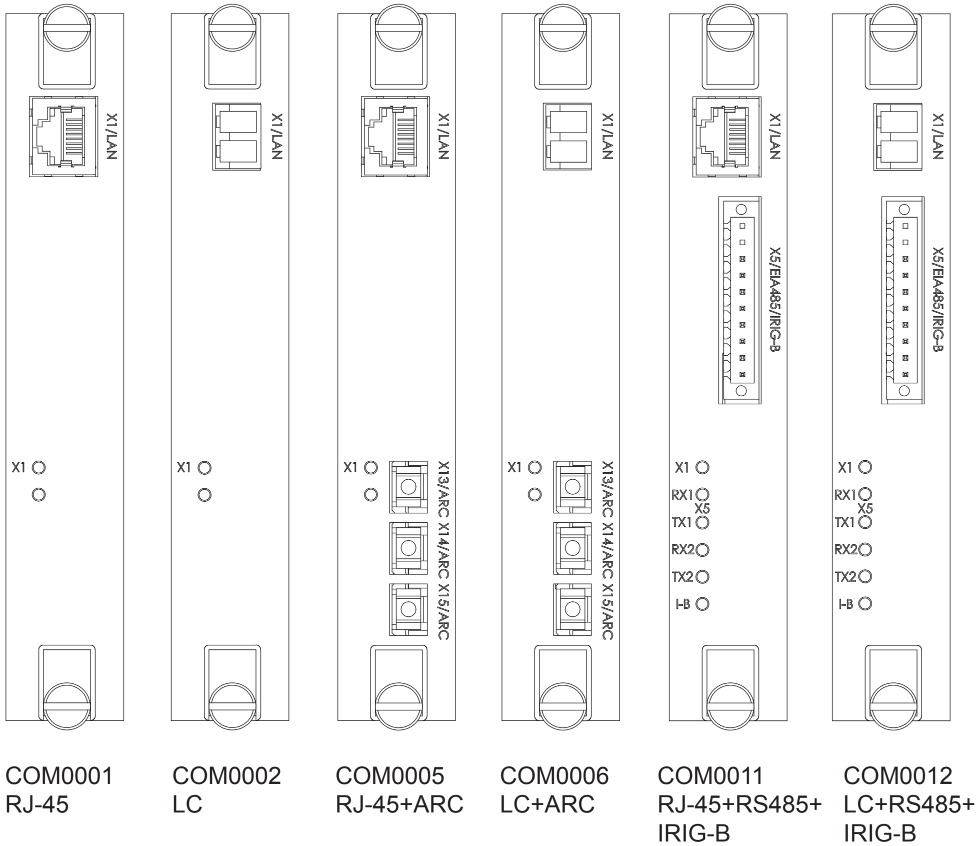
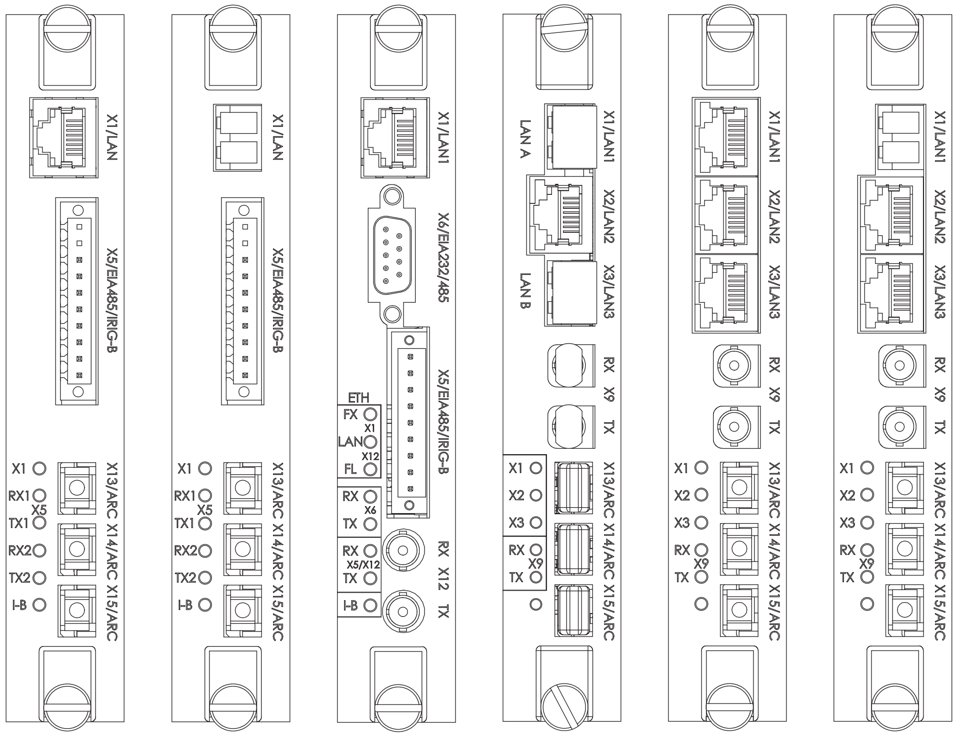


Figure 461: Communication module options COM0001…COM0012



COM0013
RJ-45+RS485+
IRIG-B+ARC

COM0014
LC+RS485+
IRIG-B+ARC

COM0023
RJ-45+
RS232/485+
RS485+ST+
IRIG-B

COM0032
2xLC+RJ-45+
ST+ARC

COM0033
3xRJ-45+
ST+ARC

COM0034
LC+2xRJ-45+
ST+ARC

Figure 462: Communication module options COM00013…COM0034

Table 619: Station bus communication interfaces included in communication modules

Module ID	RJ-45	LC	EIA-485	EIA-232	ST
COM0001	1	-	-	-	-
COM0002	-	1	-	-	-
COM0005	1	-	-	-	-
COM0006	-	1	-	-	-
COM0011	1	-	1	-	-
COM0012	-	1	1	-	-
COM0013	1	-	1	-	-
COM0014	-	1	1	-	-
COM0023	1	-	1	1	1
Table continues on next page					

Module ID	RJ-45	LC	EIA-485	EIA-232	ST
COM0032[1)]	1	2	-	-	1
COM0033	3	-	-	-	1
COM0034	2	1	-	-	1

1) Available in REM620 Ver.2.1 only

Table 620: LED descriptions for COM0001-COM0014

LED	Connector	Description[1)]
LAN	X1	LAN link status and activity (RJ-45 and LC)
RX1	X2	COM2 2-wire/4-wire receive activity
TX1	X3	COM2 2-wire/4-wire transmit activity
RX2	X4	COM1 2-wire receive activity
TX2	X5	COM1 2-wire transmit activity
I-B	X6	IRIG-B signal activity

1) Depending on the COM module and jumper configuration

Table 621: LED descriptions for COM0023

LED	Connector	Description[1)]
FX	X12	Not used by COM23A
LAN	X1	LAN Link status and activity (RJ-45 and LC)
FL	X12	Not used by COM23A
RX	X6	COM1 2-wire / 4-wire receive activity
TX	X6	COM1 2-wire / 4-wire transmit activity
RX	X5 / X12	COM2 2-wire / 4-wire or fibre-optic receive activity
TX	X5 / X12	COM2 2-wire / 4-wire or fibre-optic transmit activity
I-B	X5	IRIG-B Signal activity

1) Depending on the jumper configuration

Table 622: LED descriptions for COM0032...COM0034[1]

LED	Connector	Description
X1	X1	X1/LAN1 link status and activity
X2	X2	X2/LAN2 link status and activity
X3	X3	X3/LAN3 link status and activity
RX	X9	COM1 fiber-optic receive activity
TX	X9	COM1 fiber-optic transmit activity

[1] COM0032 is available in REM620 Ver.2.1 only

14.3.7.1 COM0001-COM0014 jumper locations and connections

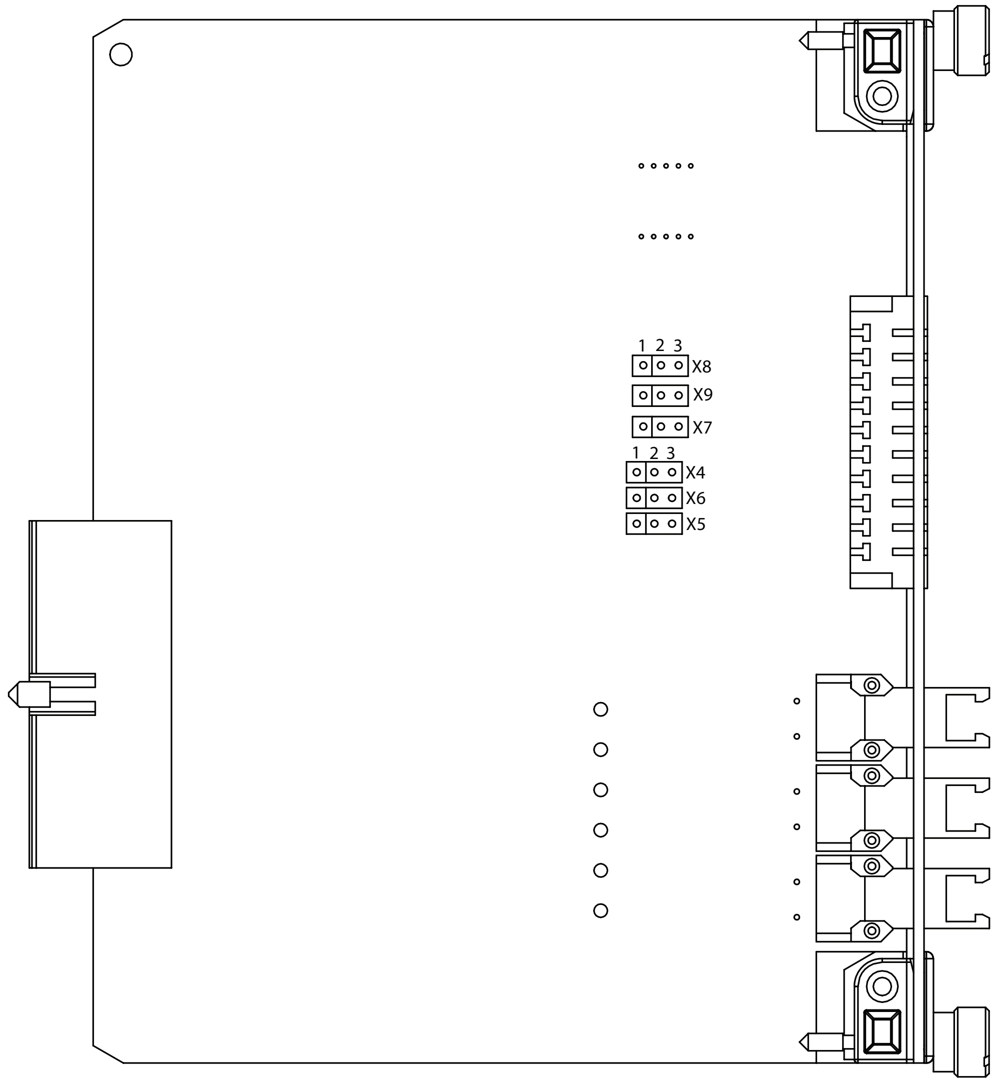


Figure 463: Jumper connectors on communication module

Table 623: 2-wire EIA-485 jumper connectors

Group	Jumper connection	Description	Notes
X4	1-2	A+ bias enabled	COM2 2-wire connection
	2-3	A+ bias disabled	
X5	1-2	B- bias enabled	
	2-3	B- bias disabled	
X6	1-2	Bus termination enabled	
	2-3	Bus termination disabled	
X7	1-2	B- bias enabled	COM1 2-wire connection
	2-3	B- bias disabled	
X8	1-2	A+ bias enabled	
	2-3	A+ bias disabled	
X9	1-2	Bus termination enabled	
	2-3	Bus termination disabled	

The bus is to be biased at one end to ensure fail-safe operation, which can be done using the pull-up and pull-down resistors on the communication module. In 4-wire connection the pull-up and pull-down resistors are selected by setting jumpers X4, X5, X7 and X8 to enabled position. The bus termination is selected by setting jumpers X6 and X9 to enabled position.

The jumpers have been set to no termination and no biasing as default.

Table 624: 4-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description	Notes
X4	1-2	A+ bias enabled	COM2 4-wire TX channel
	2-3	A+ bias disabled 1)	
X5	1-2	B- bias enabled	
	2-3	B- bias disabled1)	
X6	1-2	Bus termination enabled	
	2-3	Bus termination disabled1)	
X7	1-2	B- bias enabled	COM2 4-wire RX channel
	2-3	B- bias disabled1)	
X8	1-2	A+ bias enabled	
	2-3	A+ bias disabled1)	
X9	1-2	Bus termination enabled	
	2-3	Bus termination disabled1)	

1) Default setting

It is recommended to enable biasing only at one end of the bus.

Termination is enabled at each end of the bus.

It is recommended to ground the signal directly to ground from one node and through capacitor from other nodes.

The two 2-wire ports are called COM1 and COM2. Alternatively, if there is only one 4-wire port configured, the port is called COM2. The fibre-optic ST connection uses the COM2 port.

Table 625: EIA-485 connections for COM0001-COM0014

Pin	2-wire mode		4-wire mode	
10	COM1	A/+	COM2	Rx/+
9		B/-		Rx/-
8	COM2	A/+		Tx/+
7		B/-		Tx/-
6	AGND (isolated ground)			
5	IRIG-B +			
4	IRIG-B -			
3	-			
2	GNDC (case via capacitor)			
1	GND (case)			

14.3.7.2 COM0023 jumper locations and connections

The optional communication module supports EIA-232/EIA-485 serial communication (X6 connector), EIA-485 serial communication (X5 connector) and optical ST serial communication (X12 connector).

Two independent communication ports are supported. The two 2-wire ports are called COM1 and COM2. Alternatively, if only one 4-wire port is configured, the port is called COM2. The fibre-optic ST connection uses the COM1 port.

Table 626: Configuration options of the two independent communication ports

COM1 connector X6	COM2 connector X5 or X12
EIA-232	Optical ST (X12)
EIA-485 2-wire	EIA-485 2-wire (X5)
EIA-485 4-wire	EIA-485 4-wire (X5)

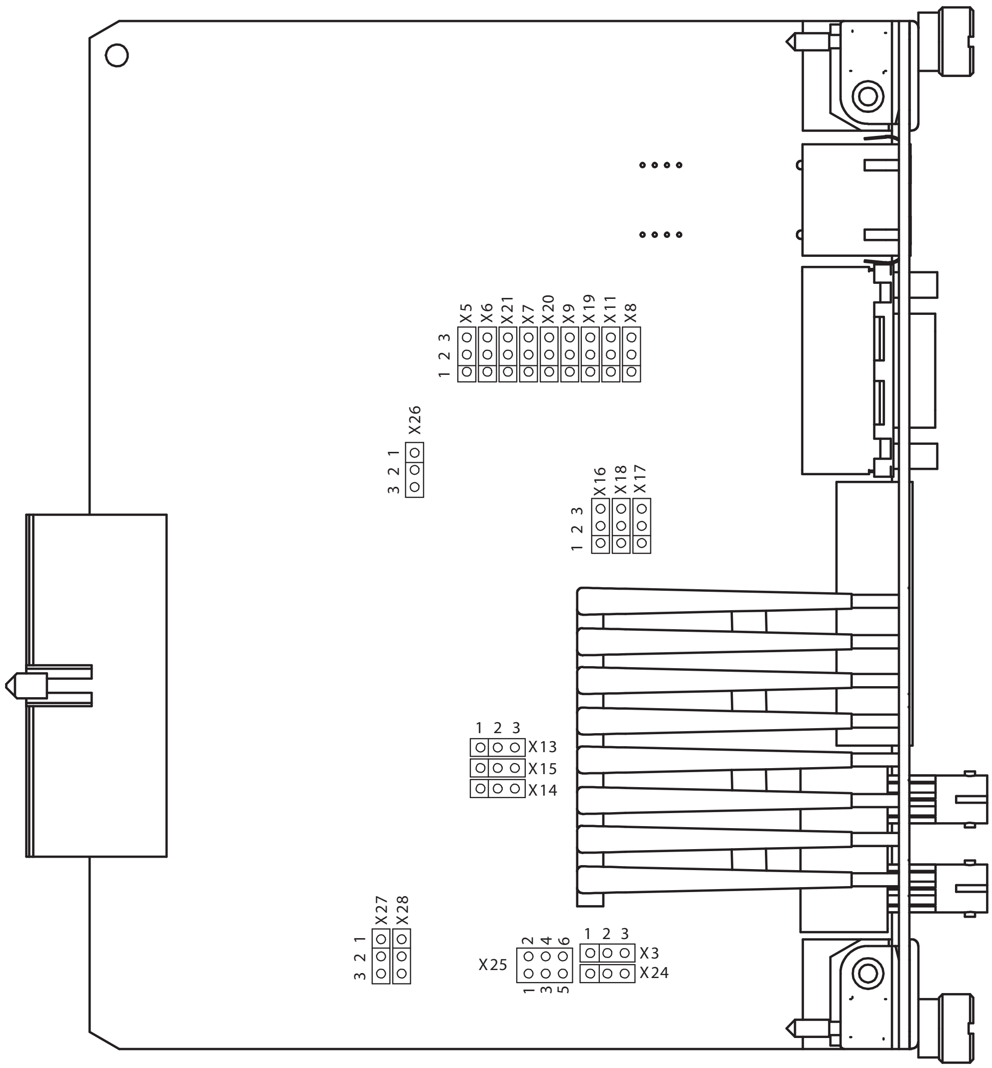


Figure 464: Jumper connections on communication module COM0023

COM1 port connection type can be either EIA-232 or EIA-485. Type is selected by setting jumpers X19, X20, X21, X26.

The jumpers are set to EIA-232 by default.

Table 627: EIA-232 and EIA-485 jumper connectors for COM1

Group	Jumper connection	Description
X19	1–2 2–3	EIA-485 EIA-232
X20	1–2 2–3	EIA-485 EIA-232
X21	1–2 2–3	EIA-485 EIA-232
X26	1–2 2–3	EIA-485 EIA-232

To ensure fail-safe operation, the bus is to be biased at one end using the pull-up and pull-down resistors on the communication module. In the 4-wire connection, the pull-up and pull-down resistors are selected by setting jumpers X5, X6, X8, X9 to the enabled position. The bus termination is selected by setting jumpers X7, X11 to the enabled position.

The jumpers have been set to no termination and no biasing as default.

Table 628: 2-wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1–2 2–3	A+ bias enabled A+ bias disabled 1)	COM1 Rear connector X6 2-wire connection
X6	1–2 2–3	B- bias enabled B- bias disabled	
X7	1–2 2–3	Bus termination enabled Bus termination disabled	

1) Default setting

Table 629: 4–wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1–2 2–3	A+ bias enabled A+ bias disabled 1)	COM1 Rear connector X6 4-wire TX channel
X6	1–2 2–3	B- bias enabled B- bias disabled	
X7	1–2 2–3	Bus termination enabled Bus termination disabled	
Table continues on next page			

Group	Jumper connection	Description	Notes
X9	1–2 2–3	A+ bias enabled A+ bias disabled	4-wire RX channel
X8	1–2 2–3	B- bias enabled B- bias disabled	
X11	1–2 2–3	Bus termination enabled Bus termination disabled	

1) Default setting

COM2 port connection can be either EIA-485 or optical ST. Connection type is selected by setting jumpers X27 and X28.

Table 630: COM2 serial connection X5 EIA-485/ X12 Optical ST

Group	Jumper connection	Description
X27	1–2 2–3	EIA-485 Optical ST
X28	1–2 2–3	EIA-485 Optical ST

Table 631: 2-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description
X13	1–2 2–3	A+ bias enabled A+ bias disabled
X14	1–2 2–3	B- bias enabled B- bias disabled
X15	1–2 2–3	Bus termination enabled Bus termination disabled

Table 632: 2-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description	Notes
X13	1–2 2–3	A+ bias enabled A+ bias disabled	COM2 4-wire TX channel
X14	1–2 2–3	B- bias enabled B- bias disabled	
X15	1–2 2–3	Bus termination enabled Bus termination disabled	
X16	1–2 2–3	B- bias enabled B- bias disabled	4-wire RX channel
X17	1–2 2–3	A+ bias enabled A+ bias disabled	
X18	1–2 2–3	Bus termination enabled Bus termination disabled	

Table 633: X12 Optical ST connection

Group	Jumper connection	Description
X3	1–2 2–3	Star topology Loop topology
X24	1–2 2–3	Idle state = Light on Idle state = Light off

Table 634: EIA-232 connections for COM0023 (X6)

Pin	EIA-232
1	DCD
2	RxD
3	TxD
4	DTR
5	AGND
6	-
7	RTS
8	CTS

Table 635: EIA-485 connections for COM0023 (X6)

Pin	2-wire mode	4-wire mode
1	-	Rx/+
6	-	Rx/-
7	B/-	Tx/-
8	A/+	Tx/+

Table 636: EIA-485 connections for COM0023 (X5)

Pin	2-wire mode	4-wire mode
9	-	Rx/+
8	-	Rx/-
7	A/+	Tx/+
6	B/-	Tx/-
5	AGND (isolated ground)	
4	IRIG-B +	
3	IRIG-B -	
2	-	
1	GND (case)	

14.3.7.3 COM0033-COM0034 jumper locations and connections

The optional communication modules include support for optical ST serial communication (X9 connector). The fibre-optic ST connection uses the COM1 port.

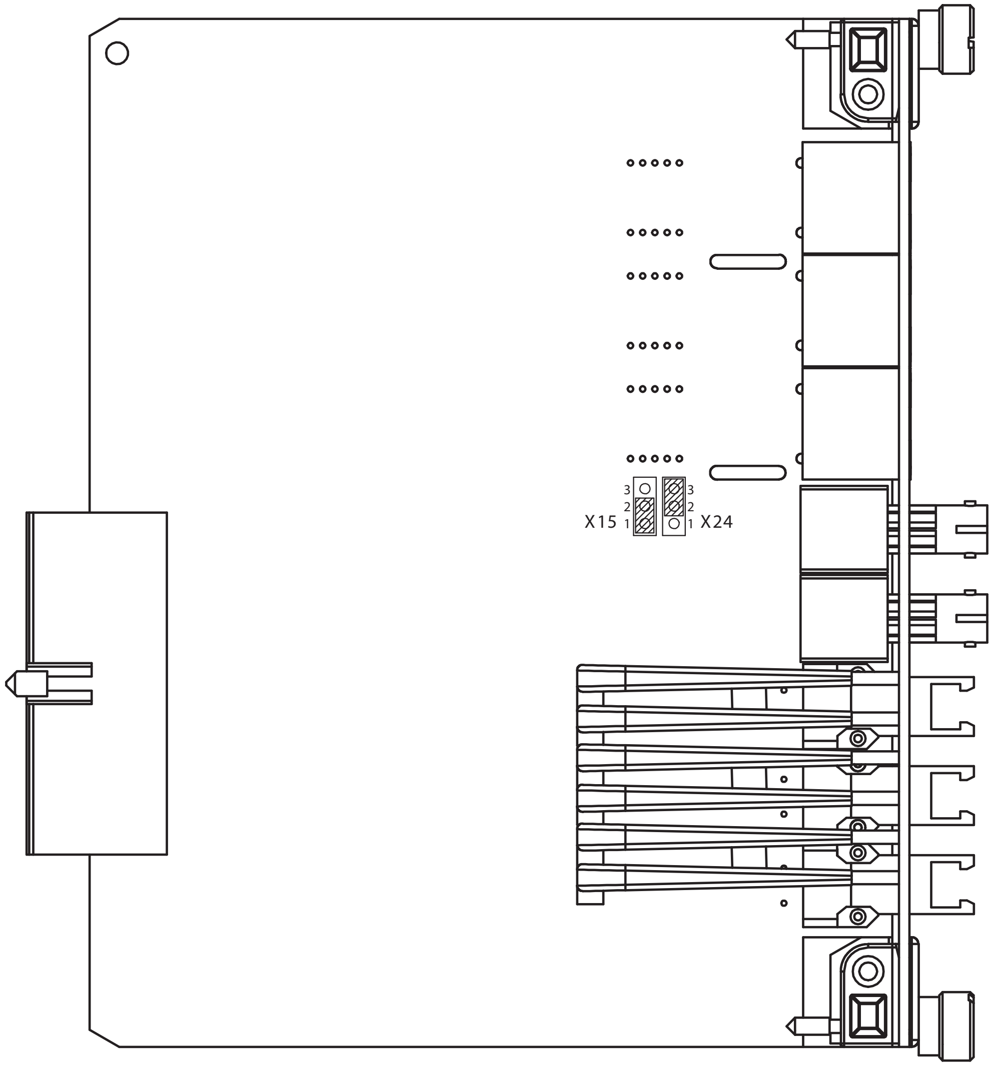


Figure 465: Jumper connections on communication module COM0033

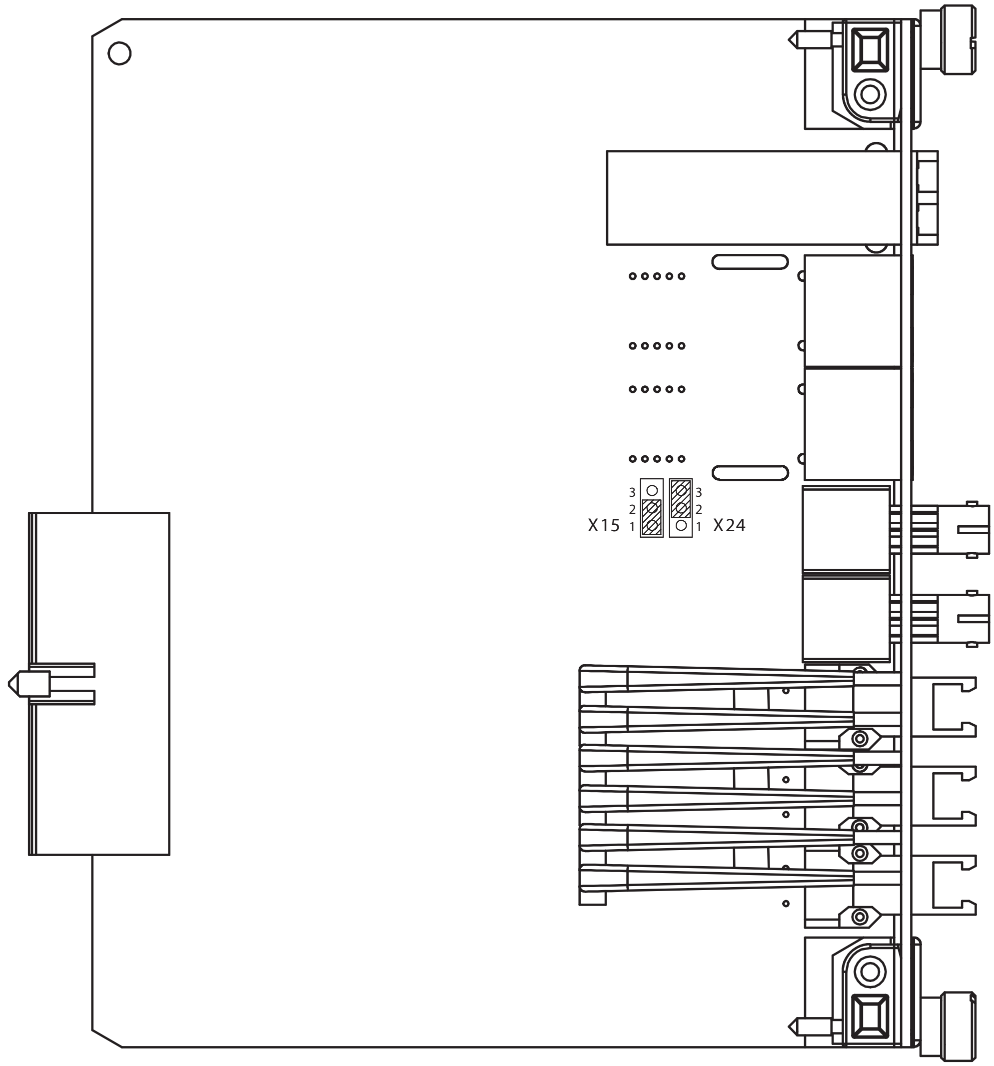


Figure 466: Jumper connections on communication module COM0034

Table 637: X9 Optical ST jumper connectors

Group	Jumper connection	Description
X15	1-2 2-3	Star topology Loop topology
X24	1-2 2-3	Idle state = Light on Idle state = Light off

Section 15 Technical data

Table 638: Dimensions

Description	Value	
Width	Frame	10.32 inches (262.2 mm)
	Case	9.69 inches (246 mm)
Height	Frame	6.97 inches (177 mm), 4U
	Case	6.30 inches (160 mm)
Depth		7.91 inches (201 mm)
Weight	Complete protection relay	max. 12.3 lbs (5.6 kg)
	Plug-in unit only	7.5 lbs (3.4 kg)

Table 639: Power supply

Description	Type 1	Type 2
V_{aux}	100, 110, 120, 220, 240 V AC, 50 and 60 Hz	24, 30, 48, 60 V DC
	48, 60, 110, 125, 220, 250 V DC	
Maximum interruption time in the auxiliary DC voltage without resetting the protection relay	50 ms at V_{aux}rated	
V_{aux} variation	38...110% of V_n (38...264 V AC)	50...120% of V_n (12...72 V DC)
	80...120% of V_n (38.4...300 V DC)	
Start-up threshold		19.2 V DC (24 V DC * 80%)
Burden of auxiliary voltage supply under quiescent (P_q)/ operating condition	DC <15 W (nominal)/ <20 W (max) and AC <17 W (nominal)/ <22 W (max)	DC <15 W (nominal)/ <20 W (max)
Ripple in the DC auxiliary voltage	Max 15% of the DC value (at frequency of 100 Hz)	
Fuse type	T4A/250 V	

Table 640: Energizing inputs

Description		Value	
Rated frequency		50/60 Hz	
Current inputs	Rated current, I_n	0.2/1 A[1)]	1/5 A[2)]
	Thermal withstand capability: • Continuously • For 1 s	 4 A 100 A	 20 A 500 A
	Dynamic current withstand: • Half-wave value	 250 A	 1250 A
	Input impedance	< 100 mΩ	< 20 mΩ
Voltage inputs	Rated voltage, V_n	60...210 V AC	
	Voltage withstand: • Continuous • For 10 s	 240 V AC 360 V AC	
	Burden at rated voltage	< 0.05 VA	

1) Ordering option for ground current input
2) Ground current and/or phase current

Table 641: Binary inputs

Description	Value
Operating range	±20% of the rated voltage
Rated voltage	24...250 V DC
Current drain	1.6...1.9 mA
Power consumption	31.0...570.0 mW
Threshold voltage	18...176 V DC
Reaction time	3 ms

Table 642: RTD/mA inputs

Description		Value	
RTD inputs	Supported RTD sensors	100 Ω platinum 250 Ω platinum 100 Ω nickel 120 Ω nickel 250 Ω nickel 10 Ω copper	TCR 0.00385 (DIN 43760) TCR 0.00385 TCR 0.00618 (DIN 43760) TCR 0.00618 TCR 0.00618 TCR 0.00427
	Supported resistance range	0...2 kΩ	
	Maximum lead resistance (three-wire measurement)	25 Ω per lead	
	Isolation	2 kV (inputs to protective ground)	
	Response time	<4 s	
	RTD/resistance sensing current	Maximum 0.33 mA rms	
	Operation accuracy	Resistance	Temperature
		± 2.0% or ±1 Ω	±1°C 10 Ω copper: ±2°C
mA inputs	Supported current range	0…20 mA	
	Current input impedance	44 Ω ± 0.1%	
	Operation accuracy	±0.5% or ±0.01 mA	

Table 643: Signal output with high make and carry

Description	Value 1)
Rated voltage	250 V AC/DC
Continuous contact carry	5 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R <40 ms	1 A/0.25 A/0.15 A
Minimum contact load	100 mA at 24 V AC/DC

1) X100: SO1
X105: SO1, SO2 when REF620 or RET620 is equipped with BIO0005
X110: SO1, SO2 when any of the protection relays is equipped with BIO0005
X115: SO1, SO2 when REF620 is equipped with BIO0005
X130: SO1, SO2 when REM620 is equipped with BIO0006

Table 644: Signal outputs and IRF output

Description	Value [1)]
Rated voltage	250 V AC/DC
Continuous contact carry	5 A
Make and carry for 3.0 s	10 A
Make and carry 0.5 s	15 A
Breaking capacity when the control-circuit time constant L/R <40 ms, at 48/110/220 V DC	1 A/0.25 A/0.15 A
Minimum contact load	10 mA at 5 V AC/DC

1) X100: IRF, SO2
X105: SO3, SO4, when REF620 or RET620 is equipped with BIO0005
X110: SO3, SO4, when any of the protection relays is equipped with BIO0005
X115: SO3, SO4 when REF620 is equipped with BIO0005
X130: SO3, when REM620 is equipped with BIO0006
X130: SO1, SO2, when RET620 is equipped with RTD0002

Table 645: Double-pole power outputs with TCM function X100: PO3 and PO4

Description	Value [1)]
Rated voltage	250 V AC/DC
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R <40 ms, at 48/110/220 V DC (two contacts connected in a series)	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC
Trip-circuit monitoring (TCM)	
• Control voltage range	20...250 V AC/DC
• Current drain through the monitoring circuit	~1.5 mA
• Minimum voltage over the TCS contact	20 V AC/DC (15...20 V)

1) PSM0003: PO3, PSM0004: PO3, PSM0003: PO4 and PSM0004: PO4.

Table 646: Signal/trip output with high make and carry and with TCM function

Description	Value [1)]
Rated voltage	250 V AC/DC
Continuous contact carry	5 A
Make and carry for 3.0 s	15 A

Table continues on next page

Description	Value [1)]
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R < 40 ms, at 48/110/220 V DC (two contacts connected in series)	1A/0.25A/0.15A
Minimum contact load	100 mA at 24 V AC/DC
Trip-circuit monitoring (TCM):	
• Control voltage range	20...250 V AC/DC
• Current drain through the monitoring circuit	~1.5 mA
• Minimum voltage over the TCS contact	20 V AC/DC (15...20 V)

1) X130: SO3/TO1 of RET620 equipped with RTD0002

Table 647: Single-pole power output relays X100: PO1 and PO2

Description	Value
Rated voltage	250 V AC/DC
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R <40 ms, at 48/110/220 V DC	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC

Table 648: High-speed output HSO

Description	Value [1)]
Rated voltage	250 V AC/DC
Continuous contact carry	6 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R <40 ms, at 48/110/220 V DC	5 A/3 A/1 A
Pickup	1 ms
Dropout	20 ms, resistive load

1) X105: HSO1, HSO2 HSO3, when RET620 is equipped wiht BIO0007
X110: HSO1, HSO2 HSO3, when any of the protection relays is equipped with BIO0007
X115: HSO1, HSO2 HSO3, when REF620 (configurations B and C only) is equipped with BIO0007

Table 649: Ethernet interfaces

Ethernet interface	Protocol	Cable	Data transfer rate
Front	TCP/IP	Standard Ethernet CAT 5 cable with RJ-45 connector	10 MBits/s
Rear	TCP/IP	Shielded twisted pair CAT 5e cable with RJ-45 connector or fibre-optic cable with LC connector	100 MBits/s

Table 650: Serial rear interface

Type	Counter connector
Serial port (X5)	10-pin counter connector Weidmüller BL 3.5/10/180F AU OR BEDR or 9-pin counter connector Weidmüller BL 3.5/9/180F AU OR BEDR[1)]
Serial port (X16)	9-pin D-sub connector DE-9
Serial port (X12)	Optical ST-connector

1) Depending on the optional communication module

Table 651: Fibre-optic communication link

Connector	Fibre type	Wave length	Max. distance	Permitted path attenuation[1)]
LC	MM 62.5/125 µm glass fibre core	1300 nm	2 km	< 8 dB
ST	MM 62.5/125 µm glass fibre core	820-900 nm	1 km	< 11 dB

1) Maximum allowed attenuation caused by connectors and cable together

Table 652: IRIG-B

Description	Value
IRIG time code format	B004,B005[1)]
Isolation	500 V, 1 min.
Modulation	Unmodulated
Logic level	TTL Level
Current consumption	2...4 mA
Power consumption	10...20 mW

1) According to 200-04 IRIG -standard

Table 653: Lens sensor and optical fibre for arc flash detector

Description	Value
Fibre-optic cable including lens	1.5 m, 3.0 m or 5.0 m
Normal service temperature range of the lens	-40...+100°C
Maximum service temperature range of the lens, max. 1 h	+140°C
Minimum permissible bending radius of the connection fibre	3.94 inches (100 mm)

Table 654: Degree of protection of flush-mounted protection relay

Description	Value
Front side	IP 54

Table 655: Environmental conditions

Description	Value
Continuous operating temperature range	-25ºC...+55ºC
Short-term operating temperature range	-40ºC...+85ºC (< 16h)[1)2)]
Relative humidity	< 93%, non-condensing
Atmospheric pressure	12.47...15.37 psi (86...106 kPa)
Altitude	Up to 6561.66 feet (2000 m)
Transport and storage temperature range	-40ºC...+85ºC

1) Degradation in MTBF and LHMI performance outside the temperature range of -25ºC to +55ºC.
2) For protection relays with an LC communication interface, the maximum operating temperature is +70ºC.

Section 16 Protection relay and functionality tests

Table 656: Electromagnetic compatibility tests

Description	Requirement	Reference
1 MHz/100 kHz burst disturbance test, all ports • Differential mode • Common mode	 ±2.5 kV ±2.5 kV	IEC60255-22-1, Class III IEC61000-4-18 IEEE37.90.1-2002
3 MHz/10 MHz/30 MHz burst disturbance test, all ports • Common mode	 ±2.5 kV	IEC61000-4-18, Level 3
Fast transient disturbance test, all ports • Common mode/differential mode	 ±4 kV	IEC60255-22-4, Class A IEC61000-4-4 IEEE37.90.1-2002
Radio frequency interference tests	10 V/m (prior to modulation) f = 80...2700 MHz (sweep and keying test)	IEC60255-22-3 IEC61000-4-3
	20 V/m (prior to modulation) f = 80...1000 MHz (sweep and keying test)	IEEE C37.90.2-2004
Electrostatic discharge test • Contact discharge • Air discharge	 ±8 kV ±15 kV	IEC60255-22-2 IEC61000-4-2, Class 4 IEEE C37.90.3-2001
Surge immunity test • Communication • Other ports	 1 kV, line-to-earth 4 kV, line-to-earth 2 kV, line-to-line	IEC 61000-4-5 IEC 60255-22-5
Power frequency magnetic field	300 A/m, >300 s 1000 A/m, 3 s	IEC 61000-4-8
Voltage dips and short interruptions	30%/10 ms 60%/100 ms 60%/1000 ms >95%/5000 ms	IEC 61000-4-11
Power frequency immunity test, binary inputs	150 V_{rms}, differential mode 300 V_{rms}, common mode	IEC 61000-4-16 IEC 60255-22-7, class A
Table continues on next page		

Description	Requirement	Reference
Emission tests • Conducted • Radiated	 0.15…0.50 MHz • <79 dB (µV) quasi peak • <66 dB (µV) average 0.5…30 MHz • <73 dB (µV) quasi peak • <60 dB (µV) average 30…230 MHz • <40 dB (µV/m) quasi peak, measured at a distance of 10 m 230…1000 MHz • <47 dB (µV/m) quasi peak, measure at a distance of 10 m	IEC 60255-25 EN 55011, class A
Pulse magnetic field immunity test	100 A/m (test level) 6.4 / 16µs (pulse waveform)	IEC 61000-4-9
Damped oscillatory magnetic field immunity test	400 transients/s at 1 MHz (repetition rate) 100 A/m for 2 s	IEC 61000-4-10

Table 657: Mechanical tests

Description	Requirement	Reference
Vibration tests (sinusoidal)	Class 2	IEC 60255-21-1
Shock and bump tests	Class 2	IEC 60255-21-2
Mechanical durability	• 200 withdrawals and insertions of the plug-in unit • 200 adjustments of protection relay setting controls	IEEE C37.90-2005

Table 658: Insulation tests

Description	Requirement	Reference
Dielectric tests	2.8 kV DC, 1 min 700 V, DC, 1 min for signal circuit and communication	IEEE C37.90-2005
	2 kV AC 50 Hz, 1 min 500 V AC 50 Hz, 1 min for communication	IEC 60255-5
Impulse voltage test	5 kV, 1.2/50 μs, 0.5 J	IEEE C37.90-2005
Insulation resistance measurement	>100 MΩ, 500 V_{DC}	IEC 60255-5
Protective bonding resistance	<0.1 Ω, 4 A, 60 s	IEC 60255-27

Table 659: Environmental tests

Description	Requirement	Reference
Damp heat test	+55°C, Rh = 95%, 96 h	IEEE C37.90-2005
	6 test cycles (12 h + 12 h), +25…+55°C, Rh = 95% 1)	IEC 60068-2-30
Dry heat test	+85°C 12h 2)3)4)	IEEE C37.90-2005
	+85°C 16 h 3)4) +55°C 96h	IEC 60068-2-2
Dry cold test	-40°C 12 h 2)3)	IEEE C37.90-2005
	-40°C 16 h 3) -25°C 96 h	IEC 60068-2-1
Storage temperature test	+85°C 96 h, -40°C 96 h	IEEE C37.90-2005 IEC 60068-2-1,-2
Change temperature test	5 test cycles (3 h + 3 h) at -25°C and +55°C 5)	IEC 60068-2-14

1) The auxiliary voltage was disconnected during the first 5 cycles of the test. The auxiliary voltage was switched on during the sixth cycle when the temperature was +55°C and the humidity 95% Rh.
2) Protection relay was soaked unpowered for 12 hours and then checked for functionality.
3) LCD may be unreadable, but the protection relay is still operational.
4) For protection relays with an LC communication interface, the maximum operating temperature is +70°C.
5) Protection relay was energized.

Section 17 Applicable standards and regulations

EMC council directive 2004/108/EC

EU directive 2002/96/EC/175

IEC 60255

IEEE C37.90.1-2002

IEEE C37.90.2-2004

IEEE C37.90.3-2001

IEEE C37.90-2005

Section 18 Glossary

100BASE-FX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses fiber optic cabling
100BASE-TX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses twisted-pair cabling category 5 or higher with RJ-45 connectors
AC	Alternating current
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
ANSI	American National Standards Institute
AR	Autoreclosing
AVR	Automatic voltage regulator
CAT 5	A twisted pair cable type designed for high signal integrity
CAT 5e	An enhanced version of CAT 5 that adds specifications for far end crosstalk
CB	Circuit breaker
CBB	Cycle building block
COMTRADE	Common format for transient data exchange for power systems. Defined by the IEEE Standard.
CPU	Central processing unit
CRC	Cyclical redundancy check
CT	Current transformer
CTS	Clear to send
DAN	Doubly attached node
DC	1. Direct current 2. Disconnector 3. Double command
DFR	Digital fault recorder
DFT	Discrete Fourier transform

DHCP	Dynamic Host Configuration Protocol
DNP3	A distributed network protocol originally developed by Westronic. The DNP3 Users Group has the ownership of the protocol and assumes responsibility for its evolution.
DPC	Double-point control
DSR	Data set ready
DT	Definite time
DTR	Data terminal ready
EEPROM	Electrically erasable programmable read-only memory
EIA-232	Serial communication standard according to Electronics Industries Association
EIA-485	Serial communication standard according to Electronics Industries Association
EMC	Electromagnetic compatibility
Ethernet	A standard for connecting a family of frame-based computer networking technologies into a LAN
FIFO	First in, first out
FLC	Full load current
FPGA	Field-programmable gate array
FTP	File transfer protocol
GND	Ground/earth
GOOSE	Generic Object-Oriented Substation Event
GPS	Global Positioning System
HMI	Human-machine interface
HSR	High-availability seamless redundancy
IDMT	Inverse definite minimum time
IEC	International Electrotechnical Commission
IEC 61850	International standard for substation communication and modeling
IEC 61850-8-1	A communication protocol based on the IEC 61850 standard series
IEEE 1686	Standard for Substation Intelligent Electronic Devices' (IEDs') Cyber Security Capabilities
IP	Internet protocol

IP address	A set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies the location for the TCP/IP protocol.
IRF	1. Internal fault 2. Internal relay fault
IRIG-B	Inter-Range Instrumentation Group's time code format B
LAN	Local area network
LC	Connector type for glass fiber cable
LCD	Liquid crystal display
LED	Light-emitting diode
LHMI	Local human-machine interface
MAC	Media access control
MMS	1. Manufacturing message specification 2. Metering management system
Modbus	A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices.
MV	Medium voltage
OSB	Out of step blocking
PC	1. Personal computer 2. Polycarbonate
PCM600	Protection and Control IED Manager
Peak-to-peak	1. The amplitude of a waveform between its maximum positive value and its maximum negative value 2. A measurement principle where the measurement quantity is made by calculating the average from the positive and negative peak values without including the DC component. The peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.
Peak-to-peak with peak backup	A measurement principle similar to the peak-to-peak mode but with the function picking up on two conditions: the peak-to-peak value is above the set pickup current or the peak value is above two times the set pickup value
PLC	Programmable logic controller

PPS	Pulse per second
PRP	Parallel redundancy protocol
RAM	Random access memory
RCA	Also known as MTA or base angle. Characteristic angle.
RJ-45	Galvanic connector type
RMS	Root-mean-square (value)
ROM	Read-only memory
RSTP	Rapid spanning tree protocol
RTC	Real-time clock
RTD	Resistance temperature detector
RTS	Ready to send
SAN	Single attached node
SBO	Select-before-operate
SCL	XML-based substation description configuration language defined by IEC 61850
Single-line diagram	Simplified notation for representing a three-phase power system. Instead of representing each of three phases with a separate line or terminal, only one conductor is represented.
SMT	Signal Matrix tool in PCM600
SNTP	Simple Network Time Protocol
SOTF	Switch onto fault
ST	Connector type for glass fiber cable
SW	Software
TCM	Trip-circuit monitoring
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Trip-circuit supervision
UDP	User datagram protocol
UL	Underwriters Laboratories
UTC	Coordinated universal time
VDR	Voltage-depended resistor
VT	Voltage transformer

WAN	Wide area network
WHMI	Web human-machine interface

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