Low Impedance Restricted Ground Fault Protection

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SIPROTEC 5 Application

Low Impedance Restricted Ground Fault protection

APN-060, Edition 1

Content

1 Low Impedance Ground Fault Protection

1.1 Introduction

The function 87N in the SIPROTEC 5 devices is a sensitive ground fault differential protection. It is applied as supplementary function to the transformer differential protection providing higher sensitivity for ground faults.

This application note will describe the function with a focus on the setting parameters and the indications and functional measured values. This will be concluded with a sample application.

This application note has an extract of EXCEL sheet "Test_cases_Transfr.xlsx" in Table 1 on page 17. This calculation sheet can be used to apply and check test cases.

1.2 Definition of currents used by 87N (REF)

The basic 87N function is shown below with relevant current measuring points.

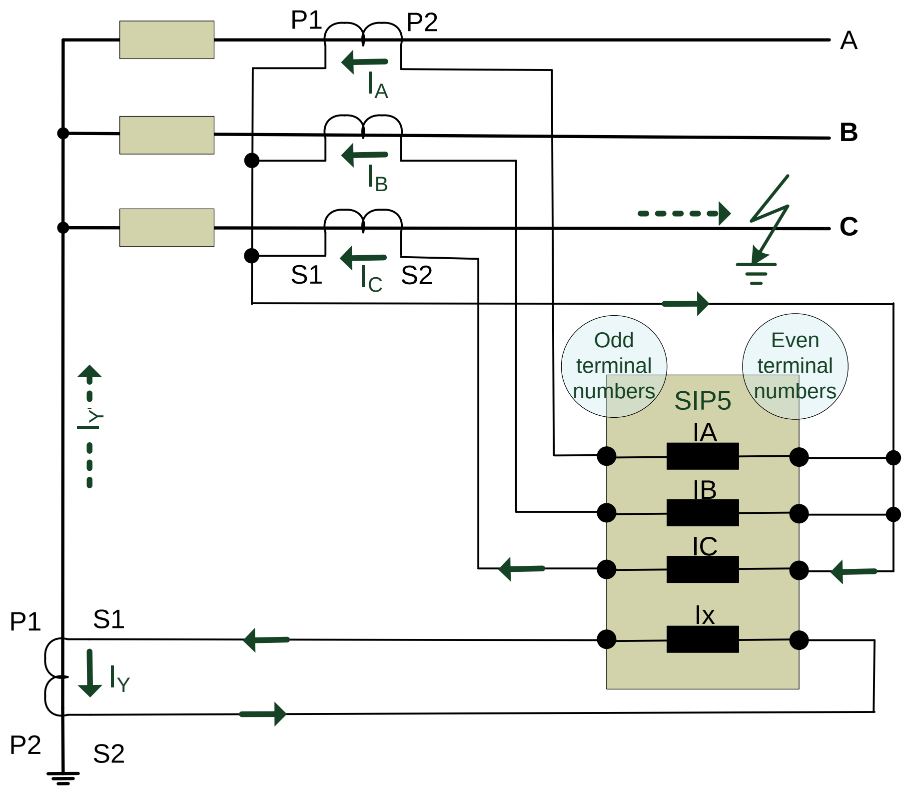

Figure 1: Current evaluated by 87N function

The polarity of the current transformers must be carefully checked and the connection to the relay terminals as well as the "star-point" setting for the measuring points must be consistent. For a 3-phase current measuring point the polarity is set with the "neutral point direction as shown below (consistent with diagram above where neutral point is towards transformer).

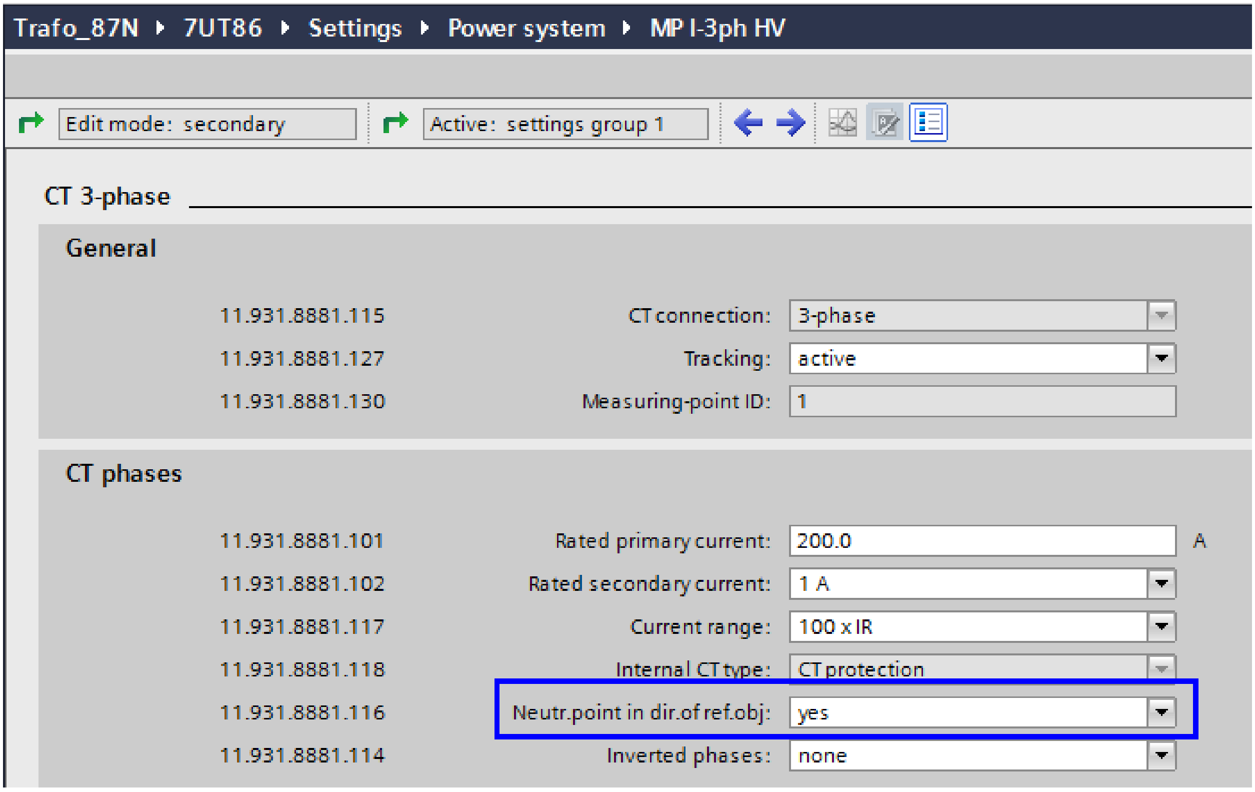

Figure 2: CT Polarity setting for 3 phase CT's on HV side

For the single-phase current measuring point (as in the star-point) there is no "neutral point", in this case the CT polarity is defined by checking which CT terminal is connected to the even/odd terminals of the relay as shown below:

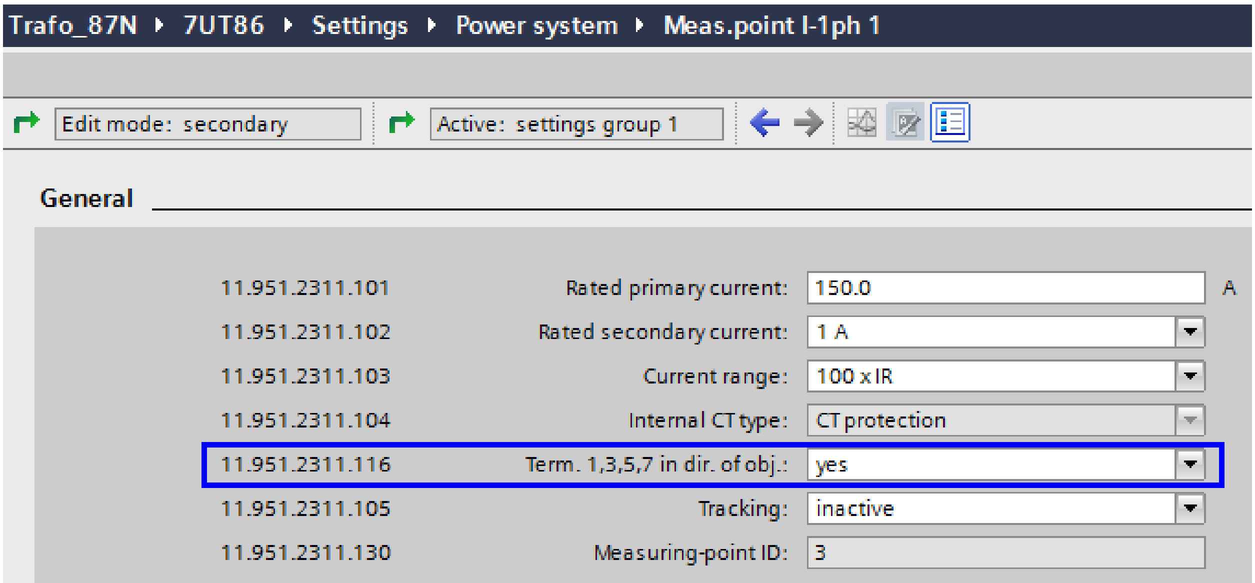

Figure 3: CT Polarity setting for 1-phase CT in star-point

The setting in this case is for the odd terminal number in the direction of the protected object. This is also consistent with Figure 1 where the side of the CT that is towards the transformer is connected to the odd terminal side of the device.

Note: In Figure 1 the phase CT side has the even terminals connected on the transformer side while in the star-point the odd terminal is connected to the transformer side. This is correctly processed if the settings as in Figure 2 and 3 are done accordingly. The neutral point of a 3 phase CT is always on the even terminal side.

1.3 Application of 87N REF Function

In SIPROTEC 5 all protection functions are applied in Function Groups. The 87N can be applied to the side of a transformer (FG Transformer side). In this case there must be neutral point, with current measurement, allocated to the transformer side. If the 87N is applied in a FG Voltage/current 3ph, then a further FG Voltage/current 1ph must be configured for the star-point current which is then allocated as neutral point current to the FG VI 3ph:

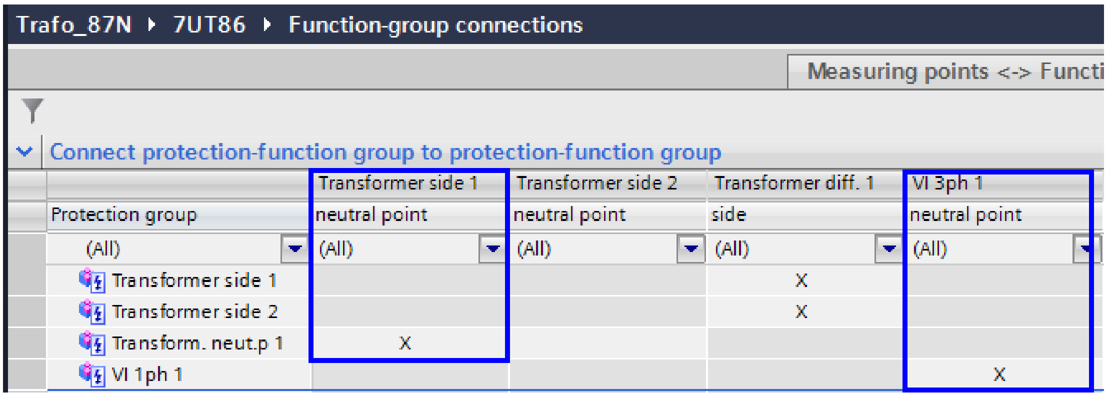

Figure 4: Example Transformer side with Neutral Point and alternative VI 3ph with VI 1ph for neutral point

For the remainder of this application note the 87N applied to the Transformer side is used.

1.4 Definition of 87N measurement values

The 87N is comparing current from 2 measuring points, the transformer terminal side (3 phase measurement) and the neutral point side (single phase measurement). These 2 measurements must be referenced to each other. For this purpose, the 87N protection function will normalize its measured values by referencing them to the rated current of the protected object. It is therefore important to know how this rated object current is defined. As described above the 87N is applied to a Function Group, and in the FG the rated primary current is specified. In the case of a FG Transformer side the rated current is derived from the rated voltage and rated apparent power:

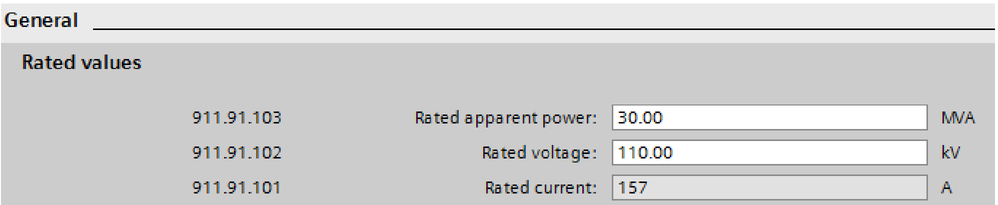

Figure 5: Rated object current derived from rated power and rated voltage in a FG Transformer side

In The case of a FG VI 3ph, the rated current is set directly via parameter.

Terminal side current

On the terminal side of the transformer the 3 currents: IA, IB and IC are measured. In the application note these currents will be referred to as IAterm, IBterm and ICterm respectively. For the 87N the corresponding zero sequence current is calculated as follows:

$$\underline{3I0_{term}} = \underline{IA_{term}} + \underline{IB_{term}} + \underline{IC_{term}}$$

To distinguish between the measured current in amps and the normalized current in per unit of rated object current the following designation is introduced assuming secondary measured values (example shown for IAterm, the same applies to the other currents in the same manner):

$$\underline{IA'_{term}} = \underline{IA_{term}} \cdot k_{m\_term} \quad \text{where} \quad k_{m\_term} = \frac{CTR_{term}}{I_{rated\ object}}$$

Note: If the above currents are primary, then the CT ratio (CTR) is replaced by the value 1.

Neutral point current

On the neutral point side of the transformer the single current IY is measured. In the application note this current will be referred to as IY. Also, for this current the above convention is applied for the per unit current:

$$\underline{IY'} = \underline{IY} \cdot k_{m\_Y} \qquad \text{where} \quad k_{m\_Y} = \frac{CTR_Y}{I_{rated\ object}}$$

Note: If the above currents are primary, then the CT ratio (CTR) is replaced by the value 1.

87N Function currents

For the 87N function the currents defined on the terminal side and in the star-point are further processed to obtain Function Measured values:

87N differential current: I'$_{DIFF}$

This current is obtained as follows from values defined above, and is therefore only available as per unit value:

$$I'_{diff} = \left|\underline{3I0'_{term}} + \underline{IY'}\right|$$

87N restraint current: I$_{Rest}$

This current is obtained as follows from values defined above, and is therefore only available as per unit value:

$$I'_{Rest} = \left|\underline{IA'_{term}}\right| + \left|\underline{IB'_{term}}\right| + \left|\underline{IC'_{term}}\right| + \left|\underline{IY'}\right|$$

The restraint current is applied to the following characteristic to increase the pick-up threshold during external faults with large fault current magnitude.

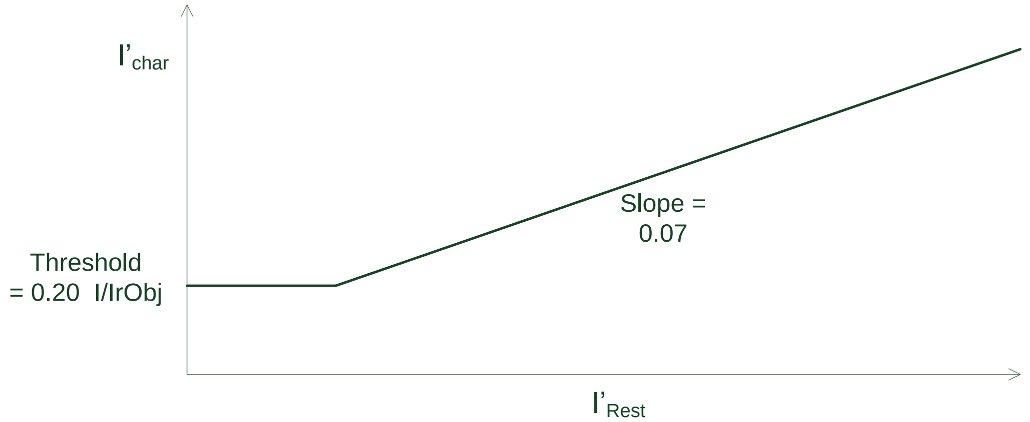

Figure 6: Curve used to obtain current that is applied in operating *characteristic I'$_{char}$*

Based on the applied setting for Threshold and Slope, the value of I'char is obtained as shown in Figure 6 above.

87N restraint current corresponding to angle difference: I$_{Angle}$

This current is obtained as follows from values defined above, and is therefore only available as per unit value:

$$I_{Angle} = \left|\underline{3I0'_{term}} - \underline{IY'}\right| - \left|\underline{3I0'_{term}} + \underline{IY'}\right|$$

When the angle difference between $\underline{3I0'_{term}}$ and $\underline{IY'}$ is less than 90° the value of I_{Angle} will be negative. When the angle difference is greater than 90° it is positive. The boundary between positive and negative I_{Angle} defines the basic boundary between internal and external faults.

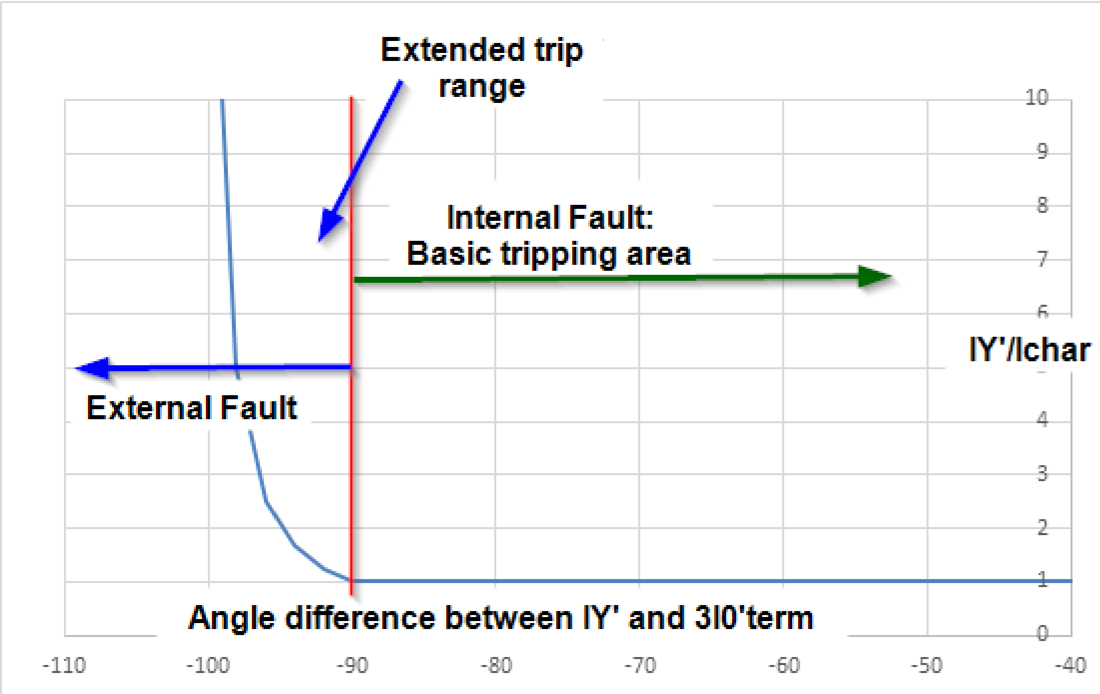

Figure 7: Operating characteristic [ignore the "-"sign on angle axis; used to obtain curve as in manual]

In the above characteristic the 87N operate is activated when above (right side) of curve. The "-" sign on the horizontal axis for the angle difference can be ignored as the curve applies to both positive and negative angle difference. The operate characteristic is defined by two basic areas:

Basic Tripping Area: This is the range where the angle difference between $\underline{3I0'_{term}}$ and $\underline{IY'}$ is less than 90°. In this range I'_{Angle} is negative and the pick-up threshold for $|\underline{IY'}|$ corresponds to I'char.

Extended Trip Range: This is the range where the angle difference between $\underline{3I0'_{term}}$ and $\underline{IY'}$ is above 90°. In this range I_{Angle} is positive and the pick-up threshold for $|\underline{IY'}|$ corresponds to $(4.05657 \cdot I'_{Angle} + 1) \cdot I'_{char}$. The factor k=4.05657 is obtained by defining the angle boundary for operate (Figure 8) to be 100° when the magnitude of IY' and 3I0' are equal.

The purpose of the extended trip range is to not prevent an 87N operate with internal faults when the contribution from $3I0'_{term}$ is very small (effectively zero). The following graph shows that when the ratio of IY' to $3I0'_{term}$ is above approx. 8.2 operate by 87N is possible at any angle difference.

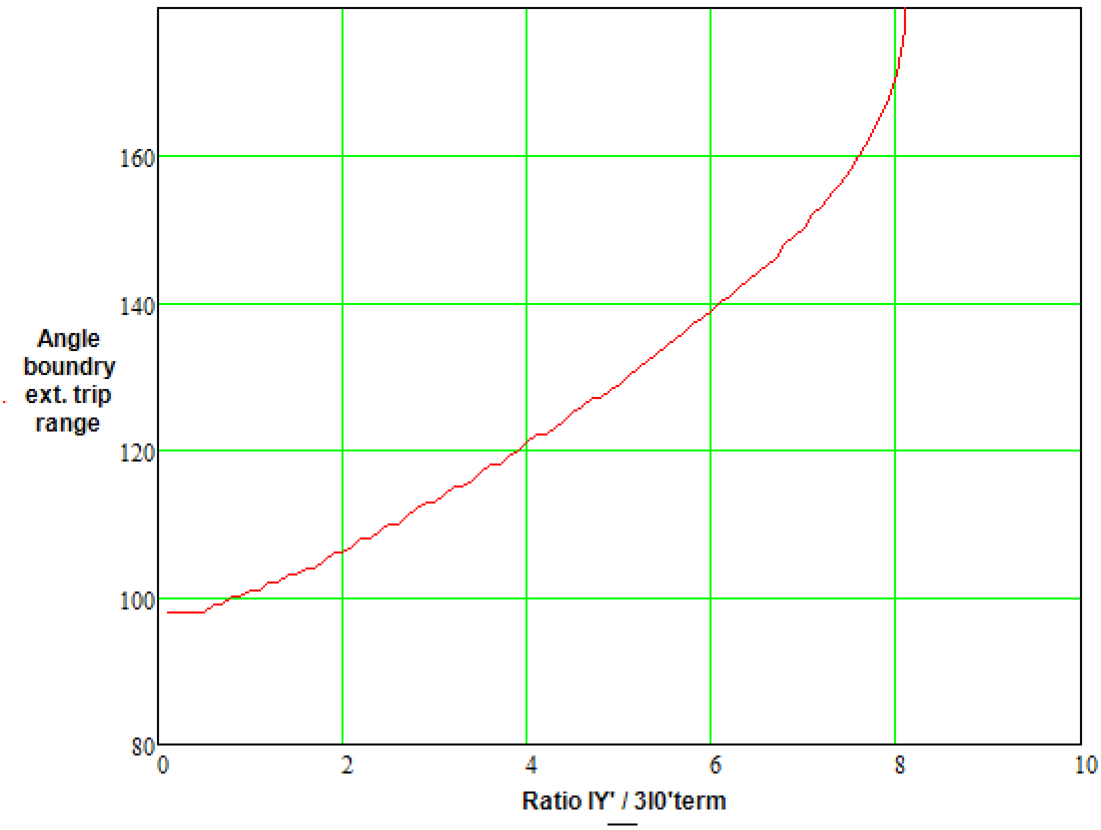

Figure 8: Angle boundary of extended trip range depending on ratio IY'/3I0'$_{term}$

Note that during external fault the ratio of IY'/3I0'$_{term}$ is approximately equal to one. That means that the boundary angle difference for external faults is 100° (corresponds to an angle deviation of 80° as the external fault should have an angle difference of 180°).

87N operate current: $I_{REF\text{-}operate}$

This current would be negative during "normal" external faults, but it is assigned the value zero in this case. Only positive values are indicated. It is calculated as follows, but defined as zero when the result is negative:

When $I'_{Angle} > 0$ then $I_{op} = \underline{IY'} - k \cdot I'_{Angle}$ with k= 4.05657

When $I'_{Angle} \leq 0$ then $I_{op} = |\underline{IY'}|$

It is an indication of how far above the operate threshold the star-point current is.

1.5 Application HV side

The diagram below shows the single line circuit for the application with REF on the HV side of the transformer with relevant parameters.

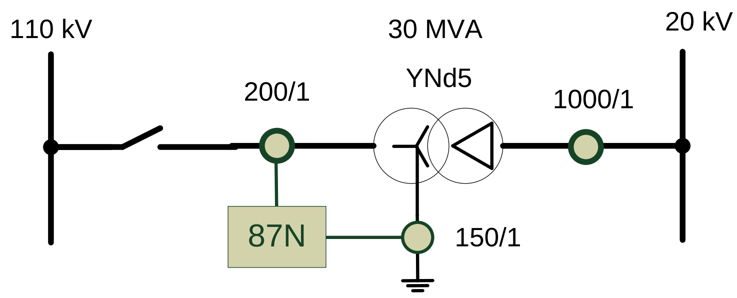

Figure 9: Single line equivalent circuit

The relay used in this application note is a 7UT86. Only the steps for 87N are presented although many of these also apply to other functions (e.g. Measuring point routing). Based on a "Two-winding transformer (87T, 50BF, 87N)" template the following configuration steps are required:

Measuring Point routing

The HV side and star-point current transformers must be applied:

Current-measuring points

		Base module								
		1A				1B				3
		1A1-1A2	1A3-1A4	1A5-1A6	1A7-1A8	1B1-1B2	1B3-1B4	1B5-1B6	1B7-1B8	3A
Measuring point	Connection type	I P 1A1	I P 1A2	I P 1A3	I P 1A4	I P 1B1	I P 1B2	I P 1B3	I P 1B4	I P
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(A
MP I-3ph HV	3-phase	I A	I B	I C						
Meas.point I-3ph 2	3-phase + IN					I A	I B	I C	IN	
MP I-1ph trf-Y					Ix					
Add new										

Figure 10: Current transformer in Measuring Point Routing

Here the HV side CT measuring point is renamed to "MP I-3ph HV" and the str-point CT is renamed "MP I-1ph trf-Y".

Function-group connections

In this section there are several important configuration steps that may make the configuration inconsistent if not applied correctly:

Measuring points <-> Function g...

Connect measuring points to function group

	Transformer side 1	Transformer side 2	Transform. neut.p 1	Circuit breaker 1	Circuit breaker 2	VI 3ph 1
Measuring point	I 3ph	I 3ph	I 1ph	I 3ph	I 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP I-3ph HV[ID 1]	X			X		X
Meas.point I-3ph 2[ID 2]		X			X	
MP I-1ph trf-Y[ID 3]			X			

Figure 11: Assign Measuring points to functions

The Side 1 is the HV side in this application, so assign the corresponding CT measuring point. In a similar manner proceed for the other function groups. Note the star-point measuring point must be assigned to the "Transform. Neut.p1". If a Transformer Neutral Point does not appear in FG selection, then it must be applied from the Library.

Connect function group to circuit-breaker groups

Protection group	Circuit breaker 1	Circuit breaker 2
(All)	(All)	(All)
Transformer side 1	X	X
Transformer side 2		X
Transformer diff. 1	X	X
Transform. neut.p 1	X	X
VI 3ph 1	X	
VI 1ph 1	X	

Figure 12: Assigne Circuit Breakers to Function Groups

The assignment of circuit breakers to function groups is required for the routing of the operate signals as well as for status feedback to the Process Monitor in some Function Groups.

Connect protection-function group to protection-function group

	Transformer side 1	Transformer side 2	Transformer diff. 1	VI 3ph 1
Protection group	neutral point	neutral point	side	neutral point
(All)	(All)	(All)	(All)	(All)
Transformer side 1			X	
Transformer side 2			X	
Transform. neut.p 1	X			
VI 1ph 1				X

Figure 13: Interconnection of Function Groups

In this application it is essential to correctly assign the Transformer neutral point to the HV side (Side 1).

Settings – Power system

In the settings only those with direct relevance to the 87N are covered. The ratio and polarity of the current transformers must be applied correctly:

CT phases

11.931.8881.101	Rated primary current:	200.0	A
11.931.8881.102	Rated secondary current:	1 A	
11.931.8881.117	Current range:	100 x IR	
11.931.8881.118	Internal CT type:	CT protection	
11.931.8881.116	Neutr.point in dir.of ref.obj:	yes	
11.931.8881.114	Inverted phases:	none	

Figure 14: HV side CT settings

On the HV side the CT ratio (200/1) must be set and the polarity checked as described in Figure 2 to match the application.

11.951.2311.101	Rated primary current:	150.0	A
11.951.2311.102	Rated secondary current:	1 A	
11.951.2311.103	Current range:	100 x IR	
11.951.2311.104	Internal CT type:	CT protection	
11.951.2311.116	Term. 1,3,5,7 in dir. of obj.:	yes	
11.951.2311.105	Tracking:	inactive	
11.951.2311.130	Measuring-point ID:	3	

Figure 15: Neutral point CT settings

In the star-point the CT ratio (150/1) must be set and the polarity checked as described in Figure 3 to match the application.

Settings – Transformer side 1

For the 87N the following settings in this section apply:

General

Rated values

911.91.103	Rated apparent power:	30.00	MVA
911.91.102	Rated voltage:	110.00	kV
911.91.101	Rated current:	157	A

Figure 16: General settings on Transformer side 1

In the general setting the Rated apparent power and the Rated voltage will be used to calculate the Rated object current.

The default settings for the REF function are shown in the screenshot below:

87N REF 1

911.10081.1	Mode:	on	
911.10081.2	Operate & flt.rec. blocked:	no	
911.10081.103	Threshold:	0.20	I/IrObj
911.10081.105	Slope:	0.07	
911.10081.109	Operate delay:	0.00	s

Figure 17: Screenshot of REF default settings

The setting of “Mode” and “Operate & flt.rec. blocked” are obvious and not further discussed here. The “Threshold” is set relative to the rated object current:

$$IrObj = \frac{Rated\_MVA}{\sqrt{3}\cdot Rated\_Vph\_ph} \qquad IrObj = \frac{30\ MVA}{\sqrt{3}\cdot 110\ kV} = 157A$$

Settings – Transformer side 1

The permissible setting range for the parameter is automatically determined by DIGSI as follows:

Lower limit: threshold ≥ max {0.05 I/IrObj. ; 0.05 I/ IrObj * ICTmax / IrObj }

Lower limit: threshold ≥ 0.05 I/ IrObj * 200A / 157A = 0.07 I/ IrObj

Upper limit: threshold ≤ min {2.00 I/ IrObj ; 100 I/ IrObj * ICTmax / IrObj }

min {2.00 I/Irated obj. ; 100 I/ IrObj * 200A / 157A } = 2 I/ IrObj

This can be checked in DIGSI:

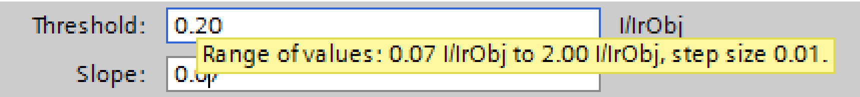

Figure 18: Screenshot of REF default settings

The default setting therefore translates to:

$$Threshold = 0.2 \cdot IrObj = 0.2 \cdot 157A = 31.4A\ primary = 0.157\ A\ secondary$$

This is adequate for this application with solid grounded neutral point as the current in the star-point CT already assumes a significant magnitude for faults close to the star-point.

The slope setting is required to stabilize the function during external Ph-Ph-G and 3ph-G faults. In order to not reduce the sensitivity when rated current is flowing on the HV side the slope setting is determined as follows:

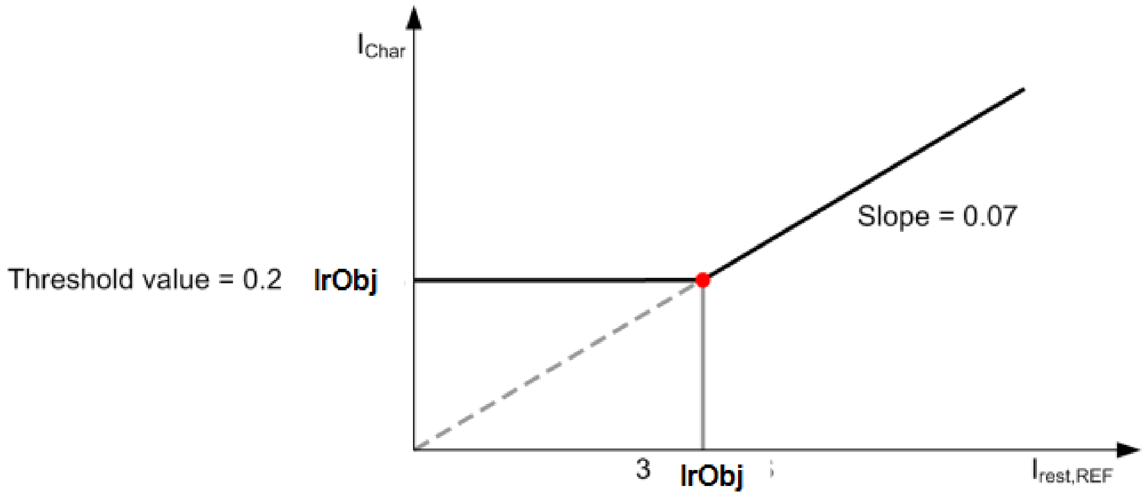

Figure 19: Curve for increased pick-up threshold with large phase current

Restraint current at rated current: $I'_{Rest\_op} = \left|\underline{IA'_{term}}\right| + \left|\underline{IB'_{term}}\right| + \left|\underline{IC'_{term}}\right| = 3 \cdot IrObj$

$$Slope = \frac{Threshold}{I'_{Rest\_op}} = \frac{0.2 \cdot IrObj}{3 \cdot IrObj} = 0.07$$

The slope setting is applied as calculated and will not affect the sensitivity when the transformer operates at or below rated power.

	Circuit breaker 1		Circuit breaker 2	
	Trip logic	50BF Ad.CBF 1	Trip logic	50BF Ad.CBF 1
Protection group	Trip	Start CB failure	Trip	Start CB failure
(All)	(All)	(All)	(All)	(All)
87N REF 1	X	X	X	X
49 Th.overl.-A 1	X	X	X	X

Figure 20: Circuit-breaker interaction on HV side

In the Circuit-breaker interaction the 87N is selected to trip both the HV and the LV circuit breaker. That concludes the settings of the 87N. The Routing Matrix etc. is not covered here.

1.6 Example to illustrate 87N Measured Values with injection

The external fault condition as in Figure 1 is injected and the recorded currents in the device are checked:

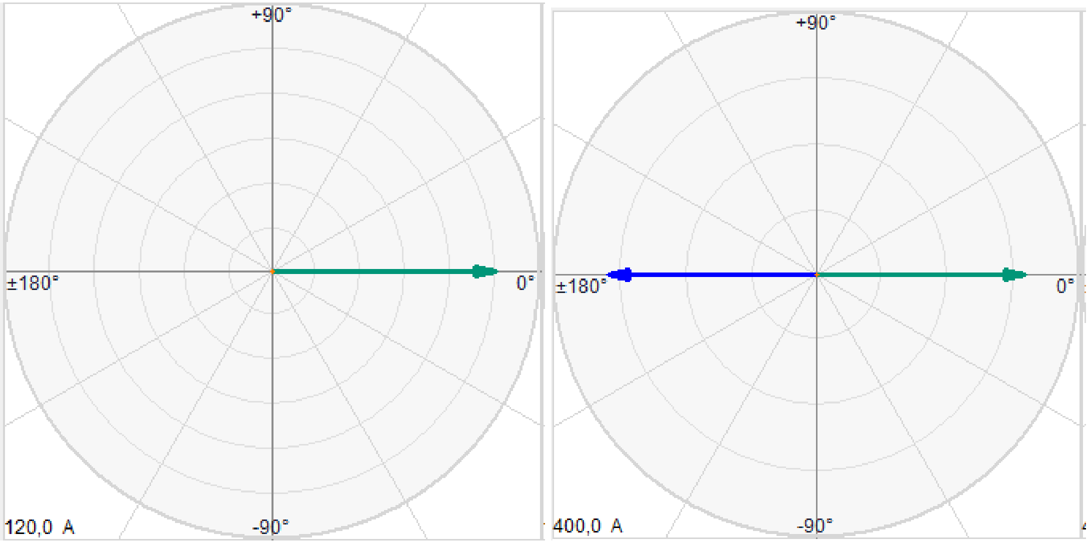

Figure 21: HV current on Left side (100 A) in phase C, LV current on right side (317 A) in B and C phase

The following Table shows the values measured after the test values:

Measuring Signal	Fundamental / Sub-Harm.	Phase
K1:MP I-3ph HV:I A	0,00000 A	0,0°
K1:MP I-3ph HV:I B	0,00000 A	0,0°
K1:MP I-3ph HV:I C	499,94 mA	83,7°
K1:MP I-1ph trf-Y:Ix	666,92 mA	83,7°
PTS1:87N 1:I REF-operate:	0,00000 I/IrObj	
PTS1:87N 1:I Angle-REF:	1,2703 I/IrObj	
PTS1:87N 1:I diff.:	0,00032 I/IrObj	
PTS1:87N 1:I restr.:	1,2706 I/IrObj	

Figure 22: 87N recorded values during external CG fault

For comparison the values during internal BG fault:

Measuring Signal	Fundamental / Sub-Harm.	Phase
K1:MP I-3ph HV:I A	0,00000 A	-127,2°
K1:MP I-3ph HV:I B	499,94 mA	0,0°
K1:MP I-3ph HV:I C	0,01171 µA	68,6°
K1:MP I-1ph trf-Y:Ix	666,92 mA	-180,0°
PTS1:87N REF 1:I REF-operate:	0,6355 I/IrObj	
PTS1:87N REF 1:I Angle-REF:	-1,2703 I/IrObj	
PTS1:87N REF 1:I diff.:	1,2706 I/IrObj	
PTS1:87N REF 1:I restr.:	1,2706 I/IrObj	

Figure 23: 87N recorded values during internal BG fault

The above and further test conditions are shown in the table below. In addition, the 87N functional measured values are calculated with the equations given in the description above. This allows a comparison of the calculated and measured value:

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
			Polarity													
CTR HV	200		yes	0	Sec inject is positive with return on even side											
CTR LV	1000		yes	0	Sec inject is positive with return on even side											
CTR Y	150		yes	-1	Sec inject is positive with return on odd side											
I object	157	A														
slope	0,07															
Thresh	0,2	I/I object														
									Measured I/IrObj				Calculated I/IrObj			
	IA		IB		IC		IY		87N	87N	87N	87N	87N	87N	87N	87N
Case	Mag	Ang	Mag	Ang	Mag	Ang	Mag	Ang	Op	Ang	Diff	Rest	Op	Ang	Diff	Rest
Ext. CG	0	0	0	0	0,5	83,7	0,667	83,7	0	1,27	0	1,27	0,0000	1,2739	0,0003	1,2742
Int BG	0	-127,2	0,5	0	0	68,6	0,667	-180	0,6355	-1,2703	1,2706	1,2706	0,6373	-1,2739	1,2742	1,2742
bound. 90°	0	0	0,5	-124,8	0	-99	0,667	-34,8	0,6354	0	0,8985	1,2706	0,6373	0,0000	0,9010	1,2742
bound. 90°	0	124,8	0,2	0	0	-154,3	0,267	90	0,2544	0	0,3595	0,5084	0,2551	0,0000	0,3605	0,5099
bound. 90°	0	-176,7	0,1	0	0	50,9	0,133	90	0,1267	0	0,1794	0,2537	0,1271	0,0000	0,1799	0,2545
													0,0000	0,0000	0,0000	0,0000
													0,0000	0,0000	0,0000	0,0000

Table 1: Test values and results

The Excel sheet as Appendix 1 is available with the Application note on request.

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