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SIPROTEC 5 Compact

Low Impedance Restricted Ground Fault Protection

APN-C.015

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SIPROTEC 5 Compact Application

Low Impedance Restricted Ground Fault Protection

APN-C.015, Edition 1

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1 Low Impedance Restricted Ground Fault Protection

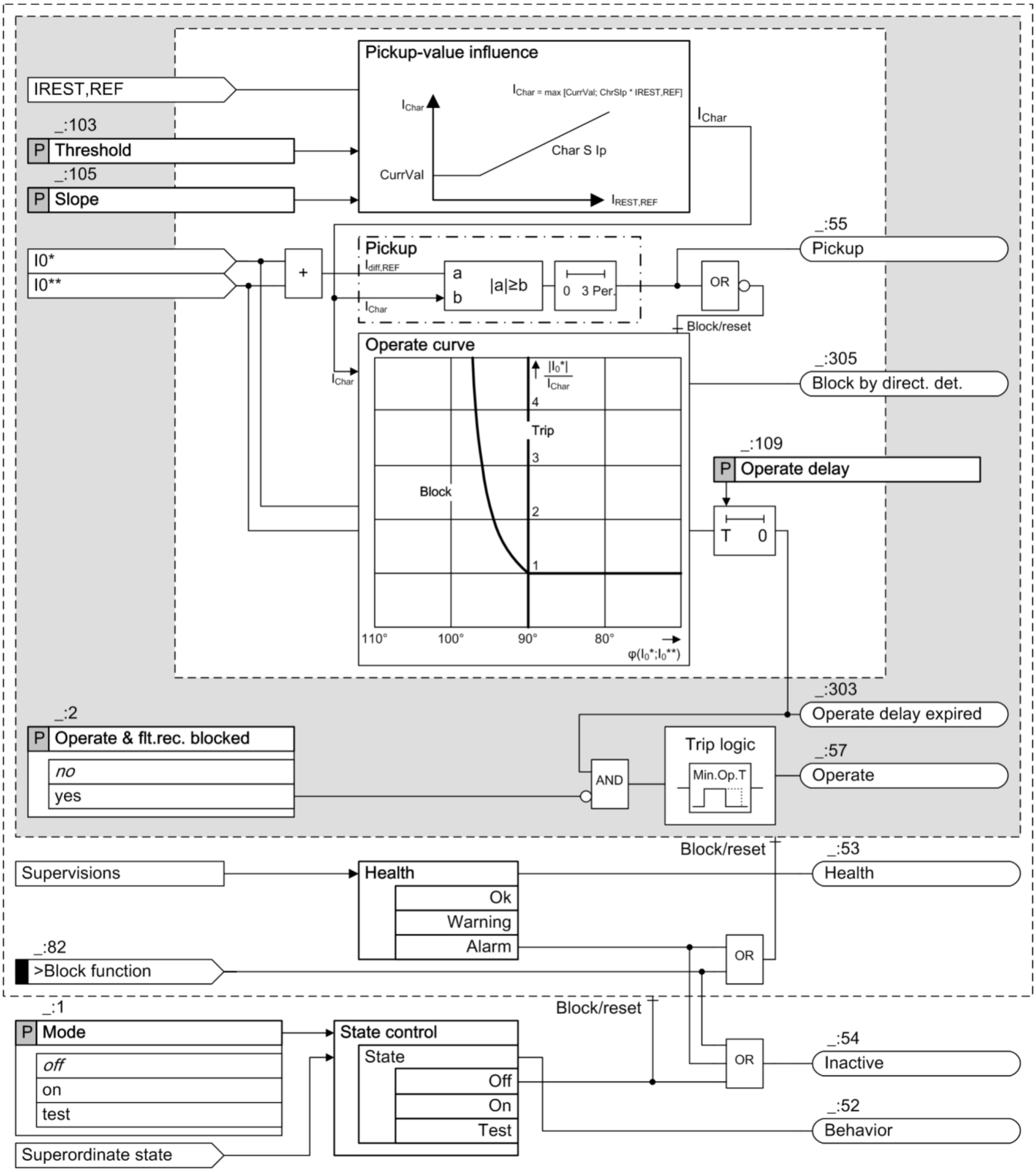
1.1 Introduction

The Restricted ground-fault protection function (ANSI 87N) detects ground faults in transformers, shunt reactors, neutral reactors or rotating machinery in which the neutral point is grounded. It has high sensitivity to ground faults near the neutral point.

This application note describes the mode of operation of this function including setting parameters and the related engineering and parameterization of the SIPROTEC 5 Compact Protection Relay 7SX800.

1.2 Function Description

Logic of the Function



Fugure 1 Logic Diagram of the Restricted Ground-Fault Protection Function

The protection function processes the neutral-point current I_0* (exactly $3I_0$) and the calculated zero-sequence current I_0** (exactly $3I_0$) from the phase currents (see following figure). The protection range extends exclusively over the transformer winding, including current transformer. The amount-adapted (compensated) currents are described by the * symbol. They are normalized to the rated object current of the respective side.

In case of an internal ground fault, the residual currents flow to the fault location. With an external ground fault, the fault current inverts itself in the phase current transformers. In this way, the direction of current flow serves as the decisive criterion for an internal fault.

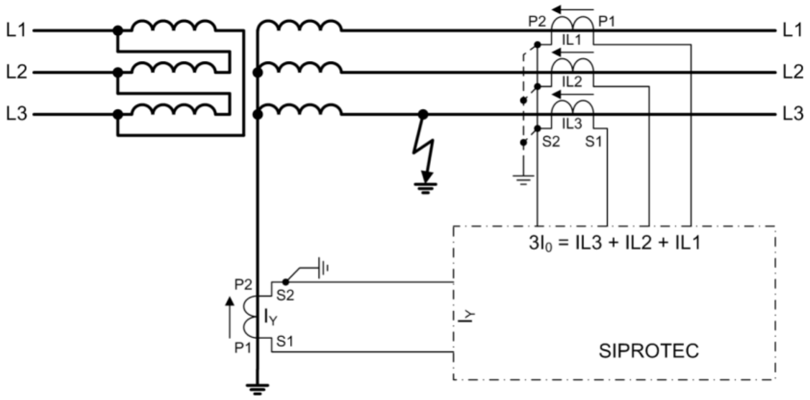


Figure 2 Basic Principle of the Function

In accordance with the logic diagram Figure 1 the protection function operates in 3 steps:

- Affect on the pickup value:
  Increasing the set pickup threshold using the restraint current. This prevents overfunction in case of high- current external ground faults.
- Pickup:
  If the calculated current $I_{Diff,REF}$ exceeds the adapted pickup threshold, pickup starts.
- Operate curve based on phase-angle difference:
  To differentiate between internal and external faults, the angle difference between the neutral-point current (I_y*) and the calculated zero-sequence current (3I0*) is taken into consideration in the operate curve. Effect of Pickup Value The restraint current ($I_{Rest,REF}$) is calculated from the measured currents. The reference arrows are defined as positive when pointing to the protected object (see Figure 2). Consider that the neutral-point current (IY) detected using the 1-phase measuring point is displayed as positive in the fault record and in the DIGSI 5 Test Suite if the current flows from the protected object to ground.

NOTE

The following calculation applies to the configurations with one current measuring point for the side. In a special case of 2 current measuring points per side, the calculation of the restraint current must be performed in greater detail.

$I_Y^* = k_{yx} \cdot 3Iy$
$3I_0^* = k_{sx} \cdot (I_{L1} + I_{L2} + IL\#)$
with
$k_{yx} = I_{N,transformerY}/I_{N,side}$ with the measured secondary current in the neutral point (Y)
$k_{sx} = I_{N,transformerS}/I_{N,side}$ with the measured secondary current on the transformer side (S)

$I_{Diff,REF} = |I_Y^* + 3I_0^*|$
$I_{Rest,REF} = |I_Y^*| + |I_A^*| + |I_B^*| + |I_C^*|$, all currents normalized to the rated object current
where:

I_Y	Measured zero-sequence current at neutral point
k_{yx}	Factor for magnitude adaptation (neutral point)
k_{sx}	Factor for magnitude adaptation (side)
$I_{N,transformer}$	Primary transformer rated current

$I_{N,side}$	Primary rated current of the transformer side (rated object current)
$I_{Diff,REF}$	Differential current
$I_{Rest,REF}$	Restraint current

Using the calculated restraint current, a current IChar which represents the pickup value for the tripping is determined from the characteristic curve (Figure 3. In this way, the protection function is stabilized in the event of external, multiphase ground faults, for example, a 2-pole ground fault. This means that the protection function becomes less sensitive.
If the Slope = 0 is set here (as an exception), the set Threshold of the operate curve is delivered independent of the restraint current.

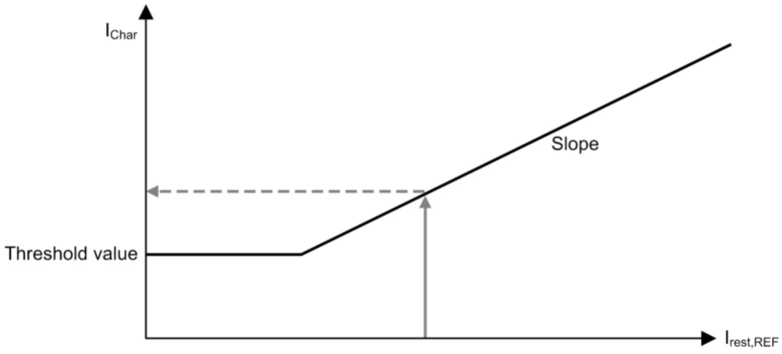


Figure 3 Stabilized Characteristic Curve

The ratio between the neutral-point current and the value for the current IChar determined from Figure 3 is observed in the operate curve.

$$I_{op\_charact.} = \frac{|I_Y{}^*|}{I_{Char}}$$

Pickup

If the $I_{Diff,REF}$ calculated differential current exceeds the calculated current I_{Char} (see Figure 3), pickup occurs and the internal processing is enabled. The pickup is indicated.

Operate Curve Based on Phase-Angle Difference

The operate curve represented in the following figure consists of 2 parts. In the right part of the characteristic curve (angle magnitude ≤ 90°), you will find the case of an internal ground fault. Under ideal conditions, the angle between the evaluated currents ($\angle(I_Y{}^*, 3I_0{}^*)$) equals 0 in the event of an internal fault. In the right section of the characteristic curve (internal fault), the trip threshold for the current $I_{op\_charact.}$ is >1. If the measured current on the transformer side yields only a very small $3I_0{}^*$ amount, it does not make sense to determine the angle difference. If, in the event of an internal fault, a small $3I_0{}^*$ current simulates an angle error because of a measuring error, the extended operate range allows reliable tripping with an angle difference of >90°.

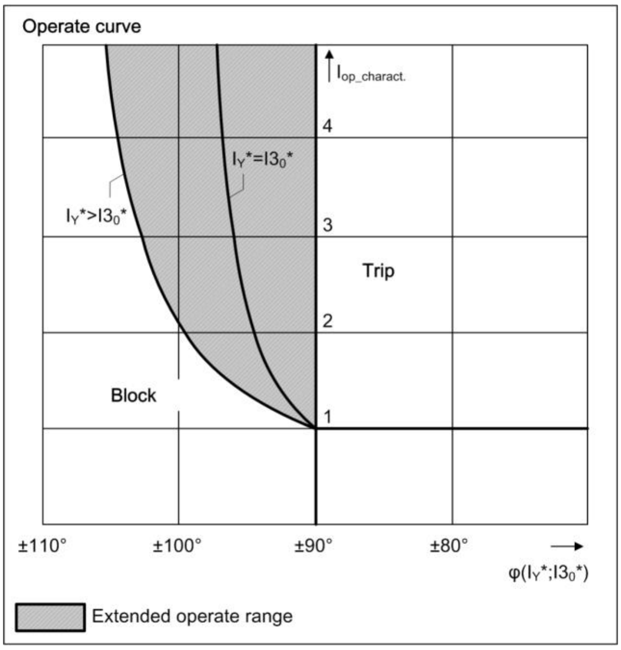


Figure 4 Operate Curve Depending on the Phase Angle

NOTE

The characteristic curve shown in Figure 6-289 shows the limit of the tripping range with the angle criterion. The extended operate range is shown symbolically for 2 conditions:

HINWEIS

Die in Figure 4 dargestellte Kennlinie stellt die Abgrenzung des Auslösebereichs mit Winkelkriterium dar.
Der erweiterte Auslösebereich ist symbolisch für 2 Bedingungen dargestellt:

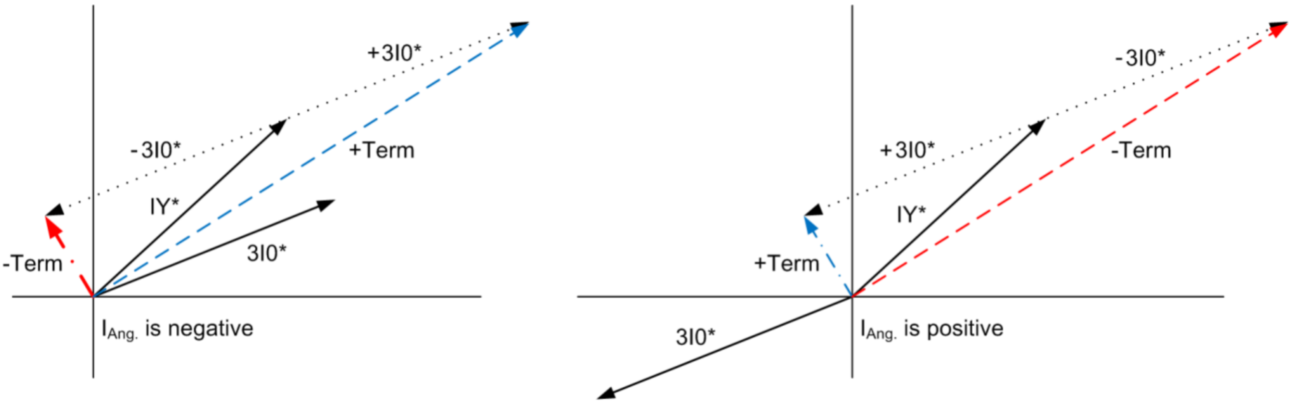
- Condition 1: $|I_Y^*| = |3I_0^*|$
- Condition 2: $|I_Y^*| = 3 \cdot |3I_0^*|$

For these conditions, the characteristic curve with $|I_Y^*| = |3I_0^*|$ represents the angle limit of the extended operate range: For an external fault with $|I_Y^*| = |3I_0^*|$, the phase angle between I_Y^* and $3I_0^*$ is ≈ 180° If a measuring error changes the angle now and this angle error is <80°, unwanted tripping does not occur. In Figure 4, that is the section to the left of 100°. If, for example, the ratio is $|I_Y^*| >> |3I_0^*|$, tripping is theoretically not possible for an angle difference of 180°. This is the case if no fault current is flowing on the transformer side and the current $3I_0^*$ results from a measuring error. With the extended operate range, internal faults are cleared in a secured way.

In case of an external ground fault, the zero-sequence current calculated from the phase currents reverses by 180°. The phase angle between the zero-sequence currents thus ($\angle(I_Y^*, 3I_0^*)$) equals ± 180°. They are located in the left part of the operate curve and recognize a clearly increased tripping limit. As specified in Figure 4, the characteristic-curve limit with regard to the angle specification on the x-axis depends on the ratio $|I_Y^*|$ to $|3I_0^*|$. If the amounts differ, the characteristic curve shifts. The current $I_{Angle,REF}$ for the Angle Decision is determined from the following subtraction and summation:

$$I_{Angle,REF} = |I_Y^* - 3I_0^*| - |I_Y^* + 3I_0^*|$$

The resulting current $I_{Angle,REF}$ results from the respective fault conditions, which are illustrated in the following figure. With an internal fault (angle difference ≈ 0°), a value results for $I_{Angle,REF}$ that has a negative sign. Even if angle errors occur, the sign remains negative. The amount of $I_{Angle,REF}$ decreases. With an external short circuit (≈180°), the value for $I_{Angle,REF}$ becomes positive. With an angle error, the current $I_{Angle,REF}$ also remains positive. The amount also decreases. The following figure shows this for $I_{Angle,REF}$ = (-Term) - (+Term).



Internal fault

External fault

Figure 5 Angle Decision in Internal and External Faults

For tripping to occur, the neutral-point current I_Y* must reach the value $I_{REF,Trip}$. The characteristic curve in the left part of the figure can be determined from the following relationship:

$I_{REF,Trip} = I_{Char} + k \cdot I_{Angle,REF}$

where:

I_{Char}	Pickup value resulting from the pickup value increase
k	Factor (permanently set to 4.05657)

With this value, the limit angle at $|I_Y{*}| = |3I_0{*}|$ is precisely 100°. No tripping is possible from this angle on. The following figure shows an example of the effect on the extended operating by the different ratio I_Y* to $3I_0$* ($I_{rest,REF}$ is not considered in the representation).

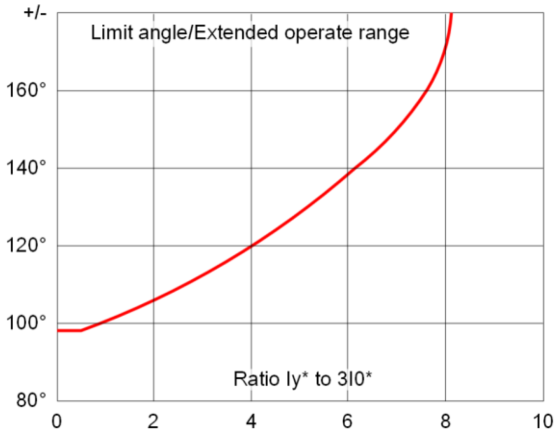


Figure 6 Ratio I_Y* to $3I_0$*

Starting with a ratio of I_Y* to $3I_0$* > 8.2, tripping is possible for each angle.

Application and Setting Notes

You can determine the setting limits for the threshold values as follows (the adaption is done automatically and a setting is only possible within the permissible range):

Lower limit:
Threshold value $\geq$ max {0.05 $I/I_{rated,S}$; 0.05 $I/I_{rated,S}$ * $I_{prim\ transf.\ max}$ / $I_{rated,\ protected\ object}$}

Upper limit:
Threshold value $\leq$ min {2.00 $I/I_{rated,S}$; 100.00 $I/I_{rated,S}$ * $I_{prim\ transf.\ max}$ / $I_{rated,\ protected\ object}$}

The value 0.05 $I/I_{rated,S}$ is the minimum possible setting value and 2.00 $I/I_{rated,S}$ the maximum possible. $I_{prim,transf.\ max}$ is the largest transformer current and $I_{rated,protected}$ object the protected object rated current. (Reference current) 100.00 $I/I_{rated,S}$ is the upper measurement limit.
The adaptation of the setting limits is done automatically. In addition, a setting is prevented outside of these limits.

1.3 Setting Calculation for Protection of a Solidly Grounded Star Winding

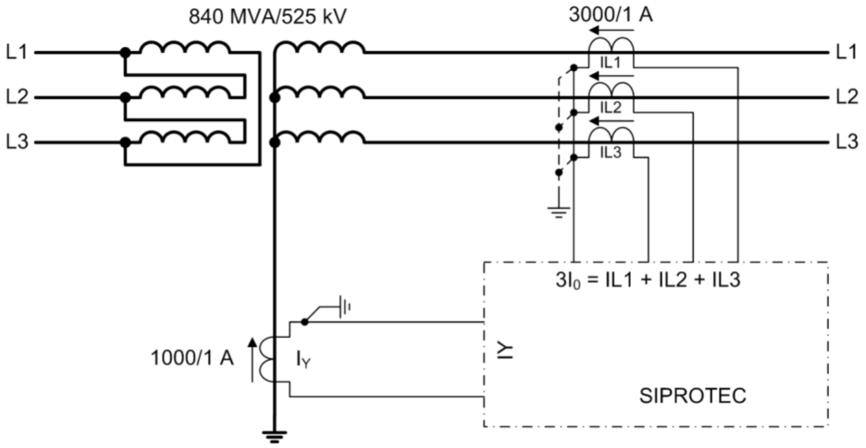


Figure 7 Application Star Side

This application is a standard application. Here the phase currents of one side and the neutral-point current are processed.

Threshold

The following view can be used to derive the threshold value. The transformer is supplied, for example, via the delta winding and a 1-pole ground fault occurs on the star side.

NOTE

For estimation of the short-circuit current, note that the inductance changes quadratically with the winding and linearly with the voltage.

The right part in the following figure represents the fault current as a function of the fault location. The fault current curve IF1 shows that the longitudinal differential protection with faults near the neutral point has sensitivity problems due to the sinking current. On the other hand, the neutral-point current IF2 is sufficiently large. There is therefore no need to set the Threshold (current through the neutral point transformer) to sensitive. Diese Applikation ist eine

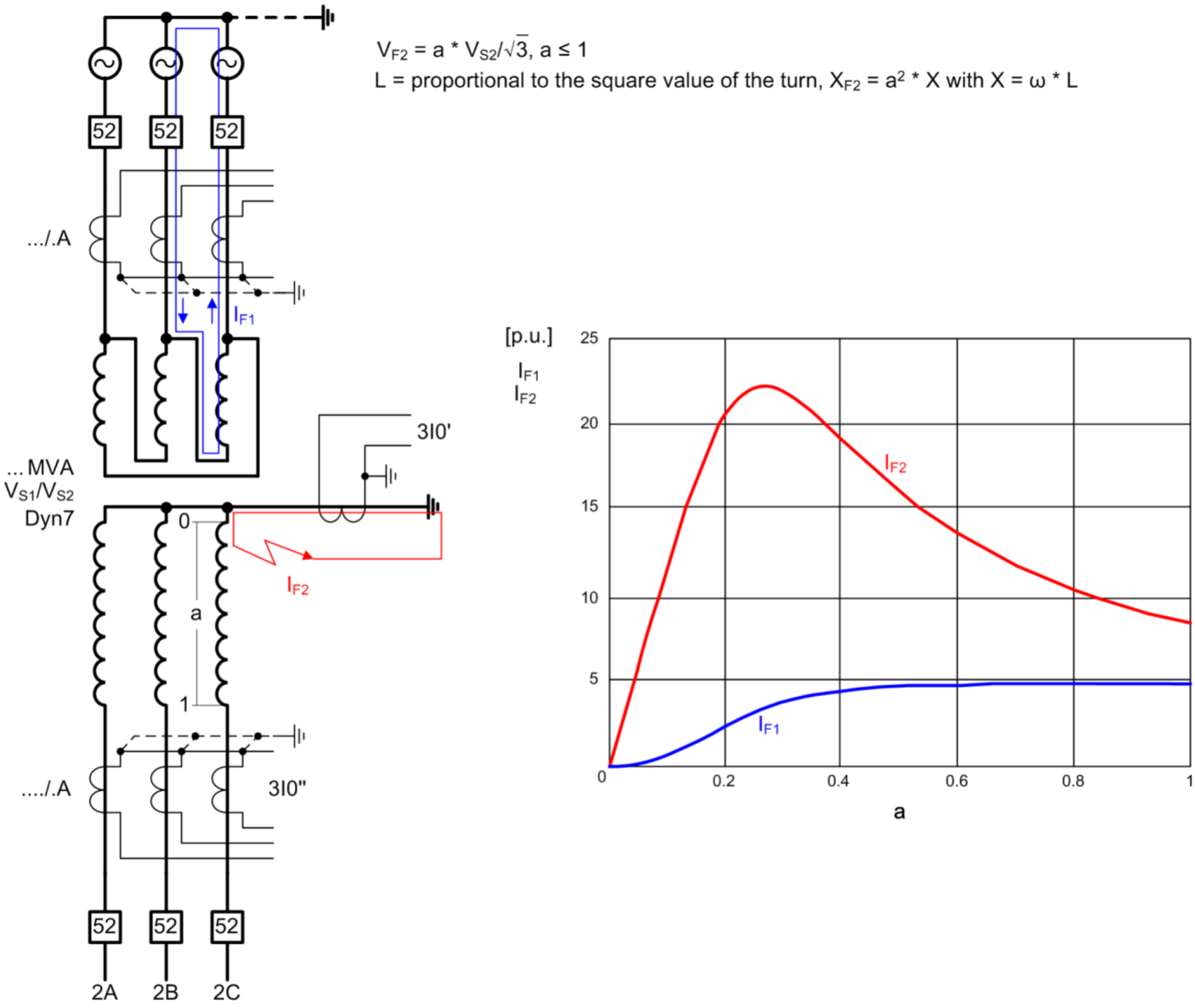


Figure 8 Principal Fault Current Curves with a 1-Pole Ground Fault

Recommended setting value (_:103) Threshold = 0.2 I/Irated,S

The previously mentioned setting limits must be maintained during the setting. The following applies for the example:

$$\text{Threshold value} \geq 0.05\ \text{I/Irated, S} \cdot \frac{I_{\text{CT max,prim}}}{I_{\text{rated,side}}}$$

The following lower limiting value results from the data from Figure 7:

$$\text{Threshold value} \geq 0.05\ \text{I/Irated,S} \cdot \frac{3000\,\text{A}}{924\,\text{A}} = 0.162\ \text{I/Irated,S}$$

$$\text{with } I_{\text{object,side}} = \frac{S_{\text{rated}}}{\sqrt{3}\,V_{\text{rated}}} = \frac{840\,\text{MVA}}{\sqrt{3}\,525\,\text{kV}} = 924\,\text{A}$$

The recommended setting value of 0.2 I/Irated,S lies above it.

- Recommended setting value (_:105) Slope = 0.07

You can stabilize the protection function with external multiphase short-circuits to ground with the parameter Slope. To determine the setting value, no pickup value increase can occur up to the rated current. After this, the gradient must be active. To derive the gradient, it is assumed that continuation of the straight line must go through the coordinate origin (see Figure 6-301). Determine the intersection from the threshold value and the restraint current at rated current. Calculate the gradient as follows:

$$I_{\text{rest,REF}} = |\underline{I}_0{}^*| + |\underline{I}_A| + |\underline{I}_B| + |\underline{I}_C| = 0 + 3\ \text{I/Irated, S} = 3\ \text{I/Irated, S}$$

$$\text{Slope} = \frac{\text{Threshold value}}{I_{\text{rest,REF}}} = \frac{0.2\ \text{I/Irated, S}}{3\ \text{I/Irated, S}} = 0.07$$

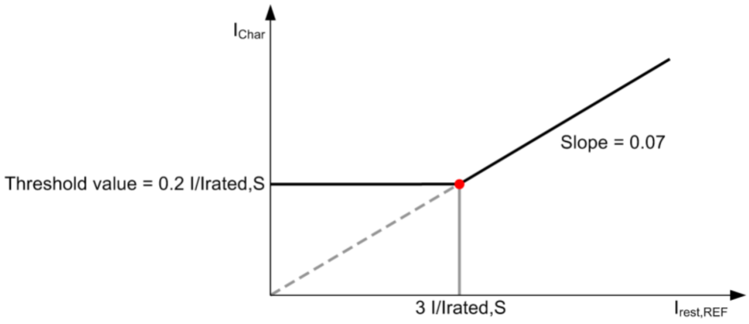
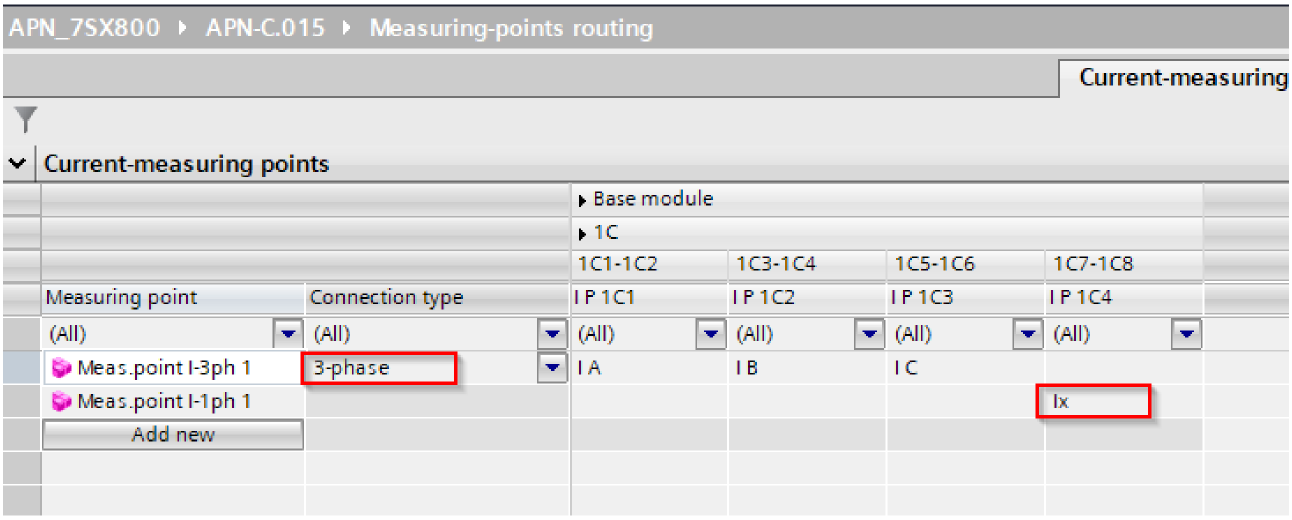


Figure 9 Derivation of the Setting Value for the Gradient

1.4 Engineering with DIGSI 5

With the button “Add new” in the measuring-points an additional single phase measuring point is created and assigned I_x. This measuring point detect the current of the star point CT. The connection type of the 3-phase measuring point is set to 3-phase.



APN_7SX800 ▸ APN-C.015 ▸ Measuring-points routing

Current-measuring

Current-measuring points

		Base module			
		1C			
		1C1-1C2	1C3-1C4	1C5-1C6	1C7-1C8
Measuring point	Connection type	I P 1C1	I P 1C2	I P 1C3	I P 1C4
(All)	(All)	(All)	(All)	(All)	(All)
Meas.point I-3ph 1	3-phase	I A	I B	I C	
Meas.point I-1ph 1					Ix
Add new					

Figure 10 Adding a 1-phase current measurement point

In SIPROTEC 5 all protection elements are assigned to function groups. The restricted ground fault protection belongs to the function group Current/Voltage 3-phase. The REF is dragged from the library and dropped in the project tree into the function group Current/Voltage 3-phase of the device. In the same way a new function group Voltage/Current 1-phase with overcurrent protection 1-phase is added.

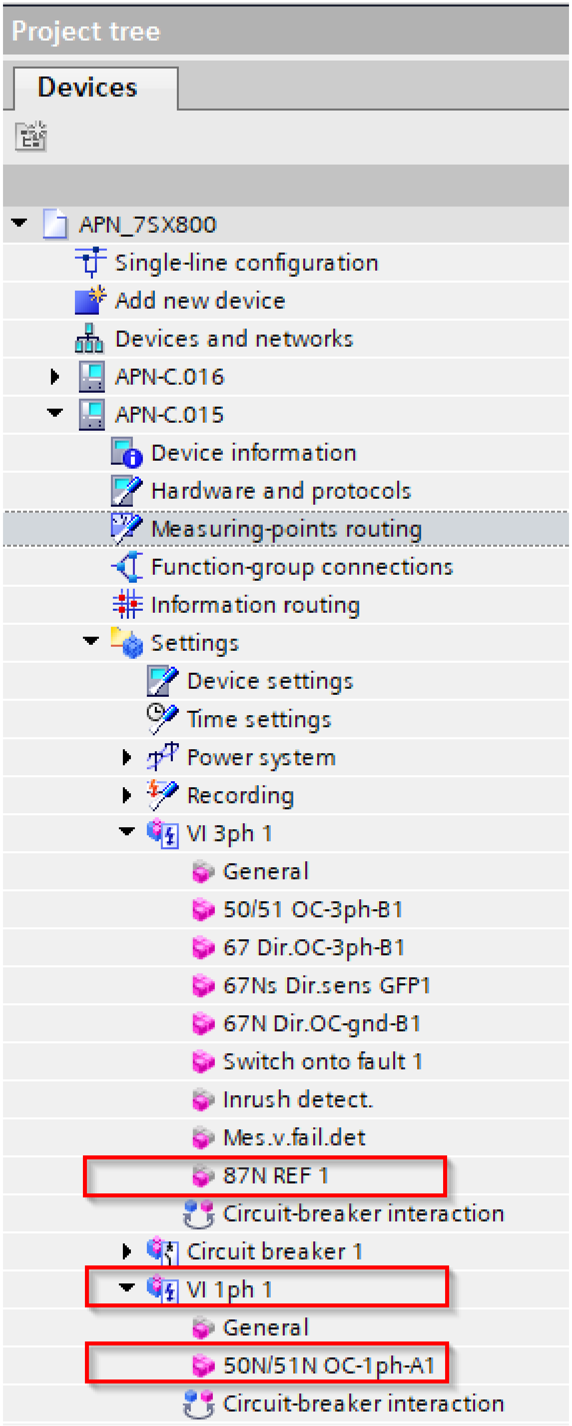
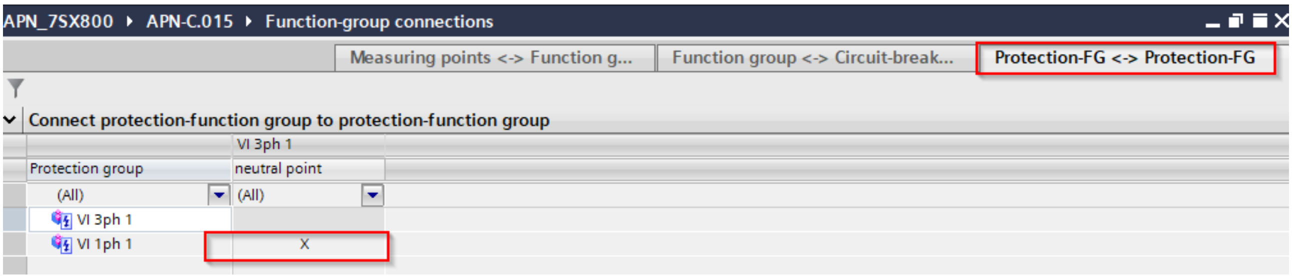


Figure 11 Adding required function group and protection elements

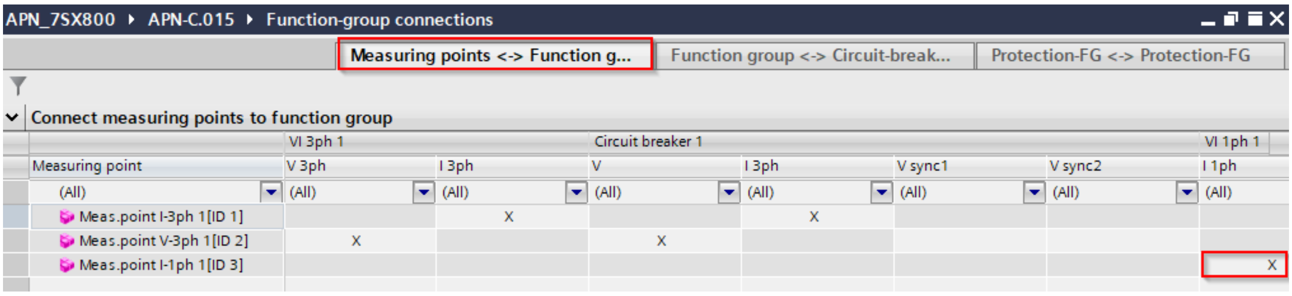
In the editor for function group connections the function groups Current/Voltage 3-phase and 1-phase have to be connected. Further the measuring point current 1-phase is assigned to the function group Current/Voltage 1-phase.



APN_7SX800 ▸ APN-C.015 ▸ Function-group connections

Connect protection-function group to protection-function group

	VI 3ph 1
Protection group	neutral point
(All)	(All)
VI 3ph 1	
VI 1ph 1	X



APN_7SX800 ▸ APN-C.015 ▸ Function-group connections

Connect measuring points to function group

	VI 3ph 1		Circuit breaker 1				VI 1ph 1
Measuring point	V 3ph	I 3ph	V	I 3ph	V sync1	V sync2	I 1ph
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)
Meas.point I-3ph 1[ID 1]		X		X			
Meas.point V-3ph 1[ID 2]	X		X				
Meas.point I-1ph 1[ID 3]							X

Figure 12 Creating function group connections

The following connection is defined for the transformer according to Figure 13. The current flow for an external ground fault is entered at the same time. It is recognized that the secondary currents each flow from the device. From this, a differential current ($I_{Diff,REF} = |I_Y + I_A + I_B + I_C| = | -I_4 - I_3|$) results, according to the reference arrow definition for the restricted ground-fault protection (positive to the protected object) with an external ground fault. To prevent that, the neutral-point current is rotated in the Transformer neutral-point function group. It follows that: $I_{Diff,\ REF} = |I_4 - I_3| = 0$.

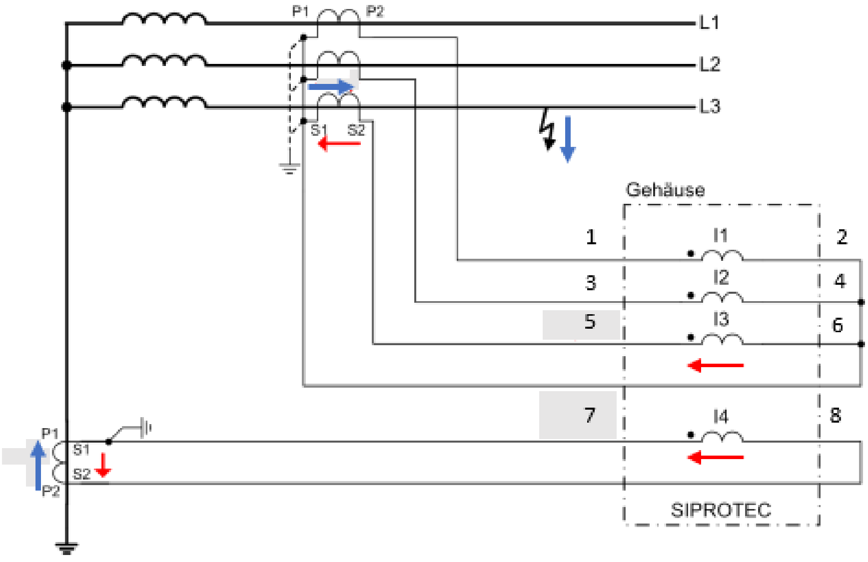


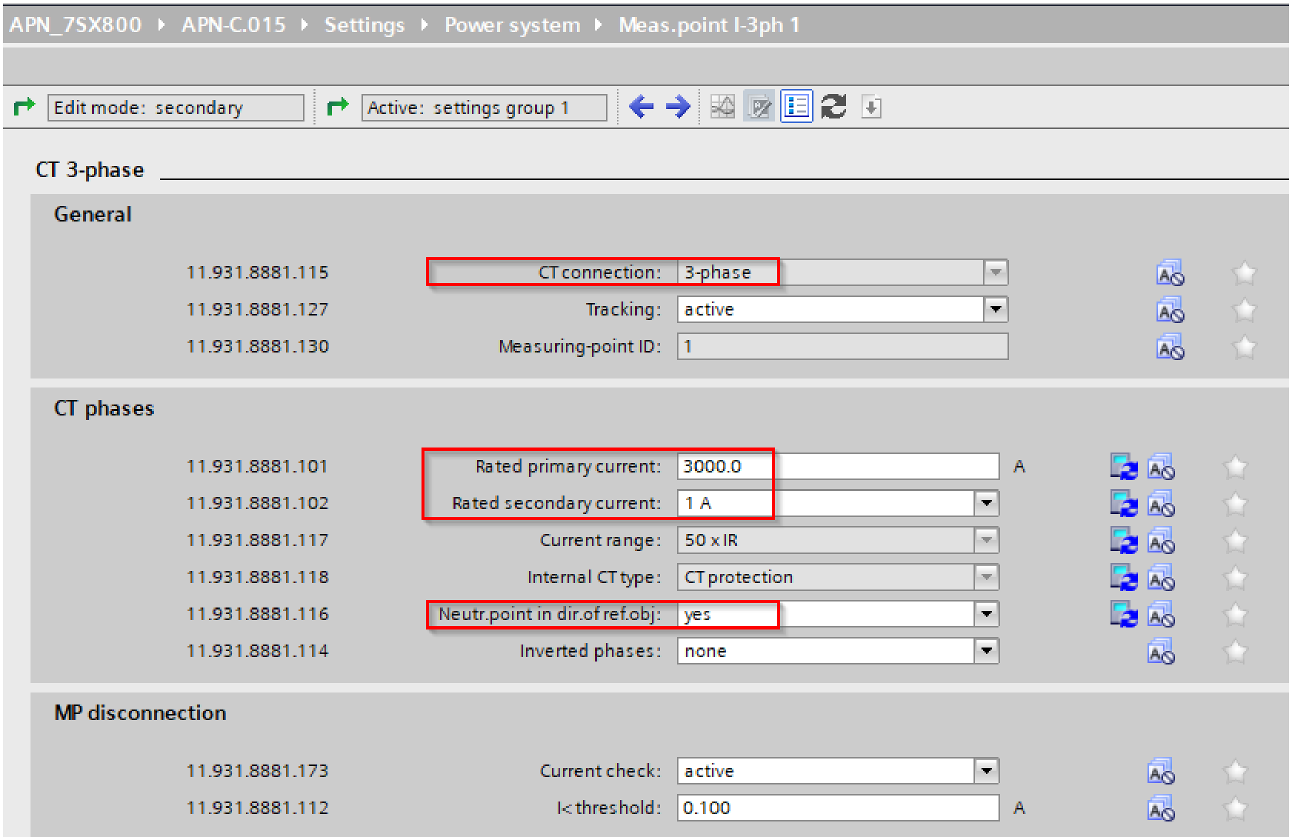
Figure 13 Current-Transformer Connection on the Transformer

The point in Figure 13 describes the polarity of the current transformer. At the same time, the current terminal is designed so that this side is fed out on an odd number terminal point. Since in the SIPROTEC 5 system each current transformer can be assigned a 1-phase measuring point, the odd number terminal points are named in the setting parameters. According to Figure 14, the setting must be yes.

- Default setting (_:115) terminal 1,3,5,7 in dir.obj.= yes

For a 3-phase transformer connection, for orientation of the neutral point, the polarity is always configured on the side of the even terminals.

Further the CT ratios have to be set.



APN_7SX800 ▸ APN-C.015 ▸ Settings ▸ Power system ▸ Meas.point I-3ph 1

Edit mode: secondary

Active: settings group 1

CT 3-phase

General

11.931.8881.115 CT connection: 3-phase
11.931.8881.127 Tracking: active
11.931.8881.130 Measuring-point ID: 1

CT phases

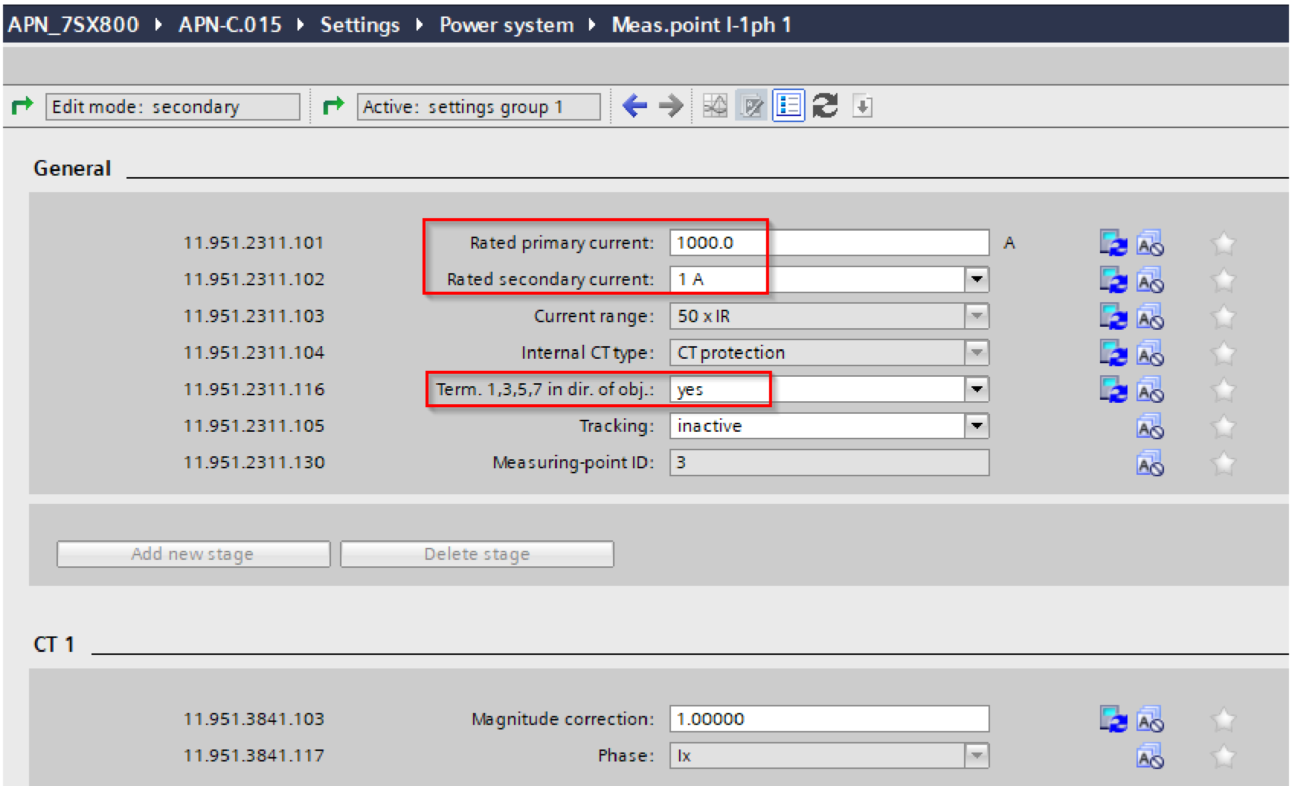
11.931.8881.101 Rated primary current: 3000.0 A
11.931.8881.102 Rated secondary current: 1 A
11.931.8881.117 Current range: 50 x IR
11.931.8881.118 Internal CT type: CT protection
11.931.8881.116 Neutr.point in dir.of ref.obj: yes
11.931.8881.114 Inverted phases: none

MP disconnection

11.931.8881.173 Current check: active
11.931.8881.112 I< threshold: 0.100 A

Figure 14: Setting the polarity of the 3-phase current transformer

The 1-phase current transformer side in direction of the protected object is used define the polarity. It must be selected whether it is connected to the even or odd relay terminal.



APN_7SX800 ▸ APN-C.015 ▸ Settings ▸ Power system ▸ Meas.point I-1ph 1

Edit mode: secondary

Active: settings group 1

General

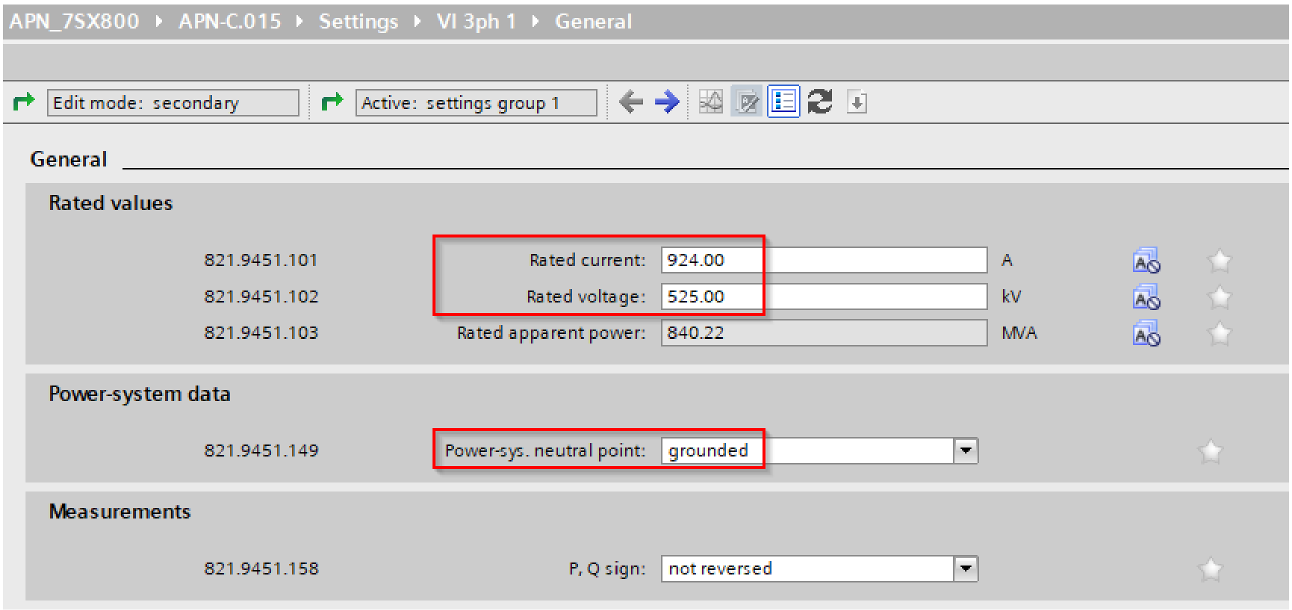
11.951.2311.101	Rated primary current:	1000.0	A
11.951.2311.102	Rated secondary current:	1 A	
11.951.2311.103	Current range:	50 x IR	
11.951.2311.104	Internal CT type:	CT protection	
11.951.2311.116	Term. 1,3,5,7 in dir. of obj.:	yes	
11.951.2311.105	Tracking:	inactive	
11.951.2311.130	Measuring-point ID:	3	

CT 1

11.951.3841.103	Magnitude correction:	1.00000
11.951.3841.117	Phase:	Ix

Figure 15: Setting the polarity of the 1-phase current transformer

Now the rating of the protected transformer winding and the type of grounding must be set.



APN_7SX800 ▸ APN-C.015 ▸ Settings ▸ VI 3ph 1 ▸ General

Edit mode: secondary

Active: settings group 1

General

Rated values

821.9451.101	Rated current:	924.00	A
821.9451.102	Rated voltage:	525.00	kV
821.9451.103	Rated apparent power:	840.22	MVA

Power-system data

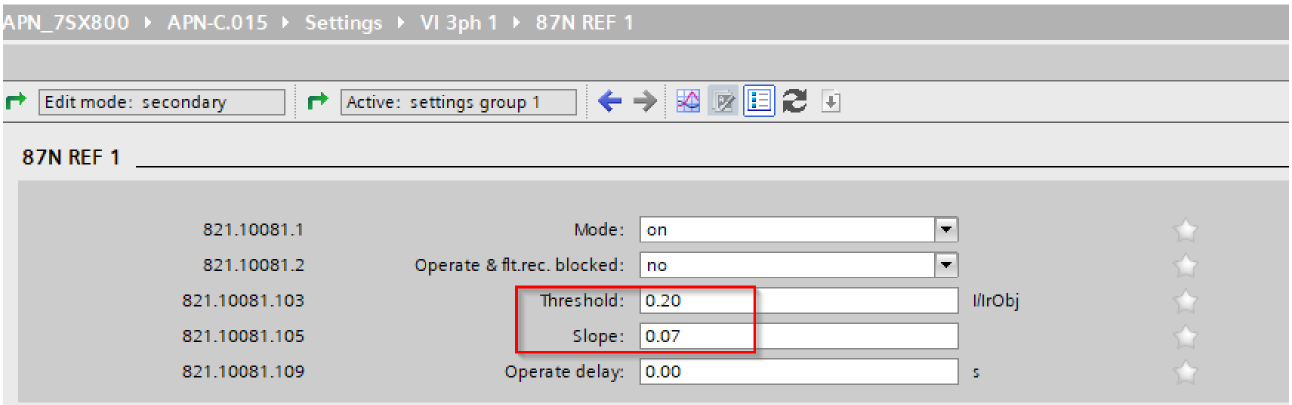
821.9451.149	Power-sys. neutral point:	grounded

Measurements

821.9451.158	P, Q sign:	not reversed

Figure 16: Setting the rating of the protected object and the type of grounding

Under Settings > VI 3ph 1 > 87N REF1 the calculated threshold and slope are entered.


APN_7SX800 ▸ APN-C.015 ▸ Settings ▸ VI 3ph 1 ▸ 87N REF 1

Edit mode: secondary

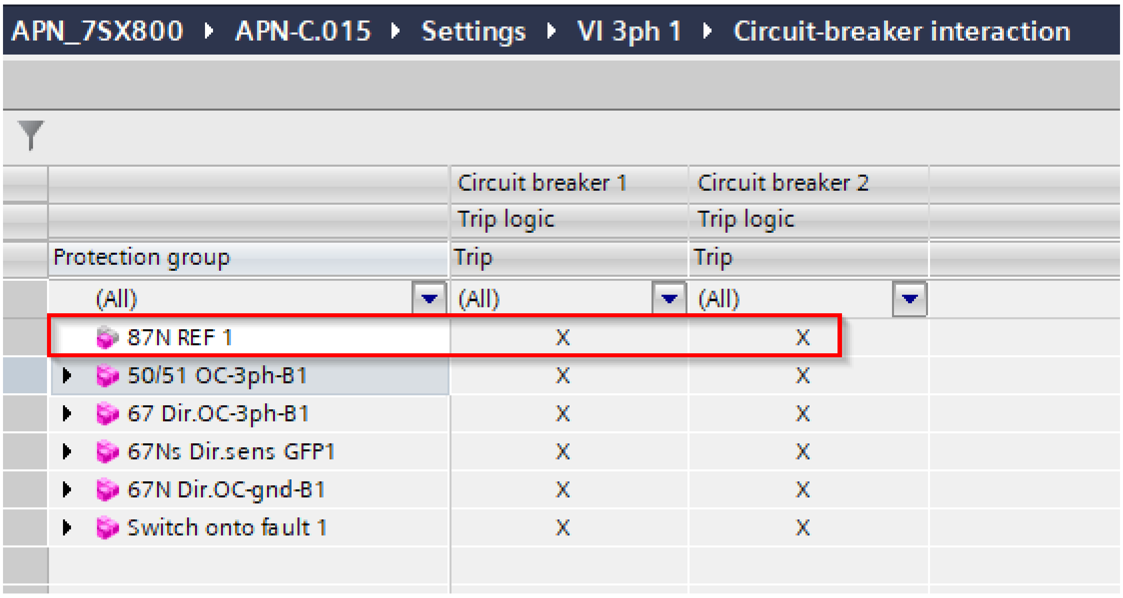
Active: settings group 1

87N REF 1

821.10081.1	Mode:	on	
821.10081.2	Operate & flt.rec. blocked:	no	
821.10081.103	Threshold:	0.20	I/IrObj
821.10081.105	Slope:	0.07	
821.10081.109	Operate delay:	0.00	s

Figure 17: Setting the characteristic

In the trip logic the restricted ground fault protection is marshalled to trip both transformer circuit breakers.


APN_7SX800 ▸ APN-C.015 ▸ Settings ▸ VI 3ph 1 ▸ Circuit-breaker interaction

	Circuit breaker 1	Circuit breaker 2
	Trip logic	Trip logic
Protection group	Trip	Trip
(All)	(All)	(All)
87N REF 1	X	X
50/51 OC-3ph-B1	X	X
67 Dir.OC-3ph-B1	X	X
67Ns Dir.sens GFP1	X	X
67N Dir.OC-gnd-B1	X	X
Switch onto fault 1	X	X

Figure 18: Marshalling the trip signals

Thereby the engineering of the restricted ground fault protection is completed.

Herausgeber
Siemens AG 2021

Smart Infrastructure
Digital Grid
Automation Products
Humboldtstr. 59
90459 Nürnberg, Deutschland

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