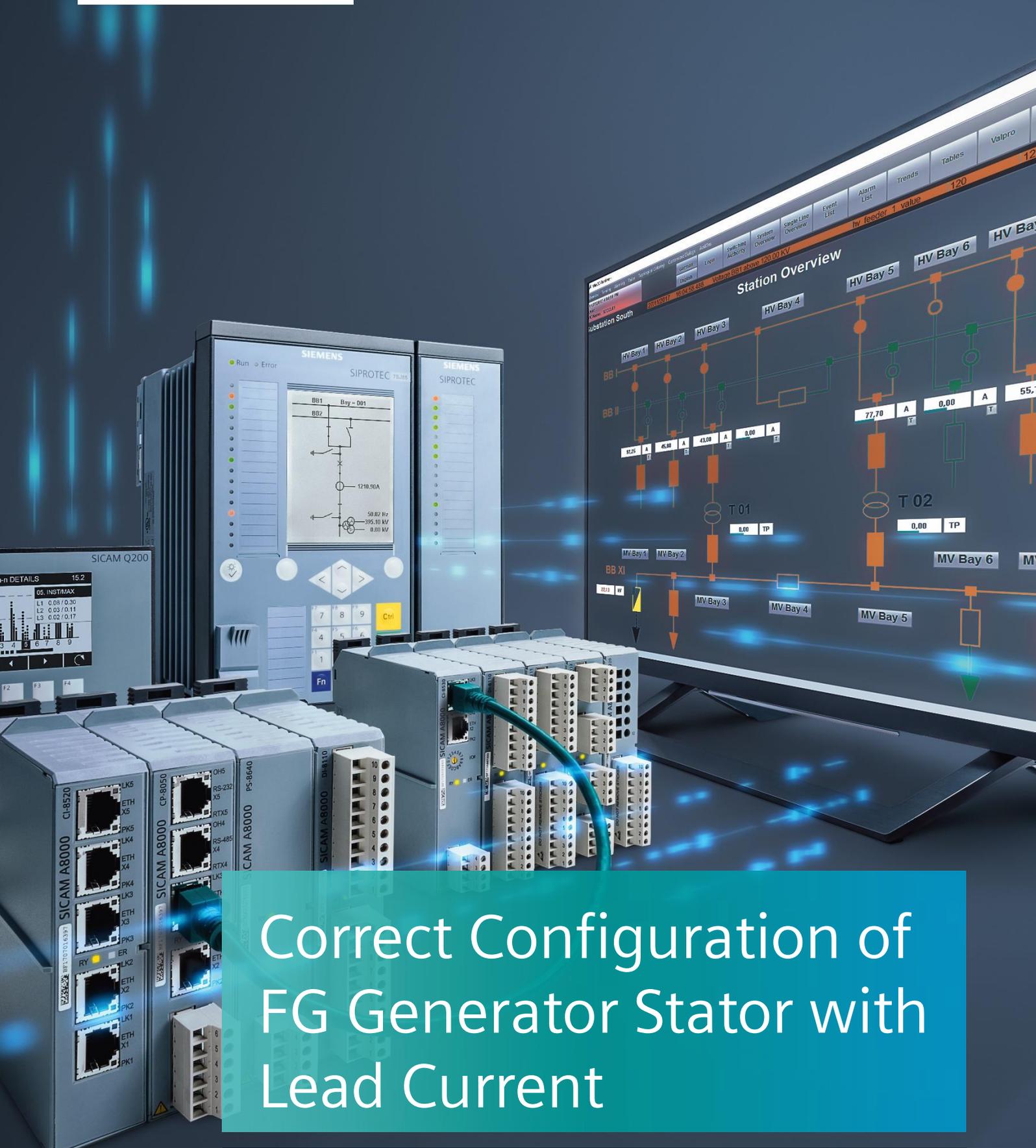# SIEMENS

Ingenuity for life

Correct Configuration of FG Generator Stator with Lead Current

SIPROTEC 5 Application

Correct Configuration of FG Generator Stator with Lead Current

APN-080, Edition 1

Content

1 Correct Configuration of FG Generator Stator with Lead Current

1.1 Introduction

For generator protection application, most of the 3-ph functions such as reverse power protection (ANSI 32R), under-excitation protection (ANSI 40), out-of-step protection (ANSI 78), etc., are typically using the neutral side current. In some cases, we are required by the customer to use the lead side current for these functions. This will lead to un-favorite functional behavior if no special treatment during the configuration is done.

The correct configuration for this connection is described in this application note.

1.2 Conventional Connection with Neutral Current

In power generation application, the generator-transformer block can be protected by the protection device 7UM85. The following Figure 1 is to demonstrate the connection diagram of the 3-ph system. The injected phasors into the protection device with rated operation condition are also illustrated.
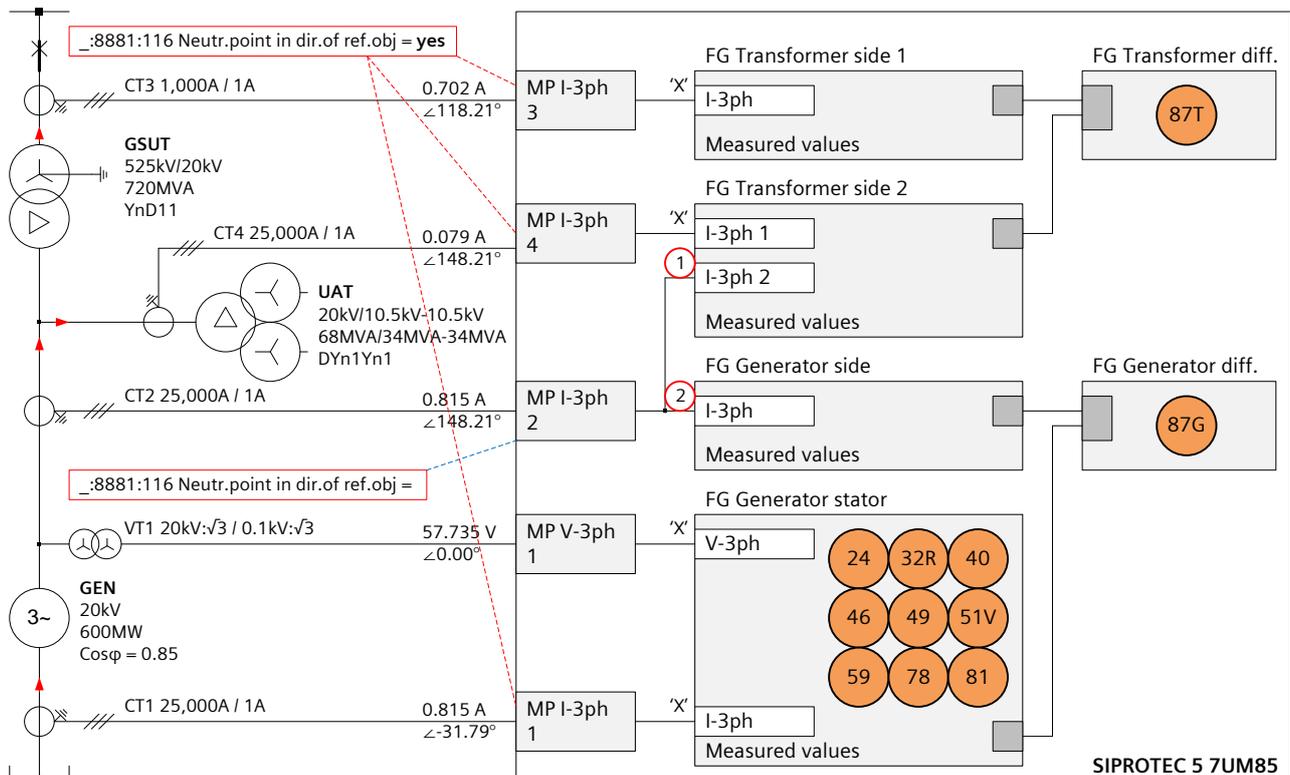

Figure 1: Conventional Connection Diagram for FG Generator Stator

This is a conventional diagram for the block protection. In the above diagram we see that most of the generator protection functions are allocated in FG Generator Stator to which the neutral side current transformer CT1 is connected. The generator differential protection (ANSI 87G) calculates the differential current ΔI from the FGs of Generator Stator and Generator Side.

According to the diagram, based on the rule of generator (GEN) differential protection or generator step-up transformer (GSUT) differential protection, the parameter "_:8881:116 Neutr.point in dir.of ref.obj" for measuring points of MP I-3ph 1, MP I-3ph 3 and MP I-3ph 4 is set to "yes". For measuring point MP I-3ph 2, it can be set to "yes" if it's referred to protected object "GEN", or "no" if it's referred to protected object "GSUT".

If above mentioned setting is "*yes*", the MP I-3ph 2 must be routed with "*X(routed)*" for FG Generator Side. As request from GSUT differential protection, it must be routed with "*I(routed - with inverted direction)*" for FG Transformer Side 2. Please refer to below Figure 2.

Connect measuring points to function group

| Measuring point | Generator side | Transformer side 1 | | Transformer side 2 | |
	I 3ph	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)
🦋 MP I-3ph 1[ID 1]					
🦋 MP I-3ph 2[ID 2]	X				I

Figure 2: Route Measuring Points if "yes" : ①= 'I', ②= 'X'

If the setting is "*no*", the MP I-3ph 2 must be routed with "*X(routed)*" for FG Transformer Side 2. As request from GEN differential protection, it must be routed with "*I(routed - with inverted direction)*" for FG Generator Side. Please refer to below Figure 3.

Connect measuring points to function group

| Measuring point | Generator side | Transformer side 1 | | Transformer side 2 | |
	I 3ph	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)
🦋 MP I-3ph 1[ID 1]					
🦋 MP I-3ph 2[ID 2]	I				X

Figure 3: Route Measuring Points if "no": ①= 'X', ②= 'I'

Below pictures show the correct operational and functional values.

Operational values	1/25		Add.Meas.Value	1/4
f	=	50.00 Hz	R1	=	0.482 Ω
Vph:A	=	11.546 kV	X1	=	0.299 Ω
Vph:B	=	11.546 kV	φ-power	=	31.79°
Vph:C	=	11.546 kV	δ-rotor	=	38.14°
Vpp:AB	=	19.998 kV		
Vpp:BC	=	19.998 kV		
Vpp:CA	=	19.998 kV		
Vph:res	=	0 kV		
Iph:A	=	20.37 kA		
Iph:B	=	20.37 kA		
Iph:C	=	20.37 kA		
Iph:res	=	0 kA		
P tot	=	599.79 MW		
Q tot	=	371.74 Mvar		
S tot	=	705.65 MVA		
cosφ	=	0.85		
P:A	=	199.93 MW		
primary			primary	

Figure 4: Correct Values of FG Generator Stator with Neutral Side Current

1.3 Non-conventional Connection with Lead Current – Incorrect Configuration

Many reasons lead to a non-conventional connection, that is, to connect lead side current to FG Generator Stator. Let's see what will happen if the following connection diagram of 3-ph system is applied.
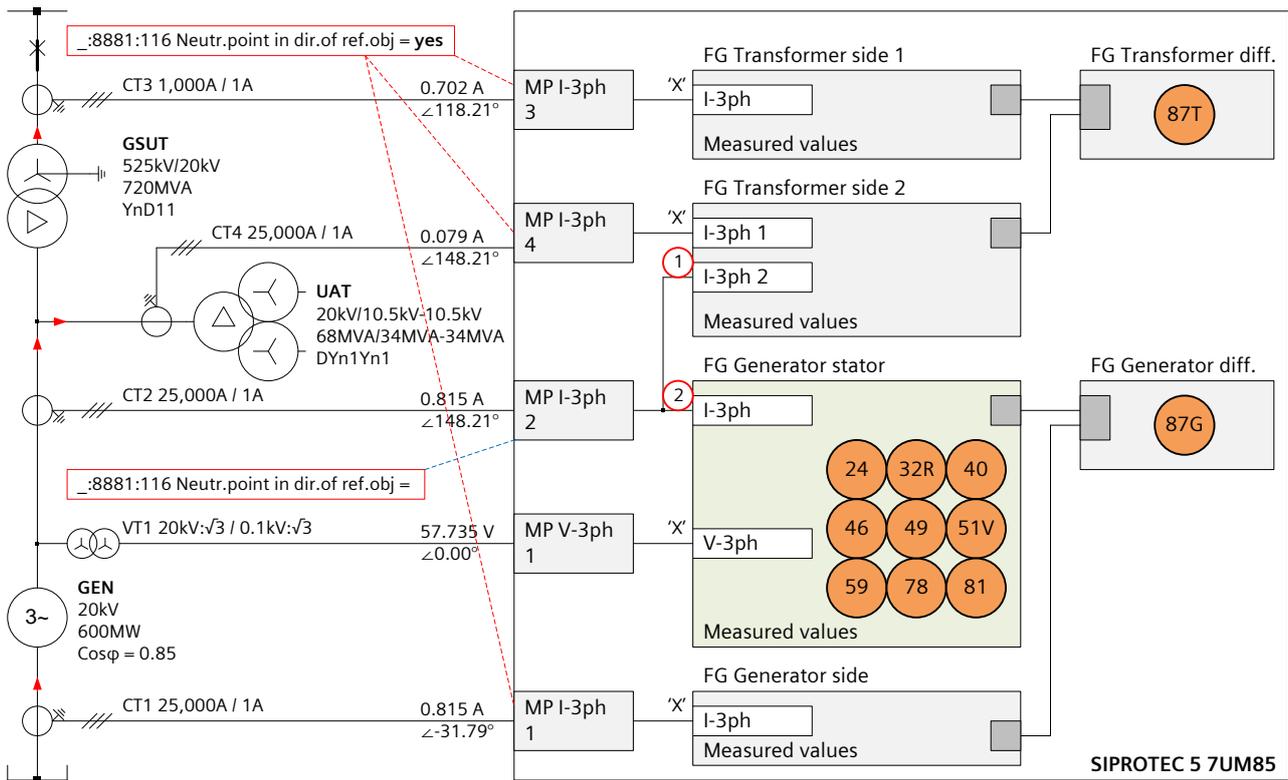
Figure 5: Connection Diagram with Lead Current for FG Generator Stator – Incorrect Solution

Following the same configuration as with the conventional connection diagram, we see the wrong operational and functional values as below.

Figure 6: Wrong Values of FG Generator Stator with Lead Side Current

Compared to Figure 4, we see that the calculated power and impedance are inverted with the direction. This must lead to un-favorite behavior, e.g. over-function of reverse power protection.

1.3.1   Analysis

When we are talking about the parameter "_:8881:116 Neutr.point in dir.of ref.obj", we are talking about the protected object. This setting is crucial for proper behavior of differential, directional and power protection. For the example shown in Figure 5, the neutral point of MP I-3ph 2 is in direction of GEN, but not in direction of GSUT.

SIPROTEC 5 Application

Correct Configuration of FG Generator Stator with Lead Current

Let's see respectively the results of protected object "GEN" and "GSUT"

Calculation with Protected Object GEN

Based on Figure 5, the parameter "_:8881:116 Neutr.point in dir.of ref.obj" is set to "yes", the MP I-3ph 2 must be routed with "X(routed)" for FG Generator Stator. As request from GSUT differential protection, it must be routed with "I(routed - with inverted direction)" for FG Transformer Side 2.

The parameter "_:8881:116 Neutr.point in dir.of ref.obj = yes" will not invert the injected current phasor, i.e., the measured current phasor MP I-3ph 2 has the same phase angle as the injected current phasor. Please refer to below picture.

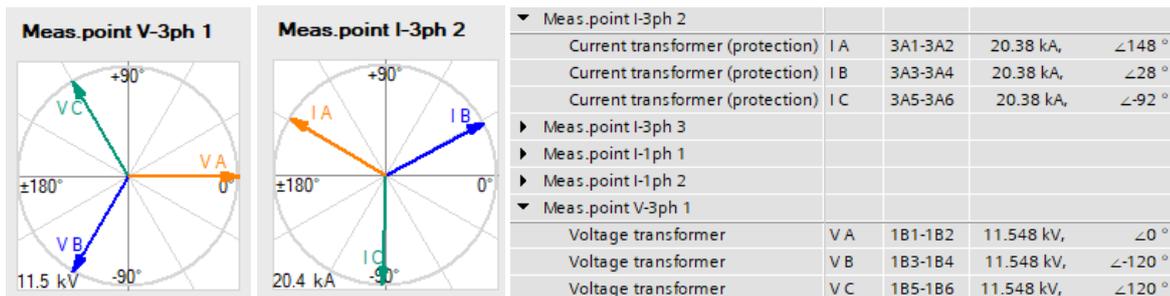| Meas.point I-3ph 2				
Current transformer (protection)	I A	3A1-3A2	20.38 kA,	∠148 °
Current transformer (protection)	I B	3A3-3A4	20.38 kA,	∠28 °
Current transformer (protection)	I C	3A5-3A6	20.38 kA,	∠-92 °
Meas.point I-3ph 3				
Meas.point I-1ph 1				
Meas.point I-1ph 2				
Meas.point V-3ph 1				
Voltage transformer	V A	1B1-1B2	11.548 kV,	∠0 °
Voltage transformer	V B	1B3-1B4	11.548 kV,	∠-120 °
Voltage transformer	V C	1B5-1B6	11.548 kV,	∠120 °

Figure 7: Measured Phasors with Protected Object GEN

MP I-3ph 2 is routed to FG Generator Stator with 'X'. FG Generator Stator will directly calculate the functional values based on the measured phasor, e.g., active power, as below,

$$P_{tot} = \sqrt{3}*U_{pp}*I_{ph}*\cos\varphi_{UI} = \sqrt{3}*20kV*20.38kA*\cos(0° - 148.21°) = -599.79 \text{ MW}$$

Calculation with Protected Object GSUT

Based on Figure 5, the parameter "_:8881:116 Neutr.point in dir.of ref.obj" is set to "no", the MP I-3ph 2 must be routed with "X(routed)" for FG Transformer Side 2. As request from GEN differential protection, it must be routed with "I(routed - with inverted direction)" for FG Generator Stator.

The parameter "_:8881:116 Neutr.point in dir.of ref.obj = no" will invert the injected current phasor, i.e., the measured phasor MP I-3ph 2 has the counter phase angle to injected phasor. Please refer to below picture.

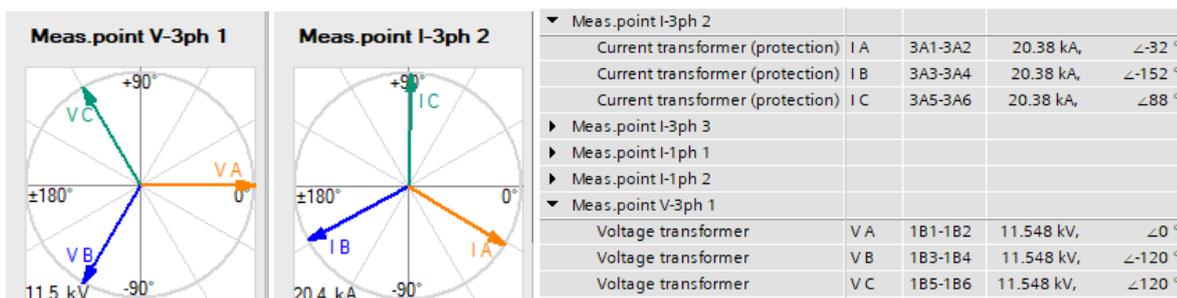| Meas.point I-3ph 2				
Current transformer (protection)	I A	3A1-3A2	20.38 kA,	∠-32 °
Current transformer (protection)	I B	3A3-3A4	20.38 kA,	∠-152 °
Current transformer (protection)	I C	3A5-3A6	20.38 kA,	∠88 °
Meas.point I-3ph 3				
Meas.point I-1ph 1				
Meas.point I-1ph 2				
Meas.point V-3ph 1				
Voltage transformer	V A	1B1-1B2	11.548 kV,	∠0 °
Voltage transformer	V B	1B3-1B4	11.548 kV,	∠-120 °
Voltage transformer	V C	1B5-1B6	11.548 kV,	∠120 °

Figure 8: Measured Phasors with Protected Object GSUT

MP I-3ph 2 is reversely routed to FG Generator Stator with 'I'. FG Generator Stator will invert the measured phasor and then calculate the functional values, e.g., active power, as below,

$$P_{tot} = \sqrt{3}*U_{pp}*I_{ph}*\cos\varphi_{UI} = \sqrt{3}*20kV*20.38kA*\cos[0° - (-31.79° + 180.00°)] = -599.79 \text{ MW}$$

Conclusion

From the above two setting cases we see, independent of the parameter "_:8881:116 Neutr.point in dir.of ref.obj" of MP I-3ph 2 setting to "yes" or "no", we have always the same wrong results for both the measurement values and the function values for example for reverse power, under-excitation, out-of-step, etc.

If we focus on FG Generator Differential, we shall set the parameter "_:8881:116 Neutr.point in dir.of ref.obj"(value "yes" or "no") and route the matrix value("X" or "I") based on the rule of Kirchhoff's Law. This means, the adapted current phasor should point towards "GEN".

GEN is generating power to the grid during normal operation. If we focus on FG Generator Stator with lead current, we shall determine the above values based on the rule of power flow. This means, the adapted current phasor should point towards "HV Busbar".

Both rules are consistent at the measuring point of the neutral side (both of "GEN" and "HV Busbar" are in direction of power grid), so the differential protection and the direction dependent functions in the FG Generator Stator work correctly.

However, both rules are inconsistent at the measuring point of lead side ("HV Busbar" is in direction of power grid but "GEN" is in the opposite direction). We have this conflict because the FG Generator stator was originally designed to be connected only to the measuring point of the neutral side where both rules are consistent. This is the root cause for the wrong behavior of FG Generator Stator when connected to the lead measuring point which we saw before.

1.3.2 Special Notice to Reversed P, Q Sign

There is a parameter "_:14611:158 P,Q sign" under path \FG Generator Stator\General\Further settings\Measurements. This parameter with setting "reversed" is to reverse only the displayed operational values. Please pay special attention, this setting has no influence on functional values and cannot avoid the un-favorite behavior. With the setting value "reversed", we can see the correct operational values (green marking) but wrong functional values (red marking) like impedance and reverse power values as shown below.

Operational values		1/25	Add.Meas.Value		1/4	General		1/4
f	=	50.00 Hz	R1	=	-0.482 Ω	P1avg	=	-600.05 MW
Vph:A	=	11.546 kV	X1	=	-0.299 Ω	Q1avg	=	-371.90 Mvar
Vph:B	=	11.546 kV	φ-power	=	-148.21°	P1fast	=	-600.05 MW
Vph:C	=	11.546 kV	δ-rotor	=	-88.06°	Q1fast	=	-371.90 Mvar
Vpp:AB	=	19.998 kV						
Vpp:BC	=	19.998 kV						
Vpp:CA	=	19.998 kV						
Vph:res	=	0 kV						
Iph:A	=	20.37 kA						
Iph:B	=	20.37 kA						
Iph:C	=	20.37 kA						
Iph:res	=	0 kA						
Ptot	=	599.79 MW						
Qtot	=	371.74 Mvar						
Stot	=	705.65 MVA						
cosφ	=	0.85						
P:A	=	199.93 MW						
primary			primary			primary		

Figure 9: Correct Operational Values but Wrong Functional Values

1.4 Non-conventional Connection with Lead Current – Correct Configuration

Knowing now the reason for the incorrect behavior, we present a possible solution in Figure 10.

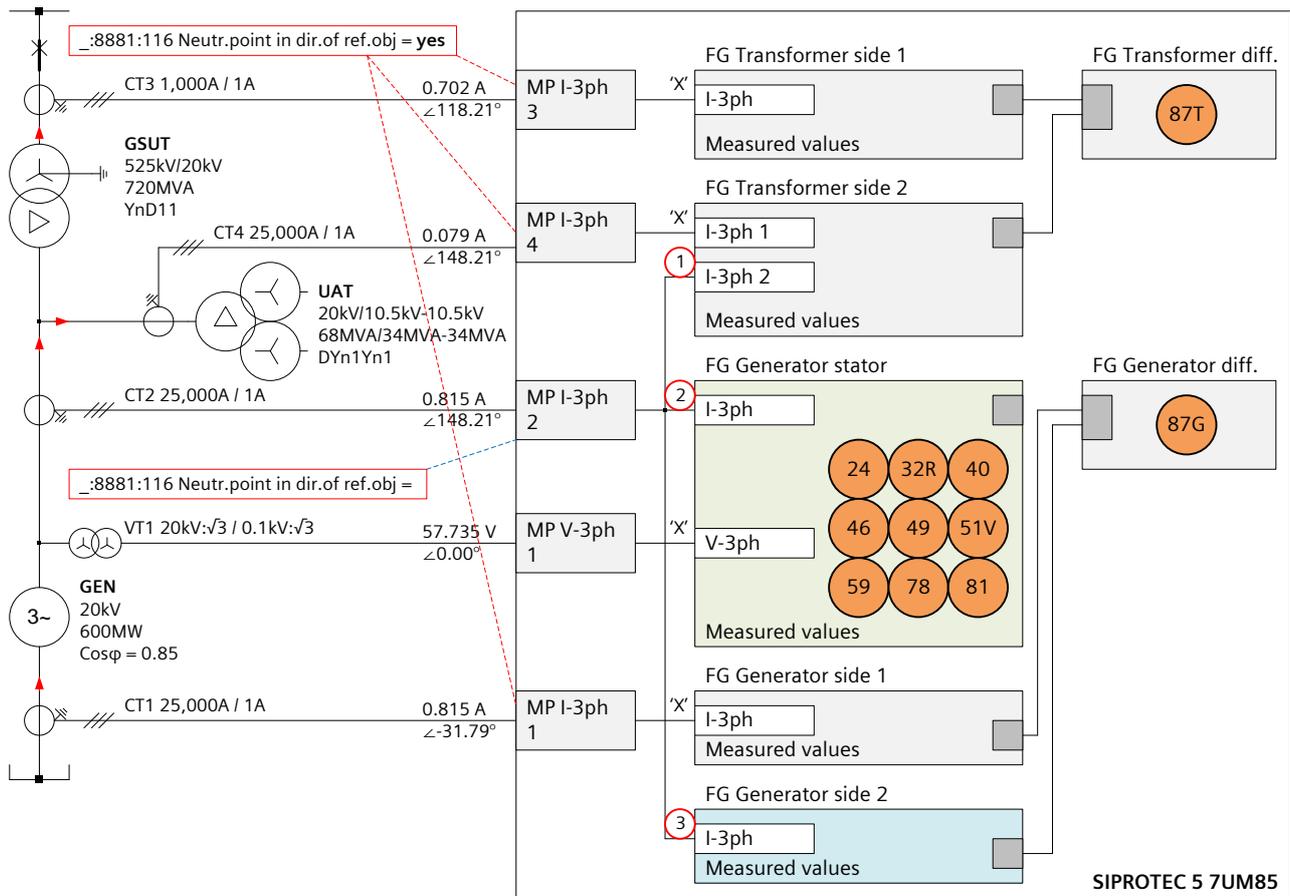## Correct Configuration of FG Generator Stator with Lead Current

Figure 10: Connection Diagram with Lead Current for FG Generator Stator – Correct Configuration

Isolation of the Connection between FG Generator Stator and FG Generator Differential.

We set up a FG Generator Stator which is independent of FG Generator Differential. For the latter we create an additional FG Generator Side 2 routed to the CT on the lead side. The FG Generator Differential is now connected to FG Generator Side 1 and FG Generator Side 2 (see Figure 10)

Then, we determine the parameter "_:8881:116 Neutr.point in dir.of ref.obj" and route the matrix value based on the rule of Kirchhoff's Law for the Generator Side 2 and based on the rule of power flow for the FG Generator Stator.

Verification of Protected Object GEN

Based on Figure 10, we follow the rule of Kirchhoff's Law for the GEN differential protection and set the parameter "_:8881:116 Neutr.point in dir.of ref.obj" to **"yes"**. Then the MP I-3ph 2 must be routed with "X(routed)" for FG Generator Side 2. As request from GSUT differential protection, the MP I-3ph 2 must be routed with "I(routed - with inverted direction)" for FG Transformer Side 2.

For the FG Generator Stator the MP I-3ph 2 is routed with "I(routed - with inverted direction)" according to the rule of power flow (the CT star-point at the generator lead side must have the same direction as the CT star-point at the generator neutral side, so that the functions of both sides have the same correct values).

Connect measuring points to function group

Measuring point	Generator stator			Transformer side 2		Generator side 2	
	I 3ph	V SGF	I SGF	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP I-3ph 1[ID 1]							
MP I-3ph 2[ID 2]	I				I		X

Figure 11: Measuring Points routing for the setting "yes" : ①= 'I', ②= 'I', ③= 'X'

The parameter "*_:8881:116 Neutr.point in dir.of ref.obj = yes*" will not invert the injected current phasor, i.e., the measured phasor MP I-3ph 2 has the same phase angle to injected phasor. Please refer to below picture.
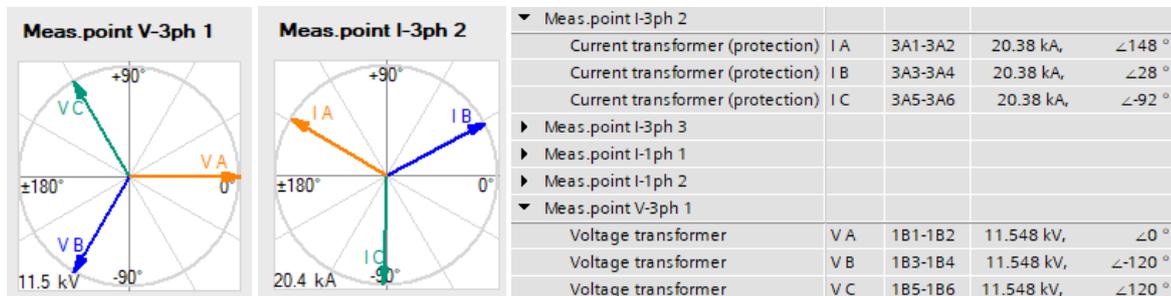

Meas.point I-3ph 2					
Current transformer (protection)	I A	3A1-3A2	20.38 kA,	∠148 °
Current transformer (protection)	I B	3A3-3A4	20.38 kA,	∠28 °
Current transformer (protection)	I C	3A5-3A6	20.38 kA,	∠-92 °
▸ Meas.point I-3ph 3				
▸ Meas.point I-1ph 1				
▸ Meas.point I-1ph 2				
▾ Meas.point V-3ph 1				
Voltage transformer	V A	1B1-1B2	11.548 kV,	∠0 °
Voltage transformer	V B	1B3-1B4	11.548 kV,	∠-120 °
Voltage transformer	V C	1B5-1B6	11.548 kV,	∠120 °

Figure 12: Analog Inputs of Special Treatment with Protected Object GEN

MP I-3ph 2 is reversely routed with 'I' to FG Generator Stator. FG Generator Stator will invert the measured phasor and then calculate the functional values, e.g., active power, as below,

$$P_{tot} = \sqrt{3}*U_{pp}*I_{ph}*\cos\varphi_{UI} = \sqrt{3}*20kV*20.38kA*\cos[0° - (148.21° + 180.00°)] = 599.79 \text{ MW}$$

Verification of Protected object GSUT

Based on Figure 10, now according to the rule of Kirchhoff's Law for the GSUT diff protection, the parameter "*_:8881:116 Neutr.point in dir.of ref.obj*" is set to **"no"**, the MP I-3ph 2 must be routed with "X(routed)" for FG Transformer Side 2. As request from GEN differential protection, the MP I-3ph 2 must be routed with "I(routed - with inverted direction)" for FG Generator Side 2.

For the FG Generator Stator, the MP I-3ph 2 must be routed with "X(routed)" according to the rule of power flow.

Connect measuring points to function group								
	Generator stator			Transformer side 2		Generator side 2	
Measuring point	I 3ph	V SGF	I SGF	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP I-3ph 1[ID 1]							
MP I-3ph 2[ID 2]	X				X		I

Figure 13: Measuring Points routing for the setting "*no*" : ①= 'X', ②= 'X', ③= 'I'

The parameter "*_:8881:116 Neutr.point in dir.of ref.obj = no*" will invert the injected current phasor, i.e., the measured phasor MP I-3ph 2 has the counter phase angle to injected phasor. Please refer to below picture.

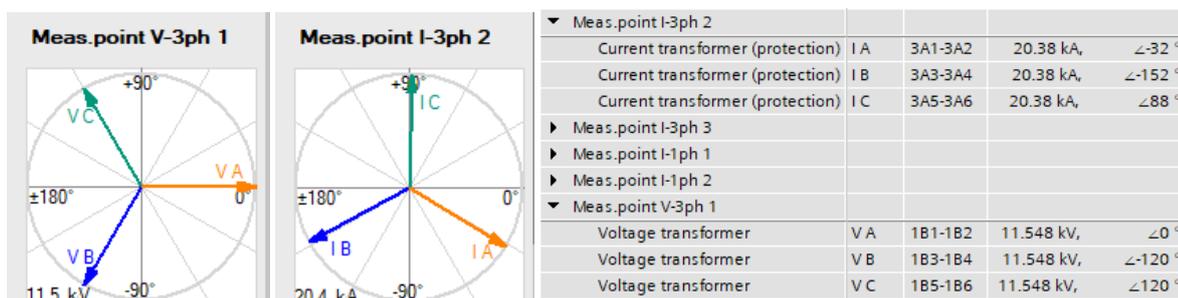| ▾ Meas.point I-3ph 2					
Current transformer (protection)	I A	3A1-3A2	20.38 kA,	∠-32 °
Current transformer (protection)	I B	3A3-3A4	20.38 kA,	∠-152 °
Current transformer (protection)	I C	3A5-3A6	20.38 kA,	∠88 °
▸ Meas.point I-3ph 3				
▸ Meas.point I-1ph 1				
▸ Meas.point I-1ph 2				
▾ Meas.point V-3ph 1				
Voltage transformer	V A	1B1-1B2	11.548 kV,	∠0 °
Voltage transformer	V B	1B3-1B4	11.548 kV,	∠-120 °
Voltage transformer	V C	1B5-1B6	11.548 kV,	∠120 °

Figure 14: Analog Inputs of Special Treatment with Protected Object GSUT

MP I-3ph 2 is routed with 'X' to FG Generator Stator. FG Generator Stator will directly calculate the functional values based on the measured phasors, e.g., active power, as below,

$$P_{tot} = \sqrt{3}*U_{pp}*I_{ph}*\cos\varphi_{UI} = \sqrt{3}*20kV*20.38kA*\cos[0° - (-31.79°)] = 599.79 \text{ MW}$$

Conclusion

After the special treatment for FG Generator Stator, with the parameter "_:8881:116 Neutr.point in dir.of ref.obj" of MP I-3ph 2 setting "*yes*" or "*no*" and the MP routing ("I" or "X") , the FG Generator Stator can properly handle the calculation of the power, the impedance, etc. that is to say, the 3-ph protection functions work well.

The correct operational and functional values are shown on the display as in Figure 4.

1.5 Conclusion

For generator protection application, normally we allocate the 3-ph functions in FG Generator Stator with neutral side current. This is also the default design of SIPROTEC 5.

In some cases, we are required, or must use the lead side current for 3-ph functions. With the before presented configuration we ensure a correct behavior of the generator differential protection and also of the directional functions of the FG generator stator like reverse power(ANSI 32R), under-excitation(ANSI 40), impedance protection(ANSI 21T) or out of step(ANSI 78) protection etc.