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Impedance Protection 3-winding Transformer

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SIPROTEC 5 Application

Impedance Protection 3-winding Transformer (with simulated test cases)

APN-061, Edition 1

Content

1 Impedance Protection 3-winding Transformer (with simulated test cases)

1.1 Introduction

Impedance based protection is a versatile option for redundant protection in many situations. Here a complicated example is used to show how a structured approach with impedance protection can provide effective and manageable protection coverage for difficult fault conditions. The example will use two 3-winding transformers with 3 voltage levels. The diagram below illustrates the example configuration:

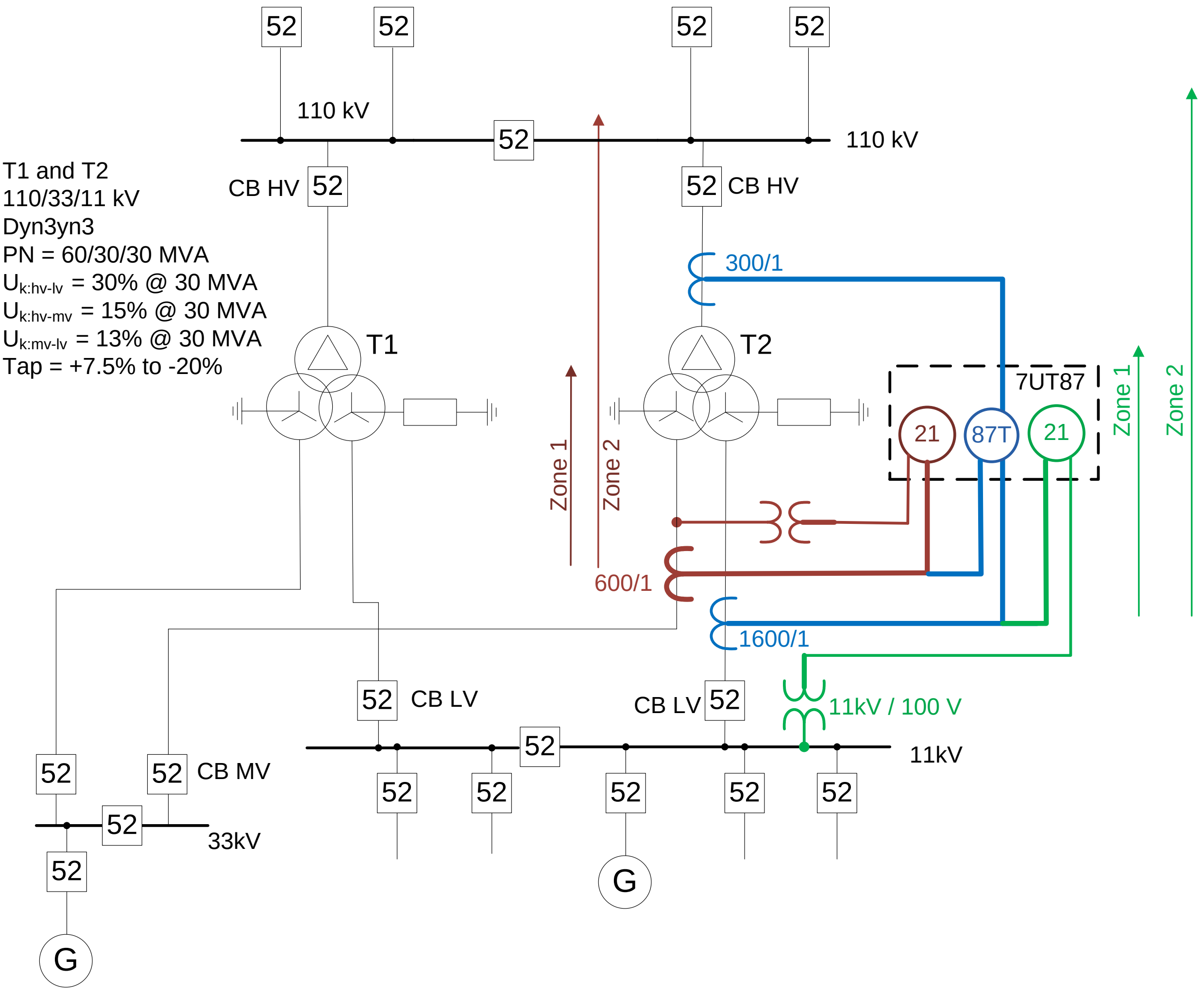

Figure 1: Single line diagram of application (only T2 protection shown)

Based on the data in Figure 1 the following application example with 7UT86 is presented. As the two transformers are identical, the same protection is applied to both (in Figure 1 only the protection for T2 is shown).

1.2 Application with transformer differential protection SIPROTEC 7UT87

The protection application will be with a 7UT86 in this example. The necessity of hardware redundancy in the protection concept is not specifically covered in the application note. The user can however apply the impedance protection functions described here in a different device (e.g. 7SA86, 7SJ85 etc.) that when used next to the transformer differential protection of the 7UT86 provides full hardware redundancy.

The star point winding(s) of the transformer are not connected in this application as it is not required for the back-up impedance protection. Unrestricted earth fault protection, also a very effective transformer protection, would require this CT connection; it is described in the relevant manuals.

1.3 Basic Configuration

For the basic configuration, the Function Groups and Measuring Points as shown below in Figure 2 are applied. The Instrument transformer data is set in the block Power System for the 5 measuring points. The measuring points and Transformer configuration are applied in the Function-group connections.

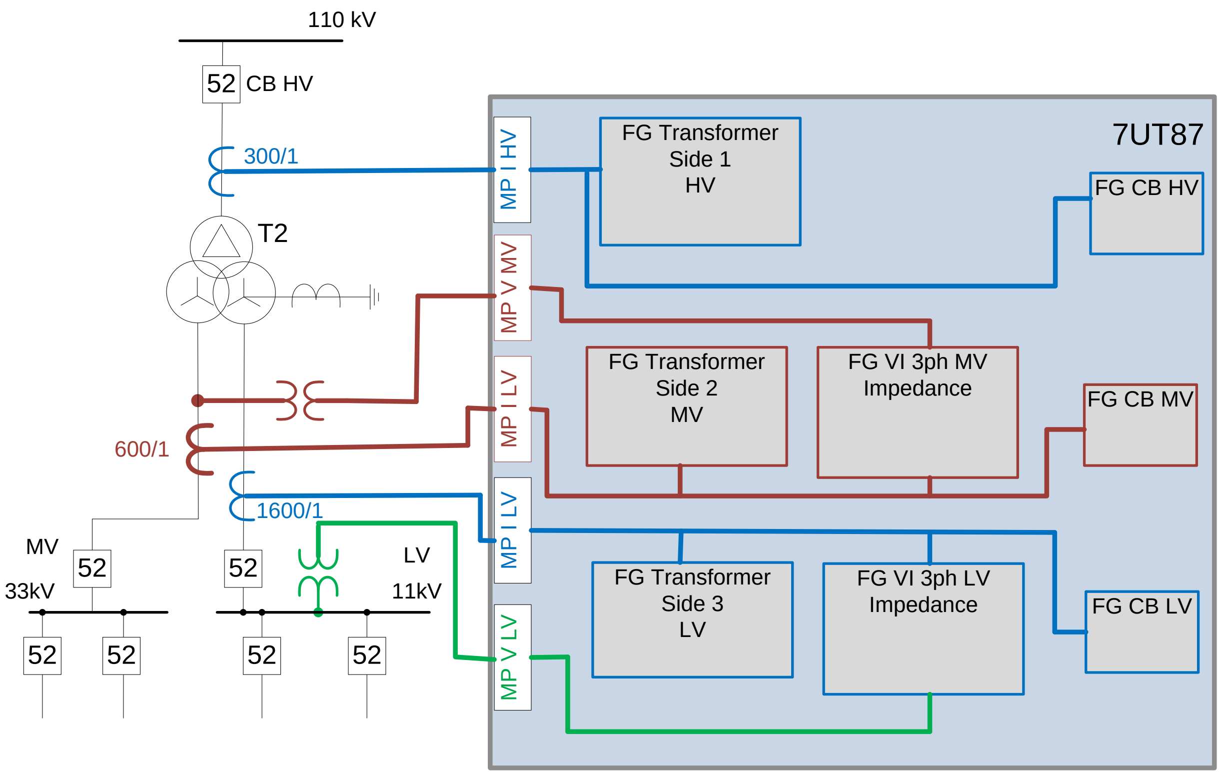

Figure 2: Schematic representation of the Function Groups and Measuring points

Due to the large number of measuring points, circuit breaker etc. it is recommended to use clear names for these, here the structure used in this example:

1.3.1 Measuring points

Current-measuring points

		Base module								Expansion module 3			
		1A				1B				3A			
		1A1-1A2	1A3-1A4	1A5-1A6	1A7-1A8	1B1-1B2	1B3-1B4	1B5-1B6	1B7-1B8	3A1-3A2	3A3-3A4	3A5-3A6	3A7-3A8
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 3A1	I P 3A2	I P 3A3	I P 3A4
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP I-3ph HV	3-phase + IN	I A	I B	I C	IN								
MP I-3ph MV	3-phase + IN					I A	I B	I C	IN				
MP I-3ph LV	3-phase + IN									I A	I B	I C	IN
Add new													

Figure 3: Current measuring points

Voltage-measuring points								
		Expansion module 3				Expansion module 4		
		3B				4B		
		3B1-3B2	3B3-3B4	3B5-3B6	3B7-3B8	4B1-4B2	4B3-4B4	4B5-4B6
Measuring point	Connection type	V 3.1	V 3.2	V 3.3	V 3.4	V 4.1	V 4.2	V 4.3
(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP V-3ph MV	3 ph-to-gnd voltages	V A	V B	V C				
M P V-3ph LV	3 ph-to-gnd voltages					V A	V B	V C

Figure 4: Voltage measuring points

The designation HV, MV and LV are used to classify the three sides.

1.3.2 Function Group Connections

Connect measuring points to function group						
	Trfr side 1 HV		Trfr side 2 MV		Trfr side 3 LV	
Measuring point	V 3ph	I 3ph	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)	(All)	(All)
MP I-3ph HV[ID 1]		X				
MP I-3ph MV[ID 2]				X		
MP I-3ph LV[ID 3]						X
MP V-3ph MV[ID 4]						
M P V-3ph LV[ID 5]						

Figure 5: Assign CT measuring points to transformer sides

Connect measuring points to function group				
	VI 3ph MV		VI 3ph LV	
Measuring point	V 3ph	I 3ph	V 3ph	I 3ph
(All)	(All)	(All)	(All)	(All)
MP I-3ph HV[ID 1]				
MP I-3ph MV[ID 2]		X		
MP I-3ph LV[ID 3]				X
MP V-3ph MV[ID 4]	X			
M P V-3ph LV[ID 5]			X	

Figure 6: Assign CT and VT measuring points to the VI 3ph MV and LV Function Groups

The impedance protection will be applied in the two Function Groups VI 3ph MV and VI 3ph LV. The corresponding measuring points must be assigned as shown above.

Connect function group to circuit-breaker groups			
Protection group	CB HV	CB MV	CB LV
(All)	(All)	(All)	(All)
Trfr side 1 HV	X		
Trfr side 2 MV		X	
Trfr side 3 LV			X
Trfr diff. 1	X	X	X
VI 3ph MV	X	X	X
VI 3ph LV	X	X	X

Figure 7: Function Group to Circuit Breaker interaction

The impedance protection will operate on transformer faults and will need to trip all three breakers in the event of a detected fault, the FG VI 3ph MV and LV are connected with all three circuit breakers.

Note, if protection functions in a transformer side (e.g. O/C) must trip more than the one breaker, then multiple assignments must be applied here too.

1.4 Transformer Differential Protection 87T

The standard function of this protection device is the differential protection for transformers. In this application it is therefore only presented in general form as the back-up impedance protection is the focus of this application. Other optional functions such as Unrestricted ground fault protection E/F (REF) are not covered here. (It is recommended to use a template when applying the device for the 1st time in DIGSI. E.g. "three-winding transformer basic (87T)"):

General

Rated values

911.91.103	Rated apparent power:	60.00	MVA
911.91.102	Rated voltage:	110.00	kV
911.91.101	Rated current:	315	A

Side data

911.91.149	Neutral point:	isolated
911.91.104	Winding configuration:	D (Delta)
911.91.163	Vector group numeral:	0
911.91.130	Side number:	Side 1
911.91.210	MI3ph1 usesMeasP with ID:	1
911.91.215	CT mismatch M I-3ph 1:	0.953

Figure 8: Transformer HV Winding

General

Rated values

912.91.103	Rated apparent power:	30.00	MVA
912.91.102	Rated voltage:	33.00	kV
912.91.101	Rated current:	525	A

Side data

912.91.149	Neutral point:	grounded
912.91.104	Winding configuration:	Y (Wye)
912.91.163	Vector group numeral:	3
912.91.130	Side number:	Side 2
912.91.210	MI3ph1 usesMeasP with ID:	2
912.91.215	CT mismatch M I-3ph 1:	1.143

Figure 9: Transformer MV Winding

General

Rated values

913.91.103	Rated apparent power:	30.00	MVA
913.91.102	Rated voltage:	11.00	kV
913.91.101	Rated current:	1575	A

Side data

913.91.149	Neutral point:	grounded
913.91.104	Winding configuration:	Y (Wye)
913.91.163	Vector group numeral:	3
913.91.130	Side number:	Side 3
913.91.210	MI3ph1 uses MeasP with ID:	3
913.91.215	CT mismatch M I-3ph 1:	1.016

Figure 10: Transformer LV Winding

The rated current and CT ratio have no significant mismatch on any of the windings.

I-DIFF

General

901.1691.11041.1	Mode:	on	
901.1691.11041.2	Operate & flt.rec. blocked:	no	
901.1691.11041.6	Operate delay:	0.00	s

Operate curve

901.1691.11041.3	Threshold:	0.20	I/IrObj
901.1691.11041.100	Slope 1:	0.30	
901.1691.11041.101	Intersection 1 Irest:	0.67	I/IrObj
901.1691.11041.102	Slope 2:	0.70	
901.1691.11041.103	Intersection 2 Irest:	2.50	I/IrObj

Starting detection

901.1691.11041.106	Starting detection:	no	
901.1691.11041.107	Thresh. startup detection:	0.1	I/IrObj
901.1691.11041.108	Factor increasing char.:	2.0	
901.1691.11041.109	Max. perm. Start. time:	5.0	s

DC offset detection

901.1691.11041.110	Factor increasing char. DC:	2.3

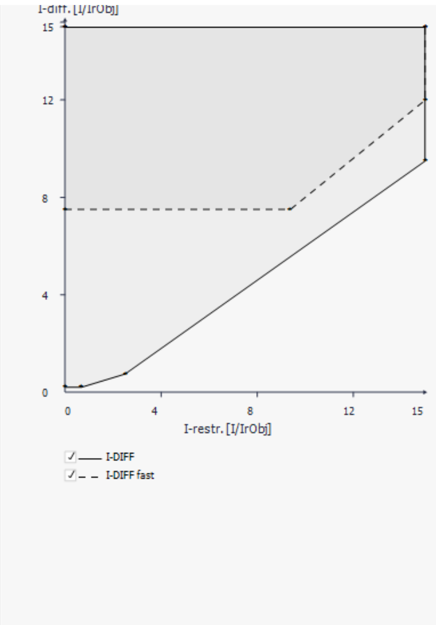

Figure 11: Diff Protection settings

Default settings are applied for the Diff Protection.

1.5 Back-Up Impedance Protection on LV side

The Function-group "VI 3ph MV" and "VI 3ph LV" are applied for the back-up impedance protection on the MV and LV side (refer to Figure 1 and 2). The corresponding current and voltage measuring points were assigned (see above) to the two Function Groups.

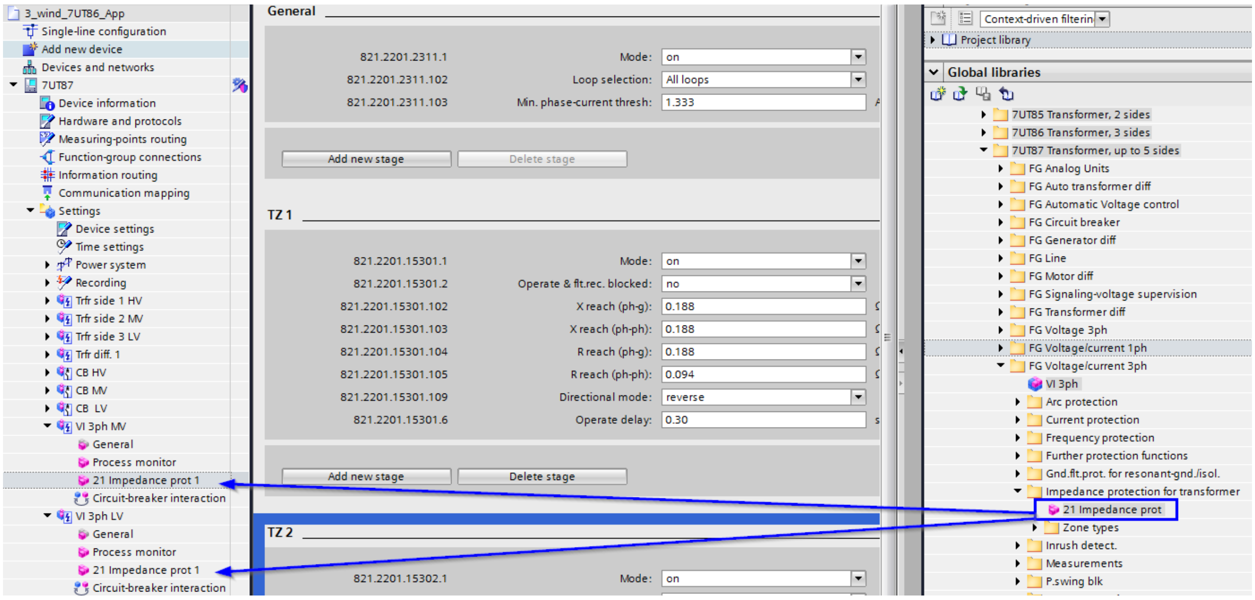

Figure 12: Drag and Drop “21 Impedance prot” into the two FGs”

In Figure 12 the Global Library is shown on the right side. Select the desired function there and drag and drop it into the FG where it must be applied.

When measuring the impedance on the “Y-connected” side looking towards the “Delta”, the apparent impedance measured during a fault on the “Delta” side terminals corresponds to the transformer short circuit impedance. This applies to both single phase and ph-ph loop measurements.

As the HV winding is “Delta” connection there will be no short circuit current in the transformer in the event of an HV Ph-G faults unless there is an external neutral grounding transformer (e.g. Zig-Zag connected). The resulting fault current will appear to be a Ph-Ph fault in the delta winding as there is no means for zero sequence current to flow.

During a Ph-Ph fault on the HV side (Delta) the single-phase measurement on the LV and MV side (Star) will apply (refer to Figure 13 below showing the LV side, but the same applies to the MV side in a three winding transformer – note the vector group is not Dyn3 in this diagram).

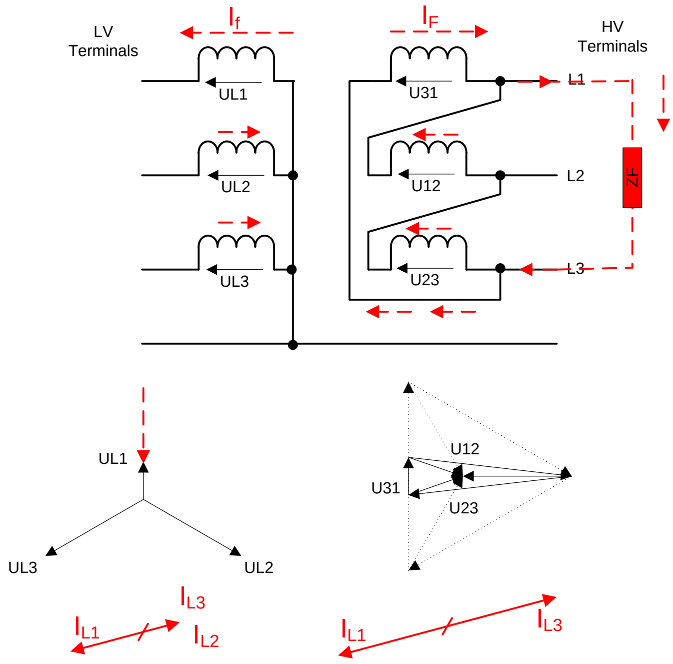

Figure 13: Example L3L1 Fault on HV Terminals (L1, L2 and L3 correspond to A, B and C)

The fault current on the “Delta” side splits up in the transformer as shown. From the Y-side the single-phase loop will measure impedance corresponding to the transformer short circuit impedance.

For this connection only the single-phase measuring elements are applicable in most cases. In order to eliminate ghost loops the following settings are applied under 21 Impedance Protection -> General:

General

821.2201.2311.102	Loop selection:	Current-dependent	
821.2201.2311.104	Overcurrent threshold:	200	A
821.2201.2311.105	Undervoltage seal in:	no	

Figure 14: General Settings of Impedance protection

The “Loop selection” set to Current-dependent ensures that the correct loop for the prevailing fault condition is selected. In the example shown in Figure 13 above, the measured current pattern with IL1 having 2x the magnitude of IL2 and IL3 and at the same time IL1 being in phase opposition to the other 2 currents ensures the selection of loop L1G:

1.5.1 Calculation of transformer short circuit impedance

Calculate the transformer impedance:

$$XT = \frac{u_k \cdot {V_N}^2}{MVA}$$

From the MV side (33 kV side) of the transformer to HV:

$$XT_{MV-HV} = \frac{15\% \cdot 33kV^2}{30\ MVA}$$

= 5.45 Ohm primary

From the LV side (11 kV side) of the transformer to HV:

$$XT_{LV-HV} = \frac{30\% \cdot 11kV^2}{30\ MVA}$$

= 1.21 Ohm primary

From the LV side (11 kV side) of the transformer to MV:

$$XT_{LV-MV} = \frac{13\% \cdot 11kV^2}{30\ MVA}$$

= 0.524 Ohm primary

From the MV side (11 kV side) of the transformer to LV:

$$XT_{MV-LV} = \frac{13\% \cdot 33kV^2}{30\ MVA}$$

= 4.72 Ohm primary

These impedances are applied to the following equivalent circuit (Note: the calculated impedances apply to the respective sides)

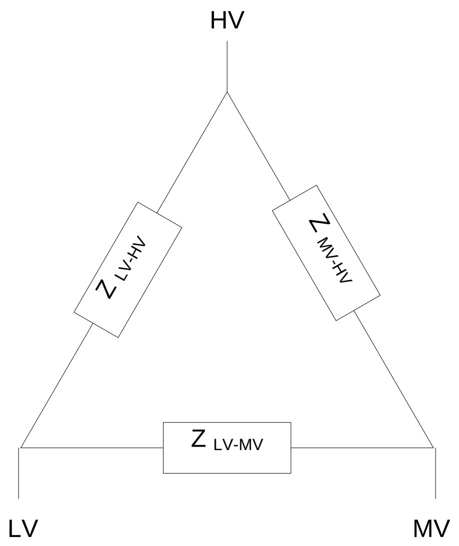

Figure 15: Equivalent circuit for transformer impedance

As the impedance protection is applied on the MV and LV terminals, the impedance "as seen" from these respective terminals must be applied in the settings of the respective zones.

1.5.2 Tap Changer – Impedance Modification

The above impedances apply to the nominal (rated voltage) tap position. If the tap position is modified the impedance towards the HV side will change. The maximum and minimum transformer impedances based on the most extreme tap position are calculated below:

From the MV side (33 kV side) of the transformer:

$$XT_{MV-HV\_\max\_tap} = \frac{15\% \cdot (33kV \cdot 107.5\%)^2}{30\ MVA}$$

= 6.29 Ohm primary

$$XT_{MV-HV\_\min\_tap} = \frac{15\% \cdot (33kV \cdot 80\%)^2}{30\ MVA}$$

=3.48 Ohm primary

From the LV side (11 kV side) of the transformer:

$XT_{LV-HV\_\max\_tap} = \frac{30\% \cdot (11kV \cdot 107.5\%)^2}{30\ MVA}$ $XT_{LV-HV\_\min\_tap} = \frac{30\% \cdot (11kV \cdot 80\%)^2}{30\ MVA}$

= 1.40 Ohm primary = 0.774 Ohm primary

The zone reaches can be applied to these primary impedances when considering the underreach zone.

Reactance	Nominal	Min-Tap	Max-Tap
$X_{MV\text{-}HV}$	5.45	3.48	6.29
$X_{LV\text{-}HV}$	1.21	0.774	1.4
$X_{MV\text{-}LV}$	4.72		
$X_{LV\text{-}MV}$	0.524		

Table 1: Calculated primary transformer impedance for reach settings

1.5.3 Settings for TZ 1 (underreach)

The function of TZ 1 will be to obtain fast back-up tripping for the differential protection. For this purpose, it must be set to not reach through the transformer under any condition. The boundary condition that applies here is infeed from only one winding (LV or MV) and a fault on one of the other terminals of the transformer. The impedance that applies is the minimum impedance with tap changer calculated for 33 and 11 kV above or the corresponding impedance between the LV and MV side.

For the MV side the $XT_{MV\text{-}HV\_min\_tap}$ = 3.48 Ohms applies as it is the smallest.

If a typical safety margin of 20% is applied:

$X_{TZ1\_33kV} = 0.8\ \cdot XT_{MV-HV\_\min\_tap} = 0.8 \cdot 3.48\Omega = 2.78\ \Omega$

For the LV side the $XT_{LV\text{-}MV}$ = 0.524 Ohms applies as it is the smallest. However, the risk of overreach from the LV side onto the MV side during faults on the MV side is so significant, that the TZ 1 on the LV side will also be blocked by the MV side reverse pick-up. See cross blocking below for the TZ 2. The TZ 1 must therefore be delayed (50 ms) to ensure co-ordination and then the reach limitation is $XT_{LV\text{-}HV\ min\_tap}$ = 0.774 Ohms:

$X_{TZ1\_11kV} = 0.8\ \cdot XT_{LV-HV\_\min\_tap} = 0.8 \cdot 0.774\Omega = 0.619\ \Omega$

As there is limited loop selection logic in this impedance function care must be taken to avoid overreach of unfaulted (ghost) loops. This is done by restricting the R-Reach setting. Typically, an R-reach of 1.5 to 2 times the X setting is sufficient.

In this case the selected R-reach is 1.5 times the X reach:

$R_{TZ1\_33kV} = 1.5\ \cdot X_{TZ1\_33kV} = 1.5 \cdot 2.78\Omega = 4.17\ \Omega$

$R_{TZ1\_11kV} = 1.5\ \cdot X_{TZ1\_11kV} = 1.5 \cdot 0.619\Omega = 0.93\ \Omega$

These settings are applied for TZ1:

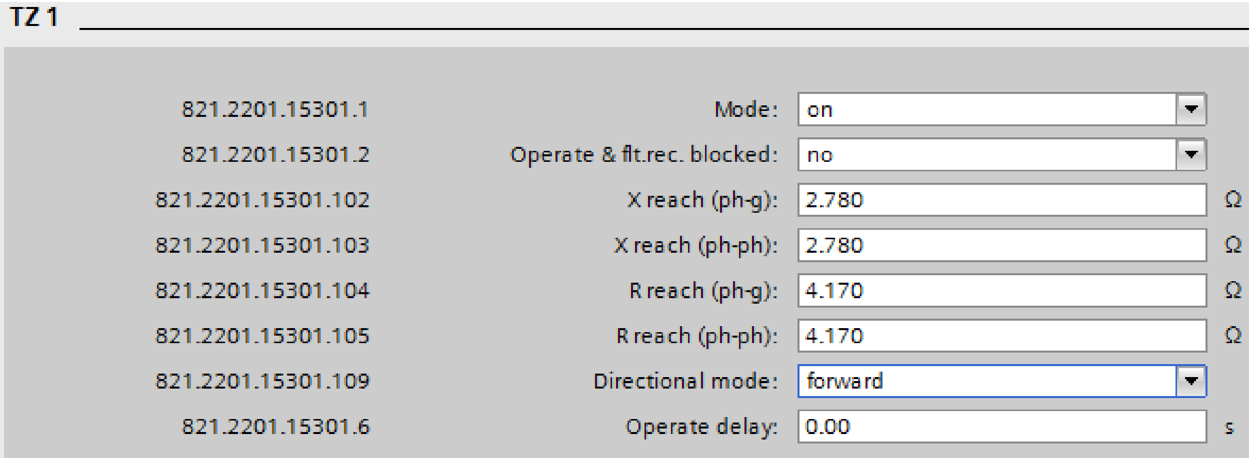

Figure 16: Primary settings for MV side TZ1

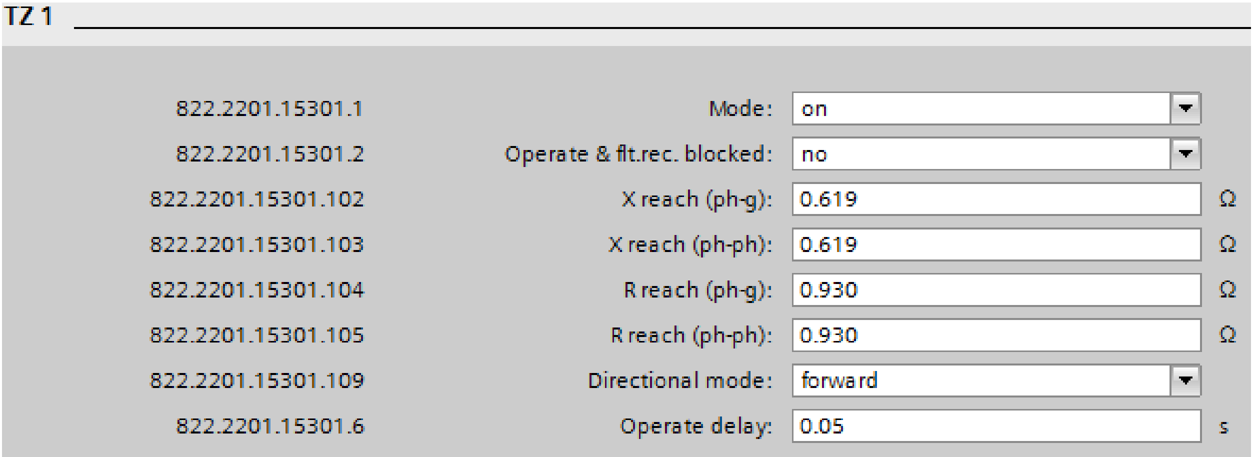

Figure 17: Primary settings for LV side TZ1

The “Ph-Ph” reach is set the same as the Ph-G reach. The “Ph-Ph” loop will only pick-up in the event of faults on the 33 kV or 11 kV (LV and MV) side. The “Ph-G” loop will also pick-up for faults on the HV delta winding side.

1.5.4 Settings for TZ 2

The function of TZ 2 is set to obtain back-up tripping in the event of faults on the HV winding and HV transformer terminals. The reach into the HV side feeders is limited but should ideally cover the HV busbar. In this manner the transformer will be tripped from the LV and MV side when the HV side is disconnected and there is still an HV fault present, even if this fault is outside the transformer diff-protection zone. For this purpose, the TZ2 must be set to reach through the transformer into the HV side from the LV and MV side.

The TZ 2 will also apply for faults on the LV and MV side of the transformer. A cross blocking logic is implemented to prevent TZ 2 tripping on the MV and LV side for faults on the LV and MV side. This is described below.

Typical grading of reach setting is 120% to 200% of transformer short circuit impedance, due to the influence of “parallel” infeed from LV and MV side, reach reduction, a reach of 200% is applied to accommodate this. For the over-reach zone the maximum respective impedance is applied for the calculation of the zone setting:

For the MV side the $XT_{MV\text{-}HV\_max\_tap}$ = 6.29 Ohms applies as it is the largest.

With the margin of 200% applied:

$$X_{TZ2\_33kV} = 2.0 \cdot XT_{MV-HV\_max\_tap} = 2.0 \cdot 6.29\Omega = 12.58\,\Omega$$

For the LV side the $XT_{LV\text{-}HV\_max\_tap}$ = 1.4 Ohms applies as it is the largest.

$X_{TZ1\_11kV} = 2.0 \cdot XT_{LV-HV\_\max\_tap} = 2.0 \cdot 1.4\Omega = 2.8\ \Omega$

As the TZ2 will be time graded and the reach into the HV side feeders is limited, the constraint used for the R-reach is the maximum load current. Under no circumstances may the load result in impedance within the set reach. The maximum resistance setting based on load current is calculated below using 200% rated current as maximum load:

$I_{MV\_Load-max} = 2 \cdot \frac{30\ MVA}{\sqrt{3} \cdot 33\ kV} = 1.05\ kA$ $\quad$ $I_{LV\_Load-max} = 2 \cdot \frac{30\ MVA}{\sqrt{3} \cdot 11\ kV} = 3.15\ kA$

Assuming a minimum operating voltage of 90%, this maximum load current can be used to determine the minimum impedance measured due to load current:

$Z_{MV\_Load-Min} = \frac{0.9 \cdot 33\ kV}{\sqrt{3} \cdot 1.05\ kA} = 16.3\ \Omega$ $\quad$ $Z_{LV\_Load-Min} = \frac{0.9 \cdot 11\ kV}{\sqrt{3} \cdot 3.15\ kA} = 1.81\ \Omega$

The established minimum load impedance is for MV and LV side is less than twice the calculated X-setting. For the MV and LV side the R reach is set based on the load:

$R_{TZ2\_33kV} = Z_{MV\_Load-Min} = 16.3\ \Omega$ $\quad$ $R_{TZ2\_11kV} = Z_{LV\_Load-Min} = 1.81\ \Omega$

These settings are applied for TZ2:

TZ 2

821.2201.15302.1	Mode:	on	
821.2201.15302.2	Operate & flt.rec. blocked:	no	
821.2201.15302.102	X reach (ph-g):	12.580	Ω
821.2201.15302.103	X reach (ph-ph):	12.580	Ω
821.2201.15302.104	R reach (ph-g):	16.300	Ω
821.2201.15302.105	R reach (ph-ph):	16.300	Ω
821.2201.15302.109	Directional mode:	forward	
821.2201.15302.6	Operate delay:	0.30	s

Figure 18: Primary settings for MV side TZ2

TZ 2

822.2201.15302.1	Mode:	on	
822.2201.15302.2	Operate & flt.rec. blocked:	no	
822.2201.15302.102	X reach (ph-g):	2.800	Ω
822.2201.15302.103	X reach (ph-ph):	2.800	Ω
822.2201.15302.104	R reach (ph-g):	1.810	Ω
822.2201.15302.105	R reach (ph-ph):	1.810	Ω
822.2201.15302.109	Directional mode:	forward	
822.2201.15302.6	Operate delay:	0.30	s

Figure 19: Primary settings for LV side TZ2

1.5.5 Cross blocking on MV and LV side for TZ 2 as well as LV side TZ 1

The respective TZ 2 reach will also detect faults on the MV and LV side. To prevent non-selective operation the following signal is applied to block the respective TZ 2.

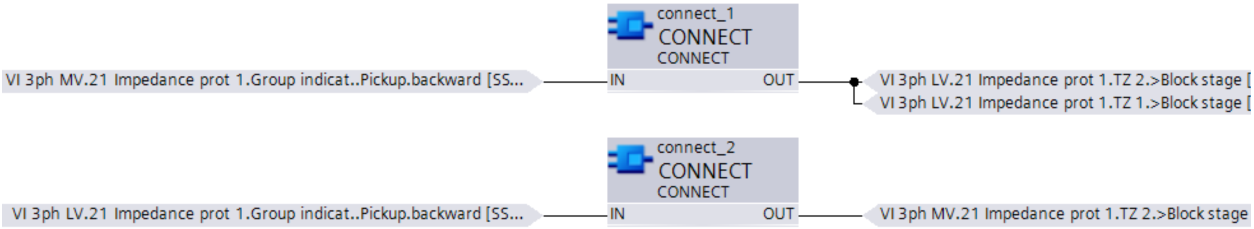

Figure 20: CFC logic for cross blocking of

A reverse (or non-directional) zone is required for the “Pickup.backward” signals in the above diagram. For this purpose, a 3rd zone is applied on the MV and LV side. This zone is set to not operate and has a reach equal to the respective Zone 1 on each side.

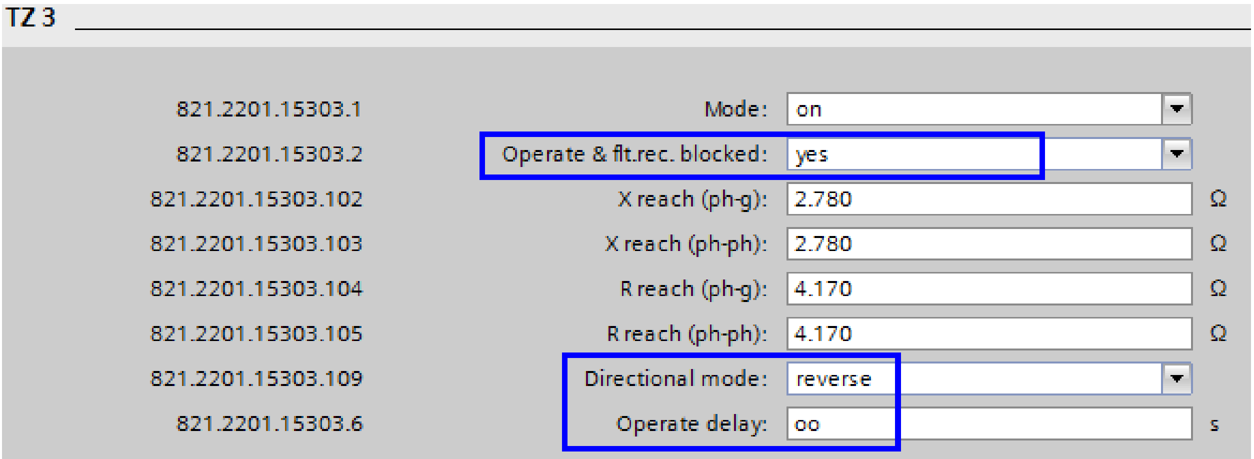

Figure 21: Reverse zone TZ 3 on MV side for cross blocking

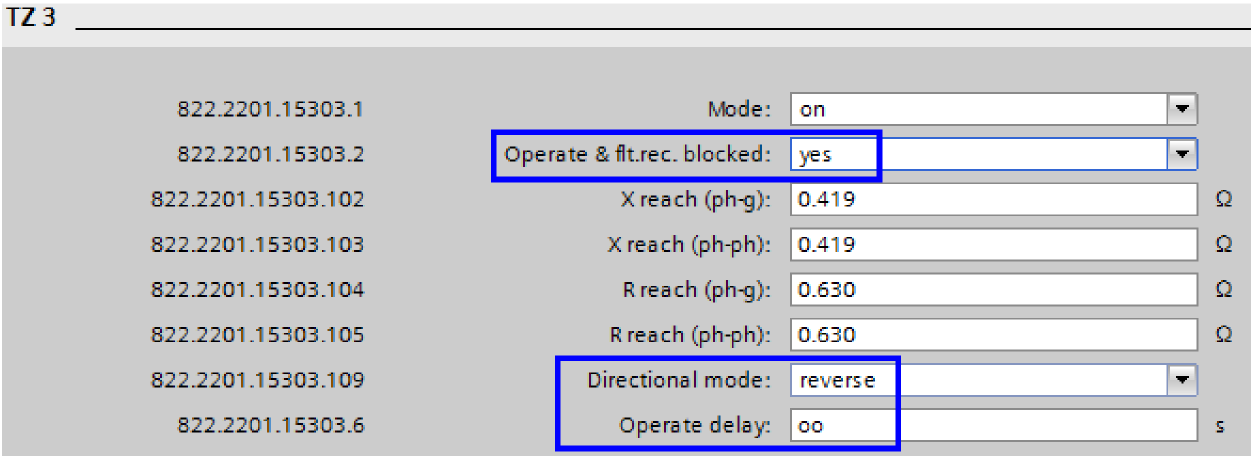

Figure 22: Reverse zone TZ 3 on LV side for cross blocking

When the impedance protection detects a reverse fault on the LV side, the TZ 2 on the MV side is blocked; a reverse pick-up on MV side blocks the LV side in a similar manner.

1.6 Simulated Test Cases

Some tests are done with the model shown below. Initially the reach of the TTZ 2 for faults on the HV side is checked. The correct operation of the cross blocking is then checked with faults on the MV and LV side. The results are provided in tabular form summarizing the relevant details:

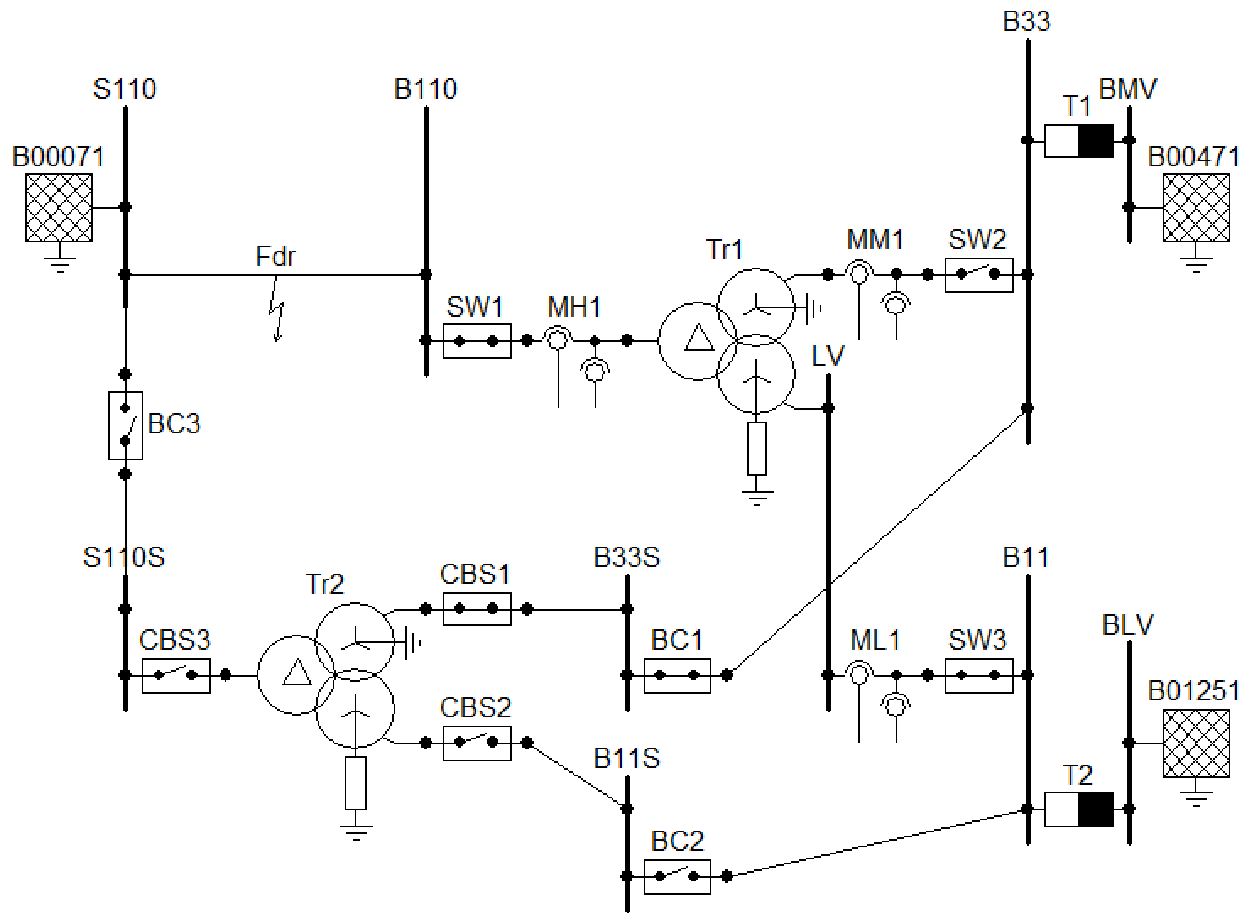

Figure 23: Model used to simulate fault conditions

The test relay is applied to Tr1 where the impedance protection will be evaluated with measured signals at MM1 and ML1.

1.6.1 Condition 1: HV Bus Faults with Tr2 out of service

Faults on the HV Bus with the parallel transformer out of service are done in this section.

<u>**Test 1:**</u> AB Fault on 110 kV Bus with LV CB open

Relative time	Fault	Entry n	Functions structure	Name	Value
	..	...	(All)	(All)	(All)
	1		Fault log		
00:00:00:00.000		2	VI 3ph MV:21 Impedance prot 1:TZ 2	Pickup	phs C forward
00:00:00:00.000		3	VI 3ph MV:21 Impedance prot 1:Group indicat.	Pickup	phs C forward
00:00:00:00.000		4	VI 3ph MV:21 Impedance prot 1:Group indicat.	Selected loop CG	on forward
00:00:00:00.300		5	VI 3ph MV:21 Impedance prot 1:TZ 2	Operate	on
00:00:00:01.984		23	VI 3ph MV:21 Impedance prot 1:TZ 2	Pickup	off
00:00:00:01.984		24	VI 3ph MV:21 Impedance prot 1:TZ 2	Operate	off
00:00:00:01.984		25	VI 3ph MV:21 Impedance prot 1:Group indicat.	Pickup	off
00:00:00:01.984		26	VI 3ph MV:21 Impedance prot 1:Group indicat.	Selected loop CG	off

Figure 24: Fault log of MV side protection

The TZ2 on the MV side operates as expected. The selected loop is CG. The test did not simulate the opening of the CB, the pick-up therefore only resets after 2 seconds.

For test 1 the impedance measured with the CG loop is checked with SIGRA, the measured primary reactance is 5.46 Ω. As expected, this matches the standard $X_{MV\text{-}HV}$ in Table 1.

Test 2: AB Fault on 110 kV Bus with MV CB open

Relative time	Fault	Entry n	Functions structure	Name	Value
	..	...	(All)	(All)	(All)
	2		Fault log		
00:00:00:00.000		2	VI 3ph LV:21 Impedance prot 1:TZ 2	Pickup	phs C forward
00:00:00:00.000		3	VI 3ph LV:21 Impedance prot 1:Group indicat.	Pickup	phs C forward
00:00:00:00.000		4	VI 3ph LV:21 Impedance prot 1:Group indicat.	Selected loop CG	on forward
00:00:00:00.300		5	VI 3ph LV:21 Impedance prot 1:TZ 2	Operate	on
00:00:00:01.990		27	VI 3ph LV:21 Impedance prot 1:TZ 2	Pickup	off
00:00:00:01.990		28	VI 3ph LV:21 Impedance prot 1:TZ 2	Operate	off
00:00:00:01.990		29	VI 3ph LV:21 Impedance prot 1:Group indicat.	Pickup	off
00:00:00:01.990		30	VI 3ph LV:21 Impedance prot 1:Group indicat.	Selected loop CG	off

Figure 25: Fault log of LV side protection

With infeed only from the LV side the LV side also detects the CG loop and operates with TZ 2.

The impedance measured on the LV side is also checked with SIGRA. The CG reactance is 1.20 Ω. As expected, this matches the standard $X_{LV\text{-}HV}$ in Table 1.

Test 3: AB Fault on 110 kV Bus with MV and LV CB closed

Relative time	Fault	Entry n	Functions structure	Name	Value
	..	...	(All)	(All)	(All)
	3		Fault log		
00:00:00:00.000		2	VI 3ph LV:21 Impedance prot 1:TZ 2	Pickup	phs C forward
00:00:00:00.000		3	VI 3ph LV:21 Impedance prot 1:Group indicat.	Pickup	phs C forward
00:00:00:00.000		4	VI 3ph LV:21 Impedance prot 1:Group indicat.	Selected loop CG	on forward
00:00:00:00.004		6	VI 3ph MV:21 Impedance prot 1:TZ 2	Pickup	phs C forward
00:00:00:00.004		8	VI 3ph MV:21 Impedance prot 1:Group indicat.	Selected loop CG	on forward
00:00:00:00.004		7	VI 3ph MV:21 Impedance prot 1:Group indicat.	Pickup	phs C forward
00:00:00:00.300		10	VI 3ph LV:21 Impedance prot 1:TZ 2	Operate	on
00:00:00:00.304		14	VI 3ph MV:21 Impedance prot 1:TZ 2	Operate	on
00:00:00:01.984		33	VI 3ph MV:21 Impedance prot 1:TZ 2	Pickup	off
00:00:00:01.984		35	VI 3ph MV:21 Impedance prot 1:Group indicat.	Pickup	off
00:00:00:01.984		36	VI 3ph MV:21 Impedance prot 1:Group indicat.	Selected loop CG	off
00:00:00:01.984		34	VI 3ph MV:21 Impedance prot 1:TZ 2	Operate	off
00:00:00:01.994		37	VI 3ph LV:21 Impedance prot 1:TZ 2	Pickup	off
00:00:00:01.994		38	VI 3ph LV:21 Impedance prot 1:TZ 2	Operate	off
00:00:00:01.994		39	VI 3ph LV:21 Impedance prot 1:Group indicat.	Pickup	off
00:00:00:01.994		40	VI 3ph LV:21 Impedance prot 1:Group indicat.	Selected loop CG	off

Figure 26: Fault log of MV and LV side protection

Both the MV and LV side protection operate with TZ 2 after the set time of 300 ms.

The reactance measured with CG loop on MV and LV side (with SIGRA) is 10.15 Ω on MV side and 2.00 Ω on LV side. As expected, both are greater than with infeed only on one winding. Further test cases with different source impedance on MV and LV side are summarized in the

Based on the test shown in table 2 above, the secure fault clearance of faults on the HV bus from the MV and LV side is confirmed. When there is significant difference in the source impedance of MV and LV side a sequential trip by the weaker side may occur (test cases 6 and 8).

1.6.2 Condition 2: MV and LV side Faults with Tr2 out of service

On the 3-winding transformer the faults on MV and LV side will also be inside the respective TZ 2 reach. To illustrate this the following tests are carried out:

Test Case	LV Bus Fault	HV Current [A]	MV current [A]	MV Reactance	Pick-up MV side	Pick-up LV side
1	AG	100	52	200	No	Reverse AG
2	AG	98.9	81.8	133	No	Reverse AG
3	AG	89	130	85.1	No	Reverse AG
4	AG	0	618	20.7	No	Reverse AG
5	BC	0	896	4.71	BC forward TZ2 blocked by LV reverse	Reverse BC
6	BC	262	737	9.91	BC forward TZ2 blocked by LV reverse	Reverse BC
7	BC	293	709	10.7	BC forward TZ2 blocked by LV reverse	Reverse BC
8	BC	320	636	12.1	BC forward TZ2 blocked by LV reverse	Reverse BC
9	BC	345	615	12.9	BC forward TZ2 blocked by LV reverse	Reverse BC
10	BC	348	612	13.0	No	Reverse BC
11	ABC	0	1030	4.71	AB, BC, CA forward TZ2 blocked by LV reverse	Reverse AB, BC, CA
12	ABC	327	725	12.3	AB, BC, CA forward TZ2	Reverse AB, BC, CA

					blocked by LV reverse	
13	ABC	348	706	13.0	Transient pick-up no operate	Reverse AB, BC, CA
14	ABC	350	704	13.1	No	Reverse AB, BC, CA

Table 2: LV Bus faults with different source impedances, check TZ 2 operation on MV side

The tests in Table 3 show that the MV side TZ 2 will not operate for Phase to Ground faults on the LV side. Also, the Ph-Ph and 3ph faults will not operate as they are blocked with the reverse pick-up on the LV side.

Test Case	MV Bus Fault	HV Current [A]	LV current [A]	LV Reactance	LV Resistance	Pick-up LV side	Pick-up MV side
1	AG	414	784	1.67	1.41	AG forward TZ2 blocked by MV reverse	Reverse AG
2	AG	440	778	1.67	1.46	AG forward TZ2 blocked by MV reverse	Reverse AG
3	AG	452	582	1.76	1.98	AG forward TZ2 blocked by MV reverse	Reverse AG
4	AG	464	433	1.69	2.58	No	Reverse AG
5	BC	0	495	0.523	0.045	BC forward TZ2 blocked by MV reverse	Reverse BC
6	BC	588	492	0.071	0.212	BC forward TZ1 blocked by MV reverse	Reverse BC
7	ABC	0	544	0.522	0.050	BC forward TZ2 blocked by MV reverse	Reverse BC
8	ABC	587	565	0.070	0.223	BC forward TZ1 blocked by MV reverse	Reverse BC

Table 3: MV Bus faults with different source impedances, check TZ 2 and TZ 1 operation on LV side

The cross blocking implemented to prevent operation of the impedance protection during faults on the LV and MV side served its purpose. In particular the cases 6 and 8 in Table 4 above are interesting as here the TZ 1 on the LV side needed to be blocked from the MV side.

1.7 Conclusion

The impedance protection on the LV and MV side of power transformer can effectively be applied to detect faults on the HV side. To prevent overreach for faults on MV and LV side a cross blocking logic was applied. It securely prevented all possible maloperations for these fault conditions. When the HV side is feeding the fault the reach of the impedance protection into the HV side is significantly reduced so that large zone settings are required for operation under these conditions.

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