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Impedance protection on power transformer

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SIPROTEC 5 Application

Impedance Protection on Power Transformer

APN-045, Edition 1

Content

1 Impedance Protection on Power Transformer (with simulated test cases)

1.1 Introduction

The following diagram is the basis for the application:

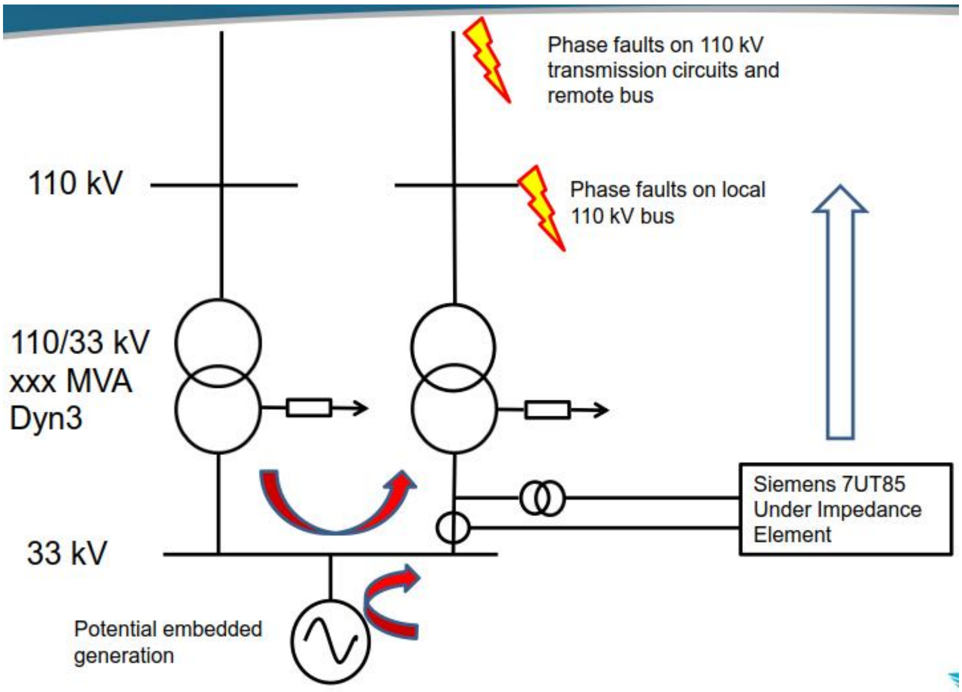


Figure 1: Single line diagram of the application

Based on the single diagram the transformer protection SIPROTEC 7UT86 is applied and represented in this application.

1.2 Application with SIPROTEC 7UT86 transformer differential protection

The SIPROTEC 7UT86 transformer differential protection has been designed specifically for the protection of three-winding transformers. It is the main protection for transformer. Additional protection functions can also be used as backup protection for protected downstream objects (such as cables, line).

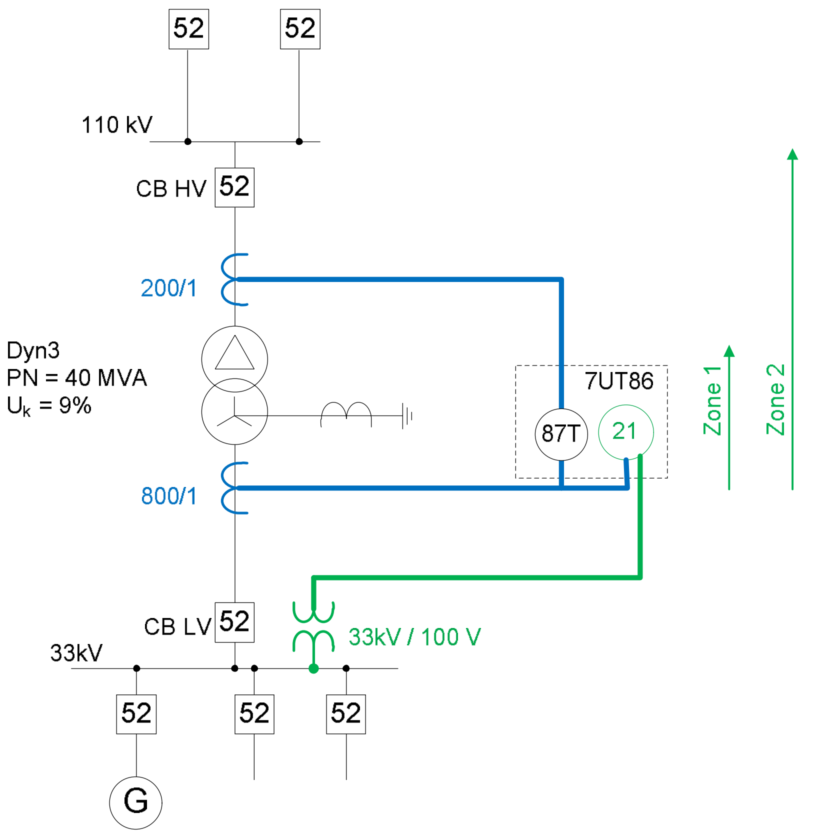


Figure 2: Single line diagram

The star point winding of the transformer is not connected in this application as it is not required for the back-up impedance protection.

1.3 Basic configuration

For the basic configuration, the Function Groups FG and Measuring Points MP as shown below in Figure 2 are applied. The Instrument transformer data is set in the block Power System for the 3 measuring points. The measuring points and Transformer configuration are applied in the Function-group connections.

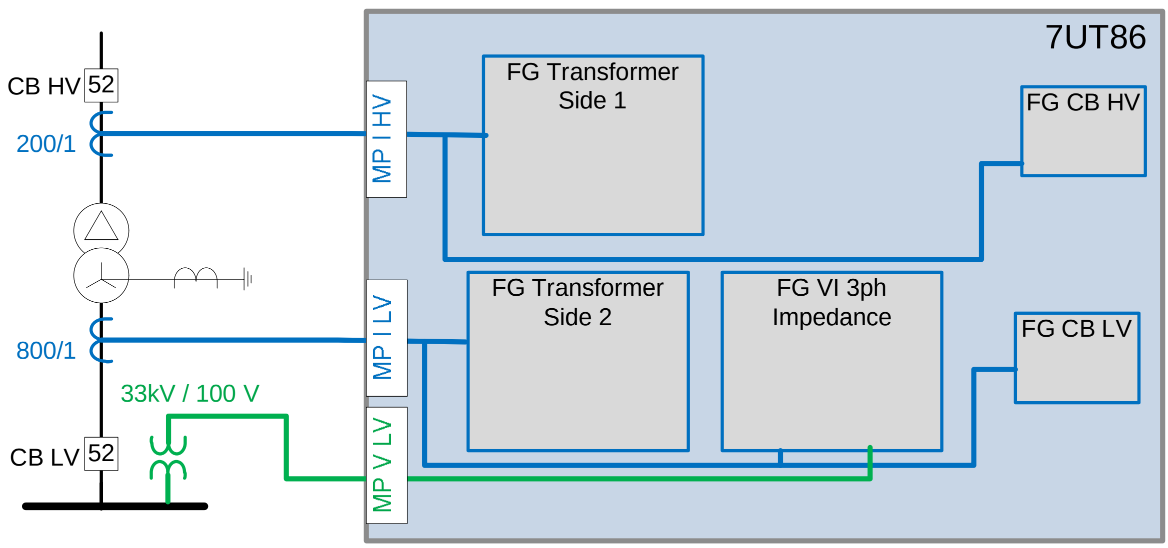


Figure 3: Schematic representation of the Function Groups and Measuring points

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 restricted E/F (REF) are not covered here.

General

Rated values

911.91.103	Rated apparent power:	40.00	MVA
911.91.102	Rated voltage:	110.00	kV
911.91.101	Rated current:	210	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 4: Transformer HV Winding

General

Rated values

912.91.103	Rated apparent power:	40.00	MVA
912.91.102	Rated voltage:	33.00	kV
912.91.101	Rated current:	700	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 5: Transformer LV Winding

The rated current and CT ratio have no significant mismatch on either winding.

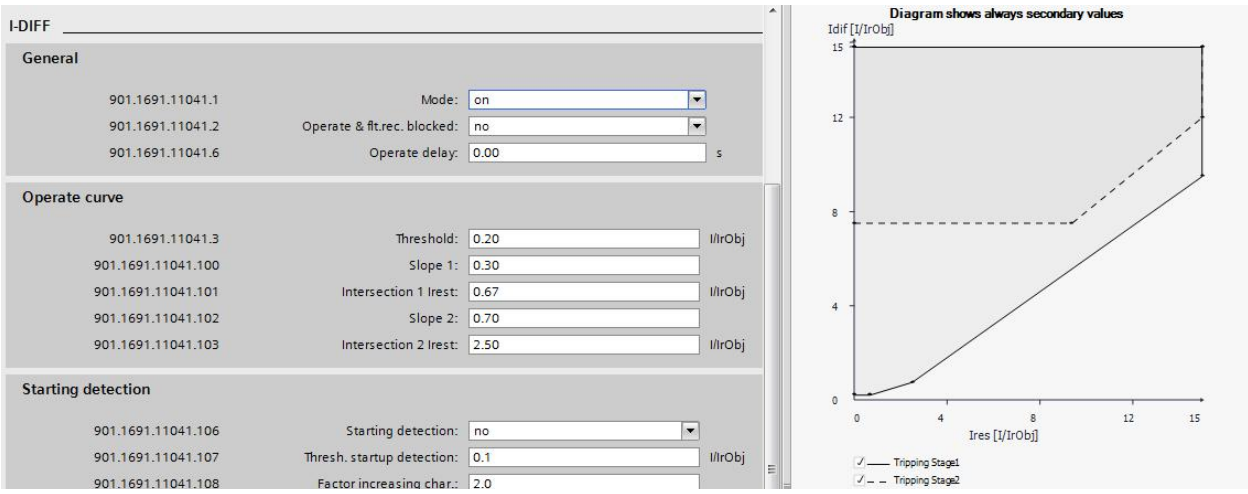


Figure 6: Differential Protection settings

Default settings are applied for the Diff Protection.

1.5 Back-up Impedance protection on LV side

The Function-group “VI 3ph LV Impedance” is applied for the back-up impedance protection on the LV side (refer to Figure 3). The LV bus voltage measured at MP V LV is used along with the LV side measured current from MP I LV.

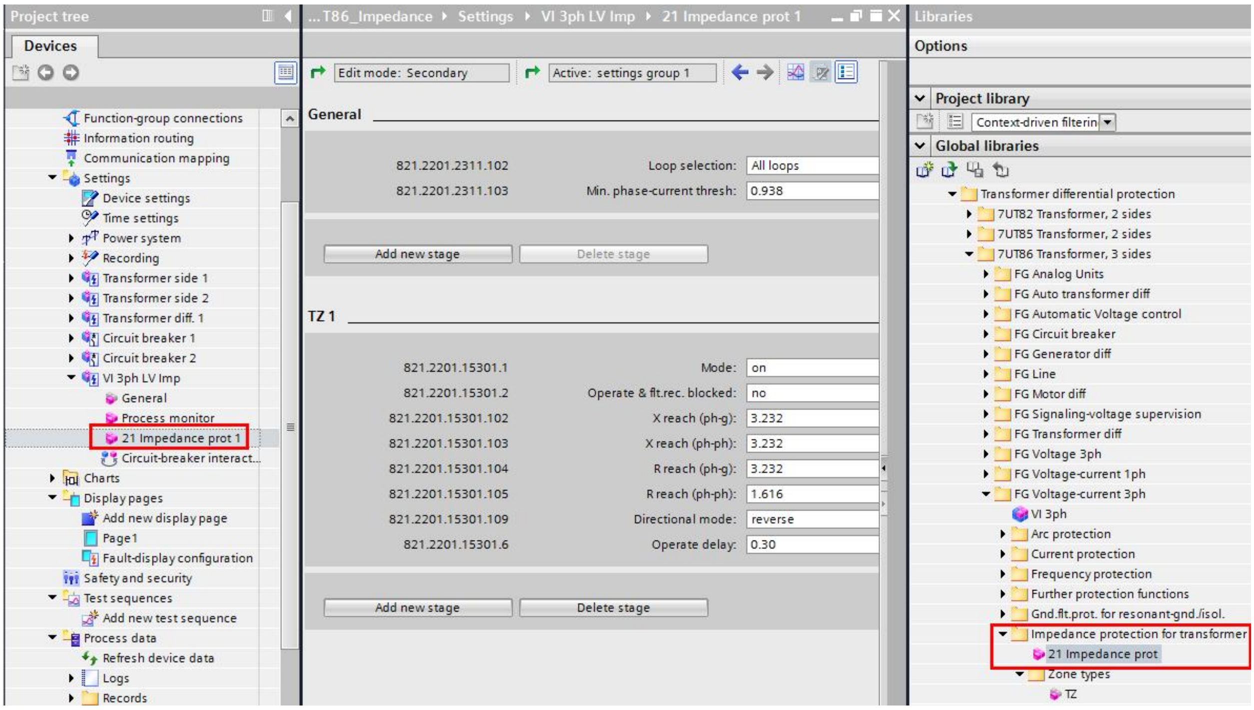


Figure 7: Drag and Drop “21 Impedance prot” into the FG “VI 3ph LV Imp”

In Figure 7 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 fault 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 side (Star) will apply (refer to Figure 8 below – note the vector group is not Dyn3 in this diagram).

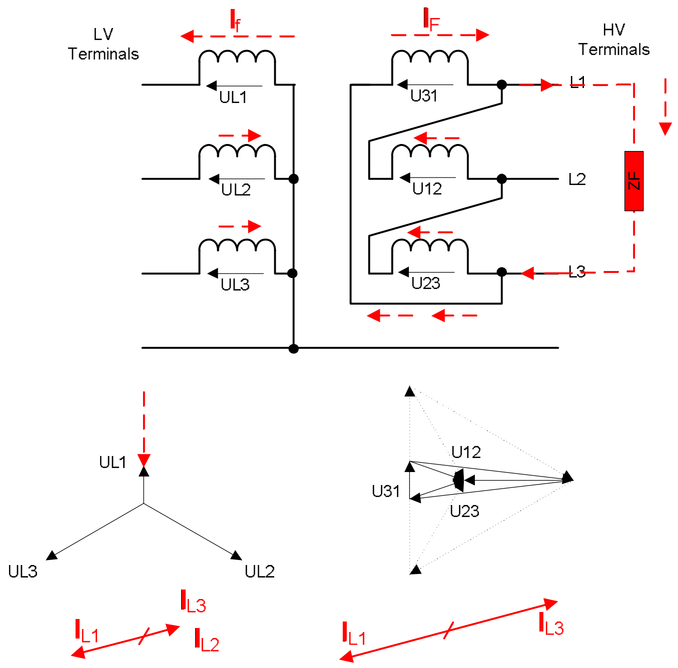
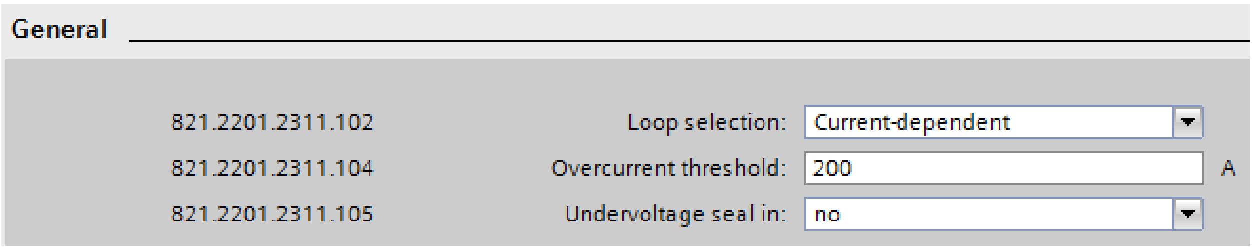


Figure 8: Example L3L1 Fault on HV Terminals (L1, L2 and L3 correspond to A, B and C)

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 9: General Settings of Impedance protection

The “Loop selection” set to Current-dependant ensures that the correct loop for the prevailing fault condition is selected. In the example shown in Figure 8 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:

1.6 Calculation of transformer short circuit impedance

Calculate the transformer impedance:

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

From the 33 kV side of the transformer:

$$XT_{33\,kV} = \frac{9\% \cdot 33kV^2}{40\,MVA}$$

= 2.45 Ohm primary

The zone reaches can be applied to this primary impedance

1.7 Settings for TZ1

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. If a typical safety margin of 20% is applied:

$X_{TZ1} = 0.8 \cdot XT_{33} = 0.8 \cdot 2.45\Omega = 1.96\ \Omega$

As there is limited loop selection logic in this impedance function care must be taken to avoid overreach of un-faulted (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:

$R_{TZ1} = 1.5 \cdot X_{TZ1} = 1.5 \cdot 1.96\Omega = 2.94\ \Omega$

These settings are applied for TZ1:

TZ 1

821.2201.15301.1	Mode:	on	
821.2201.15301.2	Operate & flt.rec. blocked:	no	
821.2201.15301.102	X reach (ph-g):	1.960	Ω
821.2201.15301.103	X reach (ph-ph):	1.960	Ω
821.2201.15301.104	R reach (ph-g):	2.940	Ω
821.2201.15301.105	R reach (ph-ph):	2.940	Ω
821.2201.15301.109	Directional mode:	forward	
821.2201.15301.6	Operate delay:	0.00	s

Figure 10: Primary settings for TZ1

The “Ph-Ph” reach is set the same as the Ph-G reach. This loop will only pick-up in the event of faults on the 33 kV (LV) winding.

1.8 Settings for TZ2

The function of TZ 2 will be 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 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. Typical grading setting is 120% to 200% of transformer short circuit impedance, in this case a reach of 150% is applied:

$X_{TZ2} = 1.5 \cdot XT_{33} = 1.5 \cdot 2.45\Omega = 3.675\ \Omega$

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 inrush current will be detected and used to block the TZ2 stage (see below). The maximum resistance setting based on load current is calculated below using 200% rated current as maximum load:

$$I_{Load-max} = 2 \cdot \frac{40\ MVA}{\sqrt{3} \cdot 33\ kV} = 1.4\ kA$$

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

$$Z_{Load-Min} = \frac{0.9 \cdot 33\ kV}{\sqrt{3} \cdot 1.4\ kA} = 21.2\ \Omega$$

In this event, the established minimum load impedance is approx 6 times larger than the established TZ2 X-reach. To maintain zone symmetry, the R-reach is limited to 2 times X reach:

$$R_{TZ2} = 2 \cdot X_{TZ2} = 2 \cdot 3.675\Omega = 7.35\ \Omega$$

These settings are applied for TZ2:

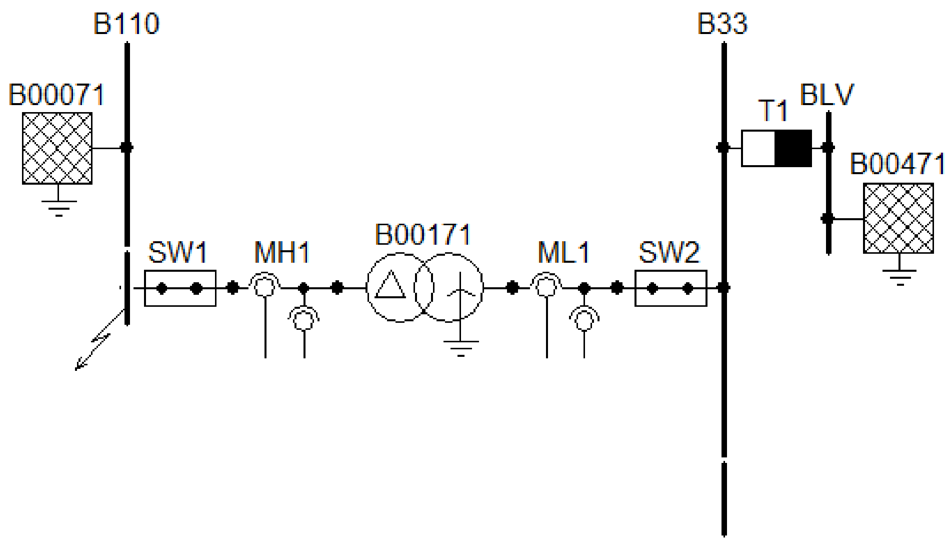
TZ 2

821.2201.15302.1	Mode:	on	
821.2201.15302.2	Operate & flt.rec. blocked:	no	
821.2201.15302.102	X reach (ph-g):	3.675	Ω
821.2201.15302.103	X reach (ph-ph):	3.675	Ω
821.2201.15302.104	R reach (ph-g):	7.350	Ω
821.2201.15302.105	R reach (ph-ph):	7.350	Ω
821.2201.15302.109	Directional mode:	forward	
821.2201.15302.6	Operate delay:	0.30	s

Figure 10: Primary settings for TZ2

1.9 Simulated Test Cases

Some tests are done with faults on the HV bus:



1.9.1 1 BC Fault on 110kV bus

Time stamp	Relative time	Fault number	Entry number	Functions structure	Name	Value
		(All)	(All)	(Custom filter...)	(All)	(All)
19.07.2017 12:54:14.336 (...		3		Fault log		
19.07.2017 12:54:14.3...	00:00:00:00.018		4	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Pickup	phs A forward
19.07.2017 12:54:14.3...	00:00:00:00.018		5	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Pickup	phs A forward
19.07.2017 12:54:14.3...	00:00:00:00.018		6	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Selected loop AG	on forward
19.07.2017 12:54:14.6...	00:00:00:00.318		8	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Operate delay expired	on
19.07.2017 12:54:14.6...	00:00:00:00.318		9	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Operate	on
19.07.2017 12:54:14.6...	00:00:00:00.318		10	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Operate	on
19.07.2017 12:54:16.3...	00:00:00:02.022		17	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Pickup	off
19.07.2017 12:54:16.3...	00:00:00:02.022		18	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Operate delay expired	off
19.07.2017 12:54:16.3...	00:00:00:02.022		19	VI 3ph LV Imp:21 Impedance prot 1:TZ 2	Operate	off
19.07.2017 12:54:16.3...	00:00:00:02.022		20	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Pickup	off
19.07.2017 12:54:16.3...	00:00:00:02.022		21	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Operate	off
19.07.2017 12:54:16.3...	00:00:00:02.022		22	VI 3ph LV Imp:21 Impedance prot 1:Group i...	Selected loop AG	off

The TZ2 zone operates after its set time delay with AG loop.

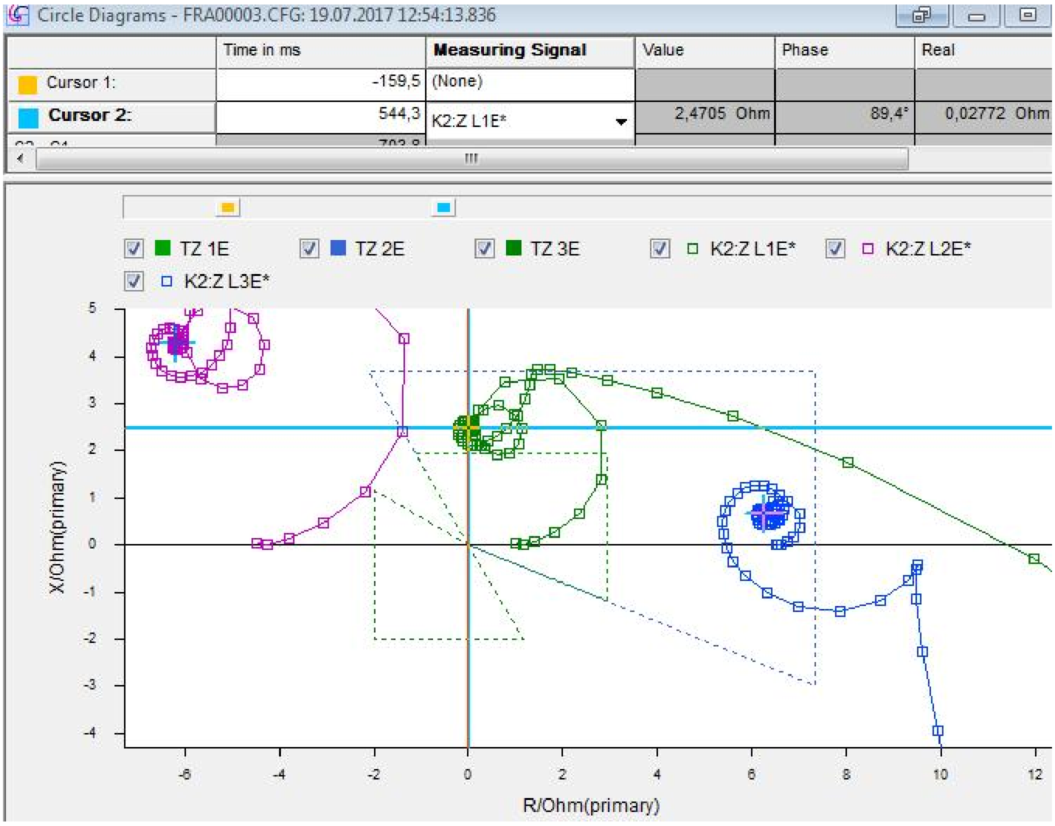


Figure 2: Secondary impedance of single phase loops (BC fault on 110 kV bus)

In Figure 10 the selected loop L1E is inside TZ2 (2.47 Ohm) The calculated transformer impedance (only reactance) was 2.45 Ohm.

The L3E loop is also inside the TZ2, but not selected due to the setting “current-dependant” under General above.

1.9.2 2 BC Fault + 10 Ohm Fault resistance on 110kV bus

Adding fault resistance has minimal effect when the 110 kV side is disconnected:

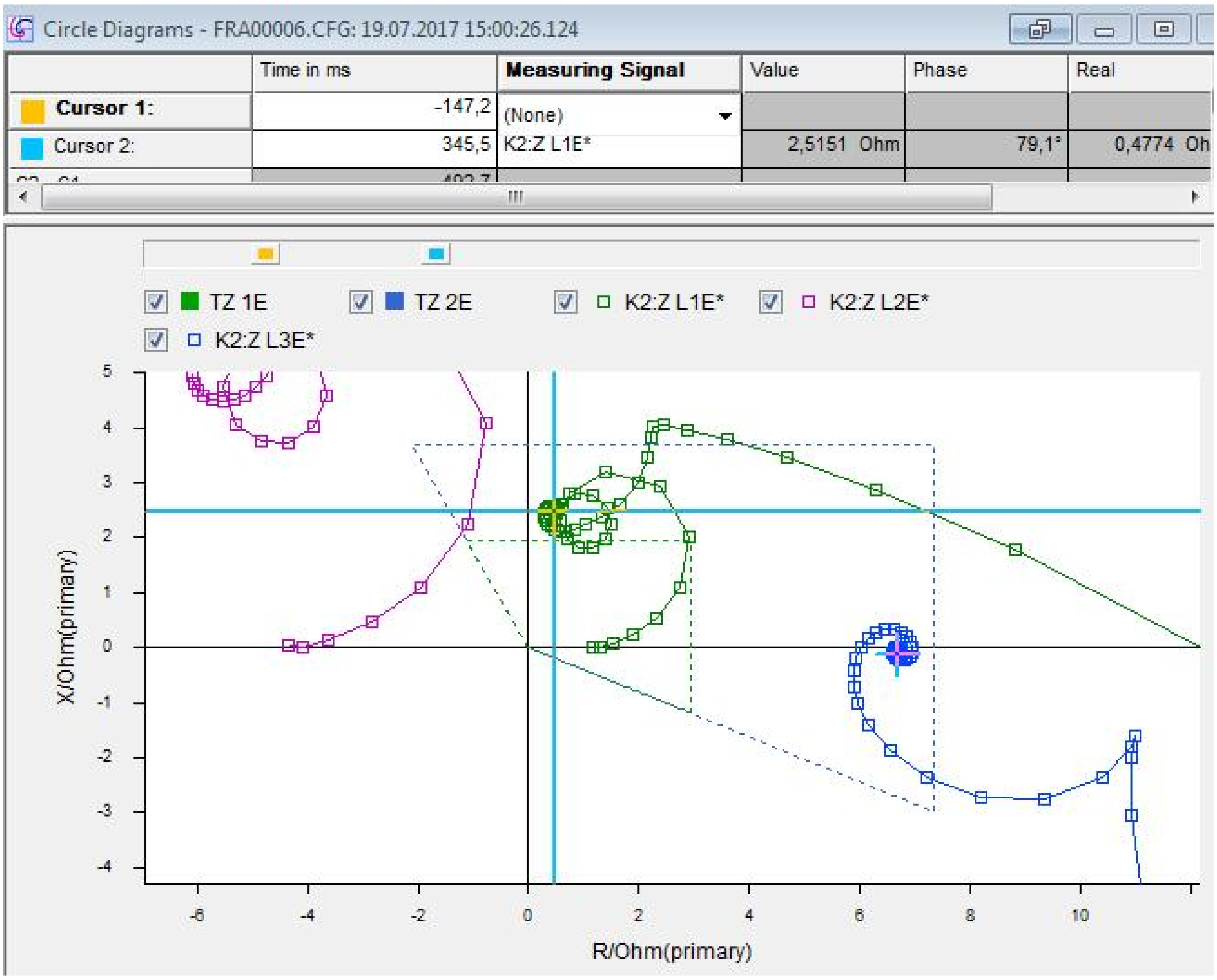


Figure 12: Secondary impedance of single phase loops (BC fault on 110 kV bus + 10 Ohm fault resistance)

The measured impedance in Figure 12 includes the fault resistance of 10 Ohm. The real component of the measured impedance is increased from 0.027 to 0.477 Ohm, a delta of 0.45 Ohm. This is due to the conversion from HV to LV:

$$R_{LV} = R_{HV} \cdot \frac{1}{n^2} = \frac{10\,\Omega}{2} \cdot \left(\frac{33\ kV}{110\ kV}\right)^2 = 0.45\,\Omega$$

This can be applied here because for this test the infeed from the HV side was switched off (HV side no longer feeding onto the fault).

In practice it shows that when the impedance protection is applied on the LV side it is not necessary to apply a very large R-setting.

1.9.3 2 AB Fault on Feeder, 20 km from 110kV Bus

To check the reach into the 110 kV side a fault on a line connected to the 110 kV bus was simulated at a distance of 20 km. This fault is still just inside the set zone 2 reach (150%) as shown below.

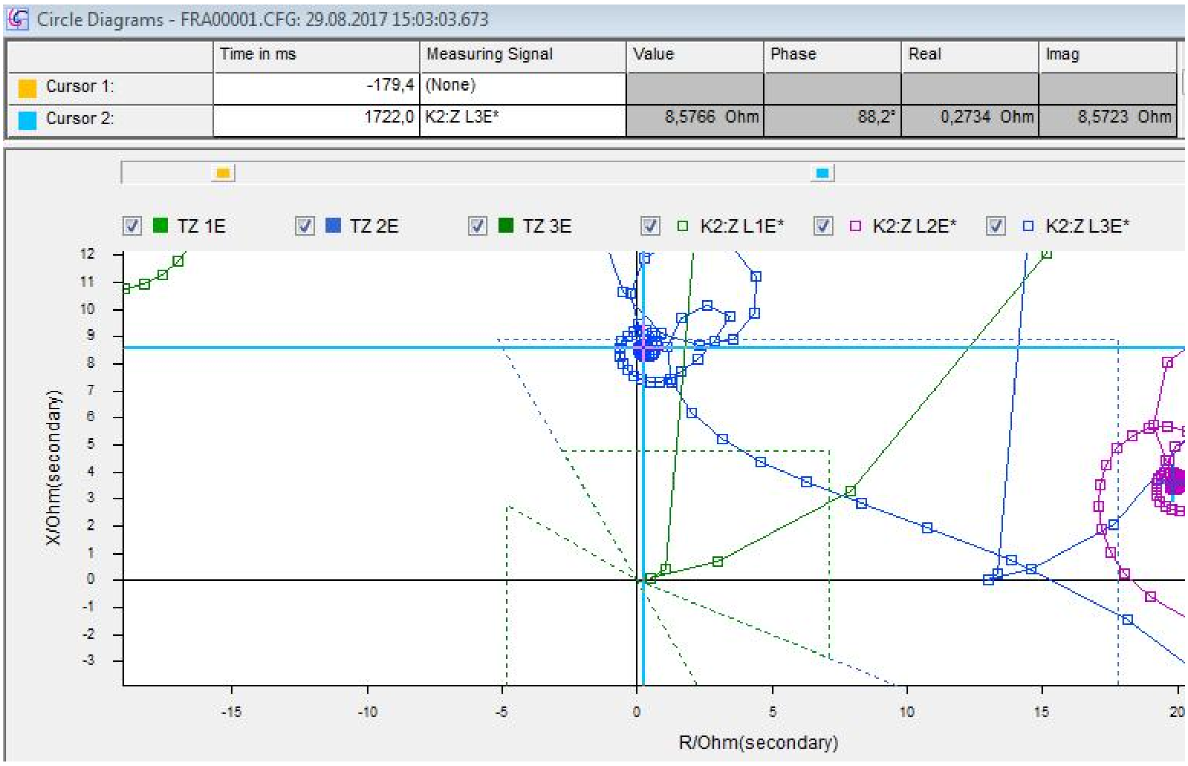


Figure 3: Secondary impedance of single phase loops (AB fault on feeder, 20 km from 110 kV bus

The unfaulted (ghost) loop impedance is outside the set Zone 2 (consideration of zone symmetry under settings above) so that the current dependant loop selection does not have to be depended on to prevent non-selective operation due to ghost impedance.

1.9.4 Influence of “Short circuit power “on MV side

For the test cases above the short circuit power on the 33 kV side was simulated at 10000 MVA. The resulting fault current in phase C (L3) for the case shown in Figure 12 was 3.94 kA. This is large due to the strong simulated infeed. In Table 1 below the results with reduced infeed are shown.

The short circuit impedance of the transformer was calculated above = 2.45 Ohm primary.

It is the dominant current limiting impedance for strong sources (in this simulation sources with more than 1000 MVA short circuit Level have an impedance of less than 1 Ohm). For weaker sources the source impedance is the dominant current limiting factor.

	SOURCE	Fault Current	Must operate!	
Fault No. 29.08.2017 In DEX5	33 kV Short Circuit Level [MVA]	33 kV side Fault Current [kA]	Zone 2 Operate	Z_source (V^2/MVA) [Ohm]
1	10000	3,94	Yes	0,11
2	5000	3,84	Yes	0,22
3	1000	3,21	Yes	1,09
4	200	1,76	Yes	5,45
5	100	1,11	Yes	10,89
6	50	0,635	Yes	21,78
7	25	0,334	Yes	43,56
8	20	0,266	Yes	54,45
9	15	0,197	Yes	72,60
10	14	0,183	No	77,79

Figure 14: Influence of Source Impedance

The zone 2 impedance function operates for fault currents down to the set current limit of 200 A primary (Figure 9: General Settings of Impedance protection).

1.10 Modified Model with Parallel Transformers

The following model is applied to check the effectiveness of the impedance protection in this application when there is only infeed via a parallel transformer.

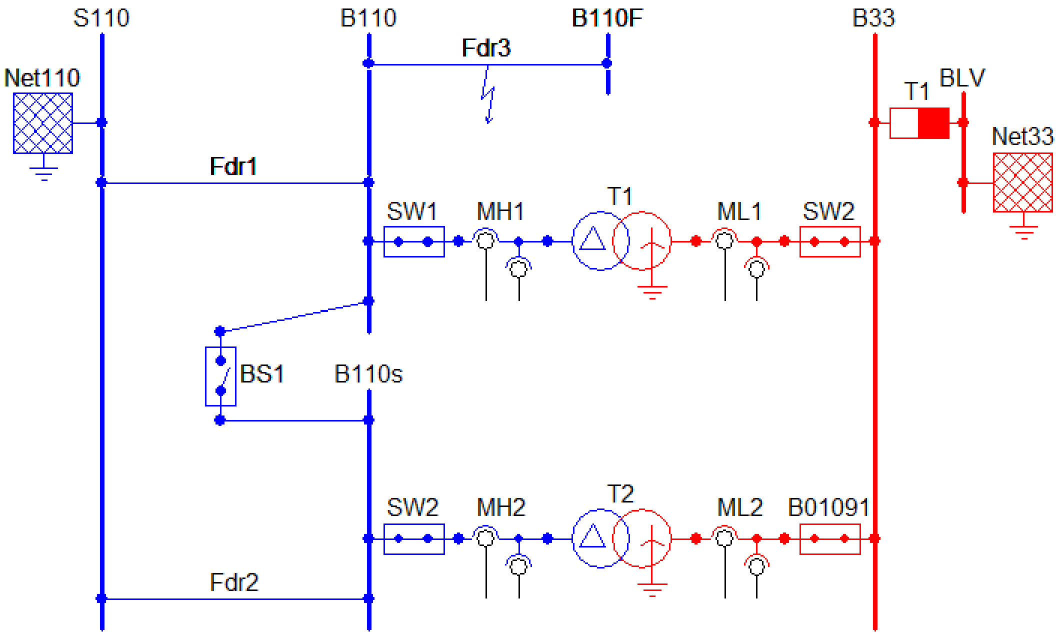


Figure 4: Model for simulation with parallel transformer

The Impedance protection is still applied on the LV side of transformer T1 using the measured voltage and current from measuring point ML1. Faults will be applied on the 110 kV side on feeder Fdr3. The bus section switch (BS1) must be open, if it is closed there will be no infeed to the fault via transformer T2. The 2 feeders (Fdr1 and Fdr2) are identical and modeled as typical 50 km over-head lines. The 33 kV source (Net33) is disconnected for these test cases. Net110 is modeled with a short circuit power of 10000 MVA which is not particularly high for 110 kV.

Transformer short circuit Z =			2,45	Ohm primary
Net110 Short circuit power =			10000	MVA
Fdr3 Fault Location [km]	Fault Current (Impedance) [A]	Primary Loop Impedance	% of Transformer Short Circuit Z	Zone 2 (150%) operate
20	1768	5,859975	239,2%	No
10	2104	4,1617125	169,9%	No
5	2320	3,287625	134,2%	Yes

Figure 16: Summary of Test results

Table 2 shows that, despite the large fault current (2 kA), the reach into the 110 kV system is significantly smaller than was the case during the earlier tests with the 110 kV side switched off (Fault at 20 km was just inside Zone 2). This is due to the dominant fault current flowing directly from the 110 kV source to the fault. As a result of this the fault infeed via the transformer acts as “intermediate infeed” and therefore has reduced reach.

1.11 Conclusion

The impedance protection on the LV side of a power transformer can effectively be applied to detect faults on the HV side. When the HV side is feeding the fault the reach of the impedance protection is significantly reduced so that large zone settings are required for operation under these conditions.

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