A Case Study of Transformer Neutral Common Grounding Effects

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ABSTRACT

The paper presents practical issue experienced with nuisance tripping of incomer earth fault protection relay due to insufficient considerations of possible ground current paths in case of common grounding connection for multiple transformers. The design scenarios considered here represent the common industrial practice in Medium voltage [MV] & Low Voltage [LV] distribution network. The effect of different grounding & power distribution designs on the ground fault currents are analysed. The exemplary cases that can be referred to perform fault current calculations necessary for each fault protection co-ordination are presented. The paper also provide guideline to avoid inappropriate grounding design in case of common grounding for multiple transformers.
The examples given in this paper can be used as a reference by power engineers to study the fault current distribution and therefore avoiding inappropriate designs in grounding studies, earth fault protection co-ordinations and associated safety practices.

Keywords
Fault current, current split, earth current, common grounding, protection, transformer neutral

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Introduction

The reliability, selectivity and safety are some of key parameters to be considered for designing power distribution system. The grounding method selected for power system design plays crucial role in detection & safe isolation of earth fault during extrinsic scenarios. The different possible types of grounding methods along with their pros and cons are very well presented in existing literatures [13][9]. The amount of current flowing through ground circuit are based on the type of fault and neutral to ground impedance [3]. The single phase to ground fault and double line to ground fault are most common fault compared to three phase to ground fault. The protection studies performed during design phase of newly built project mainly focuses on three phase fault cases considering worst case situation. The effect of ground fault current distribution are sometimes overlooked specially during modification of existing power distribution system. If the protection relay is set to follow the Inverse Definite Minimum Time [IDMT] characteristic for earth fault setting then relay will operate faster for increased earth fault current. The paper represent one such practical issue experienced and analysed the accurate earth fault current in case of different common grounding scenarios. The replacement of existing switchgears and transformers to cater additional power requirements, replacement of outdated switchboards and associated equipment's are some of the common modifications done in the existing plant. The grounding philosophy for new installations shall be carefully adopted if the common grounding at transformer neutral is part of the existing installations.
Scenarios involving various common grounding connections for delta-star connected transformer [5][7][10] are studied to see the path of fault current split. It is seen that the fault current going into the grounding system [13] can be overestimated or underestimated if the actual situation is not modeled correctly.
Four different cases are analyzed with different common grounding configurations of transformer neutral [6] and switchboard connection with respect to earth fault current [8]. All the cases are simulated in transient study software PSCAD [1] to study the current and voltage profile for earth fault at one of the switchboards.

Case-1: 8 transformers, 3 ners and 4 switchboards

Eight transformers (132kV/11kV) are connected to four switchgears as shown in figure 1. TR-1, TR-2 and TR-3 are connected to switchgear SW123. TR-5, TR-6 and TR-7 are connected to switchgear SW567. TR-4 and TR-8 are connected to another 11kV switchgears SW4 and SW8 respectively.
Neutrals of TR-1, TR-2, TR-3, TR-5, TR-6 and TR-7 are connected to a common 8 Ω Neutral Earthing Resistor [NER] (current limited to 794A). Current associated to this NER is termed as IC.
TR-4 and TR-8 neutrals are connected to dedicated 8 Ω NERs. Currents associated to TR-4 NER is termed as In1 and TR-8 NER is termed as In2.
The earth fault is simulated at switchboard SW456 bus with fault current of If and bus voltage as E456. PSCAD simulation results are shown in following figures.
Currents are considered in per unit (PU) values for simplification. NER current 794A is considered as 1 PU. PSCAD simulation graphs shows the RMS quantity of current.

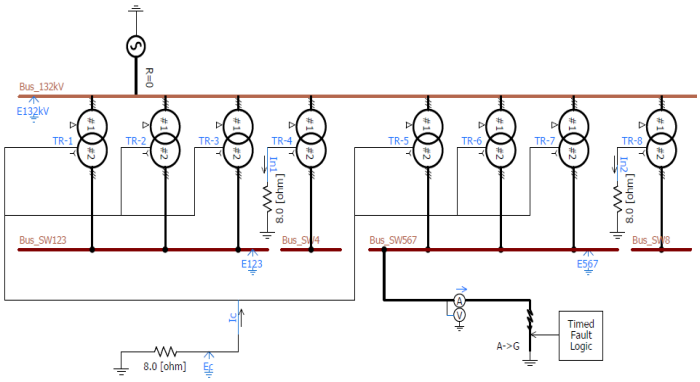

Figure 1. PSCAD model single line diagram for Case 1

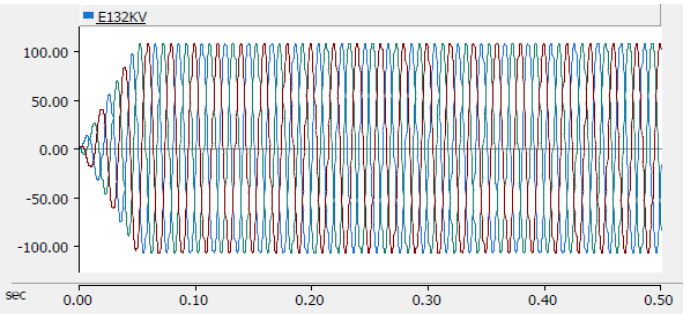

Figure 2. Transformer primary bus voltage

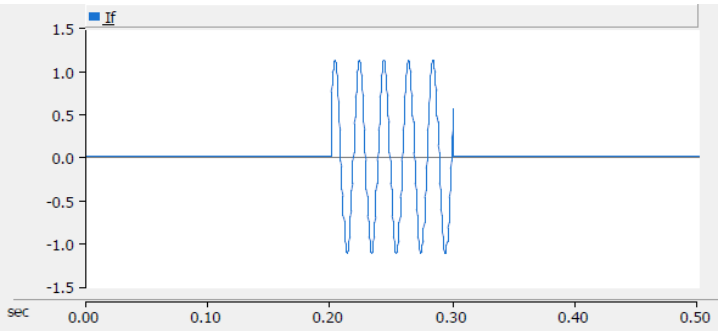

Figure 3. Earth fault current at SW456 bus (If) Fault

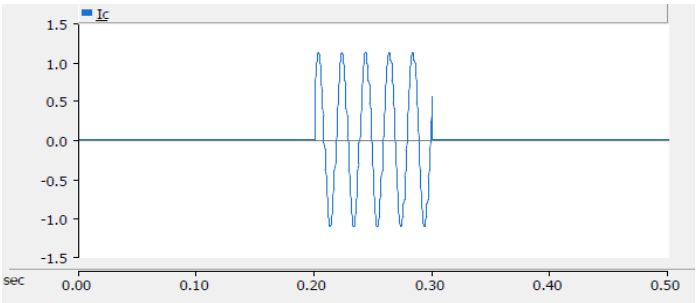

Figure 4. Earth fault current at common NER (IC)

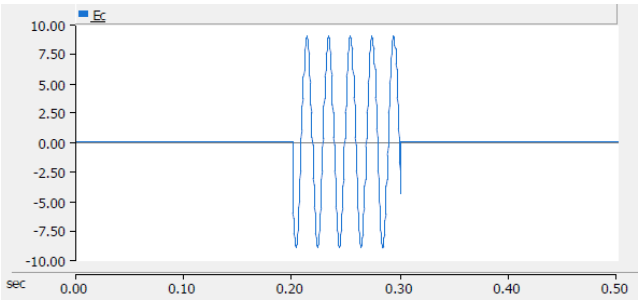

Figure 5. Voltage at common NER (Ec)

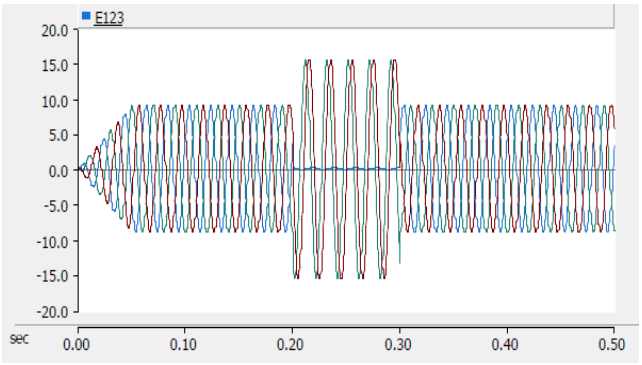

Figure 6. Voltage at switchboard SW123 bus (E123)

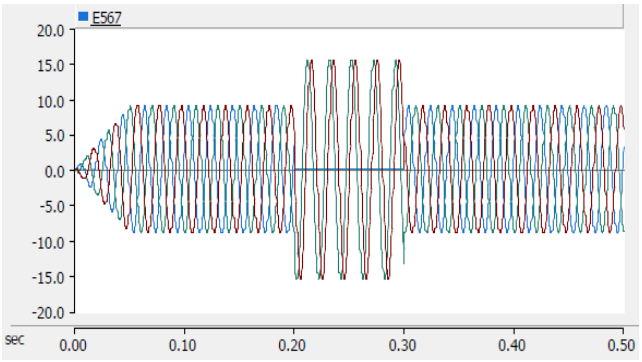

Figure 7. Voltage at switchboard SW567 bus (E567)

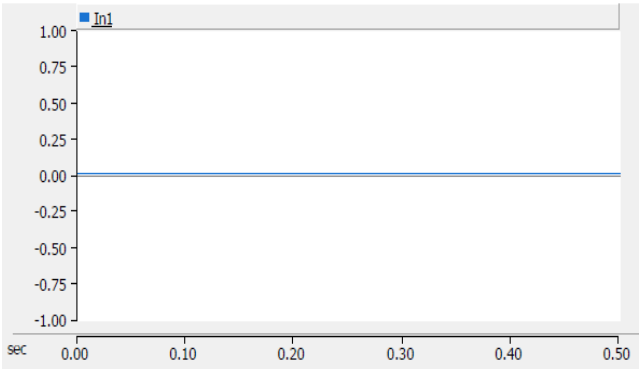

Figure 8. Earth fault current at TR-4 NER (In1)

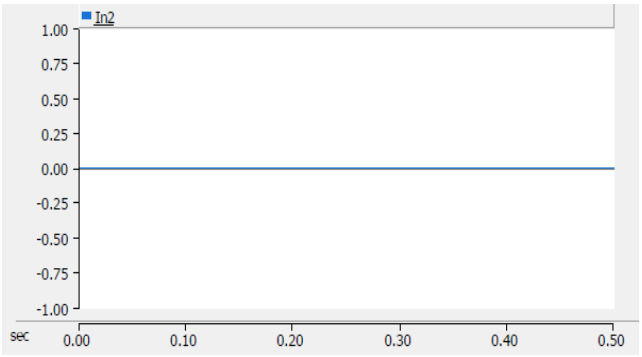

Figure 9. Earth fault current at TR-8 NER (In2)

It is observed that the Line to Ground fault at SW567 bus is restricted by the NER i.e. 1 Per Unit [PU]. Fault current flows through the common NER and TR5, 6 & 7 with current IC equal to fault current If. There are no circulating current observed through remaining transformers. If the

fault current If is sensed by the relay of outgoing feeder of the switchboard SW567, then it will be 1 PU. However, the switchboard SW123, SW4 and SW8 incomer relay will not see any earth fault current contribution and hence it will not operate for earth fault on outgoing feeder of SW567.

Case-2: transforemrs, 3 ners and 2 switchboards

The transformer neutral and NER connection is similar to case 1. Connection to switchboard is different in this case. Refer Fig. 10 to observe the transformer secondary connection.

In this case, transformers TR-1, TR-2, TR-3 and TR-4 are connected to single switchboard SW1234 and transformers TR-5, TR-6, TR-7 and TR-8 are connected to another switchboard SW5678.

The earth fault is simulated at switchboard SW5678 bus with fault current of If and bus voltage as E5678. PSCAD simulation results are shown in following figures.

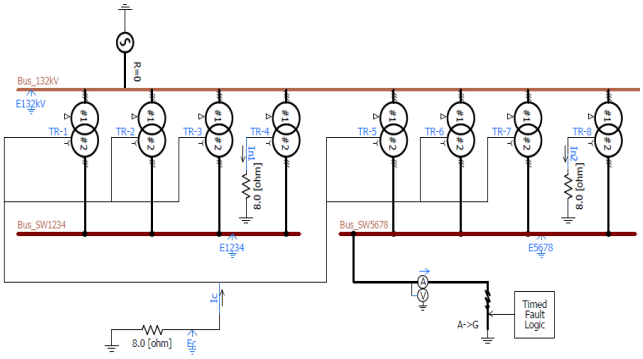

Figure 10. PSCAD model single line diagram for Case 2

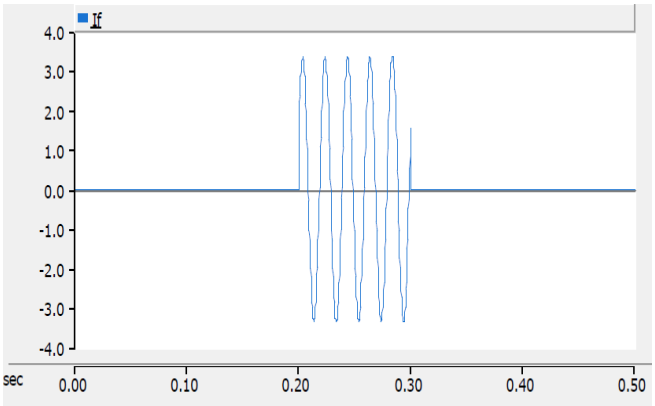

Figure 11. Earth fault current at SW5678 bus (If)

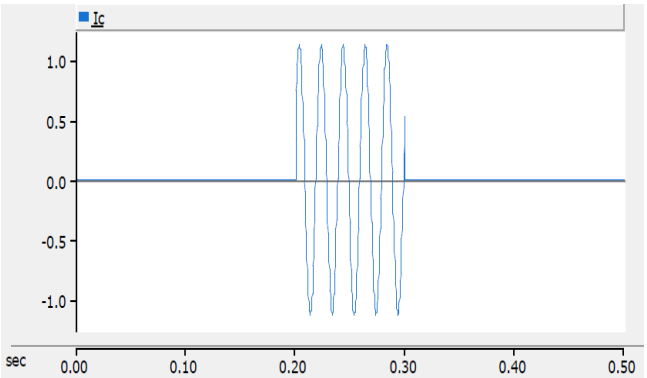

Figure 12. Earth fault current at common NER (Ic)

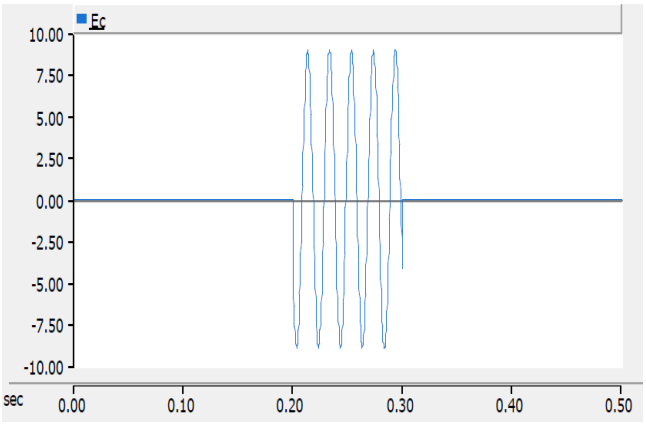

Figure 13. Voltage at common NER (EC)

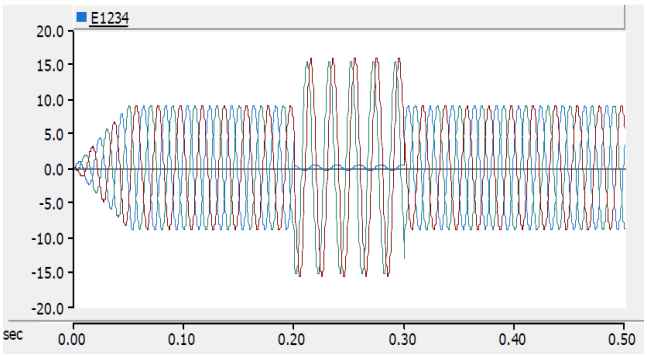

Figure 14. Voltage at switchboard SW1234 bus (E1234)

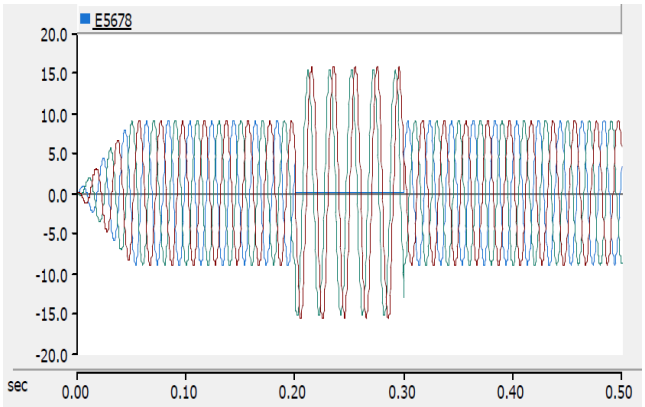

Figure 15. Voltage at switchboard SW5678 bus (E5678)

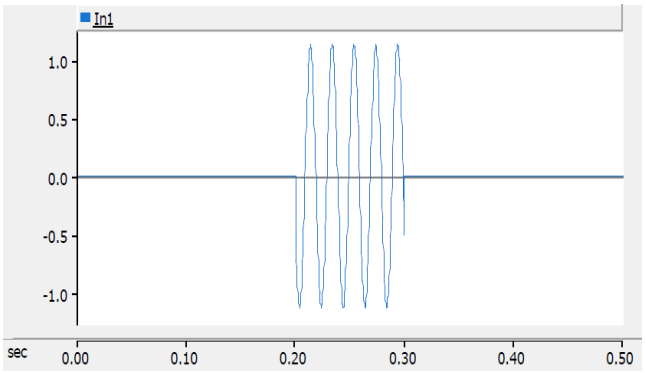

Figure 16. Earth fault current at TR-4 NER (In1)

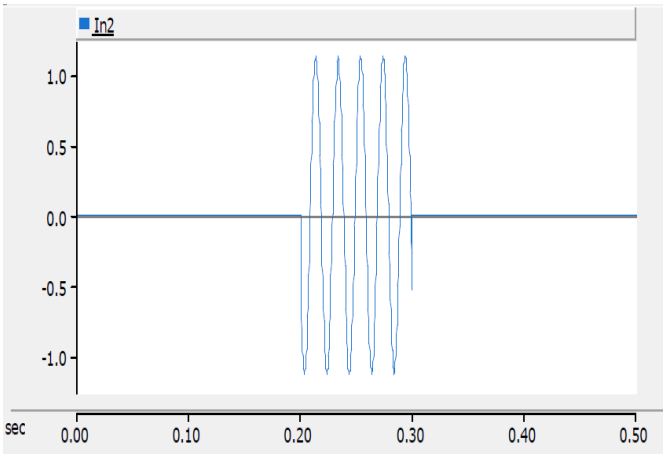

Figure 17. Earth fault current at TR-8 NER (In2)

It is observed that the Line to Ground fault current risen to 3 PU, which is due to the 3 NERs are appearing in the parallel circuits. Fault current is addition of neutral ground currents IC+In1+In2. Fault current In1 & In2 are zero sequence currents which flows through NERs of TR-4 & TR-8. These currents then contribute to the fault current If through secondary of transformers TR-1,2,3,4 and TR-8. Current In1+IC will flow through neutral earthing and then secondary of transformers TR-5, 6 & 7.

As seen in the simulation, three time fault current increase is seen in this arrangement. If the fault current If is sensed by the relay of outgoing feeder of the switchboard SW5678, then it will be 3 PU. If relay is set for IDMT characteristic then this current will operate the relay faster due to increased fault current compared to case 1.

Also, due to the earth fault contribution from switchboard SW1234, its incomer relay will see earth fault current ranging from 0.33 PU to 1 PU and hence it will pick-up and may operate for earth fault on outgoing feeder of SW5678.

Case-3: 8 transformers, 1 ner and 2 switchboards

In this case, NER connection is changed. All 8 transformer neutrals are connected to single NER.

Refer Fig. 18 to observe the transformer secondary connection.

TR-1, TR-2, TR-3 and TR-4 are connected to switchboard SW1234 and TR-5, TR-6, TR-7 and TR-8 are connected to switchboard SW5678.

The earth fault is simulated at switchboard SW5678 with fault current of If and bus voltage as E5678. PSCAD simulation results are shown in following figures.

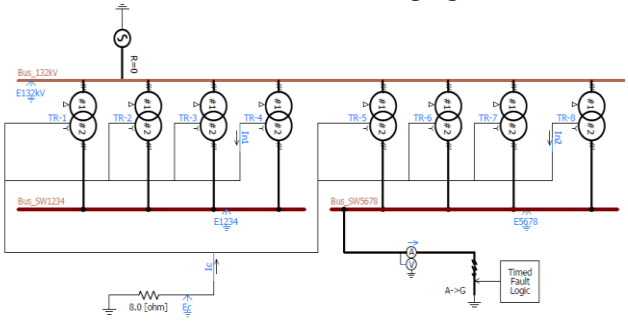

Figure 18. PSCAD model single line diagram for Case 3

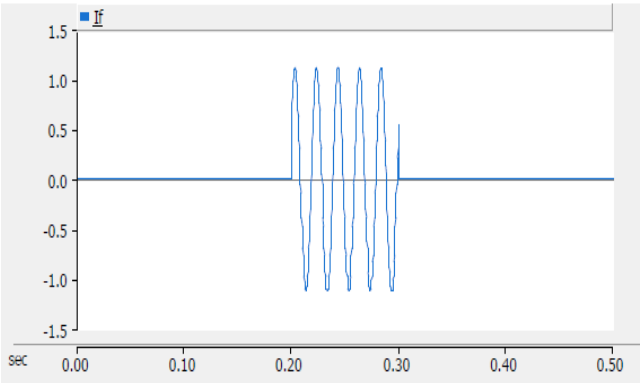

Figure 19. Earth fault current at SW5678 bus (If)

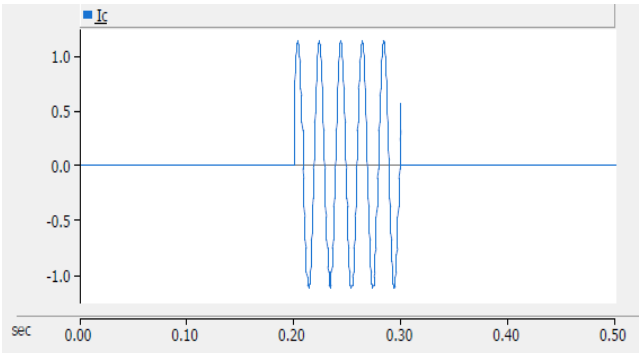

Figure 20. Earth fault current at common NER (IC)

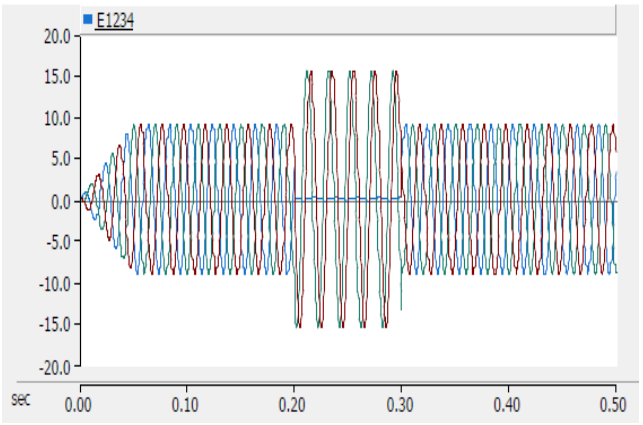

Figure 21. Voltage at switchboard SW1234 bus (E1234)

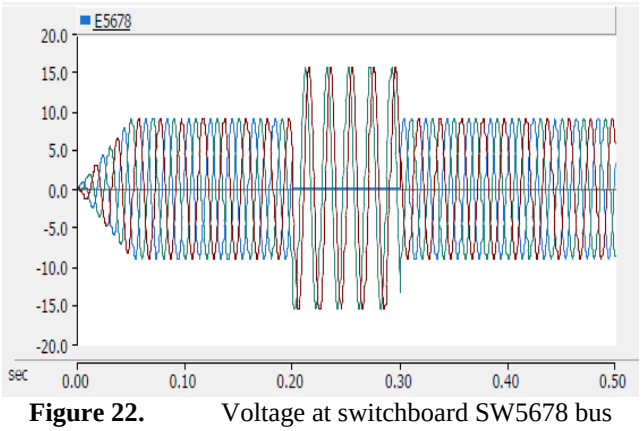

Figure 22. Voltage at switchboard SW5678 bus (E5678)

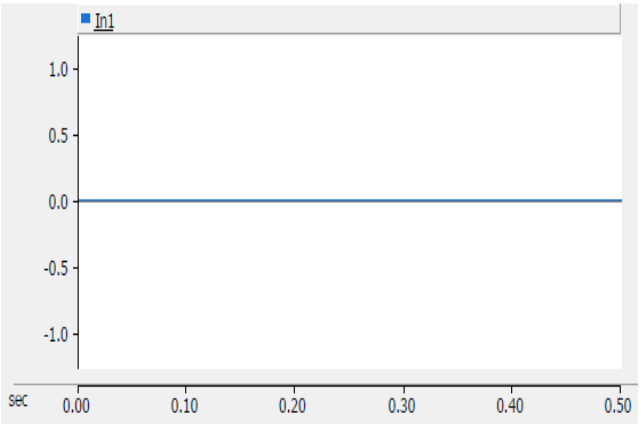

Figure 23. Earth fault current at TR-4 NER (In1)

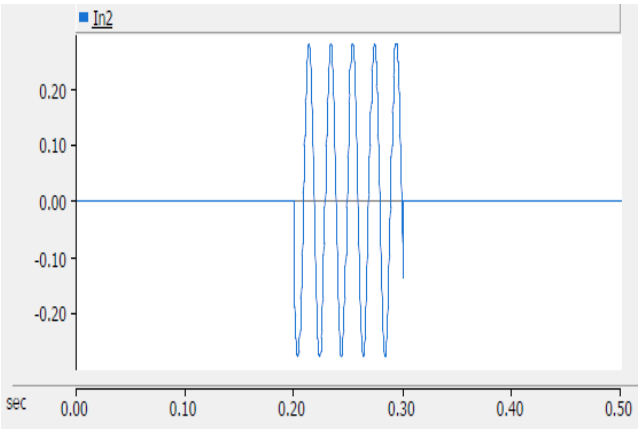

Figure 24. Earth fault current at TR-8 NER (In2)

It is observed that the Line to Ground fault is restricted by the NER i.e. 1 PU. Fault current flows through the common NER and TR-5,6,7 & 8 with current IC equal to fault current If i.e.1 PU. It is to be noted that neutral earthing current In2 is 0.25 PU. There are no circulating current observed through remaining transformers.

If the fault current If is sensed by the relay of outgoing feeder of the switchboard SW5678, then it will be 1 PU. The incomers of switchboard SW5678 will see the earth fault current of 0.25 PU.

However, the switchboard SW1234 incomer relay will not see any earth fault current contribution and hence it will not operate for earth fault on outgoing feeder of SW5678.

Case-4: 8 Transformers, 2 Ners And 2 Switchboards

In this case, 4 transformer neutrals are connected to single NER. Refer Fig. 25 to observe the transformer secondary connection.

Switchboard SW1234 and SW5678 connection to transformers are similar to Case 3.

The earth fault is simulated at switchboard SW5678 with fault current of If and bus voltage as E5678. PSCAD simulation results are shown in following figures.

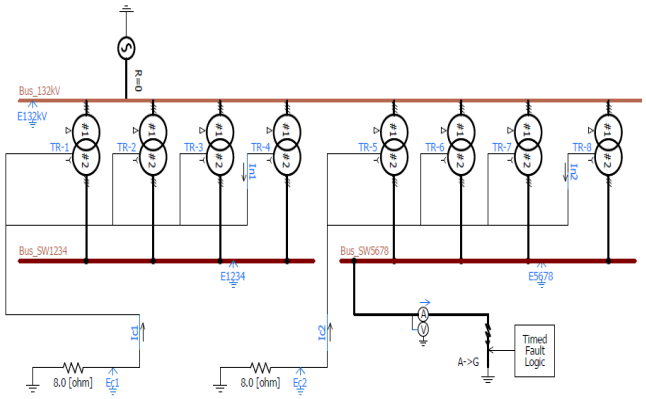

Figure 25. PSCAD model single line diagram for Case 4

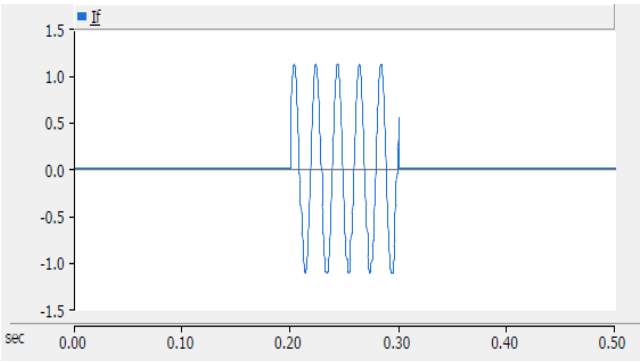

Figure 26. Earth fault current at SW5678 bus (If)

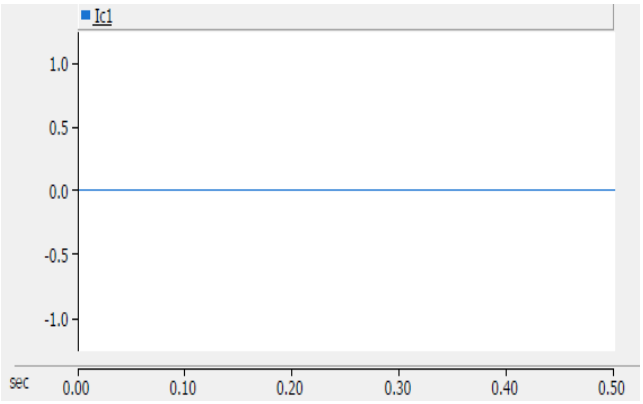

Figure 27. Earth fault current at common NER 1 (Ic1)

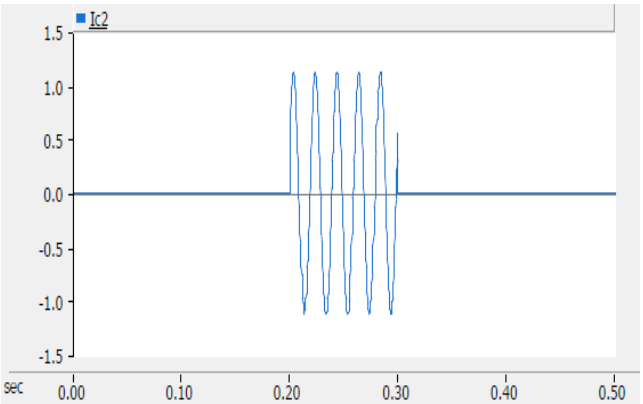

Figure 28. Earth fault current at common NER 2 (Ic2)

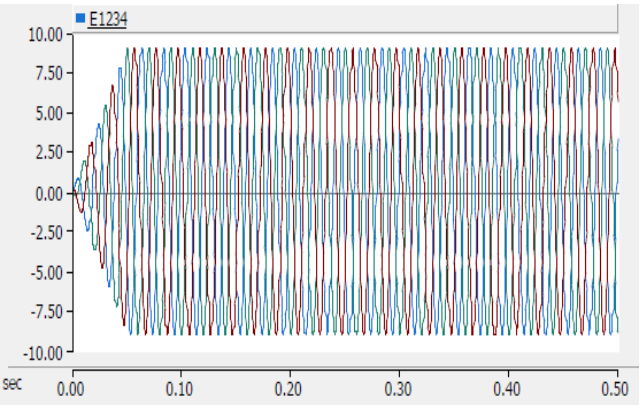

Figure 29. Voltage at switchboard SW1234 bus (E1234)

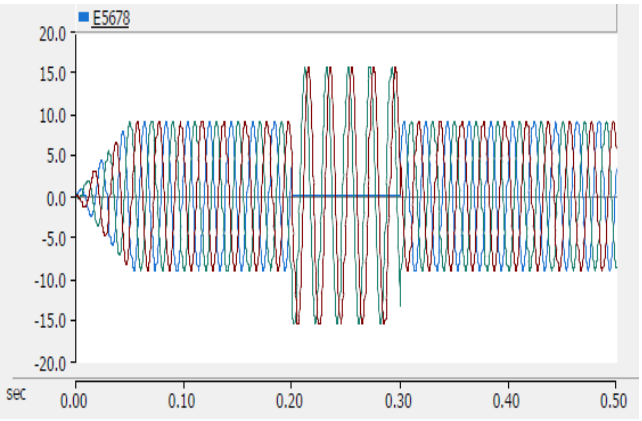

Figure 30. Voltage at switchboard SW5678 bus (E5678)

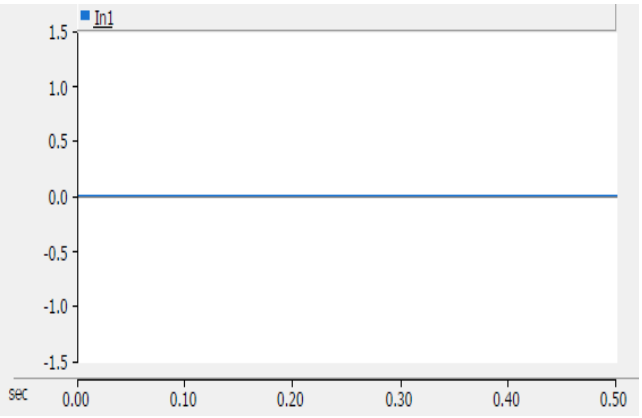

Figure 31. Earth fault current at TR-4 neutral (In1)

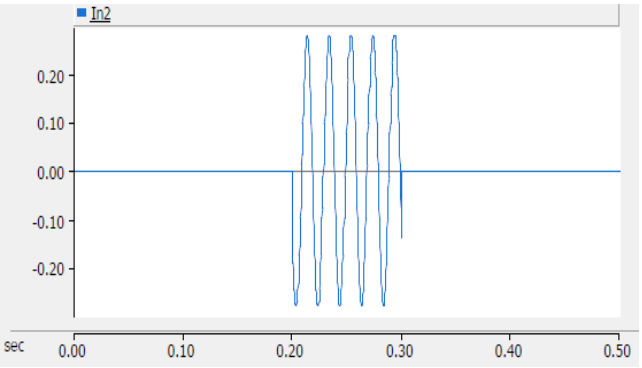

Figure 32. Earth fault current at TR-8 neutral (In2)

It is observed that the Line to Ground fault is restricted by the NER i.e. 1 PU. Fault current flows through the common NER and TR-5,6,7 & 8 with current IC1 equal to fault current If i.e.1 PU. Neutral earthing current In2 is 0.25 PU. There are no circulating current observed through remaining transformers as In1 is equal to zero.

If the fault current If is sensed by the relay of outgoing feeder of the switchboard SW5678, then it will be 1 PU. The incomers of switchboard SW5678 will see the earth fault current of 0.25 PU.

However, the switchboard SW1234 incomer relay will not see any earth fault current contribution due to electrical circuit isolation and hence it will not operate for earth fault on outgoing feeder of SW5678.

Conclusion

Case 1:

All switchgears are isolated electrically on the secondary side. In this configuration, earth fault on Switchgear SW567 bus do not have fault current contribution from other switchboards. Other switchboards are not seen any voltage fluctuations. This system is reliable however total cost is more due more number of switchboards and NERs as compared to other configurations.

CASE 2:

In this configuration, earth fault on Switchgear SW5678 have fault current contribution from other switchboard. This is due to formation of electrical path between zero sequence and positive sequence network [2][3][11] of all transformers through common grounding. It can be seen that earth fault current reaches to 3 PU for fault on any switchboard bus. This system causes higher earth fault current. Earth fault protection must be carefully designed considering the effect of circulating current.

Case 3:

In this configuration, earth fault on Switchgear SW5678 do not have fault current contribution from other switchboard due to longer electrical path between zero sequence and positive sequence network. It can be seen that earth fault current is limited to 1 PU (NER current rating) for fault on any switchboard bus. This system is simple but is not reliable as system depends on single NER. In case of any fault or issue in the NER, whole system may act as ungrounded system giving rise to overvoltage.

Case-4:

This configuration is most suitable in all conditions. The circulating currents are avoided due to isolation between zero sequence and positive sequence networks of different switchboard distributions. Earth fault on Switchgear SW5678 outgoing feeder do not have fault current contribution from other switchboard. It can be seen that earth fault current is limited to 1 PU (NER current rating) for fault on any switchboard bus.

In all study cases we could see that the electrical isolation between different distribution systems with common grounding needs to be reviewed carefully. It is seen that protection relays of switchboard incomers and faulted outgoing feeder will realize different earth fault currents and the relay operating time will vary for these earth fault current. E.g. in study case-3, for earth fault on SW5678 outgoing feeder, the incomer feeder of SW1234 may trip before SW5678 incomer. In short, for fault on one switchboard, the feeder on different switchboard will trip giving the in-accurate protection coordination. Thus accuracy in estimating the earth fault current and adopting proper earthing philosophy for new and existing installation plays important role in protection co-ordination. This will also help in safe earthing design.

Acknowledgement

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