Improvement of Differential Protection for Power Transformers by Eliminating Zero Sequence Current Effect

Sonal Niranjane[1], Prof. Dinesh D. Majumdar[2]

[1]*PG Scholar, Department of Electrical Engineering, Shri. Sai College of Engineering and Technology, Bhadrawati, India India Maharashtra, India*
[2]*Assistant Professor, Department of Electrical Engineering, Shri. Sai College of Engineering and Technology, Bhadrawati, India Maharashtra, India Maharashtra, India Maharashtra, India*

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Abstract - *The main safeguard for power transformers is differential protection. The fast expansion of the electricity network resulted in a rise in the number and types of problems. Zero sequence current (ZSC) flowing through the power transformer is caused by external line to ground faults, resulting in differential protection false tripping. This approach seeks to improve differential relay performance in the face of such defects in order to avoid erroneous trip decisions and preserve protection reliability. The tripping system is comprised of flip flop logic-based controls that create the trip signal for transformer protection against unbalanced loads and various fault circumstances.*
Using flip flop logic based current protection, a zero sequence current in the main and secondary windings was minimised during leakage and earth fault in this suggested technique. This safety method is dependent on zero sequence current passing through the power transformer's primary or secondary winding.
Finally, the suggested method is compared to traditional differential current protection. The efficacy of the protection strategy is assessed by looking at the settling time, protection time, and circuit breaker operating time, among other things.

Key Words: *Differential Protection, Power Transformer*

1. INTRODUCTION

Generators, buses, and transformers are all routinely protected by differential relays. All three phases of the main circuit breaker, as well as the generator neutral and field breakers in a power plant protection, will open when the relay in any phase activates [4]. The technique of protection for power transformers is determined by the transformer's MV A rating. Fuses are frequently used to safeguard transformers with low MV A ratings, whereas differential relays are frequently used to protect transformers with values greater than 0 MV A [4].
The differential relay (for example, the 87 or 87T transformer differential relay) operates on the premise that "in a healthy system, the current leaving a circuit equals the current entering the circuit." By rating Current Transformers (CTs) according to the transformation ratio, this differential concept may also be applied to a transformer (even if the main and secondary currents are not equal). To measure the 'differential' value between incoming and outgoing current, two sets of CTs (of the corrected ratio) are placed on either side of the transformer [6].
CT's job is to generate a current Is in its secondary winding that is proportionate to the primary current Ip. CT is utilised in a power system circuit that has a high current range of hundreds of amperes. CT's minimum range requirement is 20 A in primary current, which is translated to a secondary current range of 5 A for measurement ease and application to protective relays [7].
Michael Faraday showed the primary principle of a transformer for the first time in 1831, however he only used it to explain the theory of electromagnetic induction and did not anticipate its practical applications. A direct current-based electrical distribution system was utilised in the early years of energy distribution in the United States. During the late 1880s "War of Currents" era (also known as the "Battle of Currents"), however, George Westinghouse and Thomas Edison became adversaries due to Edison's promotion of the direct current (DC) system over the alternating current (AC) system advocated by Westinghouse and Nikola Tesla for electricity distribution. The product of current and voltage is power (P U I =). A low voltage necessitates a greater current for a given quantity of power, while a higher voltage necessitates a lower current. Due to the resistance of metal conducting wires, some power will be lost as heat in the distribution system's cables. Thus, given the limits of realistic conductor diameters and the same total transmitted power, a low-voltage, high-current based energy distribution system will have a considerably larger power loss than a high-voltage, low-current based system. This is true regardless of whether the power distribution system is DC or AC. However, converting DC power to a high-voltage, low-current form is challenging, whereas in an AC system, this can be accomplished using a simple and efficient device known as a power transformer.
Power transformers can convert nearly all of their input AC power (product U I 1 1) to their output power (product U I 2 2). The magnitudes of voltage and current will be altered, however, in line with power transformer design specifications.

2. PROPOSED APPROACH

Figure 1 shows the proposed differential protection for power transformer using SR flip flop logic. This system is measures two side of transformer primary and secondary side of current and send to ratio comparison subsystem model. In this system, current comparison with each side of transformer for individual phases are done. During fault condition the magnitude of current of faulted phase of primary side or secondary side is increases more above the rated current. Hence, the based on comparison subsystem output generated means trip signal generated for circuit breaker OFF operation and transformer is isolated for fault condition.

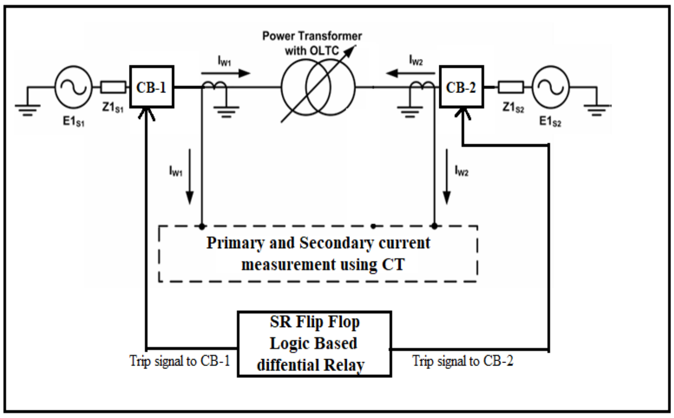

Fig-1: Block diagram of proposed approach

But this system is independent of zero sequence current effect because of system only measures the primary and secondary side CT current. If small leakages current is flowing through primary or secondary side of transformer then there is no any effect on current comparison subsystem. Hence this system not fails even if zero sequence current is present either primary or secondary side of transformer.

3. SIMULATION MODEL

3.1 Model-1: Flip Flop logic based Differential Current Protection (Two side measurement)

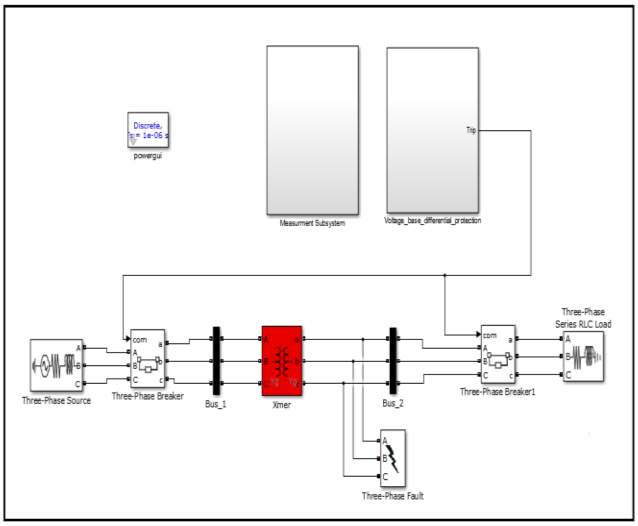

Fig-2: Complete matlab simulation model of differential current power transformer protection (Model-1)

Table 5.1: Matlab simulation model-1 parameter specification

Sr No	Name of simulation block	Parameter specification
1.	Three phase source	Phase to phase RMS voltage = 11 KV; Phase angle of phase A = 0 Degree; Supply frequency = 50 Hz; Internal connection = Star connected ground; Three phase short circuit level at base voltage (MVA) = 500 MVA; Base voltage = 11 KV; X/R Ratio = 7
2.	Three phase circuit breaker 1 and 2	Initial status of breaker = Closed; Breaker resistance = 0.001 Ohm; Snubber resistance Rs = 1 Mega-Ohm; Snubber capacitor Cs = Infinite.
3.	Three phase transformer	Primary winding connection = Star connected with ground; Secondary winding connection = Star connected with ground; Nominal MVA rating = 200 MVA; Nominal supply frequency = 50 Hz; Primary winding voltage = 11 KV; Secondary winding voltage = 33 KV; Magnetizing resistance Rm = 6×10^5 ohm; Magnetizing inductance Lm = 1925.8 H.
4.	Three phase series RLC load	Load connections = Star connected with ground; Nominal phase to phase rms voltage Vn = 33 KV; Nominal supply frequency fn = 50 Hz; Active power = 150 MW; Inductive reactive power QL =50 MVar; Capacitive reactive power = 0 Var.
5.	Three phase fault	Initial status of fault = Open; Faults type possible to simulate = LG, LL, LLG, LLL, LLLG Like AG, BG, CG, AB, BC, AC, ABG, BCG, ACG, ABC, ABCG Fault resistance Rf= 0.001 Ohm; Ground resistance Rg = 0.001 Ohm; Snubber capacitance Cs = Infinite

Figure 2 shows the main simulation model for conventional differential current protection for power transformer. The specification of power transformer protection system in represents in table 1.

Figure 3 shows the parameters measurement subsystem for bus bar 1 (primary side) and bus bar 2 (secondary side) in which three phase rms voltage and current of power transformer is measured during normal condition as well as faults conditions.

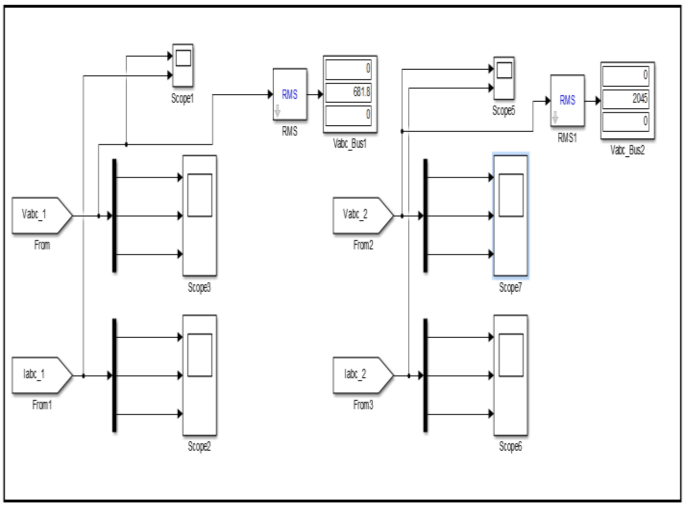

Fig-3: Primary side and secondary side of transformer bus bar measurement subsystem in matlab simulation model-1

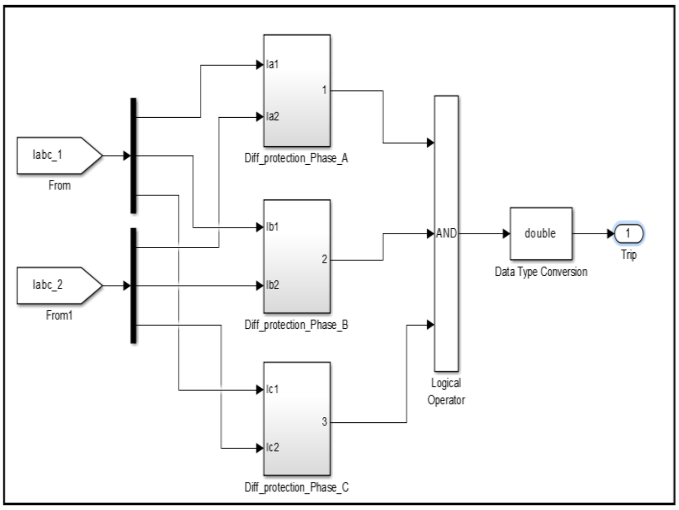

Fig-4: Differential current scheme for individual three phases of power supply (Trip signal generation subsystem)

Figure 4 shows the differential current protection system in which current of each phase of transformer primary side and secondary side is compared. Primary side voltage 11 kv and secondary side 33 kv. For maintain the current ratio of transformer, the secondary side measured CT current is multiplied with 3 for make value at same rating as per transformer primary and secondary side current comparison.

Figure 5 shows the phase A primary side and secondary side current comparison subsystem and SR flip flop subsystem model in matlab simulation. Here, primary RMS current of phase A i.e I_{a1} and secondary RMS current of phase A i.e. I_{a2} are compared. Before comparison, the transformer current ration must be made equal by multiply secondary side each phase current by 3. Because primary side voltage becomes 11 KV and Secondary Side voltage becomes 33 kv hence it is calculated as V_1/V_2 = 11/33=1/3. But, I_2/I_1=3. Hence, I_2 = 3 I_1.

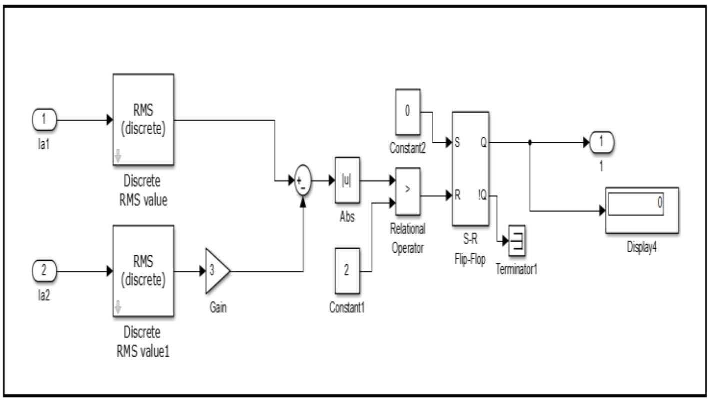

Fig-5: Differential protection subsystem detail model for phase A current comparison

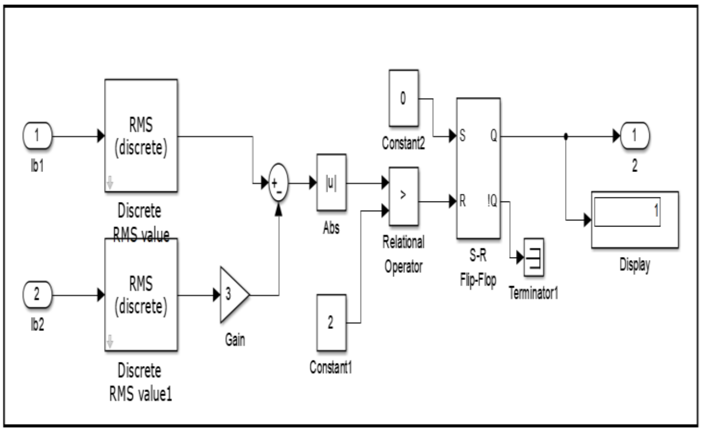

Fig-6: Differential protection subsystem detail model for phase B current comparison

Figure-6 shows the phase B primary side and secondary side current comparison subsystem and SR flip flop subsystem model in matlab simulation. Here, primary RMS current of phase B i.e I_{b1} and secondary RMS current of phase B i.e. I_{b2} are compared. Before comparison, the transformer current ration must be made equal by multiply secondary side each phase current by 3 gain. Because primary side voltage becomes 11 KV and Secondary Side voltage becomes 33 kv hence it is calculated as V_1/V_2 = 11/33=1/3. But, I_2/I_1=3. Hence, I_2 = 3 I_1.

Figure 5.7 shows the phase C primary side and secondary side current comparison subsystem and SR flip flop subsystem model in matlab simulation. Here, primary RMS current of phase C i.e I_{c1} and secondary RMS current of phase C i.e. I_{c2} are compared. Before comparison, the transformer current ration must be made equal by multiply secondary side each phase current by 3 gain. Because primary side voltage becomes 11 KV and Secondary Side voltage becomes 33 kv hence it is calculated as V_1/V_2 = 11/33=1/3. But, I_2/I_1=3. Hence, I_2 = 3 I_1.

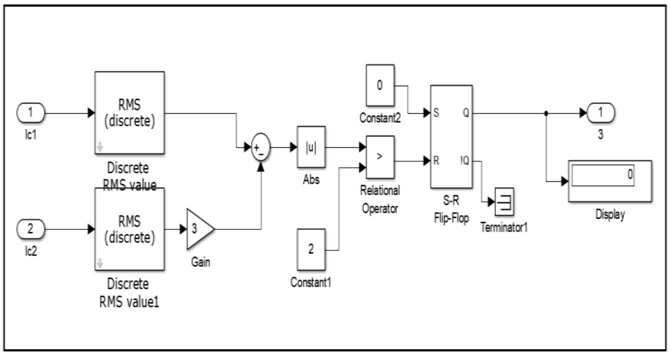

Fig-7: Differential protection subsystem detail model for phase C current comparison

3.2 Model-2: Flip Flop Logic based differential current protection of transformer (One side measurement)

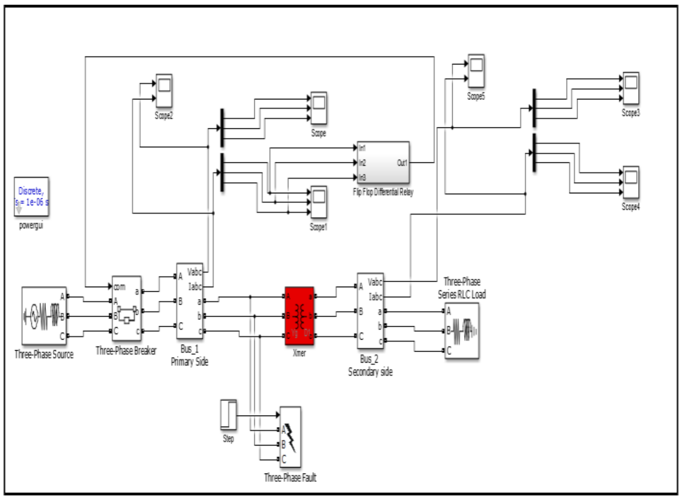

Fig-8: Complete matlab simulation model (model-2) of flip flop differential current protection of power transformer

Table-2: Matlab simulation model-2 parameter specifications

Sr No	Name of simulation block	Parameter specification
1.	Three phase source	Phase to phase RMS voltage = 11 KV; Phase angle of phase A = 0 Degree; Supply frequency = 50 Hz; Internal connection = Star connected ground; Three phase short circuit level at base voltage (MVA) = 500 MVA; Base voltage = 11 KV; X/R Ratio = 7
2.	Three phase circuit breaker	Initial status of breaker = Closed; Breaker resistance = 0.001 Ohm; Snubber resistance Rs = 1 Mega-Ohm; Snubber capacitor Cs = Infinite.
3.	Three phase transformer	Primary winding connection = Star connected with ground; Secondary winding connection = delta; Nominal MVA rating = 500 MVA; Nominal supply frequency = 50 Hz; Primary winding voltage = 11 KV; Secondary winding voltage = 33 KV; Magnetizing resistance Rm = 1.6207 × 10^6 ohm; Magnetizing inductance Lm = 5158.8 H.
4.	Three phase series RLC load	Load connections = Star connected with ground; Nominal phase to phase rms voltage Vn = 33 KV; Nominal supply frequency fn = 50 Hz; Active power = 200 MW; Inductive reactive power QL = 100 Var; Capacitive reactive power = 0 Var.
5.	Three phase fault	Initial status of fault = Open; Faults type possible to simulate = LG, LL, LLG, LLL, LLLG Like AG, BG, CG, AB, BC, AC, ABG, BCG, ACG, ABC, ABCG Fault resistance Rf= 0.001 Ohm; Ground resistance Rg = 0.001 Ohm; Snubber capacitance Cs = Infinite

Figure 8 shows the matlab simulation model of differential current protection of power transformer using SR Flip flop logic. Here, only one end of transformer i.e. either primary side or secondary side three phase rms current is used to measured for protection scheme.

4. SIMULATION RESULTS

4.1 Model-1 Results analysis

Fig-9: Three phase rms voltage and current of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time

Figure 9 shows that three phase rms voltage and current of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase A and B to ground at 0.5 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence protect from fault current flowing through primary and secondary side of transformer winding. Similarly, figure 10 shows the individual three phases voltage of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that same condition, with in half cycle after 0.5 second simulation time system voltage becomes zero due circuit breaker trip operation.

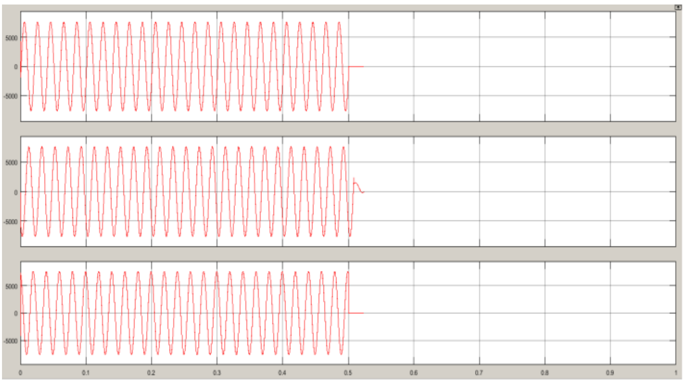

Fig-10: Three phase individual phases voltage of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time

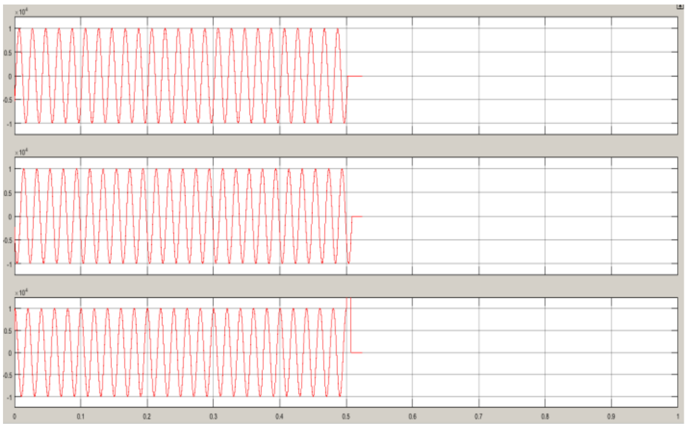

Fig-11: Three phase individual phases currents of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time

Similarly, figure 11 shows the individual three phases current of primary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that same condition, with in half cycle after 0.5 second simulation time system current becomes zero due circuit breaker trip operation.
Figure 12 shows that three phase rms voltage and current of secondary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase A and B to ground at 0.5 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence protect from fault current flowing through primary and secondary side of transformer winding.

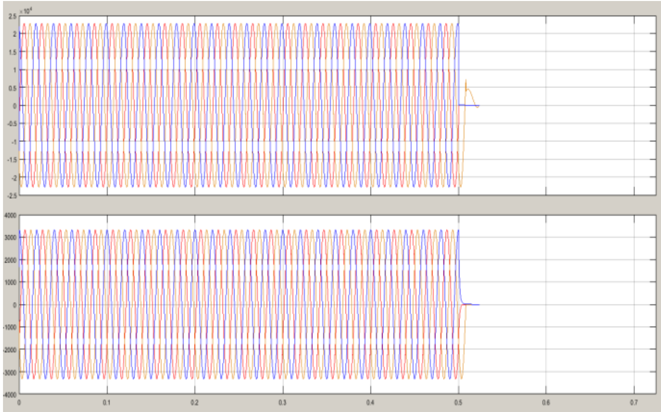

Fig-12: Three phase rms voltage and current of secondary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time

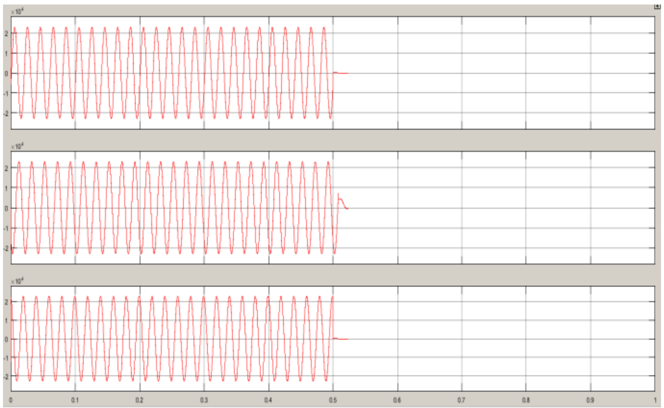

Fig-13: Three phase individual phases voltage of secondary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time

Similarly, figure 13 shows the individual three phases voltages of secondary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that same condition, with in half cycle after 0.5 second simulation time system voltages becomes zero due circuit breaker trip operation.

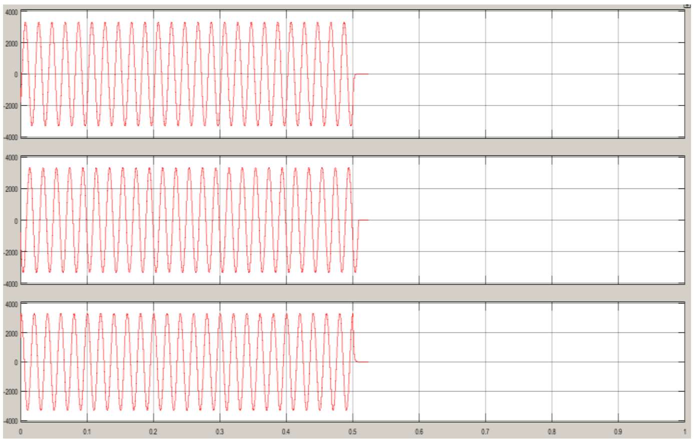

Fig-14: Three phase individual phases currents of secondary side of transformer during LLG-ACG Double line fault at primary side at 0.5 second simulation time

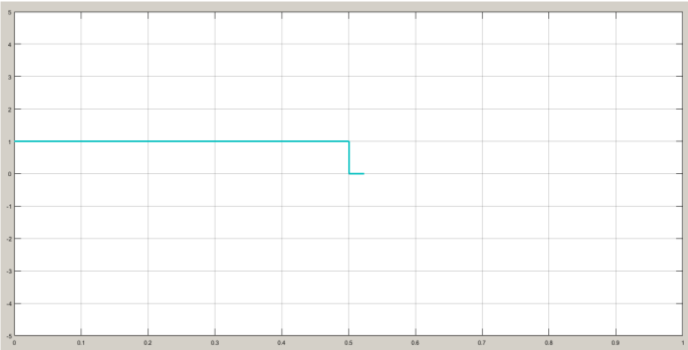

Fig-15: Trip signal generated during LLG-ACG Double line fault at primary side at 0.5 second simulation time for circuit breaker operation

Similarly, figure 14 shows the individual three phases currents of secondary side of transformer during LLG-ACG Double line to ground fault at primary side at 0.5 second simulation time. Here it is observe that same condition, with in half cycle after 0.5 second simulation time system currents becomes zero due circuit breaker trip operation.

Figure 15 shows the Trip signal generated during LLG-ACG Double line fault at primary side at 0.5 second simulation time for circuit breaker operation. The circuit breaker closed their contacts for logic 1 and opens their contacts for logic 0. From figure it is clear that, at 0.5 second simulation time tripping logic is shift from logic 1 to logic 0 for circuit breaker contact opening operation. When faults occur at 0.5 second simulation time, there is no any delay for generation of trip signal at 0.5 second. Hence system becomes very fast to detect the fault condition at primary side of transformer.

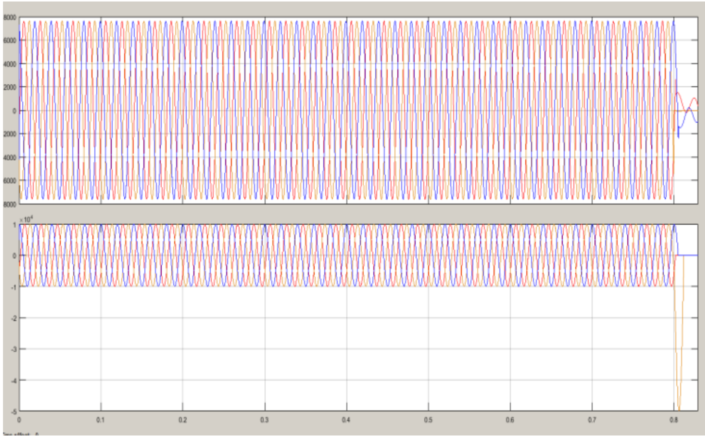

Fig-16: Three phase rms voltage and current of primary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time

Figure 16 shows that three phase rms voltage and current of primary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase C to ground at 0.8 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence protect from fault current flowing through primary and secondary side of transformer winding.

Similarly, figure 17 shows the individual three phases voltage of primary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system voltage becomes zero due circuit breaker trip operation.

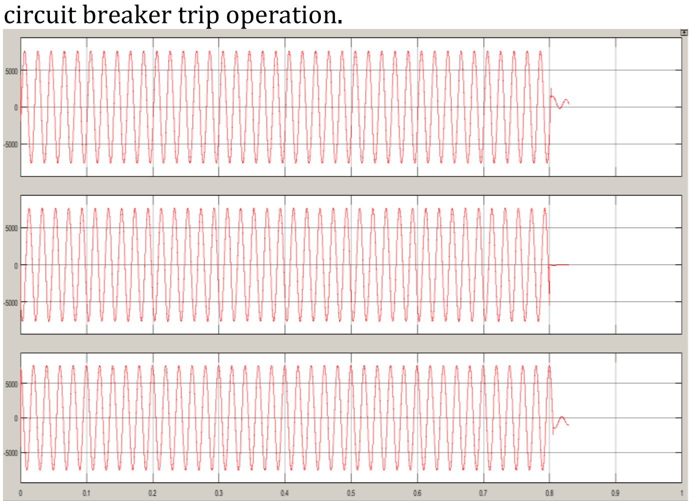

Fig-17: Three phase individual phases voltage of primary side of transformer during LG-BG line to ground fault at primary side at 0.8 second simulation time

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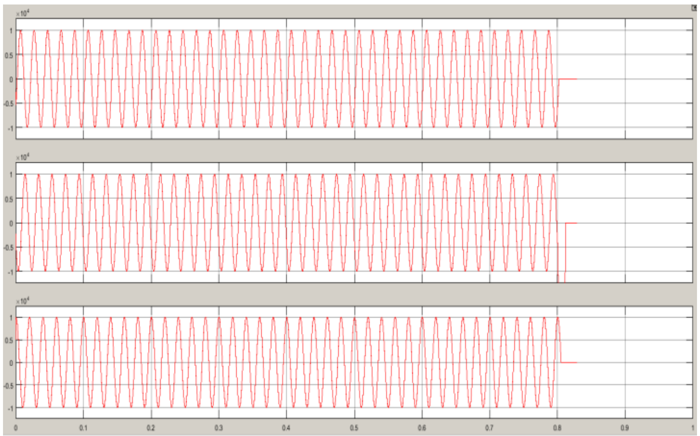

Fig-18: Three phase individual phases currents of primary side of transformer during LG-BG line to ground fault at primary side at 0.8 second simulation time

Similarly, figure 18 shows the individual three phases currents of primary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system currents becomes zero due circuit breaker trip operation.

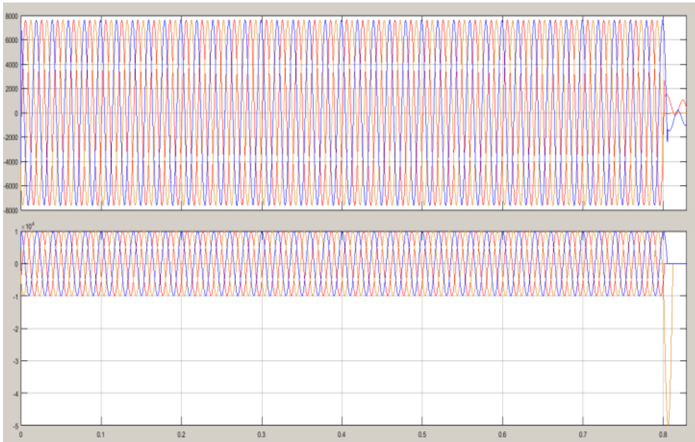

Fig-19: Three phase rms voltage and current of secondary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time

Figure 19 shows that three phase rms voltage and current of secondary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase C to ground at 0.8 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence protect from fault current flowing through primary and secondary side of transformer winding.

Fig-20: Three phase individual phases voltage of secondary side of transformer during LG-BG line to ground fault at primary side at 0.8 second simulation time

Similarly, figure 20 shows the individual three phases voltage of secondary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system voltage becomes zero due circuit breaker trip operation.

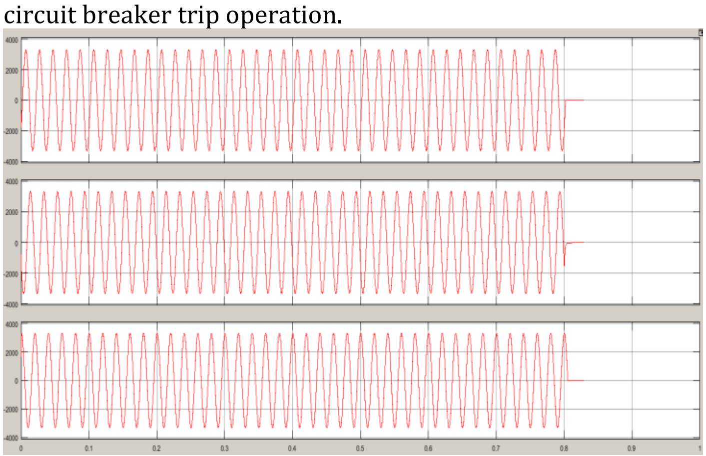

Fig-21: Three phase individual phases currents of secondary side of transformer during LG-BG line to ground fault at primary side at 0.8 second simulation time

Similarly, figure 21 shows the individual three phases currents of secondary side of transformer during LG-CG Line to ground fault at primary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system currents becomes zero due circuit breaker trip operation.

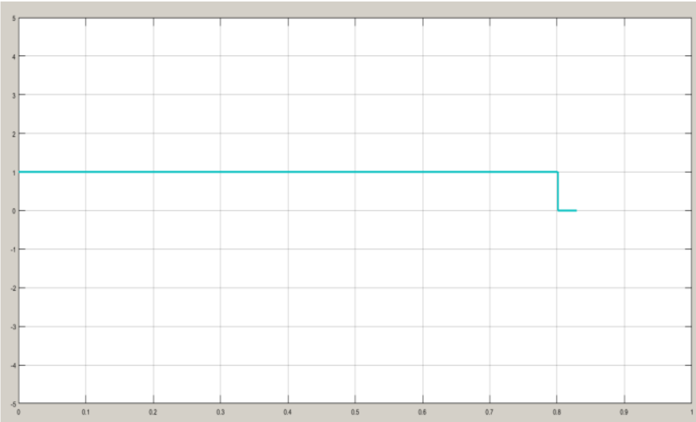

Fig-22: Trip signal generated during LLG-ACG Double line fault at primary side at 0.5 second simulation time for circuit breaker operation

Figure 22 shows the Trip signal generated during LG-CG line to ground fault at primary side at 0.8 second simulation time for circuit breaker operation. The circuit breaker closed their contacts for logic 1 and opens their contacts for logic 0. From figure it is clear that, at 0.8 second simulation time tripping logic is shift from logic 1 to logic 0 for circuit breaker contact opening operation. When faults occur at 0.8 second simulation time, there is no any delay for generation of trip signal at 0.8 second. Hence system becomes very fast to detect the fault condition at primary side of transformer.

4.2 Model-2 Results Analysis

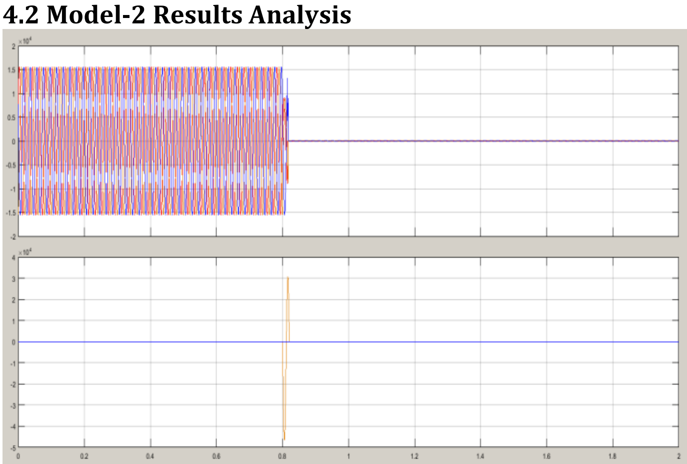

Fig-23: Three phase rms voltage and current of primary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time

Figure 23 shows that three phase rms voltage and current of primary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase A to ground (LG Fault) at 0.8 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence both windings are protecting from faulted short circuit high magnitude current flowing through primary and secondary side of transformer winding.

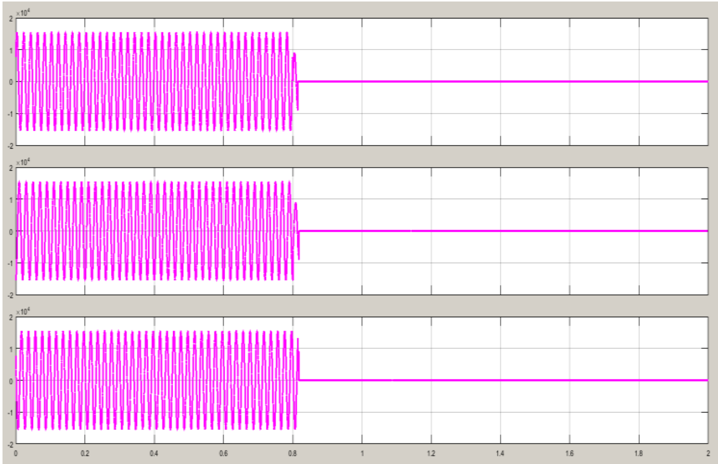

Fig-24: Three phase individual phases voltage of primary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time

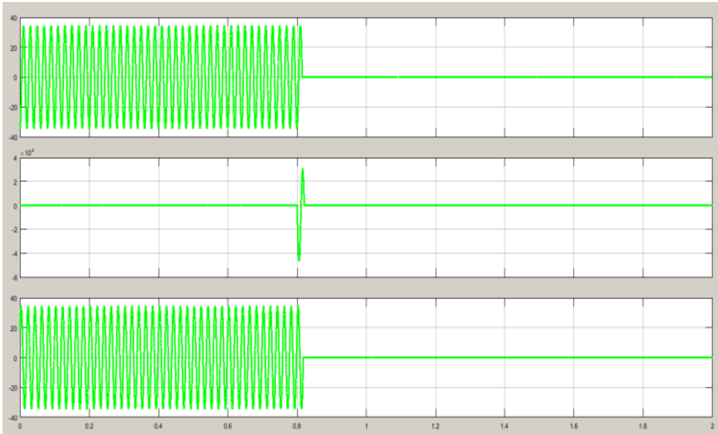

Fig-25: Three phase individual phases current of primary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time

Similarly, figure 24 shows the individual three phases voltages of primary side of transformer during LG (AG) line to ground fault at secondary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system voltages of each phases (Va, Vb, Vc) becomes zero due circuit breaker trip operation.

Similarly, figure 25 shows the individual three phases currents of primary side of transformer during LG (AG) line to ground fault at secondary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system currents of each phases (Ia, Ib, Ic) becomes zero due circuit breaker trip operation.

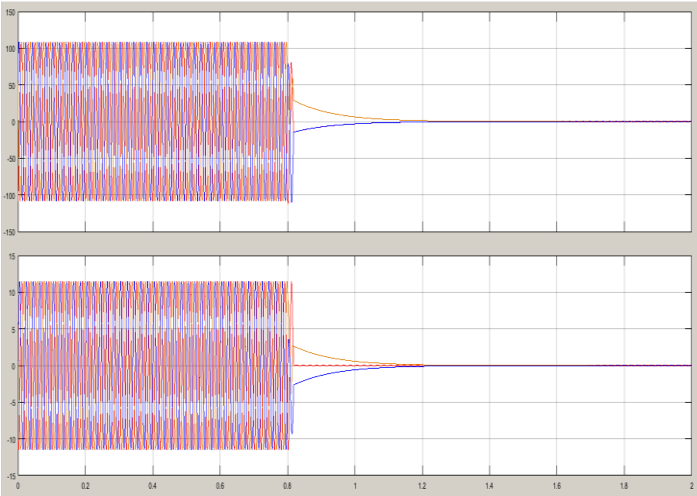

Fig-26: Three phase rms voltage and current of secondary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time

Figure 26 shows that three phase rms voltage and current of secondary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time. Here it is observe that, when faults occurs at primary winding of transformer in between phase A to ground (LG Fault) at 0.8 second simulation time. Then suddenly after half cycle simulation time circuit breaker open contacts and isolate the primary and secondary side of transformer from three phase source and load. Hence both windings are protecting from faulted short circuit high magnitude current flowing through primary and secondary side of transformer winding.

Similarly, figure 27 shows the individual three phases voltages of secondary side of transformer during LG (AG) line to ground fault at secondary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system voltages of each phases (Va, Vb, Vc) becomes zero due circuit breaker trip operation.

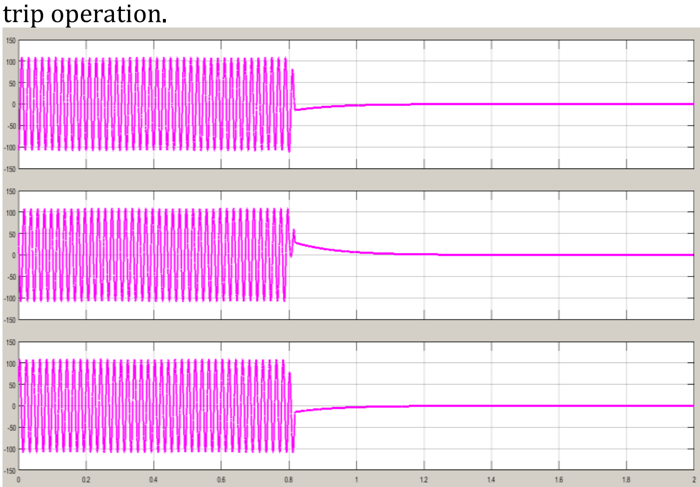

Fig-27: Three phase individual phases voltage of secondary side of transformer during LG (AG line to ground fault at primary side at 0.8 second simulation time.

Similarly, figure 28 shows the individual three phases currents of secondary side of transformer during LG (AG) line to ground fault at secondary side at 0.8 second simulation time. Here it is observe that same condition, with in half cycle after 0.8 second simulation time system currents of each phases (Ia, Ib, Ic) becomes zero due circuit breaker trip operation.

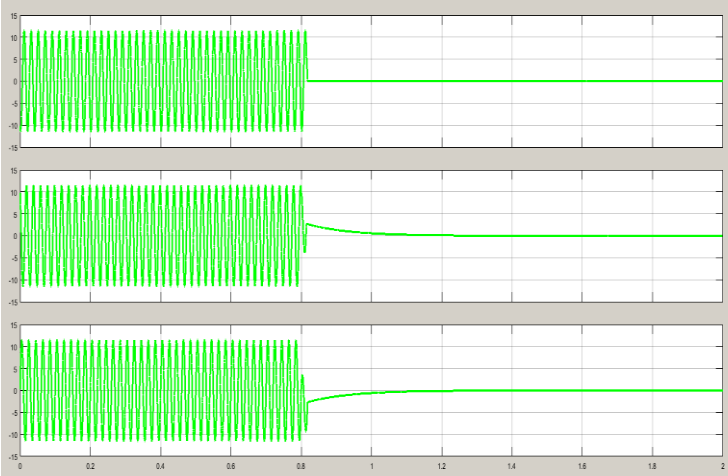

Fig-28: Three phase individual phases current of secondary side of transformer during LG (AG) line to ground fault at primary side at 0.8 second simulation time

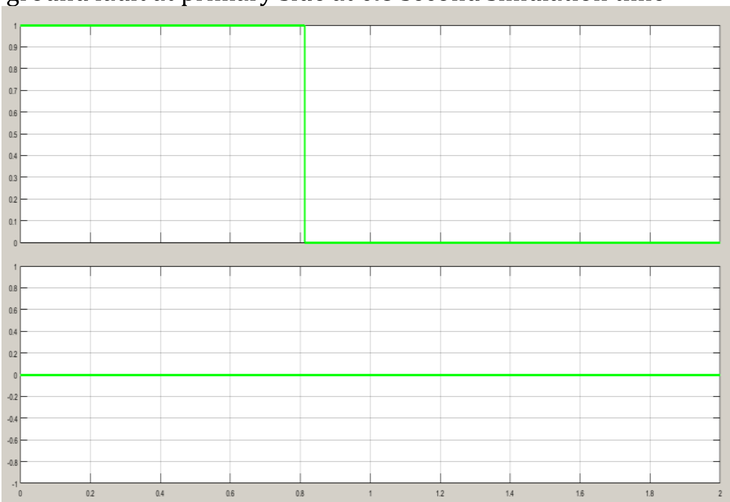

Fig-29: Trip signal generated during case-1 fault at 0.8 second simulation time

Figure 29 shows the Trip signal generated during LG-AG Line to ground fault at primary side at 0.8 second simulation time for circuit breaker operation. The circuit breaker closed their contacts for logic 1 and opens their contacts for logic 0. From figure it is clear that, at 0.8 second simulation time tripping logic is shift from logic 1 to logic 0 for circuit breaker contact opening operation. When faults occur at 0.8 second simulation time, there is no any delay for generation of trip signal at 0.8 second. Hence, system becomes very fast to detect the fault condition at secondary side of transformer.

4. CONCLUSION

The main safeguard for power transformers is differential protection. The fast expansion of the electricity network resulted in a rise in the number and types of problems. Zero sequence current (ZSC) flowing through the power transformer is caused by external line to ground faults, resulting in differential protection false tripping. The goal of this research is to improve differential relay performance against such defects such that erroneous trip decisions are avoided and protection reliability is maintained. The suggested algorithm will be used on an 11 KV transmission line with an 11kv/33kv power transformer. It has been discovered that removing ZSC from the differential protection feeling improves differential protection in such circumstances.

The topic of ZSC on transformer differential protection is explored in this study. The factors that influence the ZSC values are also investigated. In addition, due to the presence of the ZSC during external failures, this research provided a novel approach for avoiding the male functioning of the differential protection. During both external and internal failures, the suggested system worked successfully.

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