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A Novel Solution to Restricted Earth Fault Low Impedance Relay Maloperation

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Abstract**—**In this paper, various methods of providing restricted earth fault protection are discussed. The proper operation of high and low impedance Restricted Earth Fault (REF) protection for various applications has been discussed. The maloperation of a relay due to improper placement of CTs has been identified and a simple/unique solution has been proposed in this work with a case study. Moreover, it is found that the proper placement of CT in high impedance method will provide the same result with reduced CT. This methodology has been successfully implemented in Al Takreer refinery for a 2000 KVA transformer. The outcome of the paper may be included in IEEEC37.91 standard to give the proper guidance for protection engineers to sort out the issues related to mal functioning of REF relays.

Keywords**—**Relay maloperation, transformer, low impedance REF, MatLab, 64R, IEEE C37.91.

I. INTRODUCTION

TRANSFORMERS are the heart of the power system network providing voltage conversion at different levels. It becomes an integral part of power systems for inter connection of the grid and to meet the ever increasing power demands. Proper protection of the transformer becomes vital as its downtime and failure has a huge complication to the operation and maintenance team [1].

In this paper, different methods of restricted earth fault (REF) for various current transformer (CT) arrangements are discussed. The practical problem raised by Al Takreer is taken for case study here. The high and low impedance methods for REF protection have been applied for this particular case and the related issues are presented. A new solution for placing the CT in low impedance REF to prevent maloperation of the relay is proposed and the results are verified through MatLab simulation.

The paper is organized as follows: Section II describes the requirements of transformer protection and hi-lights the basic difference between high impedance and low impedance differential protection. Section III discusses the implementation of differential protection concept for REF. Section IV explains the various CT arrangements and the REF connection methodology for both high and low impedance methods. It also points out, when low impedance REF will fail and suitable solution is also discussed. Cost effective method for similar application in high impedance implementation is also discussed. Section V discusses the simulation results and shows the stability of the system for internal faults and security of the system for external faults with the proposed solution.

II. PROTECTION OF TRANSFORMERS

IEEE C37.91 standard defines various protection schemes like, differential protection, restricted earth fault protection, overcurrent protection for proper protection of transformer. The relay protecting the transformer should protect it for internal fault only. The relay should resist isolation of the transformer for external fault thereby complying with the fundamentals of power system protection philosophy. Hence the primary protection for transformer is unit protection, where the boundaries are defined by the CTs. Two methods of unit protection namely high impedance and low impedance protection schemes are discussed briefly in this section.

A. High Impedance Differential Protection

Differential relays work on the principle of Merz-price scheme of differential protection [2], where the current entering and leaving should always nullify each other. Fig. 1 (a) shows the CT connection of high impedance relay. If the resultant current measured by the relay is zero by means of CT connection, then it is called as high impedance protection, since high impedance appear in parallel to the relay CT coil. The reason for connecting the high impedance is to suppress the voltage developed across the CT coil of the relay which will be very high during a fault condition and in turn, it can cause damage. The high impedance is a non-linear resistor (NLR) whose resistance is inversely proportional to the voltage. When voltage increases, the resistance decreases. During a fault scenario, when the voltage across the relay coil becomes high, the impedance connected in parallel reduces due to its NLR characteristics. This creates a least resistance path and the voltage drops off there by protecting the relay. The fault current also is diverted through the parallel least resistance path. The NLR would have a very low resistance when the voltage is very high. During fault, it is theoretically assumed that the internal resistance of the relay coil is lowest than the least value of the NLR. However to ensure higher resistance of the relay path, a stabilising resistance is added in series to the relay as shown in Fig. 1 (b).

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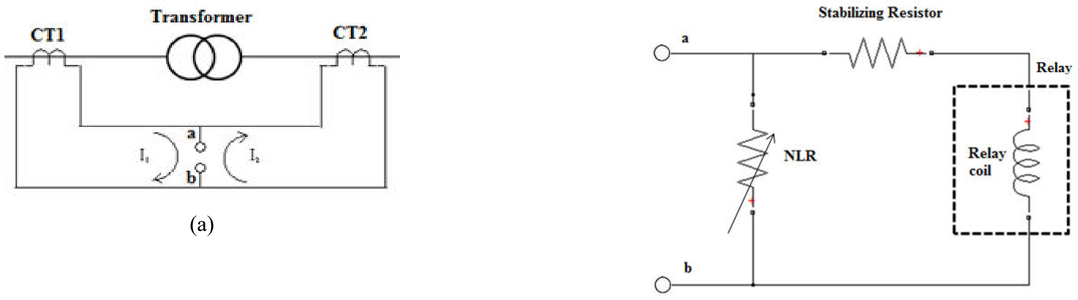

(a)

(b)

Fig. 1 Merz Price Scheme of Differential protection (a), High Impedance CT connection (b)

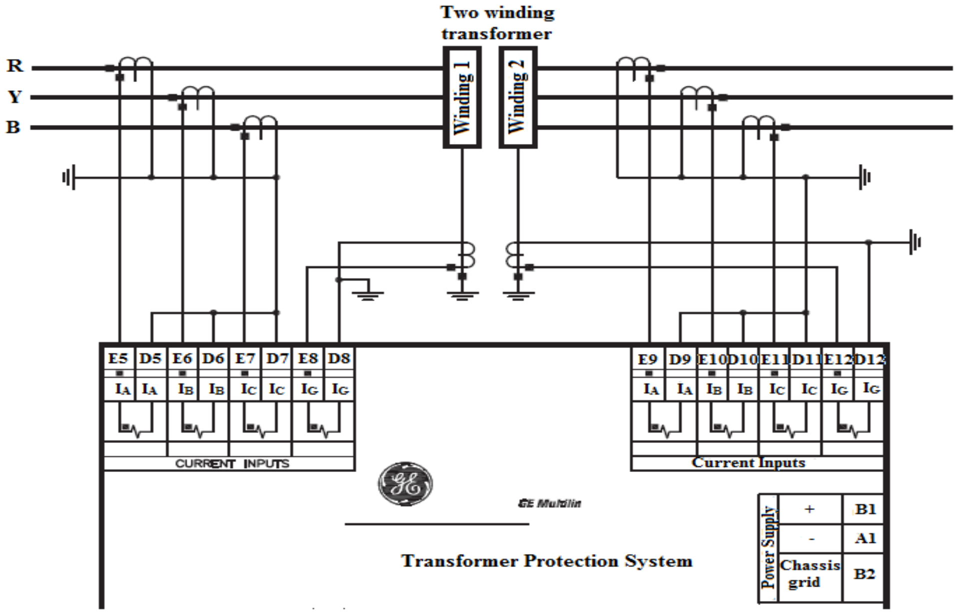

Fig. 2 Low Impedance CT connection

B. Low Impedance Differential Protection

In low impedance relays, the Merz price scheme principle is achieved internally in the relay. The external CT paralleling is eliminated and each CT is directly connected to the relay as shown in Fig. 2 [3]. Due to this fact, the currents are not added externally and hence the need for high impedance to safe guard the relay coil is defeated. The absence of the high impedance coil in the circuit makes this kind of relay to be named as low impedance differential protection. These two methods discussed will be applicable for restricted earth fault (REF) protection, if the CTs are located in the phase and neutral winding of the transformer. The need and implementation of this fault protection method is described in the next section.

III. RESTRICTED EARTH FAULT PROTECTION

Faults occurring very close to the neutral of the transformer will not be detected by the differential protection as the bias differential current will be very small and it will be in the restrain regions of the bias characteristics. To increase the sensitivity, earth fault has to be implemented for the star side of the transformer.

Transformer protection is a unit protection and hence it should not trip for external disturbances. For protection against earth faults occurring in the transformer winding, the unit protection scheme should also include earth fault protection. This earth fault relay should trip only for an earth fault occurring inside the transformer, thereby restricting the operation only to the transformer. This restriction is achieved by using the same Merz-price scheme concept between the phase and the ground CT as shown in Fig. 3. The standard code prescribed by ANSI is 64R for this protection.

The relay measures the R, Y and B phase current respectively and calculates the resultant current internally. This calculated current is denoted as I_n. The CT located in the return path of the conductor measure a current denoted as I_g. The calculated current I_n and the measured current I_g will always be equal and they flow in the opposite direction. This directional principle nullifies each other and the resultant current will always be zero during balanced, unbalanced conditions and external faults.

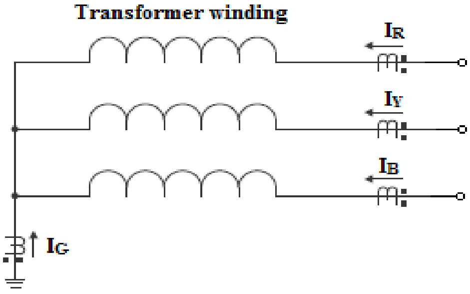

Fig. 3 CT location for REF

Let us assume a fault within the transformer between phase R winding to ground. The fault current is measured as I_g, however the current does not flow through the phase CT (Phase R), I_r current measured is not the reflection of the fault current. Hence the calculated value of I_n will not be the same as the measured current I_g, which will be detected by the relay and the circuit breaker trips on REF protection.

The different ways to connect CTs to achieve REF protection using high and low impedance methods are discussed to prevent the maloperation of the relay in the next section.

IV. CT ARRANGEMENTS FOR RESTRICTED EARTH FAULT PROTECTION

A. High Impedance Ref

Fig. 4 shows various methods for high impedance REF [4].

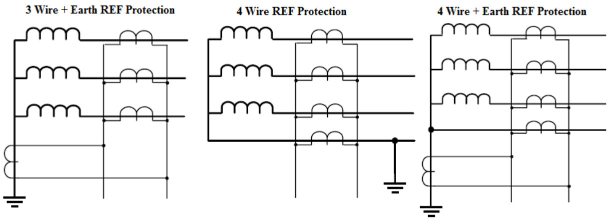

Fig. 4 High Impedance Protection CT connection for various CT arrangement

Out of the discussed methods, the 4 wire + earth REF protection method uses 5 CTs. This connection method has practical implementation issues in low impedance method. Hence this method has been considered here for detailed explanation.

In some industrial application, the transformers are used for single phase loading. The transformer star point has two paths. One path is a return conductor for single phase loading and the other path is grounded. In large transformers, this kind of wiring is not a standard practice since transformers are not meant for single phase loading. In this kind of special applications where there are 5 conductors, CTs are located in all the conductor and wired to the relay for REF protection as shown in Fig. 5. This scheme will be able to differentiate between the internal and external disturbance using the same principle explained in Section II *A*. This concept is simulated using MatLab to verify the proper functionality of the scheme based on the concepts explained in the above sections.

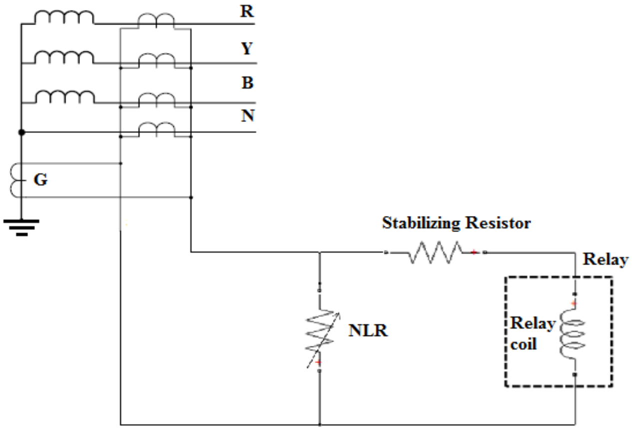

Fig. 5 High Impedance Protection CT connection for 5 CT arrangement

In this kind of special applications, the numbers of CTs are increased and the relay receives the current from all the five CTs. The MatLab schematic of Fig. 5 is shown in Fig. 6. The difference in current between all the five CTs flow in the relay for identifying the fault. The current flowing in the relay is always zero during external disturbances and unbalance. Two switches S1 and S2 are used to simulate internal and external fault conditions. Two selector switches SS1 and SS2 are used to select the CT inputs in the relay. The resistor values are modified to create an unbalance and it was observed that the resultant current flowing in the relay is always zero, confirming stability. Fig. 7 is the output of the scheme during unbalances and external fault conditions.

The neutral CT is eliminated from the relay by switching SS2 and the ground CT is shifted from location 2 to location 1 by switching SS1. The simulation is repeated for unbalance and external faults and observed that the differential current is zero as recorded in Fig. 7. Table I tabulates the different types of conditions that were simulated and the status of differential current read by the relay.

TABLE I
REF MEASUREMENT FOR DIFFERENT CTS AND LOCATIONS

Type	Condition	SS1	SS2	Differential current
I	Internal Fault	2	‘N’ in Fig 6	Yes
	External Fault	2	‘N’ in Fig 6	No
II	Internal Fault	1	No Input	Yes
	External Fault	1	No Input	No
III	Internal Fault	2	No Input	Yes
	External Fault	2	No Input	Yes

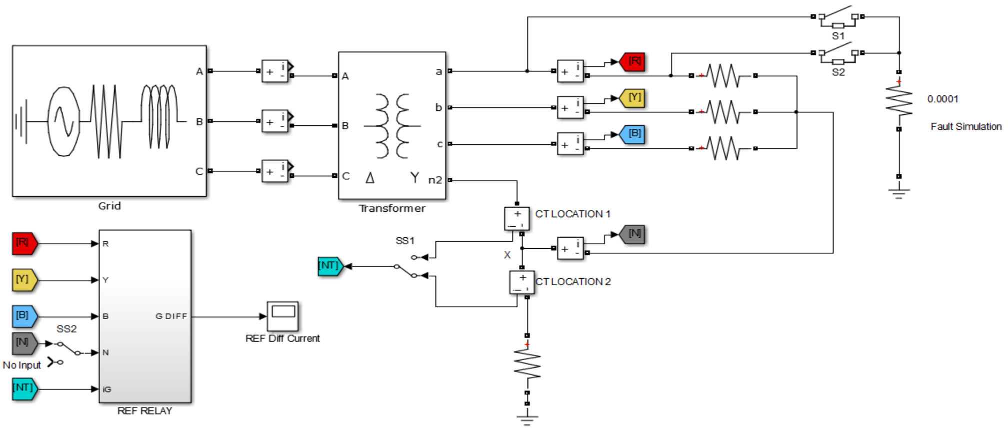

Fig. 6 Matlab model for REF simulation

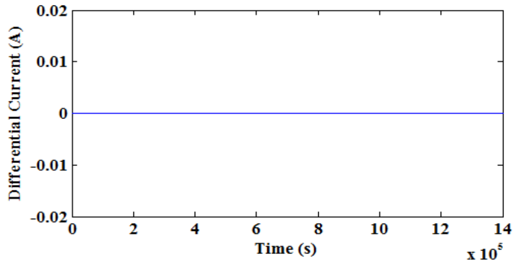

Fig. 7 Differential relay current for model shown in Fig. 6

The neutral CT is eliminated from the scheme by opening SS2. In the absence of the neutral CT, the relay reads a differential current as shown in Fig. 8.

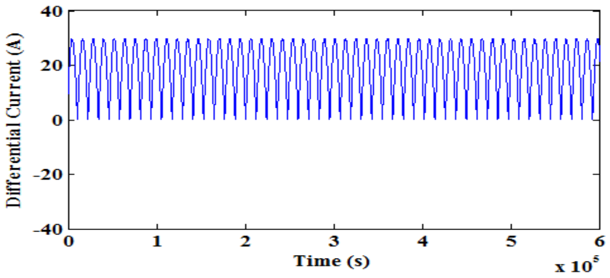

Fig. 8 Differential relay current for High Impedance REF without neutral CT

It is concluded that five CTs arrangement provides the proper stability of high impedance relays. For the same 4 wire + earth method, the performance of the low impedance REF is discussed below.

B. Low Impedance Restricted Earth Fault

REF protection is an integral part of the numerical relays and the relays support only four CT connections as shown in Fig. 2. For special application as mentioned in the previous section, the conventional method of five CTs are used in high impedance relay, however there is no provision to connect the neutral CT in the relay. Even if the neutral CT is connected to the relay, the internal algorithm will not account this current. The neutral current is internally derived by the relay as explained in Section II *B*; hence in low impedance relay REF protection is implemented using only four CTs. This is condition II of Table I.

In Al Takreer refinery, Ruwais, Abu Dhabi, the four CT arrangement shown in Fig. 8 was implemented for low impedance GE make T60 relay and the relay started mal operating for external disturbances.

This kind of CT connection results in maloperation of the relay during external unbalance loading which is the most common question raised by users with regard to suitability of low impedance relays for this kind of application. The rectification of this problem has been done by detailed study, by placing of CTs in this case via MatLab simulation and the solution is derived.

V. SIMULATION AND RESULTS

This concept explained in section IV has been simulated by creating an external fault in R phase by closing the switch S2 in Fig. 6. The simulation study has been carried out with existing CTs placement. The present scenario problem is obtained through simulation; that is the maloperation of relay. This is type III of Table I. The results are shown in Fig. 9. The relay has measured differential current for external faults. The same experiment was repeated for unbalance condition and results similar to Fig. 9 were observed.

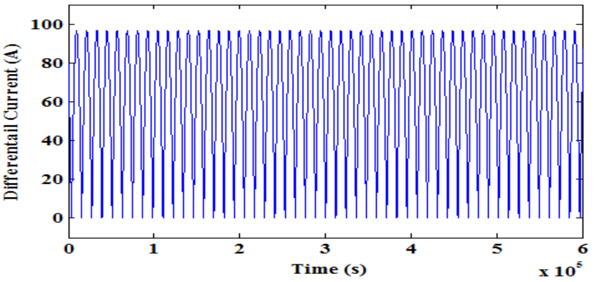

Fig. 9 Differential relay current for Low Impedance REF with ground CT in location 2 of Fig. 5

The above conditions were repeated with the CT in location 1 by switching through SS1 and the relay measurement is found to be zero in this case as observed in Fig. 10. This experiment has been repeated for unbalance loading and the same results were observed in accordance with Fig. 10.

The reason for this maloperation was identified as the wrong location of the ground CT and not with the relay. It is suggested to place the ground CT above the point X, which is in location 1 and not in location 2 as shown in Fig. 11. In case if the CT is located in location 2, the unit protection concept cannot define the boundary and hence the external disturbance / fault / unequal loading will not have a boundary. If the CT is located in location 1, then all external disturbance / faults / unequal loading will be outside the CTs thereby preventing the relay from reading a differential current.

To ensure that the solution is perfect, an internal fault is also created and differential current is measured as recorded in Fig. 12.

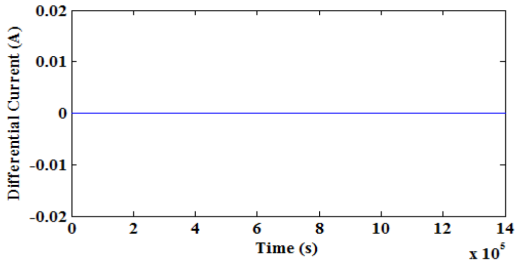

Fig. 10 Differential relay current for Low Impedance REF with ground CT in location 1 of Fig. 5

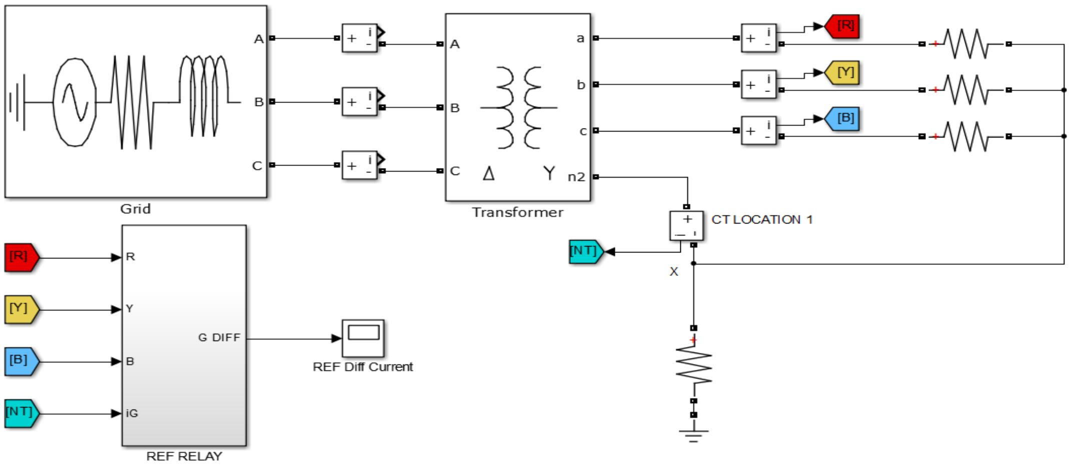

Fig. 11 Matlab model of the proposed CT location for low impdeance relay for 5 wires system

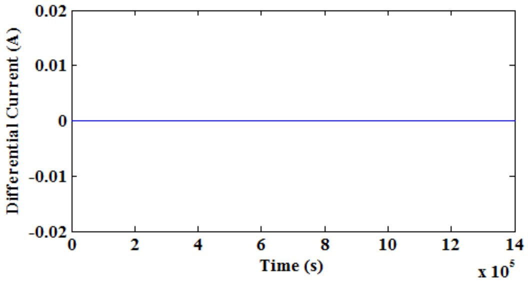

Fig. 12 Differential relay current for model shown in Fig. 10

It is observed that the location change of CT solves the present problem and also the system operate perfectly. Even though many arrangements of CT has been reported in IEEE C37.91, none of these address the issue reported in Al Takreer refinery, Ruwais, Abu Dhabi but the proposed solution has resolved the issue for a 2000 KVA transformer, hence the proposed solution may be included in the standard to guide the protection engineers in proper REF protection implementation.

VI. CONCLUSION

In this paper, the issues related to improper placement of CTs have been discussed. From the results discussed above, it is concluded that low impedance relay can be used for all the applications of high impedance relays. In addition, it also has the advantage of utilising less number of CTs for the same application. This reduces the errors due to CTs which in turn would increase the accuracy as well as provides cost benefit. The existing IEEE standard [5] does not discuss about the application of low impedance relay for 5 conductor unbalance loading system which creates a confusion in the location of the CT in many industries. This paper provides a proper solution for this issue.

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