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DIGITAL DIFFERENTIAL PROTECTION OF POWER TRANSFORMER

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Abstract
The two major items of equipment in a power system are the generators and transformers. Chances of fault occurrence on them are very rare as compared to on lines, but the damaged caused by the fault usually takes much more time and money to repair then are required to repair the damage caused by the fault on the lines. Current transformer secondary current for the winding of a power transformer are used to produce a differential current. An operating current value is obtained from the differential current value. A restraining current value is obtained from processed winding current values. Second and fourth harmonic values of the differential current are obtained and are summed with a restraining current quantity which is a result of the restraining current multiplied by a slope characteristic factor. If the operating current value is greater than the second and fourth harmonic values, an output signal is produced which may be used as a trip signal unless it is blocked by selected blocking signals generated by another portion of the system.
Key Words: MATLAB Simulation, MATLAB Modeling, Differential protection relay

1. INTRODUCTION:

Power transformer is one of the most important components in power system, for which many kinds of protective and monitoring schemes have been developed for many years. A power transformer is a very expensive electrical device, and its operation directly affects the performance of other equipment to which it is connected. Therefore, it is necessary to use efficient protection schemes and monitoring systems in order to ensure its physical integrity, as well as a long operating lifetime. The protection of Transformers is critical phenomenon. Traditionally, transformer protection methods that use its terminal behaviors are based on differential protection is considered as a most widely used technique to perform the protection function. The differential protection scheme can be used to protect both the primary and secondary windings of a three-phase transformer against faults. The method fundamentally based on the discrimination between faults and other operating conditions.

The two major items of equipment in a power system are the generators and transformers. Chances of fault occurrence on them are very rare as compared to on lines, but the damaged caused by the fault usually takes much more time and money to repair then are required to repair the damage caused by the fault on the lines. Rapid reclosing of circuit breaker is feasible on lines and it helps in saving the amount of damage while a fault in a transformer always required some attention of the supervisor staff. Fast clearing of faults, however assists in reducing the damage to the equipment and also reduces the interruption in power service caused by drop in voltage and from instability. Small distribution transformer is usually connected to the supply system through series fuses instead of circuit breakers. [1] Consequently, no automatic protective relay equipment is required. However, the probability of faults on power transformer undoubtedly more and hence protection is absolutely necessary. The transformer is major and very important equipment in power system. It requires highly reliable protective devices. The protection scheme depends on the size of the transformer. The rating of transformer used in transmission and distribution system ranges from a few KVA to a several MVA. For small transformer of medium size over current relays are used. For large size transformer differential protection is used. Types of faults in transformer • Internals fault • Transformer overload • Insulation breakdown • Oil contamination and leakage • Phase to phase fault • Phase to earth fault. [3]

2. SYSTEM ANALYSIS

2.1 Differential protection scheme this scheme is based on the principal that the input power to the power transformer under normal condition is equal to the output power. Under normal condition, no current will flow into the differential relay current coil. Whenever a fault occurs, within the protected zone, the current balance will no longer exist, and relay contacts will close and release a trip signal to cause the certain circuit breaker (CBs) to operate in order to disconnect the faulty equipment/part. The differential relay compares the primary and secondary side currents of the power transformer. Current transformer (CTs) are used to reduce the amount of currents in such a way their secondary side currents are equal. Fig. 1 shows the differential relay in its simplest form. The polarity of CTs is such as to make the current circulate normally without going through the relay, during normal load condition and external faults. [2]

The fundamental operating principle of transformer differential protection is based on comparison of the transformer primary and secondary winding currents. [10] For an ideal transformer, having a 1:1 ratio and neglecting magnetizing current, the currents entering and leaving the transformer must be equal. The differential relay actually compares between primary current and secondary current of power transformer, if any unbalance encountered in between primary and secondary currents the relay will actuate and inter trip both the primary and secondary circuit breaker of the transformer. Consider that you have one transformer which has primary rated current IP and secondary current IS. If you install CT of ratio $IP/1\ A$ at primary side and similarly, CT of ratio $IS/1\ A$ at secondary side of the transformer. The secondaries of these both CTs are linked together in such a manner that secondary currents of both CTs will oppose each other. This can be explained in other way as, the secondaries of both CTs should be connected to same current coil of differential relay in such a opposite manner that there will be no resultant current in that coil in normal working condition of the transformer.[7] But if any serious fault happens inside the transformer due to which the normal ratio of the transformer disturbed then the secondary current of both transformers will not remain the same and one resultant current will flow through the current coil of the differential relay, which will trigger the relay and inter trip both the primary and secondary circuit breakers.[9]

Mathematical model the current of the Current transformer located in the primary side of the power transformer

$$I_1 = \frac{I_P}{N_1} \qquad (1)$$

Where:

I_1 : The secondary side current of $CT1$

I_P : The primary side current of the power transformer,

N_1 : The number of turns in the secondary side of $CT1$

In the same manner for the CT located at the secondary side of the power transformer, then the CT secondary current is:

$$I_2 = \frac{I_S}{N_2} \qquad (2)$$

Where:

I_2 : The secondary side current of $CT1$

I_S : The primary side current of the power transformer,

N_2 : The number of turns in the secondary side of $CT2$

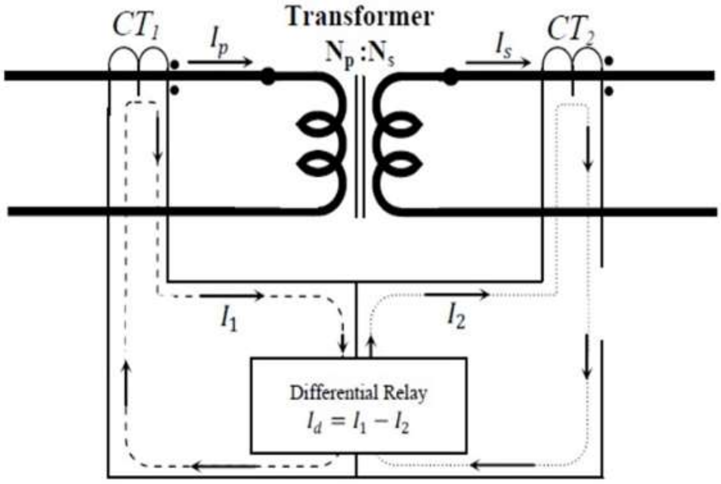

Figure 1. Differential protection for single phase two winding transformer

Since the differential current is: $Id = I1 - I2$ then, from equation (1) and equation (2) the differential current flowing in the relay operating coil current Id can be calculated as;
So,

$$I_d = \frac{I_P}{N_1} - \frac{I_S}{N_2} \quad \textbf{(3)}$$

If there is no internal fault occurring within the power transformer protected zone, the currents $I1$and $I2$ are assumed equal in magnitude and opposite in direction. That means the differential current Id = 0 as presented in figure 1. The primary and secondary side current of the power transformer are related to each other by equation

$$\frac{I_P}{I_S} = \frac{N_1}{N_2} \quad \textbf{(4)}$$

Where: $N1$ and $N2$: primary and secondary side turns of the power transformer, correspondingly. [16]

3 WORKING OF DIFFERENTIAL

3.1 Normal condition: Differential protection relies on the Kirchhoff principal that states that the sum of currents entering a node equals the sum of current leaving a node. [6] Applied to differential protection, it means that the sum of current entering a bus equals the sum of those leaving. If the sum of these currents is not zero, then it must be due to a short circuit

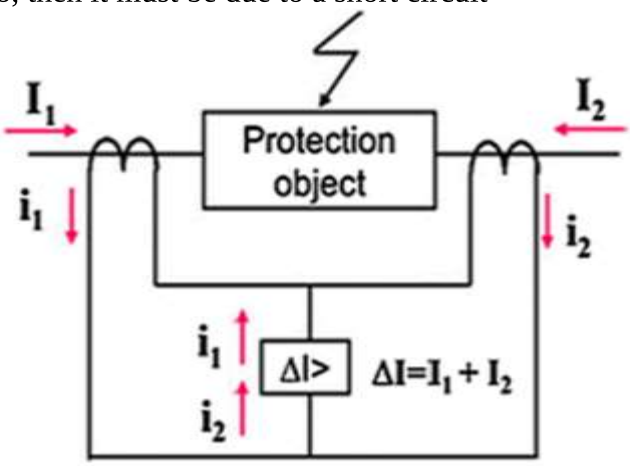

Figure 2. Protection under normal condition

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Either by an earth fault or a phase to phase fault, Differential relays take a variety of forms, depending on the equipment they protect, the definition of such a relay is "one that operates when the vector difference of two or more similar electrical quantities exceeds a predetermined amount". [4]
Figure 1illustates the implementation of a simple differential protection application. The dashed portion of the line indicates the protected zone. CTs are installed at either end of the segment and the secondary winding of the CTs are interconnected with a differential relay in parallel. [12]
3.2 Under fault condition: If there is current flow through the line to a load or external fault at X the differential protection should not trip. Provided that the 2 CTs are of the same ratio and property connected, the secondary currents of the CTs should only circulate as shown by the arrows in figure. There, no current should flow through the differential relay. [14]

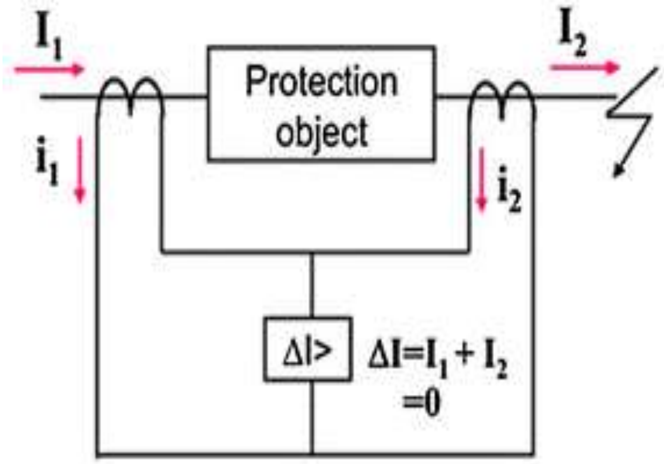

Figure 3. Protection under external fault
Figure illustrates the occurrence of an internal fault. In this case, the sum of currents entering the protected segment does not equal the current leaving. [8] This results in current flowing through the differential relay, which then initiates a trip.

4. **PROPOSED METHODOLOGY**
This method is possible due to the first woman obtaining the Master degree in electrical engineering at the MIT. She was also the first woman hired by General Electric as an electrical engineer in the United States. Also, in 1948 was the first woman nominated as Fellow at AIEE. The name of this extraordinary woman was Edith Clarke which method of transforming a three-phase signal into a two-phase signal is called: "Clarke's transform". [9] The Clarke's transformation is a well-known transformation presented by Edith Clarke in. The Clarke transforms utilized three-phase currents: ia, ib and ic to calculate currents in the two-phase orthogonal stator axis: ia and ib.
1. Very first we measuring the three-phase current on both sides of transformer.
2. Then performing Clark transformation on these phase currents. The main idea of using Clarke's transformation is to carry out in a pattern-recognition process to discriminate certain conditions of transformers.
3. Then we find the difference between phase to phase transformed current. These giving the information about the pattern difference between phase to phase current.
4. By the analysis of this we developed a lookup function which is monitoring as:
a. If the absolute instantaneous values of difference of transformed current for phase A and B are greater than 20 amp and for phase C is greater than 1e-3 amp then trips has to be released. OR
b. If the absolute instantaneous values of difference of transformed current for phase A and B are greater than 50 amp and for phase C is greater than 1e-4 amp then trips has to be released. The proposed model requires very less hardware than as compared to the base paper. [16]

5. DIFFERENTIAL PROTECTION DIFFICULTIES

Generally, three main difficulties handicap the conventional differential protection. [11] They induce the differential relay to release a false trip signal without the existing of any fault. These complications must be overcome in order to make the differential relay working properly

- Magnetizing inrush current during initial energization,
- CTs Mismatch and saturation.
- Transformation ratio changes due to Tap changer.

5.1 Magnetizing inrush current

This phenomenon, the transient magnetizing inrush or the exciting current, occurs in the primary side of the transformer whenever the transformer is switched on (energized) and the instantaneous value of the voltage is not at 90^0. At this time, the first peak of the flux wave is higher than the peak of the flux at the steady state condition. This current appears as an internal fault, and it is sensed as a differential current by the differential relay. [13] The value of the first peak of the magnetizing current may be as high as several times the peak of the full load current. The magnitude and duration of the magnetizing inrush current is influenced by many factors, some of these factors are

- The instantaneous value of the voltage waveform at the moment of closing CB,
- The value of the residual (remnant) magnetizing flux,
- The sign of the residual magnetizing flux,
- The type of the iron laminations used in the transformer core,
- The saturation flux density of the transformer core,
- The total impedance of the supply circuit,
- The physical size of the transformer,
- The maximum flux-carrying capability of the iron core laminations,
- The input supply voltage level

The effect of the inrush current on the differential relay is false tripping the transformer without of any existing type of faults. From the principle of operation of the differential relay, the relay compares the currents coming from both sides of the power transformer as explained above. However, the inrush current is flowing only in the primary side of the power transformer. So that, the differential current will have a significant value due to the existence of current in only one side. Therefore, the relay has to be designed to recognize that this current is a normal phenomenon and to not trip due to this current. [5]

5.2 False trip due to C.T characteristics

The performance of the differential relays depends on the accuracy of the CTs in reproducing their primary currents in their secondary side. In many cases, the primary ratings of the CTs, located in the high voltage and low voltage sides of the power transformer, does not exactly match the power transformer rated currents. Due to this discrepancy, a CTs mismatch takes place, which in turn creates a small false differential current, depending on the amount of this mismatch. Sometimes, this amount of the differential current is enough to operate the differential relay. Therefore, CTs ratio correction has to be done to overcome this CTs mismatch by using interposing CTs of multi taps. [14]

Another problem that may face the perfect operation of the CTs is the saturation problem. When saturation happens to one or all CTs at different levels, false differential current appears in the differential relay. This differential current could cause mal-operation of the differential relay. The dc component of the primary side current could produce the worst case of CT saturation. In which, the secondary current contains dc offset and extra harmonics. [4]

5.3. False trip due to tap changer

On-Load Tap-Changer (OLTC) is installed on the power transformer to control automatically the transformer output voltage. This device is required wherever there are heavy fluctuations in the power system voltage. The transformation ratio of the CTs can be matched with only one point of the tap-

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changing range. Therefore, if the OLTC is changed, unbalance current flows in the differential relay operating coil. This action causes CTs mismatches. This current will be considered as a fault current which makes the relay to release a trip signal.

6. IMPLEMENTATION OF THE DIGITAL DIFFERENTIAL PROTECTION USING MATLAB

This implementation is done using MATLAB/Simulink environment. Figure 7 shows the simulated power system built in MATLAB/Simulink environment. In which a three phase, 250MVA, 60Hz, (735/315) kV, Y/ power transformer is used in this system. [6]

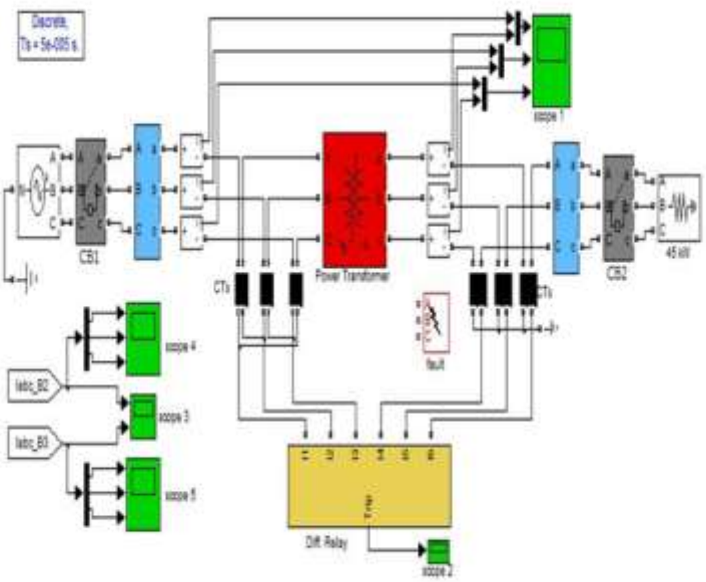

Figure 4. MATLAB/Simulink Model of the proposed system

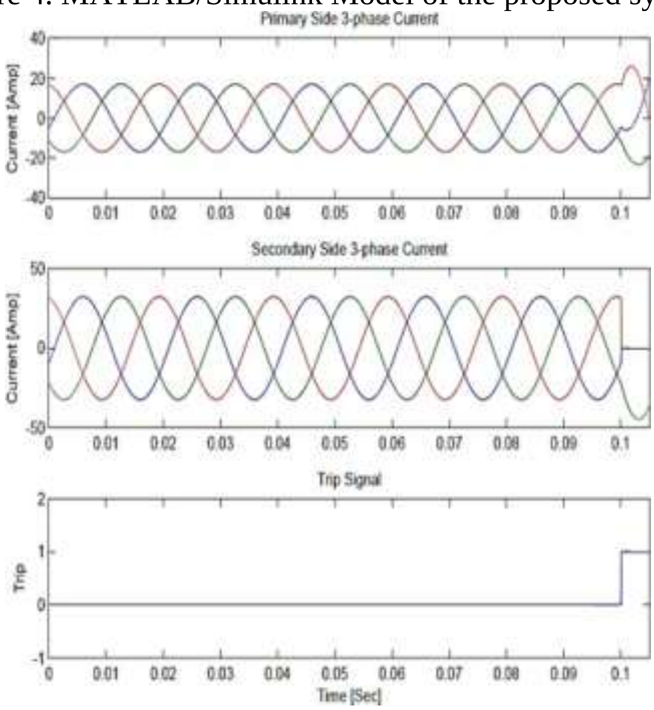

Figure 5. L-L-L-G Fault

7. ADVANTAGES

- It is used to protect a specific piece of equipment i. e. transformer, Generator, Bus section etc.
- Its operation time is very fast and easily coordinated with other types of relaying, fusing system.
- Required less power for control operation.

- No fire hazards.

8. CONCLUSION

It can be concluded that differential protection technique can be applied to the protection of any device in power system. It can be useful for protection of generator, bus bar protection, transformers protection etc. the technology of differential protection is not new but it is very useful for the unit protection. The equipment's like transformer and generators are very coasty so protection of them is very important. The disadvantage of this technique is that it cannot operate when an external fault is in the power system. This technology can be made better with the use of microcontroller. With the use of controller, the technique becomes very accurate and all relay are operated with the use of microcontroller. And also due to use of microcontroller all parameters can be controlled.

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