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Original Research Article

A Differential Protection Scheme for a Typical Three Phase Power Transformer

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ABSTRACT

This research presents a model and simulation of differential protection scheme for a three phase two-winding transformer using MATLAB/Simulink software. It is modelled to guide against false tripping during inrush magnetizing current. It also presents a fast response and fault clearing time of the protection scheme using the Simulink work tool. A 150 MVA, 330/132 kV transformer was used as case study. The digital differential protection scheme was incorporated using related Simulink block components. Data relevant to the study were collected from Transmission Company of Nigeria (TCN), Benin sub-region, and inputted into the blocks. These data include; transformer ratings, current transformer (CT) ratings, source voltage and receiving end voltage. From the simulated results, it was observed that the differential protection scheme gave a good response by discriminating between through faults and inrush magnetizing current. During the inrush magnetizing current there was no tripping of the relay. When fault was induced within the transformer, the relay gave a fast switching response of 0.52 msec after the fault had occurred.

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1. INTRODUCTION

A power system comprises of components that produce electrical energy and transmit this energy to consumers. Power systems are susceptible to disturbances under operating conditions; thus, it is important to design an efficient power system that will be able to survive all forms of disturbances. (Terzija et al., 2011). A malfunction or breakdown in a section or any device can lead to a complete collapse of the entire network or cause harm to man and his equipment being served by the power system (Seethalekshmi et al., 2011). Among the components that make up the power systems is the transformer. A transformer plays a vital and indispensable role in the power system as it functions to transform voltages from one level to another. Transformers are said to be the most expensive and strategic equipment of any electrical power system, and any fault or malfunctioning in the system could lead to its complete damage (Pukel et al., 2006). The primary objective of transformer protection is to detect internal faults in the transformer with a high degree of sensitivity and cause subsequent de-energisation and at the same time be immune to faults external to the transformer (Mahmoud et al, 2012). Therefore, there is need to incorporate a fast and reliable protection scheme for a transformer.

The first approach for the differential protection scheme was first developed by Charles H. Merze and Bernard Price in the year 1904. The technique has though been applied severally, but the protection scheme operated incorrectly as a result of the mismatch of current transformers at the primary protection zone (Dinesh et al., 2015). Researchers have carried out a good number of works on this protection scheme using different engineering software and algorithms. Adel and Rahman in 2011 carried out similar research on the same protection scheme, his work focused on a 250 MVA, 60 Hz, (735/315 kV) transformer with satisfactory results. Following the transformer capacities obtainable in our power systems in Nigeria, related study needs to be carried out with a 150 MVA, 50 Hz, (330/132 kV) transformer as case study.

The most widely accepted device for transformer protection is called a restrained differential relay. This relay compares current values flowing into and out of the transformer windings. To assure protection under varying conditions, the main protection element has a multi-slope restrained characteristic (Ali et al., 2018). This power transformer protection method should avoid and block the tripping of differential relay during inrush current and should rapidly operate the relay tripping during internal faults. As a result, it is essential to choose a proper identification scheme which can discriminate and distinguishes the magnetizing inrush current and internal fault current while a new power transformer is being installed by power companies.

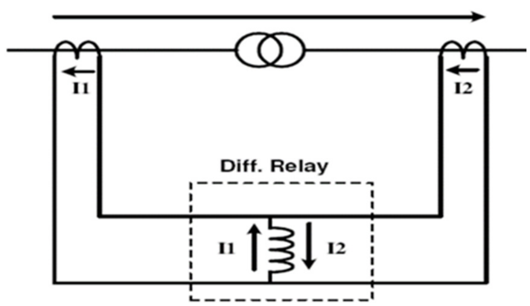

Figure 1: Differential protection

The operating current, I_{OP} can be obtained from the phasor sum of the currents entering the protected element. From Figure 1:

$$I_{OP} = |I_1 + I_2| \tag{1}$$

I_{OP} is equivalent to the fault current for internal faults and approaches zero for any other operating (ideal) conditions.
The restraining current, is given by:

$$I_{RT} = K|I_1 - I_2| \tag{2}$$

Where K is a compensation factor, usually taken as 1 or 0.5. The differential relay generates a tripping signal if the operating current, I_{OP}, is greater than a percentage of the restraining current, I_{RT} (Guzma, 2000). That is: $I_{OP} > SLP.\ I_{RT}$. The false operation of the differential protection scheme of power transformer can be ascribed to the inrush magnetizing current and CT saturation. Among these; magnetizing inrush current occurs during excitation of transformer under the condition of no-load (Ruchita and Naushin, 2016).

Magnetizing inrush current in transformer is the current which is drawn by a transformer at the time of energizing the transformer. The current lasts for few milliseconds and it is very transient in nature. The inrush current is up-to 10 to 15 times higher than the through current of transformer. The inrush magnetising current does not cause permanent damage to the transformer because it exists for a very short period of time. But still, inrush current in power transformer interferes with the operation of circuits as they have been designed to function and this is a huge problem in the system (Reena, 2014). It flows in the primary side of the transformer and causes differences in the CT output which prompts the relay to trip falsely.

It is of great importance to ensure that false tripping and unwanted outages are minimized by protective systems. Therefore, protective systems are getting more sophisticated, manufacturers are applying more advanced technology as compared to the electromagnetic and static relays that have been in use. The work presents a study on the effect of internal and external faults with a fast response on the protection scheme. It also guides against false operation during inrush magnetizing current. The scheme under study provides high resolution protection settings, phase-shift compensation within the relay, increased input and output capability and asset management functionality.

2. METHODOLOGY

Matlab/Simulink work tool was used to carry out the simulation of the differential protection scheme. The protection scheme protects the transformer against internal faults and impedes any form of interruption during inrush currents. In the differential protection scheme, a fast algorithm was introduced. This algorithm is based on the fast Fourier algorithm (FFT). The algorithm is built on the principle of harmonic-current restraint, where the magnetizing-inrush current is characterized by large harmonic components content that are not noticeably present in fault currents (Adel and Rahman, 2011). In Fast Fourier Transform, any periodic signal can be decomposed to its sine and cosine components as follows:

$$f(t) = \frac{a_0}{2} + \sum_{k=1}^{\infty} C_k Cos(kwt) + S_k Sin(kwt) \tag{3}$$

Where: a_o is the DC component of the f (t), and C_K, S_K are the cosine and sine coefficients of the frequencies present in f(t), respectively. The discrete forms of the coefficients C_K, S_K are as expressed:

$$C_k = \frac{2}{N} \sum_{n=1}^{N-1} x(n) Cos\left(\frac{2kwt}{N}\right) \tag{4}$$

$$S_k = \frac{2}{N} \sum_{n=1}^{N-1} x(n) Sin\left(\frac{2kwt}{N}\right) \tag{5}$$

$$F_k = \sqrt{C_k^2 + S_k^2} \tag{6}$$

$$2^{nd}\ harmonic\ content = \frac{F_2}{F_1} \times 100 \tag{7}$$

Equation 7 is the percentage of the 2^{nd} harmonic content. Where: F1 is the fundamental harmonic, F2 is the second harmonic content, F_K is the k^{th} harmonic coefficient for k = 1, 2,...,N and x(n) is the signal f(t) in its discrete form (Michael, 2017).

The implemented software carried out the following evaluation processes.

i. It assessed the data from the current transformers (CTs)

M.O. Oyedoh et al. / Nigerian Research Journal of Engineering and Environmental Sciences
4(1) 2019 pp. 201-209

ii. It carried out the absolute difference of the output current from the primary and secondary CTs

iii. If the differential current or operating current calculated in (ii) is less than the restraining current it is said to be in the operation mode. If it is greater than the current in restraining coil, the harmonic content is calculated

iv. If the second harmonic component (F2) is greater than 30% of the fundamental harmonic component it is seen as an inrush current and no switching takes place

v. If the second harmonic component (F2) is less than 30% of the fundamental harmonic a switching signal is sent and the relay actuates.

Figure 2 is a flow chart of the highlighted processes.

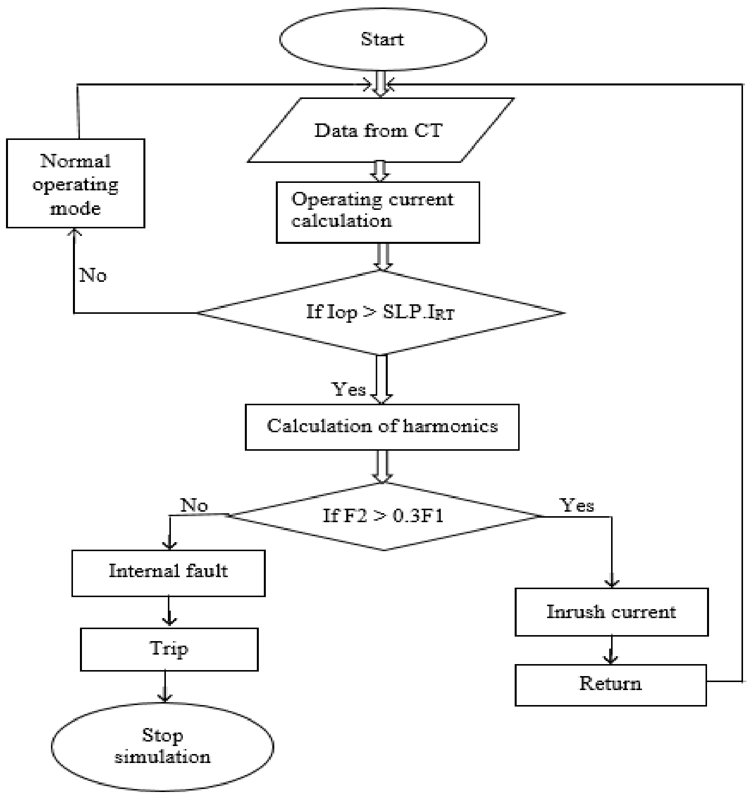

Figure 2: Flowchart of the protection scheme

2.1. Implementation of the protection scheme

The transformer under study is a 150 MVA 330/132 kV star/delta step-down transformer. The protection scheme is as shown in Figure 3. In order to make up for the 30° phase shift, the CTs configuration were connected in star/delta as the power transformer is of delta/star configuration. This is in line with the regular practice. In the software implementation, a single phase transformer was used to represent current transformer. It was configured to match the CTs configuration of 400/1 at the primary side of the transformer and 800/1 at the secondary.

M.O. Oyedoh et al. / Nigerian Research Journal of Engineering and Environmental Sciences
4(1) 2019 pp. 201-209

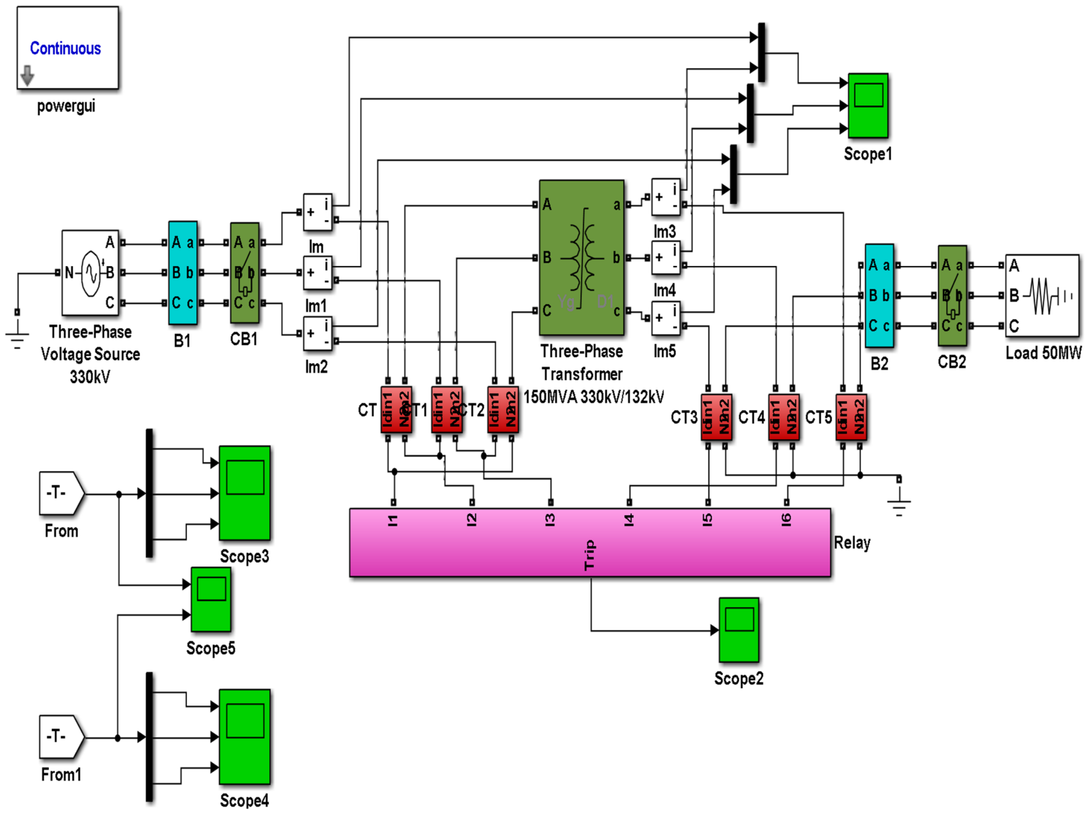

Figure 3: Differential protection scheme

3. RESULTS AND DISCUSSION

The simulation was carried out by subjecting the scheme to different conditions. For condition 1 (magnetizing inrush current), the transformer was subjected to different cases or conditions. Under this condition, the transformer was subjected to an inrush magnetizing current. In condition 1, the primary breaker (CB1) of the transformer under study was closed at 0.1 sec, and there was a flow of inrush magnetizing current at the primary, and none at the secondary side of the transformer as shown in Figure 4.

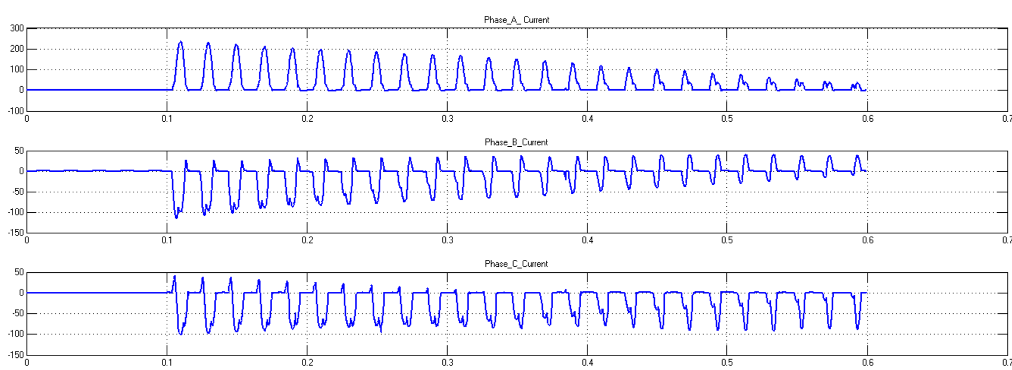

Figure 4: Inrush magnetizing waveform at the primary side of the power transformer

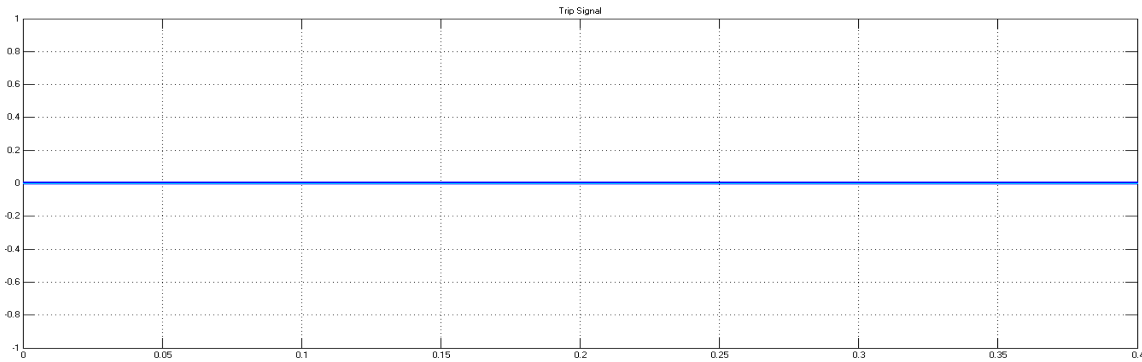

Figure 5: Trip signal

The differential and magnetizing inrush currents were equal, leading to zero operating current to trip the circuit (Figure 5). This is because the second harmonic component was more than 30% of the fundamental harmonics. The waveform of the inrush current is distorted due to saturation in the transformer core. This result is compares to that of Adel and Rahman (2011). With the algorithm built on the principle of harmonic-restraint, the protection scheme was able to discriminate between inrush magnetizing current and fault current.

For condition 2, the transformer was subjected to magnetizing current under load. In Figure 6, the transformer was powered at 0.1 sec with an evidence of magnetizing current at the primary side of the transformer. At 0.3 sec, the transformer was subjected to a 50 MW load. When the load was added, current began to flow at both primary and secondary circuits of the transformer. Following the transformation ratio, the primary and secondary current became equal after the load was switched on at 0.3 sec. This resulted to a zero differential current and as such, no trip signal was released which is as shown in Figure 7.

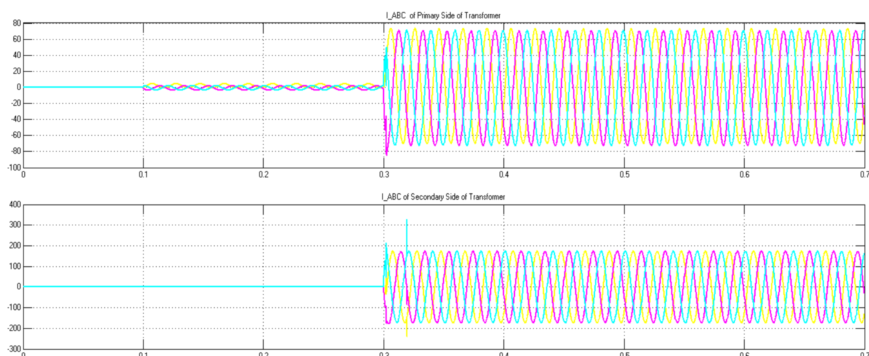

Figure 6: Inrush current with transformer on-load at the primary and secondary side of the transformer

M.O. Oyedoh et al. / Nigerian Research Journal of Engineering and Environmental Sciences
4(1) 2019 pp. 201-209

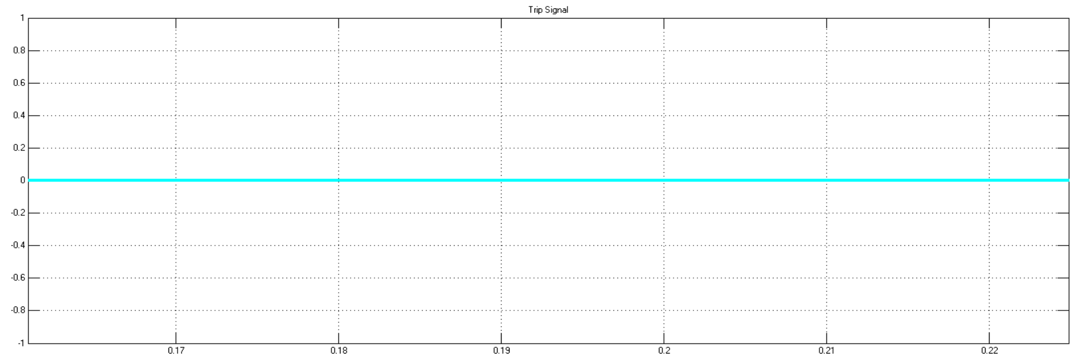

Figure 7: Normal load current (with zero trip signal)

For condition 3 (three phase to ground fault at loaded transformer), the transformer was subjected to a three phase fault which is expected to trip the circuit. The fault was subjected to the system at 0.3 sec. This caused a tremendous increase of the primary current within the transformer protected area at 0.5 sec as shown in Figure 8. Due to the difference in current between primary and secondary sides of the transformer, a signal was sent to the trip circuit leading to the actuation of the trip circuit at 0.52 msec after the fault occurred as shown in Figure 9. As observed in Figure 8, there was no current flow at the secondary end of the transformer after the circuit tripped.

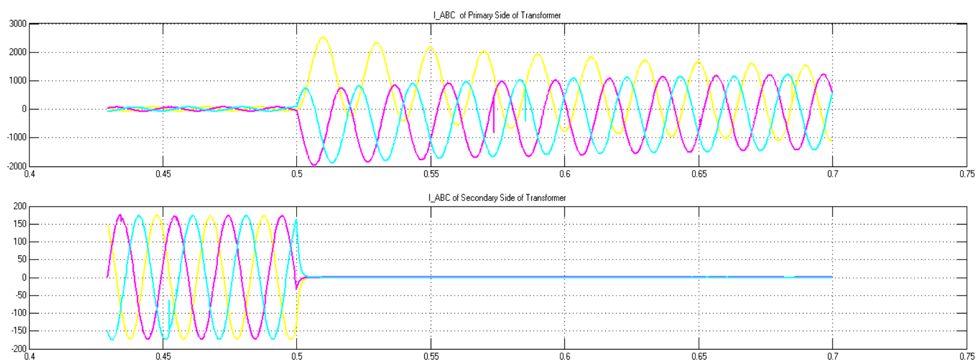

Figure 8: Primary current and secondary current with transformer subjected to three phase to ground fault

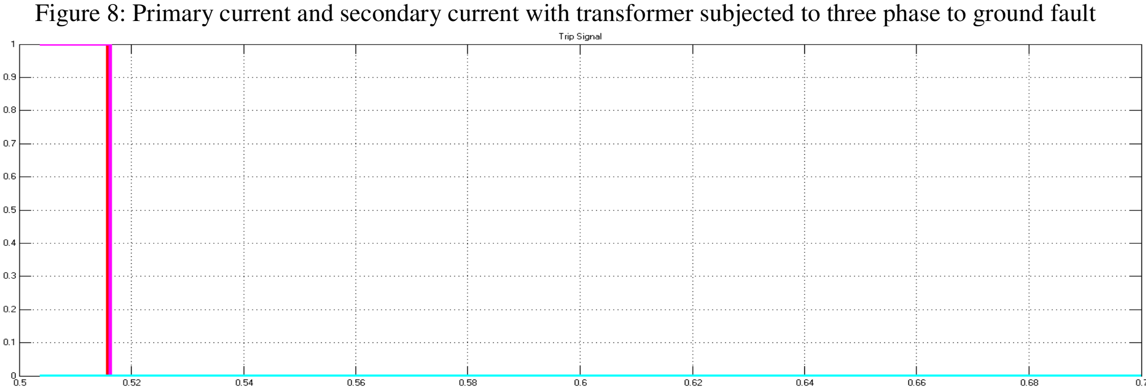

Figure 9: Trip signal due to fault

For condition 4 (phase A to ground external fault at loaded transformer), external fault was applied to check the behaviour of the protection scheme. This condition is similar to condition 2 because the fault which took place outside the protected zone resulted to increase of fault current in both primary and secondary sides of the transformer. As a result, the differential current is almost zero and as such no trip signal was achieved. This satisfies the fact that the differential protection scheme takes into effect faults that take place within its primary protection zone. This can be seen in Figure 10 and Figure 11.

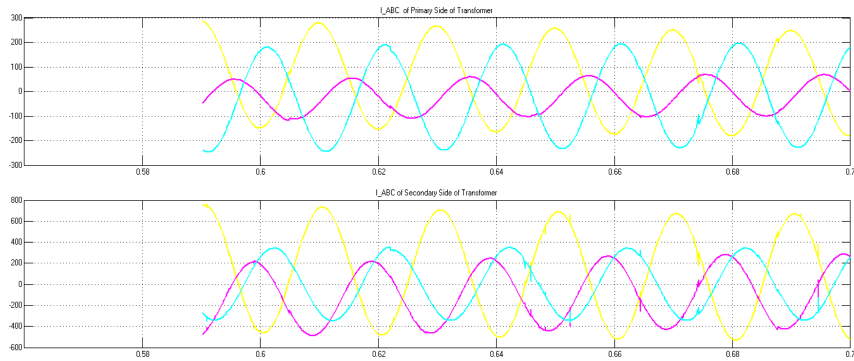

Figure 10: Primary current and secondary current during external fault

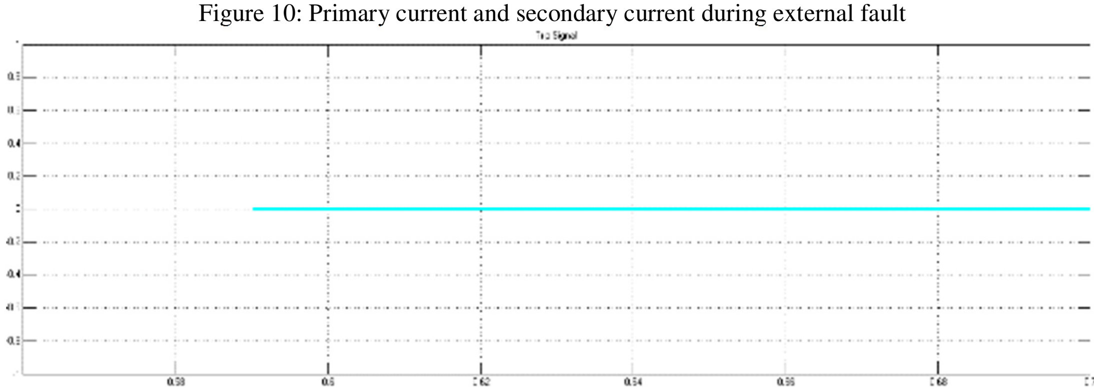
Figure 11: No trip signal during external fault

4. CONCLUSION

The differential protection scheme of power transformer was implemented successfully with an improved switching time of 0.52 msec from the point the fault signal is sent. The system was subjected to various operating conditions and simulated results were satisfactory. The fault clearing times and the simulated results were within the operating standard of the differential protection scheme. This result satisfies related work done on similar protection scheme. Therefore, the protection scheme can be credited to satisfy the basic characteristics of power systems protection which are; reliability, sensitivity, selectivity, timely and speedy.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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