Negative Sequence Current Based Turn-to-Turn Fault Identification in Power Transformer

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Abstract- *This paper proposes an effective technique for the protection of power transformer during minor internal fault condition like Turn-to-Turn fault. The proposed technique is based on the magnitude of negative sequence current and phase angle sift between source and load side negative sequence currents. The technique is able to detect Turn-to-turn fault even in case of 1% of shorted winding. All possible minor Turn to turn fault conditions (1% to 10% of shorted winding) have been considered for the testing of proposed technique. In addition to that effect of external fault with and without Current Transformer saturation has also been considered. PSCAD/EMTDC platform have been considered for the evaluation of proposed technique.*

Keywords- Internal fault, Negative sequence component, Power transformer, Turn-to-turn fault.

I. INTRODUCTION

Power transformer is one of the most important components of the power system which play an important role in the transmission and distribution of power flow. Considering its importance, its protection requires extra attention for the minor internal fault conditions. Differential current based technique is one of the most widely used protection techniques against the internal fault in power transformer from decades. Differential protection is based on the magnitude of differential current. When the differential current exceeds the minimum threshold value, differential relay issue a trip signal [1]. This technique detects all possible internal fault conditions in the power transformer but the mal-operation of the differential relay may possible due the inrush current, which result from transients in transformer magnetic flux. The transients in transformer magnetic flux may occur due to energization of transformer, voltage recovery after fault clearance or connection of parallel transformers. To avoid the mal-operation of differential relay, desensitizing or delaying the relay has been considered which affects the relay operation during minor internal faults conditions like turn-to-turn faults. Hence the turn -to-turn internal fault detection is challenging problem for the protection engineer.

Some researchers have used the significant features of the differential current for the detection of internal fault [2] - [4]. Significant features have been extracted using wavelet transform (WT) but the application of wavelet transform requires additional time for the calculation which increases the relay operating time. In addition to that some researchers have been used Artificial Neural Network (ANN) for the detection of internal faults [5]. The technique based on ANN increases the generalization ability of the proposed relay. But the major drawback of this technique is that it requires huge amount of training and testing data. ANN technique is also not able to detect all minor internal faults such as low percentage of shorted winding. Fuzzy Logic based protection algorithm has also been reported in the literature which requires fuzzy rules [6]. Above discussed techniques may also influenced by the other operating condition like external fault, current transformer (CT) saturation during external fault, over-excitation condition etc. Above discussed literature reveals that protection of power transformer for minor turn-to-turn fault requires extra attention.

Hence in this paper protection of power transformer has been done for minor turn-to-turn fault conditions. The proposed technique is based on the negative sequence current and the phase angle shift between the source and load side negative sequence current. The operation of the proposed technique is based on the two thresholds vez. Source and load side negative current threshold and phase angle shift threshold between source and load side negative sequence current. Influence of external fault with and without CT saturation has also been considered for the analysis. Effect of over-excitation condition has also been considered to check the reliability of the proposed technique.

II. SYMMETRICAL COMPONENTS

Different types of protection scheme have been reported in the literature for the power transformer protection. Literature revels that no one has paid attention for minor internal fault like turn-to-turn fault. The proposed protection algorithm improves the sensitivity and reliability of differential relay for minor internal turn-to-turn faults. The proposed algorithm is based on the theory of sequence components, more exact, on negative sequence component. According to Fortescue's theorem, three phase unbalanced phasors can be resolved into three phase balanced phasors system [7] - [10]. The phasor diagram of three phase unbalanced current is shown in Fig. 1.

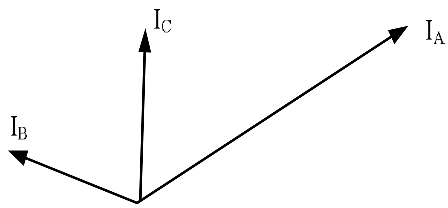

Figure 1. Phasor representation of three phase unbalance current

A) Positive sequence components

Positive sequence components consist of three phasors of equal magnitude which are displaced by 120o in phase from each other, and have phase sequence similar to the original IABC. The phasor of positive sequence component is shown in Fig. 2.

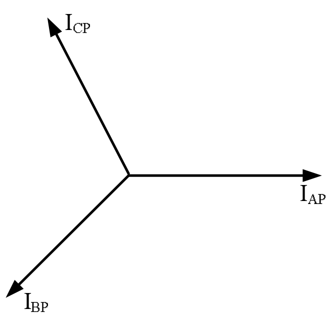

Figure 2. Positive sequence current components

B) Negative sequence components

Negative sequence components consist of three phasors of equal magnitude which are displaced by 120o in phase from each other, and have the phase sequence opposite to the original phasors IABC. The phasor of negative sequence component is shown in Fig. 3.

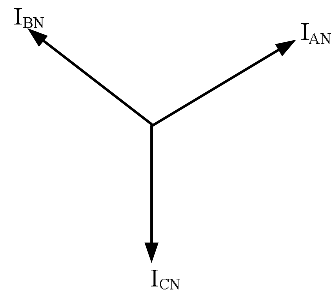

Figure 3. Negative sequence current components

C) Zero sequence components

sequence components consist of three phasors of equal magnitude and having zero degree phase displacement from each other as shown Fig. 4

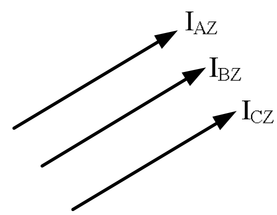

Figure 4. Zero sequence current components

The sequence component based method converts three unbalanced phases into three independent balance phases.

The new protection technique for turn-to-turn fault is based on the negative sequence currents. Negative sequence currents superimpose pure-fault quantities. Negative sequence currents have the advantage over the zero sequence currents. It is known that removing the ground from the unit will eliminate zero sequence components. However, negative sequence currents are produced even when the fault does not include earth.

III. PROPOSED ALGORITHM

The proposed method is based on the negative sequence components of the both source and load sides of the power transformer. The operation of the proposed algorithm is based on the relative position of the negative sequence current phasors of source and load side currents. In other words, this protection algorithm will compare the phase shift between the source side negative sequence current and the load side negative sequence current.

However, the comparison between the negative sequence currents of the source and load side of the power transformer is valid for zero phase displacement power transformers having unit turns ratio. In other words, the comparison is valid for the Δ-Δ or Y-Y connected power transformer having unit turn ratio. If the phase displacement of the power transformer is not equal to zero and having turn ratio other than unity than it requires compensation for phase displacement and turn ratio. Compensation is required to set the minimum pick-up value. The Δ-Y connection of three phase power transformers introduces a 30o phase shift between the source and load of power transformer. A 30o phase shift between the source and load side of the power transformer can be compensated by the proper connection of current transformer. The correct selection of CTs ratio provides compensation of current magnitude which is cause by turn ratio of power transformer.

The flow chart for the proposed algorithm is shown in Fig. 5 and explained below.

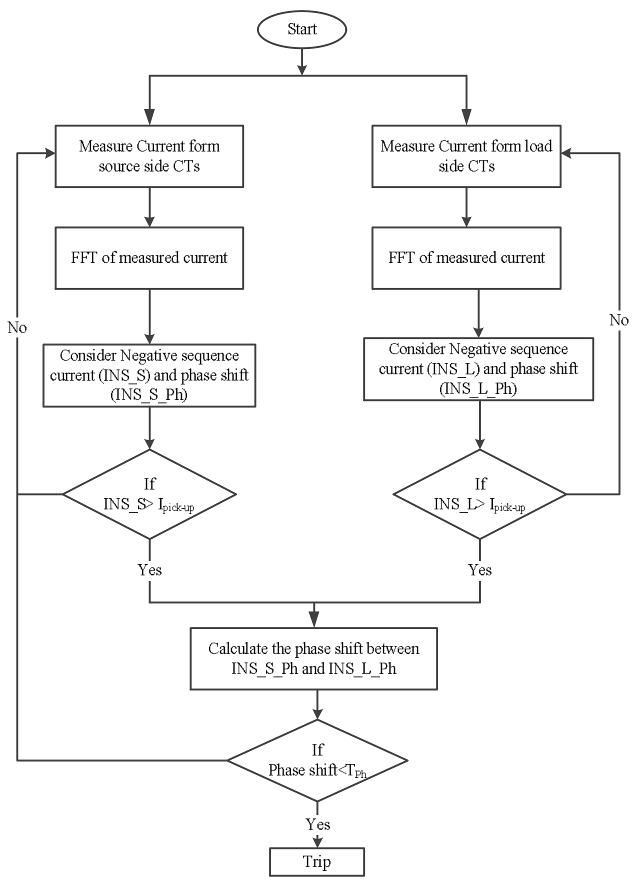

Figure 5. Flow chart for the proposed algorithm

As seen from the Fig. 5, in first step of the proposed algorithm, current measured form the source and load side CTs is processed for Fast Fourier Transformation (FFT). In the next step, only negative sequence current components of FFT have been considered for the further analysis. In the further stage, if the negative sequence current of source and load side becomes greater than the minimum pick-up value, it is detected as abnormal condition such as external fault, magnetizing inrush and internal fault condition. After that for the detection of type on abnormality, phase shift between source and load side negative sequence current have been evaluated. If the phase shift becomes less than threshold (TPh), abnormal condition is detected as internal fault condition. If phase shift is greater that TPh, condition is detected as normal condition of power transformer and the algorithm starts measurement of current form source and load side CTs again to repeat the process.

IV. SMULATIONS RESULTS

The power system used for the performance evaluation has one source connected through the three phase power transformer and load. A three phase transformer bank is made up of three single phase power transformers of rating 33.3 MVA, 23/132 kV using PSCAD/EMTDC platform. PSCAD/EMTDC is the simulation tool for analyzing power system transient developed by Manitoba HVDC Research Centre [11]. The simulated power transformer model with source and load is shown in Fig. 6. The appropriate CTs for source and load side are of ratio 1/2000 and 1/400 respectively.

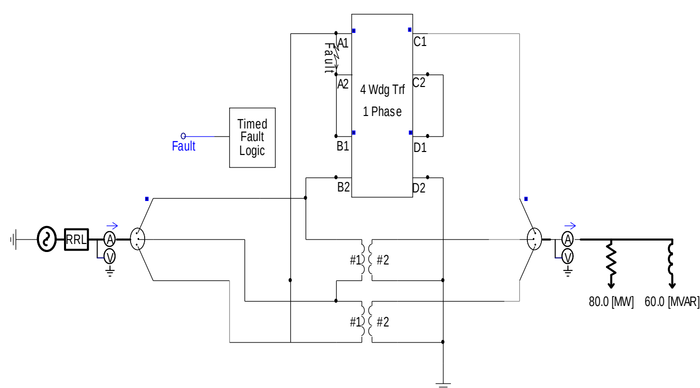

Figure 6. Simulated power transformer model using PSCAD/EMTDC platform

A) Components used for the evaluation of proposed algorithm in PSCAD/EMTDC

There are number of components used for the evaluation of the proposed algorithm which are available in the PSCAD/EMTDC library. Detailed discussion about these components is discussed below.

The first step is to extract magnitudes of negative sequence currents. To extract these magnitudes, the FFT block can be used which are available in library as shown in Fig. 7. The FFT block has the facility to determine the magnitude of harmonic contents and corresponding phase angle of the input signal as a function of time. FFT block has the facility to take one, two or three inputs at a time for the FFT analysis whose outputs are positive (Mag+), negative (Mag-), and zero (Mag0) sequence components and positive (Ph+), negative (Ph-), and zero (Ph0) sequence phase components as shown in Fig. 7. The FFT is a process of multiplying a signal by a sinusoid in order to determine its frequency components. First the input signal is sampled before it is decomposed into harmonic contents. Fig. 7 (a) and (b) show the FFT block used to extract the negative sequence components form source and load side currents respectively.

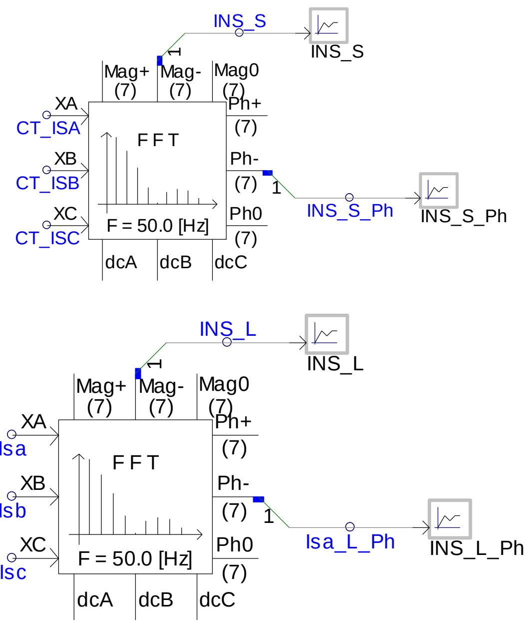

Figure 7. FFT block for the measurement of magnitude and phase angle of negative sequence component of (a) source side and (b) load side currents

In Fig. 7,

INS_S - magnitude of the negative sequence current on source side of power transformer

INS_L - magnitude of the negative sequence current on load side of power transformer

INS_S_ph - phase angle of the negative sequence current on source side of power transformer,

INS_L_ph - phase angle of the negative sequence current on the load side of power transformer.

The next step is to check the magnitude of negative sequence components (INS_S and INS_L) of both source and load side weather it is greater than minimum pick-up value. The minimum pick value has set to 10% to make it sensitive. The source and load side magnitude of negative sequence current is compared with pick-up using comparator black available in PSCAD/EMTDC library. If the magnitude of current will be greater than pick-up value than output of comparator will be high.

To compare magnitudes of negative sequence currents with a pre-set level, a comparator has been used. This component compares two inputs. The output from the comparator is a level output which is obtained when one signal is above the other signal. The comparison of source and load side negative sequence currents with a pick-up value using the comparator are shown in Fig. 8 (a) and (b) respectively.

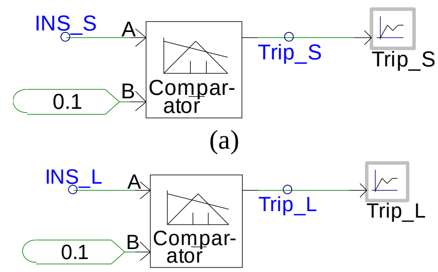

Figure 8. Comparison of negative sequence currents with a pick-up value

If the output of magnitude comparator (Trip_S and Trip_L) is high than only a phase shift comparison between source and load side negative sequence current will enable.

Phase angle comparison between source and load side negative sequence currents phasors is shown in Fig. 9 which discriminates turn-to-turn fault from other abnormal conditions.

As seen from Fig. 9 that two 2 input selectors have been used in phase shift comparison. The output from the selector will be ‘A’ or ‘B’ depending on the Ctrl value. If the value of Ctrl is 1, then the output of the selector 1 will be INS_S_Ph, and if the value of Ctrl of the selector 2 is 1, then the output will be INS_L_Ph. After that using the Differencing Junctions block, the difference between these two phase shift has been calculated. If the difference is in the range between 0o-5o, then the comparator will give output ‘1’ as final trip signal.

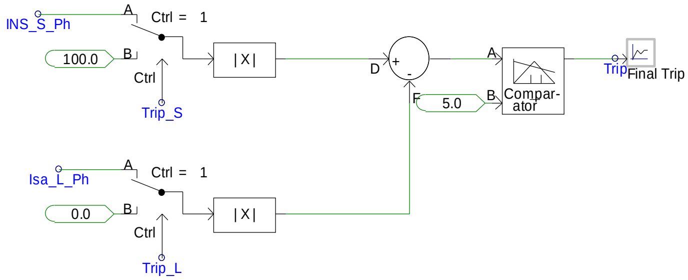

Figure 9. Logic for the comparison of phase shift between source side and load side negative sequence currents

B) Performance evaluation

This section presents the performance evaluation of the proposed algorithm based on negative sequence current. The internal turn-to-turn fault has been created by shorting 1% to 10% of winding to check the sensitivity of the proposed algorithm. The study of results is discussed in subsequent subsections.

1) Turn-to-turn fault in source side winding of power transformer

Turn-to-turn internal faults have been created at different percentage of source side winding. Fig. 10 shows the performance of the proposed algorithm for the 1% shorted turns. The internal fault occurs at time t=0.25 sec and clears at time t=0.35 sec. From top to bottom in Fig. 10, the first graph shows the negative sequence current components for source and load side current. Second graph shows the trip command issued by the magnitude comparator which enables the phase shift comparator. The third graph shows the phase angel of both source and load side negative sequence current component. As seen from the third graph that during the internal fault condition phase shift becomes approximately equal to zero degree. Bottom graph shows that final trip signal becomes high during internal fault condition. Similarly, Fig. 11 to Fig. 13 show the performance of proposed algorithm for 2%, 5% and 10% shorted turns respectively. It reveals form the figures that proposed algorithm is able to detect all possible mild inter-turn faults.

2) Turn-to-turn fault in load side winding of power transformer

Similar to the source side winding, turn-to-turn fault has been created in load side winding for different number of shorted turns. Fig. 14 to Fig. 16 shows the performance of the algorithm for the 1%, 5% and 15% of shorted turns.

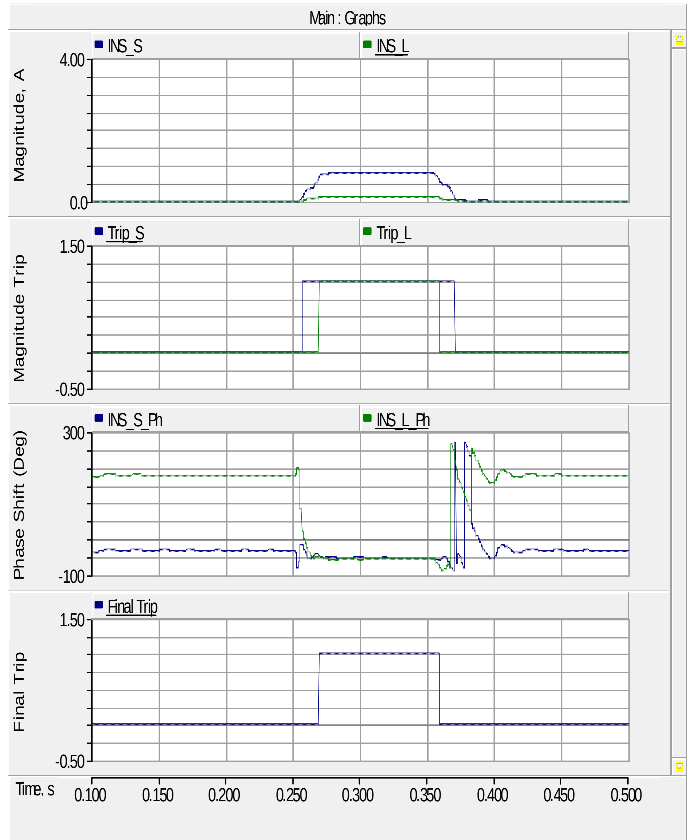

Figure 10. Performance of the proposed algorithm during 1% of source side winding shorted

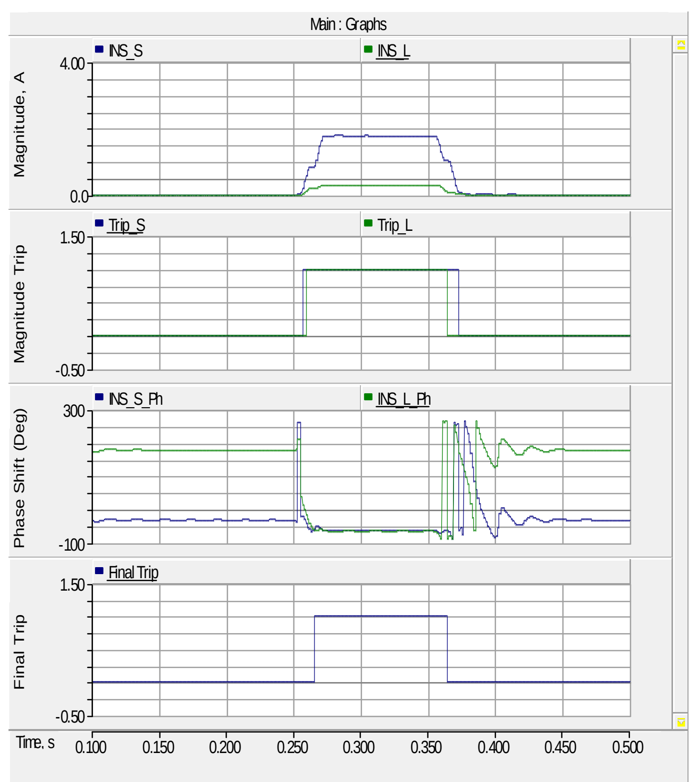

Figure 11. Performance of the proposed algorithm during 2% of source side winding shorted

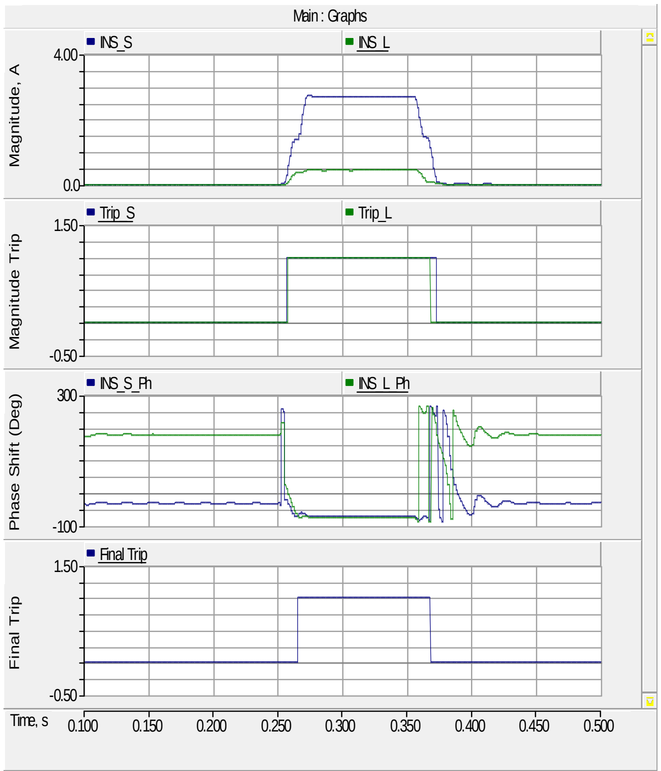

Figure 12. Performance of the proposed algorithm during 5% of source side winding shorted

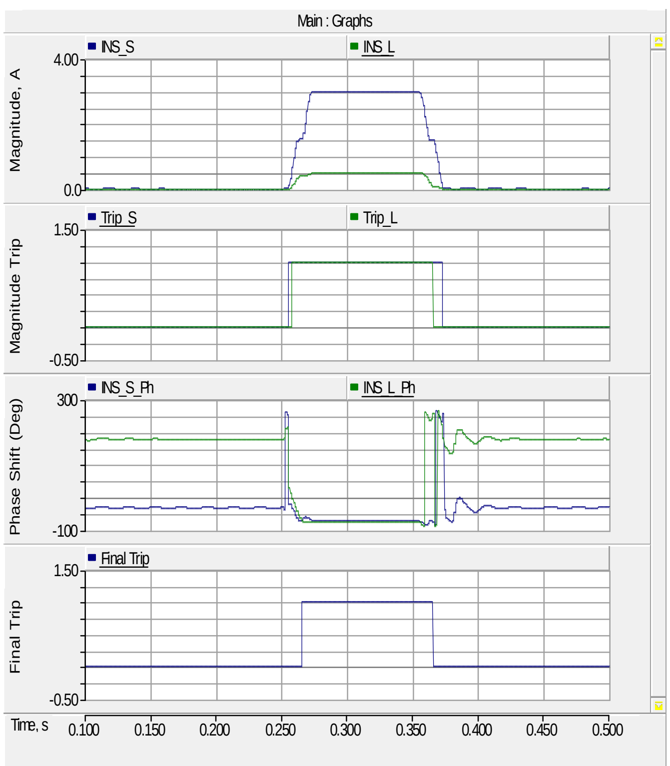

Figure 13. Performance of the proposed algorithm during 10% of source side winding shorted

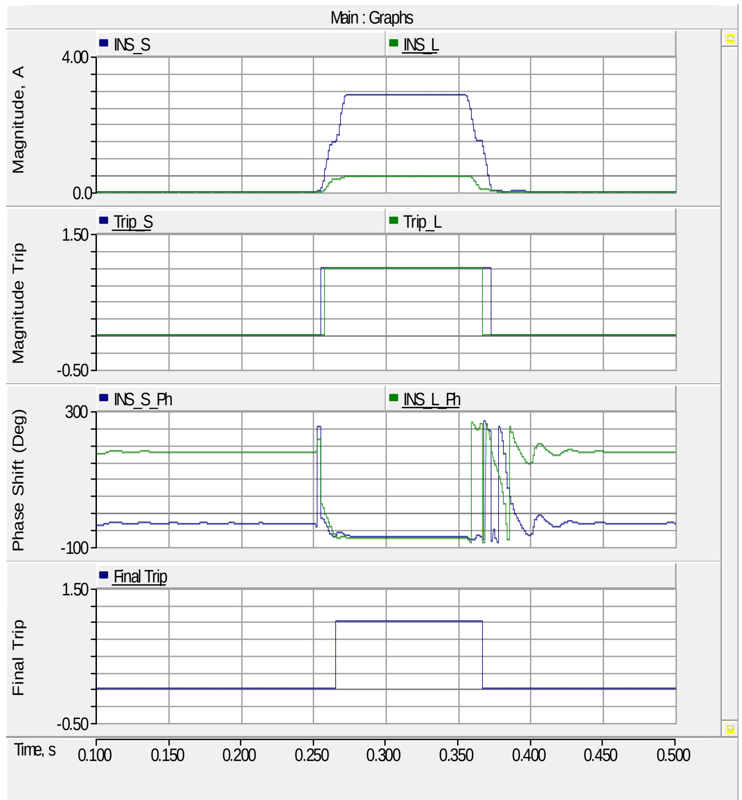

Figure 14. Performance of the proposed algorithm during 1% of load side winding shorted

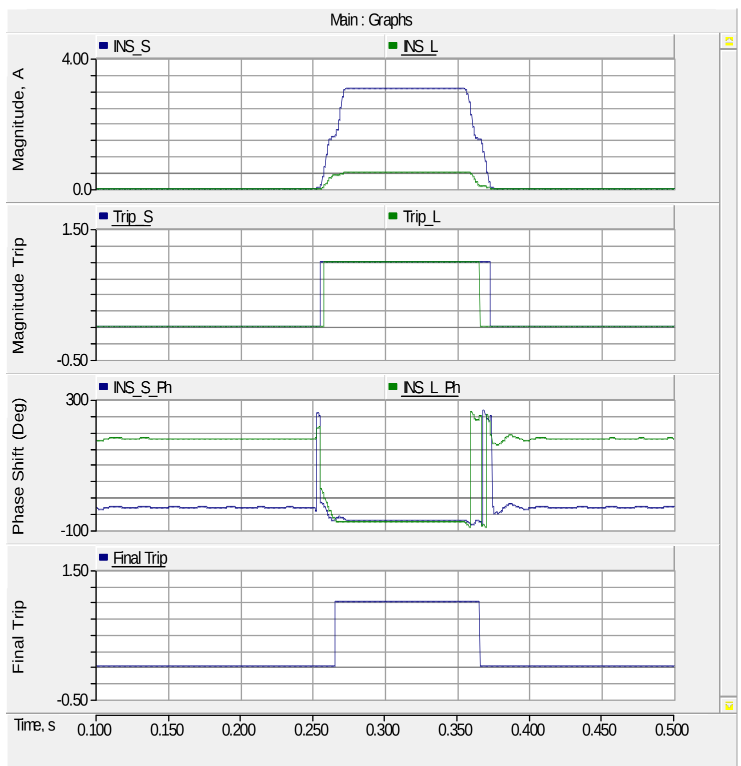

Figure 15. Performance of the proposed algorithm during 5% of load side winding shorted

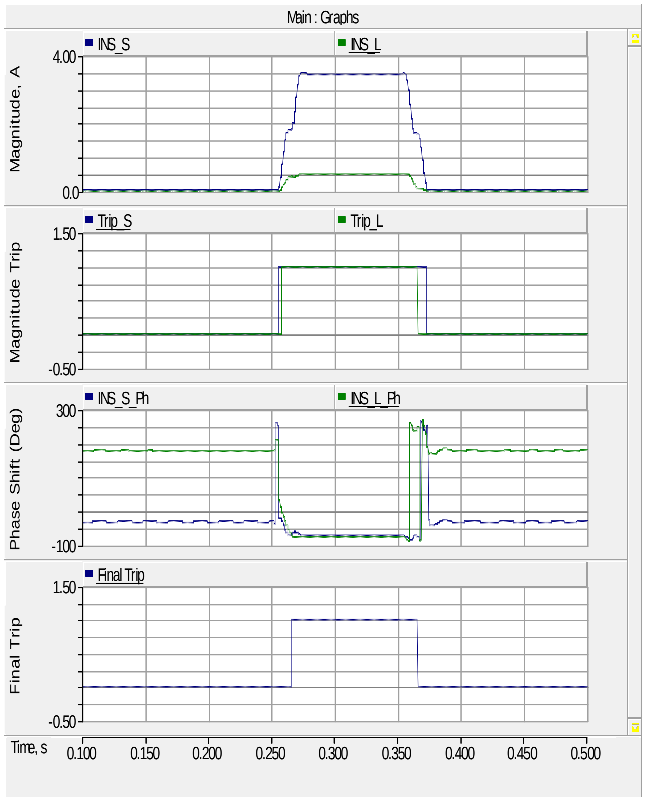

Figure 16. Performance of the proposed algorithm during 15% of load side winding shorted

3) Effect of external fault on proposed algorithm

Reliability of the proposed algorithm has been checked by considering effect of external fault. AG external fault have been created at time t=0.25 sec for the duration of 0.1 sec as shown in Fig. 17. During external fault, the output of magnitude comparator goes high as shown in figure but the output of the phase shift comparator does not go high which shows that the protection algorithm is reliable for external fault.

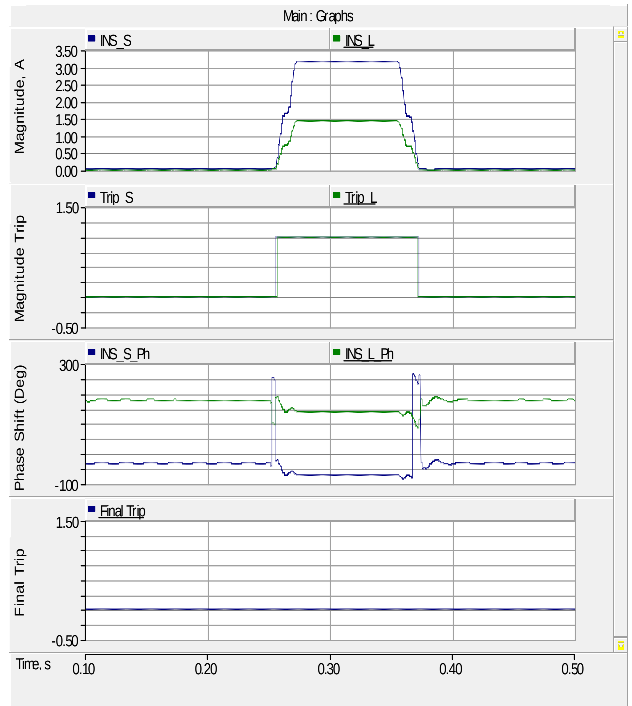

Figure 17. Effect of AG external fault on proposed algorithm

4) Effect of CT saturation during external fault

CT saturation condition during external fault may also affect the performance of the proposed algorithm [12] – [15]. Hence study of its effect on algorithm is necessary. To show the effect of CT saturation, load side CT is forced to saturate by increasing its burden resistance [16]. The waveform of saturated load side current (green solid line) along with original waveform (blue solid line) is shown in Fig. 18. The performance of algorithm considering CT saturation during external fault is shown in Fig. 19. It has been revealed form the figure that the proposed algorithm is stable under CT saturation during external fault

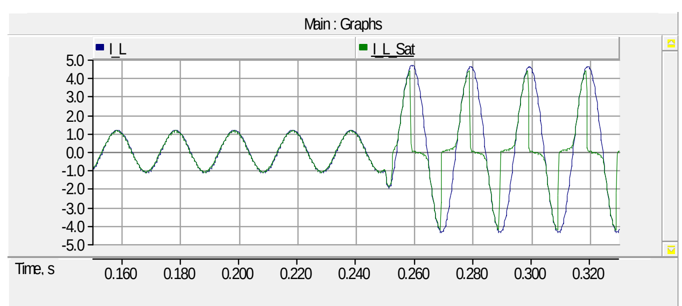

Figure 18. Load side current considering CT saturation

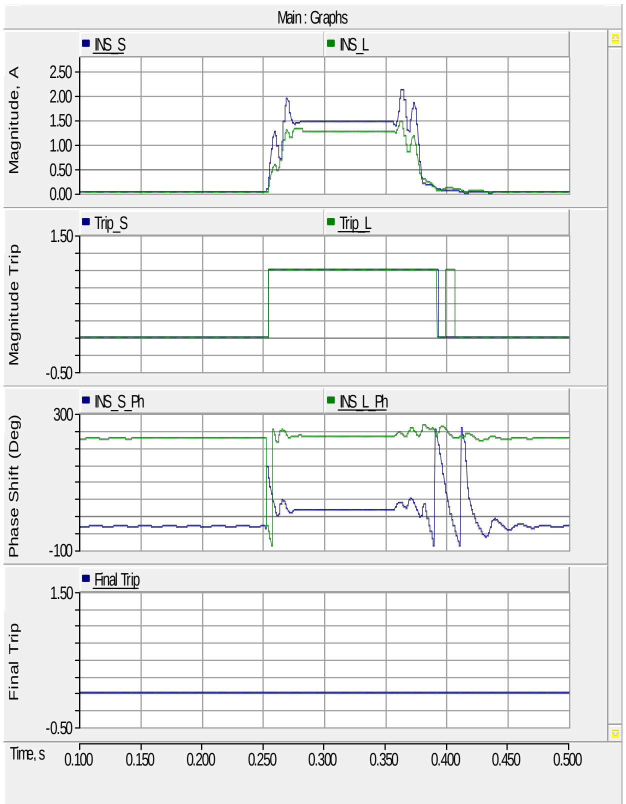

Figure 19. Effect of CT saturation during heavy external fault (ABG)

V. CONCLUSION

This paper proposed an algorithm for the detection of turn-to-turn internal fault in power transformer based on negative sequence current component and phase angle shift between source and load side current. Negative sequence current component threshold is used as a minimum threshold value which discriminates abnormal condition. Phase angle shift threshold is used to discriminate internal fault conditions for other operating conditions of power transformer. Proposed algorithm is also immune from external fault condition considering with and without CT saturation. Results show that proposed algorithm is able to detect minor internal fault of 1% winding shorted. Hence the proposed algorithm is able to detect all possible minor inter turns fault in power transformer.

REFERENCES

[1] M. Tripathy, R. P. Maheshwari, and H. K. Verma, “Advances in transform protection: A review,” Elect. Power Compon. Syst., vol. 33, no. 11, pp. 1203–1209, Nov. 2005.

[2] M. Tripathy, “Application of Neuro-Fuzzy techniques for power transformer protection,” Ph.D. Thesis, Indian Institute of Technology Roorkee, India, 2008.

[3] M.S. Sachdev, "Microprocessor relays and protection systems," IEEE Tutorial Course Text, Publication No.88EH0269-1- PWR, 1988.

[4] S. A. Saleh and M. A. Rahman, “Modeling and protection of a three-phase power transformer using wavelet packet transform,” IEEE Transactions on Power Delivery, vol. 20, no. 2, pp. 1273–1282, 2005.

[5] L. G. Perez, A. J. Flechsig, J. L. Meador, and Z. Obradovic, “Training an artificial neural network to discriminate between magnetizing inrush and internal faults,” IEEE Transactions on Power Delivery, vol. 9, no. 1, pp. 434–441, 1994.

[6] M. C. Shin, C. W. Park, and J. H. Kim, “Fuzzy logic based relaying for large power transformer protection,” IEEE Trans. Power Del., vol. 18, no. 3, pp. 718–724, Jul. 2003.

[7] R.E. Ferh, “A Novel Approach for Understanding Symmetrical Components and Sequence Networks of Three-Phase Power Systems”, online available on http://www.scribd.com/doc/6075396/Understanding-Negative-Sequence.

[8] J. D. Glover and M. Sarma, “Power System Analysis and Design”, Second Edition, PWS PUBLISHING COMPANY, 1994.

[9] H. Saadat, “Power System Analysis”, Second Edition, McGraw-Hill Companies, Inc., 2002.

[10] C. F. Wagner and R.D. Evans, “Symmetrical Components”, Reprint Edition, Robert E. Krieger Publishing Company, 1982.

[11] Introduction to PSCAD/EMTDC V3, Manitoba HVDC Research Centre Inc., Canada, 2000.

[12] Lj. A. Kojivic, “Impact of Current Transformer Saturation on Over current Protection Operation”, IEEE Power Engineering Society Summer Meeting (Cat. No.02CH37376), 2002.

[13] V. Muthukrishnan, L. Sevov, I. Voloh, “Enhanced Over current Algorithm for Performance Under CT Saturation in Industrial Applications”, 62nd Annual Conference for Protective Relay Engineers, March 30 -April 2, 2012, Austin, TX.

[14] Westinghouse Electric Corporation, “Relaying Current

Transformer Application Guide," Industrial and Commercial Power System Applications Series, July 1986.

[15] IEEE Std C37.110−1996, IEEE Guide for the Application of Current Transformers Used for Protective Relaying Purposes, 1996.

[16] A. Hosny, V.K. Sood, "Transformer differential protection with phase angle difference based inrush restraint", Electric Power Systems Research, 2014, 115, pp. 57–64