Differential Protection of Indirect Symmetrical Phase Shift Transformer And Internal Faults Classification Using Wavelet And ANN

Mr. Sachin B Jadhav[1], Prof.Pawan C.Tapre[2]
[1, 2] Dept of Electrical Engineering
[1, 2] S.N.D College of Engineering & Research Center Yeola

Abstract- *This paper illustrates a differential protection algorithm for indirect symmetrical phase shifting transformer (ISPST) using wavelet transform (WT). Further, a Multi-Layer Feed Forward Neural Network (MLFFNN) based algorithm has been developed for classification of internal fault in ISPST. Detailed coefficient at level four (D4) of phase current is used as input vector for MLFFN network. Principle component analysis (PCA) at input reduces the burden and makes the detection and classification algorithm fast. Genetic Algorithm (GA) is used to obtain the optimal structure of MLFFNN. The discrimination between internal fault and magnetizing inrush is developed based on the time elapsed between the instant of inception of disturbance and the instant of the maximum peak in frequency component D4 of WT. It distinguishes magnetizing inrush and internal fault within quarter cycle after disturbance. An ISPST is simulated using MATLAB platform to obtain the differential current signal..*

Keywords- Artificial neural Network (ANN); Digital differential protection; principle component analysis (PCA); genetic algorithm (GA); protective relaying; Wavelet Transform.

I. INTRODUCTION

This paper presents a novel power transformer differential protection algorithm by using combined wavelet transform and Artificial Neural Network (ANN) which provide the means to enhance the classical protection principles and facilitate faster, more secure and dependable protection for power transformers. Wavelet transform is used to extract the feature from transient signal and the neural network is trained by the extracted features of the transient signal to discriminate between the internal fault and magnetizing inrush current. The wavelet transform is firstly applied to decompose the differential current of power transformer in to a series of detailed wavelet components and then the spectral energies of the detailed wavelet components are calculated. The obtained spectral energies are employed to train the Optimal Feed Forward Neural Network (OFFNN). The proposed technique being pattern recognition based will be able to maintain relay stability even during sympathetic inrush and external fault condition.

II. PROPOSED DISCRIMANETION ALGORITHM

During ISPST operation, it may encounter one of the following conditions.

- Normal Condition
- Over-excitation condition
- Magnetizing inrush condition
- Internal fault condition

Out of these operating conditions differential relay should operate only in internal fault condition. But due to non-standard phase shift between two ends (source and load), protection is affected by all operating conditions. To eliminate the problem of phase shift, phase shift compensation technique is used to compensate the phase shift between two ends. After phase shift compensation, discrimination of normal condition and over-excitation from abnormal condition is done similar to the power transformer. After detection of abnormality condition, new proposed algorithm is based on waveform analysis of differential current for the discrimination of internal fault from magnetizing inrush. Differential current in case of magnetizing inrush increases very slowly near switching point but after that shows rapid slope variation with time. Whereas internal fault differential current slope shows a decreasing slope trend with time and is sinusoidal. The discrimination is based on the fact that rapid slope variation in case of internal faults occurs before than in case of magnetizing inrush as shown in graph.

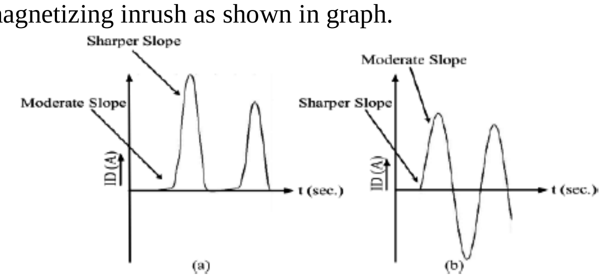

Fig.1. Behaviors of (a) magnetizing inrush and (b) Internal fault

The proposed algorithm is based on fact that the location of rapid slope variation, for magnetizing inrush current occurs after internal fault by a time interval. A large slope in time domain means that there are higher frequencies in the frequency domain. Therefore, following the internal fault, the amplitude of frequencies at the initial instant of fault has large values than the other times whereas in magnetizing inrush, the amplitude of the frequencies at the initial instant of energization has lower values than the other times. The differential current and corresponding frequency component (A7 and D1-D7) from WT due to phase A to ground (A-G) internal fault and magnetizing inrush at t=0.15 sec. are shown in graph 2 and 3 respectively.

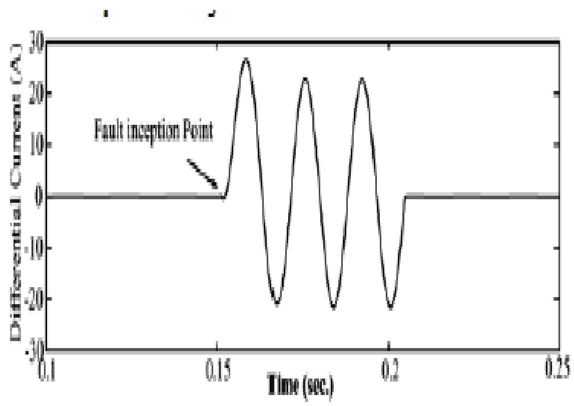

Fig.2. Differential current due to internal A-G fault in the excitation unit primary winding at t=0.15 sec.

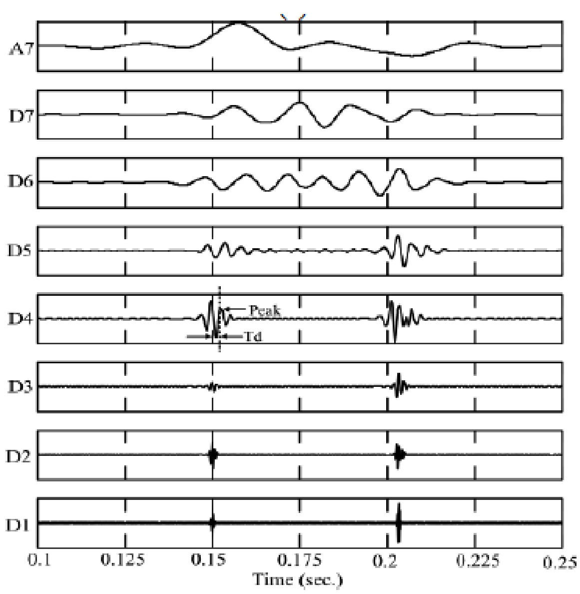

Fig.3.Frequency coefficients of differential current during internal fault.

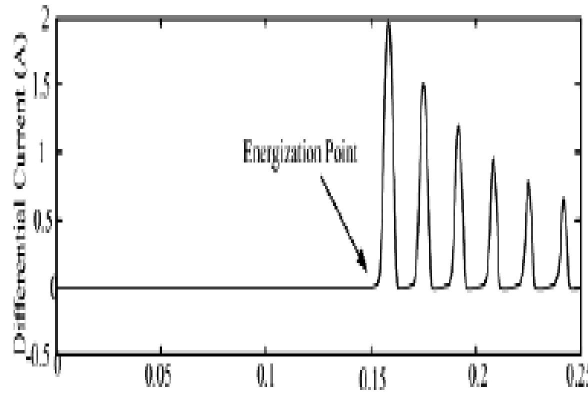

Fig.4. Differential current due to magnetizing inrush current at t= 0.15 sec.

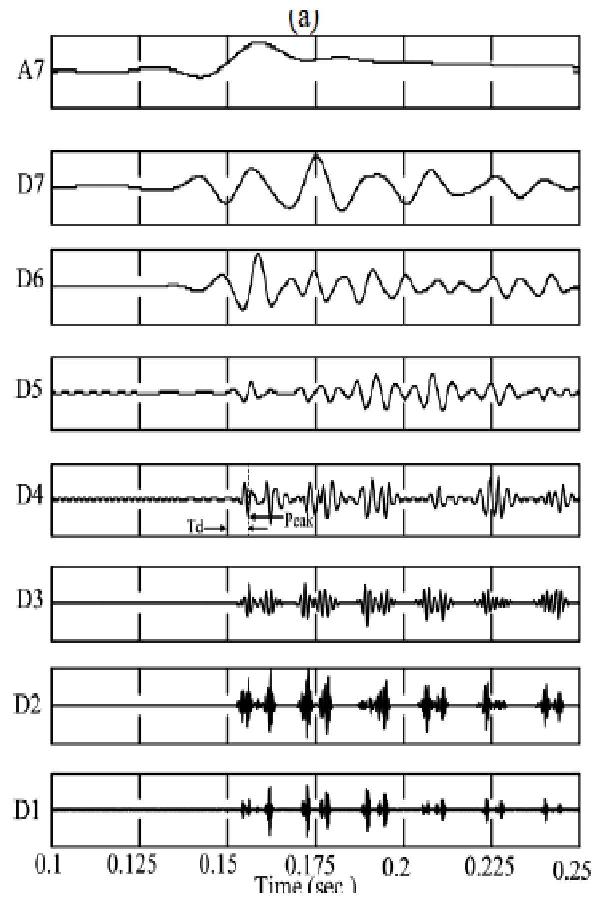

Fig.5.Frequency coefficients of differential current during magnetizing inrush

Through various simulation studies, it is found that features diminish with the decrease in frequency level and mentioned features clearly appear in D4 frequency component. The time duration between the time of disturbance and the maximum peak of D4 of the differential current is considered as discrimination criteria and called ‘Td’. The absolute value of frequency component D4 of differential current for the magnetizing inrush and internal fault current with the time interval Td is shown in graph 4. It is observed that in case of internal faults, Td <tpick-up for at least two of the three phases and in case of magnetizing inrush, Td >tpick-up for at least two of the three phases. If Td <tpick-up in any two phases, the relay will sent a trip command to circuit breaker. This simple algorithm can discriminate magnetizing inrush and internal fault within a quarter (4.1675 msec.) cycle thus confirming stable operation of power system.

After discrimination of internal fault from magnetizing inrush current, classification of types of internal fault (turn-to-turn (TT), phase-to-ground (LG), phase-to-phase (LL), phase-to-phase-to-ground (LLG) and three phase-to-ground (LLLG)) and location of internal fault (series primary (SP), series secondary (SS), excitation primary (EP) and excitation secondary (ES)) is done with the help of optimal MLFFNN. Fig.7. shows the flow chart for the proposed algorithm

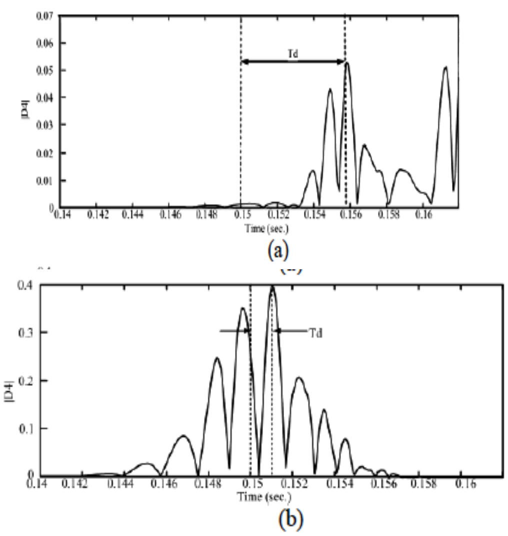

Fig.6. Absolute value of D4 for (a) magnetizing inrush (b) internal fault

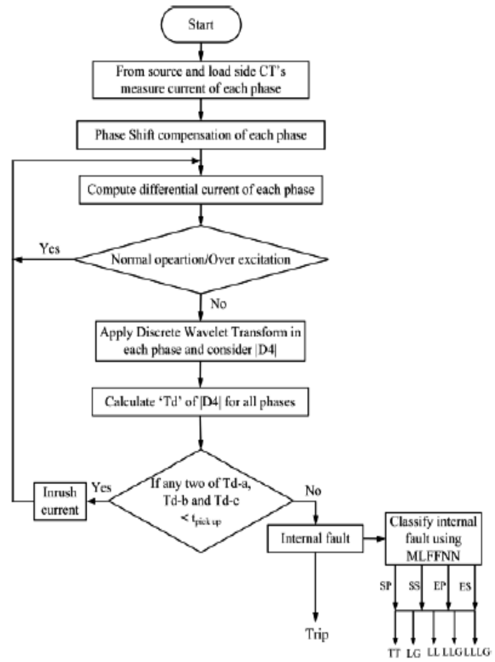

Fig.7.Complete protection scheme of ISPST

A. *Classification of Types Of Faults And Location Of Faults*

After discrimination of internal fault from magnetizing inrush condition it is very difficult to classify the types of faults and location of fault in ISPST. This section describes the classification of the different internal faults such as TT, LG, LL, LLG and LLLG in primary and secondary winding of series and excitation unit. MLFFNN is used to classify the faults after the relay has sent trip signal to circuit breaker. Back propagation learning algorithm is used for training and testing of MLFFNN. MLFFNN is a neural network with supervised learning where the neural network knows the desired output and adjusts the weight coefficients in such way, that the calculated and desired outputs are as close as possible. The MLFFNN consist an input layer, two hidden layers and an output layer as shown in fig. 9. The input layer receives the features (coefficients of frequency component D4). Since, the system works at 60 Hz frequency and the data is sampled at an interval of 166.667 μs, 100 samples are obtained in one cycle. So, in coefficient of D4, 60 samples for three phase (20 for each phase) are obtained. Principle component analysis (PCA) is used to reduce the number of samples, which reduces training time of neural network. Genetic algorithm (GA) is used to get the optimum number of neurons in first and second hidden layer. The activation functions considered in first, second hidden layer and output layer are 'logsig', 'tansig', and 'purelin' respectively.

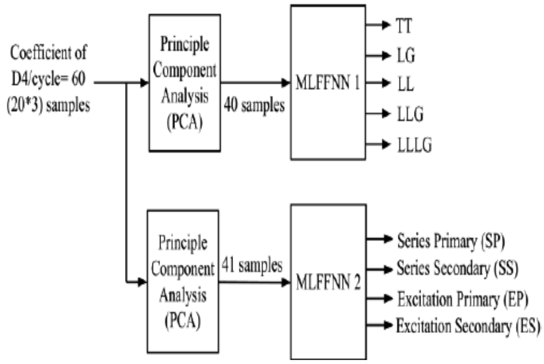

Fig.8.Two MLFFN network for classification of types of internal faults and location of faults

III. PERFORMANCE ANALYSIS

The Circuit diagram of the connection is shown in fig.17. Three phase 300MVA, 138 kV/138 kV, 1255A/1255A, 60 Hz ISPST with maximum phase shift of ±30○ is considered for the proposed algorithm. Two simulation platforms are considered to verify the recommended algorithm. Differential current are obtained for each phase with star connected CTs of ratio 2000/5A on both side of an ISPST.

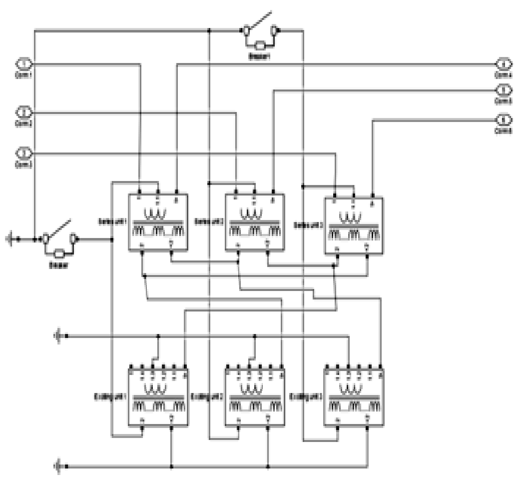

Fig.9.Circuit diagram of test system

A. Result Discussion with MATLAB

The working of the recommended algorithm is evaluated for different types of internal faults such as turn-to-turn (TT), phase A-to-ground (AG), phase A-to-phase B (AB), phase A-to-phase B-to-ground (ABG), three phase-to-ground (ABCG) in the primary and secondary sides of series and exciting transformer of an ISPST and magnetizing inrush currents. Internal faults are simulated with different fault inception angles, on-load and no-load conditions at different percentage of faulted winding. Various cases of magnetizing inrush with different percentage of residual core flux, switching-in angle, on-load and no-load conditions that affects differential current are also simulated. The table II and III shows the time duration (Td) between time of disturbance and the maximum peak of |D4| after disturbance for internal faults in series unit and excitation unit respectively at different conditions which have been discussed earlier. Table IV shows Td for magnetizing inrush condition at different switching-in angle considering different percentage of residual flux. Analysis of various simulations reveals that values of Td for various internal fault conditions are usually less than 1.5 msec. Also for the magnetizing inrush conditions, the values of Td are usually greater than 4.0 msec. Hence in this paper tpick-up is chosen as 1.5 msec. The proposed algorithm is also verified by simulation using MATLAB platform in next section.

Table 1.Td (msec.) for internal faults in series unit of an ISPST

Fault Inception Angle (Deg.)	Types Of Fault	On-Load			No-Load		
		Phase			Phase		
		a	B	c	a	b	c
0	TT	1.2	1.2	1.2	1.2	1.1	1.1
	AG	1.1	1.0	1.1	2.8	1.1	1.1
	AB	2.8	1.1	1.1	2.8	1.1	1.1
	ABG	2.8	1.1	1.1	2.8	1.1	1.1
	ABCG	1.1	1.1	1.2	1.1	1.1	1.2
90	AG	0.4	0.9	0.9	0.4	0.5	0.5
	AB	0.4	6.0	1.1	0.4	6.0	1.1
	ABG	0.4	6.0	1.1	0.4	6.0	1.1
	ABCG	1.2	4.3	1.2	4.4	4.3	1.2

Table.2.Td (msec.) for faults on the excitation of an ISPST

Fault Inception Angle (Deg.)	Types Of Fault	On-Load			No-Load		
		Phase			Phase		
		a	B	c	a	b	c
0	AG	1.1	1.1	2.8	0.3	1.9	2.8
	AB	1.2	1.1	1.1	1.1	1.1	1.1
	ABG	1.2	1.2	1.1	1.1	1.1	1.1
	ABCG	1.1	1.1	1.1	1.1	1.1	1.2
90	AG	1.1	1.2	1.1	1.1	1.1	1.1
	AB	1.1	7.8	1.1	1.1	7.7	1.1
	ABG	1.1	7.6	1.1	1.1	7.8	1.1
	ABCG	1.1	7.8	1.2	1.1	1.2	1.2

Table.3.Td (ms) for each phase differential current for inrush

% Residual Flux	Switching in Angle (Deg.)	On-Load Phase			No-Load Phase		
		a	b	a	b	a	B
0%	0	5.9	4.3	7.5	5.8	6.7	4.3
	90	1.1	7.5	8.1	6.0	6.0	8.2
50%	0	2.7	5.7	7.6	2.7	7.8	7.8
	90	4.3	7.6	2.7	4.3	7.6	2.7
80%	0	4.3	7.6	2.7	4.3	7.6	2.7
	90	4.4	4.2	5.9	6.0	7.5	7.5

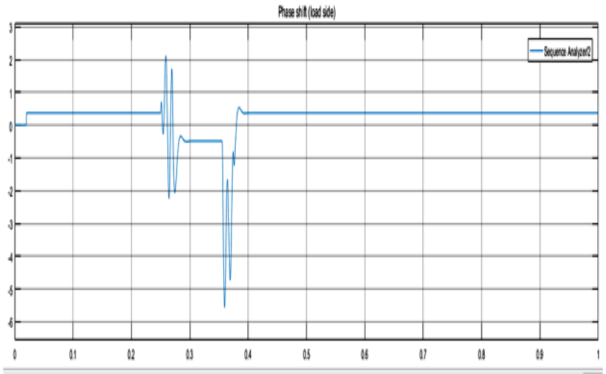

Fig.10.AB fault Phase angle

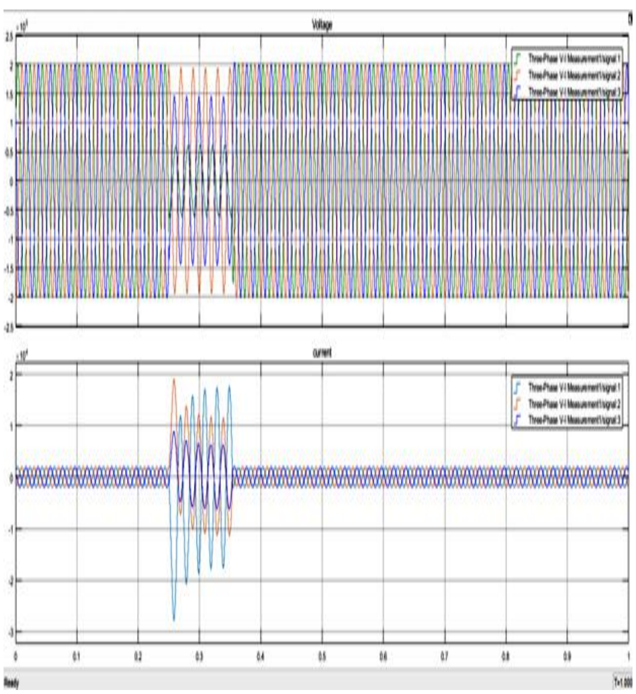

Fig.11.AB fault Voltage /Current

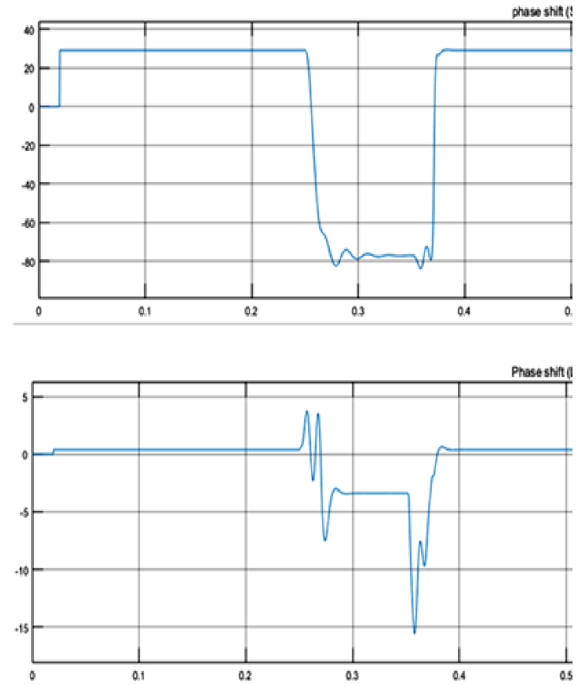

Fig.12.ABCG fault Phase Angle

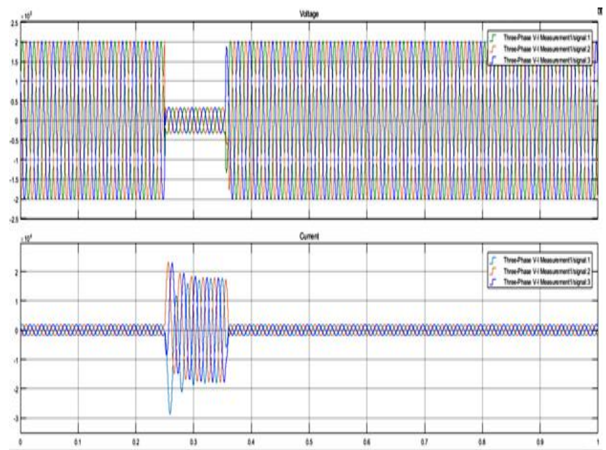

Fig.13.ABCG fault Voltage /Current

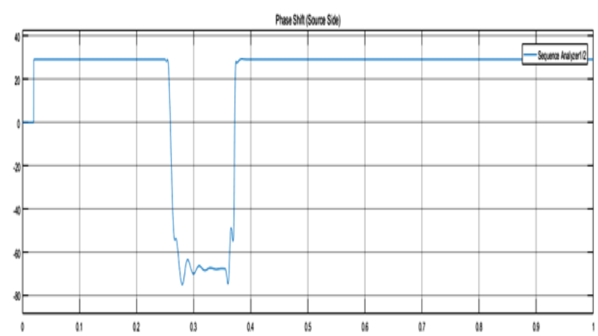

Fig.14.AG fault Phase Angle

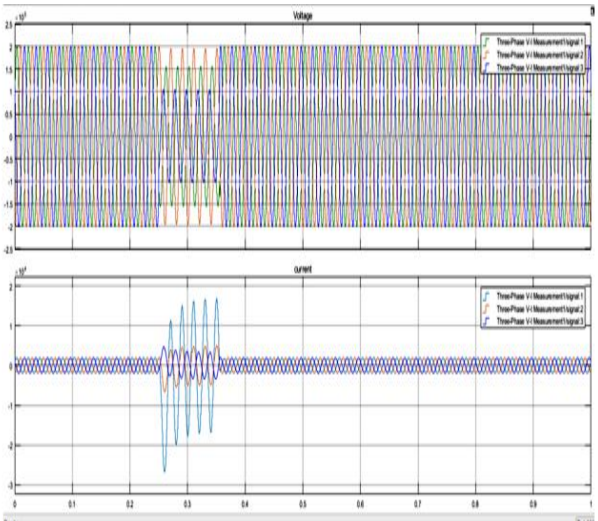

Fig.15.AG fault Voltage /Current

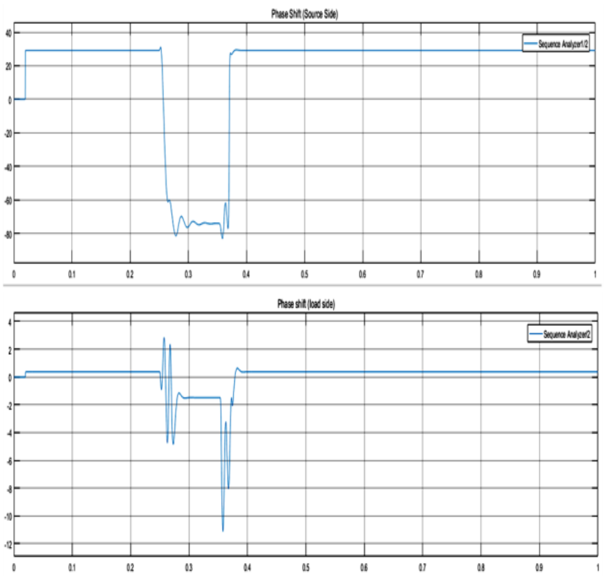

Fig.16.ABG fault Phase Angle

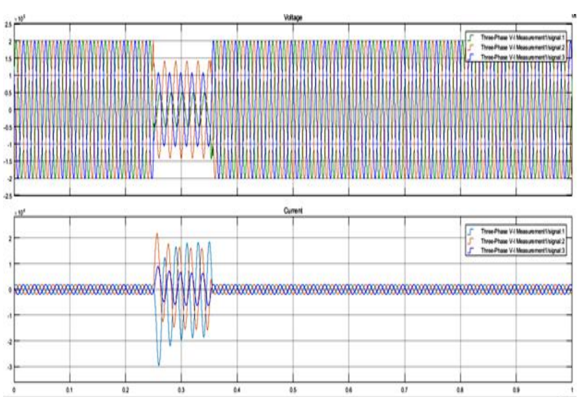

Fig.17.ABG fault Voltage /Current

B.Result Discussion with MATLAB

The proposed algorithm is implemented for ISPST model simulated in MATLAB of the same ratings used in MATLAB simulation. Different cases of magnetizing inrush and internal faults are simulated in MATLAB. Due to page limitation two cases are discussed below.

Magnetizing Inrush

It shows the three-phase differential current for magnetizing inrush at switching time t=0.15 sec. (zero degree). Frequency component |D4| of phase 'a' and 'b' differential current after switching time is revealed in fig. (b& c). As seen from the fig. (b & c), Td-a=4.8 msec. and Td-b=6.7 msec. are obtained, which is greater than tpick-up showing that there is no internal fault and no trip signal will issue.

Internal Fault

It shows the three-phase differential current for AG internal fault in excitation unit primary winding at time t=0.15 sec. (zero degree). Frequency component |D4| of phase 'a' and 'b' differential current after fault inception is shown in fig. (b& c). As seen from the fig. (b & c), Td-a=1.1 msec. and Td-b=1.1 msec. are obtained, which is less than pick-up showing that there is an internal fault in ISPST and a trip signal will issue.

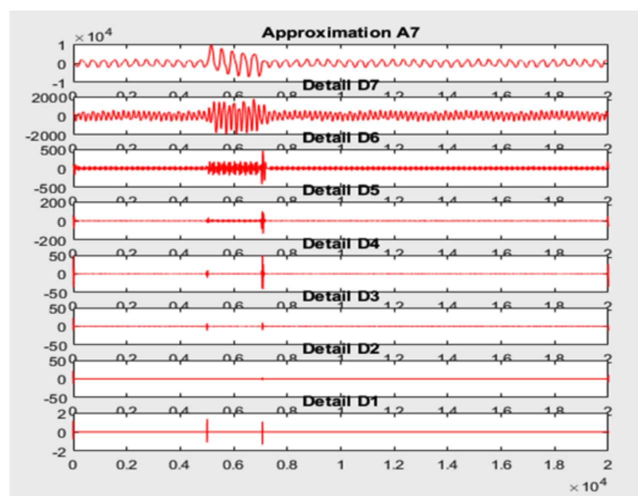

Fig.18. Wavelet AB

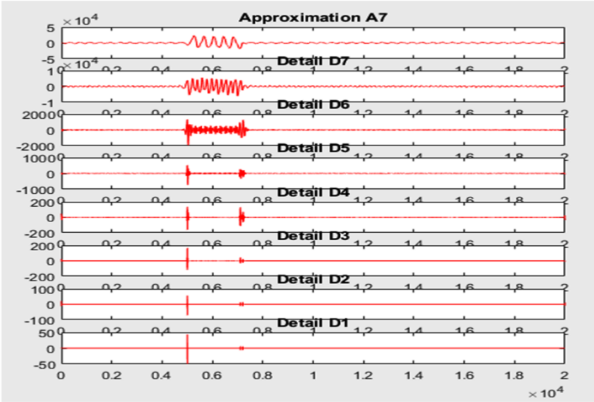

Fig.19.Wavelet ABCG

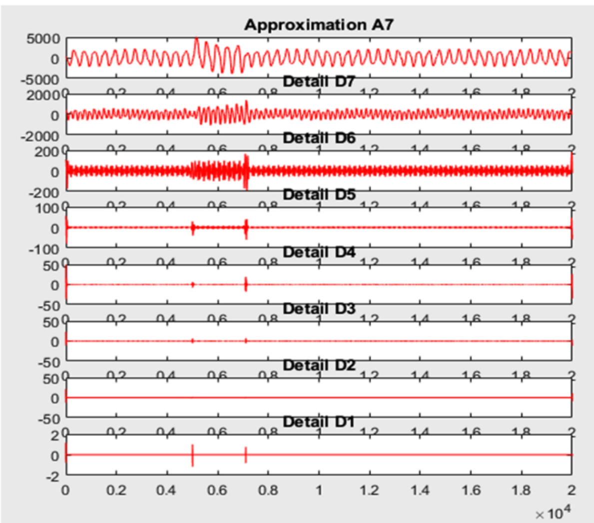

Fig.20.Wavelet AG

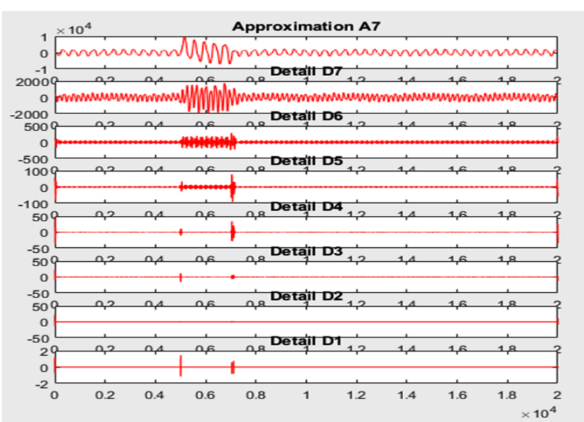

Fig.21.Wavelet ABG

IV. PERFORMANCE EVALUATION

For different operating conditions of power transformer. Out of 1234 patterns, 794 patterns are simulated for magnetizing inrush and/or sympathetic inrush conditions, and 440 patterns are generated for internal fault cases including phase-to-ground, phase-to-phase, and turn-to-turn faults respectively. Out of these 1234 patterns, 1086 patterns have been used to construct the OFFBNN. The rest 148 cases have been used to test the generalization ability of the neural network. These 148 test patterns are other than those been used to train the OFFBNN. Fig.19 shows the performance plot of training, validation and test errors and reasonability can be observed since:

- Test and validation set errors have similar characteristics.
- The final mean squared error is very small.
- N

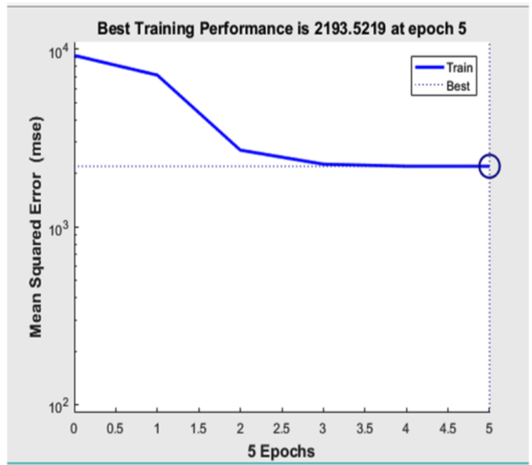

Fig.22.Typical performance of the OFFBNN

V. CONCLUSION

This paper presents a novel power transformer differential protection scheme by using combined Wavelet Transform and Artificial Neural Network which is faster, stable and accurate. Wavelet transform is used for the feature extraction from the differential relaying signal. Dead angle detection in wavelet energy of signal has an advantage that that it will always lie in the first quadrant, as the wavelet energy is always a positive value, thereby making algorithm simpler. The proposed scheme does not require any threshold index to discriminate between the internal fault and inrush condition. The proposed digital differential protection scheme is an intelligent technique based scheme and can be used as effective approach for modern power transformer protection.

REFERENCES

[1] Differential Protection of Indirect Symmetrical Phase Shift Transformer and Internal Faults Classification using Wavelet and ANN.
[2] International Journal of Electronic and Electrical Engineering. ISSN 0974-2174 Volume 7, Number 7

(2014), pp. 685-695 © International Research Publication House http://www.irphouse.com

[3] J. Pihler, B.Grcar, and D. Dolinar, "Improved operation of power transformer protection using artificial neural network, " *IEEE Trans. Power Del.*, vol. 12, no. 3, pp. 1128–1136, Jul. 1997.

[4] J. Blade and A. Montoya, "Experiences with parallel EHV phase shifting transformers," IEEE Trans. Power Del., vol. 6, no. 3, pp. 1096–1100, July 1991.

[5] Faults and Magnetizing Inrush Currents in Transformers", *IEEE Transactions On Power Delivery*, Vol. 18, No. 1, January 2003.

[6] Manoj Tripathy, R. P. Maheshwari, H. K. Verma, "Advances in Transformer Protection: A Review", Electric Power Components and Systems, Taylor & Francis Inc., 33:1203–1209, 2005

[7] Hayder, U. Schaerli, K. Feser and L. Schiel, "Universal adaptive differential protection for regulating transformers" IEEE Transactions on Power Delivery, vol. 23, no. 2, pp. 568-575, April 2008

[8] 9. International Journal of Scientific and Research Publications, Volume 2, Issue 9, September 2012 ISSN 2250-3153." An Overview of Genetic Algorithm and Modeling"