COMPARATIVE ANALYSIS OF TRANSMISSION LINE FAULT CLASSIFICATION AND LOCATION IN DYNAMIC GRID FAULT SIMULATOR USING ANFIS AND SVM APPROACHES

[1] DR.E.LATHA MERCY, [2] ARAVIND.S, [3] G.JYOSTHNA

[1] Associate Professor, Department of Electrical Engineering, Government College of Technology, Coimbatore-13.
[2] PG Scholar M.E –Power Systems Engineering, Government College of Technology, Coimbatore-13.
[3] Assistant Professor, Dept of Electrical Engineering, St. Joseph's Institute of Technology, Chennai-119.

josna.sunitha@gmail.com, mercy@gct.ac.in, aravind671991@gmail.com

ABSTRACT-*The objective of this paper is to detect, classify and locate the fault type in transmission line by training the energy values obtained from Discrete Wavelet Transform (DWT) using Adaptive Neuro Fuzzy Inference System (ANFIS) and Support Vector Machine (SVM) approaches and to have comparative study of both approaches. DWT is used in this paper to overcome the drawbacks of Continuous Wavelet Transform (CWT) as it contains more information than necessary. DWT decomposes time domain current signals into frequency-time domain current signals. Daubechies4 (db4) is used as the mother wavelet. Five decomposition levels have been applied to the current waveform obtained during normal and fault conditions. The energy values for the fault resistances 0.01, 10, 20, 50, and 100 ohms for various fault location at 60, 90,120,150 and 180 km are extracted using Discrete Wavelet Transform.*
The features extracted using DWT for different fault resistances at different fault location are used to train ANFIS and SVM. The ANFIS detector consists of three inputs, six membership functions for each input and a constant output. The energy values has been given to the Sugeno type ANFIS editor and SVM coding set in MATLAB environment to classify and locate the type of fault and the comparative analysis has been done.

Keywords- Discrete Wavelet Transform (DWT), Adaptive Neuro-Fuzzy Inference System (ANFIS), Support Vector Machine(SVM), Faultclassification and location, faulty phase, Transmission line.

I. INTRODUCTION

Transmission lines are the vital links of the electric power system that enables the power transmission from the generating stations to distribution networks. Along with other electrical equipments transmission lines suffer from the unexpected electrical disturbances which affect the quality of power supplied to the loads and also cause instability in the power system [1]. The occurrence of any transmission line faults give rise to transient condition. The various types of faults that occur in the transmission lines are line to ground fault (L-G), double line to ground fault (L-L-G), double line fault (L-L), three phase fault and three phase to ground faults (L-L-L and L-L-L-G). Among these, line to ground faults are the most common followed by double line faults and three phase faults. It is adequate to determine the type of fault and the faulty phase in the transmission line.
Fourier transforms techniques are used for the detection of the transmission line faults but these techniques give information about all frequencies that are present in the signals but does not provide information regarding the time at which these frequencies are present. Based on fault transients, several algorithms have been proposed for fault detection and classification. The wavelet transform gives information both in frequency and time domain.
The wavelet analysis allows the decomposition of a signal into different levels of resolution called Multi Resolution Analysis (MRA). Reference [2] proposed an effective feature extraction using wavelet transform. Reference [3] showed that wavelet transform is used to capture high the high-frequency travelling waves for fault detection, classification and phase selection of faults. Reference [4], [5], [6] uses combined techniques such as Wavelet Transform and Artificial Neural Network (ANN) and Wavelet Transform with Fuzzy logic [10] for fault detection. Reference [7] uses combined techniques of wavelet multi resolution analysis and ANFIS for smart fault location in transmission lines. This paper uses Discrete Wavelet Transform (DWT) and Adaptive Neuro- Fuzzy Inference System (ANFIS) for fault classification and detection.
DWT is used to extract the energy values of the current signals to detect the faults in the transmission line. The features extracted are given as input to the ANFIS to detect the type of fault and faulty phase. The simulations

for different faults are simulated in MATLAB/SIMULINK environment. The features extracted are used to train ANFIS to determine the type of fault and faulty phase.

II. DISCRETE WAVELET TRANSFORM

Wavelet is a short duration wave. It is a mathematical basis function used to divide a given continuous time signal into different scale components. It allows the decomposition of a signal into different levels of resolution. The basic function is dilated at low frequencies and compressed at high frequencies, so that large windows are used to obtain the low frequency components and small windows are used to obtain to reflect discontinuities. In wavelet transform approximations are high scale, low frequency components and details are low scale, high frequency components of the signal. The original signal decomposes through two complementary filters and emerges as two signals. This decomposition is further iterated with successive approximations being decomposed in turn, so that one signal is broken down into many lower resolution components. This is called Multi Resolution Analysis (MRA).

Wavelet transform is divided into Discrete Wavelet Transform (DWT) and Continuous Wavelet Transform (CWT). Both DWT and CWT are continuous-time transforms. The DWT is preferred than CWT as CWT provides more information than required whereas DWT provides only the required information in both frequency and time domain. Daubechies wavelet is used in this paper. Daubechies 4 (db4) is used as mother wavelet and five level decomposition is used for extracting the energy values as it is appropriate for power system fault analysis. The wavelet transform of a continuous signal x(t) is defined by,

$$\mathrm{WT}(a,b)=1/\sqrt{a}*\int_{\infty}^{\infty} X(t)*g\left(t-\frac{b}{a}\right)dt \qquad (1)$$

Where a and b are the scaling and translational parameters and g is the mother wavelet function.

The dicrete wavelet transform is defined as,

$$\mathrm{DWT}(m,k)=\frac{1}{\sqrt{a0^m}}*\sum_n X(n)g(k-na0^m/a0^m) \qquad (2)$$

Where g[n] is the mother wavelet, the scaling and translation parameters a and b are functions of an integer parameter m, $a=a0^m$ and$b=na0^m$.

The energy values are given by the sum of the square of details and approximations obtained by the decomposition. Since five level decomposition is used, the energy value of the current signal is given by the equation,, Energy=$\sum D1^2+\sum D2^2+\sum D3^2+\sum D4^2+\sum D5^2+\sum A5^2$ (3)

The energy values is obtained for normal condition and for other fault types. It is seen that the energy values during fault condition deviates from the values obtained during normal condition. If the A-G fault occurs the energy value of phase A alone deviate from the energy value of phase A during normal condition.

III. ADAPTIVE NEURO FUZZY INFERENCE SYSTEM

Based on the theory given in [8], ANFIS is used to detect the type of fault and faulty phase in the transmission line from the features extracted using wavelet MRA.

ANFIS is an intelligent adaptive data learning technique that utilises the FIS to model any system from its input-output data. The FIS model developed by Takagi-Sugeno-Kang, which is known as Sugeno model, is given in [9]. From the input-output data, ANFIS adjusts the membership functions (MFs) using least square method for linear systems and the back propagation descent method for nonlinear systems in [9].

The ANFIS detection model has three inputs, energy values of the three phases A, B and C represented by EA, EB and EC respectively and one output (type of fault with faulty phase). The input data is generated by the applying the DWT analysis on the current signals obtained for various fault conditions and for various fault resistances. The output is obtained such that, each fault type is assigned a particular value. The ANFIS is trained with generated inputs and assigned output. The table I shows the assigned output for different fault types and faulty phase.

TABLE I

S.No	Fault type	Assigned output
1	No fault	0
2	A-G	0.1
3	B-G	0.2
4	C-G	0.3
5	A-B-G	0.4
6	A-B	0.5
7	B-C-G	0.6
8	B-C	0.7
9	A-C-G	0.8
10	A-C	0.9
11	A-B-C	1
12	A-B-C-G	1.1

The network is trained for the input-output data set with a MATLAB ANFIS editor, which adjusts the MFs directly based on the data set. ANFIS is an adaptive data learning technique that utilises the FIS to automatically model the fault classification system from its input-output data.

Three variables with triangular MFs are generated for each input variable. Because ANFIS is chosen to use Sugeno class models the outputs are constant. 12 rules have been formulated using FIS and 48 input-output data are used for training ANFIS, considering the fault resistances of 10, 20, 50 and 100 ohms for each type of fault. The obtained ANFIS structure for trained data is shown in the figure 1.

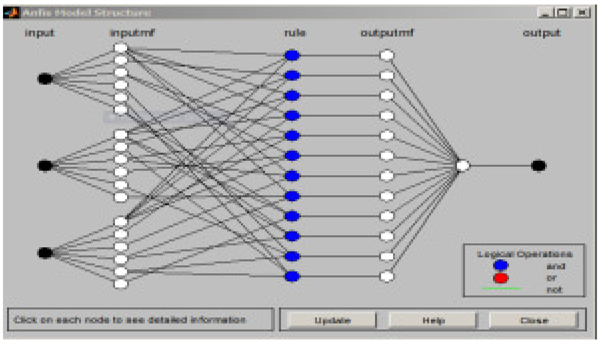


Fig.1 ANFIS structure developed in MATLAB for fault classification.

The fault classification using ANFIS is shown in figure 2.

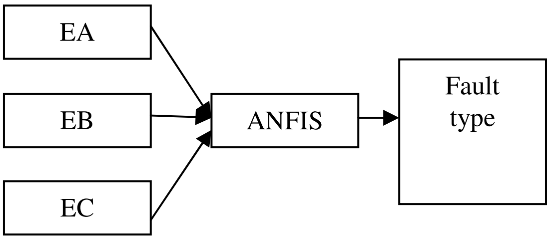


Fig 2. Fault classification using ANFIS

IV. SUPPORT VECTOR MACHINE

Support vector machines are supervised learning models with associated learning algorithms that analyze data and recognize patterns, used for classification and regression analysis. Given a set of training examples, each marked for belonging to one of two categories, an SVM training algorithm builds a model that assigns new examples into one category or the other, making it a non-probabilistic binary linear classifier. Then the test were given to SVM trained model for classification[11].

V. METHODOLOGY

The process of fault detection and classification approach is done by creating the power system model. The current signals for normal and various fault conditions are obtained for different fault resistances. The obtained current signals are transformed using DWT. The energy values obtained using DWT are used to train ANFIS. The process of fault detection and classification is shown in figure 3.

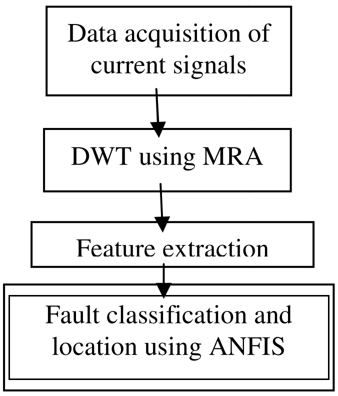


Fig.3. Process of fault detection and classification

VI. SIMULINK SYSTEM

In order to verify the proposed techniques, the two bus system model is simulated using MATLAB/Simulink for normal condition and for various fault conditions. The power system model for 2 bus transmission system is shown in the figure 4.

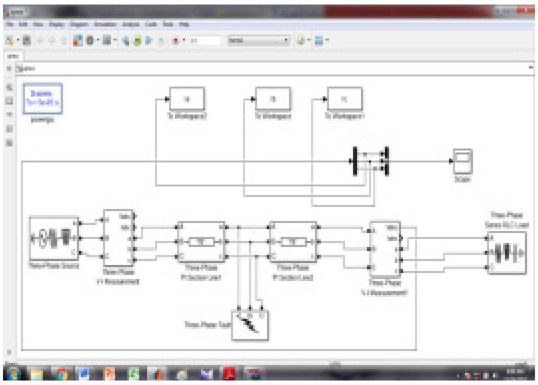


Fig.4. Simulation model.

The system is modelled and analysed for different fault conditions. It consists of three generators, three transformers, three loads and six transmission lines..

TABLE II

System data

Blocks	Parameters	Values
3Φ voltage source	Voltage (rms)	16.5KV 18KV 13.8KV
3Φ series RLC load	Power	125MW, 50MVAR 90 MW, 30MVAR 100MW, 35MVAR
3Φ transmission line πmodel	Length	150km each

The different types of single line to ground faults, different double line faults with or without ground and three phase faults with or without ground are simulated and analysed.

VII. DYNAMIC GRID FAULT SIMULATOR

The dynamic grid fault simulator (DGFS) consists of grid, transmission line and load. The dynamic grid fault simulator is shown below in figure.5.

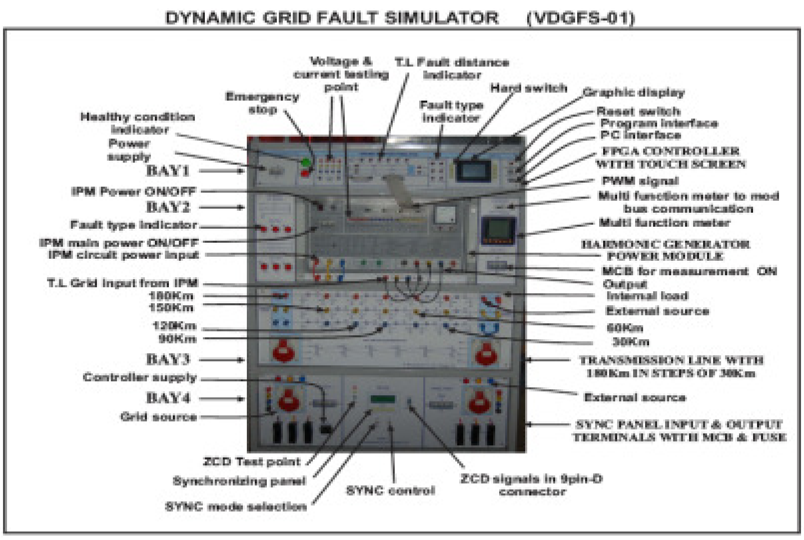


Fig.5 Dynamic grid fault simulator

TABLE III
Dynamic Grid Fault Simulator parameters

BLOCKS	PARAMETERS	VALUES
Three phase voltage sources	Voltage (rms)	440V
Three phase series RLC load	Power	750W
Three phase transmission line π section line	Length	180km

VIII. SIMULATION RESULTS

Considering the Simulink model of two bussystem, the waveforms during normal and various fault conditions are obtained.

A. WITHOUT FAULT

During normal condition the three phase current waveform is obtained as shown in the figure 6.

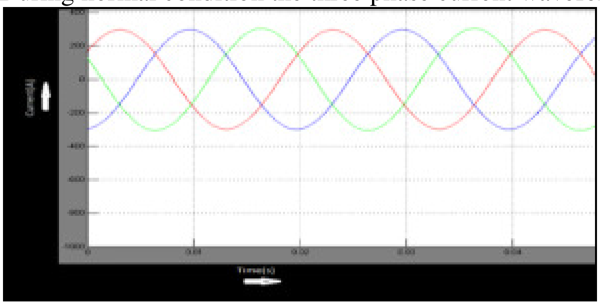


Fig.6. Without fault

B. L-G FAULTS

The L-G faults that occur in transmission system are A-G, B-G and C-G faults. Aline to ground fault of fault resistance 10 ohms is applied to line 2 in ‘A’ phase of the transmission line. The waveform as shown in figure 7 is obtained.

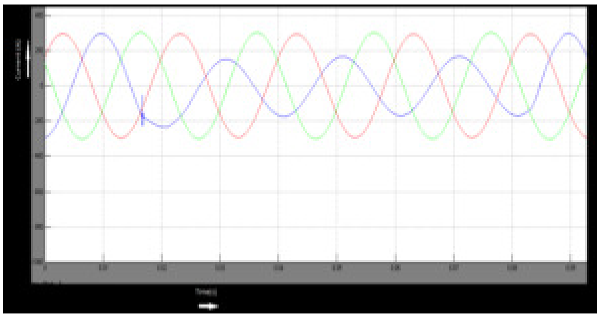


Fig.7. A-G fault

C. L-L FAULTS

The L-L faults that occur in transmission system are A-B, B-C and A-C faults. A double line fault of fault resistance 10 ohms is applied in the phases A and B of the transmission line. The waveform as shown in the figure 8 is obtained.

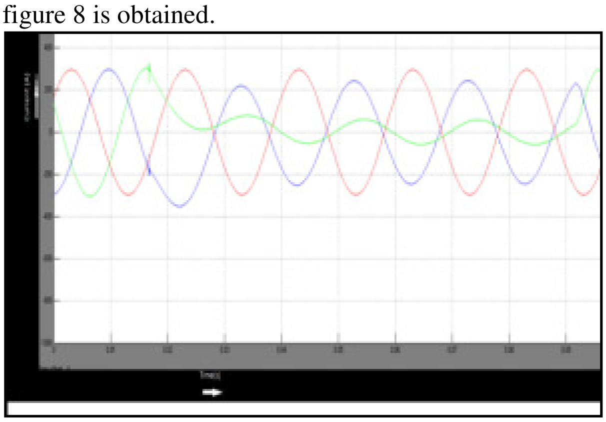


Fig.8. A-B fault

D. L-L-G FAULTS

The L-L faults that occur in transmission system are A-B-G, B-C-G and A-C-G faults. A double line to ground fault of fault resistance 10 ohms is applied in the phases A and B of the transmission line. The waveform as shown in the figure 9 is obtained.

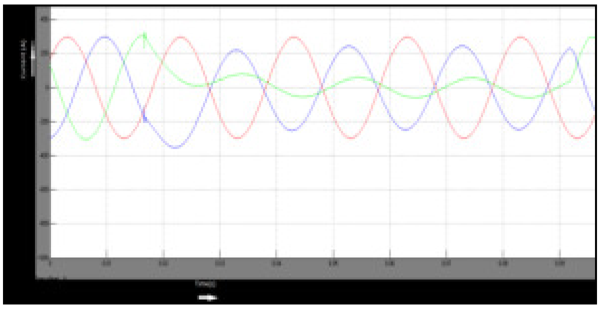


Fig.9. A-B-G fault

E. THREE PHASE FAULTS

Three phase faults in transmission system are A-B-C faults and A-B-C-G faults. The simulation results for both A-B-C and A-B-C-G faults of fault resistance 10 ohms applied in line 2 of the test system are obtained as shown in figures 10 and 11 respectively.

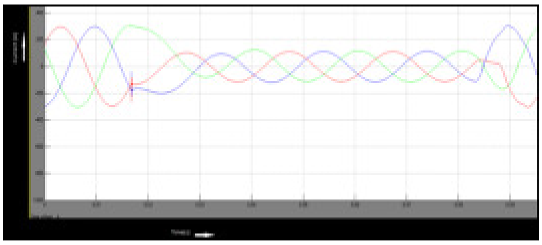


Fig.10. A-B-C fault

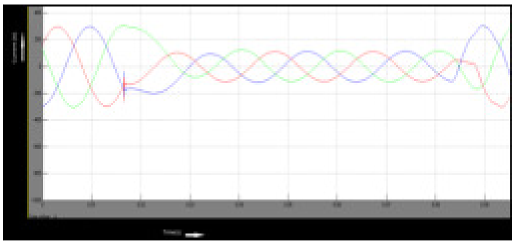


Fig.11. A-B-C-G fault

Considering the dynamic grid fault simulator, the waveforms during normal and various fault conditions are obtained

F. WITHOUT FAULT

The dynamic grid fault simulator is simulated under 440V as grid voltage connected with 750W load through 180km pi modeled transmission line. The three phase line currents shown below in figure 12.

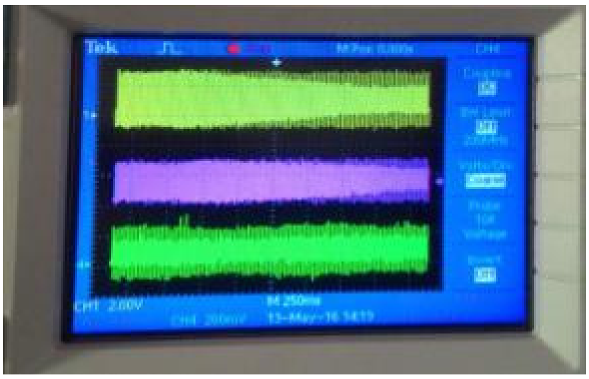
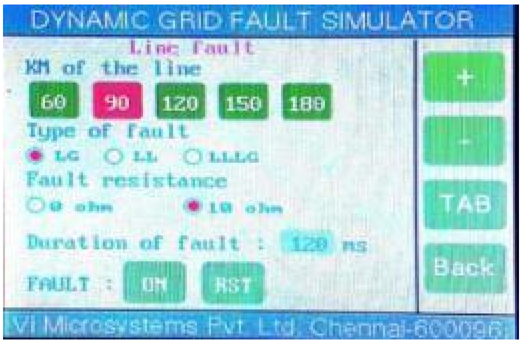


Fig.12. Current waveform for A-B-C under normal condition

G.LINE TO GROUND FAULT

When a short circuit fault occurs between A-phase and the ground, the line to ground fault occurs. A line to ground fault at 90km from generation of fault resistance 10 ohms is applied between 120ms in transmission line system and the following fault parameter and waveform as shown in figure 13 and 14 occurs



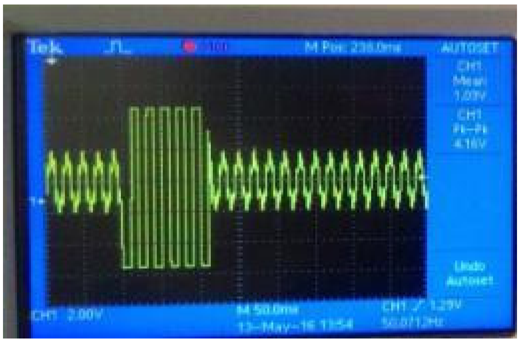
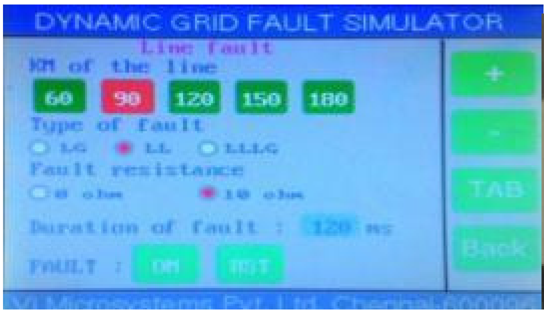


Fig.13. Fault parameter

Fig.14.Current waveform for A- phase under L-G fault condition

H. DOUBLE LINE FAULT

When a short circuit fault occurs between A-phase and B-phase, the line to line fault occurs. A line to line fault at 90km from generation of fault resistance 10 ohms is applied between 120ms in transmission line system and the following fault parameter and waveform as shown in figure 15 and 16 occurs



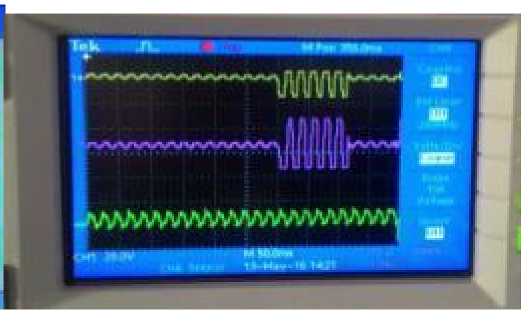
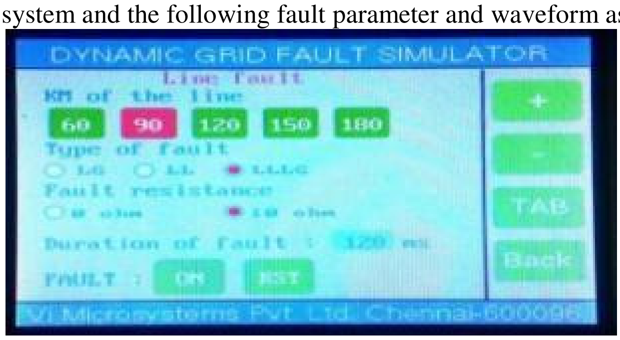


Fig.15. Fault parameter

Fig.16. Current waveform for A-B-C under L-L fault condition

I.SYMMETRICAL FAULT

Symmetrical faults are balanced faults occurs in all the three phases. The current waveforms for A-B-C-G fault at 90km from generation of fault resistance 10 ohms is applied between 120ms in transmission line system and the following fault parameter and waveform as shown in figure 17 and 18 occurs.



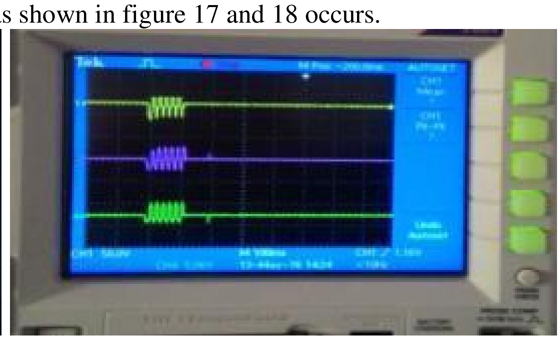
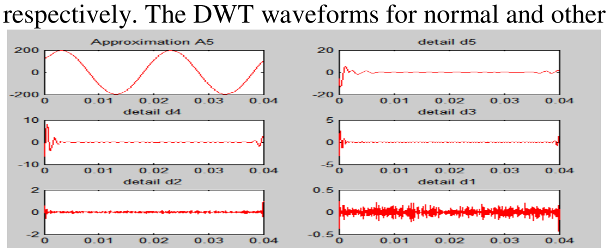


Fig.17. Fault parameter

Fig.18. Current waveform for A-B-C-G under L-L-L-G fault condition

VII. DWT RESULTS

The DWT waveforms for the phases A, B and C during A-B-G fault are shown in the figures 19, 20 and 21 respectively. The DWT waveforms for normal and other fault types can also be obtained by DWT analysis.



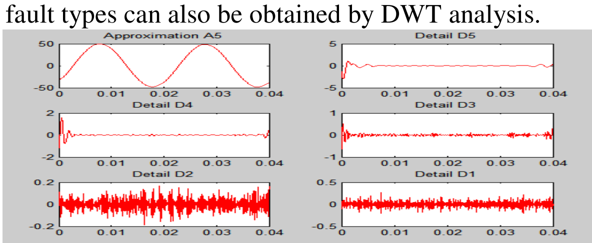


Fig.19. DWT of phase A

Fig.20. DWT of phase B

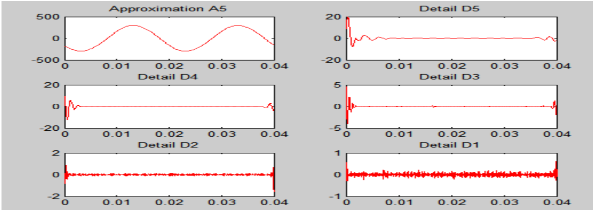


Fig.21. DWT of phase C

The energy values obtained by DWT analysis for different types of faults for the fault resistance of 10 ohms is shown in the table IV.

TABLE IV

Energy values at various conditions for the system for the fault resistance of 10 ohms

S. No	**Power system disturbance**	**Energy values**
1	Normal condition Phase A Phase B Phase C	 3.7e7 3.6e7 3.5e7
2	A-G fault Phase A Phase B Phase C	 1.3e7 3.8e7 3.6e7
3	B-G fault Phase A Phase B Phase C	 3.6e7 1.5e7 3.8e7
S. No	**Power system disturbance**	**Energy values**
4	C-G fault Phase A Phase B Phase C	 3.6e7 3.5e7 1.3e7
5	A-B fault Phase A Phase B Phase C	 1.5e6 1.0e6 3.7e7
6	A-B-G fault Phase A Phase B Phase C	 2.0e6 1.1e6 3.7e7
7	B-C fault Phase A Phase B Phase C	 3.5e7 2.3e7 1.3e6
8	B-C-G fault Phase A Phase B Phase C	 3.7e7 1.5e7 1.0e6
9	A-C fault Phase A Phase B Phase	 5.7e6 3.6e7 1.3e7
10	A-C-G fault Phase A Phase B Phase C	 6.1e6 3.7e7 2.1e6
11	A-B-C fault Phase A Phase B Phase C	 9.3e6 7.7e6 4.1e6
12	A-B-C-G fault Phase A Phase B Phase C	 9.2e6 6.2e6 4.1e6

Similarly the energy values is obtained for different fault resistances like 20, 50 and 100 ohms. It is observed that as the fault resistance increases the energy values obtained for different fault conditions approaches close to the energy values obtained during normal condition.

TABLE V
Energy Values and Per Unit energy values at various fault conditions with fault resistance of 0.01 ohm at 150km

S.No	Power system disturbance	Energy values	Energy Values(p.u)
1	LG fault A-G fault Phase A Phase B Phase C	 2.28e4 2.15e4 2.07e4	 8.595 8.371 8.2853
2	LL fault A-B fault Phase A Phase B Phase C	 2.16e4 2.15e4 2.10e4	 9.387 8.3786 9.1446
3	LLG fault A-B-G fault Phase A Phase B Phase C	 2.16e4 2.15e4 2.15e4	 8.7545 8.2171 8.4485
4	LLL fault A-B-C fault Phase A Phase B Phase C	 2.16e4 2.16e4 2.16e4	 9.3178 8.7509 8.9519
5	LLLG fault A-B-C-G fault Phase A Phase B Phase C	 2.16e4 2.16e4 2.15e4	 8.8249 9.347 8.912

IX ANFIS AND SVM RESULTS

The features extracted are trained to ANFIS to classify the fault type and faulty phase. The simulation model for ANFIS using Fuzzy toolbox in MATLAB/SIMULINK is shown in the figure 14 with three inputs and single output. When the B-G fault is applied the output is displayed as 0.2 as given by the table I.

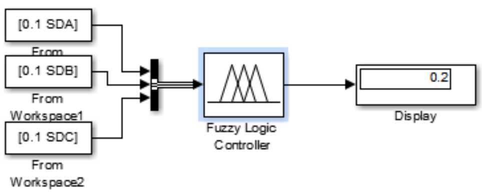


Fig.22. ANFIS MODEL

After training ANFIS using Sugeno type function in ANFIS editor, the obtained ANFIS structure is obtained as shown in the figure 22. The output of ANFIS and SVM for different faults is shown in the table VI

TABLE VI
Classification of faults

S. No	Power system disturbance	Energy values	ANFIS	SVM
1	Normal condition Phase A Phase B Phase C	 3.7e7 3.7e7 3.6e7	 0	 0
2	A-G fault Phase A Phase B Phase C	 2.6e6 3.7e7 3.7e7	 0.1	 0.1
3	B-G fault			

	Phase A Phase B Phase C	3.7e7 2.5e6 3.6e7	0.2	0.2
4	C-G fault Phase A Phase B Phase C	 3.7e7 3.7e7 2.0e6	0.3	0.3
5	A-B fault Phase A Phase B Phase C	 2.4e6 6.0e6 3.7e7	0.5	0.5
6	A-B-G fault Phase A Phase B Phase C	 2.4e7 7.0e6 3.6e7	0.5	0.4
7	B-C fault Phase A Phase B Phase C	 3.7e7 2.4e7 1.0e7	0.7	0.7
S.No	**Power system disturbance**	**Energy values**	**ANFIS**	**SVM**
8	B-C-G fault Phase A Phase B Phase C	 3.7e7 3.0e7 8.9e7	0.6	0.6
9	A-C fault Phase A Phase B Phase	 2.6e7 3.7e7 2.4e7	0.9	0.9
10	A-C-G fault Phase A Phase B Phase C	 2.6e7 3.7e7 3.1e7	0.8	0.8
11	A-B-C fault Phase A Phase B Phase C	 2.4e7 1.9e7 1.4e7	1.0	1.0
12	A-B-C-G fault Phase A Phase B Phase C	 2.1e7 1.6e7 1.1e7	1.1	1.1

TABLE VI
Classification of faults

S.No.	**Energy Value**	**Actual fault location**	**ANFIS**	**SVM**
1	A-12.1792 B-11.2645 C-11.2746	60	60	60
2	A-12.2832 B-11.7399 C-12.2115	60	60	60
3	A-9.2407 B-9.0728 C-8.9338	150	150	150
4	A-8.7354 B-9.2118 C-8.6295	180	180	180

Similarly the ANFIS and SVMare trained for the different fault resistances by extracting the features using DWT analysis.

X CONCLUSION

Thus in this paper, a new methodology called wavelet transform is used to distinguish the feature of current. ANFIS and SVM is used to discriminate the fault type. Thus by using DWT, the time and frequency domain information is obtained and used to categorize the faults. Additionally different fault conditions are simulated. The results obtained have proven the correct operation of the developed method under various fault operation conditions in the electrical transmission networks. This method proves accurate upto 100 ohms fault resistance. The fault discrimination by ANFIS and SVM is having small misclassification. Compared to ANFIS, SVM has negligible misclassification and hence can be used in real time systems for fault classification but in fault location ANFIS is better than SVM.

XI REFERENCES

[1] P. Kundur, *power system stability and control,* New Delhi, India: McGraw-Hill, 2012.

[2] X. Xu and M.Kezunovic, "Automated feature extraction from power system transients using wavelet transform," in *Proc. Int. Conf. Power System Technology,* 2002, vol.4, pp. 1994- 1998.

[3] A. A. Hajjar, M. M. Mansour and H. A.Talaat, "High-phase order power transmission lines relaying approach based on wavelet analysis of the fault generated waves," in *Proc. 39th Int. Univ. Power Eng. Conf.,* 2004, vol.1, pp.805-809.

[4] K. M. Silva, B. A. Souza, and N. S. D. Brito, "Fault detection and classification in transmission lines based on wavelet transform

and ANN," *IEEE Trans. Power Del.,* vol. 21, no. 4, pp. 2058–2063, Oct. 2006.

[5] Z. Q. Bo, R. K. Aggarwal, A. T. Johns, H. Y. Li, Y. H. Song, R. L. King, D. Novosel, and M. Kezunovic, "A new approach to phase selection using fault generated high frequency noise and neural networks," *IEEE Trans. Power Del.*, vol. 12, no. 1, pp. 106–115, Jan. 1997.

[6] N. Zhang andM. Kezunovic, "Transmission line boundary protection using wavelet transform and neural network," *IEEE Trans. Power Del.*, vol. 22, no. 2, pp. 859–869, Apr. 2007.

[7] M. Jaya Bharata Reddy, D. Venkata Rajesh, PathirikkatGopakumar and Dusmanta Kumar Mohanta, " Smart fault location for smart grid operation using RTUs and computational Intelligence techniques," 2014.

[8] M. J. B. Reddy and D. K. Mohanta, "Adaptive neuro-fuzzy inference system approach for transmission line fault classification incorporating the effects of power swing," IET*Gener., Transmiss. Distrib.,* vol. 2, no. 2, pp. 235-244, Mar. 2008.

[9] J. S. R. Jang, " ANFIS: Adaptive network fuzzy inference system," *IEEE Trans Syst., Man, Cybern.,*vol. 23, no. 3, pp. 665-685, May/June. 1993.

[10] O. A. S. Youssef, "Combined fuzzy-logic wavelet - based fault classification technique for power system relaying," IEEE Trans. Power Del.,vol. 19, no. 2, pp. 582–589, Apr. 2004.

[11] Robert Salat and Stanislaw Osowski,"Accurate fault location in the power transmission line using support vector machine approach", IEEE Transactions on Power Systems vol. 19, No.2,2004.