FAULT DETECTION AND CLASSIFICATION OF HIGH VOLTAGE TRANSMISSION LINE USING WAVELET TRANSFORM AND ARTIFICIAL NEURAL NETWORK

[1]M.ABDULRAHMAN, [2]A.NACAROĞLU

[1]Master Student, Electrical and Electronics Engineering /Gaziantep University, Gaziantep, Turkey
[2]ProfessorDr, Electrical and Electronics Engineering/Gaziantep University, Gaziantep, Turkey
Email: [1]emohnnad@gmail.com, [2]arif1@gantep.edu.tr

Abstract - This paper presents an approach to detect and classify the faults of high voltage transmission line based on combination of discrete wavelet transform and artificial neural network using extracted features from current signals of fault by wavelet transform as inputs to artificial neural networks that will be trained by using back-propagation algorithm to differentiate between non faulty and faulty cases in addition to, classification of fault type. Matlab/Simulink is utilized for designing model of transmission line and simulating different types of faults for varying fault resistance and distance.

Keywords - Transmission Line, Distance Protection Relay, Wavelet Transform, Artificial Neural Networks, Detection, Classification.

List of Abbreviation -
VT: Voltage Transformer, **CT:** Current Transformer,**CB:** Circuit Breaker,**WT:** Wavelet Transform,**DWT:** Discrete Wavelet Transform, **D:** Details, **A:** Approximations, **ANN:** Artificial Neural Network, **BPNN:** Backpropagation Neural Network, **FT:**Fourier Transform,**MSE:** Mean Squared Error.

I. INTRODUCTION

The power system basically consists of transmission lines, power transformers, circuit breakers, measurement equipment (current measurement transformers and voltage measurement transformers), control system, and protection system. The most important component that affect reliability of operation of the power system is transmission line where most of the faults occurs unexpected on the transmission line.The key requirement of the power system is reliability of operation that may be achieved by detecting, classifying, and isolating fault section as fast as possible.

It is known that the power transmission systems often operate at high voltage (in kV range) for lesser resistive losses over long distance; thus when fault occurs, excessively high current flows through the power network which may cause severe damages to equipment and devices. A single fault, even when lasting only for a fraction of a second, may affect potentially millions of customers on the grid and result in huge losses and manufacturing downtime in industry [1].

The reliability of power system operation is affected owing to occurrences of faults in the transmission lines, leading to equipment damage. In order to ensure the secure and safe operation of the power system network, it is essential to implement an effective protection scheme that is achieved through an advanced fault classification technique that supports an effective, reliable, fast and secured way of relaying operation in the protective system [2]

II. DISTANCE PROTECTION RELAY

The distance protection relay is a digital device used for protection of power transmission lines and is responsible for detecting faults and making decision to isolate faulty section, therefore, it contributes to the security and reliability of the power system. It monitors and measures the current and voltage signals of the power system each moment via CTs (current transformers) and VTs (voltage transformers) to detect any problem that may occur on the transmission line in the power system and issues the trip signal to the circuit breaker to disconnect the faulty line.

Based on data measured directly from measurement transformers (CTs & VTs transformers) and compared with the setting values, protection system has to make an accurate, fast and right decision during abnormal conditions.

If there is a fault, the distance protection system will isolate a faulty part from power system as quickly as possible to minimize the impact of fault on the equipment of the utilities and to avoid interruption of electric supply, but if there is no fault, the system has to stay ready for any fault may occur.

III. FEATURES EXTRACTION USING WAVELET TRANSFORM

Wavelet Transform:
Wavelet Transform is a mathematical tool for signal processing, it is a powerful tool in the analysis of transient phenomena such as that associated with

faults in power transmission systems and has ability to analyze signal and extract information from the transient signals simultaneously in both time and frequency domain effectively.

Wavelet analysis overcomes the limitations of FT by localizing the fault signal both in time and frequency domain. Fourier analysis does not provide information about the time of occurrence of the fault in the non-stationary current/voltage waveform of the power system. In general, WT exists in two forms: a continuous and a discrete method [2].

DWT decomposes the transient signal into low frequency signals called approximations (A) and high frequency signals called details (D), as illustrated in Figure 1.

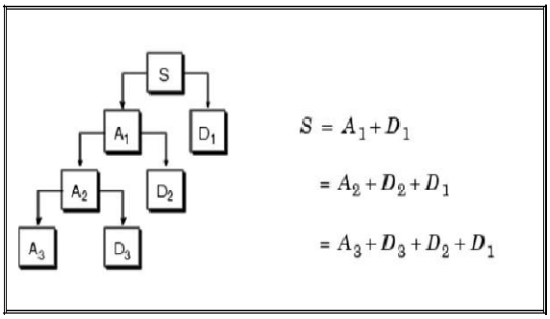


Figure1. Diagram of WT Decomposition

The extracted features such as standard deviation and energy values that contain useful information are selected, and fed as inputs to ANN.

In this work, a mother wavelet of db4 with four levels is used to extract the featuresby sampling the voltage and current signal of one cycle with the sampling frequency of 12.8 kHz and 256 samplesper cycle.The bandwidths of each level of decomposition are presented in Table 1.

Decomposition Level	Frequency Band (Approximations)	Frequency Band (Details)
1	0 to 6.4KHz	12.8 to 6.4KHz
2	0 to 3.2KHz	6.4 to 3.2KHz
3	0 to 1.6KHz	3.2 to 1.6KHz
4	0 to 0.8KHz	1.6 to 0.8KHz

Table1.Frequency Bandwidth for Approximation and Details

There are different kinds of mother wavelets, such as Symlets (sym), Daubechies (db), Coiflets (coif), etc. Among these, the Daubechies wavelets are widely used for transient study, especially db4 therefore, in this work, db4 mother wavelet is chosen to analyze the current signals.An example of wavelet analysis is illustrated in Figure2.

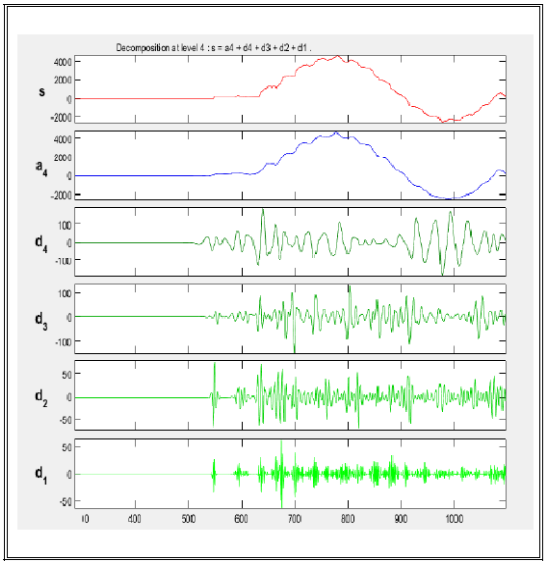


Figure 2. Example of wavelet analysis

Extraction of Features:
Using DWT, D&A coefficients from the signals are extracted, then the energy of D and A coefficients are calculated using the following equations:

$$ED_i = \sum_{j=1}^{N_m} |D_{ij}|^2 \ , \ i = 1, 2, \ldots\ldots, m \qquad (1)$$

$$EA_i = \sum_{j=1}^{N_m} |A_{ij}|^2 \ , \ i = 1, 2, \ldots\ldots, m \qquad (2)$$

where:

EDi: is the energy of the detail at decomposition level ***i***.
EAi: is the energy of the approximation at decomposition level ***i***.
D: is the magnitude of the detail coefficient
A: is the magnitude of the detail coefficient
i: is the wavelet decomposition level
N: is the number of detail or approximation coefficients at each decomposition level.

IV. ARTIFICIAL NEURAL NETWORK

An Artificial Neural Network (ANN) consists of a set of neurons that are interconnected and arranged in many layers, the connections among neurons have weights value associated with them.

An Artificial Neural Network (ANN) helps to build predictive models from large databases. The basic structure of neural network (input layer, hidden layers, and output layer) is illustrated in Figure3.

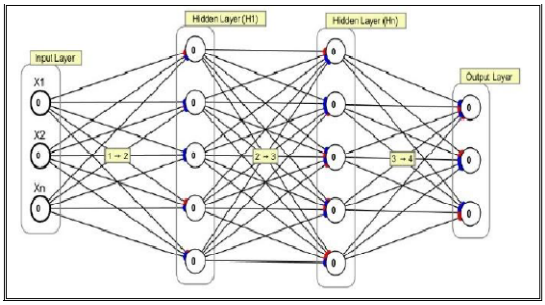


Figure 3. Basic Neural Network Structure

Structure of Neuron:

A neuron is the basic unit of a neural network, it is described mathematically with the following equation:

- $n = [W]^T * [X] + [b]$ (3)
- $n = w_1 * x_1 + w_2 * x_2 + .. + w_n * x_n + b$ (4)
- $y = f(n)$ (5)

X is inputs vector, W is weights vector.

Weight: represents the strength of the connection among neurons of different layers.

Bias: it is an extra input to neuron and equals to one and has its own connection weight.

Activation Function: is used to introduce kind of non-linearity property to the neural networks.

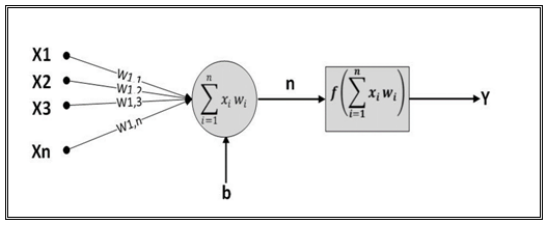


Figure 4. Basic Neuron Structure

Artificial neural network can be applied to fault detection and classification effectively because it is a programming technique, capable to solve the nonlinear problems easily. The ANNs are able to learn with experiences. They are widely accepted and used in the problem of fault detection and fault classification because of the following features:

- Various configurations of transmission lines (short, long, single circuit,double circuit, etc.)
- Simulation of the network with different power system conditions.
- The ANN output is very fast, reliable and accurate.

Learning algorithm utilized is supervised learning, so all data is labeled, and the target is having identified value and is associated with each input in the training set. Figure 4 represents the supervised architecture of ANN [3].

Back-Propagation Neural Network:

In the back propagation neural network (BPNN) the output is feedback to the input to calculate the change in the values of weights. The error for each iteration and for each point is calculated by initiating from the last step and by sending the calculated error backwards [4].

Training of Neural Network

The training process of neural network is setting values of weight to decrease the error between actual and target output. It is started with initial values (often random) for the network parameters (weights and biases) and calculate the error between actual and target output, then the parameters (weights and biases) are updated by backpropagation algorithm until reach the lowest MSE (Mean Square Error) that is used as performance index then the values of weight is the best.The Mean Square Error for each output in each iteration is calculated by:

$$MSE = \frac{1}{N}\sum_{1}^{N}(E_i - E_o)^2 \quad (6)$$

where:

N:is number of iterations, ***Ei:*** is actual output.

Eo: is output of the model.

V. DESIGN OF FAULT DETECTION AND CLASSIFICATION

The design process of proposed fault detection and classification is illustrated through flow chart in Figure 5.

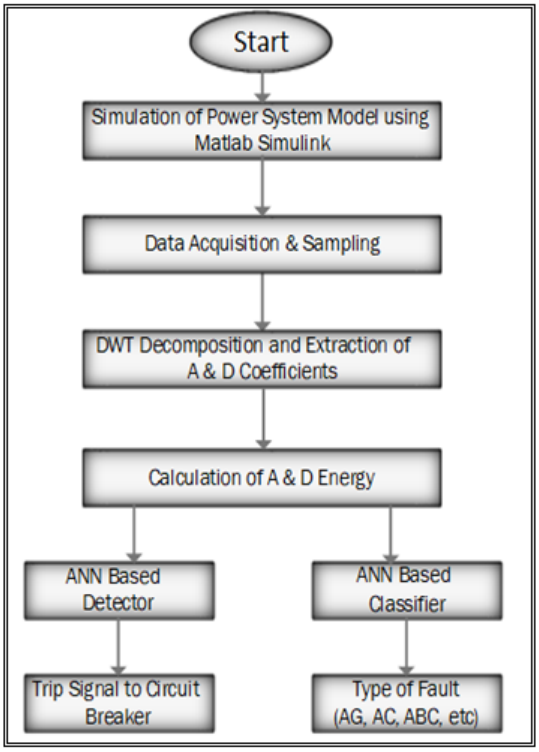


Figure 5.Flow Chart of Detection & Classification of Faults

VI. TRANSMISSION LINE MODEL AND SIMULATION

The high voltage transmission line used is 400 kV, three phase, single circuit connecting between two stations of length 300 km,and the power system frequency is 50 Hz. At each end of the transmission line, it gets into the substation through measurement equipment and circuit breaker which receives the trip order from electronic system, measurement equipment read and step down the voltage and current signals to be suitable for electronic system, these signals are transferred to protection system that analyzes them and according to analysis results it takes the correct decision if trip order should be issued or not. Figure 6 illustrates the single line diagram for power transmission line as well as measurement equipment and distance protection relay.

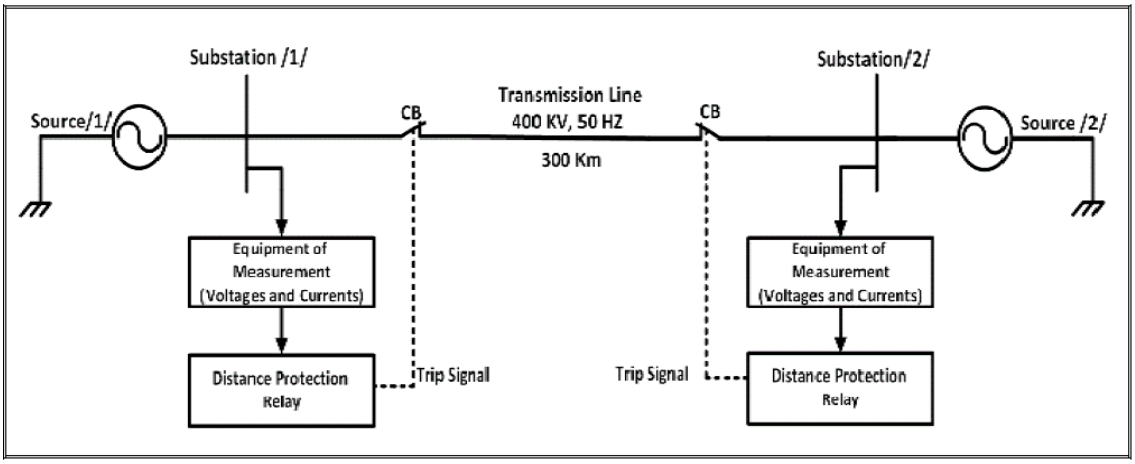


Figure 6.Single Line Diagram for Transmission Line and Measurement and Distance Relay Equipment.

The line is modelled using the **SimPowerSystems** toolbox in **MATLAB** and simulated in **MATLAB/Simulink** environment for different types of fault at many different locations and varying fault resistance to collect data for various fault cases.

Figure7 illustrates model of transmission line in MATLAB Simulink environment, three phase fault blockis to make faults under different conditions through which we can set parameters of faults like type of faults, resistance and time of faults.

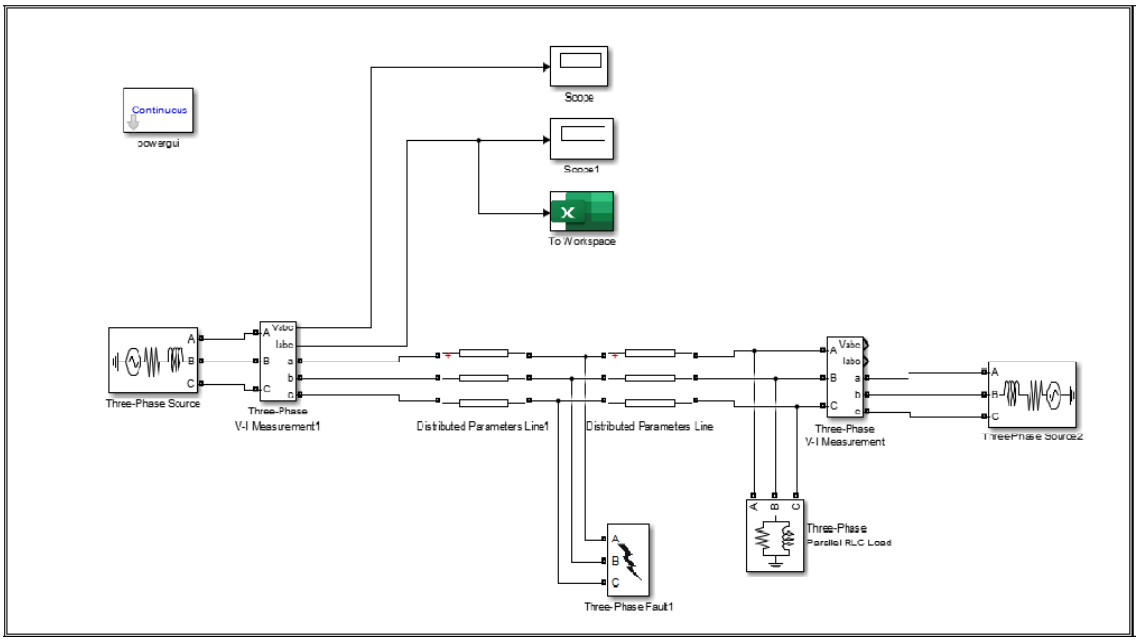


Figure 7. Model of High Voltage Transmission Line

Table2 illustrates utilized parameters for simulation of power system model.

Parameter	Value
Transmission Line	Three Phase
	Single circuit
Source Voltage/1/	400 kV
Source Voltage/2/	400 kV
Frequency	50 Hz
Load	100 MW Active, 10 MVAR Reactive
Transmission Line Length	300 km

Table2.Power System Model Data

After occurrence of the fault, one cycle of current signals are analyzed by discrete wavelet transform at sampling rate 12.8 kHz. The type of simulated short circuit faults is as following:

- Line to ground (A-G, B-G, C-G).
- Line to line (A-B, B-C, A-C).
- Line to line to ground (A-B-G, B-C-G, A-C-G).
- Line to line to line (A-B-C).
- Line to line to line to ground (A-B-C-G).

Training data and test data are generated by simulation of transmission line model for many types of faults for different faults resistance and at different fault locations.

The number of simulations performed to obtain the training data are 3080 (11 type of faults * 28 different locations of faults * 10 different values of fault resistance) as illustrated in Table3.

The number of simulations performed to obtain the test data are 539 (11 type of faults * 7 different locations of faults * 7 different values of fault resistance) as illustrated in Table4.

Parameter	Training Data Set
Fault Type	AG, BG, CG, AB, BC, AC, ABG, BCG, ACG, ABC, ABCG
Fault Resistance (Ω)	0.01, 0.05, 0.1, 0.5, 1, 5, 10, 25, 50, 100
Fault Location (Km)	10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 110, 120, 130, 140, 150, 160, 170, 180, 190, 200, 210, 220, 230, 240, 250, 260, 270, 280
Training Cases	3080

Table3. Generation of Training Data

Parameter	Test Data Set
Fault Type	AG, BG, CG, AB, BC, AC, ABG, BCG, ACG, ABC, ABCG
Fault Resistance (Ω)	0.03, 0.07, 1.2, 8, 30, 75, 115
Fault Location (Km)	15, 45, 75, 150, 175, 225, 275
Test Cases	539

Table4. Generation of Test Data

The desired output of ANN for detection of faults is assigned with 1-bit number as illustrated in Table5.

Fault Type			Target Output (Detection)
1	No Fault	NF	0
2	Fault	F	1

Table5.Target Output of Detector

The desired output of ANN for classification for each type of faults is assigned with 4-bit number as illustrated in Table6.

Fault Type			Target Output (Classification)			
			A	B	C	G
1	1 phase to Ground	AG	1	0	0	1
2		BG	0	1	0	1
3		CG	0	0	1	1
4	2 Phase	AB	1	1	0	0
5		BC	0	1	1	0
6		AC	1	0	1	0
7	2 Phase to Ground	ABG	1	1	0	1
8		BCG	0	1	1	1
9		ACG	1	0	1	1
10	3 Phase	ABC	1	1	1	0
11	3 Phase to Ground	ABCG	1	1	1	0

Table6.Target Output of Classifier

VII. DESIGN OF FAULT DETECTION AND CLASSIFICATION

Architecture of the ANNs (which includes the selection of number of layers, number of neurons in each layer, selection of activation functions, learning algorithms parameters etc.) is very important factorso as to give the best performance during simulation.Table7illustrates parameters of ANN.

Parameter	Detect.	Class.
Input	6	6
Output	1	4
Number of Hidden Layers	2	2
Size of Hidden Layer/1/	3	24
Size of Hidden Layer/2/	3	14
Function of Hidden Layer/1/	Tansig	Tansig
Function of Hidden Layer/2/	Logsig	Logsig
Function of Output Layer	Purelin	Purelin
Training Algorithm	BPNN	BPNN
Performance Index	MSE	MSE

Table7. Parameters of ANN

The neural network structures for detector and classifier are illustrated in Figure8.

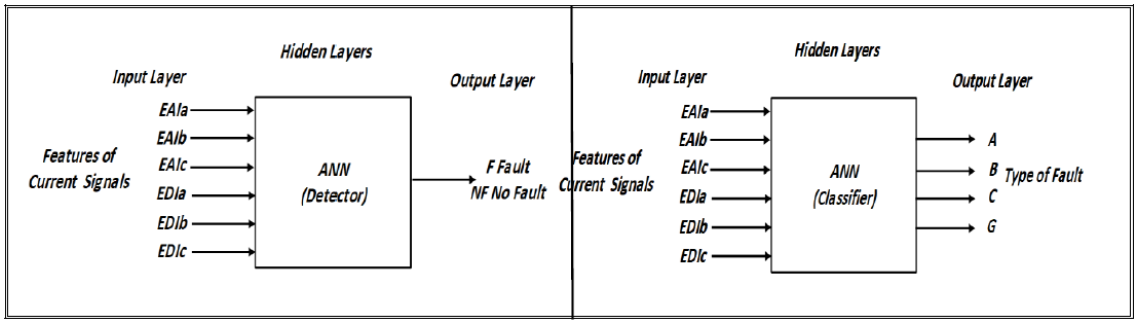


Figure 8. Structures of Detector & Classifier

VIII. TEST RESULTS AND DISCUSSION

After the training process ended, the neural networks for detector and classifier were tested using a set of test data that included various fault scenarios that have been never trained onto verify the performance of the proposed design of neural network structures. Table8. illustrates some examples for test results of detector and Table9. illustrates some examples for classifier.

As it is obvious from the results listed in Table 8, for example, for the case when the fault is between phase A to G at 15 km distance, for 0,03 Ω fault resistance, the measured output is (0.9999) and if it is compared to Table 5, it appears that the actual value is accurate greater than %99. In addition, number of cases detected correctly are 100%.

For the results of classification listed in Table 9, for the case when fault is between phase A to phase B at 175 km distance, for 1.2 Ω fault resistance, the measured value is (0.993, 1.011, -0.009, -0.012) and if it is compared to Table 6, it appears that the actual output is accurate about %99. In addition, number of cases classified correctly are 95%. Therefore, we may say that using ANN with DWT has relatively high accuracy in detecting and classifying faults of high voltage transmission lines.

Fault Conditions					Target Output (Detection)	Actual Output of ANN (Detector)
N.	Type of Fault		Fault Distance (Km)	Fault resistance (Ω)		
1	No Fault	NF	-	-	0	0.05355
2	1 phase to Ground	AG	15 Km	0.03	1	0.99996
3	2 Phase	BC	75 Km	1.2	1	1.000024
4	2 Phase to Ground	ACG	150 Km	75	1	1.000024
5	3 Phase	ABC	275 Km	30	1	1.000024

Table8.Examples from Test Results of Detector

Fault Conditions					Actual Output of ANN (Classifier)			
N.	Type of Fault		Fault Distance (Km)	Fault resistance (Ω)	A	B	C	G
1	1 phase to Ground	AG	225	8	0.9937	-0.0208	0.0157	1.0169
2		BG	175	1.2	-0.0001	1.0086	0.0003	0.9966
3		CG	15	0.07	-0.0008	0.0005	1.0022	0.9983
4	2 Phase	AB	175	8	0.9937	1.0118	-0.0092	-0.0124
5		BC	275	1.2	0.1571	1.0135	1.0498	-0.0120
6		AC	275	8	1.0048	0.0245	0.9822	-0.0049
7	2 Phase to Ground	ABG	150	0.07	0.9977	1.0064	0.0017	0.9919
8		BCG	45	0.03	0.0100	1.0170	0.9651	1.0049
9		ACG	225	0.03	0.9970	-0.0016	1.0037	0.9935
10	3 Phase	ABC	75	115	0.9866	1.0297	1.1082	-0.0703
11	3 Phase to Ground	ABCG	225	30	0.9939	1.0127	1.0296	-0.0076

Table9.Examples from Test Results of Classifier

IX. CONCLUSION

In this paper, a hybrid approach based on combination between wavelet transform and artificial neural network to detect and classify the faults in high voltage transmission lines has been proposed, this technique can be applied in digital protection systems for power transmission lines. Transmission line model is simulated using SIMULINK/MATLAB software to obtain current signals for various types of faults under different conditions in terms of faults resistance, fault type, and position of fault, then the current signals have been decomposed using DWT and energy of wavelet coefficients A& D have been

calculated to be used as inputs to ANNs used in detector and classifier. The test results illustrate favorable accuracy in detecting and classifying transmission line faults, which encourage to process another function of distance protection relay, which is the determination of the fault distanceusing the same technique that integrates DWT & ANN.

REFERENCES

[1] Malla P., Coburn W., Keegan K., Yu XH. (2019) "Power System Fault Detection and Classification Using Wavelet Transform and Artificial Neural Networks". In: Lu H., Tang H., Wang Z. (eds) Advances in Neural Networks – ISNN 2019. ISNN 2019. Lecture Notes in Computer Science, vol 11555. Springer, Cham

[2] Aker, E.; Othman, M.L.; Veerasamy, V.; Aris, I.; Wahab, N.I.A.; Hizam, H. "Fault Detection and Classification of ShuntCompensated Transmission Line Using Discrete Wavelet Transform and Naive Bayes Classifier". *Energies* 2020, *13*, 243.

[3] EiPhyoThwe, Min MinOo, "Fault Detection and Classification for Transmission Line Protection System Using Artificial Neural Network". *Journal of Electrical and Electronic Engineering*. Vol. 4, No. 5, 2016, pp. 89-96.

[4] Mala Nagaraj Bogar ,Chaitanya Krishna Jambotkar, "Power system fault detection and classification using Wavelet Transform and Back Propagation Neural Network"

★★★