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Detection and Classification of One Conductor Open Faults in Parallel Transmission Line using Artificial Neural Network

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***Abstract* – This paper presents an artificial neural network based protection scheme for detection and classification of one conductor open faults in parallel transmission line. A 220 kV double circuit transmission line of 100 km length has been simulated using MATLAB® software and its associated Simulink® and Simpowersystem® toolboxes. The fundamental components of current signals measured at relay location are used as input to train the artificial neural network. The effect of variation in fault inception angle and fault distance location has been investigated on the performance of the proposed protection scheme. The simulation results of ANN based protection technique show that proposed algorithm correctly detects/classifies all types of one open conductor faults within one cycle time. It validates the accuracy and suitability of the proposed scheme.**

***Keywords* – Parallel Transmission Lines, Open Conductor Faults, Neural Networks, Fault Detection and Classification.**

I. INTRODUCTION

The transmission lines are integral part of the power system network, as it is the link between the electricity power production and usage. A transmission line is either single circuit or double circuit configuration, in typical three phase AC systems. The double circuit is preferable over single circuit for its ability to carry more power. Also, double circuits introduce a level of redundancy, where in case of failure in one of the circuits, the other circuit should be able to maintain the power supply. Therefore, parallel transmission lines have been extensively used in modern power systems to increase the reliability and security for the transmission of electrical energy ([1]-[5]).

Transmission lines are spread over wide range and exposed to different environmental conditions, so the possibility of occurrence of fault is more in transmission line as compared to other power system components. Protection of transmission lines are essential for quick system restoration and minimize the damage. Faults in parallel transmission line can be classified as shunt and series faults. Series faults are basically open conductor faults. Among all these open conductor faults, the probability of occurrence of one open conductor faults is great.

The open circuit faults are caused by breaking of conducting path. Such fault occurs when one or more phases of conductor break or a cable joint/ jumper (at the tension tower location) on an overhead line fails. Such situations may also arise when circuit breakers or isolators open but fail to close in one or more phases. During the open circuit of one conductor , unbalanced current flows in the system, thereby heating of rotating machines. Protective schemes must be provided to deal with such abnormal conditions [6]. High impedance faults characteristically show very low currents, which often are not detectable by conventional protection devices. The most frequent and worrying type of high impedance faults occur when an energized primary conductor breaks and falls, contacting earth. This situation is especially dangerous since risks of electric shocks are posed to the public and a fire hazard also exists [7].

A serious problem is the case of open-conductor among the conductors of the transmission line, since it cannot be detected by the distance protection, if it is the main protection scheme of the transmission line. In the system, an open-conductor is not associated with any increase in current or decrease in voltage. Thus, the measured impedance by the distance relay will not decrease in case of open-conductor. In fact, the impedance measured by a distance relay on the healthy-phases increases with the occurrence of open-conductor causing the distance relay to go far away from operation region (overreach). Consequently, the case of open-conductor will continue to exist until other protection scheme detects it. The protection scheme which may detect this type of fault (according to the pre-fault current value) is the earth fault relay. However, even if the line is equipped with an earth fault protection and the pre-fault current value was large enough to initiate the operation of the earth fault relay; there will be a large time delay since earth fault relays is actually a backup protection for high voltage transmission lines (HVTLs) [8].

Various protection schemes have been reported for protection of parallel transmission lines from shunt faults. The techniques are based on the increase in fundamental component of current signals and decrease in fundamental component of voltage signals ([9]-[16]). Open conductor faults are characterized by low or approximately zero currents. Thus the protection technique reported for shunt faults are not appropriated for open conductor faults. Going through the literature survey, it is clear that various ANN based protection technique have been reported for protection of parallel transmission line against shunt faults but no ANN based scheme has been developed for open conductor fault. Consequently, there is a lack of researches considering cases of open (downed) conductor, since most of protective relays do not respond to these types of faults. Protection engineers believe that the protective devices are not designed for open-conductor fault case. Even the field experts find that no response from protective relays for case of open conductor is accepted. There are no significant research efforts in the field of using distance relay to detect the open-conductor fault, especially in HV interconnected systems. Some efforts exerted in field of studying open-conductor problems are in distribution networks ([7], [8], [17], [18]). A brief review of some open-conductor fault detection techniques can be found in ([8], [19] , [20]).

In this regard, this paper presents a protection technique based on ANN-technique for parallel transmission line against all types of one conductor open faults. The developed ANN uses samples of fundamental components of all three phase current information measured at one end only. The performance of the proposed scheme has been investigated by a number of offline tests. Effect of variation in fault parameters, such as fault location and fault inception angle has also been investigated on the performance of proposed scheme. The simulation results show that the proposed ANN- technique is able to detect all types of one open conductor fault and identify the faulty phase correctly.

II. ARTIFICIAL NEURAL NETWORK

ANNs simulate the neural systems behavior by means of the interconnection of the basic processing units called neurons. Neurons are highly rated with each other by means of links. The neurons can receive external signals or signals coming from the other neurons affected by a factor called weight. The output of neuron is the result of applying a specific function, known as transfer function, to the sum of its inputs plus threshold value called bias. With these general characteristics it is able to develop different network structures. Basic processing model of ANN has neurons, synaptic weights, summing junction and activation function ([21], [22]).

Figure 1 shows a simple neuron model in which X_1, X_2 and X_3 are the inputs and W_1, W_2 and W_3 are corresponding weights respectively. The net input, Y_1 is the sum of the weighted inputs from X_1, X_2, and X_3 and bias i.e. $Y_1 = W_1 \cdot X_1 + W_2 \cdot X_2 + W_3 \cdot X_3 + b$.

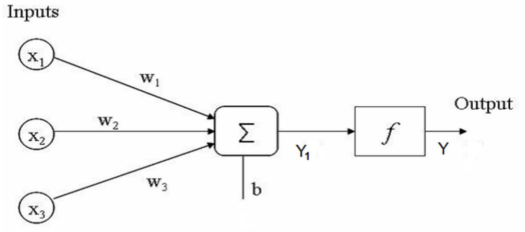


Fig.1: Simple Neuron Model

The net-input, Y_1 is passed to the activation function *f* to get the output Y. ANN has the ability to learn from examples. Once the network is trained, it is able to properly resolve the different situations that are different from those presented in the learning process. The weights of the network are adjusted automatically to get a particular target output for specific input. The neural networks can have several layers. Each neuron in one layer has direct connections with all others neurons in the next layer. There can be also hidden layers. By inserting hidden layers, increasing its size and number, the nonlinear model of system is developed. The multi layered feed forward network has the ability to handle complex and nonlinear input output relationship with hidden layers. In this method, the error can be propagated backwards. The idea of back propagation algorithm is to reduce errors until the ANN learns the training data. The training begins with the random weights and the goal is to adjust them so that the error will be minimal. The multilayered feed forward network has been chosen to process the prepared data obtained from simulation [22].

III. POWER SYSTEM NETWORK SIMULATION

The system under study in this paper is composed of 220KV double circuit transmission line 100 km in length, connected to sources at each end; its single line diagram is shown in Fig. 2 ([1], [2], [12]) . Short circuit capacity of the equivalent Thevenin's sources on two sides of the line is considered to be 1.25 GVA and X_S/R_S is 10. The transmission line is simulated with distributed parameter line model using MATALB software as shown in Fig. 3. Double circuit transmission line parameters are given in Table 1.

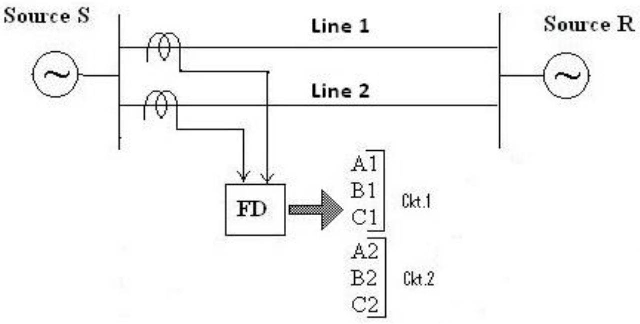


Fig.2: Single line diagram of Power System under Study

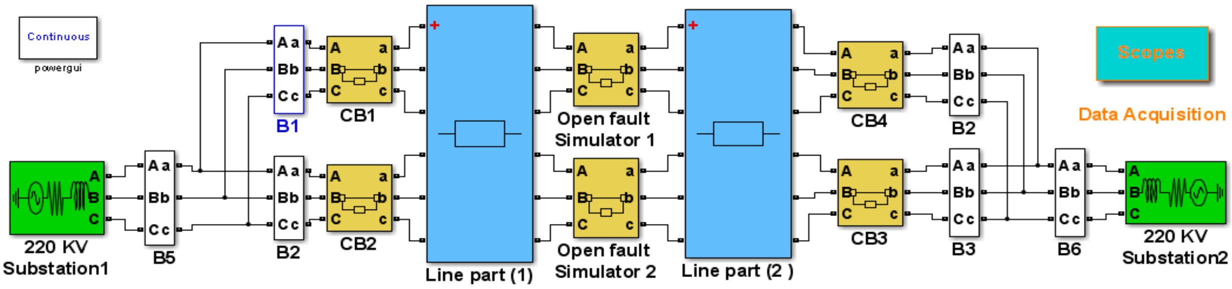
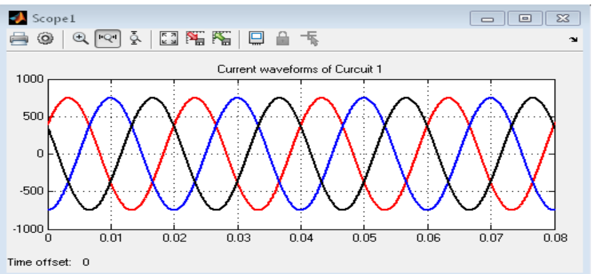


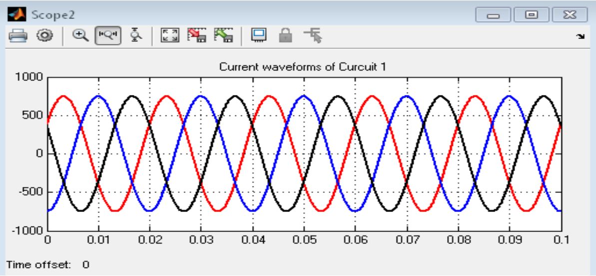
Fig.3: Power system model simulated in MATLAB Simulink software

Table 1: Double Circuit Line Parameter ([1], [2], [12])

Positive sequence resistance R1	0.01809 Ω/km
Zero sequence resistance R0	0.2188 Ω/km
Zero sequence mutual resistance R0M	0.20052 Ω/km
Positive sequence inductance L1	0.00092974 H/km
Zero sequence inductance L0	0.0032829 H/km
Zero sequence mutual inductance L0M	0.0020802 H/km
Positive sequence capacitance C1	1.2571e-008 F/km
Zero sequence capacitance C0	7.8555e-009 F/km
Zero sequence mutual capacitance C0M	-2.0444e-009 F/km



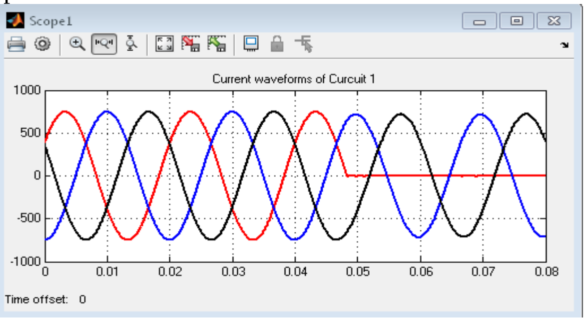
(a) Currents waveforms of circuit 1



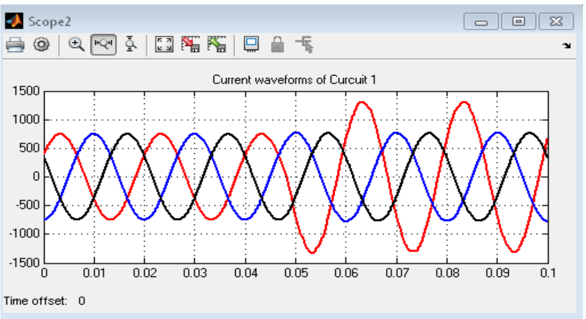
(b) Currents waveforms of circuit 2

Fig.4: Parallel transmission line currents waveforms during no fault condition

After the occurrence of open conductor faults, the magnitude of current in the faulty phase reduces to approximately zero value, while the current in the healthy phase does not change appreciably. Thus an open conductor fault can be identified by measuring the change in current magnitude from no fault to fault condition. As an example, the current waveforms during no fault condition and one open conductor fault condition are shown in Fig. 4 and 5 respectively. It can be seen from Fig. 4, that during no fault condition the instantaneous magnitude of current in all phases are same. Following the occurrence of one open conductor fault in phase “A1” at 5 km from the sending end on circuit 1 at 40 ms with inception angle of 0°, the change in current waveform from pre-fault to post-fault condition is shown in Fig.5. It is clear that following the inception of fault, the current in faulty phase”A1” reduces to approximately zero value and the current in other healthy phase”A2” increases. The proposed protection scheme is based on these changes from pre-fault to post fault conditions.



(a) Currents waveforms of circuit 1



(b) Currents waveforms of circuit 2

Fig.5. Parallel transmission line currents waveforms during open conductor fault in phase “A” of circuit 1 at 70 km from the sending end at 40 ms (Φi=0°)

IV. DEVELOPMENT OF ANN BASED FAULT CLASSIFIER FOR ONE CONDUCTOR OPEN FAULT

The proposed algorithm consists of three stages, namely fault patterns generation and preprocessing; designing of an ANN based fault detector/ classifier and training of proposed scheme for various fault conditions. In the subsequent sections these stages are discussed in detail.

1. Fault Patterns Generation and Preprocessing

Preprocessing is useful method that significantly reduces the size of the neural network and improves the performance and speed of training process. The current input signals were sampled at a sampling frequency of 1 kHz and further processed by simple 2nd-order low-pass Butterworth filter with cut-off frequency of 400 Hz [1]. Subsequently, one full cycle Discrete Fourier transform is used to calculate the fundamental component of voltages and currents. The input signals were normalized in order to reach the ANN input level (±1) ([2], [12]). After pre-processing, posts fault samples are extracted from fundamental component of the phase currents of each circuit to create input matrix for the training of ANN based fault detector/classifier.

2. Designing ANN for Fault Detection and Classification Task

After the selection of input to the neural network, next step is to determine the structure of ANN based fault detector and classifier for one open conductor fault. While designing the neural network, it is essential to determine the optimal size and architecture of the neural network. The lower the number of inputs, the smaller the network can be. However, sufficient input data must be selected to map the problem. Since fundamental component of current signals at relaying point of each phase are used as input to the network, total number of neurons in input layer for ANN is 6. Further ANN has to identify the faulty phase, thus the numbers of neuron in the output layer are 6 representing each phase. If there is no fault in the system, all outputs should be low (0). If there is fault, output should be high (1) in corresponding faulty phase. The individual input (X) and output (Y) vectors for training the ANN is given as:

$X = [\ I_{a1}\ ,\ I_{b1}\ ,\ I_{c1}\ ,\ I_{a2}\ ,\ \ I_{b2}\ ,\ I_{c2}\ \ ]$------------------------ (1)

$Y = [A1,\ B1,\ C1,\ A2\ ,\ B2,\ C2\ ]$ ------------------------ (2)

Where,

I_{a1}, I_{b1}, I_{c1}, I_{a2}, I_{b2} and I_{c2} are the fundamental components of current signals in parallel transmission line and (A1, B1, C1, A2 , B2, C2 *)* represents the phases.

3. Training of ANN Based Fault Detector and Classifier

Total six types of one open conductor fault can occur in parallel transmission line. These faults are simulated at different locations and fault inception angles 0°& 90°. Total number of faults simulated for training are 6 (open conductor faults) x 9 (distance to fault from relaying point) x 2 (fault inception angle) = 108. From each simulated fault case, ten post fault samples have been taken to create training data set for ANN. Some (20) no fault samples have also been added in training data set to discriminate faulty and no fault condition. As a result, total numbers of samples in the input matrix are 108 x 10 +20 = 1100 as summerized in Table 2.

Once the number of neurons in the input and output layer have been decided, next step is to determine the number of hidden layers and number of neuron in each hidden layer. It has been selected based on hit and trail process. Based on series of hit and trails with different number of hidden layers and neurons in each hidden layer best performance is obtained by using single hidden layer with 10 neurons. "Tangent sigmoid" transfer function has been used for both hidden layer and output layer. The ANN was trained using Levenberg–Marquardt training algorithm as it gives fastest convergence as compared with other algorithms [23]. The structure of ANN based fault detector and classifier is shown in Fig.6. The desired performance error goal was set to 10^{-8}. This learning strategy converges quickly and the mean squared error decreases in 13 epochs to $2.4379e^{-9}$ as shown in Fig. 7.

Table 2 : Training patterns generation

Total one conductor open fault	6 (*A1*, *B1*, *C1*, *A2* , B2, *C2*)
Fault location from relaying point (km)	10,20,30,…….80 and 90 km
Fault inception angle (Φ_i)	0° & 90°
Pre-fault power flow angle (δ_s)	45°
Total no. of fault cases	6*9*2 = 108
Total fault samples during training	108*10 =1080 + 20 (no fault samples) = 1100

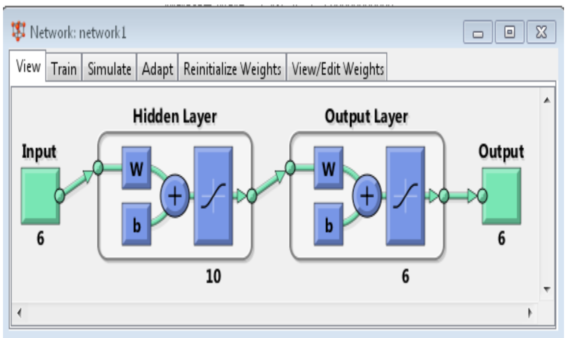


Fig.6: Structure of ANN based fault detector and classifier

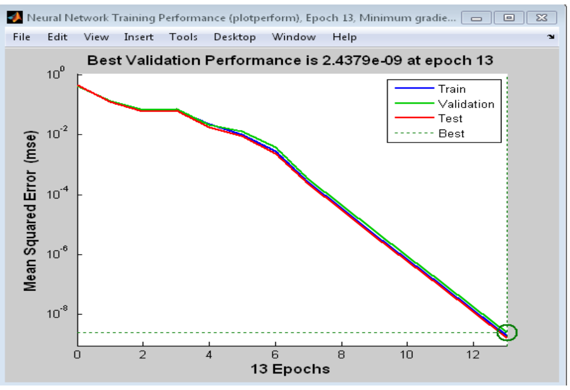


Fig.7: Training of ANN based fault detector and classifier for one open conductor fault

V. TEST RESULTS

Following the training of ANN, it is required to test the neural network for fault situations that have never been used during training. Testing is required to check the performance of proposed ANN based fault detector and classifier. The proposed ANN based fault detector is tested in MATALB/ Simulink for all types of one conductor open fault in parallel transmission line with variation in fault location and fault inception angle as described in Table 3. Total number of faults simulated for testing are 6 (open conductor faults) x 10 (distance to fault from relaying point) x 5 (fault inception angle) = 300.

Table 3: Cases of fault for testing of ANN.

Total one conductor open fault	6 (*A1*, *B1*, *C1*, *A2* , B2, *C2*)
Fault location from relaying point (km)	5,15,25,…….85 and 95 km
Fault inception angle (Φ_i)	0°, 90°,180°,270°,360°
Pre-fault power flow angle (δ_s)	45°
Total no. of fault cases	6*10*5 = 300

After testing the proposed ANN based fault detector and classifier, it has been found that the proposed algorithm is able to detect and classify all types of one open conductor fault correctly through one cycle from the fault inception time. Some of the test results of the proposed ANN based fault detector and classifier for all types of one open conductor fault in parallel transmission line with variation in fault location and fault inception angle are presented in Table 4.

In Fig. 8, plot is obtained for output of ANN based fault detector and classifier for one open conductor fault on phase (A1) at 25 km from the relaying point with fault inception angle Φ_i = 0° (fault inception time = 0.04 sec.). It is clear from Fig. 8 that the output of the proposed ANN based fault detector and classifier became high (one) at 54 ms. Therefore, the time taken by the proposed scheme for fault detection and classification is 14 ms (0.7 cycle).

In Fig. 9, plot is obtained for output of ANN based fault detector and classifier for one open conductor fault on phase (B2) at 65 km from the relaying point with fault inception angle Φ_i = 180° (fault inception time = 0.05 sec.). It is clear from Fig. 9 that the output of the proposed ANN based fault detector and classifier became high (one) at 60 ms. Therefore, the time taken by the proposed scheme for fault detection and classification is 10 ms (0.5 cycle).

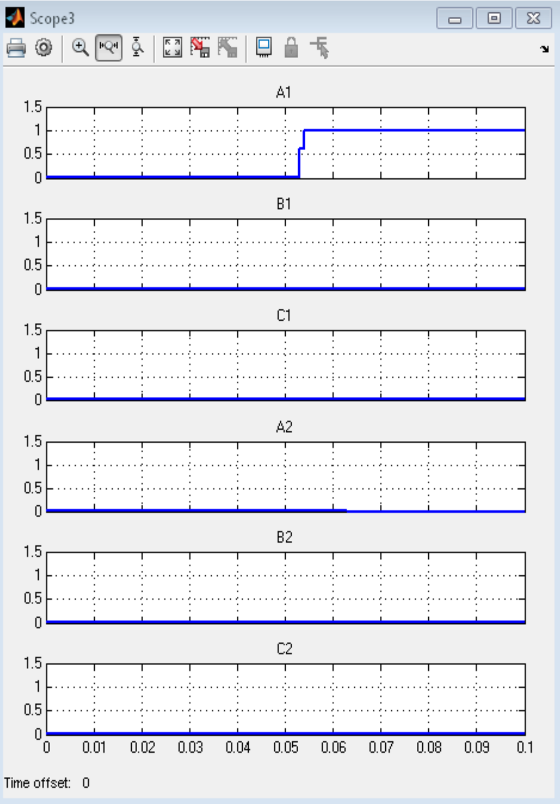


Fig.8: Test result of ANN based fault detection and classification for one conductor open fault 'A1' at 25 km from the relaying point with Φ_i=0° (t =0.04 sec.)

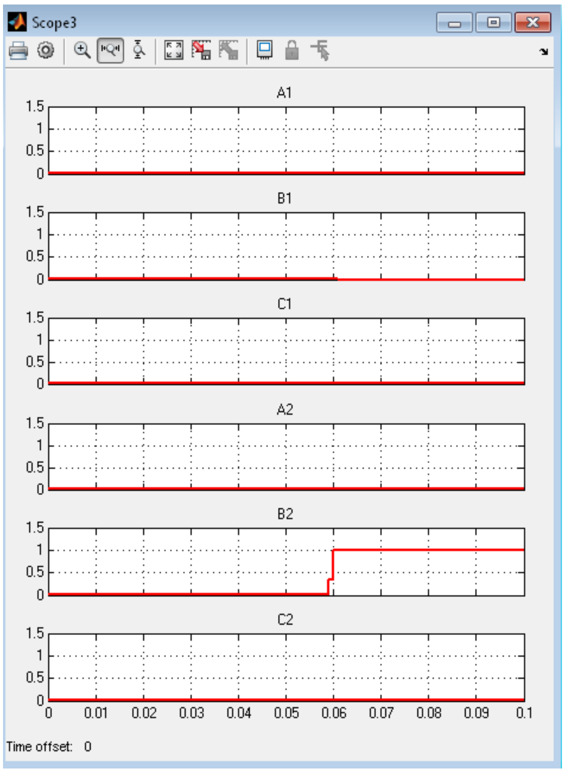


Fig.9: Test result of ANN based fault detection and classification for one conductor open fault 'B2' at 65 km from the relaying point with Φ_i=180° (t =0.05 sec.)

In Fig. 10, plot is obtained for output of ANN based fault detector and classifier for one open conductor fault on phase (C1) at 95 km from the relaying point with fault inception angle Φ_i = 90° (fault inception time = 0.045 sec.). It is clear from Fig. 10 that the output of the proposed ANN based fault detector and classifier became high (one) at 58 ms. Therefore, the time taken by the proposed scheme for fault detection and classification is 13 ms (0.65 cycle).

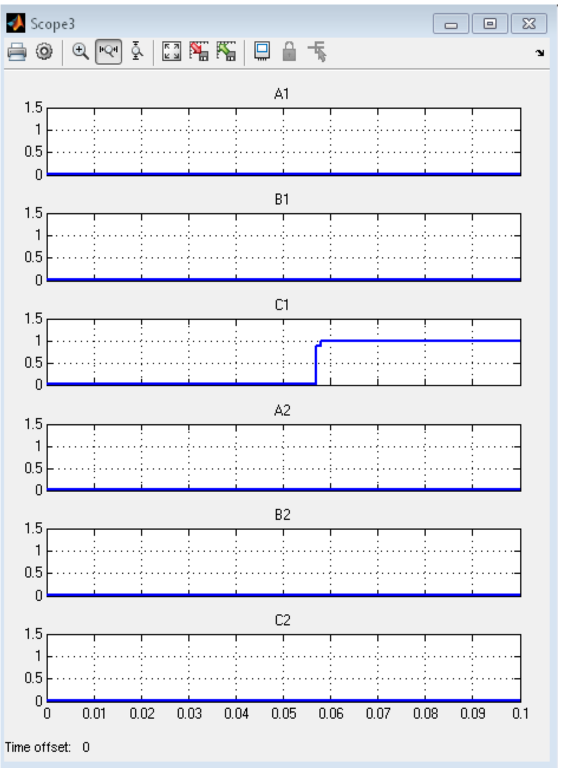


Fig.10: Test result of ANN based fault detection and classification for one conductor open fault 'C1' at 95 km from the relaying point with Φi=90° (t =0.045 sec.)

In Fig. 11, plot is obtained for output of ANN based fault detector and classifier for one open conductor fault on phase (A2) at 35 km from the relaying point with fault inception angle Φ_i = 270° (fault inception time = 0.055 sec.). It is clear from Fig. 11 that the output of the proposed ANN based fault detector and classifier became high (one) at 64 ms. Therefore, the time taken by the proposed scheme for fault detection and classification is 9 ms (0.45 cycle).

In Fig. 12, plot is obtained for output of ANN based fault detector and classifier for one open conductor fault on phase (B1) at 25 km from the relaying point with fault inception angle Φ_i = 360° (fault inception time = 0.06 sec.). It is clear from Fig. 12 that the output of the proposed ANN based fault detector and classifier became high (one) at 70 ms. Therefore, the time taken by the proposed scheme for fault detection and classification is 10 ms (0.5 cycle).

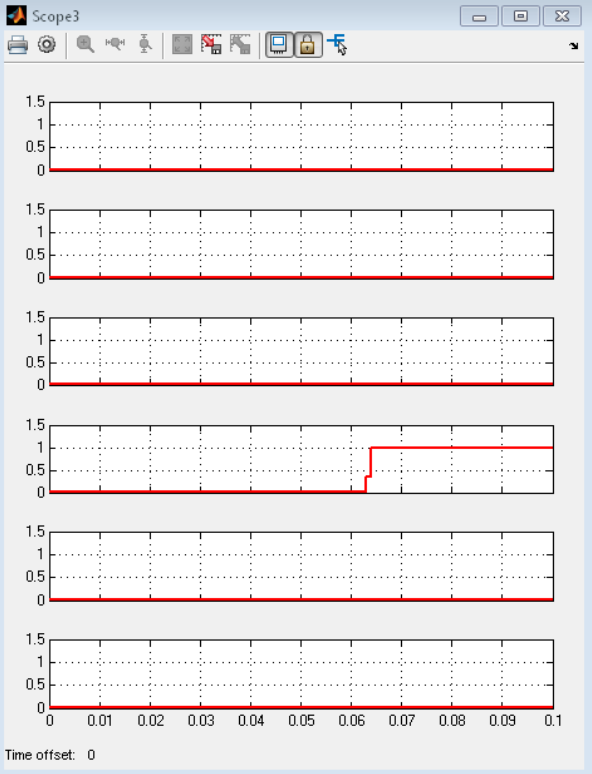


Fig.11: Test result of ANN based fault detection and classification for one conductor open fault 'A2' at 35 km from the relaying point with Φi=270°(t =0.055 sec.)

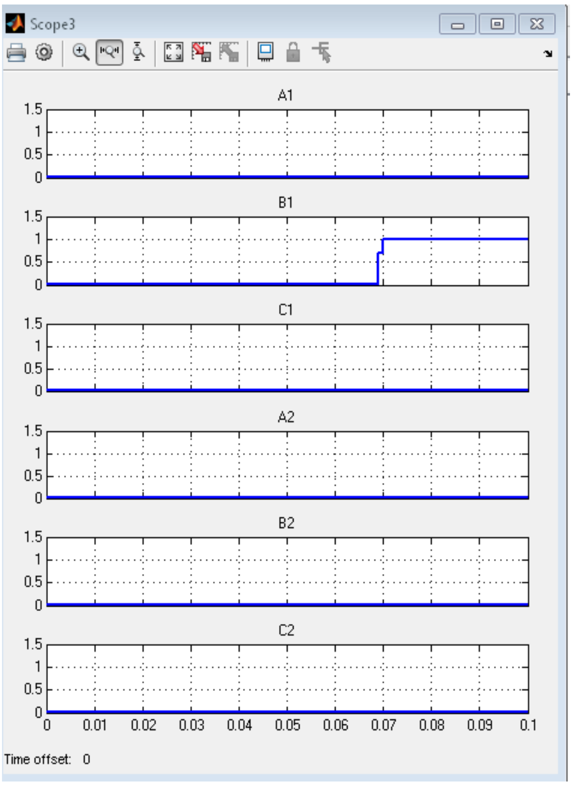


Fig.12: Test result of ANN based fault detection and classification for one conductor open fault 'B1' at 25 km from the relaying point with Φi=360°(t =0.06 sec.)

Table 4: Results of the proposed ANN based fault detector and classifier for all types of one open conductor fault in parallel transmission line under varying fault conditions such as location and fault inception angle

Fault type	**Fault location (km)**	**Fault inception Time (ms)**	**Output of ANN based fault detector/classifier**						**Fault detection time (ms)**	**Relay operation time (ms)**
			A1	**B1**	**C1**	**A2**	**B2**	**C2**		
A1O	25	*40*	1	0	0	0	0	0	54	14
B2O	65	*50*	0	0	0	0	1	0	60	10
C1O	95	*45*	0	0	1	0	0	0	58	13
A2O	35	*55*	0	0	0	1	0	0	64	9
B1O	25	*60*	0	1	0	0	0	0	70	10
A1O	15	*60*	1	0	0	0	0	0	74	14
C1O	5	*65*	0	0	1	0	0	0	77	12
B1O	75	*70*	0	1	0	0	0	0	80	10
B2O	75	*55*	0	0	0	0	1	0	60	5
A1O	55	*80*	1	0	0	0	0	0	94	14
C2O	15	*50*	0	0	0	0	0	1	57	7
B2O	15	*40*	0	0	0	0	1	0	50	10
A2O	65	*45*	0	0	0	1	0	0	54	9
B1O	85	*55*	0	1	0	0	0	0	60	5
A2O	25	*45*	0	0	0	1	0	0	54	9

VI. CONCLUSION

This paper proposes an accurate approach for fault detection and classification of one open conductor fault in parallel transmission line based on supervised feed forward neural network. A transmission line fed from sources at both ends is used. Various types of one open conductor fault, under varying fault conditions such as location of fault from relaying point (1 km to 100 km) and fault inception angle (0° to 360°) have been investigated. The approach employs the fundamental components of the phase currents of the parallel transmission line at one end only. The performance of the proposed scheme has been investigated by a number of tests. The simulation results confirm the suitability of proposed protection scheme.

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