Artificial Neural Network based Protection Scheme for One Conductor Open Faults in Six Phase Transmission Line

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ABSTRACT
The demand for electricity is ever increasing. To meet this ever increasing demand, six phase line can be a possible alternative to increase the transmission line capacity of existing line with the same right of way. This paper presents a Artificial Neural Network based protection scheme for detection and classification of all one conductor open faults in six phase line. A 138 kV six phase transmission line of 68 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 shows 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
Open conductor faults, Six Phase Transmission lines, Artificial Neural Network, Fault detection and classification.

1. INTRODUCTION
Transmission lines are essential links to transfer power from generating station to load centres. The demand of electrical energy is increasing at a rapid rate. To meet this regularly increasing demand, it is required to increase the power transfer capability of existing transmission lines. Baran and Barthold proposed the use of high phase order transmission lines in 1972 [1]. Due to the constraints on availability of land and environmental problems, high phase order transmission is considered as potential alternative to increase the power transfer capability of existing transmission lines. Among the high phase order lines, six phase line is the most promising alternative for transferring more power with existing right- of –way. Six phase transmission line posses several advantages such as higher power transfer capability with compact structure, lower audible and radio noise and lower insulation requirement [1-3]. Preliminary works reported in [1-5] explore the feasibility of six phase transmission lines. Transmission line 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 six phase line can be cassified as shunt and series faults. Series faults are basically open conductor faults. The number of possible series faults which can occur in six phase line as 62 as compared to only 6 on three phase system [4-5]. Among all these open conductor faults, the probability of occurrence of one open conductor faults is maximum. Various protection schemes have been reported for protection of six phase line. A non unit distance protection scheme has been reported in [6-8]. Rebbapragada *et al.* [6] proposed the applicability of the commercially available digital protection scheme for the protection of six phase test line. Apostolov *et al.* [7] analyzed the implementation of microprocessor based relays with programmable logic. A step distance scheme utilizing three phase relays is presented by Oppel *et al.*[8] A wavelet and microprocessor based relaying scheme has been reported in [9]. All these protection techniques are developed for protection against shunt faults only. However none of them provide protection against series faults.

Considering the advantages of artificial neural network (ANN) such as generalization and learning ability, input-output mapping, several protection techniques based on ANN have been developed for protection of three phase lines [10-11]. Bouthiba [10] proposed and tested the ANN based relaying algorithm to detect and locate the faults of the double end fed single circuit transmission line. Another technique based on ANN using superimposed, negative and zero sequence components of currents double end fed single circuit transmission line fault detector and phase selector for all type of faults was proposed by Pasand et. al [11]. Coury et al. [12] developed a complete protection scheme utilizing three phase currents and voltages samples of pre and post fault condition for detection, classification and estimating zone of fault for a single circuit transmission line. Gilany et.al [13] proposed an ANN based protection scheme for improving the performance of distance relays against open conductor faults in three phase lines.

For six phase line, a technique based on modular artificial neural network has been reported for six phase transmission line against all shunt faults [14]. Single stand alone ANN based technique for protection of six phase line has been reported in [15] against six phase to ground faults. Both the techniques are based on the increase in fundamental component of current signals and decrease in fundamental component of voltage signals. 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 three phase line against shunt and series faults and six phase line against shunt faults only but no ANN based scheme has been developed for open conductor fault. In this regard, this paper presents a protection technique based on ANN for six phase line against all types of one conductor open faults. The developed neural network uses samples of fundamental components of all six 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 have also been investigated on the performance of proposed scheme. The Simulation results show that the proposed ANN based technique is able to detect all types of one open conductor fault and identify the faulty phase correctly.

1. POWER SYSTEM MODEL

The six phase transmission line studied is composed of 138 kV, 68 km in length, connected to sources at each end; its single line diagram is shown in Fig. 1. Short circuit capacity of the sources on two sides of the line is considered to be 1.25 GVA and X/R is 10. The transmission line is simulated using MATLAB® 7.01 software and its simpower system and simulink toolboxes as shown in fig.1. To create one open conductor open fault in the line circuit breakers are used in the line.

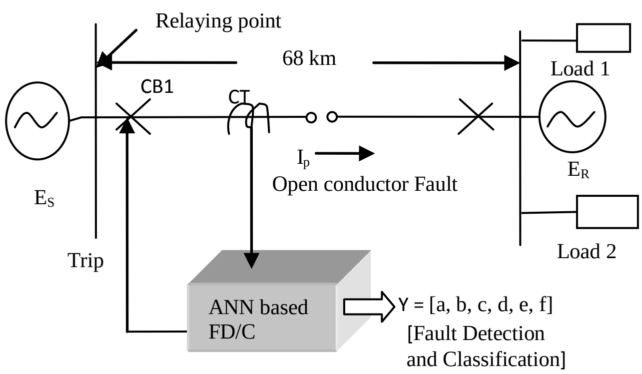

Fig 1: Single Line Diagram Of Six Phase Transmission Line under study

2. SERIES FAULT ANALYSIS

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. 2 and 3 respectively. It can be seen from fig. 2, that during no fault condition the instantaneous magnitude of current in all six phases are same. Following the occurrence of one open conductor fault in phase 'b' at 45 km from the sending end with inception angle of 0°, the change in current waveform from pre-fault to post-fault condition is shown in fig. 3. It is clear that following the inception of fault, the current in faulty phase reduces to approximately zero value whereas the current in other healthy phases remain unchanged. The proposed protection scheme is based on these changes from pre-fault to post fault conditions.

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

The proposed algorithm consists of three stages, namely preprocessing and feature extraction; 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.

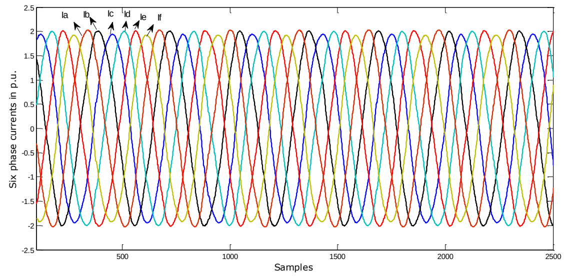

Fig 2: Six phase current waveforms during no fault condition

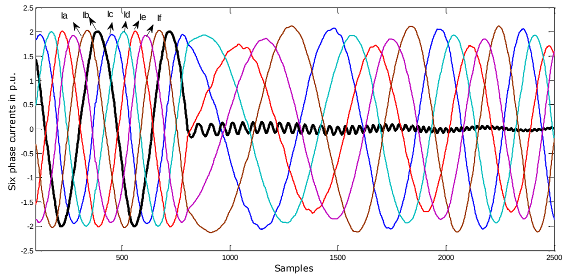

Fig 3: Six phase current waveforms during one conductor fault on phase "b" at 45 km with Φ_i=0°

3.1 Preprocessing and Feature Extraction of Current Signals:

To reduce the size and improve the performance and speed of the neural network; preprocessing is a helpful method. Preprocessing involves the following steps:

- Instantaneous current samples at relay location are obtained by simulating the six phase power system model shown in fig.1.
- These instantaneous values of current signals are processed through low pass Butterworth filter with cut-off frequency of 480Hz.
- After filtering, the current signals are sampled at a sampling frequency of 1.2 kHz.
- Following the filtering and sampling, one full cycle Discrete Fourier transform is utilized to calculate the fundamental components of current signals in each phase.

For fault detection/classification task; fundamental component of current signals at relay location are used as input to proposed algorithm. The signals/samples obtained from pre-processing stage are excessively huge for detection/classification task. Therefore, current samples are altered into a reduced representation for the proposed scheme. After pre-processing, five posts fault samples are extracted from fundamental component of six phase currents to create input matrix for the training of ANN based fault detector/classifier.

3.2 Designing ANN for Fault Detection / 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:

$$X = [I_{aF}, I_{bF}, I_{cF}, I_{dF}, I_{eF}, I_{fF}] \quad \text{…….(1)}$$

$$Y = [a, b, c, d, e, f] \quad \text{…… (2)}$$

where I_{aF}, I_{bF}, I_{cF}, I_{dF}, I_{eF} *and* I_{fF} are the fundamental components of current signals in six phases and ‘a’, ‘b’, ‘c’, ‘d’, ‘e’, and ‘f ’ represents the phases.

3.3 Training of ANN Based Fault Detector/ Classifier

Total six types of one conductor fault can occur in six phase line. All these faults are simulated at different locations and fault inception angles 0°, 90° & 180°. Total number of faults simulated for training are 6 (open conductor faults) x 9 (distance to fault from relaying point) x 3 (fault inception angle) = 162. From each simulated fault case, five post fault samples have been taken to create training data set for ANN. Some (25) 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 162 x 5 +25 = 835 as described in Table 1.

Table 1. Training patterns generation

Total one conductor open fault	Location of fault from relaying point (km)	Fault inception angle (Φ_i)	Total no. of fault cases	Total fault samples during training
6	0.6, 5, 10, 20, 30, 40, 50, 60, 65	0°, 90° & 180°	6*3*9= 162	27*5=810 + 25 (no fault samples) = 835

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 5 neurons. ‘Tangent sigmoid’ transfer function has been used for both hidden layer and output layer.

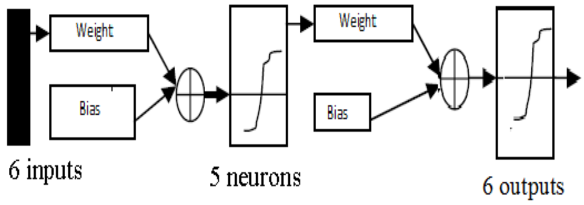

Fig 4: Structure of ANN based fault distance locator

The training of ANN employs Levenberg-Marquardt algorithm which is designed to approach second-order training speed without having to compute the Hessian matrix. The structure of ANN based fault detector and classifier is shown in fig.4. The desired performance error goal was set to 10^{-8}. This learning strategy converges quickly and the mean squared error (mse) decreases in 15 epochs to 3.693e-9 as shown in fig. 5.

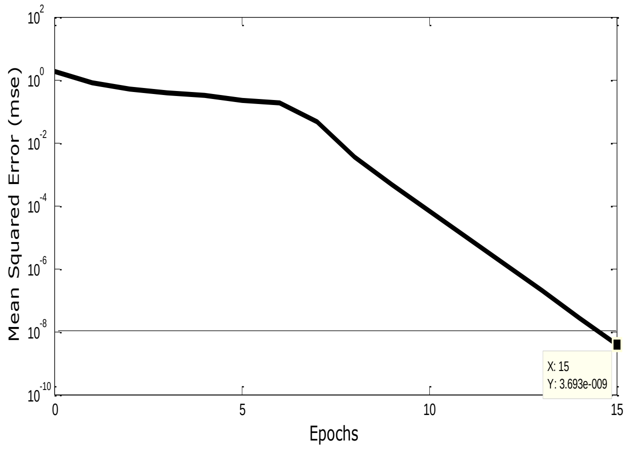

Fig 5: Training of ANN based fault detector and classifier for one open conductor fault

4. TEST RESULTS

Following the training of ANN, it is required to test the 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 using testing data set considering all six types of open conductor fault with variation in fault location from 1 km to 67 km and fault inception angle between 0° to 360°.

Table 2. Test results of ANN based fault detector and classifier

Total one conductor open fault	Location of fault from relaying point (km)	Fault inception angle (Φ_i)	Total no. of fault cases	Total fault samples during testing
6 (a, b, c, d, e and f)	1 km to 67km	0° to 360°	354	354*5=1770 +10 (no fault samples)

Total 354 fault cases are simulated and tested. The detailed description of generation of testing patterns is shown in Table. II. As mentioned earlier, some no fault samples have also been added to check the appropriateness of proposed scheme during no fault conditions also.

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 i.e. an accuracy of 100%. One open conductor fault on phase ‘b’ at 2 km from the relaying point with fault inception angle Φ_i = 180° (fault inception time t_i = 0.041 sec.) is depicted in fig. 6. It is clear from the fig. 6 that the proposed protection scheme is detecting the fault and identifying the faulty phase i.e. ‘b’. Further, the time taken by the proposed protection scheme has also been evaluated. The time taken by the relay is the difference between the time at which fault has been identified to fault inception time. It can be seen from the fig. 6 that the output of the proposed ANN based fault detector/classifier became high i.e. ‘one’ 51.05 ms. Therefore, the time taken by the proposed scheme for detection of fault and identification of faulty phase i..e ‘phase b’ is 10.05 ms (i.e. 51.04 ms-41 ms). Like for the examples discussed here, the fault detection/classification time for all the tested cases is found to be less than one cycle time i.e. 16.67 ms, which is considered as benchmark for digital relays.

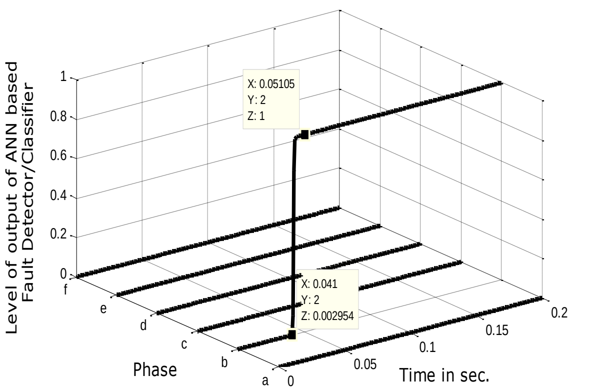

Fig.6: Test result of ANN based FD/C for one conductor open fault ‘b’ at 2 km with Φ_i=180° (t_i =0.041sec.)

Some of the simulation results for varying fault types with different locations are given in table 3. It can be seen that the proposed protection scheme is able to detect and classify the type of fault accurately and maximum time taken by the proposed scheme is 15.07 ms. L_A represents actual location in km of fault from relaying point.

Table 3. Response of protection scheme (fault detector/ classifier) for different fault locations

Fau-lt Ty-pe	L_A in km	Output of ANN based fault detector/classifier (Six phase)						Relay Operati on time in (ms)
		A	B	C	D	E	F	
b	2	0	0.99	0	0	0	0	1.86
a	15	1	0	0	0	0	0	14.44
e	45	0	0	0	0	0.99	0	7.74
a	64	1	0	0	0	0	0	15.07
d	66	0	0	0	0.99	0	0	8.56
e	67	0	0	0	0	0.99	0	8.37

Further as an example, the test result of an open conductor fault “a” at 64 km from the relaying point, with Φ_i=180° is shown in fig.7. The time taken by ANN based FD/C is 15.07 ms for detecting/classifying the fault as one conductor open fault on phase “a”.

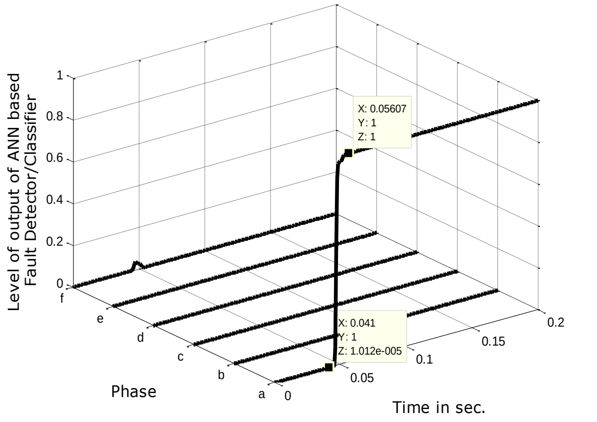

Fig.7: Test result of ANN based FD/C for one conductor open fault ‘a’ at 64 km with Φ_i=180° (t_i =0.041sec.)

Likewise, another open conductor fault ‘e’ at 45 km with Φ_i=180°(t_i =0.041sec.) is analyzed and test result are shown in fig. 8. Thus variation in fault location does not influence the performance of the proposed ANN based protection scheme.

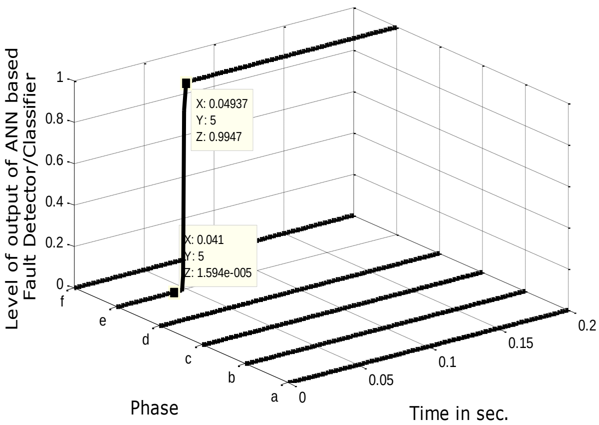

Fig.8: Test result of ANN based FD/C for one conductor open fault ‘e’ at 45 km with Φ_i=180° (t_i =0.041sec.)

5. CONCLUSION

This paper proposes an accurate algorithm for fault detection/classification of one open conductor fault in six phase 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 67 km) and fault inception angle (0° to 360°) have been investigated. The algorithm employs the fundamental components of six phase currents of the line at one end only. The performance of the proposed scheme has been investigated by a number of offline tests. The simulation results confirm the suitability of proposed protection scheme.

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