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Location of Transmission Line Faults Using Wavelet Transform and Artificial Neural Networks

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Abstract: **- In Power system transmission lines are used for transmitting power to the load point. These transmission lines especially overhead transmission lines are susceptible to different types of faults – symmetrical and unsymmetrical faults. For ensuring the reliability of supply the determination of fault location is very important. Traditional methods for fault location were based on impedance and reactance methods. Both these methods are based on phasor quantities which produce delay in locating and detection of faults. Accuracy can be improved by processing travelling waves generated under fault condition. In the present paper these travelling waves are processed by using wavelet transform technique which gives the time and frequency response of the given wave. For achieving more accuracy Artificial Neural networks are trained under different fault conditions for locating faults. Wavelet transformation technique is used for extracting the three phase voltages and currents thereby avoiding additional filters. These quantities are fed as an input to the neural network and the output of this network will be the location of faults. Only difficulty with this method is the selection of required number of neurons for the network that gives accurate results. The simulations are performed using Artificial Neural Network toolbox in MATLAB.**

Index Terms— Artificial Neural Networks, Clark's Transformation, Karrenbeur Transformation Travelling waves and Wavelet transform.

1. INTRODUCTION

The major disturbances in a transmission network are the short circuit faults. These short circuit faults may results in loss of stability in the system. In this situation isolation of faulty parts from the rest of the system in a minimum possible time is the main task of the protection system , which involves the following steps:

1. Fault detection
2. Fault location
3. Fault classification

Faults in the transmission lines are normally classified into series and shunt faults [1]. Series faults are referred as the faults that occur serially in the transmission lines. Shunt faults are the most common faults which are again subdivided into symmetric and unsymmetrical faults. Symmetrical faults are otherwise called as balanced fault which is the most severe fault but the percentage of occurrence of this fault is only 5%. Unsymmetrical faults are otherwise called as unbalanced faults which are again subdivide into three

1. Single Line to Ground fault
2. Line to Line fault
3. Double Line to Ground fault

Among these faults Single Line to ground fault is most commonly occurring fault and its occurrence probability is 70%.When these faults occurs the current in the network increases in an uncontrollable manner, which results in the damage of equipments. The protective relays are used for detecting this high current, it will send a trip signal to the circuit breaker which will trip the healthy lines from faulty lines.

Most commonly used relay for long transmission lines are distance relay which operates on the impedance measurement of the line after fault calculation [2]. Accurate location of fault cannot be detected using distance relays thus the fault clearance time of distance relay is less which effects stability of the system. Also the performance of distance relay under power swing condition is less satisfactory [16]. These disadvantages of distance relays are overcome with the arrival of travelling wave based relay. Travelling wave based relay provides fast clearance of fault, immunity to power swing, current transformer saturation and distributed capacitance current of long transmission line.

Travelling wave based relay records the voltage or current travelling wave generated under fault conditions. These travelling waves propagate at the velocity of light thus by knowing the time of arrival of travelling waves the distance of fault can be easily determined [3] . Travelling wave relay uses single ended recording technique or double ended recording technique. The performance of relay is affected by the multiple reflections of the travelling waves and also with the fault inception angle. The fault inception angle affects the intensity of travelling waves. If the fault inception angle is 90º the intensity of travelling waves are more, the intensity reduces as the fault inception angle reduces and the detection of fault is not possible when the fault inception occurs at 0º. Another disadvantage of travelling waves is that it requires

high sampling frequency. Because of its fast fault clearance property it is preferred over ordinary distance relay.
Detection of time of arrival of travelling waves is the main issue in travelling wave based relay. Traditional technique involves the use of filter banks for extracting the frequency information of the signal which is based on Fourier transformation. But Fourier transformation is localized only to frequency thus the time information of the signal is lost. As a solution to this problem a new technique called wavelet transform is used for the extraction of fault information which provides both frequency and time localization of the signal. Wavelet transform is a signal processing technique which is introduced in the year 1980. Wavelet transform has proved to be a powerful tool for the analysis of transient signals. The signals are analyzed with the help of different wavelet families. Literature [4] –[20] gives the method for locating and classifying the fault using wavelet transform. The method proves to be more accurate for the measurement of the distance of fault and for the classification of fault.
The wavelet transformation techniques involve lots of calculations and the algorithm is also complex. In order to overcome these difficulties fault location and classification task is provided to Artificial Neural networks is proposed in this paper. ANN network has the ability to convert these non linear problems to linear problem. The method utilizes the advantages of wavelet transformation technique and also ANN. The input to the network is the modulous maxima of wavelet decomposed three phase voltages and currents thus the requirement of additional filters is overcome. Five networks are trained and tested. One for fault classification and other four networks are designed for fault location purpose. By using ANN for location and classification purpose the complexity of algorithm is reduced. The problem with this method is training time is more and also there is no thumb rule for selection of number of neurons. The number of neurons is selected by trial and error method.

II. WAVELET TRANSFORM

Transformation of a signal is just another method for representing the signal. Unlike Fourier transformation technique wavelet transformation provides both time and frequency information of a signal which is very useful in the analysis fault. It is a very powerful tool for analysis of a non stationary signals. In order to avoid the resolution problem multiresolution technique is used which analyses the signal at different frequencies with different resolutions.. Wavelet transform analysis are divided into two 1. Continuous wavelet transform and 2. Discrete wavelet transform techniques. In this paper Discrete wavelet transformation techinique is used for the analysis of the signal.
The Discrete Wavelet Transform is just a sampled version of Continuous Wavelet Transform and its computation may consume significant amount of time and resources, depending on the resolution required. In the case of DWT, a time-scale representation of the digital signal is obtained using digital filtering techniques. The signal to be analyzed is passed through filters with different cut off frequencies at different scales. The resolution of the signal, which is a measure of the amount of detail information in the signal, is determined by the filtering operations. The DWT is computed by successive low pass and high pass filtering of the discrete time-domain signal as shown in figure 5.1. This is called the Mallet algorithm or Mallet-tree decomposition.

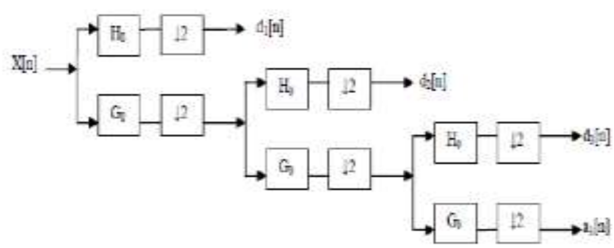

Fig1 Daubechius wavelet

The original signal x(n) is first passed through an high pass filter g(n) and low pass filter h(n). After filtering half of the samples are eliminated according to the Nyquist rate. Since its highest frequency is reduced to half the signal can therefore be subsampled by 2, simply by discarding every other sample. This constitutes one level of decomposition. This process increases frequency resolution. The frequencies that are most prominent in the original signal will appear as high amplitudes in that region of Discrete wavelet transform signals that includes those particular frequencies. This procedure offers good frequency resolution. The frequency bands which are not prominent will have low amplitudes and that part can be discarded without major loss of information, allowing data reduction.
The major wavelet families which we use commonly are Daubechies, Biorthogonal, Symlets, Coiflets, Mexican Hat, Morlet, Meyer and complex wavelets. Among these wavelets Daubechies wavelets are commonly used for observing the fault transients since the characteristics shape of daubechies wavelets are similar to the shape of fault transients. In this paper daubechies 4 (db4) wavelet damily are used for extracting the time and frequency information of fault transients.

Artificial Neural Network
An Artificial Neural Network can be described as a set of elementary neurons that are usually connected in biologically inspired architectures and organized in several layers. A weight is attached to each neurons and training an ANN is the process of adjusting weights tailored to the training set.

An Artificial Neural Network learns to produce a response based on the inputs given by adjusting the node weights. Due to their outstanding pattern recognition abilities ANNs are used for several purposes in a wide variety of fields including signal processing, computers and decision making.

III. RESULTS

The Artificial Neural Networks has wide application in Power system protection problem. The excellent pattern recognition and classification ability of ANN is utilized for the fault classification and location purpose. In this paper a neural network based fault location is depicted.

The three phase voltages and currents are used which provides more information about the location as well as the type of fault. This method uses wavelet transform as a feature extraction tool thus there is no need for design an extra filters. As it is stated in section II wavelet transform has a strong capability of extracting the signal component under different frequency bands while retaining the time domain information. Secondly the extracted features will be handled by the feed forward back- propagation network using Levenberg's- Marquadst algorithm.

The three phase voltages and currents are first decoupled using Clark‟s transformation technique and is decomposed using daubechies4 wavelet. The modulus maxima of decomposed values are used as the input to the Artificial neural network. Mainly four networks are trained for the other four types of faults namely

1. Single line to ground fault
2. Line to Line fault
3. Double Line to ground fault
4. Three phase fault

IV. DATA PREPROCESSING

A reduction in the size of the neural network will improves the performance of the same and this can be achieved by performing feature extraction. By doing this all the important and relevant information present in the voltage and the current waveforms can be used effectively. Voltage and the current waveforms generated are sampled at 400 KHz. The voltage and the current signals of all the three phases are noted along with the corresponding pre- fault values.

The input to the neural network is the ratio of the modulus maxima of three phase voltages and currents before and after the occurrence of the fault. The inputs are in matrix format. Thus there is six input at each time (three phase voltages and three phase currents).

V. OVERVIEW OF TRAINING PROCESS

Two important steps in the application of neural networks for any purpose are training and testing. The first of the two steps namely training the neural network is discussed in this section. Training is the process by which the neural network learns from the inputs and updates its weights accordingly. In order to train the neural network we need a set of data called the training data set which is a set of input output pairs fed into the neural network. Thereby, we teach the neural network what the output should be, when that particular input is fed into it. The ANN slowly learns the training set and slowly develops an ability to generalize upon this data and will eventually be able to produce an output when a new data is provided to it. During the training process, the neural network‟s weights are updated with the prime goal of minimizing the performance function. This performance function can be user defined, but usually feed forward networks employ Mean Square Error as the performance function and the same is adopted throughout this work.

As already mentioned, all the voltages and currents fed into the neural network are scaled with respect to the corresponding voltage and current values before the occurrence of the fault. The outputs, depending upon the purpose of the neural network might be the fault condition, the type of fault or the location of the fault on the transmission line.

For the task of training the neural networks for different stages, sequential feeding of input and output pair has been adopted. In order to obtain a large training set for efficient performance, each of the ten kinds of faults has been simulated at different locations along the considered transmission line. In view of all these issues, about 100 different fault cases for each of the 10 kinds of faults have been simulated. Apart from the type of fault and the distance of the fault along the transmission line is determined. Fault distance has been varied at an incremental factor of every 10 km on a 200 km transmission line.

VI OVERVIEW OF TESTING PROCESS

The next important step to be performed before the application of neural networks is to test the trained neural network. Testing the artificial neural network is very important in order to make sure the trained network can generalize well and produce desired outputs when new data is presented to it.

There are several techniques used to test the performance of a trained network, a few of which are discussed in this section. One such technique is to plot the best linear regression fit between the actual neural network‟s outputs and the desired targets. Analyzing the slope of this line gives us an idea on the training process. Ideally the slope should be 1. Also, the correlation coefficient (r), of the outputs and the targets measures how well the ANN‟s outputs track the desired targets. The closer the value of „r‟ is, to 1, the better the performance of the neural network. Another technique employed to test the neural network is to plot the confusion matrix and look at the actual number of cases that have been classified positively by the neural network. Ideally this percentage is a 100 which means there has been no confusion in the classification process. Hence if the confusion matrix indicates very low positive classification rates, it indicates that the neural network might not perform well. The last and a very obvious means of testing the neural network is to present it with a whole new set of data with known inputs and targets and calculate the percentage error in the neural networks output. If the average percentage error in the ANN"s output is acceptable, the neural network has passed the test and can be readily applied for future use.

The Neural Network toolbox in Simulink by The Math Works divides the entire set of data provided to it into three different sets namely the training set, validation set and the testing set. The training data set as indicated above is used to train the network by computing the gradient and updating the network weights. The validation set is provided during to the network during the training process (just the inputs without the outputs) and the error in validation data set is monitored throughout the training process. When the network starts over fitting the data, the validation errors increase and when the number of validation fails increase beyond a particular value, the training process stops to avoid further over fitting the data and the network is returned at the minimum number of validation errors. The test set is not used during the training process but is used to test the performance of the trained network. If the test set reaches the minimum value of MSE at a significantly different iteration than the validation set, then the neural network will not be able to provide satisfactory performance.

VII FAULT LOCATION

This section deals about the design, of the neural network based fault locators for each of the various types of faults. This forms the second step in the entire process of fault location after the inception of the fault. The following subsections deal with the various kinds of faults and their error performances individually.

VII.1 SINGLE LINE TO GROUND FAULTS

There are mainly three types of single line to ground faults(A-G, B-G and C-G fault) where A,B and C are the corresponding phases and G indicates ground. Feed forward back – propagation neural networks have been used for the purpose of single line – ground fault location, mainly because of the availability of sufficient relevant data for training. In order to train the neural network, several single phase faults have been simulated on the transmission line model. For each of the three phases, faults have been simulated at every 10 Km on a 200 Km long transmission line. In each of these cases, the wavelet decomposed modulus maxima value of voltage and current samples for all three phases are given as inputs to the neural network. The output of the neural network is the distance to the fault from the measuring end.

Firstly, a few of the various neural networks with varying combination of hidden layers and number of neurons per hidden layer are tested for their error performance. Among them a 5 layer network is selected in which input layer consists of 28 neurons and number of neurons in the hidden layer are in the order of 24-18-15.Efficiency of the trained networks is analyzed based on their regression performance and their performance in the testing phase. The regression plot of selected network is shown in the figure 8.2. Regression plot indicates the degree of success of trained data. The performance function used is the least square error value. If all the training data set lies on the line it means that the successful training is done and the probability of occurrence of error is less.

In the regression plot obtained for the distance measurement of single line to ground fault the training set data lies exactly in the line that means the training is successful but there is a small deviation in testing and validation plot. Therefore 100 % accuracy cannot be achieved for all sets of data. The accuracy can be improved by varying the number of neurons as well as number of layers of the network through trial and error method. The results of the trained network are tabulated in the table 8.2 at the end of this chapter. The error associated with the method is also given in the table.

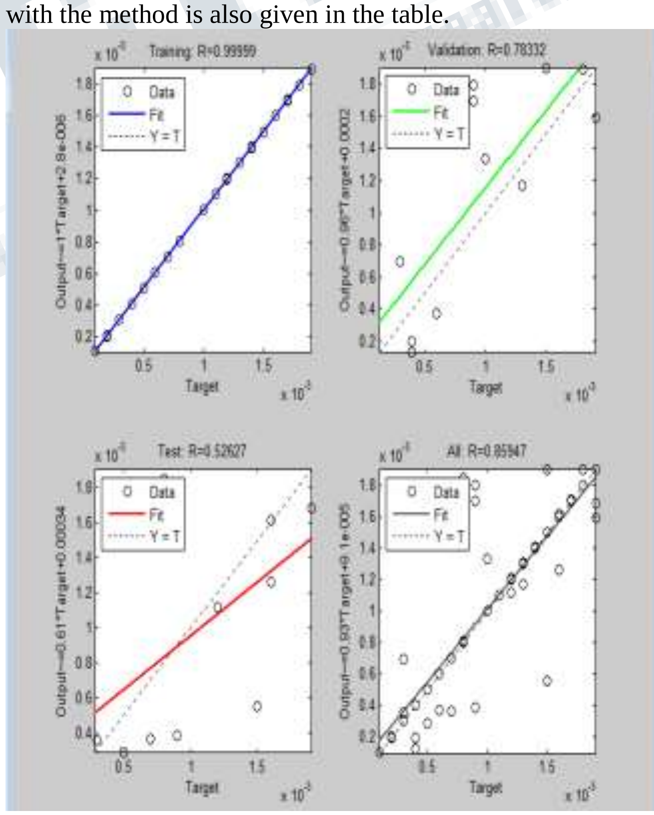

Fig 2 Regression plot of singleline to ground fault

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VII.2 LINE TO LINE FAULT

In this section the design and testing of neural network for estimating the location of fault for line to line fault is given. Mainly there are three types of line to line faults (A-B, B-C and A-C fault). The design procedure for designing neural network for line to line to fault is same as that of single line to ground fault. In order to train the neural network, several line – line faults have been simulated on the transmission line model. For each pair formed by the three phases, faults have been simulated at every 10 Km on a 100 Km long transmission line. Among different networks tested network with 5 layers. The input to the network is modulus maxima of three phase voltages and currents and output is the distance of fault. The number of neurons in the input layer is 26 and the number of neurons in the hidden layer is in the order of 21-22-18. The network is tested for different cases and the regression plot of selected network is given below.

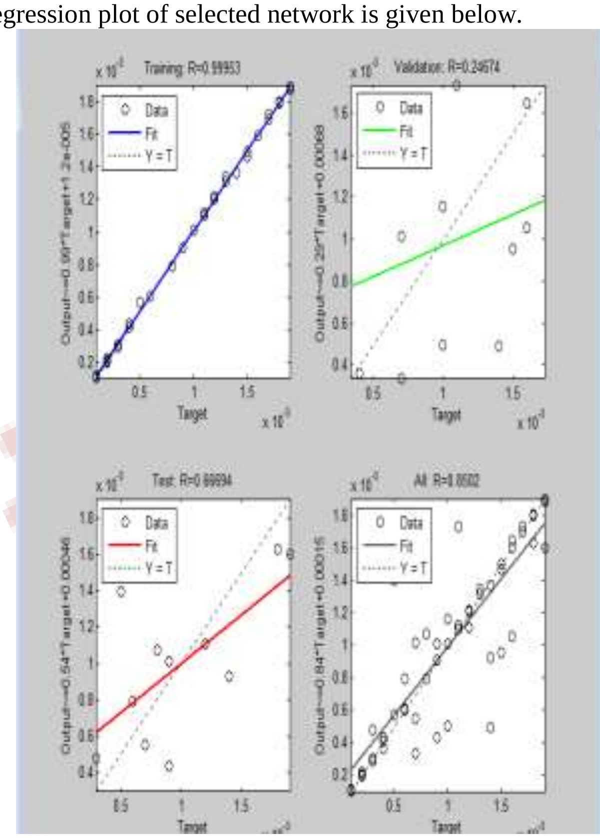

Fig 3 Regression Plot of Line to Line fault

VII.3 DOUBLE LINE TO GROUND FAULT

In this section the design and testing of neural network for estimating the location of fault foe double line to ground fault is given. Mainly there are three types of double line to ground faults (A-B-G, B-C-G and A-C-G fault). The design procedure for designing neural network for double line to ground to fault is same as that of single line to ground fault. In order to train the neural network, several double line to ground faults have been simulated on the transmission line model. For each pair formed by the three phases, faults have been simulated at every 10 Km on a 100 Km long transmission line. Among different networks tested network with 5 layers. The input to the network is modulus maxima of three phase voltages and currents and output is the distance of fault. The number of neurons in the input layer is 32 and the number of neurons in the hidden layer is in the order of 24-24-18. The network is tested for different cases and the regression plot of selected network is given below.

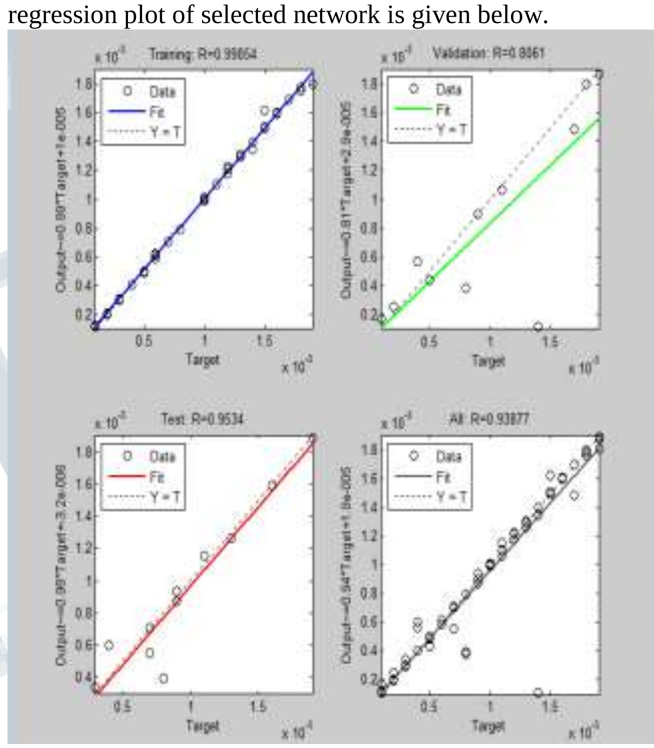

Fig 4 Regression plot of Double line to ground fault

VII.4 THREE PHASE FAULT

In this section the design and testing of neural network for estimating the location of fault for three phase fault is given. The design procedure for designing neural network for three phase fault is same as that of single line to ground fault. In order to train the neural network, several three phase faults have been simulated on the transmission line model. For each pair formed by the three phases, faults have been simulated at every 10 Km on a 100 Km long transmission line. Among different networks tested network with 5 layers. The input to the network is modulus maxima of three phase voltages and currents and output is the distance of fault. The number of neurons in the input layer is 24and the number of neurons in the hidden layer is in the order of 18-22-18. The network is tested for different cases and the regression plot and test results are given below.

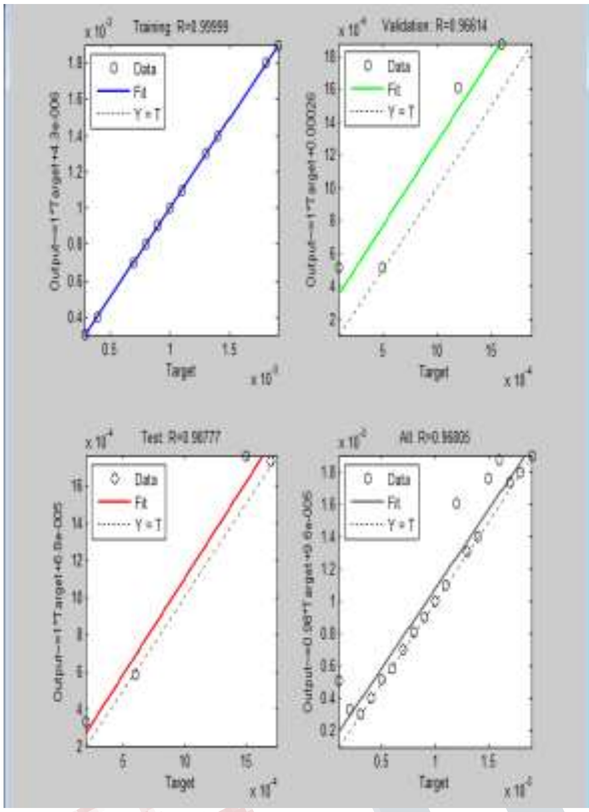

Fig 5 Regression plot of Three phase fault

VIII.CONCLUSION

Power system fault location and classification by combining wavelet transform and Artificial Neural Network is done in this paper. Wavelet Transform is used for extracting the time and frequency information of the fault transient signals. The complex algorithm for the fault classification and fault location is replaced by ANN trained networks. Five networks are trained one for fault classification and other four networks are designed for locating the faults- Single line to ground fault, Double line to ground fault, Line to line fault and Three phase faults. The trained network locates and classifies the faults with adequate accuracy and it eliminates the complex algorithm used in the previous method. The accuracy is highly depending on training process. For improving accuracy more and more training by varying number of neurons should be done The method is immune to fault resistance up to 60 Ω .The mean square deviation is about 1.509.

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