FAULT DETECTION AND CLASSIFICATION IN DOUBLE CIRCUIT TRANSMISSION LINE USING DWT AND ANN

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Abstract— Fault diagnosis is a major area of investigation for power system and intelligent system applications. When the fault occurs on the transmission lines, the current and voltage waveforms contain significant high frequency transient signals. This paper presents a DWT and ANN approach for fault detection and classification in transmission line. The DWT is applied for decomposition of fault transients, because of its ability to extract information simultaneously from both time and frequency domain. The data sets which are obtained from the DWT are used for training and testing the ANN architecture. The feasibility of fast forward back propagation algorithm is tested on transmission line using MATLAB software. The proposed algorithm is very simple and accurate in fault detection and classification. Simulation results show that the proposed algorithm gives satisfactory results and will be very useful in the development of a power system protection scheme.

Keywords— DWT (Discrete Wavelet Transform), ANN (Artificial Neural Network), fault detection, fault classification, fast forward back propagation algorithm.

I. INTRODUCTION TO WAVELETS

An electrical power system consists of utility grid, hybrid energy sources like wind and solar. The main factor which decreases the efficiency of transmission lines are faults. The heavy short circuit currents are likely to cause damage to equipment if the fault has been located and cleared on time. So detection, classification and clearance of these faults must be met as fast as possible. Nowadays, the penetration of renewable energy (RE) sources such as wind and solar has increased significantly. When the RE sources are entered in the distribution networks, the behavior of protective devices has changed due to the fact that the RE sources are widely distributed. Hence, the accurate location of fault in the presence of RE sources has become a challenging task. Hence an accurate fault detection and classification is needed to improve the protection of the system and facilitates saving of time.

II. DISCRETE WAVELET TRANSFORM

Discrete Wavelet Transform is found to be useful in analyzing transient phenomenon such as that associated with faults on the transmission lines. The fault signals are generally non stationary signals, any change may spread all over the frequency axis. Under this condition the Fourier transform techniques are less efficient in tracking the signal. Short term Fourier Transform uses a fixed frequency window to localize sharp transitions for non-stationary signals. The practical power system faults encounter the change in frequencies. The wavelet transform technique is well suited to wide band signals that may not be periodic and may contain both sinusoidal and non sinusoidal components. The wavelet transform has the ability focus on short time intervals for high frequency components and long time intervals for low frequency components. Multi-Resolution Analysis (MRA) is one of the tools of Discrete Wavelet Transform (DWT), which decomposes original, typically non-stationary signal into low frequency signals called approximations and high frequency signals called details, with different levels or scales of resolution. It decomposes signal into different scales and resolutions. Figure 2.1 shows the wavelet filter bank.

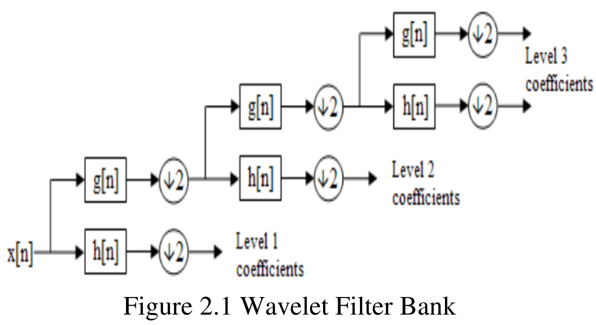


Figure 2.1 Wavelet Filter Bank

It uses filters with different cut off frequencies to analyze a signal (image in our case) at different resolutions. The signal is passed through a series of high-pass filters, g also known as wavelet functions, to analyze the high frequencies and it is passed through a series of low-pass filters, h also known as scaling functions, to analyze the low frequencies. In first decomposition signal is decomposed into D1 and A1, the frequency band of D1 and A1 is f_s /2-f_s /4, 0- f_s /4, where f_s is the sampling frequency. In the second decomposition step the A1 is decomposed to give A2 and D2. The frequency band of D2 component is f_s /4- f_s /8, and A2 is 0-f_s /8 the signal of desired frequency component can be obtained from repetitive decompositions. The mother wavelet determines the filters h and g used to analyze signals.

Fault Detection Using DWT:

Discrete Wavelet Transform is found to be useful in analyzing transient phenomenon such as that associated with faults on the transmission lines. In this paper, DWT is used for fault detection purpose due to following reasons. It provides a fast, reliable, accurate fault analysis and it also easier to implement and it provides less computation time and resources required compared to the continuous wavelet transform.

The three phase current signal of transmission line are taken as input and decomposed using discrete wavelet transform to obtain feature extraction. The features extracted by processing discrete wavelet transform are maximum and minimum detail coefficient at five level decomposition levels (d1, d2, d3, d4, d5). The maximum and minimum detail coefficient of line current at level 4 and level 5 are used for the study. The maximum and minimum detail coefficient of line current at level 4 and level 5 are calculated for all different fault types such as Single Phase to Ground, Double Phase Fault, Double Phase to Ground Fault and Three Phase Fault using wavelet toolbox. The maximum and minimum detail coefficient of normal condition (pre-fault) values at level 4 and level 5 are taken as reference and compared with abnormal one's. If the maximum and minimum detail coefficient value of the signal exceeded that of a normal condition, a fault is detected. The features obtained by processing the discrete wavelet transform are provided to neural network for fault classification purposes.

III. Artificial Neural Network

Artificial Neural Networks (ANN) are inspired by biological nervous systems and they were first introduced as early as 1960. ANN is made up of many computational processing elements called neurons or nodes. These nodes operate in parallel and are connected through topologies that are loosely modelled after biological neural system. ANN has three layers i.e input layer, hidden layer and output layer. Patterns are presented to the network via input layer, which communicate to one or more hidden layer where the actual processing is done. The hidden layers then links to an output layer as shown in Fig.3.1

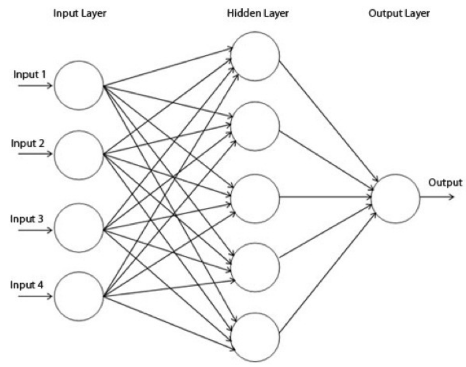


Figure 3.1 Architecture of ANN

The number of input in a neural network is equal to the number of nodes in the input layer. Similarly, the number of outputs in neural network is equal to the number of nodes in the output layer. The number of hidden layers and number of nodes in the hidden layer are varying depending on its application. There are two distinctive network topology with regard to the way neurons are connected namely feed forward and feedback network. In the feed forward network, an outcrop in a layer is an input to the next layer. In the feedback network, an outcrop in a layer can be its own input to the previous layers. To get the intended output for the given inputs, the network weights need to adjust. The process of weights adjustment is called network learning / training. Learning process is the most important step when applying neural network. The learning techniques are classified into supervised learning and unsupervised learning. In supervised learning, each input signal is associated with the labeled output. In unsupervised learning, the outputs are not known in advance.

A. *Fault Classification Using ANN*

Once a fault has been detected, the next step is to identify the type of fault. Back propagation algorithm, a supervised learning is used as the network will be trained using the data created from the simulation model of transmission line. The maximum and minimum detail coefficient of all the three phases (A, B, C) at level 4 and level 5 are taken as input to neural network. The network designed here has six inputs and four outputs associated with the four fault categories. The outputs contain variables whose values are given as either 0 or 1 corresponding to the three phases and the ground (i.e, A, B, C and G) and can be generalized to represent all the fault categories. The fault classification algorithm is shown in the Figure 3.2

Any ANN can be categorized based on the below parameters:

- The topology used to interconnect various neurons.
- The activation function used by neurons to process the sum of weighted inputs.
- The learning algorithm used by the network.

Let us look at each of the above in detail

1) **Neural Network Topologies:** The architecture used to arrange the neurons in an ANN defines its network topology. Within the network, neurons are usually arranged into one or more layers. The simplest way to define a layer is a set of neurons that do not interconnect with each other. ANN usually have three layers one input layer, one or more hidden layers and one output layer. The task of selecting the

correct network topology has a huge impact on the performance of the ANN and is hence, a crucial component

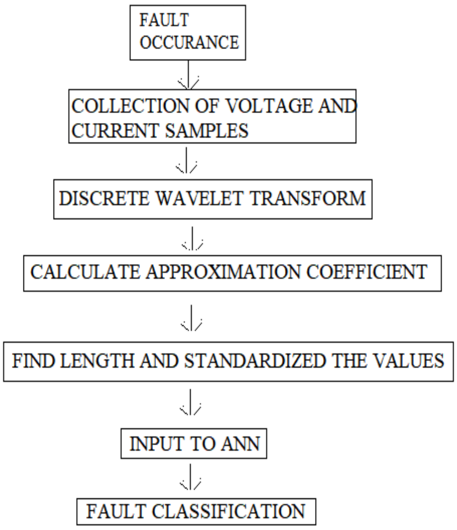


Figure 3.2 Fault Classification Algorithm

of the ANN design phase. There are three commonly used network topologies:

- Feed forward neural network:
- Recurrent neural network:
- Modular neural networks:

2) Activation functions: The activation function used by the neurons is determined based on the type of problem the ANN will try to solve. These functions are usually implemented as a linear function, non-linear function, sigmoid function or a hyperbolic tangent function. Sigmoid function takes the value from 0 to 1, while in case of hyperbolic tangent it takes the value from -1 to 1

3) Learning paradigms: The learning process of a neural network comprises of adjusting the weights at the inputs, so that the system can generate the expected output for a given set of inputs. The accuracy of the ANN can be improved by using more varied datasets during the learning phase. There are three common types of learning algorithms:

• Supervised Learning: The ANN is provided a set of inputs and their corresponding desired outputs. The ANN processes the input, compares actual output with desired output and makes necessary corrections in input weights to minimize the difference between actual and target output. Typical applications of these learning algorithms include speech recognition and image processing.

• Unsupervised Learning: An ANN using this model is provided with just the input data set. The ANN works to find patterns in data set. These patterns can be used to map them on distribution graphs and to identify data clusters.

• Reinforced learning: In this case, the input for the ANN is determined by its interactions with the environment. The long term goal of this kind of learning process is to determine a policy of actions that create the most optimum output in a given environment. The biggest advantage of these algorithms is that they are able to adapt to a volatile environment and learn actions that can achieve the target result.

IV. MODELLING OF MICROGRID

A. *Technical Challenges In Micro Grid Protection*

One of the major challenges is a protection system for micro grid which must respond to main grid as The micro grid concept has to face a number of challenges in several fields, not only from the protection point of view, but also from the control and dispatch perspective. Generation systems in both Medium Voltage (MV) and Low Voltage (LV) systems, making power flow bidirectional

- Two operational modes: grid connected and islanded/stand-alone;
- Topological changes in LV network due to connection/disconnection of generators, storage systems and loads;
- Intermittence in the generation of several micro sources connected in the micro grid;
- Increasing penetration of rotating machines, which may cause fault currents that exceed equipment ratings.
- Insufficient level of short-circuit current in the islanding operation mode, due to power electronics interfaced distributed generation (DG);
- Reduction in the permissible tripping times when faults occur in MV and LV systems, in order to maintain the stability of the micro grid.

B. *Modelling Of Hybrid Micro Grid Connected To Utility Grid*

Non-conventional energy resources, such as solar PV, fuel cell and wind energy have attracted energy sectors to generate power that interconnected at point of common coupling to the main power grid with an aim to improve reliability in power supply against the load demand. Both wind and solar, is unsystematic in nature and dependence on climatic changes. Fortunately, the problems can moderately overcome by integrating the resources to form a hybrid micro grid system, strength of one source overcome the limitation of the other source. The energy resources connected to the micro grid to allocate the shortage power as per conditional demands. However, the interfacing of micro grid with these energy resources lead to several power quality and islanding problems which must be detected, analyzed and mitigated effectively. The proposed system model is described in Figure 4.1

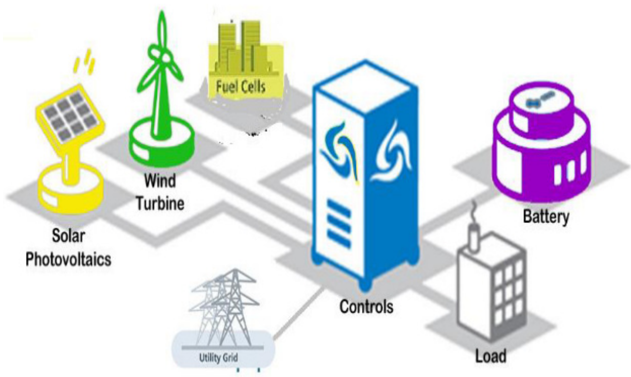


Figure 4.1 Micro grid connected energy resources to utility grid

Photovoltaic (PV) system refers to an array of cells containing a solar photovoltaic material that converts solar radiation into direct current electricity. The DC is carried through wiring to an inverter which converts the current to AC so it can be connected to main grid. Maximum power obtaining from solar has directly related to solar irradiance intensity and temperature. Several photovoltaic cells connected in series, which is a PV module. The output current is equal to difference of light generated current to diode current which is given in the equation 4.1

$$I = I_{ph} - I_D \qquad \ldots 4.1$$

Where,

I_D = Current of the diode

I = Cell output current and voltage.

I_{ph} = Light generated current.

The wind turbine acts as a prime mover to a connected DC generator. Pulse Width Modulation (PWM) is used to obtain three phase AC voltage from the output of DC generator. Wind turbine extracts maximum kinetic energy from the wind, which strikes rotor blade. The power coefficient 'Cp' is a measure of how much the energy extracted by the turbine. CP may be expressed as a function of the Tip Speed Ratio (TSR) given by equation 4.2

$$\lambda = \omega_m R/V$$

$$P = 1/2 C_P \rho V^3{}_W AW \qquad \ldots 4.2$$

Where,

ω_m = mechanical angular rotor speed of the wind turbine.

P = Power (W).

C_p = Power coefficient.

V_w = Wind velocity (m/s).

A = Swept area of rotor disc (m2).

ρ = Density of Air (kg/m3).

C. Micro Grid Fault Analysis With System Modelling

In micro grid, fault analysis can be categorizing mainly two types one of the fault in main grid and other is in micro grid considered as internal and external faults. External fault could be in MV bus or distribution transformer and internal fault could be in LV feeder or LV consumer. As micro grid need to operate in both island and grid connected mode there have challenge in micro grid protection system with conventional protection strategy. The major micro grid protection problem is related to large difference between fault current in main grid connected and islanded mode. Also there have sensitivity and selection problem due to different fault current in different scenario. But it is essential to have high sensitive to faults and selectively isolate/sectionalize in the case of DGs with low fault current level. As conventional protection system doesn't offer solution for all micro grid protection challenge, but it needs advanced protection strategy. The protection scheme must ensure that safe operation of the micro grid in both modes of operation, that is the grid connected mode and island mode. Due to contribution of host grid in grid connected mode fault currents are large. This allows to employment of conventional over current relay, but the fact is that due to existence of distributed resources the protection coordination may be compromised.

V. Simulation And Results

The Proposed system consists of 230 kV transmission line connected with the RLC load through distributed energy resources like wind farm and solar. On occurrence of fault severe short circuit current flows through the line which can damage the system and its connected resources. Hence using discrete wavelet transform the fault signals are decomposed and the approximated coefficients are chosen and then through standardizing the values the fault have been detected. Then these data samples are given to artificial neural network for fault classification through feed forward back propagation algorithm. For the purpose of fault studies, the current signals of all the three phases are used. The frequency of sampling was taken to be 20 kHz with a base frequency of 50 Hz. Figure 5.1 shows the general simulation block diagram of double circuit transmission line under faulted condition.

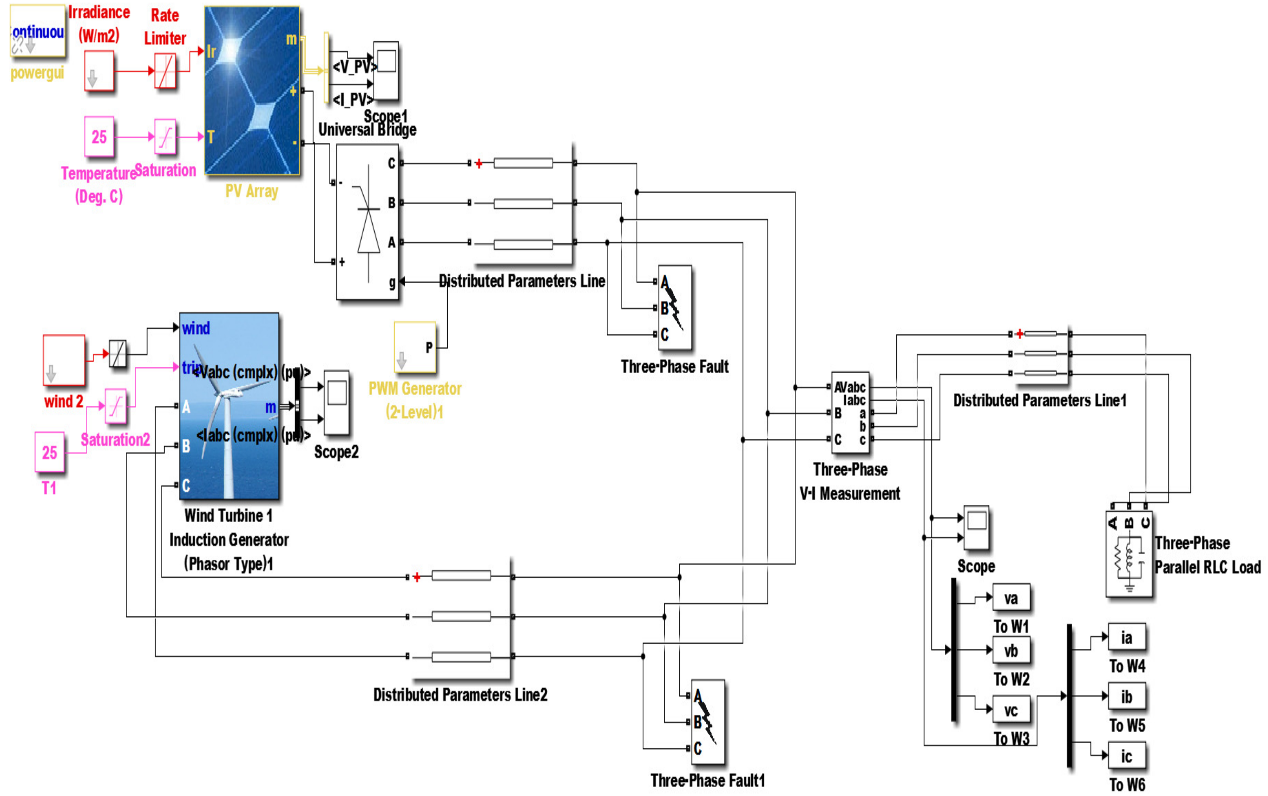


Figure 5.1 Double Circuit Transmission line under faulted conditions

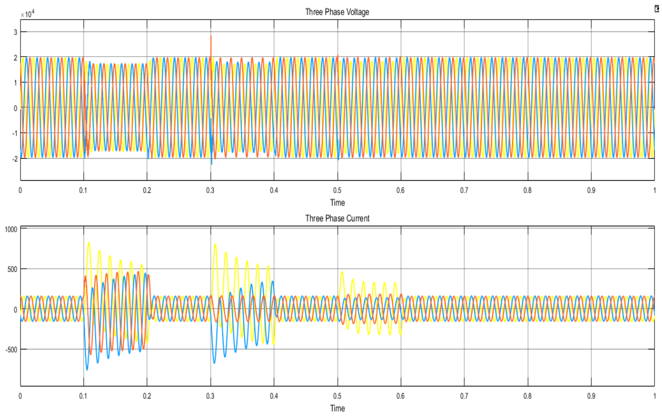
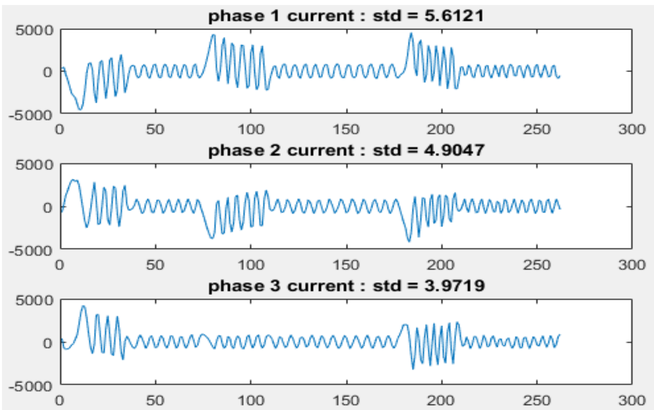


Figure 5.2 Three Phase Voltage and Current under Fault conditions

Figure 5.2 shows the three phase current and voltage signals under L-G, L L-G, L L L-G fault conditions for 0.1 seconds each.



A. Fault Detection: Results And Discussions

As discussed earlier in this section, the fault data is created using simulation model of transmission lines. These three phase current signal are decomposed up to fifth detail level using db6 mother wavelet to obtain feature extraction. The feature extracted by processing DWT are maximum and minimum detail coefficient of three phase current signal at level 4 and level 5 which are used for fault detection and classification. The maximum and minimum detail coefficient of normal condition (pre fault) values at level 4 and level 5 are taken as reference and compared with abnormal one's. If the maximum and minimum detail coefficient value of the signal exceeded that of a normal condition, a fault is detected.

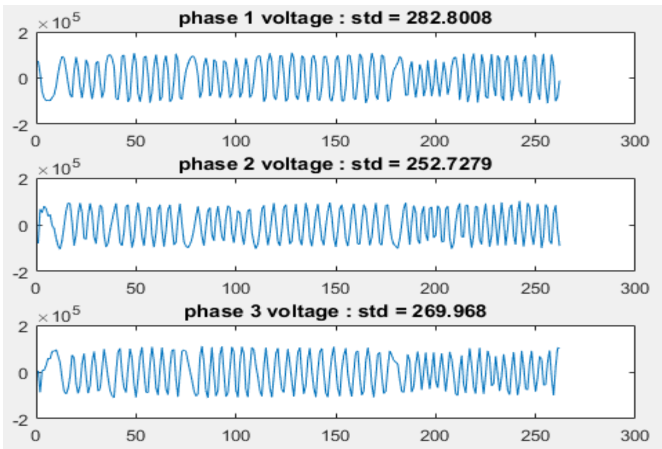


Figure 5.4 Detected Phase Voltages using Discrete Wavelet Transform

Figure 5.3 Detected Phase Currents using Discrete Wavelet Transform

Figure 5.3 and 5.4 shows the Phase currents and voltages of the faulted line which are detected using Daubaches wavelet which decomposes the signal into approximated and detailed coefficients. In which approximated coefficients are used to identify the length of the signal and then standardizing it. The coding and syntax are given in appendix.

B. Fault Classification: Results And Discussions

With the help of fault detection process, absence and presence of faults are known however the discrimination of fault is not possible just with the help of DWT transformed signal. In this proposed system, ANN is used for fault classification purpose. The feature obtained by processing DWT are provided as an input to ANN The features used for fault classification are maximum and minimum detail coefficient of three phase current signal of d4 and d5.

Training of the Neural Network:

A feed forward back propagation neural network with 1 hidden layer is used for fault classification purpose. Input layer consists of six neurons which takes the maximum and minimum detail coefficient of three phases of the transmission line. The number of neurons in hidden layer is fixed with 10 neurons. Output layer has four neurons, output indicates fault type. This neural network structure is trained using back propagation training algorithm for the training data of transmission line model. The data using for training data division is done randomly, training algorithm used is Scaled conjugate Gradient algorithm. Performance function used is cross entropy. The different training parameter encountered during the training process is gradient, cross entropy and validation check. The training parameter plot is shown in Figure 5.5. For better training purpose, cross entropy value should decrease when the training process continues; validation check gives us maximum number of fails in the Neural Network training process.

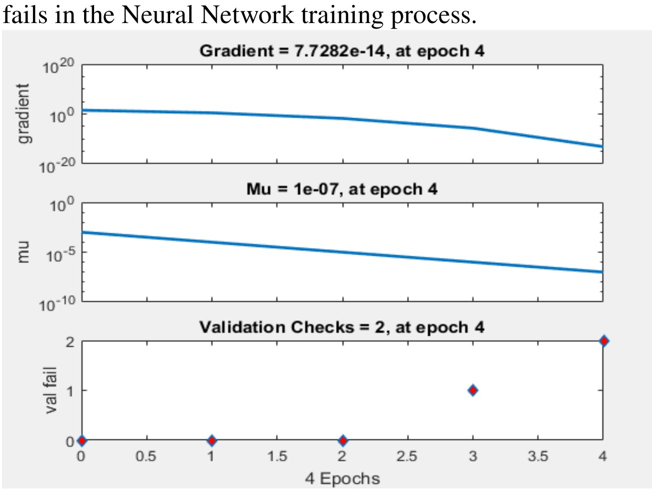


Figure 5.5 Training Parameter Plot

Performance Plot:

The training data (maximum and minimum detail coefficient of three phases), when fed for training the neural network, is divided into three parts. The data samples are divided into train, test and validation sets randomly by the program, in the ratio 0.7:0.15:0.15. The performance plot of proposed system is shown below in Figure 5.6

The above Performance results are reasonable because of the following considerations:

- The final mean-square error is small.
- The test set error and the validation set error

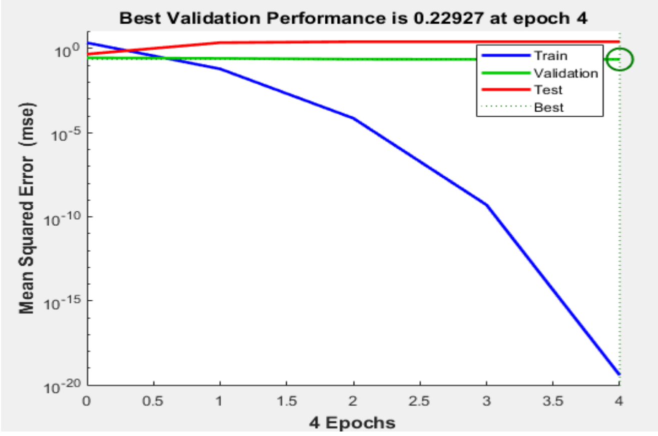


Figure 5.6 Performance Plot of ANN

Regression Plot:

The next step in validating the network is to create a regression plot, which shows the relationship between the outputs of the network and the targets. If the training were perfect, the network outputs and the targets would be exactly equal, but the relationship is rarely perfect in practice. The three plots represent the training, validation, and testing data. The dashed line in each plot represents the perfect result – outputs = targets. The solid line represents the best fit linear regression line between outputs and targets. The R value is an indication of the relationship between the outputs and targets. If R = 1, this indicates that there is an exact linear relationship between outputs and targets. If R is close to zero, then there is no linear relationship between outputs and targets. Figure 5.7 shows the regression plot.

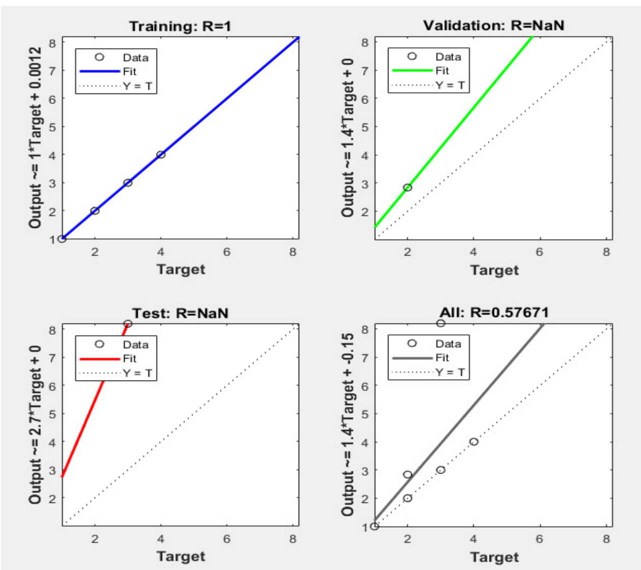


Figure 5.7 Regression plot

Improving Results:

If the network is not sufficiently accurate, initialize the network and the train again. Each time on initializing a feed forward network, the network parameters are different and might produce different solutions. As a second approach, increase the number of hidden neurons above 20. Larger numbers of neurons in the hidden layer give the network more flexibility because the network has more parameters it can optimize. (Increase the layer size gradually. If the hidden layer too large, the problem might be under-characterized and the network must optimize more parameters than there are data vectors to constrain these parameters.)

VI. Conclusion And Future Scope

A. Conclusion

This project describes an innovative technique based on wavelet multi resolution analysis is used to detection, discrimination and location of the fault in the double circuit transmission system comprising of solar and wind turbine. The test system is created and simulated using the power system block set with SIMULINK software. The three phase current signals of transmission line are decomposed up to fifth detail level using DWT to obtain feature extraction. The features extracted by processing the discrete wavelet transform are maximum and minimum detail coefficient value of d4 and d5, which are used for fault detection and classification. The proper selection of db6 as mother wavelet has played a significant role of extracting the useful information for fault detection and classification. A feed-forward BP-ANN structure using scaled conjugate gradient algorithm is presented for fault classification. ANN is the best approach for determining the correct fault type in transmission line fault classification.

B. Future Scope

- Investigation of fuzzy logic for more complicated transmission line protection.
- The proposed model can also be extended to other power system protection problems such as finding fault location.
- Ann based relay protection can be added for the protection of the system.
- To get more accurate results Condition Monitoring and Fault Diagnostics (CM/FD) methodology can be used.

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