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Computational Intelligence for fault detection in power distribution network using ANN

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Abstract-: Early detection and location of faults in networks has been a major challenge in power systems engineering as it results in loss of energy,revenue and damage to equipment and facilities.Transmission and distribution lines are vital links between generating units and consumers. They are exposed to atmosphere, hence chances of occurrence of fault in transmission line is very high, which has to be immediately taken care of in order to minimize damage caused by it. This paper focuses on detecting the faults on electric power distribution network using artificial neural networks.

Analysis on neural networks with varying number of hidden layers and neurons per hidden layer has been provided to validate the choice of the neural networks in each step. The developed neural network is capable of detecting single line to ground and double line to ground for all the three phases. Simulation is done using MATLAB Simulink to demonstrate that artificial neural network based method are efficient in detecting faults on distribution system and achieve satisfactory performances.

Index Terms- Distribution systeme, fault detection, Artificial neural network (ANN), MATLAB/Simulink

I. Introduction

The advent of large generating stations and highly interconnected transmission lines makes early fault detection and rapid equipment isolation imperative to maintain system stability. Transmission line is used to transfer power or voltage to long distance destination. Power or voltage generated from source is supplied to the load through the Transmission Line. While transmitting, Transmission Line encounters various faults due to momentary tree contact, a bird or an animal contact or due to other natural reasons such as thunderstorms or lightning.

Distribution and utilization of electrical energy is the final stage in electricity delivery to end users with voltage levels of 11kV and 0.415kV at the distribution substation and consumer end respectively. Fault occurrences in power distribution systems are almost unavoidable and when it occurs, results to major challenges such as waste of time, stress, increase cost required to locate and diagnose fault, and then do the necessary repair before returning the line to service. In typical power distribution systems, various kinds of faults occur at different times for different reasons/causes such as insulation failures, short circuit conditions etc.

Earlier systems use conventional method for the fault detection which results in the late detection and inaccurate results [1]-[5]. Conventional algorithms are based on deterministic computations on a well-defined model for transmission line protection. Bergon model was extensively used to model transmission line. Conventional distance relays consider power swing as a fault and tripping because of such malfunctioning would lead to serious consequences for power system stability.

In Nigeria, fault location is estimated by trial and error method and in most cases is dependent on the information provided by customer(s).These information in some cases result in energizing the line, section by section until the protective relay trips the circuit breaker tied to the line and the faulty section is identified and then isolated. This procedure may be repeated severally, thus subjecting these equipment to stresses and time wastage most especially if the customers report is/are technically wrong.

It is therefore, vital that fault analysis and identification be carried out quickly for quick system restoration through various improved intelligent techniques. A better approach to fault detection and diagnosis in distribution network is the use of Artificial Intelligent (AI) technique such as Artificial Neural Network (ANN), due to its following characteristic properties such as: fast learning, fault tolerance, ability to produce correct output when fed with partial input and recognize various learning patterns and behaviors where exact functional relationships are neither well defined nor easily computable.

To improve the performance, Neural Network architecture is used which results in the earlier fault detection. From quite a few years, intelligent based methods are being used in the process of fault detection. Three major artificial intelligence based techniques that have been widely used in the power and automation industry are:

. Expert System Techniques

. Artificial Neural Networks

. Fuzzy Logic Systems

This paper presents a method of fault detection and diagnosis in power distribution system using ANN. The detection and diagnosis of faults in power distribution network could be time consuming. The aim of using ANN is to provide faster, easier and less costly means of fault detection and diagnosis in order to increase system reliability and security. Rumuola distribution network in Rivers state, Nigeria is used as a case study. Real-time line parameters were obtained and various fault computations were analyzed.

II REVIEW OF METHODS FOR FAULT DIAGNOSIS

Faults in power systems results to outages, thus affecting power quality in terms of service continuity and disturbance propagation and in most cases, cause high economic losses, equipment damages etc. Fault location includes the determination of physical location of the fault (Mora-Flürez et al., 2009). Some strategies for fault location in distribution systems have been developed to estimate the relative distance to the fault from data acquisition provided by the protection devices. The performance of these techniques can be affected due to some particular characteristics of the respective system, such as unbalanced system, non-homogeneous conductors, etc (Ziolkowski et al., 2007). Researchers have done considerable work in the area of fault diagnosis particularly in radial distribution systems. Traditional outage handling methods were based on customers calls and with the use of GPS technology, their location is determined, thus knowing the actual location/ of the fault in the network. there are also cases were these faults occurs, yet no calls made by customers, resulting in difficulty in locating such faults by power providers. In recent years, some techniques have been discussed for fault location particularly in radial distribution systems. These methods use various algorithmic approaches, where the fault location is iteratively calculated by updating fault current. Researchers have also used mathematical equations to estimate fault location that requires information such as circuit breaker status, fault current waveforms, and fault indicator status for non-radial system (Zhu et al., 1997; Senger et al., 2007). In this approach, fault types and faulted phases are identified and used to compute the apparent impedance based on selected voltages and currents. Girgis (1993) presented equations to calculate all kinds of faults occurring at the main feeder and a single-phase lateral. Loads were considered as constant impedance though its dynamic nature was not considered. Performance assessment of cables used could also pose a major challenge. Saha et al., (2007) proposed method is devoted for estimating location of faults on radial systems, which could include many intermediate load taps. In this method non homogeneity of the feeder sections was also considered

II. A. AI and Statistical Analysis Based Methods

Artificial Intelligent is one of the categories which falls under knowledge based methods. There are several artificial intelligent methods such as Artificial Neural network (ANN), Fuzzy Logic (FL), Expert System (ES) and Genetic Algorithm (GA). These methods help operators or engineers to do less laborious work as time spent in diagnosing technical tasks/challenges is substantially reduced and human mistakes are avoided. Therefore, many researchers used artificial Intelligence based methods in distribution system fault locations. Al-Shaher et al., (2003) developed fault location method for distribution systems using ANN. The researcher used feeder fault voltage, circuit breaker status, real power of feeders during normal condition, and real power of feeders during short circuit, etc, to train the ANN. A Refined Genetic Algorithm (RGA) was adopted to solve the problem, based on the “natural selection, best survival” theory. The RGA found the most reasonable hypothesis or hypotheses based on the evaluation result of each hypothesis evaluated by set covering theory. Thukaram et al.,(2002) offered a method which estimated the voltage magnitude and phase angle at all load buses through state estimation. A threshold was used to detect the fault path. Chen et al.,(2002) used a cause- effect network to represent causality between faults and the actions of protective devices. The cause effect network’s features of high-speed inference and ease of implementation made it feasible to implement an on-line fault section estimation system. Based on the actions of protective devices, the network could quickly find faulted sections. Lee S.J et al .,(2009) presented an alternative solution to the problem of power service continuity associated to fault location. A methodology of statistical nature based on finite mixtures is proposed. A statistical model was obtained from the extraction of the magnitude of the voltage sag registered during a fault event, along with the network parameters and topology. The approach is based in the statistical modeling and extraction of the sag magnitude from voltage measurements stored in fault data bases. The determination of groups of well-defined characteristics allows an optimization in the classification of data thus ensuring good model accuracy.

II. B. ARTIFICIAL NEURAL NEYWORK

ANNs are composed of simple elements operating in parallel inspired by biological nervous systems. As in nature, the connections between elements largely determine the network function. Typically, ANNs are adjusted/trained, so that a particular input leads to a specific target output based on comparison of the output and target, until the network output matches the target. Feed-forward NN based on supervised back propagation learning algorithm is used to implement fault detector and locators. This work uses ANN based approach which uses the fluctuations in current level as the key feature to detect faults. Neural network is capable of working with real time data and responses to the changes in surrounding environment immediately and this makes the system more flexible for the fault detection.

ANN based methods do not require a knowledge base for the detection of faults unlike the other artificial intelligence based methods. The prime motive behind this work is that a very accurate fault detector could make if employed in a power transmission and distribution system, in terms of the amount of money and time that can be saved. The main goal of Fault Detection is to detect a fault in the power system with the highest practically achievable accuracy. When the physical dimensions and the size of the transmission lines are considered, the accuracy with which the designed fault detector detects faults in the power system becomes very important.

Special features of ANN for fault tolerant systems:

. ANN is made of massive interconnection of elementary processing units, information processing can be carried out in a parallel distributed manner. This makes real time processing of large volumes of data more readily realizable.

. ANN can model any degree of nonlinearity and thus are useful in solving these problems which are inherently nonlinear.

. ANN approach is non-algorithmic and requires no prior knowledge functions relating the problem variables. Also being non algorithmic, they do not make any approximations unlike as the case with most of the mathematical models.

. ANN is capable of handling situations of incomplete information, corrupt data and thus is highly fault tolerant.

As power system grow both in size and complexity, it becomes necessary to identify different faults faster and more accurately using more powerful algorithms. Back propagation algorithm of neural network is used for the fault diagnosis system. Different fault like single line to ground fault and double line to ground faults are detected using ANN.

III. **ANN based fault detection system**

Artificial intelligence, cognitive modeling, and neural networks are information processing paradigms inspired by the way biological neural systems process data. Artificial intelligence and cognitive modeling try to simulate some properties of biological neural networks.

Artificial neural networks have been applied successfully to speech recognition, image analysis and adaptive control, in order to construct software agents (in computer and video games) or autonomous robots and specially in fault detection system [16], [17]. Neural network theory has served both to better identify how the neurons in the brain function and to provide the basis for efforts to create artificial intelligence. Fig 1 shows a single neuron. The following diagram shows a simple neuron with:

Neuron consists of three basic components, namely weights, thresholds/biases and a single activation function. Values w_1, w_2 ……w_n are weights to determine the strength of input vector $X = [x_1, x_2, ….., x_n]^T$. Each input is multiplied with its associated weight of the neuron XT.W.

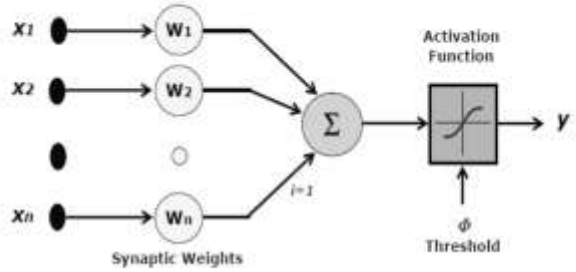
$I= X^T.W = x_1 w_1 + x_2 w_2 + …… + x_n w_n =\sum x_i w_i$

Threshold, φ is the neuron‟s internal offset. The neuron fire or produces positive output only if the total input I is above the threshold value. It affects the activation of the node output y as

$Y = f(I) = f \{\sum x_i w_i - \varphi_k \}$

To generate the final output Y, the sum is passed on to a non-linear filter f called activation function or transfer function, which releases the output Y. There are various activation functions which are chosen depending on the type of problem to be solved by the network. The most common activation function includes linear function, tangent hyperbolic function, threshold function and sigmoidal function. Most popular sigmoidal function follows the transition equation shown below.

$Y = f(I) = 1/(1+ e^{-\alpha t})$, where α is the slope of sigmoidal function followed.



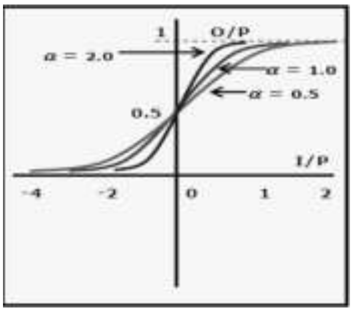


Fig. 1: A single neuron and sigmoidal activation function

The capability of the neural network increases as number of neurons increases. This capability multiplies as number of layers in neural network structure increases. The weights connecting neurons are varied continuously while training the neural network. In NN applications, the challenge is to find the right values for the weights and the threshold. Various algorithms are developed in neural network field depending on different problems and applications where it has been used. Back Propagation, Radial Basis Functions, Multi-Layer Perceptron algorithm, Adaptive Resonance Theory (ART), Self Organizing Maps (SOM) and Counter Propagation Networks (CPN) are few algorithms of neural networks.

Various neural network architecture, training algorithms and transfer functions were studied to decide upon the final neural network model for fault detection system. Back propagation algorithm, a supervised learning is used as the network will be trained using the data created from the simulation model.

The following method was adopted in this work:

. Obtain one line diagram of Rumuola power distribution system, fault current and voltage values

. Develop a functional NN program in Matlab to detect and diagnose faults including flow chart of the fault analysis.

. Test run the software for different fault values.

This is achieved by inputting patterns which contain root mean square (rms) values of voltages and currents in the instance of fault before operation of circuit breakers are fed into the ANN program using Matlab. These data is then used for detection and location of faults. ANN is trained off-line with different fault conditions and used on-line. The diagnostic system is able to detect and diagnose the faulted locations corresponding to input pattern consisting of switching status of relays and circuit breakers.

III. A **Training of the Neural Network**

The neural network architecture with three hidden layers was fixed for the simulation purpose. Hidden layers consist of 7-10-3 neurons as shown in Fig. 2. Input layer consists of three neurons which takes the current of three phases of the transmission line. Output layer consists of one neuron which indicates if fault is there. A threshold of 0.9 is fixed based on simulation in order to avoid false alarms. As shown in figure, the training algorithm used is gradient descent variant of back propagation algorithm. Figure shows the number of iteration, time taken to train the Neural Network. It also shows the different performance plots of the Neural Network after training of the network.

The different training parameter encountered during the training process is gradient, mean square error and validation check. For better training purpose, mean square error value should decrease when the training process continues; validation check gives us maximum number of fails in the Neural Network training process.

These training parameter plots are shown in Fig. 3

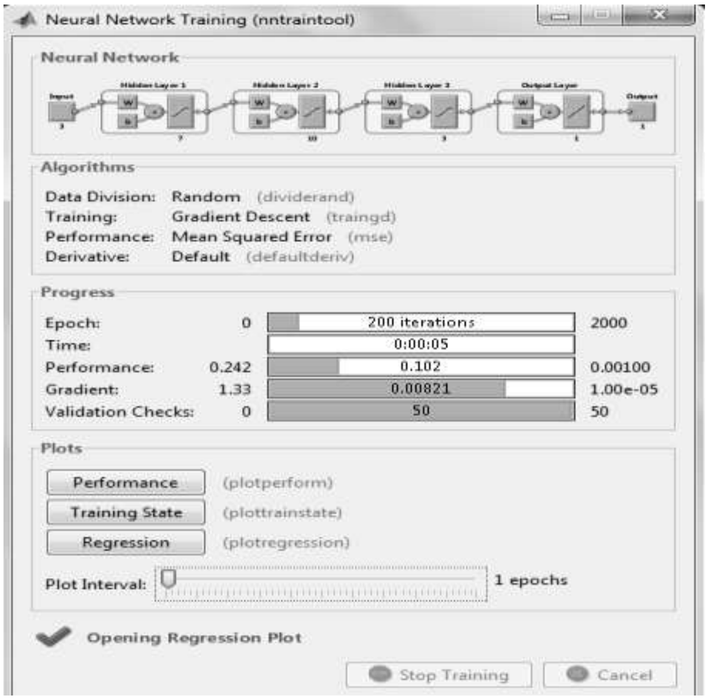


Fig 2: Neural network training in Simulink tool

111. B. **Performance Plot**

As discussed earlier in this section, the training data is created using simulation model of transmission lines. Single line to ground and double line to ground fault was introduced in different phases at different time instants. This training data, when fed for training the neural network, is divided into three parts.

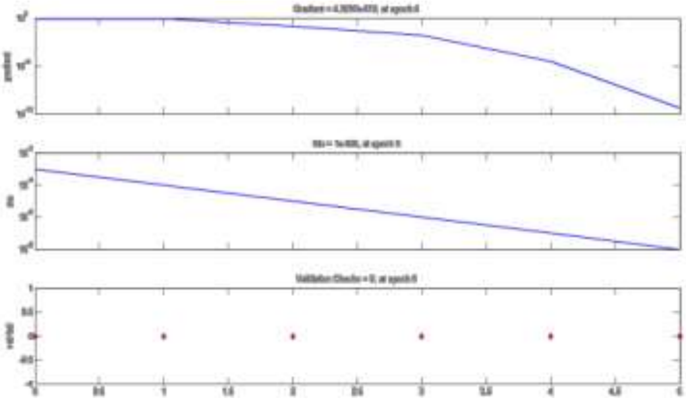


Fig 3: Training parameter plots

The figure 4 shows the performance of Neural Network when Neural Network is trained with particular input vectors and target vectors. The plot shows that the variation of different parameters throughout the training process. After training is completed satisfactorily, the neural network is tested with the available sample data to evaluate the performance of the updated trained neural network. If the performance is not up to the expectations, some variations may me experimented with the neural network structure by varying number of hidden layers of number of neurons in each layer. Different training algorithm may also be experimented with various activation functions.

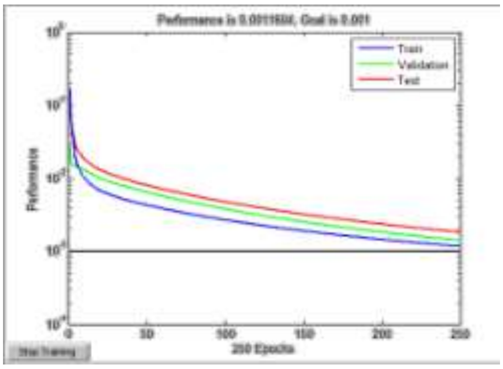


Fig 4: Performance plot

Once the neural network with satisfactory performance is developed, its Simulink model is developed using „gensim‟ function so that it can be used with other block in the simulation model. Neural network simulation model is shown in Fig. 5

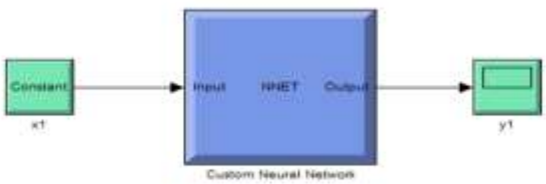


Fig 5: Simulink model of developed neural network

IV **DISCUSSION OF RESULTS**

Four steps were taken in the training process: Assembling of the training data (i.e. fault voltage values and -Line fault locations, Creating the network object parameters, Training the network and Simulating the network response to new fault voltage inputs. Both Tan-Sigmoid and linear Transfer Functions were used in the hidden and output layer respectively. Also, the default Levenberg-Marquardt algorithm (trainlm) was adopted to achieve a better training speed. Figures 4.0 and 5.0 shows plot of data versus network output untrained and trained valuesrespectively for a single line to ground (SLG) fault. Other fa ult studies (double line to ground, three phase to ground faults etc) were also obtained using same approach The distance which spans over length of 389.601 meters between the 300KVA and 500KVA transformers servicing Ikwere road and Anele close in Rumuokwuta is used to determine the actual NN fault locations for three Phase fault as shown in table 1.0. For Double Line to Ground fault, a distance of 213.417 meters between a 200KVA and a 500KVA transformer by Ebony/Orazi road in Rumuola was used to determine the actual NN fault locations at various fault voltages as shown in table 2.0. ANN Line to Line fault location was determined using the two 500KVA transformers located on Rumuola road, which are 446.963 meters apart at different fault voltage values as shown in table 1.0. Also, a distance of 877.978 meters between two 500KVA transformers located on Rumuola road were used to determine the NN fault location at various Single Line to Ground fault voltages. If any fault phase voltage values results in the network (S-L-G,L-L-G,D-L-G, or 3-Phase Fault) as shown in table 1.0,its fault position is located within the distances as shown. For instance, when S-L-G fault occurs and results to a phase voltage value of 0.0003kV,locating/tracing it along the line will almost exactly be at 0.3055m and same applies for every other kinds of fault in the network

V. CONCLUSION

This research finding will assist utility company in ensuring more accurate means of detection and diagnosis of faults as well as minimizing damages and reduction in waste of man-hours during the process of fault location in distribution network. The results obtained demonstrate NN effectiveness and high precision in determination and detection of fault location over different sections of the feeder under various kinds of faults. From the results obtained, it can be concluded that ANN is a more time and cost efficient method of fault detection when compared to the conventional trial and error method presently used in Nigeria. Although the simulation was done off-line, the work can be adapted for a real power system and the algorithm used for fault location on an energized system. Thus, the uses of ANN quickly give accurate prediction of fault location. It can be inferred that the trained NN can adapt to recognize learned patterns of behavior in the electric power system, where exact functional relationships are neither well defined nor easily computable. The NN is trained with in-line fault locations with their corresponding fault voltages to ensure a fast learning rate and ability to produce correct output when fed with a different input.

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