A Review of the Modeling of Advanced Protection Scheme for a 33/11kv Injection Substation Using Artificial Neural Network

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Abstract- Fault occurrences in a distribution network often take time to detect and locate. This delay may lead to major or multiple faults. Even when the fault location is finally resolved, isolating the fault can present other challenges. It is not unusual for an entire network to be shut down in order to isolate a minor fault. This can impose severe negative impacts on the supplier as well as the consumers. This report endeavors to design a timely and reliable electric power fault detection and location for a 33/11kV injection substation. The network is modeled and simulatedin the MATLAB/Simulink environment. The trainingtesting and evaluation of the intelligent locator isdone based on a multilayer perceptron feed forward artificial neural network with back propagationalgorithm. Neural network pre-processing refers to the steps taken to prepare and clean input data before it is fed into a neural network for training or inference. The learning process involves the algorithm making predictions based on the input data and comparing these predictions to the actual outputs.The modeling in this research first identified fault conditions, to be sure that a fault has occurred to begin with. Then the scheme should also be able to classify the fault to establish what type of fault that has occurred. And finally, the scheme should localize the fault, to a particular line or lines, and the approximate distance from the detection point.

Indexed Terms- Artificial Neural Network, Transmission/Distribution Networks, Injection Substation and Modeling of Advanced Protection Scheme.

I. INTRODUCTION

Electrical networks include generating, transmission, and distribution networks or grids. The Nigerian power sector has witnessed an increasing load demand in recent times, it is essential to plan, manage, and expand the power system in order to meet up with the energy demand in order to avoid transmission system collapse due to over bearing demand. The Calabar 132kV sub-transmission infrastructure is carefully examined, and it becomes clear that the transmission companies are unable to adequately control the reactive electrical power flow of the network, which results in voltage losses and load shedding. These networks are linked to insufficient electricity distribution and insufficient generation capacity. Inadequate or non-existent reserves and insufficient control infrastructure are other significant factors impacting stability. Therefore, to ensure effective performance, a thorough network analysis, planning, optimization, operation, and control must be made as soon as possible to prevent a complete system failure. Similar to how the most recent collapse of the national power grid was witnessed [30][31][32]. Greater demand is not only in terms of power generation, but, due to geographical spread of the population, expansion of transmission and distribution grids is taking place at an ever-increasing rate. In Nigeria, daily electric power interruption is largely becoming a consistent phenomenon in what is a wide area network of electricity distribution and this is basically due to insufficient power generation, transmission faults and distribution system faults and failures [1]. Electricity supply that is effective, dependable, and reasonably priced is a key component of economic success in every nation. With an estimated population of 200 million, Nigeria is one of the nations in the West African sub-region with only about 45% of them have a connection to electricity. The projected 7MW total grid generation capacity currently powers residential regions as well as commercial, industrial, social, as well as institutional centers. This is utterly insufficient for real development. Based on this, the goal of this research is to integrate and diversify the power industry in order to utilize all available energy sources, including renewable ones [36][37]. Unavailability of power supply to customers can occur several times a day and some times for weeks and in worst cases for months. There are instances where several interruptions occur in a day especially at the residential loads, which causes untimely failure of home gadgets, darkening of light bulbs, and reduced efficiency and performance of high-power appliances. Damage of electronic devices and burning of light bulbs have also occurred due to voltages surges.

Considering the fact that the presently installed capacity in Nigeria cannot serve all the customers, it is has become necessary that power outages be planned in terms of scheduled maintenance or unplanned in form of faults on the network [2]. That is, when power is generated and available in the system, the distribution subsystem must be up to its task of delivering quality power to the customers. It becomes imperative then, to set high reliability standard, evaluation and protection of distribution substations and its facilities [3]. The principal cause for energy failures in electricity systems is electric faults, especially those in distribution systems. These defects are caused by a variety of factors, such as failure of facilities, lighting, storms, harmful weather, rain, breakdown of isolations devices, trees, birds and so on [1][2].

The management and detection of faults has been an established problem in power distribution systems. The societal and economic costs owing to loss of loads from distribution outages have been progressively severe [4]. Nevertheless, a number of methods have been proposed for fault detection, identification and location. Fault detection, identification, and location typically have to be treated as an integrated problem in power systems. The fast and precise location of faults on the distribution system improves the reliability of the system and supply continuity, faster power supply recovery and therefore lower service shutdown times [5]. For several decades, companies and electricity generation specialists have studied the causes of power failures on power distribution systems [6]. Several strategies have been suggested to allow operational engineers to detect faults as quickly as feasible, based on the essential problems of failure location.

The provision of sufficient, reasonably priced, and reliable electric power is a vital requirement to nurture or drive this necessary desired transformation for Nigeria to make significant progress in terms of growth in its key sectors such as infrastructure, economics, and security. Additionally, the nation's electric power consumption and supply must be comprehensively planned and achieved as a matter of urgent necessity if it is to keep pace with developed countries around the world that have demonstrated phenomenal growth in economic development and transformed into industrialized nations. Epileptic power supply issues have recently gotten worse at an alarming rate [33][34][35] .

Epileptic power supply issues have recently gotten worse at an alarming rate. In particular, low power output and the national grid breakdown brought on by unrest brought on by bandit attacks on the facilities housing the transmission lines. The strength of any healthy economy is directly correlated to the expansion of the industrial sector, which is made possible by the accessibility of a reliable power supply. Today's industries in Nigeria produce their own power, largely as a result of the discontent with the available supply [33][34]. Additionally, the cost of manufacturing is high due to the spike in petrol, diesel, and petroleum prices, which raises market prices for other goods and drives up inflation. If the demand and supply for electric energy can be balanced, other problems in Nigeria will be significantly less difficult to tackle. Note that this trend is often witnessed across the different tiers of the Nigerian power sector such as the commercial, residential and of course the industrial zones of the power sector [33][34][35].

In order to maintain the balance between load demand and supply, it is necessary to develop more robust, efficient and accurate ways to detect and classify faults. Artificial neural network (ANN) model is very versatile and superior in solving this type of problems when compared with other methods [7]. This is done with the following input considerations:

a) Reliability: Fast and accurate detection, classification of faults in order to ensure only a relatively short loss in supply of only a few hours, with business likely to suffer considerable less financial loss.
b) Safety: Protection of the station and utility equipment and personnel, leading to protection of consumers supply quality.

Therefore, accuracy and speed in detecting and locating faults along distribution networks, in this case, the 33/11kV injection substation, are vital.

The main aim of this thesis is to implement a model for the fast and accurate monitoring, recognition and identification of faults in a 33/11kV injection substation network. The objectives of this study are to:

1. An adequate Protection System designed to detect faults quickly and accurately, and to disconnect the affected elements to minimize the number of consumers affected by a fault and protect equipment and utility personnel.
2. Design a Machine Learning Artificial Neural Network (ANN) to simulate and analyze faults in the model.
3. Apply the machine intelligence algorithm to recognize faults in the model.
4. Evaluate the performance of the recognition algorithm.

II. LITERATURE REVIEW

2.1 The Electric Power System

An electric power system (EPS) is a power delivery system. This power delivery system is a network of electrical mechanisms used for the generation, transportation, delivery and eventually, the consumption of electric energy [8]. This can be largely divided in to the generation systems (GS), serves as the source of the power, the transmission system (TS), that transports the power from the generating centers to the load centers and the distribution system (DS) that distributes the power to domestic, commercial and industrial consumers [9].

2.2 Overview of a Distribution System

The GS and TS are what experts call the upstream power delivery system (PDS). The upstream feeds power to the distribution substation, which may be called the downstream PDS. Distribution substations include step-down transformers (distribution substation transformers) that decrease sub-transmission voltages to primary distribution voltages [10]. Since the distribution of electric power to different consumers is done with a much lower voltage level compared to the transmission of power over long distances, various types of equipment are installed in a substation are to ensure accurate measurement, switching operations and protection purposes [11].

The high voltage/medium voltage (HV/MV) at the substation steps down the sub-transmission voltage level toa suitable value for primary distribution lines, which are also referred to as feeders. This voltage is finally stepped down by the distribution transformer (MV/LV) to a level acceptable for final consumption (415V/230V). The secondary distribution lines, low voltage (which are mostly single phase with few three phase circuits) feed the energy to the consumers. Figure2.3 represents the configuration of a line diagram of a power distribution system, [12].

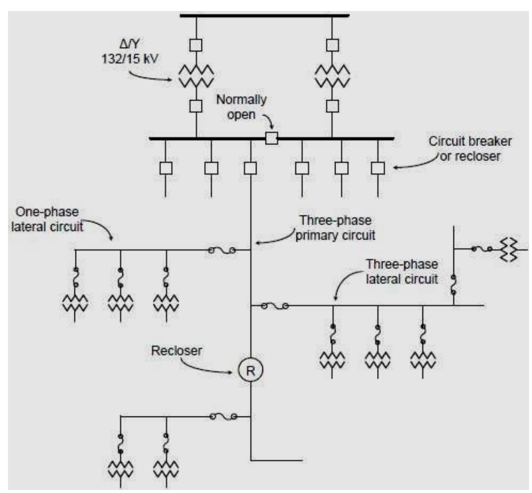


Fig2.3: Line diagram of a distribution system

i. Primary Distribution System

Energy coming from the sub-transmission system is received at the substation of theprimarydistributionsystemwherethevoltageisfurthe rsteppeddowntomedium-voltage levels (e.g.25and11kV).Similar to sub-transmission system; primary distribution system feeds large loads, [14]. The three-phase, four-wire multiple grounded primary system is the most widely used. The fourth wire in these Y-connected systems is used as a neutral for the primaries, or as a common neutral when both primaries and secondary's are present [13]. Usually the windings of distribution substation transformers are Y-connected on the primary distribution side, with the neutral point grounded and connected to the common neutral wire.

The neutral is also usually grounded at frequent intervals along the primary, at distribution transformers, and at customers' service entrances. In many cases distribution substation transformers are grounded through an impedance of, approximately one ohm resistance, to limit short circuit currents and improve coordination of protective devices. In rural areas with low-density, loads are usually served by overhead primary lines with distribution transformers, fuses, switches, and other equipment mounted on pole, [10].

ii. Secondary Distribution System
Secondary DS has the direct connection to the end-users (customers). Energy is fed to customers for utilization at suitable voltages from distribution transformers up to meters at customers' premises. Low power customers, such as commercial and residential loads are fed by the secondary distribution system. The system is made up of step-down Medium Voltage/Low Voltage (MV/LV) distribution transformers and low-voltage lines (e.g.415and 240V) [12].

In residential areas, 120/240-V, single-phase, three-wire service is the most common, where lighting loads and outlets are supplied by 120-V, single-phase connections, and large household appliances such as electric ranges, clothes dryers, water heaters, and electric space heating are supplied by 240-V, single-phase connections, [12].

2.3 The Distribution System Substation
The design of a distribution substation takes into account certain important factors such as load level, auxiliary equipment required, anticipated reliability and the type of system (urban,suburbanorrural), [14].

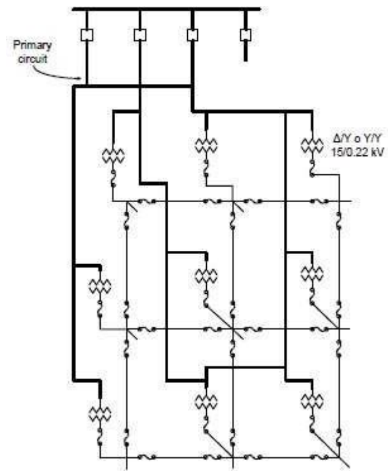
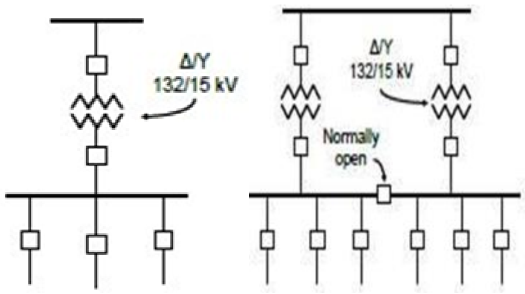


Fig 2.4: Substation configuration

i.) Rural Substation
A rural substation is usually made up of a single high-voltage (HV) andmedium-voltage (MV) bus. The transformer protection depends on its ratedpower, and is usually sufficient to supply the entire power demand because of the low load level ofthe rural environment (Figure 2.5(i)). Primary distribution lines, which are protected by either over current relays or reclose, are connected to the medium voltage.

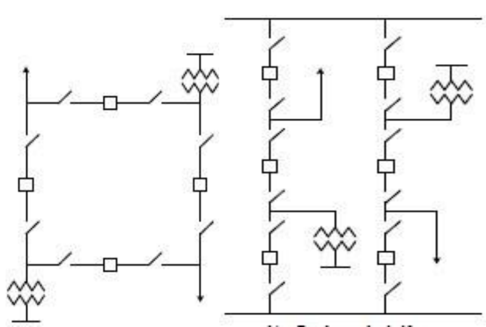
ii.) Suburban Substation
The configuration of a sub-urban substation is made up of a single high-voltage bus and one medium-voltage bus for each substation transformer. Having the advantage of a more uniform load distribution among transformers, preference is given by some utilities to the use of a single medium-voltage bus for all substation transformers, [15][14][12]. Suburban substations have higher load requirement than rural substations, more than one transformer is usually required for suburban systems. The medium voltage buses are connected to one another via a normally-open tie-switch (Figure2.5 (ii)).When a transformer fails, the ties witch is operated, and the load served by the failed transformer would be supplied by another in-service transformer(s). This split bus configuration prevents the presence of circulating currents, encourages voltage control and reduces fault level.



i Rural substation ii. Suburban substation

iii.) Urban Substation

There are two common types of designs for urban substations; these are the ring-bus and breaker-and-a-half configurations. In the ring-bus design, the buses of the medium-voltage are in a closed loop and separated by circuit breakers. The substation transformers 'secondary side and the distribution feeders will usually be connected to the mid-point of any section of the bus, in-between two circuit breakers (Figure 2.6(i)). In breaker-and-a-half design in ring-bus configuration), one or more branches are connected between two medium-voltage buses and each branch consists of three circuit breakers. The primary distribution lines or secondary side of a substation transformer can be connected between any two adjacent circuit breakers (Figure 2.6(ii)). For the purpose of load transfer or maintenance, modifications could be done on either configuration, [15][14][16].



i) Ring-bus ii) Breaker-and-a-half

Fig 2.6: Urban substation layout

2.4 Distribution Substation Components

Several electrical equipment are usually installed in power distribution substation for efficiency and safe operations of the system. Some of the components are listed and described briefly in this section, [14].

a) Voltage Transformer

A transformer is a device made up of a primary winding and a secondary winding connected by their electromagnetic fields. Power is transferred from one winding to another without changing the frequency and steps-up or steps-down voltage level. To provide appropriate voltage level needed by every section of the distribution system, transformer scarry out voltage reduction successively, [16]. Transformer operation is illustrated by equation (2.1)

$$\frac{V_s}{V_p} = \frac{n_s}{n_p} \qquad (2.1)$$

Where Vp =potential difference (voltage) input on the primary coil, Vs = potential difference (voltage) output on the secondary coil, np = number of turns (coils) of wire on the primary coil and ns= number of turns (coils) of wire on the secondary coil.

b) Potential Transformer

The most widely available standard potential transformers are single-phased, with primary and secondary windings on common core and the secondary voltage maintains a fixed relationship with primary voltage, [15][16]. Potential transformers are used to step down the voltage of the primary circuit to a safe value (120 V), to serve as input signal for protection and monitoring devices. The potential transformer may be defined as an instrument transformer used for the transformation of voltage from a higher value to the lower value. This transformer steps down the voltage to a safe limit value which can be easily measured by the ordinary low voltage instrument like a voltmeter, wattmeter and watt-hour meters, etc. The secondary terminal voltage and voltage ratio error are given by equations (2.2) and (2.3) respectively.

$$V_S = V_p \text{x} \frac{C_p}{C_p + C_s} \qquad (2.2)$$

$$Ratio\ Error = \frac{K_n I_{S-} I_p}{I_p} \qquad (2.3)$$

Where Kn is the nominal ratio, i.e., the ratio of the rated primary voltage and the rated secondary voltage; Vs – secondary terminal voltage, Vp – primary terminal voltage, Is –secondary terminal current, Ip –primary terminal current, Cs–secondary capacitor and Cp—primary capacitor.

c) Current Transformer

A current transformer (CT) is a type of transformer that is used to increase or reduce an alternating current (AC) by a specified multiple. It produces a current in its secondary which is proportional to the current in its primary [17]. Current transformers, along with voltage and potential transformers are instrument transformers. The primary winding of a current transformer is insulated from its secondary winding. Its secondary winding supplies current at a fixed relationship that is directly proportional to that of its primary current. Line current is converted by current transformer into values appropriate for protection and monitoring devices and isolates there lays from line voltages.

The primary winding is in series with the circuit of the line current to be measured while the secondary winding is in series with protection and monitoring devices [15] [16]. A current transformer, like any other transformer, must satisfy the amp-turn equation. The turns-ratio (T.R.) is given by equation (2.4).

$$\text{T.R.} = \frac{n_p}{n_s} = \frac{I_s}{I_p} \qquad (2.4)$$

Where I_s – secondary terminal current, I_p – primary terminal current, n_p= number of turns (coils) of wire on the primary coil and n_s = number of turns (coils) of wire on the secondary coil.

d) Cable Conductors (Lines)

A line or cable is a medium through which electrical energy is transferred from one point to the other. This could be in overhead or underground form. A low-tension line is a low voltage line and a high-tension line is a high voltage line. In India LT supply is of 415 Volts for three-phase connection and of 240 Volts for single-phase connection. High tension or HT supply is applicable for bulk power purchasers who need 11 k or above, [11]. Overhead lines are usually made of bare aluminum, commonly Aluminum Conductor Steel Reinforced (ACSR) type while underground lines are usually cables made of polymer-insulation, such as Cross-Linked Polyethylene (XLPE) and Ethylene Propylene Rubber (EPR). Distribution lines are characterized by their rated voltage and current carrying capacity.

e) Circuit Breaker

A circuit breaker is designed to isolate a circuit automatically at a particular overcurrentvalue in order to protect itself and other equipment. It is simply a switching component designed to close and open a circuit by non-automatic measures [18] [19]. It is divided into the power, op-amp and relay sections respectively. Figure 2.7 shows a schematic diagram of a circuit breaker.

f) Relay

Relays are typically low-powered switching devices used to activate high-powered devices. Relays protect feeders and equipment by giving tripping commands to the cor responding circuit breakers to interrupt the current produced by a fault, [19].

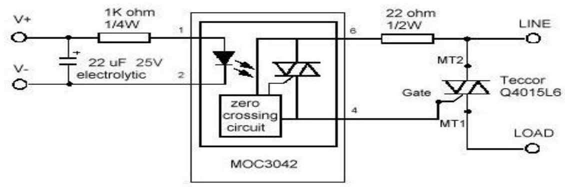


Fig 2.8: Solid State Relay

g) Recloser

Recloser are intelligent switching devices that can sense excess current (overcurrent) conditions, and interrupt fault current, and then re-energize the line by re-closing automatically. When permanent fault occurs, after about three or four operations (usually preset), the recloser locks open thereby isolating the fault location section from the rest of the system, [19].

h) Fuse

A fuse contains a strip of wire that melts when an excess current or short-circuit current passes through it. The fuse’s time-current curves determine the melting and clearing times. A fuse, usually K and T types, is used in distribution systems to protect laterals, secondary circuits, and low power transformers, [19].

i) Sectionalizer

A sectionalizer is a protective device used together with source-side protective devices to automatically isolate faulted sections of electrical distribution systems. Such source-side protective devices could be reclosers or circuit breakers. When current flow above a preset value is sensed by the sectionizer, the source-side protective device opens to de-energize the circuit, then the sectionalizer counts the over current interruption, [20].

j) CapacitorBank

Capacitor banks are generally three-phase installations in the substation or at mid-point of a primary circuit line of a distribution system. They perform voltage regulation and reduce system losses by correcting power factor. It is a local source of reactive power,[20].

k) Switch

A switch is a device used for isolating a system element for repair or maintenance. It must be able to carry and break currents during normal operating conditions. A switch is not designed to break fault current, although hit may have a fault making capacity. It may have definite operating overload conditions and carry currents under specified abnormal conditions such as those of a short circuit for certain time, [18] [19].

l) Voltage regulator

A voltage regulator is a transformer with an on-load tap changer having a nominal transformation of ratio 1:1. Voltage regulators are installed, to compensate for the voltage drop produced, at the mid-point of long primary lines, [18].

m) Switchyard

This is the arrangement of all equipment used for proper operation of a substation where step-down transformer is installed. All the equipment are installed on suitable concrete cement foundation and, commonly referred to as switchyard,[16]. A few of the equipment are connected to control panels which are installed in a control room with the help of control cable(s).

III. METHODOLOGY

The application of the several guidelines in the approach for the development of Machine Intelligence based Technique (Artificial Neural Network in particular) for fault recognition and location in a power distribution system and, in particular the 33/11 kV injection substation. The application of these viral guidelines in the approach for the development of Machine Intelligence based Technique (Artificial Neural Network in particular) for fault recognition and location in a power distribution system and, in particular the 33/11 kV injection substation. This thesis uses an artificial neural network that will detect, classify and locate a fault when it occurs on the input line of 33/11-kV injection substation. The network is modeled and simulated in the MATLAB/Simulink environment.

The training testing and evaluation of the intelligent locator is done based on a multilayer perceptron feed forward artificial neural network with back propagation algorithm, [21]. The performance of the detector-classifier and each locator was evaluated using Mean Square Error (MSE) and confusion matrix. The developed model is simulated in MATLAB with available historical data to forecast the load on 33/11 kV electric power substation.

It is imperative to properly locate projection switchgear in and around the substation. However, before that can be done properly, the modeling must first identify fault conditions, to be sure that a fault has occurred to begin with. Then the scheme should also be able to classify the fault to establish what type of fault that has occurred. And finally, the scheme should localize the fault, to a particular line or lines, and the approximate distance from the detection point.

Performance of the neural network during training and testing is observed based on metric like mean square error (MSE) and mean absolute percentage error (MAPE). The non-linear activation used in each neuron in the hidden and output layers is the sigmoid activation, [22]. The system was first simulated and analyzed without faults and then with different types of faults to recognize the presence of faults, and identify different types of faults at the input end of the substation system.

3.1 Relevance of the Problem

There are many criteria that are involved when selecting the most suitable fault protection strategy. Traditional distribution systems typically have high fault currents so existing faults protection schemes are easily applicable. However, detection and location of fault in a distribution system often takes time, especially in difficult weather conditions or terrain, and this delay usually compounds the fault situation,

[23]. When the location is eventually known, isolating the fault can sometimes be a difficult task. The developed model will help to address these problems of delay and location of faults in distribution systems.

3.2 Neural Network Design and Training
An appropriate neural network architecture was chosen for fault detection. Common architectures include feed forward neural networks, recurrent neural networks (RNNs), or Long Short-Term Memory (LSTM) networks, depending on the temporal nature of the data. This research made use of the RNN architecture; Recurrent Neural Networks (RNNs): RNNs are suitable for sequential data, making them applicable for time-series data in fault detection, [24] [25].

3.2.1 Pre-processing
Neural network pre-processing refers to the steps taken to prepare and clean input data before it is fed into a neural network for training or inference. The learning process involves the algorithm making predictions based on the input data and comparing these predictions to the actual labeled outputs, [26]. The algorithm then adjusts its internal parameters using optimization techniques to minimize the difference between its predictions and the true outputs. This process is often referred to as training, and the optimization is typically done through methods like gradient descent, [27].

Mean Square Error (MSE) is a commonly used metric in statistics and machine learning to measure the average squared difference between the actual and predicted values. It is particularly useful in regression analysis, where the goal is to predict a continuous outcome. The MSE is calculated by taking the average of the squared differences between the actual values (often denoted as Y_i) and the predicted values (often denoted as $\hat{Y}_i$) for each data point. The formula for MSE is: $MSE = \frac{1}{N}\sum_{i-1}^{N}(Y_i - \widehat{Y}_i)^2$ 4.3

MSE is a valuable metric for assessing the accuracy of regression models, providing a quantitative measure of the average squared difference between predicted and actual values. Just like the standard deviation measure, the lower the MSE, the better the model is at predicting the target variable. It provides a relative measure of how well a model performs compared to others.

Although, it has its merits and demerits, it has the advantage of satisfactory performance, the ability to discover complex non-linear relationships among variables and performing the task relatively faster than other paradigms. It, however, suffers from the disadvantage of multiple local minima and maxima (in other words over fitting), because it relies on the old experimental principle of risk minimization, [28]. MATLAB Neural Network Toolbox simulation was employed to evaluate the classifier's performance on the problem in this study.

IV. DISCUSSION

4.1 Neural Network Fault Identification Training
This process involved varying number of hidden layers as well as the number of neurons per hidden layer to achieve a satisfactory performance, [25]. The error performance plots of neural networks with 2 layers and 1 hidden layer are shown respectively. After extensive simulations, the desired network had five hidden layers with 8 neurons in the first hidden layer, 10 neurons in the second hidden layer, 20 neurons in the third hidden layer, 15 neurons in the fourth hidden layer and 6 neurons in the fifth hidden layer.

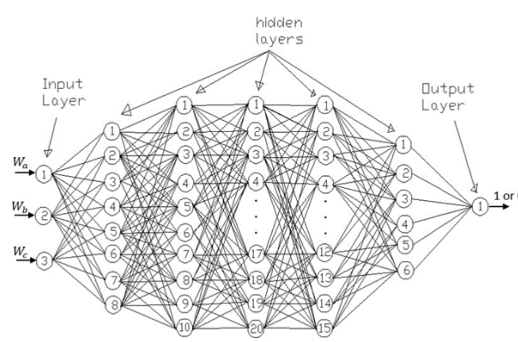


Fig 4.1: Structure of the chosen ANN for Fault Detection (3.8.10.20.15.6.1)

From figure 4.1 above, gives the structure of the chosen neural network for fault detection. The input layer, hidden layers and the output layer are all labeled. It can be seen that there are 3 neurons in the input layer, 5 hidden layers with 8,10,20,15 and 6 neurons in them respectively and one neuron in the output layer. Pictorially, figure 4.1 represents how the neurons in the respective layers are connected together through the synaptic weights. It further shows the interconnections between the input layer and the hidden layers, and also between the hidden layers and the output layer. Each and every neuron Figure 4.1 is connected to all the neurons in the layer in front.

4.2 Neural Network Fault Classification

Artificial Neural networks, especially those employing back-propagation, have been widely used in various applications. Back-propagation networks have varying combinations of hidden layers as well as number of neurons per hidden layer, as have been analyzed. The back-propagation algorithm is a supervised learning technique used to train neural networks for tasks such as classification or regression. In these networks, the error or the difference between the predicted output and the actual target output is calculated, [26]. This error is then propagated backward through the network to update the weights of the connections using a process called gradient descent. The gradient descent algorithm adjusts the weights in the opposite direction of the gradient of the error with respect to the weights, thereby reducing the error.

Figure 4.2 shows the structure of the chosen ANN for the purpose of fault classification and the neural network has 3 neurons in the input layer, 12, 35 and 24 neurons in the hidden layers respectively and four neurons in the output layer as shown. Each of the neurons in the output layer would indicate the fault condition on each of the three phases (A, B and C) and the fourth neuron is to identify if the fault is a ground fault. An output of 0 corresponds to no fault while an output of 1 indicates that the phase is faulted and the combinations give the fault type.

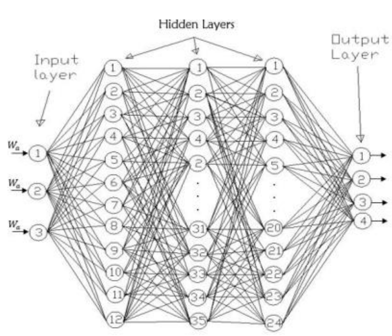


Fig 4.2: Chosen ANN for Fault Classification (3.12.35.24.4).

4.3 Locating Faults with ANNs

In order to adequately protect the 33/11 kV Injection Substation, there is need for the design, development and the implementation of the neural network based fault locators for each of the various types of faults. This forms the third step in the entire process of fault location after the detection and classification of the fault. The following subsections deal with the various kinds of faults and their error performances individually.

Figure 4.3 illustrates the structure of the chosen ANN for single line–ground faults with 3 neurons in the input layer,8,10,and 20 neurons in the 3 hidden layers respectively and1neuron in the output layer (3.8.10.20.1). The picture shows how the neurons in the respective layers are connected together through the synaptic weights. It further shows the interconnections between the input layer, the hidden layers, and also between the hidden layers and the output layer. Each and every neuron in the network is connected to all the neurons in the layer in front.

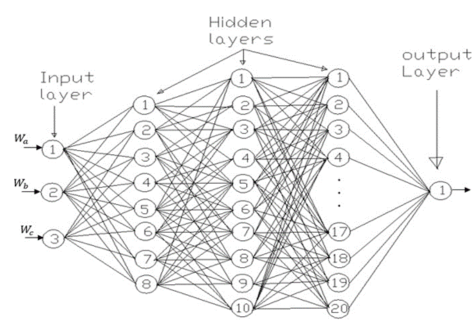


Fig 4.3: Structure of the chosen ANN with configuration (3.8.10.20.1).

4.4 Protection System

Station protection in terms of substations feeder's protection includes following:

(a) Fault detection (b) Fault classification (c) Faulty feeder isolation (d) Fault location estimation All of the before mentioned functionalities need to have a satisfactory result in both grid-connected and islanded mode, in case the substation has a capability to become a part of the micro grid. Within these functions, the method that will be presented in the following chapter can be used to send a direct trip sequence in case of the fault, as well as provide the backup tripping function due to its high sensitivity, [29].

After a protection system successfully detects the various faults in the system, it will be imperative to send a signal to the associated circuit breakers. The circuit breakers will then respond to the command and trip. In reality, there is a chance that the circuit breakers fail to trip, or have such a long switching delay that the protection system considers it to be failed. In a situation of circuit breaker failure, it would still be necessary for additional effort from the system in order for the signal to be applied and, make sure that the faulted part is isolated.

CONCLUSION

During the course of this research, artificial neural networks (ANNs) were used for fault detection (recognizing a fault, when one occurs), fault identification (identifying the types of fault) and fault localization (of the section of the lines system where the fault occurred). The standard 3-phase currents are expressed as a ratio of their values when there is no fault served as the inputs to the neural networks. The research studied different types of faults such as single line-ground, line-line, double line-ground, three-phase and three-phase to ground faults using multiple artificial neural network configurations. All the neural network configurations utilized in this research were the back-propagation neural network architecture (and the Leven berg-Marquardt training algorithm in particular).

The work was completely designed and simulated in the MATLAB and SIMULINK (Sim Power Systems toolbox), while Artificial Neural Networks Toolbox was used for training and performance analysis of the neural networks (MATLAB R2017a). The use of artificial neural networks (ANNs), utilized in the modeling of an advanced protection scheme for a 33/11 kV injection substation, from fault detect/recognition to identification and fault location stages showed very satisfactory outcomes in the MATLAB and SIMULINK environments. The results obtained from the various simulations confirmed that satisfactory performances were attained by each and every proposed artificial neural network configuration.

The size of the ANNs (the number of hidden layers and number of neurons per hidden layer) were varied iteratively based on how the neural network applied previously performed in relation to the size of the training data set. A high level of emphasis was placed on the importance of choosing the most suitable ANN configuration, in order to obtain the satisfactory performance from the network.

Some of the most significant conclusions derived from this research work are:

1 The back-propagation neural networks (BPNN) were used for all the artificial neural networks for fault recognition, fault classification and fault location in this research. BPNNs are very effective when complex or large training datasets are involved, as explained in section below.

2 This work has added to the body of evidence that, because low average percentage errors realized in the results of simulations in this research, artificial neural networks have a high degree of precision and accuracy in fault detection, classification and location in comparison to the other existing methods.

3 Artificial Neural Networks are adequate, efficient and reliable tools for an electrical power system fault recognition, classification and location particularly important for the transition to Smart Grid power systems.

4 The specific structure, performance and training algorithm of a particular artificial neural network (ANN) configuration should be analyzed in detail before it is chosen for practical applications (this research made use of a tedious iterative/trial-and-error process in selection of ANNs).

5 In modeling an advanced protection system for a 33/11 kV substation, a comprehensive and integrated approach, that combines the use of techniques and devices such as the automated activation devices with the regular power system switchgear can enhance the fault detection and protection capabilities of the entire smart grid, ensuring reliable and efficient operation.

In conclusion, this research has established that artificial neural networks (ANNs) are efficient and effective inelectricalfault detection, classification and location. In addition, it has been shown that effective fault isolation and service restoration in distribution systems require a combination of advanced technologies, real-time communication, and strategic planning to minimize downtime and enhance the reliability of the power supply to end-users.

RECOMMENDATION

An important recommendation for further work is that future researchers should the technical linkages between the fault detection, classification and location system and the switchgear.

Future extension to this research would be to analyze other neural network architectures, apart from back propagation neural networks (BPNN) such as radial basis neural network (RBF) and support vector machines (SVM) networks, to provide a comparative analysis on each of the architectures and their performance characteristics.

Further testing of the techniques on a real-life setting of the 33/11 kV injection substation to confirm practical effectiveness would also be suggested.

Due to computer rounding errors and drift, regular testing, simulation, and updates to the system are also essential to adapt to changing conditions and emerging technologies.

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