Chapter 1

Significance and Basics of Power Systems

1.1 Introduction

Modern world heavily depends upon electric grids for critical service capabilities such as healthcare, transportation, household heating and cooling and industrial manufacturing etc. Grid integrity more often effected by many reasons such as energy delivery systems age, natural disasters and man-made mistakes. Urban infrastructure energy delivery systems highly depend on the electric grid, if any vulnerability to electric grid outages becomes a major national concern. Electric power transmission is the bulk movement of electrical energy from power plants, to electrical substations. Essentially an electrical grid is an interconnected network for delivering electricity from producers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant sources to demand centres and distribution lines that connect individual customers or businesses. Transmission lines are a vital part of the electrical distribution system, as they provide the path to transfer power between generation and load. Transmission lines operate at voltage levels ranging from 100kV to 1000kV. These transmission lines are interconnected for reliable operation of the electric grid. In recent years many new technologies such as advanced sensors, intelligent automation, communication networks have been integrated into the electric grid to enhance its performance and efficiency [1].

In recent years, power quality has become the main concern in power systems engineering with major power systems faults occurs on distribution lines. The faults that occur on the transmission lines have a more significant and widespread impact on the consumers. The performance of a power system is affected by faults on the transmission lines, which results in interruption of the power flow. As the power system configuration becomes more complex quick detection of faults and accurate estimation of fault location is critical. The rapid repair, restoration of the power supply is essential for minimizing the local and regional economic impacts, reducing overall power outages and improving customer satisfaction.

When a fault occurs in the transmission line, it initiates a transition condition. Transients produce overcurrents in the power system, which can damage power system

equipment's depending upon fault severity. Transmission protection systems are designed to identify the faults and isolate only the faulted section of the network with compromising the network security of the system with significant accuracy. With the advent of new measurement devices like phasor measurement units (PMU), digital fault recorders (DFR) are often used to provide detailed information about the health of the grid. These operating technologies (OT) in power systems led to a massive amount of data from the monitoring of transmission lines [1]. Using machine learning algorithms with that data opens potential to implement smart and robust fault diagnosis methods.

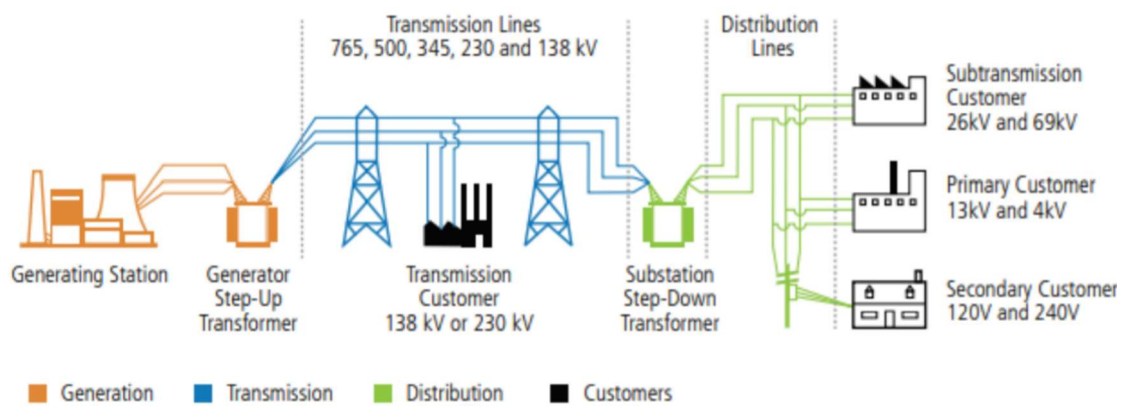## 1.2 Basics of Power systems

Fig. 1.1 Building Blocks of Electric Power System [2]

Electric power systems are real-time energy delivery systems. Real-time means power is generated, transported and supplied the moment the switch is turned on. Electric power systems are not capable of storing the generated energy like water systems and gas systems. The generator produces energy as demand calls for it. Fig. 1.1 shows the basic block diagram of the electric power system. The power system consists of three major parts i.e. generation, transmission and distribution. In the generating stations, electrical energy is produced and then transformed in the power stations to high voltage electrical energy that is more suitable for long-distance transportation. The generating stations transform other sources of energy into electrical energy. For example, thermal, hydraulic, chemical, solar, wind, geothermal, nuclear and other sources of energy are used in the production of electrical energy. High voltage (HV) power lines in the transmission portion of the electric power system will transport the electrical energy from generating stations to long distances to the consumer locations. Finally, the substations at the remote locations are transforming this HV electrical energy to lower high voltage power lines called "feeders" that are most suitable for distribution of electrical energy. This electrical

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energy is again transformed to even lower voltage services for residential, commercial and industrial consumption.

The power generation and distribution have four stages:

a) *Generation:* Power plants will produce electrical energy that is ultimately delivered to the consumers through transmission lines, substations and distribution lines. Electrical energy must be generated at the same rate as it is consumed. A sophisticated control system is required to ensure that the power generation closely matches with the consumption.

b) *Transmission:* Transmission lines are necessary to carry high-voltage electricity over long distances and connect generators to consumers. Transmission line voltages are typically at above 110kV, with some transmission lines are even operating at 765kV. Power generators, however, produce electricity at lower voltages. The generated voltage is stepped-up to transmission voltages with the help of step-up transformers.

c) *Distribution:* Distribution systems are responsible for delivering electrical energy from distribution substation. Most of the distribution systems in India operates at 11kV. These networks carry power to consumers like a business and residential entities.

d) *Load:* This stage accounts for electrical energy used by various loads on the power system. Electricity is consumed and measured several ways depending on whether the load is residential, commercial, or industrial and whether the load is resistive, inductive, and capacitive.

1.3 Power Transmission Networks

High voltage transmission lines transmit power long distances much more efficiently due to two reasons. First, high voltage transmission lines offer less resistive loses over distribution lines. Secondly, raising the voltage to lower the current one to use lower conductor size, or have more conductor capacity available for growth. Transmission lines systems relay the power from production sites to the users. Failure of these structures can lead to power cuts and therefore disrupt the day to day life of people as well as the industries dependent on electricity.

The power system is a network of power stations, transmission lines and substations. Energy is usually transmitted within the system with three-phase AC.

Transmission lines are either overhead power lines or underground cables. Overhead transmission lines are not insulated and are vulnerable to weather but can be less expansive to install than underground cables.

Typically, there are three types of line configurations used in the transmission network. These line configurations include (a) radial (one-terminal), (b) two-terminal, and (c) multi-terminal of which three-terminal is possibly the most prominent multi-terminal type. It should be noted that "terminals" in this context, refers to source terminals and not-tapped transformer terminals or stations. The two-terminal line configuration is the most dominant type followed by radial, and the three-terminal lines are the exceptions.

1.4 Problem Statement

Transmission lines or transmission network is a crucial part of the electric grid as it carries high voltage power from generating site to the substations where the voltage stepped-down for end-use consumption transported via distribution lines. Though the frequency of faults is much higher in distribution lines, faults on transmission lines have more widespread impact and faults in buried transmission lines take longer to locate and repair. The voltage level of the transmission line is very high if any fault occurred in the line leads to unsafe conditions. Therefore, safeguarding against exposed fault is the most critical task in the protection of the power system. The protection schemes or mechanisms for the transmission lines become challenging as configurations of the transmission lines become increasingly complex.

Faults on transmission lines and the varying environmental conditions present a complex classification and detection problem. With the advent of new machine learning methods and supervised and unsupervised learning methods, these challenges may be more effectively addressed. Machine learning methods are based on the idea that systems can learn from data, identify patterns and make decisions with minimal human intervention. The ability to automatically apply complex mathematical calculations to big data – over and over, faster and faster give these algorithms potential to identify insights in the data which would be otherwise an impossible task for humans. The availability of high-resolution/high-volume data, due to the proliferation of intelligent electronic devices in smart grids, paves ground to implement more accurate and intelligent machine

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learning methods for fault classification and location identification on the transmission lines.
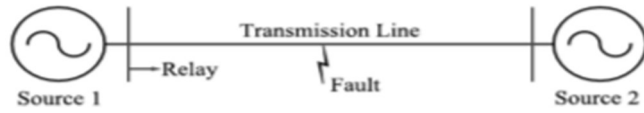

Fig. 1.2. The studied system with sources at both ends

In this thesis, we had considered a simple three-phase system as shown in fig. 1.2 for analysis. The length of the transmission line is 200 km and the operating frequency is 50 Hz. The line voltage of the transmission line is 220 kV. The transmission line connects two sources and has positive impedance Z_1 = 4.76 + j59.75 Ω and zero sequence impedance Z_0 = 77.70 + j204.26 Ω [3].

Chapter 2

Background and Related Work

2.1 Introduction

Electrical power gird is most complex power system consisting of power plants, transmission lines, and distribution lines. Fault classification, location identification is necessary to improve the protection mechanism and have a reliable supply. Most of the electrical faults result in mechanical and material damage to the lines and the equipment, which must be repaired before returning the line to service. As we know repairing and restoration is extremely important for maintaining critical and societal services. The restoration process can be delayed if the location estimation cannot do accurately. Various fault classification and location estimation methods had been proposed over the years, and each method has its advantages and disadvantages.

2.2 Faults on Transmission Lines

The fault is an abnormal condition in the electrical systems. The faults in the electric transmission lines are short circuit faults and open circuit faults [4]. Open circuit faults are very rare in the transmission lines but the short circuit faults are very common these faults are may be due to natural climatic conditions and mis-operation.

2.2.1 Series Faults

Series faults represent open conductor and take place when unbalanced series impedance conditions of the lines are present. These faults disturb the symmetry in one or two phases and are therefore unbalanced faults. Series faults are characterized by an increase of voltage and frequency and fall in current in the faulted phases [4].

2.2.2 Shunt Faults

There are two types of shunt faults which can occur on transmission lines, balanced faults and unbalanced faults also known as symmetrical and unsymmetrical faults as shown in fig. 2.1. The shunt faults are the most common type of fault taking place in the field. They involve power conductors or conductor-to-ground or short circuits between conductors. In shunt faults, increment the current and suffers fall in voltage and frequency [5].
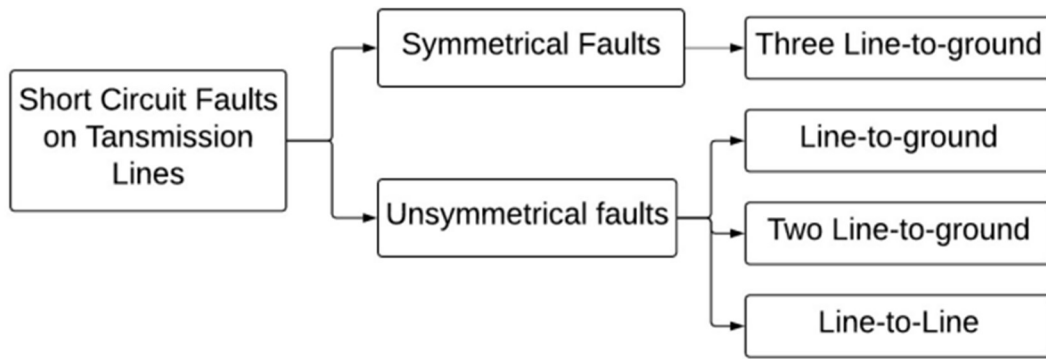
Fig. 2.1. Classification of Short Circuit faults

a) Symmetrical Faults:

Symmetrical faults are most severe faults and rarely occurs in the power system. These faults are balanced. These faults are of two types LLL fault and LLL-G faults, when ground involves in the fault then that is called as LLL-G fault else called as LLL fault. The analysis can be done by using per phase. Fig.4 describes balanced faults in the transmission lines.
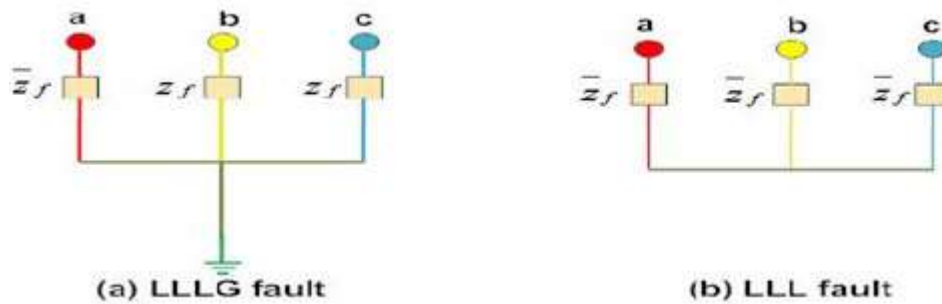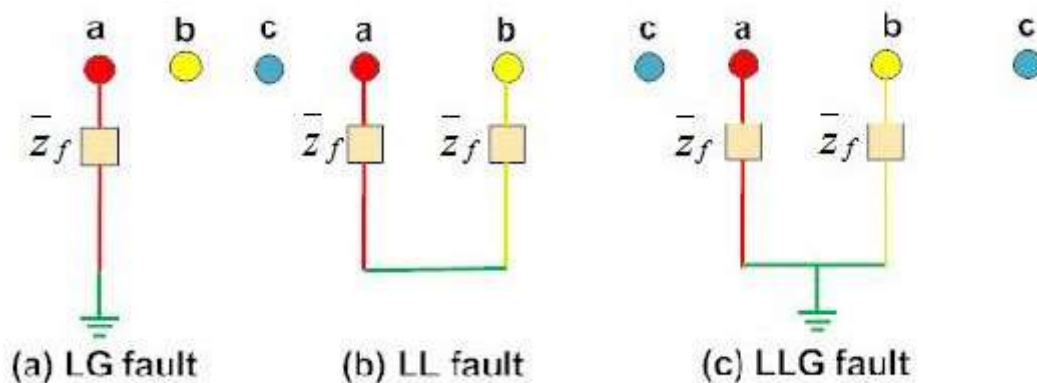

Fig. 2.2 Symmetrical Faults

b) Unsymmetrical Faults:

Fig. 2.3 Unsymmetrical Faults

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These faults are very common and less severe than the symmetrical faults. These faults are classified as single line to ground fault(L-G), line to line fault (L-L), double line-to-ground fault (LL-G). These faults are unbalanced in nature and cause unbalanced currents to flow in the phases.Fig.5 describes unbalanced faults. The study of un-symmetrical faults can be done by using symmetrical components.

- Single line to ground fault:

  When one phase of transmission line comes in contact with the ground either by ice, wind, falling tree or any other incident results in L-G fault. About 70% of the faults in the transmission lines comes under this category. It causes the conductor to make contact with earth or ground.

- Line to line fault:

  During heavy winds, one phase could touch another phase which results in line-to-line fault. Approximately 15% of all transmission lines faults are line-to-line faults. The line to line faults occurs when two conductors make contact with each other mainly while swinging of lines due to winds. These are also called unbalanced faults since their occurrence causes unbalance in the system.

- Double line to ground fault:

  When two phases come in contact with the ground it will lead to this type of fault. Two phases will be involved instead of one in the line-to-ground fault condition. 15 to 20 % of faults in the transmission lines are double line to ground faults.

2.3 Causes of Electrical Faults

a) Climatic conditions:

It includes lighting strikes, heavy rains, heavy winds, salt deposition on overhead lines and conductors, snow and ice accumulation on transmission lines, etc. These environmental conditions interrupt the power supply and also damage electrical installations [5].

b) Failure of equipment:

Electrical equipment like generators, motors, transformers, reactors, switching devices etc. causes short circuit faults due to malfunctioning, ageing, insulation failure of

cables and winding. These failures result in high current to flow through the devices or equipment which further damages it [5].

c) Human errors:

Electrical faults are also caused due to human errors such as selecting improper rating of equipment or devices, forgetting metallic or electrical conducting parts after servicing or maintenance, switching the circuit while it is under servicing, etc [5].

d) Fires:

Ionization of air, due to smoke particles, surrounding the overhead lines results in spark between the lines or between conductors to the insulator. This flashover causes insulators to lose their insulating capacity due to high voltages [5].

2.4 Literature Survey

Power system fault diagnosis is a very important topic for the smart grid and the power quality is concern. Research is going on this area from a few decades. Some of the literature is presented here.

Youssef O.A.S [6] proposed a method for classifying faults using wavelet transform. Her results show that the proposed algorithm is a fast and secure technique for classifying the faults.

W. M. Lin et al [7] proposed a radial basis function neural network with OLS learning procedure was used to identify various patterns in voltages and currents. This method used to classify faults on transmission lines.

Kashyap et al [8] proposed fault classification method based on DWT and probabilistic neural network. Here DWT will decompose transients and then given to neural network to classify the faults.

D Chanda et al [9] proposed a method for the fault location identification based on DWT with multiresolution analysis. D-8 wavelet transform is used for the decomposition of the current signal.

Sanaye Prasad et al [10] proposed a novel application of the neural network approach to the protection of transmission line is demonstrated. This method uses current signals to find the hidden relationship in the input pattern. Fault detection and classification were done within a quarter cycle.

A K Pradhan et al [11] proposed discrete wavelet transform integrated with a fuzzy logic system is designed for fault classification of a transmission line possessing a series capacitor at the midpoint. The approach uses information obtained from the wavelet decomposition of current signals for faulty phase selection and section identification. Two different FLSs are designed for the two classification objectives in this paper.

H. Khorashadi-Zadeh et al [12] proposed a novel application of neural network approach to protection of double circuit transmission line is demonstrated. This method uses current signals to train the neural network.

P. K. Dash et al [13] proposed a scheme for fault classification using minimal radial basis function network. In this approach, the training time was drastically reduced and provides a systematic approach for selecting the number of neurons in the hidden layer

R. N. Mahanty et al [14] proposed a scheme based on radial basis function neural network for fault classification and location identification. In this method, instantaneous voltage and current samples are used for training. For fault classification, both pre-fault and post fault samples are fed to the network. For fault location identification only post fault samples are used.

D. Thukaram et al [15] used ANN and SVM approach for locating faults in radial distribution systems. In this method firstly data was analysed using principle component analysis then faults are classified using support vector classifiers and feedforward neural networks.

A R Sedighi et al [16] proposed a method for high impedance fault detection based on pattern recognition systems is presented in this paper. Using this method, HIFs can be discriminated from insulator leakage current and transients such as capacitor switching, load switching (high/low voltage), ground fault, inrush current and no load line switching. Wavelet transform is used for the decomposition of signals and feature extraction, feature selection is done by principal component analysis and Bayes classifier is used for classification.

K M Silva et al [17] proposed a novel method for transmission-line fault detection and classification using oscillographic data. The fault detection and its clearing time are determined based on a set of rules obtained from the current waveform analysis in time

and wavelet domains. The method can single out faults from other power-quality disturbances, such as voltage sags and oscillatory transients, which are common in power systems operation. An artificial neural network classifies the fault from the voltage and current waveforms pattern recognition in the time domain.

M Jayabharata et al [18] presents a real-time wavelet-Fuzzy combined approach for digital relaying. The algorithm for fault classification employs wavelet multi resolution analysis (MRA) to overcome the difficulties associated with conventional voltage and current based measurements due to effect of factors such as fault inception angle, fault impedance and fault distance. The proposed algorithm for fault location, different from conventional algorithms that are based on deterministic computations on a well-defined model to be protected, employs wavelet transform together with fuzzy logic.

C K Jung [19] describes the fault location algorithm using neuro-fuzzy systems in combined transmission lines with underground power cables. The neuro-fuzzy system consists of two parts to perform different tasks. One is to discriminate the fault section between overhead and underground using the detailed coefficients obtained by wavelet transform. The other system calculates the fault location.

U B Parikh et al [20] presents a combined wavelet-support vector machine (SVM) technique for fault zone identification in a series compensated transmission line. The proposed method uses the samples of three-line currents for one cycle duration to accomplish this task. Initially, the features of the line currents are extracted by the first-level decomposition of the current samples using discrete wavelet transform (DWT). Subsequently, the extracted features are applied as inputs to an SVM for determining the fault zone.

J Upender et al [21] presents the development of an algorithm based on discrete wavelet transform (DWT) and probabilistic neural network (PNN) for classifying the power system faults. The proposed technique consists of a preprocessing unit based on discrete wavelet transform in combination with PNN. The DWT acts as an extractor of distinctive features in the input current signal, which is collected at the source end. The information is then fed into PNN for classifying the faults.

S R Samantaray et al [22] presented a new approach for fault zone identification and fault classification for TCSC and UPFC line using decision trees.

A Jamehbozorg et al [23] proposed a novel method for fault classification in single-circuit transmission lines is presented. The proposed method needs voltages and currents of only one side of the protected line. After detecting the exact time of fault inception, the fault type is recognized using a decision-tree algorithm (DT) which is formerly trained by applying the odd harmonics of the measured signals.

M Korkali et al [24] proposed a novel analytical and computational approach to fault location for power transmission grids. The proposed methodology involves an online and an offline stage. The online stage is based solely on the utilization of the time-of-arrival (ToA) measurements of travelling waves propagating from the fault-occurrence point to synchronized wide-area monitoring devices installed at strategically selected substations. The captured waveforms are processed together at the time of fault to identify the location of the fault under study.

Q Jiang et al [25] presents a general fault-location method for large transmission networks which uses phasor measurement unit (PMU) voltage measurements where the injected current at a fault point can be calculated by using the voltage change and its relevant transfer impedance on any bus.

A Capar et al [26] proposes a performance-oriented fault location algorithm for series compensated transmission lines. The algorithm estimates the fault location based on the calculated fault voltage and current using two end measurements and line parameters. Fault location computations are carried out considering faults existed before or after the compensator location on the line.

Florian Rudin et al [27] discusses the possibility of using deep learning architecture using convolutional neural networks (CNN) for real-time power system fault classification. This work is about fault classification only and not about localization. It aims to classify power system voltage signal samples in real-time and determine whether they belong to a faulted or non-faulted state. The data is produced by simulating a simple two-bus power system with a three-phase balanced load.

Amit Jain et al [28] proposed a methodology for detection and classification of faults using PMU measurements.

Kunjin Chen et al [3] present in this paper a novel method for fault detection and classification in power transmission lines based on convolutional sparse autoencoder. Contrary to conventional methods, the proposed method automatically learns features

from a dataset of voltage and current signals, based on which a framework for fault detection and classification is created.

2.5 Survey of Methods

From the literature, we may come to know that there are several ways to detect, classify and location identification of faults on trans mission lines.

The survey is mainly divided into two parts:

- Fault classification techniques - Methods that determine the fault type
- Fault Location Techniques - Methods that calculate the distance of the fault

Both techniques play a vital role in the development of protection mechanisms for a given power system model. There are plenty of techniques proposed over the past years. Those techniques have their advantages and disadvantages. The fault classification and location identification must be very fast to improve power quality.

2.5.1 Fault Classification Techniques:

a) Discrete Wavelet Transform:

Discrete Wavelet Transform (DWT) is a very important technique for the feature extraction from certain frequency bands in signals. Discrete wavelet transforms with Multi-Resolution Analysis (MRA) can be used to analyse the high-frequency signals for a short duration. The main drawbacks of DWT are the choice if appropriate mother function suitable for the application, computational complexity and time etc[29].

b) Artificial Neural Networks:

Artificial neural networks are (ANN) are a family of non-linear statistical models and learning algorithms that are intended to imitate the behaviour of connected neurons in biological neural systems. Different ANN models have been used for different applications. Feedforward neural network (FNN) the simplest neural network configuration which can be characterized as a single layer or Multi-Layer-Perceptron. An FNN often has an input layer, output layer and at least one hidden layer. From the late 1980s, researchers are using the Back-propagation algorithm with FNN. There are several types of FNN networks such as Radial basis function networks (RBFN), Probabilistic neural networks (PNN) etc [29].

c) Support Vector Machines:

Support vector machine (SVM) was invented by Cortes and Vapnik in 1995. The main idea of SVM classifiers is to find the optimal hyperplane that maximizes the margin between two groups of examples. SVM uses non-linear kernel functions to map the examples into higher dimensions. SVM prevents overfitting due to its structural risk-minimizing nature. SVM is a very powerful tool for classification problems. SVM with other techniques were also implemented such as DWT, ST etc. Even though SVM gives better results, it has a problem with parameter optimization [29].

d) Decision Trees:

Decision Trees (DT's) refers to the class of tree-like graphs capable of decision making. DTs will look like trees models with nodes. Concretely, three types of nodes found in a DT, namely root node, internal nodes and leaf nodes. Decision-making starts from the root node and the flow goes along the path that satisfies the test conditions. Decision trees can be trained with many algorithms such as greedy algorithm, random forest etc. Decision trees are easy to understand by humans as per the conditions, but the main drawback is their stability [29].

2.5.2 Fault Location Identification Techniques:

The accurate location of faults in the transmission lines and distribution system greatly reduces the time to restore the power. The conventional fault location methods can be classified into two groups, Travelling Wave-Based Schemes and Impedance Measurement Based Schemes.

a) Travelling Wave Based Fault Locators:

Travelling waves will get generated due to switching operations and faults such as short circuit faults and open circuit faults. Travelling waves phenomenon for fault location is classified into four different types. Two of them are generated wave analysis and the remaining two are external wave injection to the transmission line at a single end and both ends. The time of reflection of the wave is proportional to the fault location [29].

b) Impedance Measurement Based Fault Locators:

These schemes provide another alternative for the fault location estimation problem. Let us consider that a single line to ground fault occurred in a transmission line with a fault resistance at a distance x from the sending end. The fault will draw the fault current based on the fault resistance. The measurements units which are placed at sending

end and receiving end will measure currents and voltages for double end algorithms, for single-end algorithms measurement will be done at sending end only [29].

c) Other Fault Locators:

The above-mentioned techniques are normal mathematical derivations, instead of conventional fault location techniques soft computing techniques such as wavelet transform, artificial neural networks or genetic algorithms were also introduced. But these methods have their problems that result from the line modelling accuracy, data availability [29].

2.6 Performance Measures:

There are several performance measures we can consider to estimate the performance of the network such as Mean Square Error (MSE), Mean Absolute Error (MAE), Correlation Coefficient etc. Let us consider that we have n number of predictions generated, y is the predicted output and $\hat{y}$ is the actual output. Mean square error is the average squared difference between the estimated values and the actual value.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2$$

Mean absolute error is the average absolute difference between estimated output and actual output.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|Y_i - \hat{Y}_i|$$

Correlation Coefficient, denoted by 'r', how closely the predicted output is matched with actual output. The closer the absolute value of r to one, the better that the data are described by a linear equation.

Chapter 3

Machine Learning

3.1 Introduction

In nowadays everything getting digital, each and everything going to be automated using computers. There is a lot of data has been generating every day. Handling of this huge amount of data leads to the Big Data concept. By using this data, we can automate things and estimate the future. Artificial Intelligence (AI) is available for everyone in many forms such as mobile phones, personal assistants, personal computers etc. This AI makes our daily life simple and becomes one of our members. To obtain AI it requires some algorithms to make a decision. This is where Machine Learning (ML) comes into the picture.
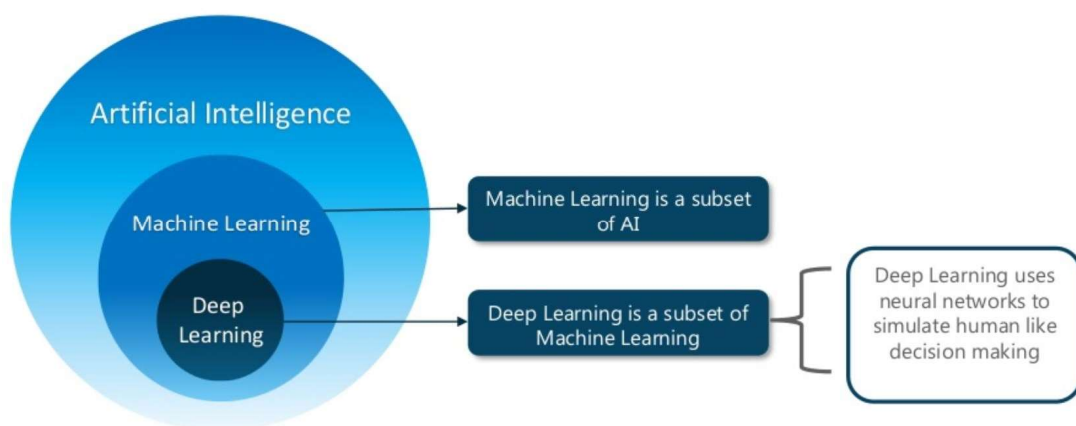

Fig. 3.1 Subsets of Artificial Intelligence

Machine Learning is a subset of AI. ML uses past data to make a decision. But ML requires supervised learning i.e. ML learns from the data using the labels. But this cannot be done always, for that reason Deep Learning (DL) comes into existence. DL is a subset of ML [30]. It does not require supervisory control over learning. The learning process of DL is called unsupervised learning. It can learn from the raw data itself. DL takes the help of neural networks to simulate human-like decision making. The fig. 3.1 describes the difference between AI, ML, DL. Artificial Neural Networks (ANN) are inspired by the animal's neurons to make decisions.

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3.2 Artificial Neural Networks

ANN is an information processing paradigm that is inspired by the way of the biological nervous system such as the human brain processes the information. It is composed of a large number of highly interconnected processing elements [Neurons] working together to solve a specific problem [31]. AN ANN comprises, of different layers-
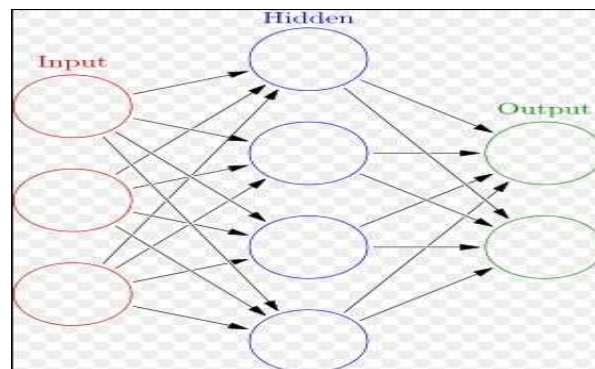

Fig. 3.2 Artificial Neural network

Input layer:

It contains neurons which receive input from the outside world on which network will learn and process.

Hidden layer:

It is situated in between the input and output layer. The main purpose of a hidden layer is to transform the input into something which is then utilized by the output layer.

Output layer:

It contains the units that will respond to the information about how it's learned any task.

On the other hand, ANN contains

1) Neurons

2) Activation functions

Neurons:

Biological neurons also called as nerve cells or simply neurons are the fundamental units of the brain and nervous system, the cells are responsible for receiving sensory input from the external world via dendrites, and gives output through the axons.

Cell Body:

The body of the neuron cell contains the nucleus and carry out biochemical transformation necessary to the life of neurons.
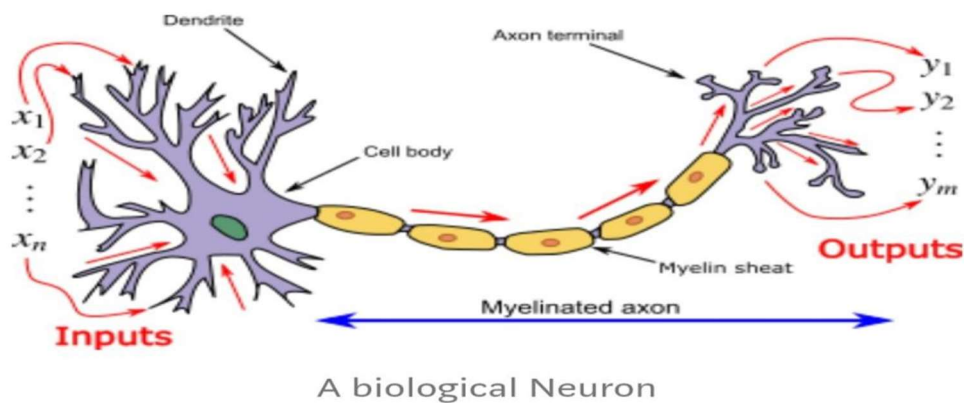

Fig. 3.3 A biological Neuron

Dendrites:

Each neuron has fine hair like sigmoid structures. They branch out in around the cell body and also accept the incoming signals.

Axon:

It is a long thin tubular structure that works like a transmission line.

Synapse:

Neurons are connected in a complex spatial arrangement. When axons reached its final destination it branches again called terminal arborization. The end of the axons has highly complex and specialized structures called the synapse. The connection between two neurons takes place at these synapses.

Dendrites receive input through the synapse of other neurons. The processes these incoming signals overtime and coverts that processed value into an output, which is sent out to other neurons through the axons and synapses.

The following diagram represents the general model of ANN which is inspired by a biological neuron. It is also called perceptron and gives a single output.
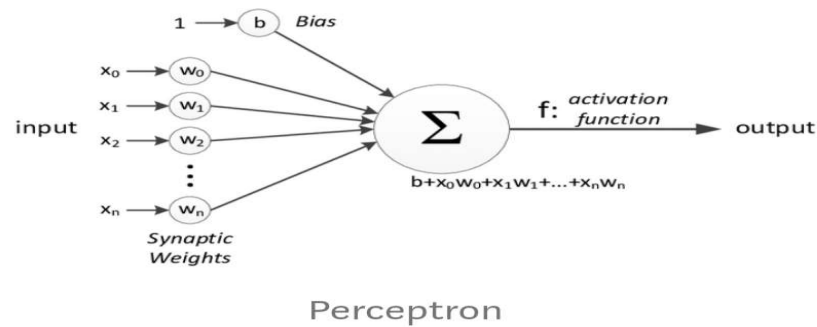

Fig. 3.4 Perceptron

In the above figure, for one single observation X0, X1, X2, X3………X(n) represents various inputs [independent variables] to the network. Each of these connections is multiplied by connection weight or synapse. The weights are represented as W0, W1, W2, W3, ..,W(n). Weight denotes the length of a particular node.

b is a bias value. A bias value allows you to shift activation function up or down. In the simplest case, these products are summed and fed to a Transfer function (Activation function) to generate α results. These results are sent as outputs.

Mathematically

$$x_0 w_0 + x_1 w_1 + x_2 w_2 + \cdots + x_n w_n + b = \sum_{i=1}^{n} x_i w_i + b$$

Activation Function:

The activation function is very important to an ANN to learn and make sense of something complicated. Their main purpose is to convert an input signal of a node in an ANN to an output signal. The output signal is used as input to the next layer in the stack.

Activation function decides whether a neuron should be activated or not by evaluating the weighted sum and adding bias to it. The main motive is to introduce non-linearity into the output of the neuron. Suppose if we do not apply activation function then the output signal would be a simple linear function. Now, a linear function is easy to solve because of less complexity and require less power. There are different types of activation functions. some of them are

a. Threshold Activation function

b. Sigmoid Activation function

c. Hyperbolic tangent function

3.2.1 Importance and Learning Techniques of ANN:

Importance:

ANN can be applied to fault detection, classification and fault location in power system effectively because it is a programming technique, capable of solving non-linear data easily. The problem in which the information available is in the massive form it can be dealt with ANN. Also, ANN can learn with experiences. They are widely accepted and used in the problem of fault detection, classification and fault location due to the following features:

- The Number of transmission line configurations are possible from a short length, long length, the single-circuit transmission line to double circuit transmission line etc.
- There are several methods to stimulate the network with different power system condition in a fast and reliable manner.
- The condition of the electrical power system will change after each disturbance. Hence, a neural network is capable to incorporate the dynamic changes in the power system.
- The ANN output is very fast, reliable and accurate depending on the training of data because its working depends upon a series of simple operations.

Learning Techniques:

Learning or training is an adjustment of weights to achieve the required target. Learning of neural network can be done by:

1. Forming a new connection
2. Deleting existing connections
3. Adjusting connection weights
4. Adjusting the neurons threshold values
5. Developing new neurons

6. Removing existing neurons

Among the above mentioned, methods changing the weights is the most commonly used method. Three important methods of learning are

- Unsupervised Learning (provides input pattern)
- Supervised Learning (provides training pattern with desired output)
- Reinforcement Learning method (provides feedback to the network)

In Supervised Learning both input and the desired output is known before training of Neural network whereas in Unsupervised Learning we do not know the exact association between input and output. We train the ANN with the known input values, so it is very important to select suitable values for the better training of the network. Two, well known Unsupervised Learning Algorithms are Adoptive Resonance Theory (ARP) and Self Organized Map (SOP). Because of the non-linear behaviour of activation function, a numerical method is required to solve non-linearities. The Backpropagation method is based on the steepest descent approach and is extensively used for training known as LEVENBERG -MARQUARDT Algorithm.

3.2.2 Characteristics of ANN

Artificial neural network irrespective of style and logic if the implementation has a few basic characteristics. some of them are mentioned below

- ANN consists of a large number of "neurons" as processing elements.
- All these processing elements have a large number of weighted connections between them
- The connections between the elements provide a distributed representation of data.
- A learning process is implemented to acquire knowledge.

3.2.3 Advantages and Disadvantages of ANN

Advantages of ANN:

a) Storing information on the entire network:

Information in traditional programming is stored on the entire network, not on a database. The disappearance of a few pieces of data in one place does not prevent the network from functioning.

b) Ability work with complete knowledge:

After training the ANN, the data may produce output even without complete information. The loss of performance here depends on the importance of missing information.

c) Having fault tolerance:

Corruption of one or more cells of ANN does not prevent it from generating output. This feature makes the networks fault-tolerant.

d) Parallel processing capability:

ANN have numerical strength so, it can perform more than one task at the same given time.

Disadvantages of ANN:

a) Hardware dependence:

Artificial neural networks require processors with parallel processing power by their structure. For this reason, the realization of the equipment is dependent.

b) Unexplained behaviour of the network:

This is the most important problem of ANN. When ANN is probing solution it doesn't give a clue as to why and how. This reduces trust in the network.

c) Determination of proper network solution:

There is no specific rule for determining the structure of ANN. The appropriate network structure is achieved through experience and trial and error.

d) Amount of data:

There is no improvement in the performance of ANN with a large amount of data.

3.3 Deep Neural Networks

Deep neural networks (DNN) are utilizing ANN's to make decisions. The drawbacks of ANN's can be overcome by using DNN. Here the main concept is data. ANN performance cannot be improved with a large amount of data but deep learning requires large data for better results. Traditional ML algorithms were limited in their ability to process natural data in its raw form, it requires feature extraction to process the data. For ML algorithms we have to specify the features of data that is supervised learning. So that ML requires less amount of data as compared to ANN. But DNN's can extract features on their own i.e. unsupervised learning.

Deep Learning is the most exciting and powerful branch of machine learning. Deep Neural network is also an Artificial neural network with multiple hidden layers in between the input and output layer. If there are more than one or two hidden layers then it is often referred to as Deep Neural network [30]. Deep learning models can be used for a variety of complex tasks.
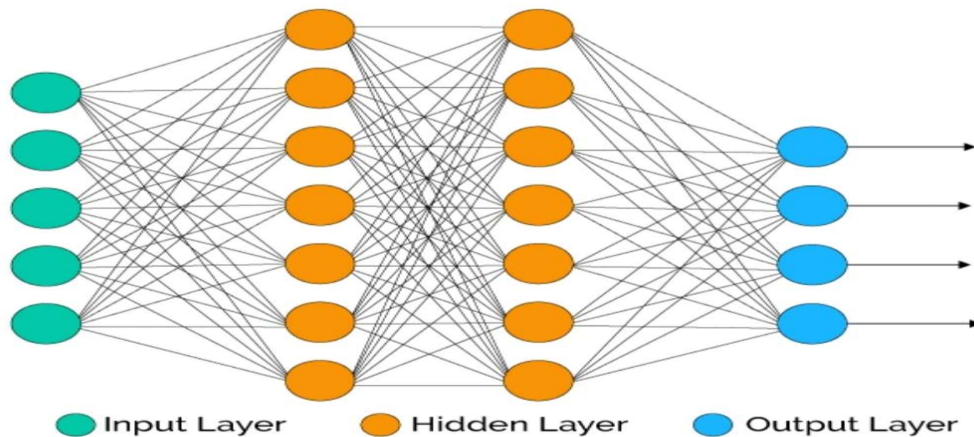

Fig. 3.5 Deep Neural Network

To overcome the drawbacks of ANN we are going for DNN. In Deep Learning, a computer model learns to perform classification tasks directly from image, text, or sound. It achieves the state of art accuracy, sometimes exceeding human-level performance. Fig. 3.5 represents DNN with two hidden layers between the input and output layers. Models are trained by adding a large set of data and neural network architectures that contain many layers.

The performance of Deep neural network is more effective as the amount of data gets increased compared to other old traditional neural networks. There are different types

of deep neural networks. But here were mainly concentrating on Recurrent Neural Network.
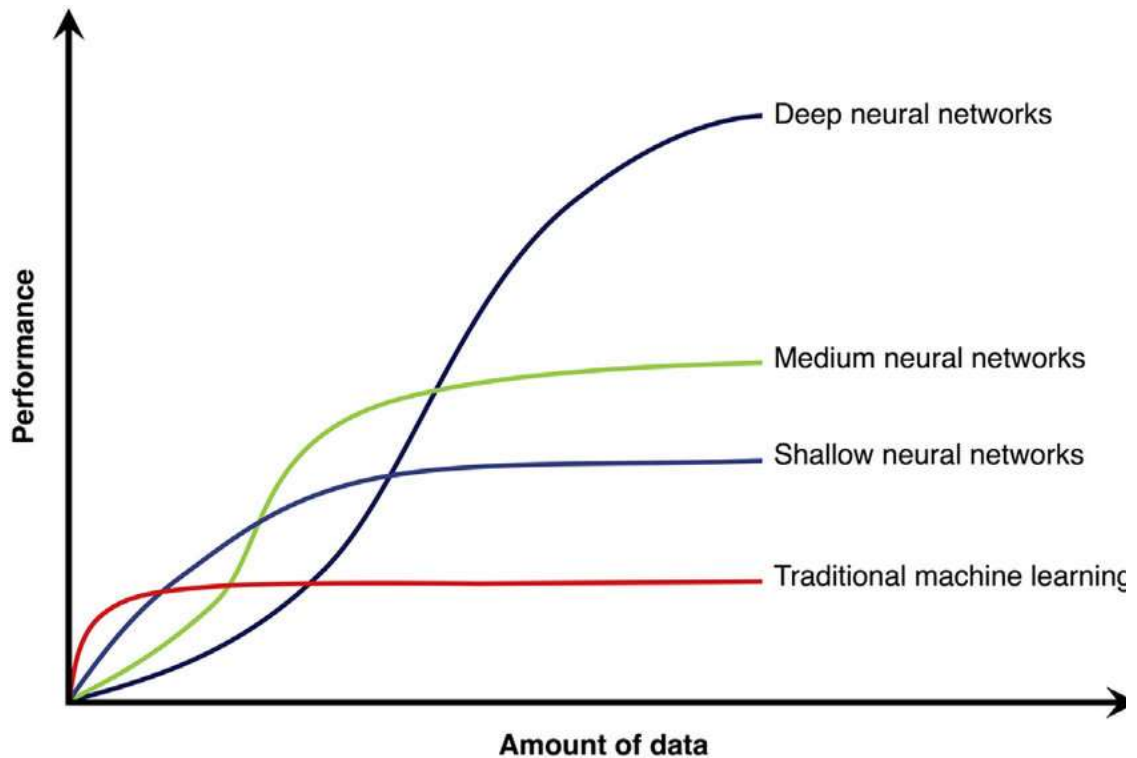

Fig. 3.6. Impact of data available on the performance of networks

3.4 Recurrent Neural Networks

Recurrent neural network (RNN) is a class of ANN. RNN's are derived from feedforward neural networks with Backpropagation through time (BPTT) and have dynamic capabilities to generate and process temporal information. The recurrent neural network has loops to persist information in the network. These networks are extremely powerful in processing sequential data. In traditional neural network all the inputs and outputs are independent of each other; But in cases like when it is required to predict the next word of a sentence, the previous words are required and hence there is a need to remember the previous words, this is how the RNN came into existence. which solved this issue with the help of the hidden layers. The main and most important feature of RNN is a hidden state, which remembers some information about a sequence.

The fig. 3.7. shows an RNN being *unrolled* (or unfolded) into a full network. By unrolling we simply mean that we write out the network for the complete sequence. For example, if the sequence we care about is a sentence of 5 words, the network would be

unrolled into a 5-layer neural network, one layer for each word. The formulas that govern the computation happening in an RNN are as follows.
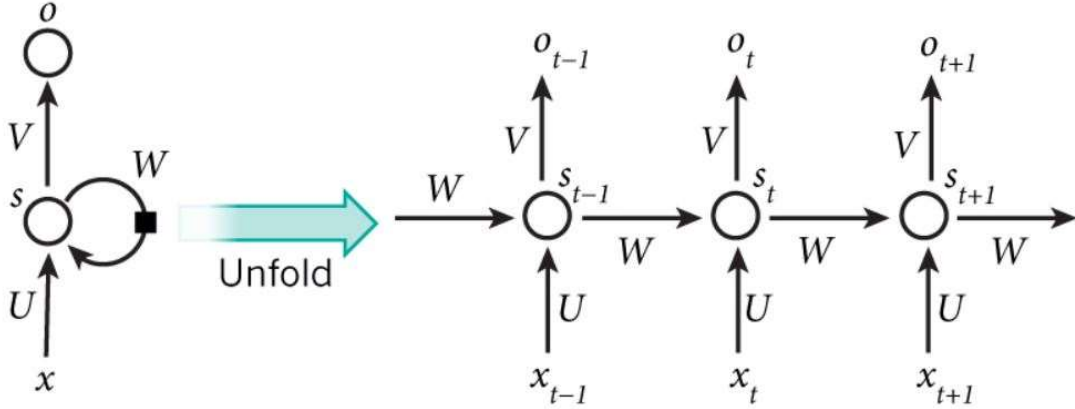

Fig. 3.7. A recurrent neural network and the unfolding in time

- x_t is the input at time step t. For example, x_1 could be a one-hot vector corresponding to the second word of a sentence.
- s_t is the hidden state at time step t. It's the "memory" of the network. s_t is calculated based on the previous hidden state and the input at the current step: $s_t = f(Ux_t + Ws_{t-1})$. The function f usually is a nonlinearity such as tanh or ReLU. s_{-1}, which is required to calculate the first hidden state, is typically initialized to all zeroes.
- o_t is the output at step t.

RNN has a memory which remembers all information about what has been calculated. It uses the same parameters for each input as it performs the same task on all inputs (or) hidden layers to produce the outputs. This reduces the complexity of parameters, unlike other neural networks.

Recurrent neural networks have many architectures such as Fully Recurrent Neural Networks, Recursive Neural network, Hopfield Network, Elman networks and Jordan networks or Simple Recurrent Network, Echo State Network, Long short-term memory (LSTM), Gated Recurrent Units, Bi-directional RNN, Continuous-time RNN [32],

25

Partially Recurrent Neural Network (PRNN) etc. Each architecture has some unique features and capabilities. The partially recurrent structure adds a feedforward connection, through a synapse, from the input axon to the layer after the 1st hidden layer. In this case, the recurrent structure acts as a state for the feedforward structure. General recurrent networks (GRN's) are to temporal data as multi-layer perceptron's (MLP's) are to static data. They are categorized by a layer that feeds back upon itself using adaptable weights. If all of the layer's axon's feedback their output, then the network is fully recurrent, otherwise it is called partially recurrent.

In this thesis, we are considering the PRNN for the problem.

RNN can be used for image processing, video processing, speech recognition, natural language processing etc.

Chapter 4

Simulation and Results

4.1 Tools Used

To complete any task we require some components, that may be software tools and/or hardware tools. In this project, we require some software's to run the simulations. Before implementing any project in terms of hardware we had to verify that simulations should give desired results. After simulation results verification hardware implementation will be very easy.

In this project, we are implementing the DNN to the power systems, but practical power systems are very complex and expansive. For that reason, we had to collect the faults data from simulations, so that we were utilized MATLAB/SIMULINK to generate the data. For neural networks, we have used NeuroSolutions software.

4.1.1 MATLAB/SIMULINK

MATLAB (Matrix Laboratory) is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces and interfacing with programs written in other languages. MATLAB was written in Java programming language.
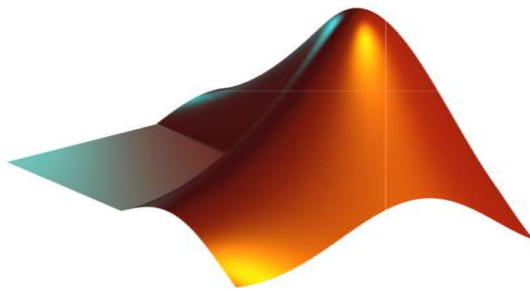

Fig. 4.1 MATLAB

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses MuPAD symbolic engine allows access symbolic computing abilities. An additional package, SIMULINK adds graphical multi-domain simulation and model-based design for dynamic and embedded systems [33].

4.1.2 NeuroSolutions

NeuroSolutions is a neural network development environment developed by NeuroDimension. It combines a modular icon-based network design interface with an implementation of advanced learning procedures, such as conjugate gradients, Levenberg-Marquardt and backpropagation through time. The software used to design, train and deploy network (supervised learning and unsupervised learning) models to perform a wide variety of tasks such as data mining, classification, function approximation, multivariate regression and time-series prediction [34].

NeuroSolutions provides many ways to create and train the neural network. Those are NeuralBuilder, NeuralExpert and user-defined neural networks. It also offers excel add-on to operate NeuroSolutions software from an excel sheet.

NeuralBuilder provides many architectures to the user. It provides more than ten types of neural networks. Once the network architecture is selected, the user can customize the parameters such as hidden layers, number of processing elements and learning algorithms.

NeuralExpert centers the design specifications around the type of problem the user would like the neural network to solve (Classification, Prediction, Function approximation or Clustering). Given this problem type and the size of the users, dataset, the NeuralExpert intelligently selects the neural network size and architecture that will likely produce a good solution.

4.2 Data Generation

For the neural network of training, the data will be compulsory. That was generated in MATLAB/SIMULINK. The power system shown in fig. 1.2 was modelled in SIMULINK. In the model, we were assumed that generators voltage was 220 kV phase-to-phase rms. The Simulink model was shown in fig. 4.2. The transmission line considered as distributed parameters line with positive sequence impedance of $Z_1 = 4.76 + j59.75 \ \Omega$ and zero sequence impedance $Z_0 = 77.70 + j204.26 \ \Omega$ has length of 200 km. The faults were created at the locations of 0 km, 50 km, 100 km, 150 km, 200 km with fault impedance of 0.01 Ω, 5 Ω, 10 Ω, 15 Ω, 20 Ω [3]. Once the fault was created the currents and voltages were measured by using three-phase measurement block in per unit. But these measurements were instantaneous, to convert this instantaneous current and voltage signals to rms values, we were used RMS block. This data has been exported to

the workspace with the help of ToWorkspace block. This data had been exported to excel files with the help of Spread Sheet Toolbox. We are simulated a-g, b-g, c-g, ab, bc, ac, ab-g, bc-g, ac-g, abc and No-Fault.
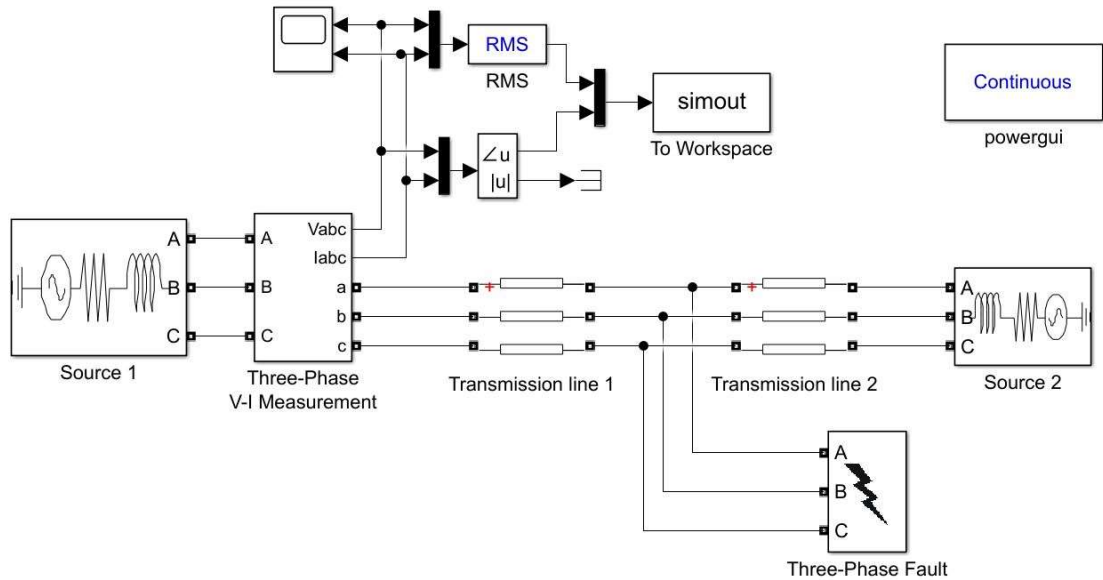

Fig. 4.2 Simulink Model

4.3 Training of Network

The data set obtained from MATLAB were exported to excel sheet. The training and testing of the neural network had done using 'NeuroSolutions for Excel' add-on. Firstly, the data samples have to be preprocessed to eliminate bad data. Here we were randomized the rows. Three-phase voltage and current magnitudes had been tagged as inputs to the neural network and Faults as desired outputs. 80% of data for training, 5% of data for cross-validation and 15% of data for testing. This process is common for both fault classification and location identification. Here we are using two networks for fault classification and location identification problems.

Table 4.1 Network Parameters for fault classification and location identification

Parameter	Description
Neural Network	PRNN
Learning Rule	Momentum
Weight Update	Online
Hidden Layers	5
Processing Elements	35-35-35-35-35

29

4.3.1 Fault detection and classification

Table 4.1 represents the network parameters for the classification problem. After selecting all the parameters and probes we need to train the network. The NeuroSolutions breadboard will look like in the fig.4.3.
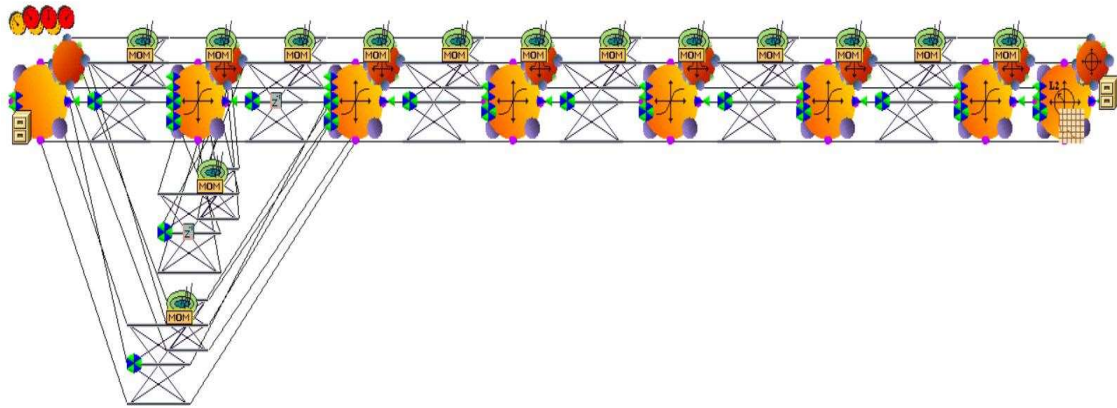

Fig. 4.3 Classification breadboard

After training the neural network NeuroSolutions will automatically generate a training report containing training curves and MSE. The fig. 4.4 shows the training curves of the classification problem.
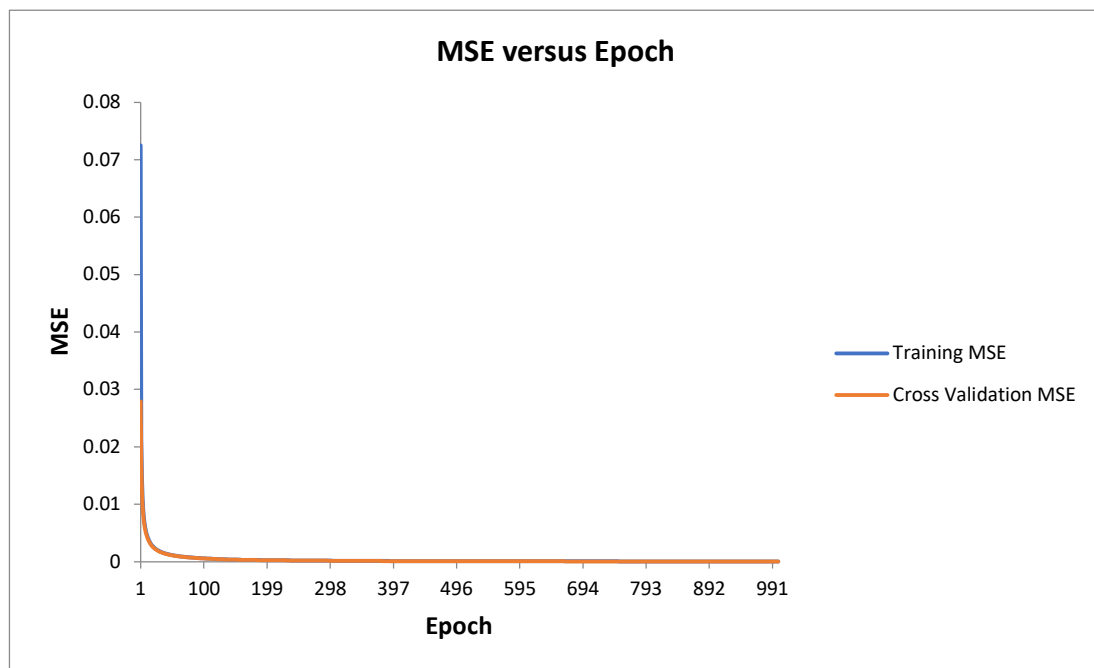

Fig. 4.4 Training curves fault detection and classification

Table 4.2 shows the training results for the fault detection and classification problem.

Table 4.2 Training results for fault detection and classification

Best Networks	Training	Cross-Validation
Epoch #	1000	1000
Minimum MSE	4.22383E-05	3.7915E-05
Final MSE	4.22383E-05	3.7915E-05

4.3.2 Fault Location Identification

Using the same neural network parameters for the location identification problem. For classification problem the outputs are faults but here the output is the location of the fault. This problem comes under regression but the above problem is classification. We are using the same network parameters so that the network breadboard looks like fig. 4.3. After training the network the training curves were shown in fig. 4.5.
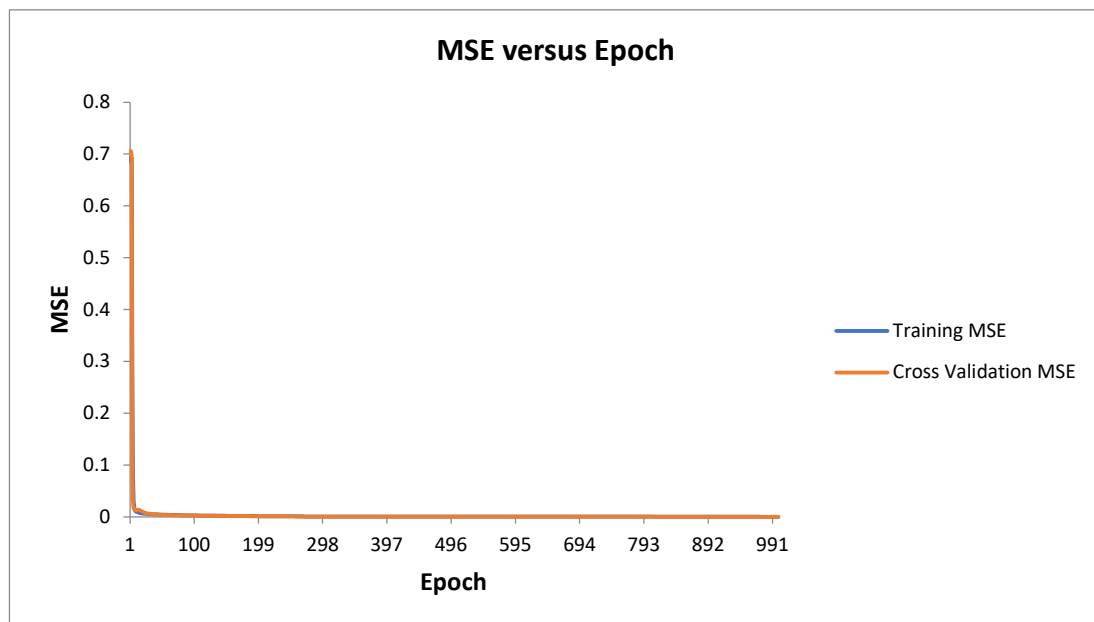

Fig. 4.5 Training curves for fault location identification

Table 4.3 shows the training results for fault location identification problem.

Table 4.3 Training results for fault location identification

Best Networks	Training	Cross-Validation
Epoch #	1000	1000
Minimum MSE	0.000151775	0.000134924
Final MSE	0.000151775	0.000134924

4.4 Testing of Network

After training the neural networks we have to test the neural networks with unknown data so that we can evaluate the performance of the network.

4.4.1 Fault detection and classification

After training the testing of the neural network had done with testing data. Table 4.4 shows the number of samples classified for a certain fault. Table 4.5 shows the performance metric of the network with testing data.

Table 4.4 Fault classification and classification results

Output / Desired	No-Fault	AG	BG	CG	AC	BC	CA	ABG	BCG	CAG	ABC
No-Fault	151	0	0	0	0	0	0	0	0	0	0
AG	0	366	0	0	0	0	0	0	0	0	0
BG	0	0	391	0	0	0	0	0	0	0	0
CG	0	0	0	380	0	0	0	0	0	0	0
AC	0	0	0	0	393	0	0	0	0	0	0
BC	0	0	0	0	0	369	0	0	0	0	0
CA	0	0	0	0	0	0	373	0	0	0	0
ABG	0	0	0	0	0	0	0	356	0	0	0
BCG	0	0	0	0	0	0	0	0	410	0	0
CAG	0	0	0	0	0	0	0	0	0	329	0
ABC	0	0	0	0	0	0	0	0	0	0	382

Table 4.5 Fault detection and classification network performance

Performance	No-Fault	AG	BG	CG	AC	BC	CA	ABG	BCG	CAG	ABC
MSE	3.76583E-06	0.000258642	8.80984E-06	5.34328E-06	3.77744E-06	6.22469E-06	3.48316E-06	4.5409E-06	1.27944E-05	4.4779E-06	2.73689E-06
MAE	0.0013214413	0.0064296595	0.0019571132	0.0013649944	0.0013240566	0.0017317866	0.0013589411	0.001498223	0.0021510007	0.0013341545	0.0011243854
r	0.999995114	0.998652115	0.999995224	0.9999970318	0.9999979301	0.9999964841	0.9999980127	0.9999973549	0.9999985429	0.9999971576	0.9999984784
% Correct	100	100	100	100	100	100	100	100	100	100	100

4.4.2 Fault Location Identification

To repair the transmission lines if any faults occurred, it is necessary to find the location of the fault. Table 4.6 shows the performance of the network for locating faults.

Table 4.6 Fault Location Identification network performance

Performance	Location
MSE	3.158307138
MAE	1.276490649
r	0.99969047

4.5 Results

Power system fault diagnosis will be a major concern for the power quality and reliability of the power supply. The proposed method is capable of detection, classification and location identification by using PRNN. From the testing data set, we can conclude that PRNN can classify the faults accurately.

We were also used NeuralExpert for fault location identification. The performance of the network is shown in table 4.7

Table 4.7 Performance of function Approximation network for fault location identification

Performance	Location
MSE	13.83166315
MAE	2.763306481
R	0.99857872

If we compare both tables 4.6 and 4.7, we will come to know that PRNN is identifying the location more accurately than the function approximation network.

4.6 Application of Proposed Methods in Smart Grids

An illustrative diagram of implementing the proposed method in power systems is shown in Fig. 4.6. With intelligent electronic devices such as remote terminal units installed at the terminals of substations in the monitored region, a fault monitoring and diagnosing system based on the proposed method can be established. The system can give real-time alerts at the moment of fault occurrence, and protective actions can be taken if possible. The high generalizability of the proposed method means that it can be widely adopted by power transmission systems as well as power distribution systems.
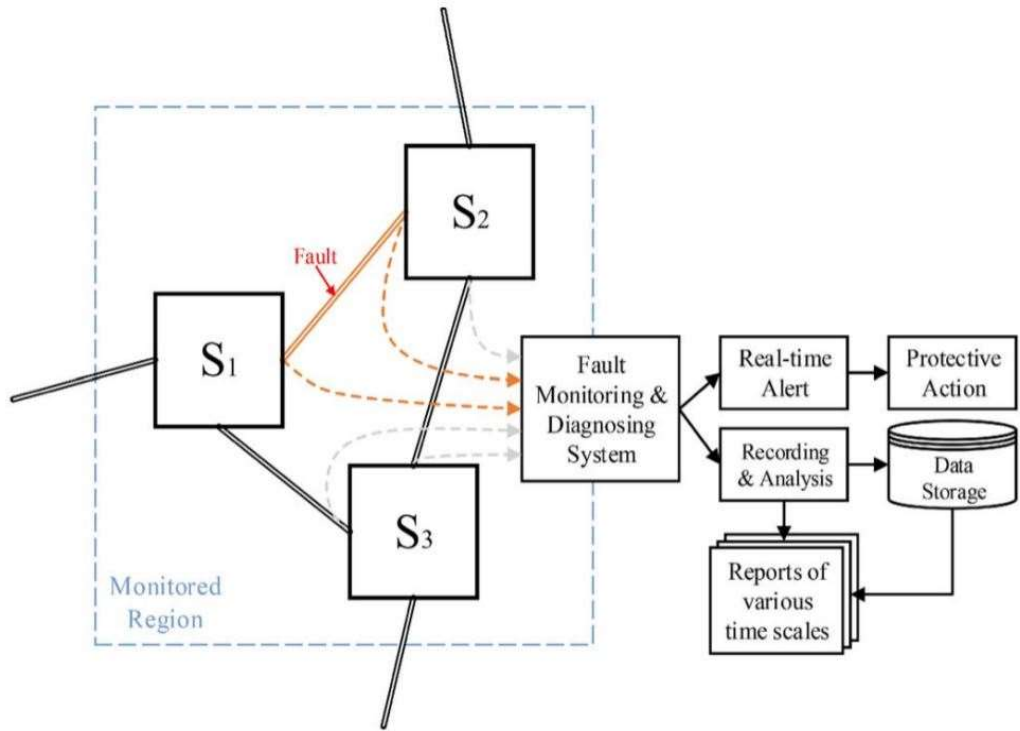
Fig. 4.6 Application of the proposed method in smart grids

Also, data recording and preliminary data analysis run continuously and store the data and analysis results in the database. Reports on a daily, weekly, monthly, seasonal and yearly basis can be generated via further analysis using stored data, which may help grid operators assess the reliability of the grid in the monitored region and evaluate the necessity of transforming or upgrading the grid infrastructure [35].

Chapter 5

Conclusions and Future Scope

Transmission lines safeguard against exposed fault is the most critical task in the protection of the power system. The purpose of a protective relaying is to identify the abnormal signals representing faults on a power transmission system. So, fault classification and location is necessary for reliable and high-speed protective relaying.

DL is evolving very rapidly due to the data availability and the computational power of computers. Apart from CPU units, GPU units are also capable of doing deep learning computations. The power system fault diagnosis problem is addressed using deep neural networks in this thesis. Here we are used post fault data for fault classification and location identification. The partially recurrent neural network giving a satisfactory performance for the given data set. The classification network is classifying the faults accurately. The fault location identification network is also locating the faults with very less error.

The power fault diagnosis is a very large area to study. There are several parameters to consider for a particular network. Here we are considered a simple three-phase transmission line having sources at both ends. The future scope of this project is to study the effect of fault inception angle variation, the variation of high fault resistance. We can study large systems with multiple buses in the network.