STATIC SECURITY ASSESSMENT FOR POWER SYSTEMS USING ARTIFICIAL NEURAL NETWORKS

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF APPLIED SCIENCES
OF
NEAR EAST UNIVERSITY

By

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In Partial Fulfillment of the Requirements for the Degree of Master of Science
in
Electrical and Electronic Engineering

NICOSIA-2013

Mohammed Bahaaelden: Static Security Assessment For Power Systems Using Artificial Neural Network

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ACKNOWLEDGEMENTS

I would like to begin by thanking the Almighty God who has been my help and the source of my strength throughout the duration of my studies.

My grateful and special thanksgo to my supervisor Assoc. Prof. Dr. ÖzgürCemalÖzerdemwho has shown plenty of encouragement, patience, and support as he guided me through this endeavourfostering my development as a graduate student.

I would like to thank Prof. Dr. Adnan Khashman for his total support and encouragement during the two years of my study in the university.I would like also to thank Assist. Prof. Dr. Ali SERENER, Prof. Dr. İlkay SALİHOĞLU and Assist. Prof. Dr. Huseyin CAMUR for their help during my graduate studies.

I would like to say thanks to my father Sabah Bahaaelden for cooperating with me during my studies. My special thanks go to my family for their prayers and support at each step of my life. A special thanks to my brother Mohammed Kmail without forgetting my best friend Mohammed Jamal and Ahmed Faiz.

ABSTRACT

Preservingthe power system at a secure position is considered the foundation stone in the power system operating to ensure the arrival of electricity to the customers with high quality and without interruptions. Due to the associated obstacles with conventional methods in the static security assessment, the Artificial Neural Networks(ANNs) willbe utilized to overcome these problems and to prevent the status of the power system from sliding into more dangerous situations which is leading to the collapse of parts or the whole system.In addition, the usage of this technique will help the system's operator for detecting the vulnerable areas at that system. The essential objective of this research is to examine the reliability by utilizing artificial neural network in the Static Security Assessment (SSA) to identify the power system's operating states (Normal, Alarm, Emergency and Extreme Emergency states). Therefore, Back propagation neural network is carried out on the IEEE-9 bus test system. The utilized data will be gathered by Newton-Raphson power flow simulationusing Power World Simulator's program for various system topologies over a domain of load grades to form the utilized data in the artificial neural network. The error between the actual outcomes of Newton-Raphson technique (actual line flows and bus voltages) and estimated results of feed forward back propagation neural network (estimatedline flows and bus voltages) is obtained to be utilized in terms of accuracy.The percentage of classification accuracy to determine the status of IEEE 9 bus system and the vulnerable areas by feed forward back propagation neural network is90.51852 %. The average time required by artificial neural network to predict the power system's operating states is 0.013 seconds while the average time required by Newton-Raphson technique is 0.0627 seconds. As a result of that,Artificial Neural Network proves the ability to determine the vulnerable areas and to assess the static security by supplying the current power system's operating status with high speed in IEEE 9 bus system.

Keywords: Artificial Neural Networks, Static Security Assessment, Newton-Raphson power flow, Back propagation neural network,Feed Forward Back Propagation Neural Network, Percentage Classification Accuracy.

ÖZET

Güçsistemleriningüvenliçalıştırılmasıelektrikarzgüvenliğininsağlanması, kesintisizelektrikenerjisiiletimivedağıtımıiçinönemarzetmektedir. Bu çalışmada, StatikgüçgüvenliğideğerlendirilmesindegelenekselyöntemlerinyanındaYapaySinirAğları (ANN) kullanılarakarzgüvenliğiaçısındankarşılaşılabileceksorunlarveelektrikgüçsistemininkararsız birnoktayauaşarakçökmenoktasınagelmesiniengelleyeceksonuçlaraulaşılmıştır. Bu sistemgüçsistemi control operatörününsistemaçısındantehlikearzedebilecekyüklenmeleriöncedenfarkederekmüdahal eedebilmesineyardımetmektedir. TezinanatemasıyapaysinirağlarıkullanarakStatikGüvenlikDeğerlendirilmesi (Static Security Assessment(SSA)) güvenilirliğiniincelemektir, bunoktadasistemçalışmadurumlarıolarak Normal, Alarm, AçilveÇokAcilkullanılacaktır. Bu amaçla Power World Simulator programıaracılığıile IEEE-9 bus sistemitasarlanarak Newton-Raphsongüçakışmethoduylaverilereldeedildiktensonra YapaySinirAğlarıyöntemiyleanalize dilmiştir.Bu yönemlegüçgüvenliğiaçısındantehlikearzedenbölgelerintespitedilmesiaçısındaneldeedilend oğruluk 90.51852 % veçalışmadurumlarınıntespitiiçingerekenzaman 0.013 saniyedir.Newton-Raphsonyöntemiileise 0.0627 saniyedir. Bu sistemledahahızlıbirtespityapılmıştır.

Anahterkelimeler: YapaySinirAğları,StatikGüvenlikBelirlemesi, Newton-Raphsongüçakışı, Back propagationYapaySinirAğları, Feed Forward Back Propagation YapaySinirAğları, YüzdelikSınıflandırmaDoğruluğu.

DEDICTION

My parents: Thank you for your unconditional support with my studies I am honoured to have you as my parents. Thank you for given me a chance to prove and improve myself through all my walks of life. Please do not ever change. I love you

My family: thank you for believing in me: for allowing me to further my studies. Please do not ever doubt my dedication and love for you

My spirit: who has always encouraged me and give me hope and strength to continue forward and increasing my patience and pregnant in all difficulties

My brothers and sisters: hoping that with this research I have proven to you that these is no mountain higher as long as God is on our side. Hoping that you will walk again and be able to fulfill your dreams.

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LIST OF SYMBOLS

$X_1, X_2 \ldots X_m$:	Inputs of the neuron.
$W_1, W_2 \ldots W_m$:	Weights of the neurons.
b:	Bias
V:	Summation of these inputs, weights and bias
F:	The Activation Function
Y(x):	Sigmoid transfer function
i:	The input layer.
h:	The hidden layer.
j:	The output layer
I_i:	Input of the Input – Layer.
O_i:	Output of the Input – Layer.
I_h:	Input of the Hidden – Layer.
O_h:	Output of Hidden – Layer.
I_j:	Input of the Output – Layer.
O_j:	Output of Output – Layer.
$F'(I_j)$:	Function for Input of the Output – Layer.
T_j:	Target at the out layer
Δ_j:	The error signal at the output layer.
η:	The learning step size.
α:	Momentum factor.
Δ_h:	The error signal at the hidden layer.
$\vert V_K \vert$:	Voltage magnitude at bus k.
S_K:	Apparent power at bus k.
P_{GK}:	Real power of generator at bus k.
Y_{bus}:	Bus-Admittance matrix.
θ:	Phase angle of $Y_{bus.}$
J:	Jacobian matrix
Q_{GK}:	Reactive power of generator at bus k.
P_{Losses}:	Real losses in the transmission lines.
Q_{Losses}:	Reactive losses in the transmission lines.

P_D:	Real power of load demand.
Q_D:	Reactive power of load demand
N:	Total number of buses.
δ:	Phase angle of the voltage.
R:	Series resistance of transmission line.
X:	Series reactance of transmission line.
I:	Current in the transmission line.

LIST OF ABBREVIATIONS

ANN:	Artificial Neural Network.
ADALINE:	Adaptive Linear Neuron.
AC:	Alternating Current.
AS:	Alert State.
AVR:	Automatic Voltage Regulator
B:	Shunt charging susceptance
BPNN:	Back Propagation Neural Network
C:	Shunt capacitance.
DC:	Direct Current.
ES:	Emergency State.
EES:	Extreme Emergency State.
G:	Shunt conductance
G-S:	Gauss-Seidel method.
IEEE:	Institute of Electrical and Electronics Engineers
KCL:	Kirchhoff's current low.
LMS:	Least Mean Square error.
MW:	Megawatt
MVAR:	Mega volt ampere reactive.
MADALINE:	Multilayer ADALINE
MLP:	Multi-Layer Perceptron
MSE:	Mean Square Error.
N-R:	Newton-Raphson method
NS:	Normal State.
P:	Real power.
P.U. :	Per-unit
PR:	Pattern Recognition.
Q:	Reactive power.
R:	Resistance.
S:	Apparent power
SLP:	Single Layer Perceptron.
SVM:	The Multi-class Support Vector Machine

SSA:	Static Security Assessment.
X:	Reactance
Z:	The series impedance.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

Power system security assessment is very important to determine whether, following a contingency (disturbance), power system status reaches a steady state operating stage without exceeding or penetrating the boundaries of the power system security. Power system's operating statuses can be divided into Normal, Alert, emergency and Extreme Emergency states [1, 2]. These operating statuses can be identified in the system monitoring stage where it equips up-to-date measurement and information from all parts of the system such as (line power flow, bus voltage, magnitude of the line current, status of the circuit breaker and switch status information) through the telemetry system in a control centre [3, 4]. In static security assessment, the power system's operating statuses can be defined according to the thermal limits of transmission line and the limits of bus voltages as shown below:

- Normal state: All equipment and devises operates naturally and in a secure position without violation in the system operating limits. In addition, the equipped energy is received without interruption and a continuous power with steady voltage to satisfy all the requirements of the customers [1, 4, 5, 6].
- Alert state: The security limits remain within the acceptable borders of transmission lines and voltage magnitude at all buses, but a small disturbance can lead to violation of some security limits [1, 3, 5, 7, 8, 9].
- Emergency State: A power system enters the emergency state when at least one of the security limits is violated. The system operator must detect this state very fast to prevent the power system from sliding into the most dangerous cases by taking the immediate corrective action to bring the system back to the least dangerous instances and the most safety [3, 7, 8].
- Extreme Emergency state: The extreme emergency state is a result of the delayed detection for hazardous situations or incorrect protective action by system operator and the continuity in this situation is going to lead the system to collapse and blackout in that system [10].

Nowadays because of the increasing concern on economical and environmental issues, the power systems are obliged to operate under stressed operating conditions nearer to their security constraints. Under such vulnerable and fragile conditions, any small disturbance is going to make the power system at risk and probably will lead to the collapse of that system [1]. Fast and accurate security assessment became an important key issue to ensure that all operating limits fall within acceptable security conditions [8].

For power system security assessment, it is necessary to predict the bus voltages and line flows for various operating circumstances of normal and contingency situations to help the system operator to identify the power system's operating statuses then to maintain the status of a power system at a secure position or a safe point [11 and 12]. Where a contingency is a failure of any one piece of equipment, in addition, the outage of transformer or transmission line and the sudden change in loads are the most expected contingency situations [13]. Therefore, to prevent the power system from shifting into an undesirable emergency situations and hazardous disturbances, the security level or the power system's operating statuses must be previously well detected with high accuracy and speed [14].

The conventional techniques like Newton-Raphson method that is used for static security assessment consists of solving the non-linear power flow equations to find out the voltages at each bus and power flows at each transmission line for every contingency scenario, followed by examination whether the security limits fall within acceptable boundaries [11, 12 , 15].

The procedure of conventional methods requires a very large memory size to store all contingency cases and the enormous amount of computation time which made them waste of time and infeasible in real time. As well as, the traditional techniques cannot get the high accuracy and the required speed. For these reasons, the conventional techniques undermine the usage of static security assessment in real-time application and time consuming for large electric power systems. In addition, because of several blackouts that led to the enormous financial casualties and the losses in life at some cases, the Artificial Neural Network (ANN) will be used as an alternative method to overcome these obstacles and associated problems with traditional techniques [2, 7, 14, 16, 17, 18, 19, 20].

Neural networks are utilized in the applications of the power system, where more than 350 papers have been published in the use of neural network at various fields of the power systems as shown below in figure 1.1.

2

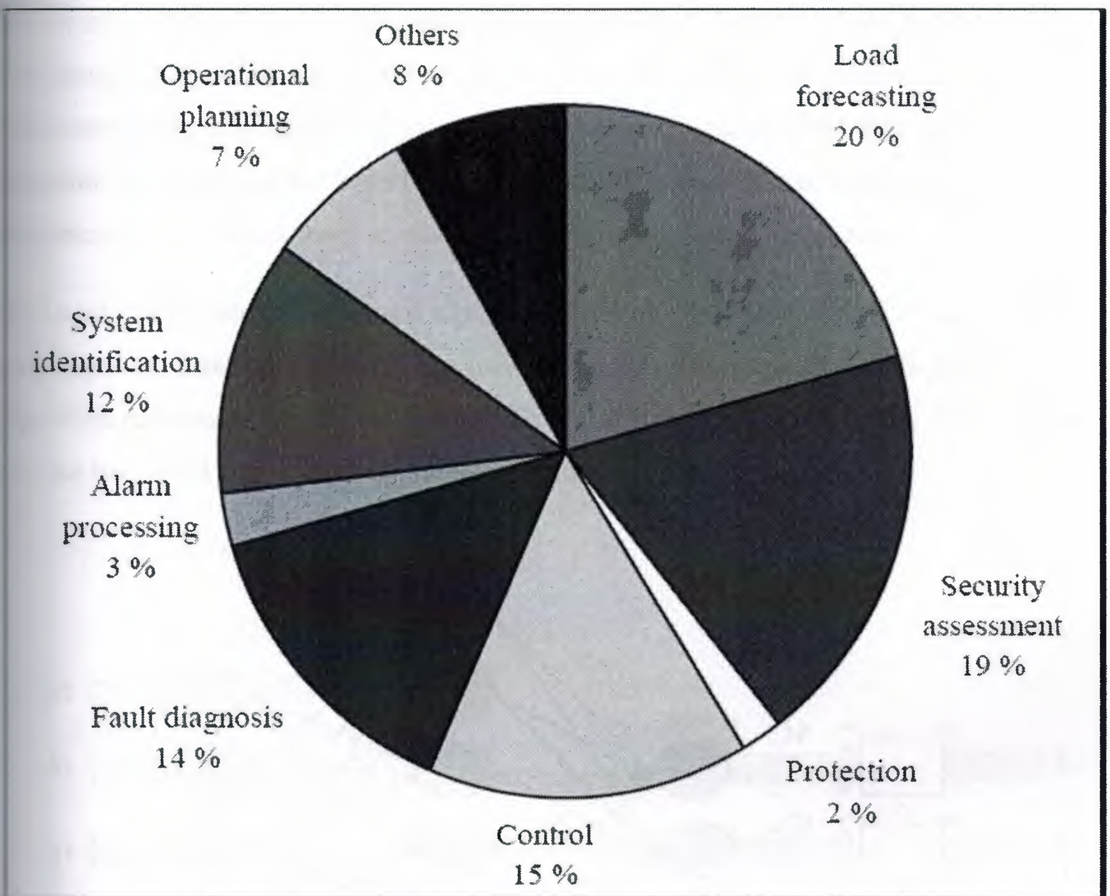

Figure 1.1: Neural networks applications at various areas of power systems [21].

From this figure, the security assessment of the power system obtained the utmost attention by the scientists and the researchers through their scientific papers. This field represents the most important area and the backbone for the rest of the power systems fields. The Artificial Neural Network (ANN) is a mathematical function designed to model the basic function of a biological neuron and it is invented to mimic the way in which the human brain executes a specific mission or task of interest. The Artificial Neural Network (ANN) have shown perfect promise as an intelligent method of predicting the security of large scale power system networks because the artificial neural network has high potential in terms of precision and speed. Besides that, an artificial neural network has significant ability to learn and builds a complex non-linear mapping through a group of input/output patterns or examples. In addition, the artificial neural networks had been magnificently implemented in the large scale power system networks compared to other techniques such as AC power flow and DC power flow [1, 4, 19, 22].

In recent years, many researchers have demonstrated the Multilayer Feed forward with a back propagation algorithm is appropriate to solve the problem of static security assessment. The multilayer feed forward with back propagation algorithm has high precision on account of the error between the actual and the desired output will be minimized to the lowest level as well as the implementation is very easy.

The back propagation algorithm is a powerful tool which is developed for training the multilayer artificial neural network to solve difficult problems and the back propagation algorithm consists of two passes through the multilayer neural network: the forward pass and the backward pass are shown below in figure 1.2.

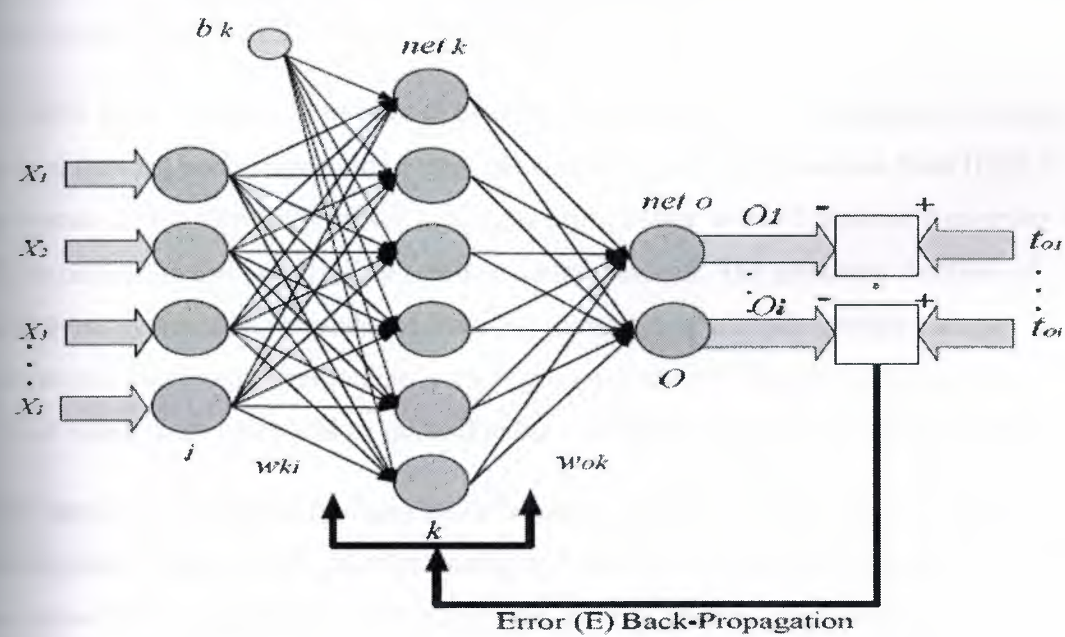

Figure 1.2: Architecture of the Back-propagation model [16].

In these two paths (the forward pass and the backward pass), the incoming information to the input layer is propagated ahead through the layers (hidden layer and output layer) until the actual output will be calculated. All connections among the layers of the network have weights. The architectures of the multilayer neural networks consist of many processing elements called neurons and these architectures are shaped by linking the neurons into all layers, these neurons at the layers are connecting with each other by weights. Each neuron consists of many inputs and one output. Each input is multiplied with its associated weight and the summation of all inputs with their associated weights will produce the output of that neuron. Then this value is sent through an activation function. This technique will be utilized in feed forward calculation until the signal will reach the output layer or final stage, where in it each output of an output neuron will be determined.

The actual output is subtracted from a desired output (target) to obtain the error of the multilayer neural network. This error is propagated backward though the network, the weights of the output layer and the hidden layer are continuously updated until to make the actual output very close to the desired output. The architecture of the multilayer neural network consists of input layer, output layer and at least one hidden layer between them. In general, the sigmoid activation function is preferable to use in back-propagation neural network because its properties of differentiable everywhere and introducing non linearity in the system [1, 4, 7, 21, 23, 24, 25, 26, 27, 28, 29, 30, 31].

The IEEE 9-bus system will be used to determine the static security assessment by using the feed forward back propagation neural network. The generated database from IEEE 9-bus system by the Newton-Raphson technique using Power World Simulator's program will be utilized to train and test the artificial neural network. The generated database of IEEE 9-bus system will be produced from N-1 contingency analysis (outage a single transmission line) with variation the loads to generate different operating scenarios or various cases, these cases will be utilized in the training process and the testing process.

There are several problems by using artificial neural network to assess the security of power system. There are not fixed standards to determine the number of hidden layer and the number of the neurons in each hidden layer, too few neurons can lead to reduce the level of the training process or the training process will not be in the required path. If the number of neurons in the hidden layer was too many, this case can lead to remember just the original data (memorization).

The unfamiliar data (the various data that was not taken at the training process) can lead to fail the testing process during implementation by the artificial neural network. There is an obvious problem in the selection the values of the momentum factor and the learning rate coefficient where they have a significant role in the learning capability of the neural network. The values of the momentum factor and the learning rate coefficient should be between 0 and 1. These two parameters will be added to minimize the error function to the minimum and to accelerate the learning process as well as to prevent the artificial neural network from falling in the local minima's problem. In this problem, the multilayer feed forward with a back propagation algorithm will stuck in a specific place and the value of the error function will not minimize to the desired value.

There is a problem in the spent time at the training process. Because the power system security assessment requires the large numbers of the training data to cover all possible scenarios for various disturbances, the feed forward back propagation neural network requires a long period of time for training these cases or scenarios.

In addition, there is another problem related with data sensitivity. This problem lies in an absence of the clear law to identify what kind of input data can be used to get the best outcomes in the output [1, 4, 23, 24, 25, 32, 33, 34, 35, 36].

To achieve the static security assessment of any power system, the operating status of that power system must remain at a normal state under predictable or unexpected circumstances. To achieve this, the proper identification and the rapid detection of the power system's operating statuses by feed forward back propagation neural network are going to utilize to forecast the vulnerable areas in the power system (the weak areas are the most susceptible for the insecure statuses (alarm state, emergency state and extreme emergency state)), where the detection of these areas will help the system operator to take rapid and preventive action which it helps to take the operating system back to the secure position and to avoid remaining the system at the unsafe situations that lead to the collapse or the total blackout for that system [7 ,37].

1.2 Literature Review

The main objective of an electric power system is to supply a continuous electrical energy to the costumers without interruptions and good quality. To achieve that, the static security assessment will be discussed. Because of the huge problems that associated with the traditional methods during their usage in the security assessment of any power system and to maintain the status of power system at safe status before and after contingency, many research have been published in the use of artificial neural networks to work around the problem of the static security assessment and these are summarized as:

In [1] the authors presented the application of different Neural Network (NN) models for classifying the power system states as secure/insecure. Because of the problems of Traditional technique in security assessment, making it infeasible for real time application. Pattern Recognition (PR) method is recognized as an alternative tool to solve the problem of the security assessment. The Neural Network (NN) models were experimented on 14 Bus, 30 Bus and 57 Bus IEEE standard test systems.

In [2], an Artificial Neural Network (ANN) to assess the static security of 8- buses test system was presented. The method was contrasted with that using of a nearest neighbour search. The Artificial Neural Network (ANN) was shown to perform noticeably better in term of real time, classification and data storage requirement.

The feed forward back propagation neural network to determine the security status of a power system was presented in [4].

In [6], the application of artificial neural network (ANN) in power system security assessment and the problems of conventional techniques were discussed.

In [7] the authors submitted the Artificial Neural Network to assess the steady state security of a power system. The ANN used is a feed forward multilayer network trained with a back propagation algorithm and it tested on 14-Bus IEEE standard test systems.

In [11], the feed forward back propagation neural network was utilized to assess the static security of a test system. Where this algorithm was experimented on the 5 bus and was verified on the IEEE-14 bus test system.

The application of Artificial Neural Network (ANN) for steady state monitoring of a power system was presented in [12]. To demonstrate the effectiveness of this system in steady state security assessment of a power system, the multilayer perception model with back propagation (BP) algorithm has been tested on the IEEE-14 Bus system.

The Multi-class Support Vector Machine (SVM) based Pattern Recognition (PR) technique for static security assessment in power systems was submitted in [14]. This method is tested on IEEE 57 Bus, 118 Bus and 300 Bus benchmark systems.

The design of Artificial Neural Network (ANN) to solve the problems of the static security assessment was clarified in [15].

In [16], the classification of power system states using an artificial neural network model Kohonen's self-organizing feature map was investigated. The estimate goal for this classification was to assess power system static security in real time application.

A new method of using query-based learning in neural networks to solve static security assessment problems in a power system was proposed in [17].

An Artificial Neural Network (ANN) based Pattern Recognition for static security assessment, transit security assessment and dynamic security assessment of the power systems were presented in [18].

In [31], An Artificial Neural Network (ANN) based external system equivalent approach was proposed for on-line voltage security assessment of power system.

In [36], an overview of the application of artificial neural networks to power system security assessment was illustrated. In this paper, the author explained various architectures of neural networks such as multilayered perceptron (the most popular choice), Hopfield and Kohonen networks as well as the extent of their potential in determining the static security was clarified.

In [38], an artificial neural network-based architecture which combines supervised and unsupervised learning for the static security assessment of the power systems was presented.

In [39] the authors used the Kohonen Neural Network to determine the static security assessment of a power system and this system was tested on the IEEE 30-bus system.

In [40], a neural-network-aided solution to the problem of static-security assessment of a large scale power system was proposed. It was based on a pattern-recognition technique where a group of neural networks was trained to classify the secure/insecure status of the power system for specific contingencies based on the pre-contingency system variables.

[41] Has presented in his Master thesis the application of artificial neural networks in the static security assessment. The objective of this research was to investigate the reliability of the Static Security Assessment (SSA) in determining the security level of power system from serious interference during operation. Therefore, back propagation Artificial Neural Network (ANN) was implemented to classify the security status in the test power system. To illustrate the proposed technique, 4 bus test system and IEEE 24 bus test system were considered.

1.3 Objectives of the Thesis

The objectives of this thesis are:

1. To verify the appropriate architecture for used artificial neural network in static security assessment of the IEEE-9 Bus system.
2. To develop the static state security assessment of power system using artificial neural network method.
3. To achieve the performance of the technique in terms of accuracy and efficiency against conventional method such as Newton-Raphson technique.
4. To detect the vulnerable areas (weak areas) and this is going to maintain the status of power system at safe position.
5. To identify the power system's operating statuses correctly and that depends on the right choice of the parameters (number of hidden layers, numbers of neurons in each hidden layer, the values of the momentum factor (α) and the learning rate coefficient (η) for training the neural networks.
6. To reduce the average time required by conventional method (Newton-Raphson technique).
7. To utilize the outcomes of this work in real time application.
8. To assist the trainees in the electrical stations to gain the required experience through the identification on the most popular N-1 contingency and its impact on the status of the power system.
9. To identify subjects appropriate for further research on the topic.

1.4 Thesis Overview

The thesis consists of six chapters arranged as follow: The first chapter presents the introduction and literature review on the topic. The second chapter discusses the Artificial Neural Network (ANN) and its application. In addition, it discusses the back-propagation algorithm for training multilayer neural network and usage a sigmoid activation function in that algorithm. In the third chapter, the study is pointed toward the solution of the power flow problems by using Newton-Raphson technique, In addition. It presents the problem of a static security assessment and the power system's operating statuses.

The forth chapter discuses the application of artificial neural networks in the static security assessment as well as the procedures of the feed forward back propagation neural network to assess the static security and to illustrate the proposed technique, IEEE-9 Bus system is considered. In addition, it presents the power flow solution for IEEE-9 Bus system by Newton-Raphson method using Power World Simulator's program.

The fifth chapter tabulates the experimental results and discussion of this thesis.

The sixth chapter shows the conclusions and suggestion for future work.

CHAPTER TWO

NEURAL NETWORKS

2.1 Overview

Artificial Neural Network (ANN) is a mathematical function designed to mimic the basic function of a biological neuron and it has used in many application such as Prediction, Classification of inputs and Data Filtering.

The training of the network by using back propagation algorithm is produced where in the forward pass the actual output is calculated and in the backward path the weights between output layer and hidden layer and between hidden layer and input layer will be adjusted, then steps of this algorithm is repeated until the error is reduced and the importance of sigmoid transfer function is presented also in details.

2.2 History of Artificial Neural Networks (ANNs)

A neural network is a machine that is designed to simulate the way of a human brain works, which is composed of a large number neurons working to gather to solve a specific problem.

The history of Artificial Neural Network can be traced back to the early 1940s. The first important paper on neural network was published by physiologist, Warren McCulloch and Walter Pitts in 1943, they proposed a simple model of neuron with electronic circuit, this model consists of two input and one output, in 1949 Donald Hebb proposed a learning law that become starting point for neural network training algorithm, in the 1950 and 1960, many researchers (Block, Minsky, Papert and Rosenblatt) worked on Perceptrons, where the first type of neural network is called Perceptrons. The Perceptron is a very simple mathematical representation of the neuron where most Artificial Neural Network is based on it to this day as shown below in figure 2.1

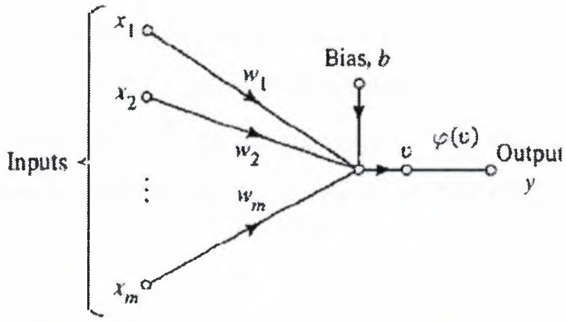

Figure 2.1: Perceptron [23].

This figure shows that the inputs of the neuron are represented by X_1, X_2... X_m then multiplied by corresponding weight W_1, W_2... Wm similar to the synaptic strength in a biological neuron, the externally applied bias is denoted by *b*. Summation of these inputs with their corresponding weights and bias 'b' is symbolized by V, where V is calculated by equation 2.1:

$$V = \sum_{i=1}^{m} Wi * Xi + b \qquad (2.1)$$

After that, the activation function is compared with value of a certain threshold. If the total summation of the inputs multiplied by their corresponding weight is more than the threshold the output (O) will be "fires" and if the total summation of the inputs multiplied by their corresponding weight is less than the threshold the output (O) will be "not fires".

Bernard Widrow and Marcian Hoff in 1959, they developed model called "ADALINE" (Adaptive Linier Neuron) and "MADALINE" is composed of "many ADALINE" (Multilayer ADALINE).

Widrow and Hoff in 1960 developed a mathematical method for adapting the weight, where this algorithm was depended on minimizing the error squared, and then this algorithm would become called as least mean square error (LMS). In1962, Frank Rosenblatt was able to demonstrate the convergence of a learning algorithm. In 1969, Marvin Minsky and Seymour Papert published a book in which they showed that Perceptron could not learn this function which are not linearly separable [23, 24, 42, 43].

The effect of these problems was to limit of the funding available for research into artificial neural networks therefore the neural networks research declined throughout 1970 and until mid of 1980.After a proof of the limitations of neural network in the 1970's, but much work was done on self-organizing maps by Willshaw and von der Malsburg. Hopfield presented a paper on neural networks with feedback known as Hopfield Networks.

The back propagation algorithm was first developed by Werbos in 1974; the most development happened around 1985- 1986 when Rumelhart, Hinton and Willimas invented (back-propagation), where back-propagation is a powerful tool for training multilayer neural network. Appearance of back-propagation method has spectacular the range of problems to which neural network can be applied [23, 24, 42, 43].

2.3 Biological Neurons.

The brain is composed of about 10 billion neurons each neurons is consists of five basic component that showed in figure 2.2

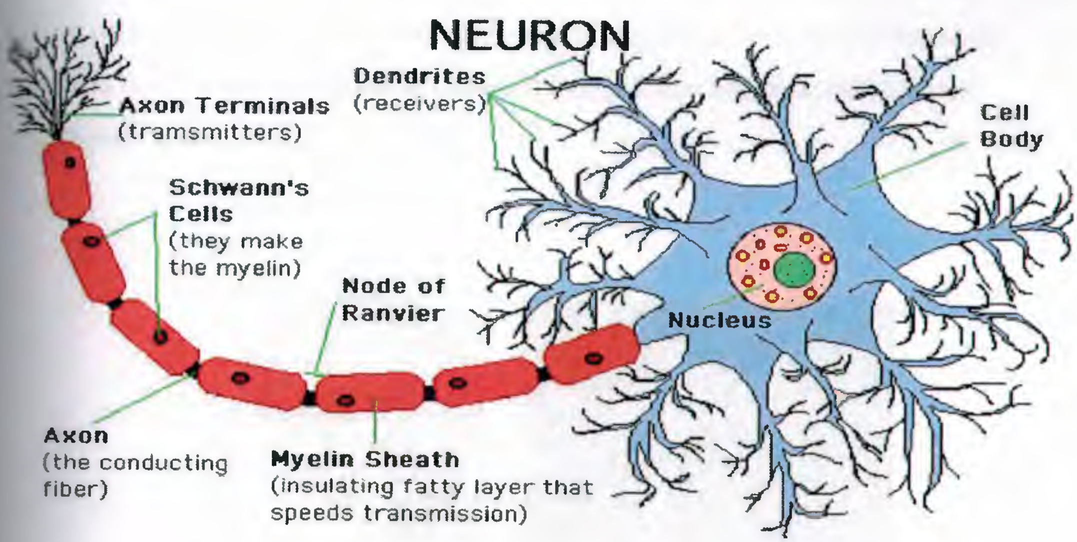

Figure 2.2: Schematic Diagram of a Biological Neuron [44].

- Dendrites: they are nerve fibre connected to cell bodies (soma), which are responsible for receiving signal from a connection point called a synapse.

- The neuron's Cell body or soma: in which convert the incoming activations to the output activation.
- Axon: they are fibres performing as transmission lines that send activation to other neurons.
- A synaptic junction: which has both a receiving and transmitting side, when a signal is received then transmitted though chemical process in which specific transmitted substances are released from the sending side of synaptic junction, in turn changing the electrical potential inside the cell body (soma) of receiving neuron, if this potential exceed a threshold would be firing down the axon to other neurons.
- The neuron's nucleus: where includes the genetic material in the form of DNA. This exists not just in neuron but exists in most types of cells [23, 45, 46].

2.3.1 How does the Human's Brain Work?

The human brain has close to 100 billion nerve cells, called neurons. Each neuron is connected to thousands of others, creating a neural network that shuttles information in the form of stimuli, in and out of the brain constantly. Each of the yellow blobs in the figure 2.3 are neuronal cell bodies (soma), each neuron has long, thin nerve fibres called dendrites that bring information in and even longer fibres called axons that send information away.

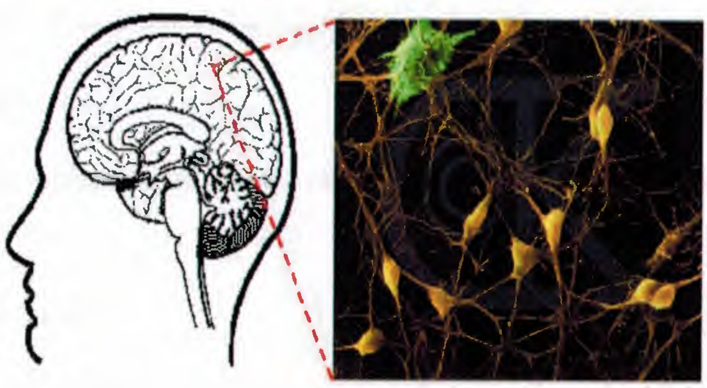

Figure 2.3: Biological neurons of human brain [47].

The neuron receives information in the form of electrical signals from neighboring neurons across one of thousands of synapses, small gaps that separate two neurons and act as input channels.

Once a neuron has received this charge it triggers either a "go" signal that allows the message to be passed to the next neuron or a "stop" signal that prevents the message from being forwarded, so it is important to note that a neuron fires only if the total signal received at the cell body exceeds a certain level.

For example, when a person thinks of something, sees an image, or smells a scent, that mental process or sensory stimulus excites a neuron, which fires an electrical pulse that shoots out through the axons and fires across the synapse. If enough input is received at the same time, the neuron is activated to send out a signal to be picked up by the next neuron's dendrites [23, 24, 47].

2.4 Neural Network and their applications

Neural network is a complex mathematical algorithm, and somewhat suitable to resolve all the issues that are not subject to the lows of mathematical constant and simulate the way of the human brain to identify the sound, word and images.

Majority applications of artificial neural network fall under three following sections:

- Classification :

Usage of the input values to assess the classification. E.g. character recognition.

- Prediction :

Usage of the input values to speculate the output. E.g. predict weather, pick the best stocks in the market.

- Filtering the data :

Make an input signal smoother such as: extraction the noise from the telephone's signal [23, 42].

2.5 Transfer Function of Artificial Neural Networks (ANNs)

Artificial Neural Network (ANN) was introduced by McCulloh and Pitts, where ANN is a mathematical function designed to mimic the basic function of a biological neuron, which is composed of a large number of (neurons) working together to solve a specific problems from training data that composed of inputs, weights of input and output.

Every input of that neuron is labeled X_1, X_2...X_n then multiplied by a corresponding weights W_1,W_2...W_n summation of the inputs with corresponding weights, and produces an output called (target) "NET" as shown in figure 2.4. Then the value of the result is compare with the value of the threshold.

$$net = \sum_{i=1}^{n} Wi * Xi \qquad (2.2)$$

Then the value of the result is compare with the value of the threshold,

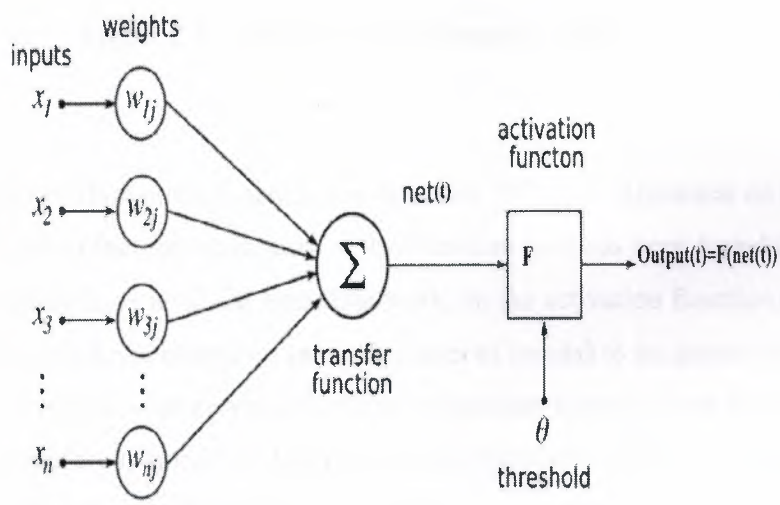

Figure 2.4: Schematic diagram of an artificial neuron [23, 25].

The Activation Function "F" is called transfer function, where the activation function "F" acts as a squashing function such that the output of a neuron in a neural network is between certain values. The transfer function translates the input signals to output signals. There are many of activation functions are such as Hard-limit Transfer Function, Linear Transfer Function and Sigmoid Transfer Function (logistic function) as shown below in figure 2.5

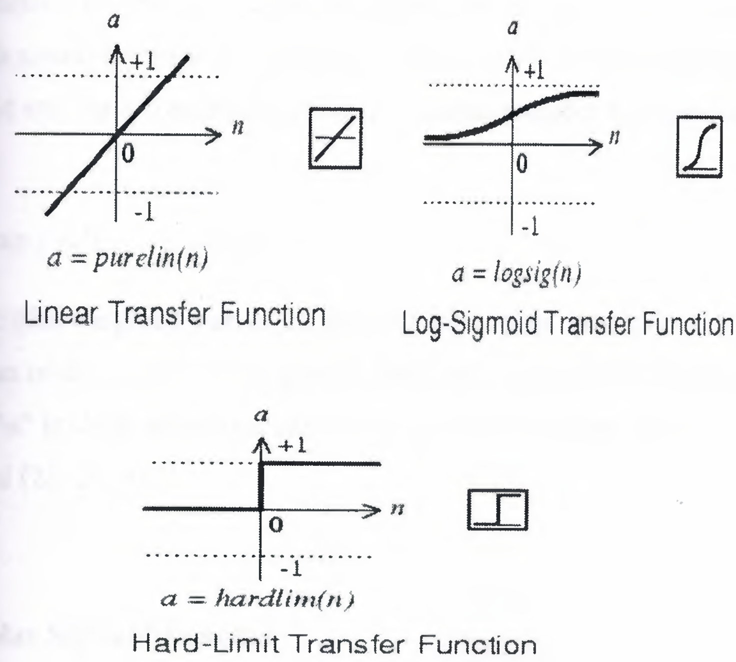

Figure 2.5: Types of transfer functions [48].

Where the output of Hard-limit function can be either "0" or "1" depended on the threshold. As a result of the non-continuity of this function so it has been found that it is not sufficient for multi-layer artificial neural network, so the activation function used to transform the activation level of neuron (weighted sum of inputs) to an output signal, the sigmoid function is most common type of activation function where it is an example of the logistic function therefore majority of Artificial Neural Networks (ANNs) use Sigmoid Transfer Function (logistic function) [23, 24, 25, 42].

2.5.1 Logistic Function

A Logistic function is a common sigmoid curve, which has "s-shape", given its name in 1844 or 1845 by Pierre François Verhulst who studied it in relation to population growth. Logistic functions are often used in neural networks to introduce nonlinearity in the model and/or to clamp signals to within a specified range. A logistic function is also known as a log-sigmoid function which the nonlinear curved s-shape function is called sigmoid function. Sigmoid function is most common type of activation function (A function used to transform the activation level of neuron (weighted sum of inputs) to an output signal) used to construct the neural network .It is mathematically well behaved, differentiable at everywhere and strictly increasing function .A sigmoid transfer function can be written in the form:

Y(x) =1 / (1+exp (-αx))   where "α" =1   (2.3)

Where Y(x): (the weighted sum of all synaptic input plus the bias) of neuron "x", and "y" is the output of the neuron. The sigmoid function is achieved by using exponential equation, and "α" is slope parameter and by varying "α" different shapes of the function can be obtained [23, 26, 49].

2.5.2 Unipolar Sigmoid Function

Activation function of Unipolar Sigmoid Function is achieved by using logarithmic function where the output is limited between "0" and "1", the logarithmic sigmoid function is given by:

G(x) =1 / (1+exp (-x))   (2.4)

The input's range of the unipolar transfer function is between plus infinity and minus infinity and squashes the output into the range between ("0" to "1"), as shown below in figure 2.6

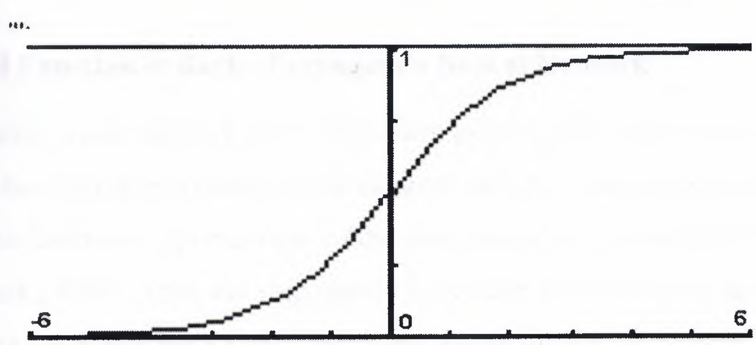

Figure 2.6: Unipolar Sigmoid Functions [26].

In the other word, the unipolar sigmoid is used when the range of the desired output is bounded between (zero to one) when the input has any value between (plus and minus infinity) [23, 26, 49].

2.5.3 Bipolar Sigmoid Function

The Bipolar Sigmoid Function is similar to the sigmoid function but this activation function takes the input (which may have any value between plus infinity and minus infinity) and the output is changed into (-1 to 1) .In the other word the bipolar sigmoid is used when the range of the desired output is bounded between (- one to one) when the input has any value between (plus and minus infinity), as shown below in figure 2.7 [23, 26, 43, 49].

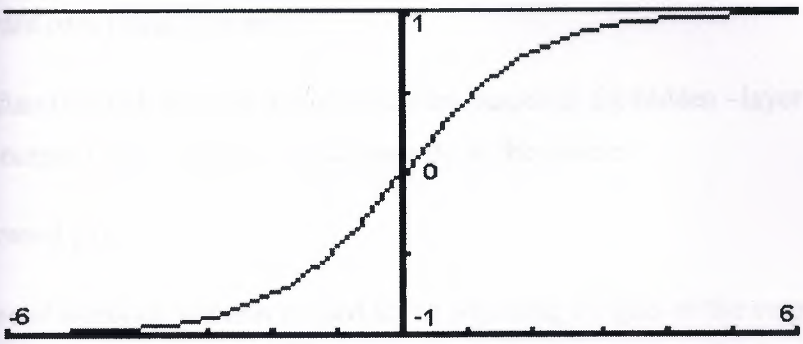

Figure 2.7: Bi-Polar Sigmoid function [26].

2.6 Sigmoid Function in Back –Propagation Neural Network

The artificial neural network (ANN) has been given more and more interest in the last decades and has been introduced in different application in many aspects of science. The activation functions represent one of the most important components in the artificial neural network (ANN). They are responsible for giving the priority for the different inputs of the networks and then have a very important rule in output production.
The earlier neural networks has been constructed using hard-limit (a Threshold logic) activation functions where the output can be either zero or one, but the increasing need of the ANN in non-linear systems has imposed to use the activation functions with has non-

linear properties that are not based on switching (hard-limit) functions and can give proportional output to the given input.

The use of such functions for continuous valued targets with bounded range has attracted the attention of researchers in the domain of ANN.

The sigmoid function which introduced in 1844 has been chosen to be introduced in the function of artificial neural network due to their non-linearity and continuity of the output which seems to be more effective and useful for using in the back-propagation neural network, where Back_ propagation is an efficient and a popular method which was invented in 1986 by Rumelhart, Hinton and Williams for training multilayer neural network (the network have input layer and one or more than hidden layers and the output layer) to solve difficult problems, the training process consists of two passes through the layers of the network, the forward pass and backward pass.

In the forward pass (feed-forward):

The sigmoid function will be used to determine the output of the hidden –layer and the output of the output layer to introduce nonlinearity in the system.

In the backward pass:

The derivative of sigmoid function is used in the adjusting weights of the output layer and hidden layer to calculate the error of the back_ propagation process therefor the derivative of sigmoid function is usually employed in learning of the network.

Because of the properties (differentiable everywhere and introducing non linearity in the system), so the logistic function (sigmoid function) is preferable to use in back-propagation neural network [23, 24, 25, 26, 27].

2.6.1 Single Layer Perceptron (SLP).

A single-layer perceptron network (SLP) is the simplest kind of neural network. A single-layer perceptron (SLP) comprises of a number of external inputs then multiplied by corresponding weights and followed by the output layer as shown in figure 2.8.

A single-layer perceptron network can be considered the simplest kind of feed-forward network, where feed forward means that data flows from input to output layer in one direction, the output will be activated when the sum of the products of the inputs and the corresponding weights is above the threshold, where the output will be deactivated when the sum of the products of the corresponding inputs and the corresponding weights is below the threshold [50].

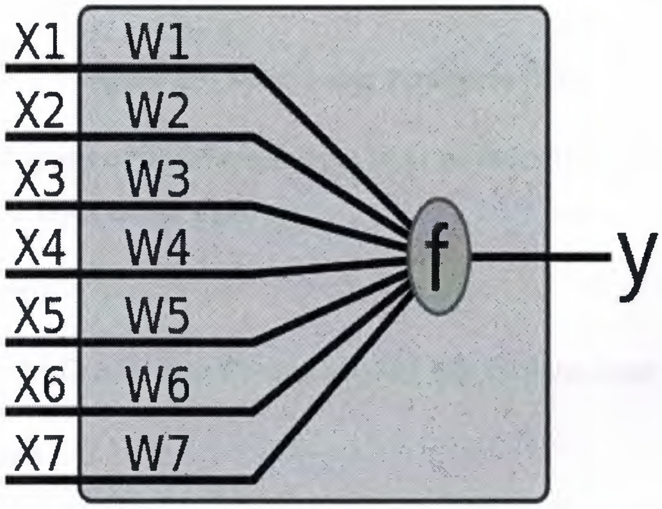

Figure 2.8: Single Layer Perceptron [50].

2.6.2 Multi-Layer Perceptron (MLP).

Multi-Layer perceptron (MLP) is a second type of feed forward neural network, with one or more layers between input layer and output layer called hidden layers, therefore all neural networks have an input layer and an output layer as shown in figure 2.9, the number of input neurons normally corresponds to the number of independent variables which are fed the network, the number of hidden layers may vary from network to another network and the number of output neurons depends on what order the network is executing .

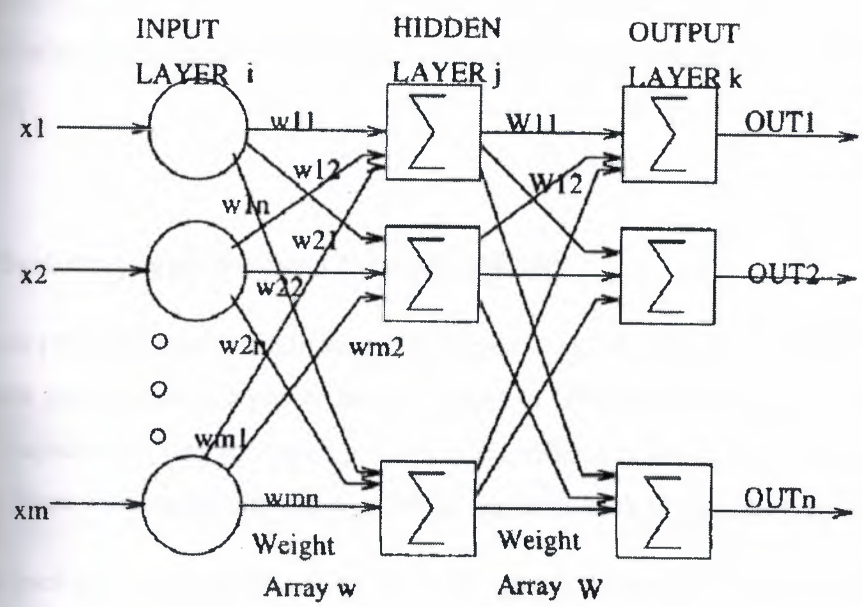

Figure 2.9: Multi-Layer Perceptron [24].

This network is consists of three layers: input layer on the left, one hidden layer in the middle and an output layer on the right.

- Input Layer :

An input layer is the first layer in a neural network that receives input data.

- Hidden layer :

There can be one or more hidden layers in feed forward neural networks with one or more neurons.

- Output layer :

There is one output layer in feed forward neural networks. The output layer is located after the input layer and the hidden layer, where the output layer is the third and last layer in artificial neural network. Multi-layer perceptron (MLP) can solve more complicated than single-layer where it can solve problems and obstacles which are not linearly separable by using Back Propagation algorithm, which can be used with any number of layers

When every node in each layer of the Artificial Neural Network is connected to every node in the neighbouring layer in this case the Artificial Neural Network is called the network of fully connected, where the Artificial Neural Network is called the network of partially connected when some of connection links are lost from the network [23, 24, 27, 28, 32, 33, 42, 43, 50]

2.6.3 Back Propagation Neural Network (BPNN)

The Back propagation algorithm was first proposed by Paul Werbos in the 1970's. Where back propagation is a powerful tool created in 1986 when various researchers invented a systematic way for training multilayer artificial neural network to solve difficult problems them with highly algorithm called as the error back propagation algorithm.

The error back propagation consists of two basic passes through the network layer: the forward pass and the backward pass.

- In the forward pass the input is applied to the layers of the network, and its effect propagate through the network layer by layer, finally the outputs is produced as actual output of the network.
- During the backward pass the synaptic weights are adjusted (updated) by the error- correction rule. Specifically, the actual output is subtracted from a desired output called target to produce an error of the network, this error is propagated backward though the network, the synaptic weights at output layer and hidden layer are updated (adjusted) so as to make the actual output of the network closer to the desired output (target) [23, 24, 25, 28, 29, 30].

The forward pass and backward pass of the back propagation algorithm are shown below in figure 2.10.

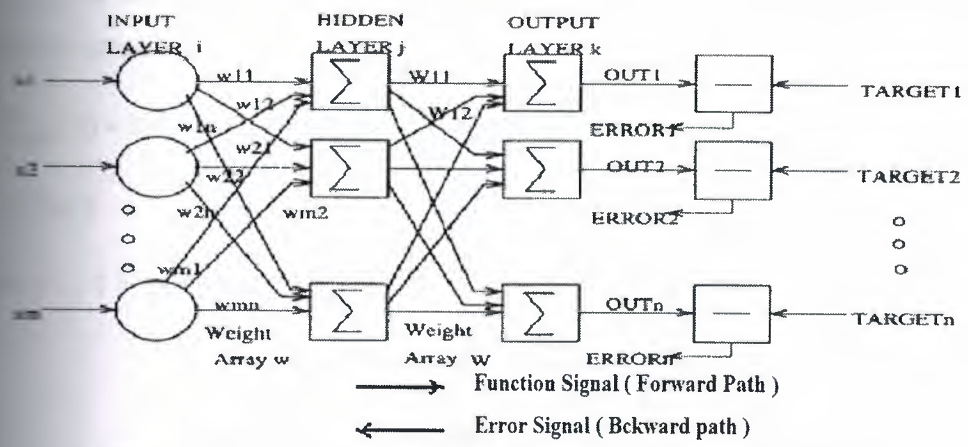

Figure 2.10: Back Propagation Neural Network Architecture [24, 51].

2.6.4 Feed Forward Path and Calculations

The Feed Forward process started to learning neural network by using back propagation method where the simple three layer back propagation is shown below in figure 2.11.

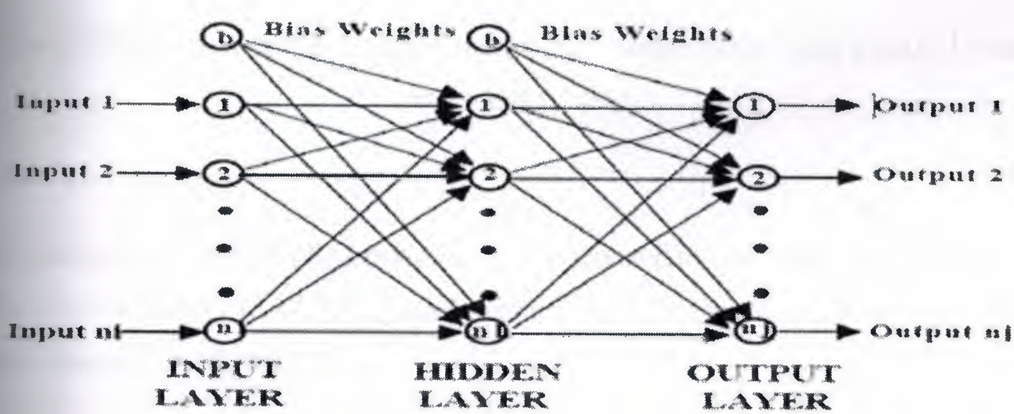

Figure 2.11: Back Propagation Network Structure [25].

Back propagation network consists of three layer: input layer (i), hidden layer (h) and output layer (j), when the inputs is passing forward through the layers the output are calculated by using a sigmoid activation function as shown in figure 2.12.

The output of any neuron (multiple inputs and signal output) in all the layers is given by using these equations:

$Net = \sum_{i=1}^{n} Xi * Wi$ (2.5)

$Out = F\ (net)$ (2.6)

$F\ (Net) = 1 / 1 + \exp(-net)$ (2.7)

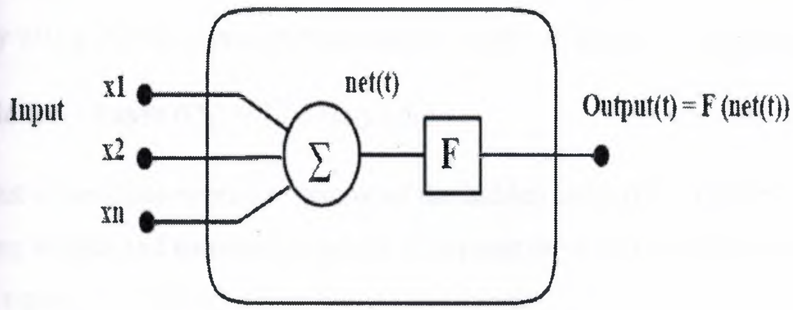

Figure 2.12: Artificial Neuron [25].

Where "F" is the sigmoid activation function, the derivative of sigmoid function is usually employed in learning of the network which is cab being obtained as follows:

$$\partial F\ (net) / \partial\, net = \exp(-net) / (1 + \exp(-net))\ ^{\wedge 2} = (1 + \exp(-net)) * (\exp(-net) / 1 + \exp(-net)) = out\ (1 - out)$$

$$= F\ (net)\ (1 - F\ (net)) \qquad (2.8)$$

Because of its properties (differentiable everywhere and introducing non linearity in the system), so the logistic function (sigmoid function) is preferable to use in back-propagation neural network [25, 32, 50, 52].

2.6.5 Input Layer (i), Hidden Layer (h) and Output Layer (j) in the Feed Forward Path.

The feed forward path starts when the input data is passed forward through the network, where output of the input layer (O_i) is equal to input of the input layer (I_i) as written in this equation:

Input of the Input - Layer (I_i) = Output of the Input - Layer (O_i) (2.9)

Then each output of an input neuron in output of the input layer (O_i) is multiplied by their corresponding weight and summed to gather to present input of the hidden layer (I_h) as described in equation (2.10).

Input of the Hidden - Layer (I_h) = $\sum_i W_{hi} * O_i$ (2.10)

After that every output of a hidden neuron in output of the hidden layer (O_h) is calculated by using logistic function (sigmoid function) as written in equation (2.11).

Output of Hidden – Layer (O_h) = 1 / 1+exp (-I_h) (2.11)

Each output of an input neuron in output of the hidden layer (O_h) is multiplied by their corresponding weight and summed to gather to present input of the output layer (I_j) as described in equation (2.12).

Input of the Output - Layer (I_j) = $\sum_h W_{jh} * O_h$ (2.12)

Then every output of a neuron in output of the output layer (O_j) is calculated by using logistic function (sigmoid function) as written in equation (2.13).

Output of Output – Layer (O_j) = 1 / 1+exp (-I_j) (2.13)

From this equation (2.12), the output in the output layer (O_j) is a function for Input of the Output - Layer f (I_j).

These equations (2.9, 2.10, 2.11,2.12 and 2.13) that have been used above very important in the feed forward path for calculating the output which is totally defers from the desired output (Target), since all weights in all layers of the network are small random value usually between (-1 and +1) and (0 and +1) or other small values, then the error of each neuron in the output layer is calculated to be used in other layer of the network to update the weights [25, 50].

2.6.6 Backward Pass Propagation

After the actual output was calculated in the feed forward path, the backward Pass propagation begins by calculation the Error of each neuron in the output layer, which is essentially equal (Target – Actual output that was calculated in the feed forward path).

Rumelhart and McClelland define the error in the network by the deference between the output value is supposed to have, called target and denoted by "T_j", and Actual output that was calculated in the feed forward path which is symbolized by "O_j", where the small letter "j" indicates for the output layer.

Equation (2.14) performs the error which is symbolized by "E_p".

$$E_p = \sum_{j=1}^{Nj} \left(T_{pj} - O_{pj}\right)^{\wedge 2} \tag{2.14}$$

So the error for each output unit "j" is based on the difference between the estimated and desired output for that unit.

Where the small letter "p" indicates what the value is for a given pattern, the purpose of training network is going to get the actual output (O) of each neuron at output layer more closer to its Target (T) subsequently the error minimized .

From equation (2.12), the output in the output layer (O_j) is a function for Input of the Output - Layer f (I_j) as described in equation (2.15):

$$O_j = f\,(I_j) \tag{2.15}$$

The first derivative of this function performs backbone in error back propagation, in the output layer the error signal will be calculated by using equation (2.16) and (2.17), where the error signal is denoted by "Δ_j", and the derivative of this function is denoted by "$\dot{F}$".

$$\Delta_j = \dot{F}\,(I_j) * (T_j - O_j) \tag{2.16}$$

$$\Delta_j = O_j\,(1 - O_j) * (T_j - O_j) \tag{2.17}$$

This error value is will used to udate weights in output layer (j) and hidden layer (h) therefor the error valueis propagated back through the layers where this process is repeated many times even this error will be decreased [7, 23].

These equations (2.9, 2.10, 2.11, 2.12, 2.13, 2.14, 2.15, 2.16 and 2.17) that have been used above, which are going to adjust the weights by using these steps:

- Feed the patterns into the layers of the network and make these patterns propagate through input's layers passing hidden's layers the to the output's layer.

- Calculating the error by doing comparison between the estimated output (actual output) and desired output (Target).
- Determine the derivative of the error for each output neuron.
- Using this derivative to update (adjust) the weights of the output layer and the hidden layers [9].

Therefore the important structure of any program that is solved by using back-propagation neural network is shown below in figure 2.13.

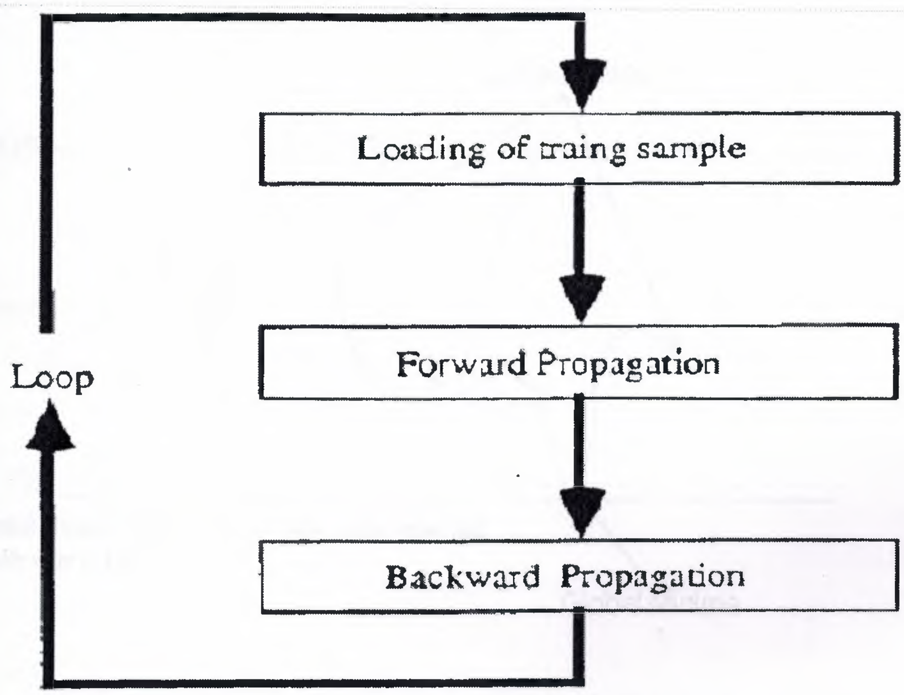

Figure 2.13: Structure of any program by using back-propagation neural network [53].

2.6.7 Learning Rate and Momentum Factor

These two important parameters are effecting on the learning capability of the neural network.

First is the learning rate coefficient (the learning step size) which is denoted by "η", where the learning step size (η) defines how much the weights should change to decrease the error function (Mean Square Error (MSE)). If the learning step size coefficient (η) is very small then the learning process (convergence) will be very slow, if the learning rate coefficient (η) is too large then the error function is going to increase and instability probably will happen and the global minima will be missing, therefore the learning rate coefficient (η) should be chosen very carefully to accelerate the convergence and keeping the network in stability at the same time.

Second is momentum factor which is denoted by "α", where the momentum factor (α) is a method performed by Rumelhart, Hinton and Williams for improving the training time of the back propagation algorithm by solving a specific problem called "Local Minima" as shown below in figure 2.14

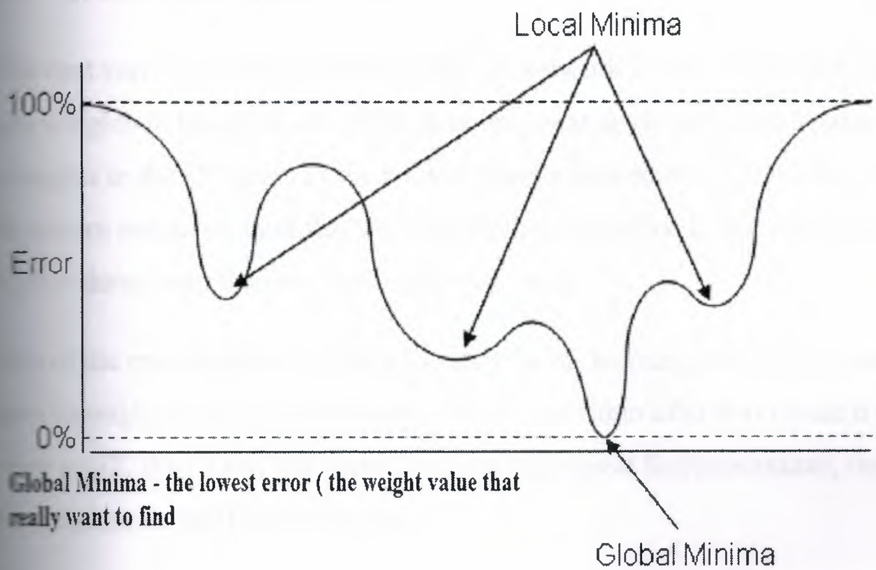

Figure 2.14: Areas of Local Minima and Global Minima [26].

The Local Minima occurs because the algorithm always changes the weights in such a way to cause the error function fall, but the error might briefly have to rise as part of more general fall. If this is the case, the algorithm will get stuck somewhere because it cannot ascend to top of that hill and in this case the error will not decrease.

The momentum factor (α) is a very important coefficient to avoid the falling in hole of the Local Minima, where in this place the error is above zero, with the aim to arrive the global minimum, where in this place the error is approximately zero.

The vocabulary "momentum" is derived from the analogy of a rolling ball with high momentum passing over a tight pit, if the ball rolls slow, the ball is going to drop and confine in the pit. If the ball rolls fast enough, the ball will not trap in the pit.

The values of the momentum factor (α) and the learning rate coefficient (η) usually range between 0 and 1 and in general these two parameters are used for accelerating back propagation process [23, 24, 25, 32, 33, 34, 35].

2.6.8 Training the Inputs data

The best way for learning and teaching the network is to feed the first pattern and update all the weights in the all layers of the network, next apply the second pattern and change all the weights in the all layers of the network (same procedures in the first pattern), then the third pattern and so on until the last pattern, then return back to the first pattern and repeat that procedures until the error becomes very small.

One of the most popular faults in the starting of learning patterns is to feed the first pattern through layers of the network, run the algorithm after that repeat it until error will be very small, then apply the second pattern and repeat that procedures, then the third pattern and so on until the last pattern.

If this case happened, the network is finished its work with only the last pattern will be learned, that means when the next pattern applied to the network, the network will be forget the previous pattern and so on until reaching to the last pattern.

The total error of the network will be evaluated by adding up all the errors for each individual neuron and then for each pattern as shown below in figure 2.15, in other word the network continues coaching all the inputs data of the network until the total error falls down to the value of the desired objective (Target) and then the algorithm stops.When the network has been coached, in general the network is going to recognize not just the original inputs data, but also the network is going to predict another values from the inputs data, or in other cases, the network is going to recognize not only the original patterns (inputs data), but also the network is going to recognize corrupted and noisy patterns. The network is going to use the adjusted (updated) weights in the learning stage as the weights in the test stage [35]

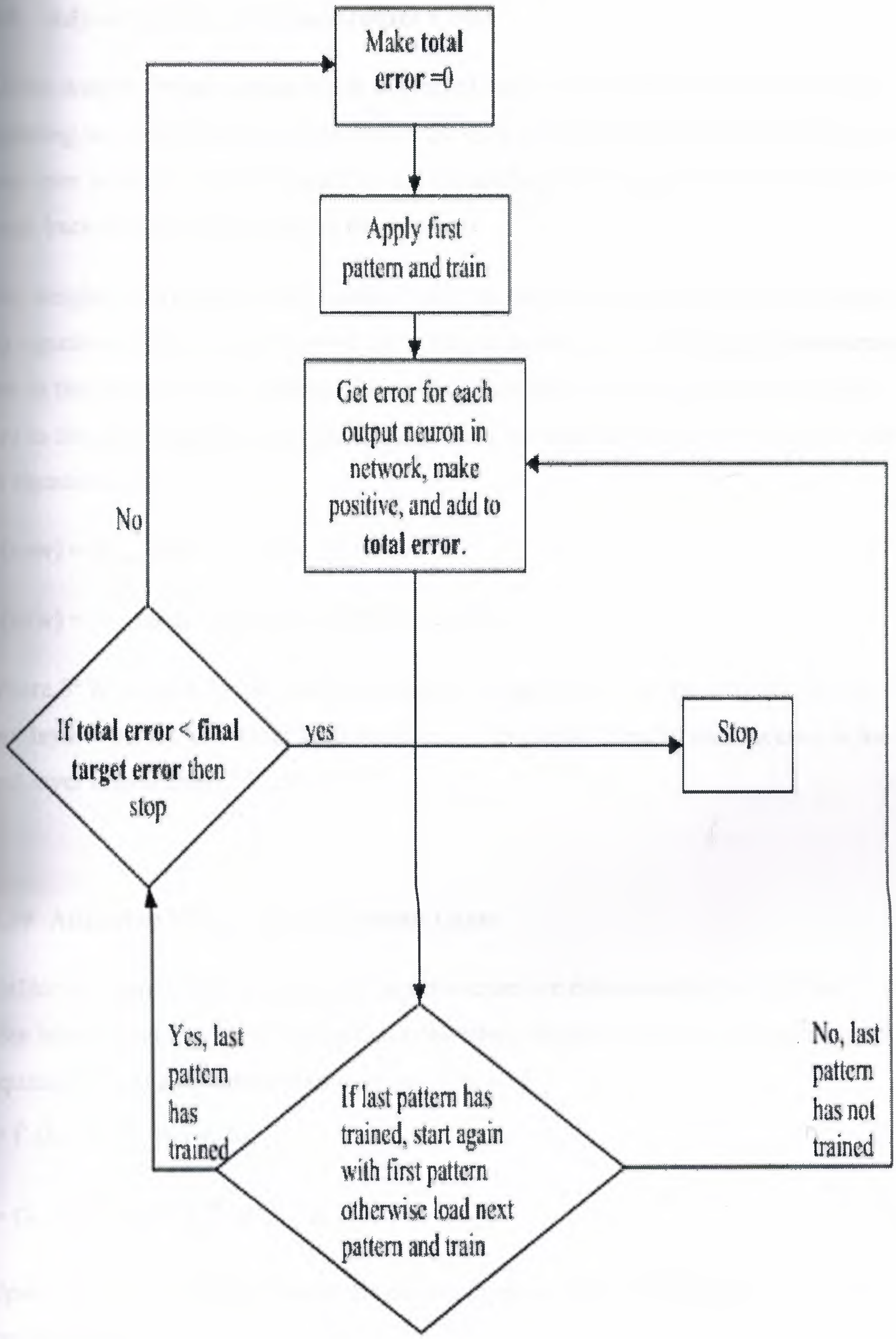

Figure 2.15: Procedure for calculating the total error [35].

2.6.9 Adjusting Weights in the Output Layer

All the weights in the various layers are initialized to small random number, the process of updating weights begins from the end of the feed forward path, in other word, from the output layer in the feed forward path, and the error function is going to update the weight through backward to other layers of the network.

The weights (W_{jh}) between the hidden layers (h) and the output layers (j) are updated using equation 2.18, in order to avoid the falling in hole of Local Minima's phenomenon, where in this place the error is above zero, with the aim to arrive the global minimum, where in this place the error is approximately zero, the momentum factor (α) can be added as in equation 2.19.

$$W_{jh}\,(new) = W_{jh}\,(old) + \eta * \Delta_j * O_h \qquad (2.18)$$

$$W_{jh}\,(new) = W_{jh}\,(old) + \eta * \Delta_j * O_h + \alpha * [\delta * W_{jh}\,(old)] \qquad (2.19)$$

Where $\delta * W_{jh}$ stands for the previous weight change. Adjusting the weights for the output layer is easier than other layers because of the target value of each neuron in the output layer is available [24, 25, 32, 50].

2.6.10 Adjusting Weights in the Hidden Layer

Unlike the output layer neurons, the target vectors are not available for neurons in the hidden layers. Rumelhart and McClelland describes the error term for a Hidden neuron as in equation (2.20) and, subsequently, in equation (2.21).

$$\Delta_h = \dot{F}\,(I_h) * \sum_{j=o}^{Nj} W_{jh} * \Delta_j \qquad (2.20)$$

$$\Delta_h = O_h * (1 - O_h) * \sum_{j=o}^{Nj} W_{jh} * \Delta_j \qquad (2.21)$$

Updating of the weights between the hidden layer and the input layer are calculated using equation (2.22).

$$W_{hi}\,(new) = W_{hi}\,(old) + \eta * \Delta_h * O_i + \alpha * [\delta W_{hi}\,(old)] \qquad (2.22)$$

This way is similar to the way that was used in adjusting weights in the output layer [24 and 25].

2.7 Learning in Back Propagation Algorithm

The proposed training algorithm used in the back propagation algorithm is shown below in many steps:

- Initialize the weights of the layers to small random values.
- Select a training vector (input and the corresponding output).
- Propagate the inputs data forward through the network and calculating the actual outputs in the feed forward path.
- Calculating the error from the difference between actual output and target.
- Reduce the error function by updating the weights in the output layer and the hidden layer in the backward path.
- Go to step 2 and repeat for the next pattern until the error is acceptably small or a maximum number of iterations is reached (epoch) [28, 54, 55].

Because of the simplicity in use impressive speed for training and teaching Artificial Neural Network (ANN), and because of their distinctive ability to extract meaning from the complicated data and recognize patterns beside of its massive ability to predict and data filtering, all that made the back propagation learning algorithm a powerful tool and widely used technique in the learning and training of the Artificial Neural Networks (ANNs).

2.8 Using MATLAB for Implementing Back-Propagation

The name MATLAB stands for matrix laboratory. It is an interactive system that provides fast matrix calculation. This is very useful feature, since most of the numerical calculations in neural computing are matrix operation. MATLAB'S excellent graphical feature can also be utilized in examining error [24].

2.9 Summary

This chapter presented a general overview of Artificial Neural Networks (ANNs) and their application in various aspects of the life. The importance of sigmoid transfer function at back propagation neural network was displayed in detail. Feed forward path and backward path at back propagation algorithm. Adjusting weights in the hidden and the output layers were submitted in detailed form.

This chapter gave a good background to understand usage of the back propagation neural network in assessment security of power flow that will be presented in detail later.

CHAPTER THREE

POWER FLOW AND SECURITY ASSESSMENT

3.1 Overview

The power flow analysis is an immensely substantial toll in the designing and planning of the power system. The idea of the load flow problem is to obtain the voltage magnitudes and angles for each bus (swing bus, generator bus and load bus) in the power system. The security assessment and its types will be discussed to identify the system operating states (a normal state, an alert state and an emergency state). To determine the problem of the power flow analysis, the bus admittance matrix (Y_{bus}) and equivalent π-circuit for the transmission lines are going to obtain by using the procedures of the Newton Raphson method. The Newton Raphson method is chosen to solve the load flow problem because of a tremendous ingenuity to formulate the problem and an excellent ability of the convergence for the unknown variables.

3.2 Introduction

Power flow analysis came into existence in the early 20th century. There were many research works done on the load flow analysis. In the beginning, the main purpose of the load flow analysis was to find the solution irrespective of time. Over the last 20 years, efforts have been expended in the research and development on the numerical techniques [57].

Power-flow or load-flow studies are of the great in planning and designing the future expansion of power system as well as in determining the best operation of existing systems. The principal information obtained from a power-flow study is the magnitude and phase angle of the voltage at each bus and the real and reactive power flowing in each line (flow in the line) [56].

Therefore the load flow study is an important tool involving numerical analysis applied to a power system [58].

Where it analyzes the power systems in normal steady-state operation and it usually uses simplified notation such as a one-line diagram and per-unit system. The power flow problem consists of a given transmission network where all lines are represented by a Pi-equivalent circuit and transformers by an ideal voltage transformer in series with an impedance [59]. Therefore In order to perform a load flow study, full data must be provided about the studied system, such as connection diagram, parameters of transformers and lines, rated values of equipment, and the assumed values of real and reactive power for each load [58].

There are different methods to determine the load flow for a particular system such as: Gauss-Seidel, Newton-Raphson, and the Fast-Decoupled method [60].

The Newton-Raphson power flow method is going to be used in this thesis because of exact problem formulation and very good convergence characteristic while Gauss-Seidal power flow method is simple to understand, but this method is not recommended because of poor convergence characteristics, where the Fast-Decoupled power flow method may fail to converge in certain cases. So for these reasons Newton–Raphson power flow method became more popular or widely used, where the Newton–Raphson method is preferred over all traditional methods [59, 61].

A power system is said to operate in a normal state if all the loads in the system can be supplied power by the existing generators without violating any operational constraints. Operational constraints include the limits on the transmission line flows, as well as the upper and lower limits on bus voltage magnitudes therefore Static security of a power system addresses whether, after a disturbance, the system reaches a steady state operating point without violating system operating constraints called 'Security Constraints'. These constraints ensure the power in the network is properly balanced, bus voltage magnitudes and thermal limit of transmission lines are within the acceptable limits given, If any of the constraint violates (system under contingency situation), the system may experience disruption that could result in a `black-out' [1, 3] .

So the power system security can be defined as ability of the system to reach a state within the specified secure region following a contingency (outage of one or several line and transformer) [63].

3.3 Static Security Assessment (SSA)

Power system security has been recognized as an important aspect in planning, design and operation stages since 1920s. Nowadays, power systems are forced to operate under stressed operating conditions closer to their security limits. Under such fragile conditions, any small disturbance could endanger system security and may lead to system collapse so the security assessment is analysis performed to determine whether, and to what extent, a power system is “reasonably” safe from serious interference to its operation security assessment can be classified as static, dynamic and transient security assessment[63, 64, 65].

In this thesis a static security assessment is going to be discussed and depending on it in this design of thesis as shown below in figure 3.1.

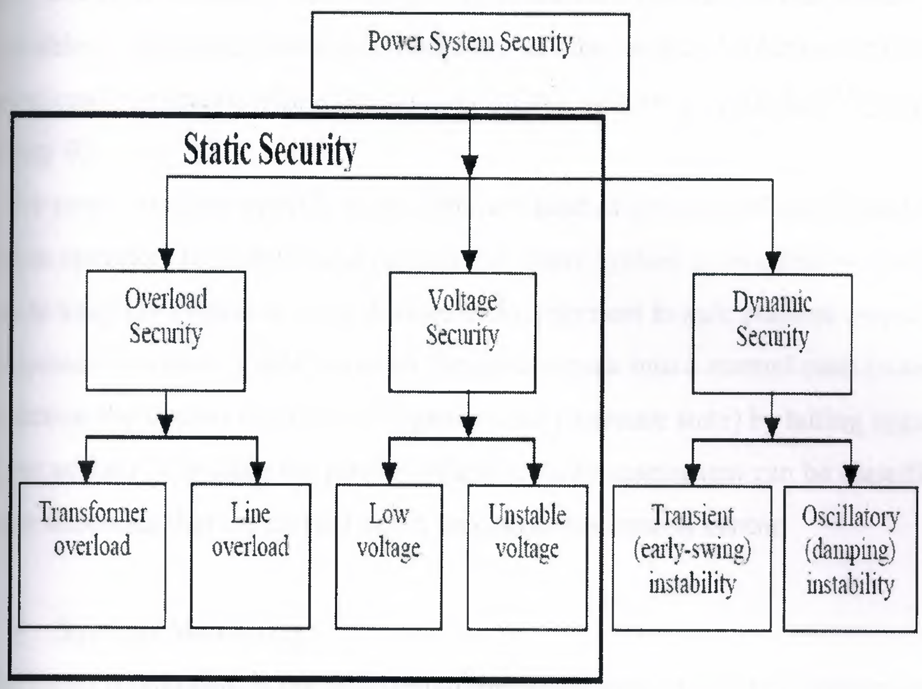

Figure 3.1: Types of Power System Security [66].

Static security is one of the main and important aspects of power system security assessment, where it is ability of power system to keep at normal steady state before and after contingency (unexpected failures) or to reach a steady state operating point without violating in the system operating (limits of bus voltages and transmission line's thermal limit) and continue feeding and transfer the power supply to consumers without interruption, where violation in the system operating may be lead to the blackout or collapse in that system [65].

The interruption or contingency in power system was considered from important causes that leading the system to be at position of insecure mode as a result of crossing the thermal limits of transmission line and the limits of bus voltages, where these contingencies are happening because of outage of transmission line, equipment damage, sudden change in load of system and loss of transformer, therefore any system can be called as "secure system" or "normal system" if this system can remain in the normal operation limits (the thermal limits of transmission line and the limits of bus voltages) before and after contingency and the situation of this system is symbolized by digit one "1" (binary 1), and any system can be named as "insecure system" or "emergency system" when the normal operating limits (the limits on the transmission line flow as well as the upper and lower limits on bus voltage magnitude) are violated, so this system is going to be unable to withstand credible contingency in other words, Violations will be some operational constraints where the situation of this system is symbolized by digit zero "0" (binary 0).

The power systems provide much different kind of devices and equipment to enable the system operators to monitor and manage the entire system in an effective manner as well as is to keep the system with its devices and equipment in safe position (secure mode), also the system operators is able to return the system back into a normal state (secure state) and protection the system from the emergency state (insecure state) by taking appropriate and urgent actions , therefore the power system security assessment can be classified into three major functions that are carried out in an operations control centre:

- Systems Monitoring:

Systems monitoring is the first step of the power system security assessment, where system monitoring provides up-to-date measurement and information from all parts of the system such as (line power flow, bus voltage, magnitude of the line current, output of the generator, status of the circuit breaker and switch status information) through the telemetry system then analyzing them in order to identify and determine the system operating state [3, 4].

The system operating states can be broken into Normal state, Alert state, Emergency state, Extreme Emergency state and Restorative state as shown below in figure 3.2.

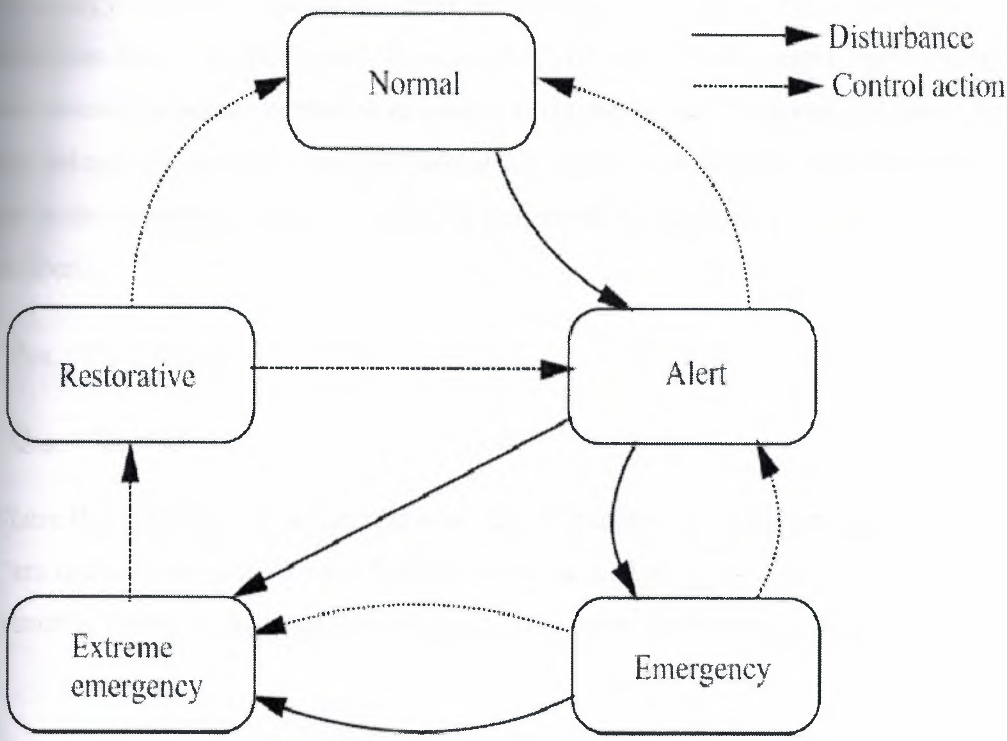

Figure 3.2 Power System Operating States [10].

Normal state:

All equipment and devises operates naturally and in a secure position (without damages or outages in transmission lines, transformers and other parts of system that lead the system to be at insecure state), since there are no violation in the system operating limits (the limits on the transmission line flow as well as the upper and lower limits on bus voltage magnitude as described in equation (3.1) and equation (3.2) respectively).

$$| V_{K\ min} | < | V_K | < | V_{K\ max} | \qquad k = 1, 2, 3........n \qquad (3.1)$$

$$S_K < S_{max} \qquad k= 1, 2, 3.........n \qquad (3.2)$$

Where $|V_K|$ is the voltage magnitude at bus k, S_K is the complex power (apparent power) which is flowing at line.

The energy is going to reach the consumer without any interruption, if any line of the transmission lines is tripped or any equipment of the system is damaged, but the power system remains at secure condition as long as does not exceed the upper and lower limits on bus voltage magnitude as well as the thermal limits on the transmission line so the power in the network is correctly balanced as written in equation (3.3) and equation (3.4) respectively.

$$\sum_{k} P_{GK} = P_D + P_{Losses} \qquad k = 1, 2, 3 \ldots\ldots N \qquad (3.3)$$

$$\sum_{k} Q_{GK} = Q_D + Q_{Losses} \qquad k= 1, 2, 3 \ldots\ldots N \qquad (3.4)$$

Where P_{GK} and Q_{GK}, represent real and reactive powers of generators at bus (k), P_D and Q_D, are the total real and reactive load demands as well as P_{Losses} and Q_{Losses} are the real and reactive losses in the transmission lines of the system network [1, 4, 5, 6].

Alert state:

In this state, the system variables are remain within limits (the limits on the transmission line flow as well as the upper and lower limits on bus voltage magnitude), the alert state is similar to the normal state in that all limits are not exceeding the acceptable borders of transmission lines and voltage magnitude at all buses, but when a contingency happens, a small disturbance can lead to violation of some security limits (future disturbance is going to violate some thermal limits of transmission lines or upper and lower limits of voltage magnitude), the system can be in the alert state by damage, loss and outage of any part of operating system as well as unacceptable increasing in the system load, thus the security level falls below a certain limit [1, 3, 5, 7, 8, 13].

Where the thermal limits are the maximum amount of electrical current that transmission lines can bear, when the transmission lines sustain more than its thermal limits then the transmission lines are going to damage over a specified time period due to an increase in temperature on the transmission lines.

The changing in voltages of the system must be remained within the upper limits and the lower limits of voltage magnitude then the electric power is going to reach the consumer without any interruption and the damages in the electric system or customer facilities will be not available, where the damages in the operating system may cause highly collapse of system voltage as a result of blackout of some parts or entire system [67].

Where there are several main blackouts that have occurred in last half century, the first main blackout was on November 9th 1965 in United States. And this blackout happened because of heavy loading conditions which led to the fall of one of the electric transmission lines, where this blackout impacted 30 million people and New York City had lived in darkness for 13 hours [68].

The second major blackout was on July 13th 1977 in United States, and this blackout happened because of in Con Edison System, where a thunderstorm dropped several electric transmission lines, as a result of the dramatic increasing in the loads on transmission lines, causing all transmission lines during 35 minutes. After 6 minutes entire system was out of work where this blackout impacted 8 million people and they had lived in darkness and resulted in economic losses estimated at 350 million U.S. dollars [68, 69].

The third main blackout was on July 23rd 1987 blackout in Tokyo. And this blackout happened because of high peak demand due to massive hot weather conditions, where this blackout impacted 2. 8 million people from residents of Tokyo [68].

The fourth main blackout was on July 2nd 1996 in United States because of short circuit in transmission line, where this blackout impacted 2 million people [68].

The fifth major blackout was on August 14th 2003 in United States-Canada that appeared in the Midwest and affected of the North-eastern and Midwestern United States and southern Canada. And this blackout happened because of falling (tripping) of the electric transmission lines due to a tree contact, where this blackout impacted 50 million people in these countries [9, 68].

The sixth major blackout was on November 4th 2006 in Europe. And this blackout began with 480KV transmission line falling, where this blackout impacted 15 million people in Europe [68].

Emergency or Unsecured state:

A power system enters the emergency mode condition when operating limits (thermal limits of transmission line as well as the upper and lower limits on bus voltage magnitude) are violated. When the system in the emergency state, and suddenly a contingency occurs if the operator of system did not take the immediate corrective action in due course to bring the system back to the alert state, the system will cross from the emergency state to the Extreme Emergency state or collapse of the system [3, 7, 8].

Extreme Emergency state:

The extreme emergency state is a result of an extreme disturbance or incorrect protective action or inefficient emergency control action, where the system in this state is close to collapse or shut down. A proper control action must be taken to rescue the system as much as possible from occurrence of blackout and collapse (breakdown) as well as to transit the system into a restorative state. If these protective actions do not affect, the result is total blackout and shutdown in that system [10].

Restorative state:

Restorative state is the transition state between normal or alert and extreme emergency states, where in this state the operator of the system will make an immediate corrective action in due course to restore services to power system, then the system will transit to one of the safest states [3, 10, 64].

- Contingency analysis:

A contingency is a failure of any one piece of equipment, as well as that, the outage of transformer or transmission line. The outage occurs whenever a transmission line or transformer is removed from service for purposes of scheduled maintenance or they may be forced by weather conditions, faults, and technical errors by operator of the system or other contingencies where and new steady-state operating conditions are established. Therefore operator of the system must be able to guess how the bus voltages and line flows will be changed in the new steady state by using long and deep experience of the operator or specific programs, which can evaluate the contingency analysis. So the contingency analysis is used to forebode the possible systems outage and their effect [4, 13].

There are three types of contingencies:

(N-1) contingency condition: in this condition, only one of system component will fall (transformer or transmission line).

(N-2) contingency condition: in this condition, two one of system component will fall.

(N-X) contingency condition: in this condition, multiple elements of system component will fall, where x is the number of the outage components, under these types of contingencies, operator of the system must be able to choose the corrective preventive action, which it appropriates with that contingency condition [4, 13].

- Security control:

In this condition the operating system will be at insecure mode, operator of the system must take the corrective preventive action to bring the system back to the normal state and to avoid collapse of the system [4, 64].

3.4 A Brief History of the Power Flow

As soon as usage of an interconnected network for transporting of electric power led to improve the economy and the reliability, and this effect recognized very well over half a century ago. But the ability to predict the critical information (the voltages at all buses and flows on network components) was still the problem, for this reason the challenge started by development a tool that would produce this critical information. This tool was called the load-flow or the power flow, this tool came very famous and widely used by power engineers because of its brilliant and imaginative ability to predict the voltages at all buses and flows on network components. In the past the calculator boards were used to solve problems of the load-flow, where these boards were a type of analogue computer. When the modern digital computer entered, the mainframe machine architectures were developed by IBM Corporation and the first papers on the power flow algorithms were published by theorists. Gauss-Seidel method was the earliest algorithms to solve the power-flow problem, but this method is not recommended because of poor convergence characteristic with large system, because of this problem in Gauss-Seidel method, the iterative method is called Newton, which has represented the solution of matrix equation in large system.

In the sixties, many extensions have been made in power- flow methods. In the seventies, the Fast-Decoupled power flow method was presented. The Fast-Decoupled enhanced a speed of algorithm. Until these days, the development is still going to the best results in problem of power flow [70].

Concept of Power Flow

Power flow or load flow is the heart and one of the most important parts of power system planning and operation, as well as that, power flow studies are an amazing starting point for dynamic and transient stability studies.

In 1962, the concept of load flow problem was introduced by Carpentier. The main goal of the power-flow solution is to obtain complete voltage angle and voltage magnitude information for each bus bar connected to the network of that power system with corresponding to specified system operating conditions, as well as that, real powers and reactive powers at various transmission lines as shown below in figure 3.3.

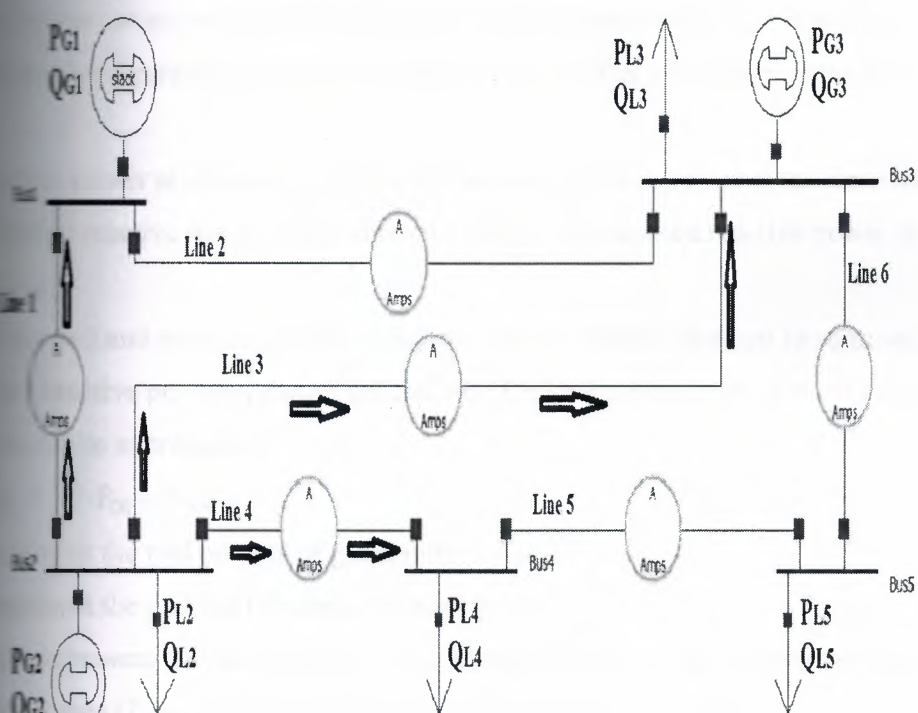

Figure 3.3: Single line diagram of 5-Buses power flow.

This line diagram contains: 5 buses, 3 generators, 4 loads and 6 transmission lines. The second bus was taken to study the power flow on it, where all currents at the second bus flowing from this bus to other buses that they connected with it. Generator is connected with this bus and it injects real power of generator (P_G) and reactive power of generator (Q_G). Load is connected to this bus and it draws real power of load (P_l) and reactive power of load (Q_l).

Where the second bus is connected with the first bus by the first transmission line, and it connected with the third bus by the third transmission line, as well as that, it is connected with the fourth bus by the fourth transmission line. The voltage, real power and reactive power of this bus are equal to:

Voltage (V) at second bus = voltage magnitude |V| * voltage angle (δ).

Real power at second bus (P_2) = real power of generator at the second bus (P_{G2}) – real power of load at the second bus (P_{L2}).

Reactive power at second bus (Q_2) = reactive power of generator at the second bus (Q_{G2}) – reactive power of load at the second bus (Q_{L2}).

Also the total real and reactive powers at the second bus are equal to:

Real power at second bus (P_2) = transmitted real power at the first line (P_{21}) + transmitted real power at the third line (P_{23}) + transmitted real power at the fourth line (P_{24})

Reactive power at second bus (Q_2) = transmitted reactive power at the first line (Q_{21}) + transmitted reactive power at the third line (Q_{23}) + transmitted reactive power at the fourth line (Q_{24}) .

So the real and reactive power injection at the second bus is equal to summation of the real and reactive powers flowing out the bus. The real power balance at all buses and total system can be expressed as:

$$\sum_i^n P_{Gi} + \sum_i^n P_{Di} - P_{losses} = 0 \qquad i = 1, 2, 3......N \qquad (3.5)$$

P_{Gi} represent the real powers of generators at bus (i).

P_{Di} represent the real load demands at bus (i).

P_{losses} represent the real losses in the transmission lines of the system network. Where the real losses ($P_{lossess}$) at each transmission line can be expressed as:

$$P_{losses} = |I^2| * R \qquad (3.6)$$

R represents resistance of transmission line.

I act the current in the transmission line.

The reactive power balance at all buses and total system can be expressed as:

$\sum_{i}^{n} Q_{Gi} - \sum_{i}^{n} Q_{Di} - Q_{losses} = 0$ i = 1, 2, 3……N (3.7)

Q_{Gi} represents the reactive powers of generators at bus (i).

Q_{Di} represent the reactive load demands at bus (i).

Q_{losses} represent the real losses in the transmission lines of the system network. Where the reactive losses (Q_{losses}) at each transmission line can be expressed as:

$$Q_{losses} = |I^2| \cdot X \quad (3.8)$$

X represents series reactance of transmission line.

I is the current in the transmission line.

All transmission lines are represented by a Pi-equivalent circuit at medium length. The load flow solves the problem of the power system in normal steady-state operating and planning, for making the power system more easily a one-line diagram and per unit system will be used.

The steady state power and reactive power provided by each bus in a power system are solved by using nonlinear algebraic equations, where these equations are algebraic because of these equations do not contain derivative functions in the formulating of these equations, therefore there is no differential equation only algebraic equation. And these equations are nonlinear because of these equations contain sinusoidal functions (sine & cosine).

Because of the equations of the power system are nonlinear in nature, therefore iterative numerical techniques will be used such as: Gauss-Seidel (G-S), Newton-Raphson (N-R), and the Fast-Decoupled method.

The Newton-Raphson (N-R) power flow method is going to use in this thesis because of exact problem formulation and a faster convergence characteristic, while Gauss-Seidal (G-S) load flow method is simple to understand, but this method is not recommended because of poor convergence characteristic, where the Fast-Decoupled power flow method may fail to converge in certain cases [57, 58, 59, 60, 61, 71].

After finding the voltages at various bus bar and real and reactive powers at all transmission lines, the operating conditions (thermal limits of transmission lines and voltages limits) will be assessed to prevent the system from many problems and to guarantee that system will stay at secure position.

For all these reasons, the load flow study represents the backbone of the power system [72].

Bus Classification

The meeting point of different components in the network of the power system knows as the bus bar. In practical life, the bus is a conductor manufactured from aluminium or copper.

In the power system every node or bus is associated with four essential elements and they are reactive power which is symbolized as (Q), real power which is symbolized as (P), phase angle of the voltage at various buses which is symbolized as (δ) and voltage magnitude which is symbolized as |V|. During solution of the power flow, two of these quantities are required to be solved by equations of the power flow and the rest of the quantities are specified. The buses of the power system are divided into three categories [57, 58, 72]. They are:

- Load bus

At this bus, the real power and the reactive power are specified. The voltage angle and the voltage magnitude are unknown, so the demand is to find out the voltage angle and the voltage magnitude through the solution of power system. Load bus is called P-Q bus because of the load is connected to this bus [57, 58, 72].

- Voltage control bus or generator bus

At this bus, the voltage magnitude and real power (active power) remain constant through the solution of power system. So the voltage magnitude and real power (active power) of generator bus are specified. Therefore the demand is to find out the reactive power and the voltage angle through the solution of power system. Generator bus is called P-V bus because of the generator is connected to this bus. The voltage magnitude of this bus will stay constant through the solution of power system because this bus has automatic voltage regulator (AVR) system, for that this bus is called voltage control bus [4, 57, 58, 72].

- Slack bus or swing bus

At this bus, the voltage magnitude |V| and the voltage angle (δ) are specified, where the reactive power and the real power are unknown. Generally, during the practical solution the voltage magnitude |V| = 1 per unit and the voltage angle (δ) = 0 degree, the real power slack bus refers to the total real powers generation at all buses minus the total real powers drawn by the loads plus real losses of the transmission lines and the reactive power in this bus refers to the total reactive powers generation at all buses minus the total reactive powers drawn by the loads plus reactive losses of the transmission lines, therefore the slack bus is also known as the reference bus where there is only one slack bus in the power system design [56, 57, 58, 72]. The table 3.1 contains a summary of bus classification:

Table 3.1: Bus Classification

Types of Bus	Known Variables	Unknown Variables
Load or P-Q bus	Real power (P), reactive power (Q).	Voltage magnitude |V|, voltage angle (δ).
Generator or P-V bus	Real power (P), voltage magnitude |V|.	Voltage angle (δ), reactive power (Q).
Slack or swing bus	Voltage magnitude |V|, voltage angle (δ).	Real power (P), reactive power (Q).

So this table will be used to solve the problem of the power flow.

3.4.3 Transmission Lines

At medium length (80 km-240 km), a transmission line can be represented by equivalent-π model as shown below in figure 3.4.

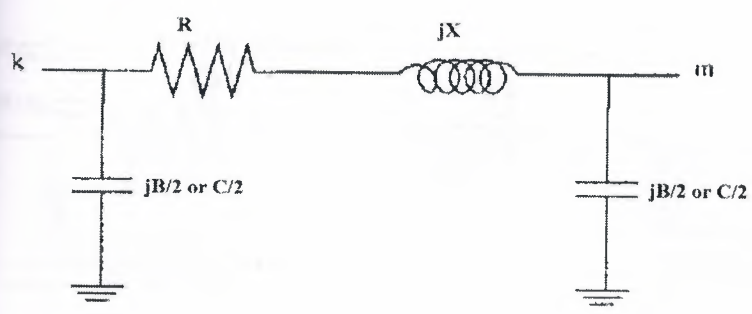

Figure 3.4: Equivalent π-models for a transmission line [3].

A transmission line is represented by an equivalent π circuit with series impedance (R + jX) and shunt charging susceptance (B) or shunt capacitance (C) is divided evenly at each equivalent-pi model, where the shunt conductance (G) was omitted because it is variable, therefore the shunt conductance do not include into account.

The shunt conductance (G) locates between the ground and the conductors or between conductors. The usage of the shunt conductance is to account the leakage current at the insulation of cable and through the insulators of overhead lines.

The series resistance (R) and reactance (X) of transmission line in the equivalent-pi model are responsible for losing active and reactive powers in the transmission line, where R+jX called impedance and it is symbolized by (Z). The losses of real power and the reactive depend on the quantity of the current square through the transmission line as written before in equation (3.6) and (3.8):

$$P_{loss} = |I^2| * R \tag{3.6}$$

$$Q_{loss} = |I^2| * X \tag{3.8}$$

In the equivalent π-models of a transmission line, the shunt charging susceptance (B) or shunt capacitance (C) results from the difference of the potential between transmission-line conductors, the shunt capacitance (C) exists between parallel conductors and it is omitted when the length of a transmission line is less than 80 km.

The shunt charging susceptance equal to the shunt admittance and it is symbolized by (Y/2) in the equivalent π-models of a transmission line [48].

Each half of shunt capacitance (C/2) is injecting the reactive power into the transmission line [26]. The effect of three parameters (R, X and C/2) can be observed at figure 3.5.

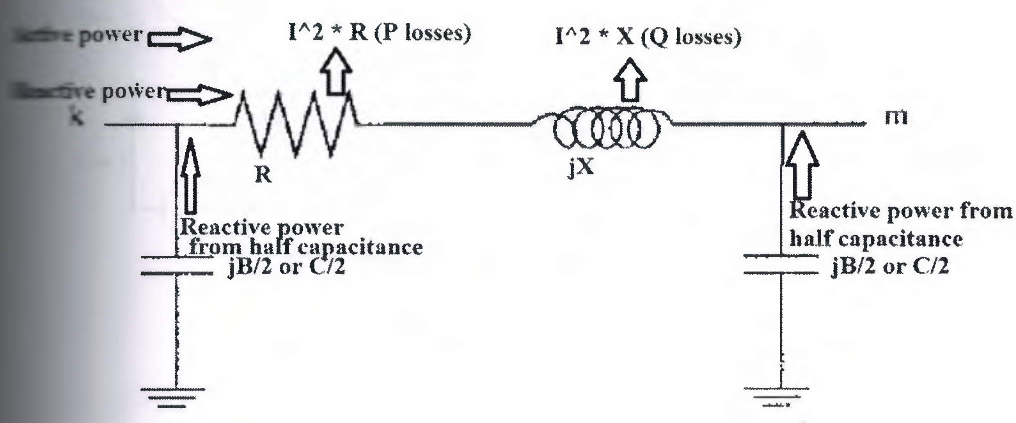

Figure 3.5: Effect of Transmission Line's Parameters at π-Model.

The transmission line in figure 3.5 connects between bus (k) and bus (m), the active power at bus (k) transmitted to bus (m) with a loss that equalled to the current square * the series resistance, where the reactive power from the half capacitance at two sides of the transmission line does not effect on the transmitted active power.

The reactive power at bus (k) transmitted to bus (m) with a loss that equalled to the current square * the series reactance, each half of capacitance at two sides of the transmission line injects a reactive power to the connected line between bus (k) and bus (m) [56].

The transmission line has important role for transferring the electric power to the customer without exceeding the thermal limit of the conductor at that line, the transmission line reaches the thermal limit (current-carrying capacity) of the conductor if the electric current heats the material of the conductor to a certain temperature usually more than 100 Celsius, if the conductor material afforded more than that temperature, the transmission line will cut after a certain period. The thermal limit of the conductor depends on several factors such as: speed of the wind and the ambient temperature etcetera [13].

3.4.4 Bus-Admittance Matrix

The most common approach to solve power-flow problems is to create what is known as the bus admittance matrix and it is symbolised as (Y_{bus}). Consider the simple power system as shown below in figure 3.6.

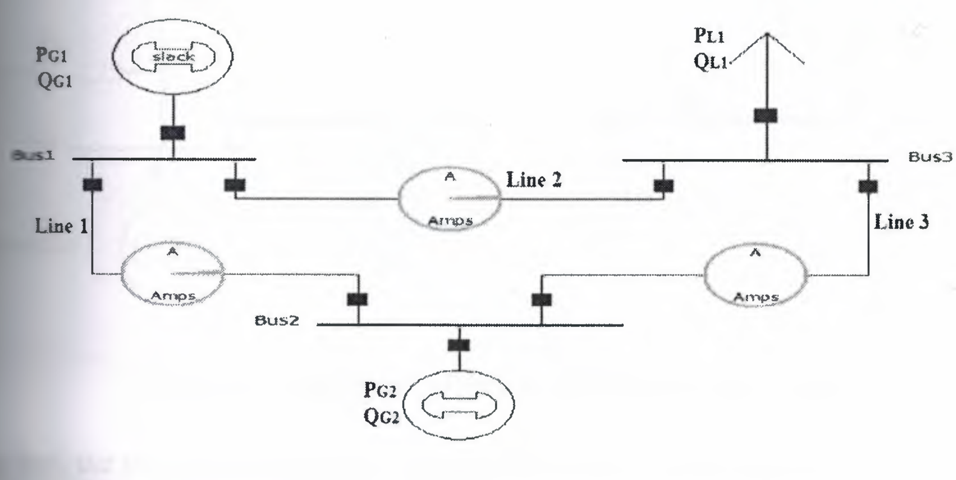

Figure 3.6: Single line diagram of 3-Buses power system

That single line diagram consists of three buses and three transmission lines, the bus admittance of this simple system can be calculated by using equation (3.9):

$$I_{bus} = Y_{bus} * V_{bus} \tag{3.9}$$

Obviously the bus admittance matrix gives the relationship between the voltage at each bus and the current injection at every bus. The bus admittance matrix can be achieved by applying Kirchhoff's current low (KCL) at each bus of the system.

The series impedance of all transmission lines at π model are converted to admittance by using equation (3.10):

$$Y_{ij} = 1/Z_{ij} = 1/(R_{ij} + j\,X_{ij}) = G + j\,B_{ij} \tag{3.10}$$

Where Z_{ij} is the series impedance of the transmission line between any two bus i and j. The power flow solution starts with modelling the transmission line of figure 3.6 by equivalent π-models as shown below in figure 3.7.

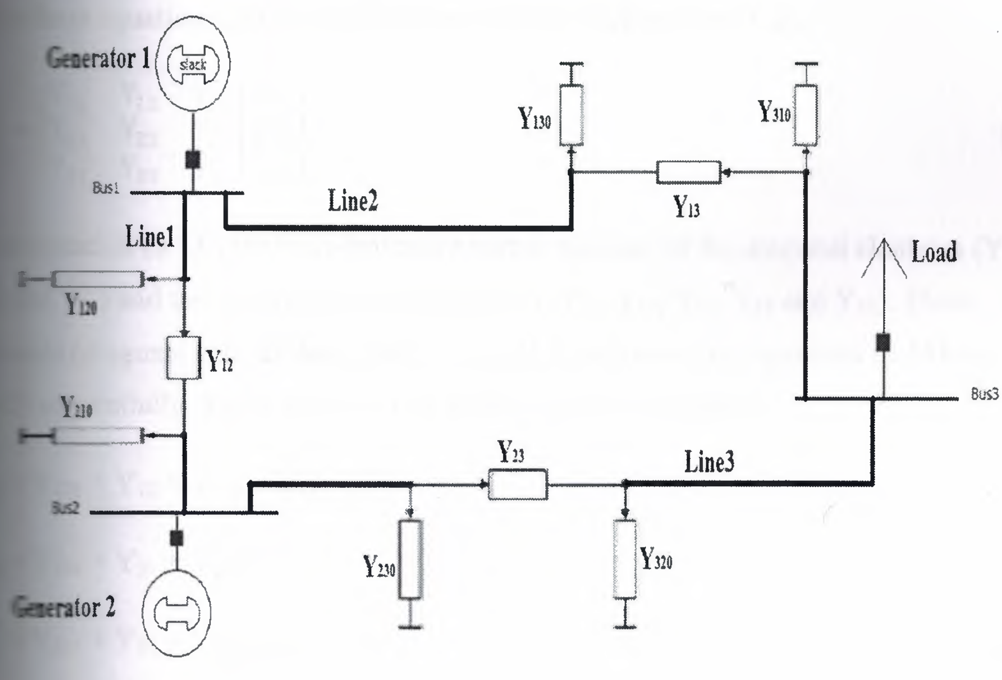

Figure 3.7: Equivalent π-models of 3-Buses Power system

The first, the second and the third transmission lines are represented by π model, where Y_{ij} represents series admittance and Y_{ij0} represents the first and the second half of the shunt admittance. Applying Kirchhoff's current low (KCL) at each bus of the system.

$$I_1 = Y_{120} * V_1 + Y_{12} * (V_1 - V_2) + Y_{130} * V_1 + Y_{13} * (V_1 - V_3)$$

$$I_2 = Y_{210} * V_2 + Y_{21} * (V_2 - V_1) + Y_{230} * V_2 + Y_{23} * (V_2 - V_3)$$

$$I_3 = Y_{310} * V_3 + Y_{31} * (V_3 - V_1) + Y_{320} * V_3 + Y_{32} * (V_3 - V_2) \quad (3.11)$$

Arranging these equations in a matrix form as:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} (Y_{120} + Y_{12} + Y_{130} + Y_{13}) & -Y_{12} & -Y_{13} \\ -Y_{21} & (Y_{210} + Y_{21} + Y_{230} + Y_{23}) & -Y_{23} \\ -Y_{31} & -Y_{32} & (Y_{310} + Y_{31} + Y_{320} + Y_{32}) \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

(3.12)

Also these equations can be written in another form of the matrix as:

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} \quad (3.13)$$

From equation (3.13), the bus admittance matrix consists of the diagonal elements (Y_{11}, Y_{22} and Y_{33}) and the off diagonal elements (Y_{12}, Y_{21}, Y_{13}, Y_{31}, Y_{23} and Y_{32}). These elements (diagonal and off diagonal) can be calculated by using equations (3.14) and (3.15) sequentially. So for the diagonal elements (self-admittance):

$$Y_{11} = Y_{120} + Y_{12} + Y_{130} + Y_{13}$$

$$Y_{22} = Y_{210} + Y_{21} + Y_{230} + Y_{23}$$

$$Y_{33} = Y_{310} + Y_{31} + Y_{320} + Y_{32} \quad (3.14)$$

And for the off diagonal elements (shunt admittance):

$$Y_{12} = Y_{21} = - Y_{12}$$

$$Y_{13} = Y_{31} = - Y_{13}$$

$$Y_{23} = Y_{32} = - Y_{23} \quad (3.15)$$

From these equations, the diagonal element (self-admittance) is the sum of admittances which is directly connected to this bus bar and can be expressed as:

$$Y_{ii} = \sum_{j=1}^{N} Y_{ij} \qquad i \neq j \qquad j = 1, 2 \ldots\ldots\ldots N \tag{3.16}$$

The mutual admittance (off-diagonal admittance) is equal to the negative of the element between any two buses (i and j) and can be expressed as:

$$Y_{ij} = Y_{ji} = - Y_{ij} \tag{3.17}$$

In general the formats of the nodal current and Y_{bus} matrix for n-bus power system can be written as:

$$I_i = \sum_{j=1}^{N} Y_{ij} * V_j \qquad j = 1, 2 \ldots\ldots N \tag{3.18}$$

$$Y_{bus} = \begin{bmatrix} Y_{11} & -Y_{12} & \cdots & -Y_{1n} \\ -Y_{21} & Y_{22} & \cdots & -Y_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ -Y_{n1} & -Y_{n2} & \cdots & Y_{nn} \end{bmatrix} \tag{3.19}$$

From all these equations, the bus admittance matrix (Y_{bus}) has the following characteristics:

The bus admittance matrix (Y_{bus}) has a general complex form (G + j B).

Dimension of bus admittance matrix (Y_{bus}) is (N * N), where N is number of buses in the power system. If 10-buses system will be calculated, then the dimension will be (10 * 10) Y_{bus} matrix.

The bus admittance matrix (Y_{bus}) is a sparse matrix, where large numbers of the elements in the bus admittance matrix (Y_{bus}) are zeroes because the transmission lines between any two buses did not connect with all buses especially in large systems.

The bus admittance matrix (Y_{bus}) is a symmetric matrix as shown in the off diagonal elements of Y_{bus} matrix ($Y_{ij} = Y_{ji}$), where the off diagonal element can be obtained as a negative sign of the series admittance between any two buses.

diagonal elements are the sum of admittances which is directly connected to this bus bar (the series admittance between any two buses and the shunt admittance between the reference and a bus in that system) [3, 56, 70, 72].

Formation of Power Flow Equations

The solution of load flow problem starts with identification the types of buses in the power system (load bus, swing bus and generator bus), where the aim of power flow solution are finding out the voltage magnitude and the voltage angle at various buses, as well as that, real powers and reactive powers at various transmission lines.

The basic step in the load flow is derived from the node-voltage equation for n-bus as given before in equation (3.18):

$$I_i = \sum_{j=1}^{n} Y_{ij} * V_j \qquad j = 1, 2 \ldots.N \tag{3.18}$$

Where I_i is the vector of the currents injection at various buses (i), Y_{ij} is the bus admittance matrix between any two buses and V_j is the voltage vector of different buses where Y_{ij} and V_j can be written in polar form (magnitude and angle) as:

$Y_{ij} = | Y_{ij} | \angle \theta_{ij}$ $| Y_{ij} |$ is the magnitude of Y_{ij} and $\angle \theta_{ij}$ is the phase angle of Y_{ij}

$V_j = | V_j | Ð\, \delta_j$ $| V_j |$ is the magnitude of V_j and $Ð\, \delta_j$ is the phase angle of V_j (3.19)

The complex power injection at bus i can be written as:

$$S_i = P_i - jQ_i = V_i * I_i^* \tag{3.20}$$

Equation (3.18) is substituted in equation (3.20) as:

$$S_i = P_i - jQ_i = V_i * [\, \textstyle\sum_{j=1}^{n} Y_{ij} * V_j]^* \tag{3.21}$$

$V_i = | V_i | \angle \delta_i$ where $| V_i |$ is the magnitude of V_i and $\angle \delta_i$ is the phase angle of V_i

Substitute the magnitude and the angle of (V_i, V_j and Y_{ij}) in equation (3.21):

$P_i - jQ_i = |V_i| * Đ\,\delta_i * [\sum_{j=1}^{n} |Y_{ij}| * Đ\,\theta_{ij} * |V_j| * Đ\,\delta_j]^*$ (3.22)

Equation (3.22) can be reformulated in polar form as:

$P_i - jQ_i = |V_i| * \sum_{j=1}^{n} |Y_{ij}| * |V_j| * e^{(\delta_i - \delta_j - \theta_{ij})}$ (3.23)

The negative signs of the angles (V_i and V_j) came from the conjugate of the current I^*, where the conjugate means same magnitude but a negative angle. Separating the real and imaginary parts of equation (3.23) and these equations can be expressed as:

$P_i = |V_i| * \sum_{j=1}^{n} |Y_{ij}| * |V_j| * \cos(\delta_i - \delta_j - \theta_{ij})$ (3.24)

$Q_i = |V_i| * \sum_{j=1}^{n} |Y_{ij}| * |V_j| * \sin(\delta_i - \delta_j - \theta_{ij})$ (3.25)

From these equations above, the power flow equations has the following characteristics:
Power flow equations represent as an algebraic equation because the power flow equations ((3.24) and (3.25)) do not contain on a differential equation in its formulation.
Power flow equations are a nonlinear equations equation because the power flow equations ((3.24) and (3.25)) have sinusoidal terms (sine and cosine) and the product of voltages.
Obviously the power flow equations ((3.24) and (3.25)) are representing a relationship between the power injection (P and Q) at any bus (i) and the bus admittance matrix Y_{bus} between any two buses, as well as that, the voltage magnitude and the voltage angle of that bus in a power system. Since the idea of power flow is to find the voltage magnitude and the voltage angle for each bus except the swing bus because it is already given ($|v| = 1$ per unit and $\angle_{Swing} = 0^o$, so the equations of power flow will be (N-1) equations where N is a number of buses in a power system [3, 57, 58, 60, 72].

3.5.1 Newton-Raphson (NR) method

The Newton-Raphson (NR) method is the most popular procedure to solve nonlinear equations ((3.24) and (3.25)) of the power flow. Newton-Raphson is an iterative solution to get the best convergence at the voltage magnitude and the voltage angle. The solution of the power flow problem by Newton-Raphson (NR) method are based on the nonlinear equations ((3.24) and (3.25)) and these equations are similar to the nonlinear form and can be rewritten as:

$$Y = f(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \\ \vdots \\ f_n(x) \end{bmatrix} \tag{3.26}$$

$$X = \begin{bmatrix} \delta \\ |V| \end{bmatrix} = \begin{bmatrix} \delta_2 \\ \vdots \\ \delta_n \\ |V|_2 \\ \vdots \\ |V|_n \end{bmatrix} \tag{3.27}$$

$$Y = \begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} P_2 \\ \vdots \\ P_n \\ Q_2 \\ \vdots \\ Q_n \end{bmatrix} \tag{3.28}$$

$$Y = f(x) = \begin{bmatrix} P(x) \\ Q(x) \end{bmatrix} = \begin{bmatrix} P_2(x) \\ \vdots \\ P_n(x) \\ Q_2(x) \\ \vdots \\ Q_n(x) \end{bmatrix} \tag{3.29}$$

Where all vectors (P, Q, |V| and δ) in these equations are started from the second bus because the first bus is usually considered as a slack (swing) bus, where the voltage magnitude and the voltage angle of the slack bus are already given. The active power (P), the reactive power (Q) and the voltage magnitude (|V|) are in per-unit but the angles (δ) are in radians. The nonlinear equations ((3.24) and (3.25)) were being reformulated to be represented later in the Taylor's series. Taylor's series expansion for Y = f(x) is written below in equation (3.30) as:

$$Y = f(X_o) + df/dx\,|_{X = X_0} + (X - X_0) + \text{higher-order terms} \tag{3.30}$$

By neglecting higher-order terms and solving for X, resulting in:

$X_1 = X_0 + (df/dx\,|_{x = x_0})^{-1}\,(Y - f(X_o))$ (3.31)

The speculation may not be very close, therefore an iterative method will be used and can be written as:

$X^{(i+1)} = X^{(i)} + 1\,/\,(df/dx\,|_{x = x_0})^{(i)}\,(Y - f(X^{(i)}))$ (3.32)

Equation (3.32) can be rearranged as:

$X^{(i+1)} - X^{(i)} = J^{-1\,(i)}\,(Y - f(X^{(i)}))$ (3.33)

Where $X^{(i+1)}$ is next updated value, $X^{(i)}$ is the present value where $(df/dx\,|_{x = x_0})^{(i)} =$

$$\begin{bmatrix} \frac{\partial f_1}{\partial x_1} & \frac{\partial f_1}{\partial x_2} & \cdots & \frac{\partial f_1}{\partial x_n} \\ \frac{\partial f_2}{\partial x_1} & \frac{\partial f_2}{\partial x_2} & \cdots & \frac{\partial f_2}{\partial x_n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{\partial f_n}{\partial x_1} & \frac{\partial f_n}{\partial x_2} & \cdots & \frac{\partial f_n}{\partial x_n} \end{bmatrix}_{x = x\,(i)}$$

Because of component (J^{-1}) in equation (3.33) takes much time and more complicated in calculation therefore the equation (3.33) can be rearranged as:

$J^{(i)}\,\Delta X^{(i)} = \Delta Y^{(i)}$ (3.34)

Where $\Delta X^{(i)} = X^{(i+1)} - X^{(i)}$, $\Delta Y^{(i)} = Y - f(X^{(i)})$ and $J^{(i)}$ is the Jacobian matrix. The iterative solution is going to continue until the component ($\Delta Y^{(i)}$) or the power mismatches become very small and reach its convergence [57, 59, 60, 72]. For the power flow terms ($\Delta Y^{(i)}$, $\Delta X^{(i)}$ and $J^{(i)}$) can be expressed as:

$$\Delta Y^{(i)} = \begin{bmatrix} \Delta P_k^{(i)} \\ \Delta Q_k^{(i)} \end{bmatrix} = \begin{bmatrix} P_{spceified\ k} & - & P_{cacculated\ k}^{(i)} \\ Q_{spceified\ k} & - & Q_{cacculated\ k}^{(i)} \end{bmatrix}$$ (3.35)

The terms ($\Delta P^{(i)}$ and $\Delta Q^{(i)}$) in equation (3.35) represent the deference between the specified (scheduled) powers and the calculated power at (i) iteration and bus (k), known as the power mismatches or the power residuals, where the power mismatches mean a specific difference between the real and the reactive power at that bus (k) or the difference between the real and the reactive power at that bus (k) are more than the specified accuracy or the acceptable tolerance [13, 57, 58, 59, 60, 72].

The Jacobian matrix ($J^{(i)}$) represents a linear relation between the changes in the voltage angle ($\Delta\delta_k^{(i)}$) and the voltage magnitude ($\Delta|V_k^{(i)}|$) from side and the changes in the real power ($\Delta P_k^{(i)}$) and the reactive power ($\Delta Q_k^{(i)}$) from another side as written below in equation (3.36):

$$\begin{bmatrix} \Delta P^{(i)} \\ \Delta Q^{(i)} \end{bmatrix} = \begin{bmatrix} J_{11}^{(i)} & J_{12}^{(i)} \\ J_{21}^{(i)} & J_{22}^{(i)} \end{bmatrix} \begin{bmatrix} \Delta\delta^{(i)} \\ \Delta|V^{(i)}| \end{bmatrix} \quad (3.36)$$

The Jacobian matrix ($J^{(i)}$) at (i) iteration is divided into four sub matrixes and each sub matrix can be expressed as:

$$J_{11} = \begin{bmatrix} \partial P_2/\partial\delta_2 & \dots & \partial P_2/\partial\delta_n \\ \vdots & & \vdots \\ \partial P_n/\partial\delta_2 & \dots & \partial P_n/\partial\delta_n \end{bmatrix} \quad (3.37)$$

$$J_{12} = \begin{bmatrix} \partial P_2/\partial|V_2| & \dots & \partial P_2/\partial|V_n| \\ \vdots & \vdots & \vdots \\ \partial P_n/\partial|V_2| & \dots & \partial P_n/\partial|V_n| \end{bmatrix} \quad (3.38)$$

$$J_{21} = \begin{bmatrix} \partial Q_2/\partial\delta_2 & \dots & \partial Q_2/\partial\delta_n \\ \vdots & \vdots & \vdots \\ \partial Q_n/\partial\delta_2 & \dots & \partial Q_n/\partial\delta_n \end{bmatrix} \quad (3.39)$$

$$J_{22} = \begin{bmatrix} \partial Q_2/\partial|V_2| & \dots & \partial Q_2/\partial|V_n| \\ \vdots & \vdots & \vdots \\ \partial Q_n/\partial|V_2| & \dots & \partial Q_n/\partial|V_n| \end{bmatrix} \quad (3.40)$$

The partial derivative in the Jacobian matrix ($J^{(i)}$) is real power and the reactive power at voltage control bus (P-V bus) and load bus (P-Q bus) in that power system with respect the voltage magnitude (|V|) and the voltage angle (δ) for voltage control bus (P-V bus) and load bus (P-Q bus) in that power system because the real power and the reactive power for voltage control bus (P-V bus) and load bus (P-Q bus) are already given but the voltage magnitude (|V|) and the voltage angle (δ) for voltage control bus (P-V bus) and load bus (P-Q bus) in that power system are unknown.

At the voltage control bus (P-V bus), the voltage magnitude (|V|) is given but the reactive power (Q) is not known, therefore ($\partial Q/\partial|V|$) term of the voltage control bus (P-V bus) will be deleted from the Jacobian matrix. The elements of the Jacobian matrix began from the second bus because the first bus is a reference bus. Therefore, the numbers of the equations to be solved in Newton Raphson method are (N – 1) equations for the real power (P) because the real powers at the various buses are specified and (N-1-B) for the reactive power (Q) but for B of these equations the reactive power are not known, so the total equations for Newton Raphson method will be (2 * (N-1) – B) equations.

The power mismatches and the Jacobian elements in the equation (3.36) are used to find the voltage error vector $\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$ by using Gauss Elimination Method and the aim of the Gauss Elimination Method is to make all elements under the main diagonal are equal to the zero, the voltage magnitude and the voltage angle are updated after each iteration by using equations (3.41) and (3.42) respectively:

$$\delta^{(i+1)} = \delta^{(i)} + \Delta\delta^{(i)} \quad (3.41)$$

$$|V^{(i+1)}| = |V^{(i)}| + \Delta|V^{(i)}| \quad (3.42)$$

The iteration will stop until the power mismatches (power residuals) are less than the specified accuracy or the acceptable tolerance, then the dependent variables or the state variables (the voltage magnitude and the voltage angle) can be calculated and the problem of the power flow will be solved [13, 57, 58, 59, 60, 72].

Algorithm for Newton-Raphson method

The procedure to solve the problem of the power flow by using Newton-Raphson way is as follows:

Step 1: Read the input data for power flow system (the admittance of the transmission lines between any two buses and the transformer, as well as that, the input power voltage magnitude |V|, voltage angle (δ), real power (P) and the reactive power (Q)) for a specific bus (swing bus, voltage control bus (P-V bus) and the load bus (P-Q bus)) in the power flow system.

Step 2: Transformation each input of the data for power flow system into equivalent per-unit value, where per-unit value can be defined as the ratio of the actual value to the base value as written below in equation (3.43):

$$\text{Per-unit (p.u.) value} = \text{Actual value} / \text{Base value} \tag{3.43}$$

The voltage-Ampere base (S_{base}), the base current (I_{base}) and the base impedance (Z_{base}) can be determined by using equations (3.44) and (3.45) respectively:

$$S_{base} = V_{base} * I_{base} \tag{3.44}$$

$$Z_{base} = V_{base} / I_{base}$$

$$\text{OR} \tag{3.45}$$

$$Z_{base} = (V_{base})^2 / S_{base}$$

The per-unit system will be used to make the power flow system more ease and simplicity during performing of the load flow.

Step 3: Compute the bus admittance matrix (Y_{bus}).

Step 4: Assume an initial estimate for state vector (voltage magnitude and voltage angle) $\begin{bmatrix} \delta \\ |V| \end{bmatrix}$, so for all busses in power system except the swing bus and voltage control bus (P-V bus), the voltage magnitudes of these buses will be chose as one per-unit and for all the buses except the swing bus, the voltage angles will be chose as zero degree. Because of the voltage magnitude (|V|) and the voltage angle (δ) of the slack bus are already given, as well as that, the voltage magnitude (|V|) of the voltage control bus (P-V bus) is also given, therefore the exception consists of the swing bus and voltage control bus (P-V bus).

Step 5: Set the iteration (i) equal to zero.

Step 6: Calculate the injected real power (P) by using equation (3.24).
Step 7: Calculate the injected reactive power (Q) by using equation (3.24).

Step 8: The estimated values (voltage magnitude (|V|) and voltage angle (δ)) are used to calculate the Jacobian matrix (J).

Step 9: Find the voltage error vector $\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$ by using equation (3.35).

Step 10: Set the tolerance value.

Step 11: Update the voltage magnitude (|V|) and voltage angle (δ) by using equations (3.41) and (3.42) respectively.

Step 12: Check the power mismatches (ΔP and ΔQ) of the voltage control bus (P-V bus) and load bus (P-Q bus), if the power mismatches (ΔP and ΔQ) less than the specified tolerance then the iterative process will be stopped, if the power mismatches (ΔP and ΔQ) more than the specified tolerance then the iterative process will increase(iteration = iteration + 1) and repeat this procedure procedures from step 6 until the power mismatches (ΔP and ΔQ) of the voltage control bus (P-V bus) and load bus (P-Q bus) become too small and within the acceptable tolerance [57, 58, 72].

After the iteration process is stop, the final voltage magnitude (|V|) and voltage angle (δ) are calculated therefore the problem of power flow system will be solved.

The final voltage magnitude (|V|) and voltage angle (δ) is used to find the rest values, which are basically the real power and the reactive power at the swing bus (slack bus), as well as that, the reactive power at the voltage control bus (P-V bus). Therefore the key of the power flow problem is to find the voltage magnitude (|V|) and voltage angle (δ) and these values will be substituted to find the rest of the unknown values. The flow chart of Newton-Raphson procedure is shown in figure 3.8.

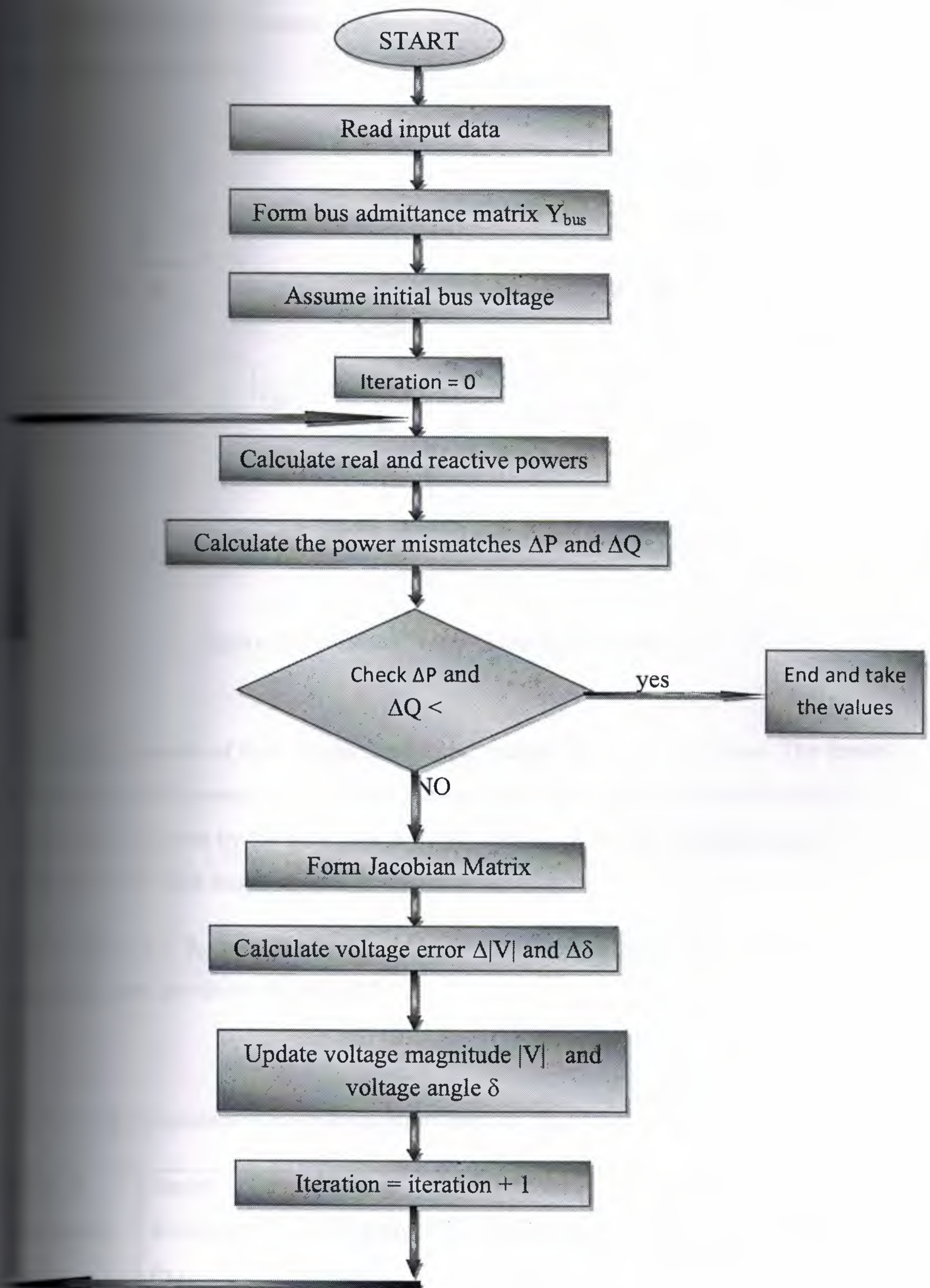

Figure 3.8: Flowchart for Newton-Raphson algorithm.

To understand the steps of Newton-Raphson algorithm, Consider a small 3-bus system is shown below in figure 3.9.

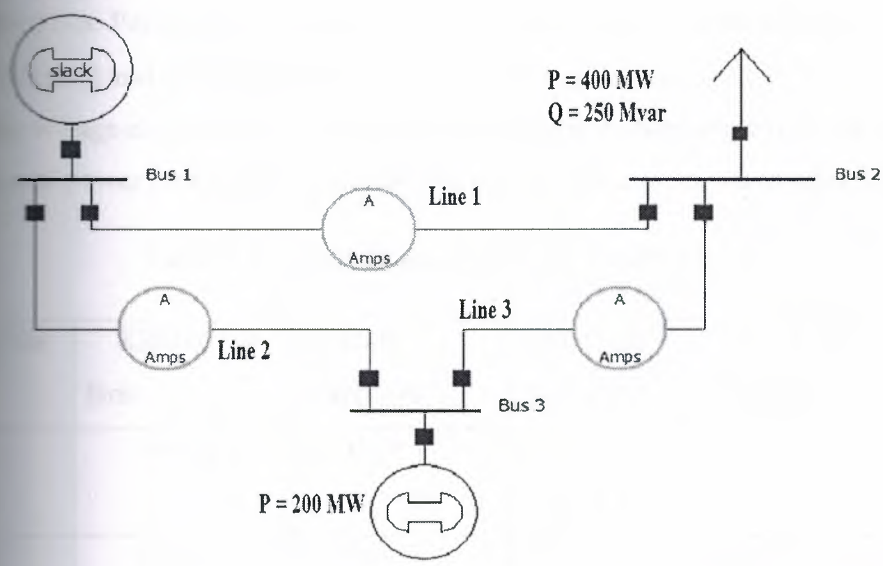

Figure 3.9: 3-Buses Power- Flow system [44].

This system consists of three buses, three lines, two generators and one load. The drawn real and the reactive powers by the load at the second bus are 400 MW and 250 MVAR. The injected real power by the generator at the third bus is 200 MW. The first bus is considered as the slack bus to absorb the losses of the system.

The base values are: S_{base} = 100 MVA and V_{base} = 138 KV. The parameters of the transmission lines are shown in table 3.2.

Table 3.2: The parameters of the transmission lines for figure 3.9.

Number of Transmission line	Series Resistance R (p.u.)	Series Reactance X (p.u.)	Shunt Charging B (p.u.)	Shunt Conductance G (p.u.)
1	0.02000	0.04000	0.0000	0.0000
2	0.01000	0.03000	0.0000	0.0000
3	0.01250	0.02500	0.0000	0.0000

For the second bus: Per-unit (p.u.) value = - (400 + j250) / 100 = - 4 – j2.5 p.u. so the drawn real and reactive powers: P = -4 p.u. and Q = -2.5 (p.u.).

For the third bus: Per-unit (p.u.) value = + (200) / 100 = 2 (p.u.) so the injected real power (P = 2 (p.u.) and the voltage magnitude is already given per unit (|V| =1.04), at the terminal, the voltage magnitude ($|V_1|$ = 1.05 (p.u.)) and the voltage angle ((δ) = 0 degree). The solution of power flow starts with classification the buses as shown in table 3.3.

Table 3.3: Buses Classification for Figure 3.9.

Number of the Bus	Kind of the Bus	Known Variables	Unknown Variables	Required to Approximate
1	Swing	$\|V_1\| = 1$ $\delta_1 = 0$	P_1 , Q_1	....
2	Load	$P_2 = -4$ $Q_2 = -2.5$	$\|V_2\|$, δ_2	$\|V_2\|$, δ_2
3	Generator	$P_3 = 2$ $\|V_3\| = 1.04$	Q_3 , δ_3	δ_3

The initial guesses are assumed for the second bus and the third bus:

Voltage magnitude ($|V_2|$) for the load bus (P-Q bus) = 1 (p.u.) and Voltage angle (δ_2) for the load bus (P-Q bus) = 0 degree. Voltage angle (δ_3) for the load bus (P-V bus) = 0 degree.

The bus admittance matrix ($Y_{bus)}$ will be calculating:

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} \\ Y_{21} & Y_{22} & Y_{23} \\ Y_{31} & Y_{32} & Y_{33} \end{bmatrix}$$

$Y_{11} = Y_{12} + Y_{11}$ = 1 / (0.02 + 0.04) + 1 / (0.01 + 0.03) = 20 – j50

$Y_{22} = Y_{21} + Y_{23}$ = 1 / (0.02 + 0.04) + 1 / (0.0125 + 0.0250) = 26 – j52

$Y_{33} = Y_{32} + Y_{31}$ = 1 / (0.01 + 0.03) + 1 / (0.0125 + 0.0250) = 26 – j62

Y_{12} = - (1 / (0.02 + 0.04)) = Y_{21} = -10 + j20

Y_{13} = (- 1 / (0.01 + 0.03)) = Y_{31} = -10 + j30

Y_{23} = (- 1 / (0.0125 + 0.0250)) = Y_{32} = -16 + j32

This results the following Y_{bus}:

$$Y_{bus} = \begin{bmatrix} 20 - j50 & -10 + j20 & -10 + j30 \\ -10 + j20 & 26 - j52 & -16 + j32 \\ -10 + j30 & -16 + j32 & 26 - j62 \end{bmatrix}$$

The bus admittance matrix (Y_{bus}) is converted to polar form but the angles are in the radian form:

$Y_{11} = 20 - j50 = 53.8517 \angle -1.1903$

$Y_{22} = 26 - j52 = 58.1378 \angle -1.1071$

$Y_{33} = 26 - j62 = 67.2310 \angle -1.1737$

$Y_{12} = Y_{21} = -10 + j20 = 22.3607 \angle 2.0344$

$Y_{13} = Y_{31} = -10 + j30 = 31.6227 \angle 1.8925$

$Y_{23} = Y_{32} = -16 + j32 = 32.777087 \angle 2.0344$

From equations (3.24) and (3.25), real and the reactive powers are calculated as:

$P_2 = |V_2| * |V_1| * |Y_{21}| * \cos(\delta_2 - \delta_1 - \theta_{21}) + |V_2| * |V_2| * |Y_{22}| * \cos(\delta_2 - \delta_2 - \theta_{22}) +$

$|V_2| * |V_3| * |Y_{23}| * \cos(\delta_2 - \delta_3 - \theta_{23})$

$Q_2 = |V_2| * |V_1| * |Y_{21}| * \sin(\delta_2 - \delta_1 - \theta_{22}) + |V_2| * |V_2| * |Y_{22}| * \sin(\delta_2 - \delta_2 - \theta_{22}) +$

$|V_2| * |V_3| * |Y_{23}| * \sin(\delta_2 - \delta_3 - \theta_{23})$

$P_3 = |V_3| * |V_1| * |Y_{31}| * \cos(\delta_3 - \delta_1 - \theta_{31}) + |V_3| * |V_2| * |Y_{32}| * \cos(\delta_3 - \delta_2 - \theta_{32}) +$

$|V_3| * |V_3| * |Y_{33}| * \cos(\delta_3 - \delta_3 - \theta_{33})$

[illegible] initial values are:

[illegible] = -1.14 (p.u.)

[illegible] = -2.28 (p.u.)

[illegible] = 0.5616 (p.u.)

[illegible] tolerance is assumed as (0.0001). By using equation (3.35), the power mismatches are [illegible] as:

[illegible] = $P^{(1)}_{Specified_2}$ - $P^{(0)}_{Calculated_2}$ = - 4 + 1.14 = - 2.86

[illegible] = $Q^{(1)}_{Specified_2}$ - $Q^{(0)}_{Calculated_2}$ = - 2.5 + 2.28 = - 0.22

[illegible] = $P^{(1)}_{Specified_3}$ - $P^{(0)}_{Calculated_3}$ = 2 - 0.5616 = 1.4384

[illegible] value of tolerance is greater than the power mismatches, then Jacobian partial [illegible] for the unknown parameters will be formed as:

[illegible] = - $|V_2|$ * $|V_1|$ * $|Y_{21}|$ * sin ($\delta_2 - \delta_1 - \theta_{21}$) - $|V_2|$ * $|V_3|$ * $|Y_{23}|$ * sin ($\delta_2 - \delta_3 - \theta_{23}$)

[illegible] = $|V_2|$ * $|V_3|$ * $|Y_{23}|$ * sin ($\delta_2 - \delta_3 - \theta_{23}$)

[illegible] = $|V_1|$ * $|Y_{21}|$ * cos ($\delta_2 - \delta_1 - \theta_{21}$) + 2 * $|V_2|$ * $|Y_{22}|$ *cos ($\delta_2 - \delta_3 - \theta_{23}$) + $|V_3|$ * $|Y_{23}|$ * cos ($\delta_2 - \delta_3 - \theta_{23}$)

[illegible] = $|V_3|$ * $|V_2|$ * $|Y_{32}|$ * sin ($\delta_3 - \delta_2 - \theta_{32}$)

[illegible] = - $|V_3|$ * $|V_1|$ * $|Y_{31}|$ * sin ($\delta_3 - \delta_1 - \theta_{31}$) - $|V_3|$ * $|V_2|$ * $|Y_{32}|$ * sin ($\delta_3 - \delta_2 - \theta_{32}$)

[illegible] = $|V_3|$ * $|Y_{32}|$ * cos ($\delta_3 - \delta_2 - \theta_{32}$)

[illegible] = $|V_2|$ * $|V_1|$ * $|Y_{21}|$ * cos ($\delta_2 - \delta_1 - \theta_{22}$) + $|V_2|$ * $|V_3|$ * $|Y_{23}|$ * cos ($\delta_2 - \delta_3 - \theta_{23}$)

$\partial Q_2 / \partial \delta_3 = - |V_2| * |V_3| * |Y_{23}| * \cos(\delta_2 - \delta_3 - \theta_{23})$

$\partial Q_2 / \partial |V_2| = |V_1| * |Y_{21}| * \sin(\delta_2 - \delta_1 - \theta_{22}) + 2 * |V_2| * |Y_{22}| * \sin(-\theta_{22}) + |V_3| * |Y_{23}|$

$* \text{Sin}(\delta_2 - \delta_3 - \theta_{23})$

The following Jacobian matrix (J) can be rearranged as:

$$J = \begin{bmatrix} 54.28 & -33.28 & 24.86 \\ -33.28 & 66.04 & -16.64 \\ -27.14 & 16.64 & 49.72 \end{bmatrix}$$

The power mismatches and the Jacobian elements are used to find the voltage error vector $\begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$ as:

$$\begin{bmatrix} \Delta P^{(i)} \\ \Delta Q^{(i)} \end{bmatrix} = \begin{bmatrix} J_{11}^{(i)} & J_{12}^{(i)} \\ J_{21}^{(i)} & J_{22}^{(i)} \end{bmatrix} \begin{bmatrix} \Delta\delta^{(i)} \\ \Delta|V^{(i)}| \end{bmatrix}$$ and that will be resulted:

$$\begin{bmatrix} -2.86 \\ 1.4384 \\ -0.22 \end{bmatrix} = \begin{bmatrix} 54.28 & -33.28 & 24.86 \\ -33.28 & 66.04 & -16.64 \\ -27.14 & 16.64 & 49.72 \end{bmatrix} \begin{bmatrix} \Delta\delta_2^{(0)} \\ \Delta\delta_3^{(0)} \\ \Delta|V_2^{(0)}| \end{bmatrix}$$

The voltage error vector can be solved by using Gauss Elimination Method This produces:

$$\Delta\delta_2^{(0)} = -0.04526$$
$$\Delta\delta_3^{(0)} = -0.00771$$
$$\Delta|V_2^{(0)}| = -0.02654$$

The voltage magnitude (|V|) and voltage angle (δ) are updated by using equations (3.41) and (3.42) respectively:

$\delta_2^{(1)} = 0 - 0.04526 = -0.04526$

$\delta_3^{(1)} = 0 - 0.00771 = -0.00771$

$|V_2^{(1)}| = 1 - 0.02654 = 0.97346$

The procedure of the power flow problem is reputed again and again until the power mismatches is going to be less than the specified tolerance, therefore after the second

...on the voltage magnitude ($|V_2^{(3)}|$), the voltage angle ($\delta_2^{(3)}$) and the voltage angle (δ_2...) of the voltage error vector are equalled to:

$\delta_2^{(3)} = -0.04706$ radian

$\delta_3^{(3)} = -0.008705$ radian

$|V_2^{(3)}| = 0.97168$

Since the voltage magnitude ($|V|$) and voltage angle (δ) of the unknown parameters at the various buses are calculated, therefore the problem of the load flow is solved. The real (P) and the reactive (Q) powers of the unknown parameters at the different buses will be calculated as:

$P_1 = |V_1| * |V_1| * |Y_{11}| * \cos(\delta_1 - \delta_1 - \theta_{11}) + |V_1| * |V_2| * |Y_{12}| * \cos(\delta_1 - \delta_2 - \theta_{12}) +$

$|V_1| * |V_3| * |Y_{13}| * \cos(\delta_1 - \delta_3 - \theta_{13})$

$Q_1 = |V_1| * |V_1| * |Y_{11}| * \sin(\delta_1 - \delta_1 - \theta_{11}) + |V_1| * |V_2| * |Y_{12}| * \sin(\delta_1 - \delta_2 - \theta_{12}) +$

$|V_1| * |V_3| * |Y_{13}| * \sin(\delta_1 - \delta_3 - \theta_{13})$

$Q_3 = |V_3| * |V_1| * |Y_{31}| * \sin(\delta_3 - \delta_1 - \theta_{31}) + |V_3| * |V_2| * |Y_{32}| * \sin(\delta_3 - \delta_2 - \theta_{32}) +$

$|V_3| * |V_3| * |Y_{33}| * \sin(\delta_3 - \delta_3 - \theta_{33})$

So the real and the reactive powers of the unknown parameters at the different buses are:

$P_1 = 2.1842$ (P.U.)

$Q_1 = 1.4085$ (P.U.)

$Q_3 = 1.4617$ (P.U.)

The per-unit values of the unknown parameters (real and the reactive powers) can be calculated by using equation (3.43):

$P_{1_{actual}} = 100 * 2.1842 = 218.42$

$Q_{1_{actual}} = 100 * 1.4085 = 140.85$

$Q_{3_{actual}} = 100 * 1.4617 = 146.17$

The voltage angle of the second bus ($\delta_2^{(3)}$) and the voltage angle of the third bus ($\delta_3^{(3)}$) will be converted to the degree form as:

$\delta_2^{(3)} = -0.04706$ radian $* 180 / \pi = -2.69634°$

$\delta_3^{(3)} = -0.008705$ radian $* 180 / \pi = -0.49876°$

The solution of power flow problem is shown in table 3.4.

Table 3.4: The solution of power flow problem by using Newton-Raphson method [44, 73].

Number of the Bus	Voltage Magnitude (p.u.)	Phase Angle (degree)	Real Power of generator (MW)	Reactive Power of generator (MVAR)	Real Power of load (MW)	Reactive Power of load (MVAR)
1	1.05	0.0	218.42	140.85	0.0	0.0
2	0.97168	- 2.69634	0.0	0.0	400	250
3	1.04	- 0.49876	200	146.17	0.0	0.0
Sum			418.42	287.02	400	250

This table is showed that the injected real and the reactive powers by all generators are 418.42 MW and 287.02 MVAR but the drawn real and the reactive powers by all loads are 400 MW and 250MVAR, the difference between the injected real powers and the drawn reactive powers is caused by the losses in all transmission lines. Thus the problem of power flow was solved [44, 73].

CHAPTER FOUR

APLICATTION OF NEURAL NETWORK IN STATIC POWER SYSTEM SECURITY ASSESSMENT

4.1 Overview

With the escalation of the requirement for electrical power to reach the consumers at an continuous way and without interruptions, also in order to avoid dangerous situations that lead to the collapse of the system. In addition, the everlasting problems that faced the traditional methods made them useless for researchers and designers it therefore was necessary to find alternative methods to avoid these obstacles.

In this chapter, the usage of artificial neural network (ANN) in static security assessment as alternative technique is going to clarify. The static security assessment and its importance or its impact at the power system, also power system's operating statuses is going to discuss. IEEE 9-Bus System will be solved by Newton-Raphson method using Power World Simulator's program. Training and testing the artificial neural network will be studied in this section.

4.2 Introduction

The security of power system is considered an extremely important concern in the designing and operating survey of the power system. A main aim and the essential objective of a power system analysis is to supply a continuous supply of energy with good quality in voltage and frequency to satisfy all the requirements of the consumer without violation in any limit of the operating system's conditions [7, 14].

At the present time power system is the most complex control in the presence, because the large number of enormous ramifications and the wide spread between continents. Where these complications due to the growing economic and environmental pressures, therefore the power systems are forced to work under stressed operating conditions of the power system. So they are operated very close to their security confines. While a tremendous development made the limits of the power system security a fragile and easy to violate, so any small disturbance from the various emergency situations makes the system at the risk position and lead to system blackout or shut down. Therefore fast and accurate security assessment become a key issue to guarantee secure operating limits of power system, the term of security refers to the degree of reliability for that power system before and after various disturbances [1, 6, 14, 18, 22, 37].

Static security of any power system is defined as the ability of system to reach an operating state within the identified safety and supply quality after the contingency, which helps the system to stay within safety limits. As well as, technical and economic outcomes can be obtained by guaranteeing the security limits of the power system. Conversely, the inability of the system to operate in a safe way can lead to damage of power system's equipment, loss of some components of the system, tremendous financial losses and in some cases, the loss of human lives. One of the most important reasons for the occurrence of such cases is the inability of the system operator at dealing with emergencies and unexpected rapidly [15, 39, 40].

Static security assessment is the process that has to be achieved regularly and periodically at a center control room in the power plant. Security assessment is the task performed to calculate whether, and to what range, system remains reasonably safe from sudden emergency situations (disturbances) that occur during system operation. If the state of the power system security is not apparently well recognized, then the system may shift to an undesirable state and it lead to the system collapse or blackout. Hence a term of the security assessment helps for warning the system operators and gives them enough time to take appropriate and effective action for that situation, for all these reason power system security plays a substantial role in the power system designing and operation.

The static security assessment (SSA) in the large-scale power system is considered a mathematically daunting task because the traditional methods involves the solution of some nonlinear models (full AC load flow) containing a tremendous number of variables which requires a very large memory size to store all of these variables. Therefore the security assessment mission may become computation-intensive, waste of time and infeasible in real time. As well as, the traditional techniques cannot get the high accuracy and the required speed. For all these reasons, these conventional techniques undermine the usage of static security assessment in real-time application [2, 14, 16, 17, 18, 19, 20, 22, 31, 36, 39, 74].

Scientists, engineers and researchers are concentrating their attempts to enhance the security of power system and reliability. In addition, accelerate the speed of detecting the emergency situations with high accuracy. As a result of these reasons artificial intelligent systems were used in static power system security assessment. In recent years and with evolution of artificial intelligent methods, various techniques have been submitted to overcome the problems and the troubles faced by traditional methods that are used in static security assessment.

Artificial intelligent techniques such as Fuzzy Logic, Self-Origination Feature Map and Artificial Neural Network (ANN) to increase the accuracy and the speed to be applied in large scale power system network, where the performance of these techniques are very high when was applied in determining the static security assessment.

In this thesis, Artificial Neural Network (ANN)-based Multilayer Feed forward with a back propagation technique is going to be employed as alternative approach to determine the static security assessment of power system. Artificial Neural Network (ANN) has shown excellent promise as means of forecasting the security of large-scale electric power systems. By Artificial Neural Network, security region can be performed by using the artificial neural network through examples; the training data can be gained from off-line simulation or from on-line operation, the amount of used data much less than those of the used data in traditional methods (Gauss Seidel iterative approach, Newton-Raphson technique, and fast decoupled power flow method) which helps to reduce the size of memory. In addition, the artificial neural network can be applied with success and a high speed at on-line security assessment.

Since the artificial neural networks (ANN) are fast in response time, ease of adaptation between the input and output data of power system as well as this method is founded to determine the status of the power system with the required speed particularly during the unsafe situations. Therefore the artificial neural network (ANN)-based multilayer feed forward with a back propagation technique become the best and most important candidate for on line application of power system [2, 14, 16, 19, 20, 22, 36, 38, 40, 75].

Static Security Assessment (SSA)

Power system security assessment is very important to determine whether, after a contingency (disturbance), the power system reaches a steady state operating stage and without exceeding or penetrating the boundaries of the power system security. Where these boundaries (constraints) ensure the survival of the power system in equilibrium and they consist of the limits of the transmission line flow as well as the upper and lower limits on bus voltage magnitude.

In steady state security assessment of the power system, it is very crucial to forecast the bus voltages and transmission line flows for various operating statuses of the power system. The power system security assessment can be classified into three major functions that are carried out in an operations control centre, which are system monitoring, contingency analysis and security constrained optimal power flow. In the system monitoring, it provides up-to-date measurement and information from all parts of the system through the telemetry system then analyzing them in order to identify and determine the system operating statuses. The power system operating statuses can be classified into Normal state, Alert state, Emergency state, Extreme Emergency state and Restorative state.

In static security assessment process, power flow equations are demanded to determine complete voltage angle and voltage magnitude for each bus bar connected to the network of that power system with corresponding to specified system operating conditions, as well as that, real powers and reactive powers at various transmission lines. The power flow is repeated and solved for different contingences (outage of the transmission line and the sudden increase in required load) and the results are compared or checked with the operational constraints of power system (thermal limits of the transmission lines and the limits of voltage magnitudes at various buses) in order to determine the security status of the power system.

The power flow equations (load flow analysis) will be solved by using the most popular method, which is known as Newton-Raphson (NR) technique. The reason for choosing this method due to the enormous speed of convergence as the iteration starts close to the required root.

The term of a contingency refer to the failure of any one piece of equipment. The outage of transmission line and increase the load are the most popular contingences that will be

...ed in order to predict potential Systems outages and their impact on the system as a whole. After carrying out (N-1) contingency analysis, the load-flow equations are ...ded to determine the new changes in the load flow for each emergency (contingency) situation at that power system.

...nt years, rapid security assessment is very crucial task to warn and enable the ... operator to determine the status of the system very quickly as well as it can take the ...ate remedial action to prevent from any interruption and the damages in the power ... or customer facilities, where the harm in the operating system may cause highly ...pse of system voltage as a result of shutdown of some parts or entire system. ...fore, Artificial Neural Network (ANN) will be used to predict bus voltages and line ... for various conditions of the power system. Many scientists and researchers have ...strated that feed-forward with back propagation algorithm appropriate to be used in ... security assessment. Because the feed forward back propagation neural network ...ique has great accuracy on account of the error between the actual output and the ... output will be decreased to the minimum, high speed in implementation, not ...icated and easy in application. For all these reasons, the feed forward back ...ation neural network algorithm represents the best choice and the most popular for a ... security assessment [2, 4, 11, 36].

... The Procedures for designing Artificial Neural Network in Static Security Assessment

...sign of the Artificial Neural Network (ANN) involves the following steps:

- Collection database
- Selection of the Artificial Neural Network (ANN) structure
- Training the Artificial Neural Network (ANN) using the database
- Testing the Artificial Neural Network (ANN) using the database

4.4.1 Collection database

To create the database to be used in the training and testing the Artificial Neural ...work (ANN), so an IEEE-9 bus system was taken as shown below in figure 4.1.

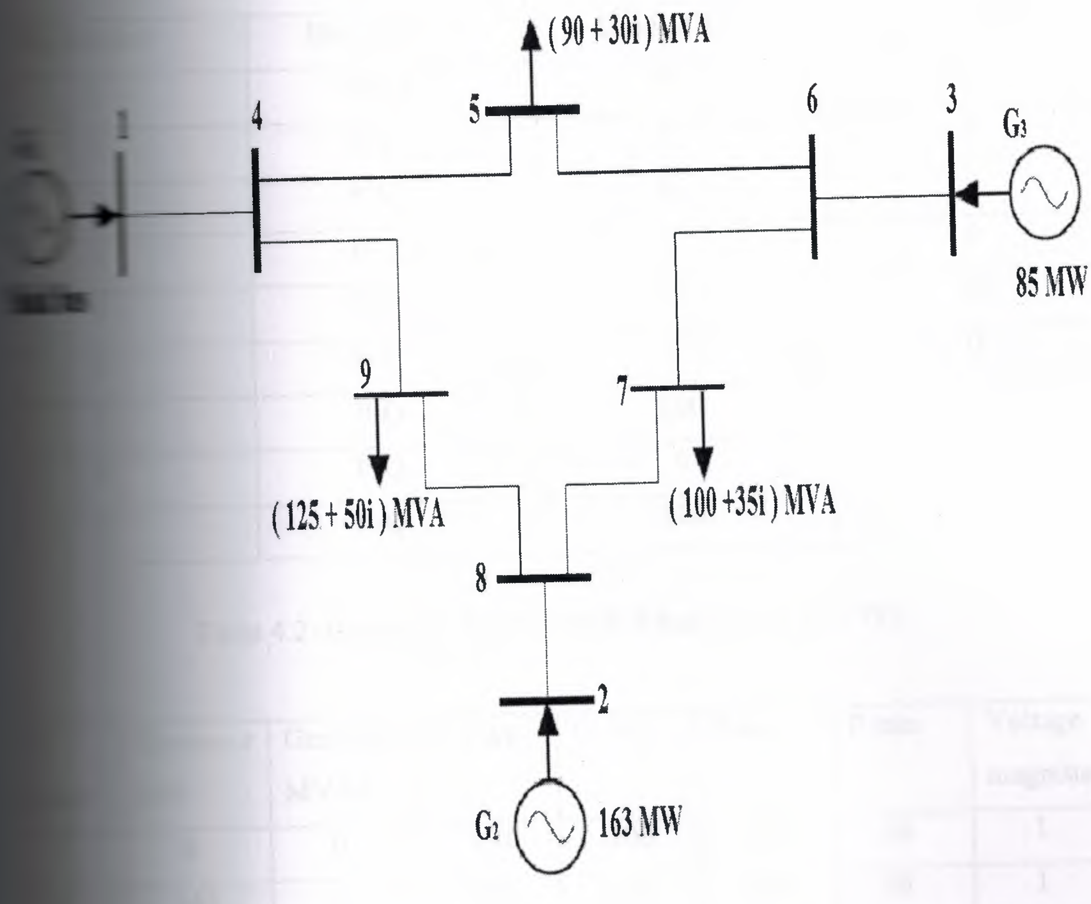

Figure 4.1: The topology of IEEE 9-Bus system [77].

From figure 4.1 that is described above, the IEEE - 9 bus system consists of nine buses, three generators at the first bus, the second bus and third bus, and three loads at the fifth bus, the seventh bus and the ninth bus. In addition, the IEEE - 9 bus system comprises of eight transmission lines connected between various buses which are the line between the fourth and fifth bus, the line between the fifth and sixth bus, the line between the sixth and seventh bus, the line between the seventh and eighth bus, the line between the eighth and ninth bus, the line between the ninth and fourth bus, the line between the third and sixth bus and the line between the second and eighth bus, while the line between the first and fourth bus is connected to the slack bus to determine the losses in whole transmission lines.

The bus data, generator data and branch data for the IEEE-9 bus system have been showed in table 4.1, 4.2 and 4.3 respectively [4, 12].

Table 4.1: Bus data for IEEE 9-bus system [77, 78].

Bus number	Bus type	Load MW	Load MVAR
1	Slack	0	0
2	P-V	0	0
3	P-V	0	0
4	P-Q	0	0
5	P-Q	90	30
6	P-Q	0	0
7	P-Q	100	35
8	P-Q	0	0
9	P-Q	125	50

Table 4.2: Generator data for IEEE 9-bus system [77, 78].

Bus number	Generator MW	Generator MVAR	Q max	Q min	P max	P min	Voltage magnitude
1	0	0	300	-300	250	10	1
2	163	0	300	-300	300	10	1
3	85	0	300	-300	270	10	1

Table 4.3: Brunch data for IEEE 9-bus system [77, 78]

From bus	To bus	Resistance (R)	Reactance (X)	Shunt charging (B)
1	4	0	0.0576	0
4	5	0.017	0.092	0.158
5	6	0.039	0.17	0.358
3	6	0	0.0586	0
6	7	0.0119	0.1008	0.209
7	8	0.0085	0.072	0.149
8	2	0	0.0625	0
8	9	0.032	0.161	0.306
9	4	0.01	0.085	0.176

Where the base power is 100 MV and voltage base is 345 kV [77]. The maximum limits of the apparent power (S) that can carry by the transmission line are shown below in table 4.4.

Table 4.4: The maximum limits of the apparent power

From Bus	To Bus	Maximum Apparent Power (MVA)
1	4	300
4	5	150
5	6	150
3	6	300
6	7	150
7	8	150
8	2	150
8	9	150
9	4	150

A large number of data is going to generate by Newton-Raphson (NR) power flow technique using Power World Simulator's program, where these data will be created as a result of various emergency situations that occur during system operating under normal circumstances or normal operating conditions as shown below in following steps:

Step 1: Build the IEEE 9-bus system with its data components (Bus data, Generator data, Branch data and the maximum limits of the apparent power for transmission lines) by using Power World Simulator's program.

Step 2: By using Newton-Raphson (NR) power flow method in Power World Simulator's program, the power flow for every transmission line (active and reactive power) will be calculated. In addition, the voltage at every bus bar is going to obtain.

Step 3: Change all the active loads in the range (-10 MW to +10 MW) from the main loads, where the change in the main load will be at a rate (2 MW) from that range. At each change (2 MW) in that range (-10 MW to +10 MW), the Power World Simulator's program is going to calculate the new load flow in every line and the voltage at every bus bar where all these procedures present the first case (case $_1$).

Step $_4$: (N-1) contingency will be presented by outage single transmission line and repeat (step $_3$) where all these procedures present the second case (case $_2$).

Step $_5$: Since the IEEE 9-bus system consists of eight transmission lines, so the (step $_4$) is repeated for each transmission line of the IEEE 9-bus system to perform case $_3$, case $_4$, case $_5$, case $_6$, case $_7$, case $_8$ and case $_9$ respectively. In addition, these nine cases will be used for training the Artificial Neural Network (ANN).

Step $_6$: Reset these cases then change all the active loads in the range (-09 MW to +10 MW) from the main loads, where the change in the main load will be at a rate (4 MW) from that range. At each change (4 MW) in that range (-09 MW to +10 MW), the Power World Simulator's program is going to calculate the new load flow in every line and the voltage at every bus bar where all these procedures present the first case (case $_1$).

Step $_7$: Repeat Step $_4$ and Step $_5$ but these nine cases will be used for testing the Artificial Neural Network (ANN).
To implement the first step (Step $_1$), the IEEE 9-bus system will be simulated by using Power World Simulator's program as shown below in the following procedures:

- Open the program and from the upper corner click "file", then choose "New Case".

- To insert buses, go to "Edit Mode" then click "Insert" and select "bus". Insert the number and the name of that bus into "Bus Option". Repeat this process for all buses (nine buses). Make the first bus as a slack bus through "Bus Option" and click "Bus Information" then select "System Slack Bus".

- To insert generators, go to "Edit Mode" then click "Insert" and select "Generator". Insert the Generator data into "Generator Option". Repeat this process for all generators (three generators).

- To insert the transmission lines, go to "Edit Mode" then click "Insert" and select "Transmission Line". Input the Brunch data and the maximum limits of the apparent power (MVA) into "Transmission Line / Transformer Option". As a result, the IEEE 9-bus system was built as shown below in figure 4.2.

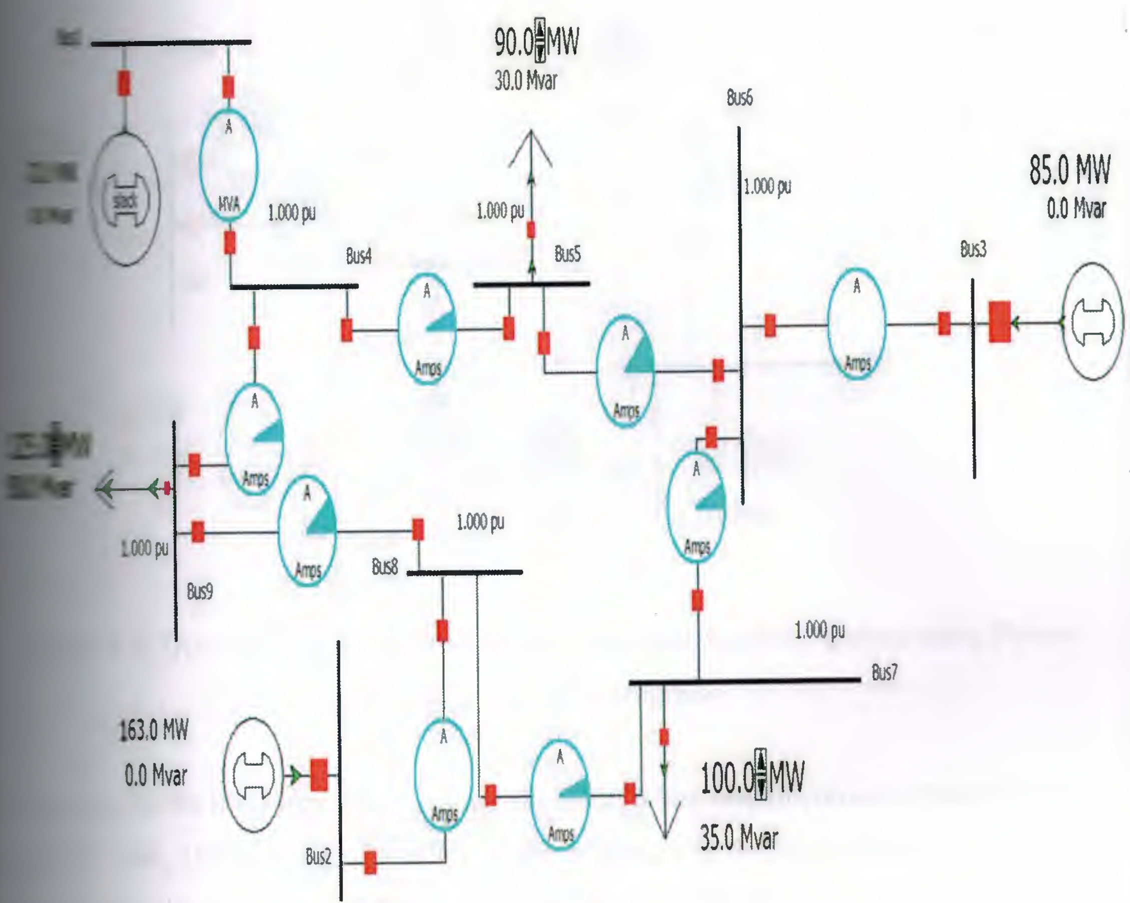

Figure 4.2: IEEE 9-Bus System by using Power World Simulator's program.

To implement the second step (Step $_2$), go to "Run Mode" then click "Simulation" from the upper left corner and select "Solve and Animate". The power flow for every transmission line (active and reactive power) was calculated. In addition, the voltage at every bus bar and thermal limits of transmission lines were obtained as shown below in figure 4.3.

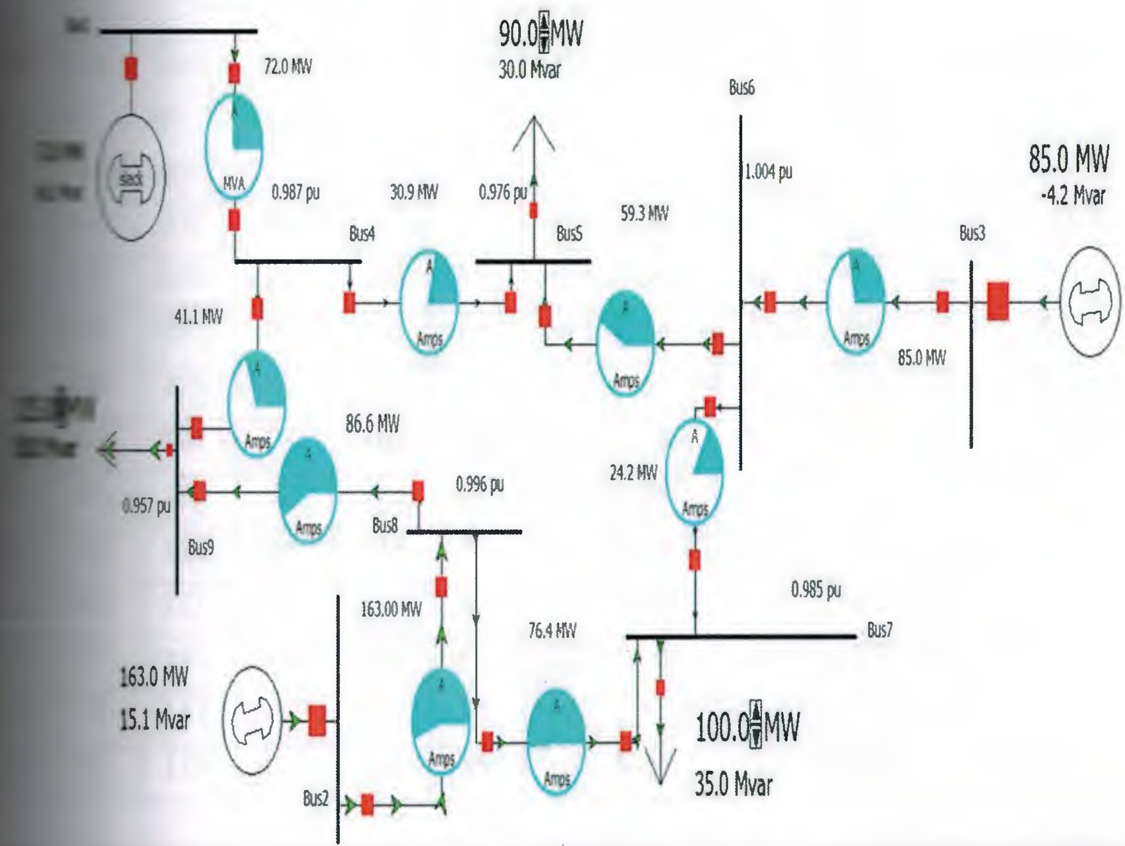

Figure 4.3: Diagram of IEEE 9-Bus system by Newton-Raphson method using Power World Simulator's program.

To implement the third step (Step $_3$), since the IEEE 9-bus system consists of three active loads (90 MW, 100 MW and 125 MW), so these changes in the loads will be (80 MW - 100 MW) for the first load, (90 MW – 110 MW) for the second load and (115 MW – 135 MW) for the third load with increase 2 MW each time. These procedures are implemented by going to the "Run Mode" then right click at the real load and choose "Load Field Information Dialog". "Bus Field Options" is opened and change the first active load to 80 MW in the "Field Value". In the "Load Field Information Dialog" go to the "Delta per Mouse Click" and change it to 2 MW. Repeat these procedures for the rest of the loads. Click "Simulation" from the upper left corner and select "Solve and Animate". Record data and increase each load by click on it, again click "Simulation" from the upper left corner and select "Solve and Animate". These processes is repeated until the changes in the loads reach the maximum level (100 MW for the first load, 110 MW for the second load and 1 35 MW for the third load) as shown below in tables (4.3, 4.4, 4.5 and 4.6) respectively:

Table 4.5: Real powers in MW (training data for case1)

[illegible]	Load at bus 7	Load at bus 9	Line 1 – 4	Line 2 – 8	Line 3 – 6	Line 4 – 5	Line 5 – 6	Line 6 – 7	Line 7 - 8	Line 8 - 9	Line 4 - 9
[illegible]	110	135	102	163	85	45.5	54.9	28.9	81.9	81.1	56.5
[illegible]	108	133	96	163	85	42.6	55.8	28	80.8	82.2	53.4
[illegible]	106	131	90	163	85	39.6	56.6	27	79.7	83.3	50.3
[illegible]	104	129	84	163	85	36.7	57.5	26.1	78.6	84.4	47.3
[illegible]	102	127	78	163	85	33.8	58.4	25.2	77.5	85.5	44.2
[illegible]	100	125	72	163	85	30.9	59.3	24.2	76.4	86.6	41.1
[illegible]	98	123	66	163	85	28	60.2	23.3	75.3	87.7	38.1
[illegible]	96	121	60.1	163	85	25	61.1	22.4	74.2	88.8	35
[illegible]	94	119	54.1	163	85	22.1	62	21.5	73.1	89.9	32
[illegible]	92	117	48.2	163	85	19.2	62.8	20.5	72	91	28.9
[illegible]	90	115	42.2	163	85	16.3	63.7	19.6	70.9	92.1	25.9

Table 4.6: Reactive powers in MVAR (training data for case1)

[illegible]	Load at bus 7	Load at bus 9	Line 1 – 4	Line 2 – 8	Line 3 – 6	Line 4 – 5	Line 5 – 6	Line 6 – 7	Line 7 - 8	Line 8 - 9	Line 4 - 9
[illegible]	110	135	25.9	16.3	7.3	11.6	18.4	23.5	11.5	15.9	34.1
[illegible]	108	133	25.4	16	7.6	12	18	23.5	11.5	15.5	34.5
[illegible]	106	131	25	15.8	7.8	12.4	17.6	23.6	11.4	15.1	34.9
[illegible]	104	129	24.6	15.5	8.1	12.8	17.2	23.6	11.4	14.8	35.2
[illegible]	102	127	24.3	15.3	8.3	13.2	16.8	23.7	11.3	14.4	35.6
[illegible]	100	125	24.1	15.1	8.5	13.5	16.5	23.7	11.3	14.1	35.9
[illegible]	98	123	23.9	14.9	8.7	13.9	16.1	23.7	11.3	13.8	36.2
[illegible]	96	121	23.8	14.7	8.8	14.2	15.8	23.8	11.2	13.5	36.5
[illegible]	94	119	23.8	14.5	9	14.5	15.5	23.8	11.2	13.1	36.9
[illegible]	92	117	23.8	14.4	9.2	14.9	15.1	23.8	11.2	12.8	37.2
[illegible]	90	115	23.9	14.2	9.3	15.2	14.8	23.9	11.1	12.5	37.5

Table 4.7: Thermal lines (training data for case1)

Load at bus 5	Load at bus 7	Load at bus 9	Line (%) 1 – 4	Line (%) 2 – 8	Line (%) 3 – 6	Line (%) 4 – 5	Line (%) 5 – 6	Line (%) 6 – 7	Line (%) 7 - 8	Line (%) 8 - 9	Line (%) 4 - 9
100	110	135	35	55	28	31	39	25	55	54	44
98	108	133	33	55	28	29	39	24	54	55	42
96	106	131	31	55	28	28	40	24	53	56	41
94	104	129	29	55	28	26	40	23	53	56	39
92	102	127	27	55	28	24	41	23	52	57	38
90	100	125	25	55	28	22	41	23	51	58	36
88	98	123	23	55	28	21	42	22	50	58	35
86	96	121	22	55	28	19	43	22	50	59	34
84	94	119	20	55	28	18	43	21	49	60	32
82	92	117	18	55	28	16	44	21	48	61	31
80	90	115	16	55	29	15	44	21	48	61	30

Table 4.8: Voltage magnitudes at various buses (training data for case1)

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4 (P.U.)	V5 (P.U.)	V6 (P.U.)	V7 (P.U.)	V8 (P.U.)	V9 (P.U.)
100	110	135	0.987	0.974	1.003	0.983	0.995	0.957
98	108	133	0.987	0.974	1.003	0.983	0.995	0.957
96	106	131	0.987	0.975	1.003	0.984	0.995	0.957
94	104	129	0.987	0.975	1.003	0.984	0.996	0.957
92	102	127	0.987	0.975	1.004	0.984	0.996	0.957
90	100	125	0.987	0.975	1.004	0.985	0.996	0.957
88	98	123	0.987	0.976	1.004	0.985	0.996	0.958
86	96	121	0.987	0.976	1.004	0.985	0.996	0.958
84	94	119	0.987	0.976	1.004	0.986	0.996	0.958
82	92	117	0.987	0.976	1.004	0.986	0.996	0.958
80	90	115	0.987	0.976	1.004	0.986	0.996	0.958

The voltage magnitudes are not taken at the first bus, second bus and the third bus because the voltage magnitudes of theses buses are already known.

To implement the fourth step (Step $_4$), go to "Run Mode" click on the circuit breaker to outage the specified transmission line. Click "Simulation" from the upper left corner and select "Solve and Animate" as shown in figure 4.4. Implement the procedures of the third step (Step $_3$) where all these procedures present the second case (case $_2$).

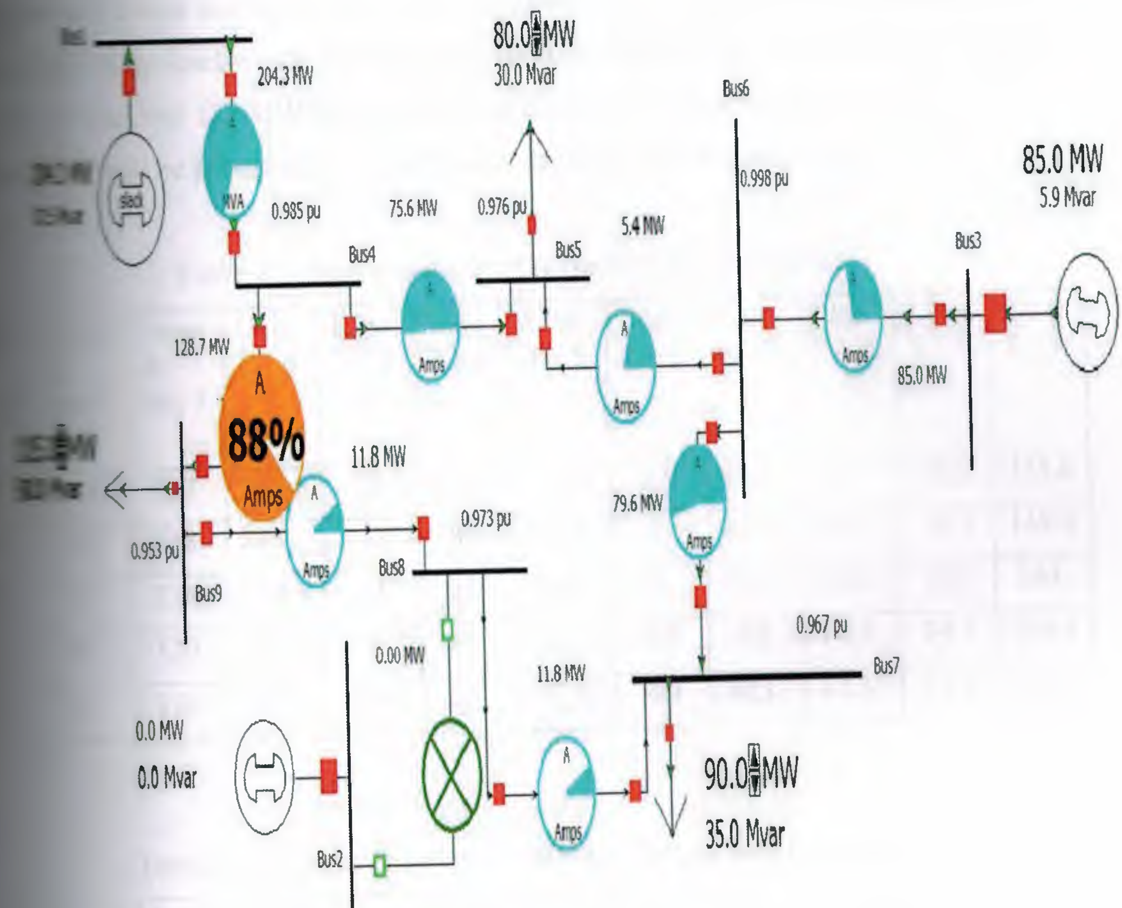

Figure 4.4: Diagram of the outage a single transmission line of IEEE 9-Bus system.

To implement the fifth step (Step $_5$), separate the rest of the transmission lines of EEE 9-Bus system where this outage will be one by one to perform nine cases (case for each outage).

For the implementation of the sixth step (Step $_6$), since the IEEE 9-bus system consists of three active loads (90 MW, 100 MW and 125 MW), so these changes in the loads will be (81 MW - 97 MW) for the first load, (91 MW – 107 MW) for the second load and (116 [illegible] – 132 MW) for the third load with increase 4 MW each time. These procedures are [illegible]ted by going to the "Run Mode" then right click at the real load and choose [illegible] Information Dialog". "Bus Field Options" will opened and change the first [illegible] to 81 MW in the "Field Value". In the "Load Field Information Dialog" go to [illegible] per Mouse Click" and change it to 4 MW. Repeat these procedures for the rest [illegible] loads. Click "Simulation" from the upper left corner and select "Solve and [illegible]". Record data and increase each load by click on it, again click "Simulation" from [illegible] left corner and select "Solve and Animate". These processes are repeated until [illegible] in the loads reach the maximum level (97 MW for the first load, 107 MW for [illegible] load and 132 MW for the third load). After repeating the fourth step, (N – 1) [illegible] will be presented as shown below in tables (4.7, 4.8, 4.9 and 4.10).

Table 4.9: Real powers in MW (testing data for case2)

[illegible]	Load at bus 7	Load at bus 9	Line 1 – 4	Line 2 – 8	Line 3 – 6	Line 4 – 5	Line 5 – 6	Line 6 – 7	Line 7 – 8	Line 8 – 9	Line 4 – 9
[illegible]	107	132	257.6	0	85	101.8	2.9	87.8	20.9	20.9	155.8
[illegible]	103	128	245	0	85	95.6	1	85.9	18.7	18.7	149.4
[illegible]	99	124	232.4	0	85	89.4	1	83.9	16.6	16.6	143
[illegible]	95	120	219.9	0	85	83.3	2.9	82	14.5	14.5	136.6
[illegible]	91	116	207.4	0	85	77.2	4.9	80.1	12.3	12.3	130.3

Table 4.10: Reactive powers in MVAR (testing data for case2)

[illegible]	Load at bus 7	Load at bus 9	Line 1 – 4	Line 2 – 8	Line 3 – 6	Line 4 – 5	Line 5 – 6	Line 6 – 7	Line 7 – 8	Line 8 – 9	Line 4 – 9
[illegible]	107	132	60.2	0	16.6	7.8	32.9	24.4	10.6	28.9	27.7
[illegible]	103	128	54.2	0	13.8	8	31.8	23.5	11.5	28.7	25.9
[illegible]	99	124	48.6	0	11.2	8.2	30.8	22.7	12.3	28.4	24.2
[illegible]	95	120	43.4	0	8.8	8.3	29.7	22	13	28.1	22.7
[illegible]	91	116	38.6	0	6.5	8.3	28.8	21.3	13.7	27.8	22.1

Table 4.11: Voltage Magnitudes per unit (testing data for case2)

[illegible]	Load at bus 7	Load at bus 9	V4 (P.U.)	V5 (P.U.)	V6 (P.U.)	V7 (P.U.)	V8 (P.U.)	V9 (P.U.)
[illegible]	107	123	0.977	0.964	0.992	0.954	0.959	0.939
[illegible]	103	128	0.979	0.967	0.993	0.957	0.962	0.942
[illegible]	99	124	0.981	0.97	0.995	0.96	0.966	0.946
[illegible]	95	120	0.983	0.973	0.996	0.963	0.969	0.949
[illegible]	91	116	0.985	0.975	0.997	0.996	0.972	0.952

Table 4.12: Thermal lines (testing data for case2)

[illegible]	Load at bus 7	Load at bus 9	Line 1 – 4 (%)	Line 2 – 8 (%)	Line 3 – 6 (%)	Line 4 – 5 (%)	Line 5 – 6 (%)	Line 6 – 7 (%)	Line 7 – 8 (%)	Line 8 – 9 (%)	Line 4 – 9 (%)
[illegible]	107	132	88	0	29	68	22	60	16	24	108
[illegible]	103	128	84	0	29	64	21	58	15	23	103
[illegible]	99	124	79	0	29	60	21	57	14	22	99
[illegible]	95	120	75	0	28	56	20	56	13	21	94
[illegible]	91	116	70	0	28	52	19	54	12	20	89

The voltage magnitudes are not taken at the first bus, second bus and the third bus because the voltage magnitudes of theses buses are already given.

After repeating the fifth step ($Step_5$), the tested nine cases will be created and will be used to test the Artificial Neural Network (ANN).

[illegible] Selection of the Artificial Neural Network (ANN) structure

The selection of an appropriate artificial neural network structure consists of input layer, hidden layer and output layer. In addition, the values of the momentum factor (α) and the learning rate coefficient (the learning step size (η)) and these important parameters are affecting on the learning capability of the network. A small amount of the learning rate coefficient (η) will make the learning process very slow.The large amount of the (η) will cause missing of the desired minimum, so an appropriate learning rate (η) will be chosen and a suitable momentum factor (α) will be selected to prevent the algorithm from falling in the hole.

The value of the desired Mean Square Error will be chose according to the importance of the subject and its usage in that particular area. From important elements that affect in finding the best mean square error is Epoch (the of training iteration), where the best mean square error is specified either it reaches the desired Mean Square Error or it reaches the maximum number of epoch. The process of the epoch is shown below in figure 4.5.

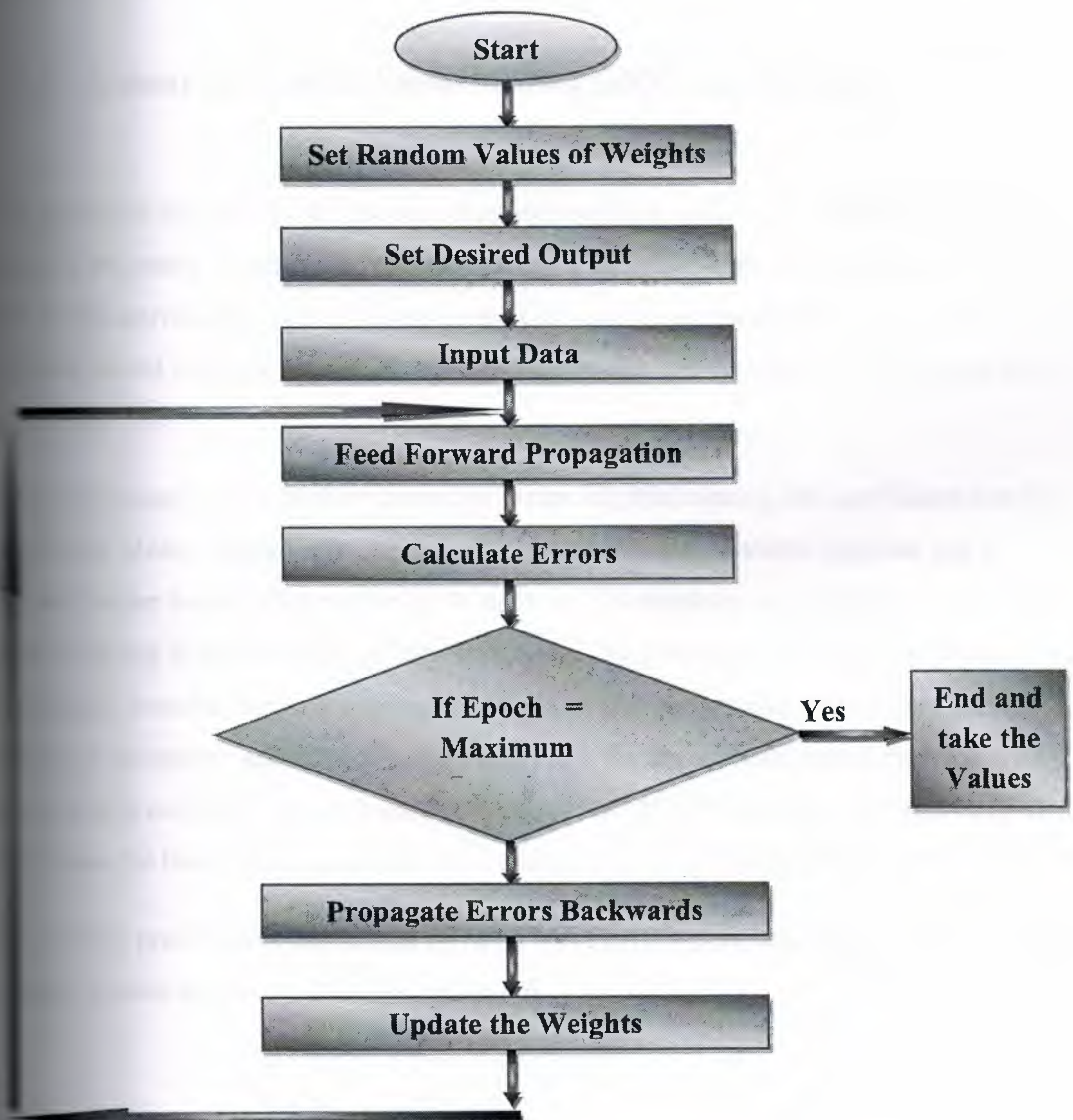

Figure 4.5: The back-propagation neural network epoch.

appropriate transfer function is going to select according to the characteristics of the system. The only significant problem is how to select the numbers of the hidden layers and numbers of neurons in each hidden layer. The number of the hidden layers will be altered according to the characteristics of the database and the degree of their complexity. The numbers of neurons in each hidden layer must be not too many even not very few. Very few numbers of neurons in the hidden layer will cause the algorithm do not training properly and too many numbers of the neurons in the hidden layer will cause the taken time for the training process will increase significantly. Therefore the numbers of the hidden layers and numbers of neurons in each hidden layer will be selected very carefully [4, 22, 32, 50, 75, 76].

4.4.3 Training the Artificial Neural Network (ANN) using the database

The generated database by the Newton-Raphson method using Power World Simulator's program are going to use in the training process. The inputs to the artificial neural network will be the active and reactive powers of the first nine cases, while the outputs to the artificial neural network will be the voltage magnitudes and the thermal limits of the first nine cases.

The appropriate values of the momentum factor (α), the learning rate coefficient size (η), the desired Mean Square Error, number of iteration (epochs), transfer function and a number hidden layers will be selected. In addition, the numbers of neurons in every hidden layer are going to select very carefully. Because of the properties of non-linear problem, the sigmoid transfer function is going to use. These parameters will choose very carefully to achieve the proper and effective training process for the artificial neural network. The database will normalize within a domain from "0" to "1". The data normalization will help to decrease the time of the training process and easy to deal with these databases [4, 79].

The training process will implement by using MATLAB's program. The procedures of the training process are shown below in figure 4.6.

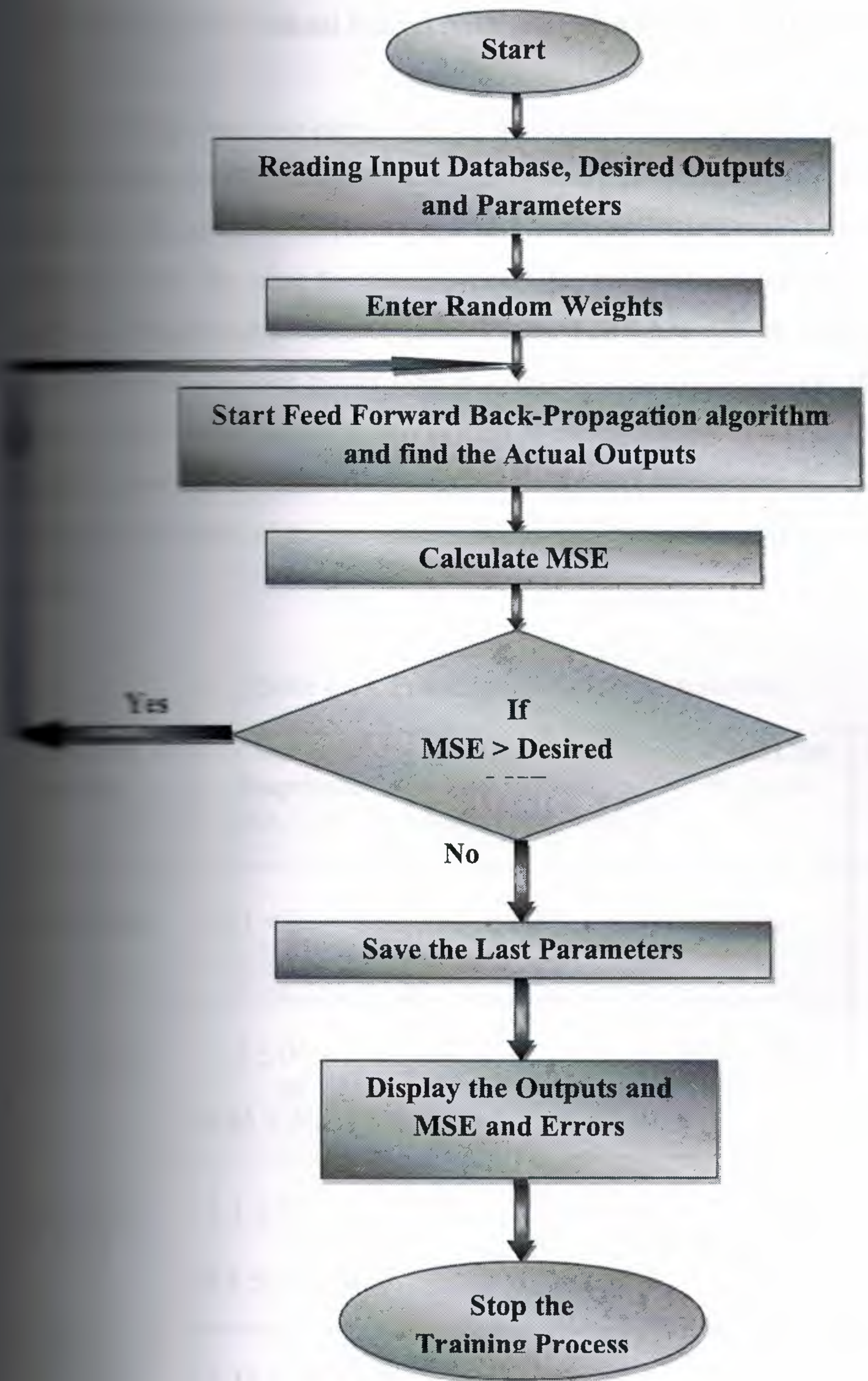

Figure 4.6: Flow Chart of the Training Process.

Testing the Artificial Neural Network (ANN) using the database

After the training process is completed, the aartificial neural network is going to test with different loading conditions and N-1cotingency analysis (different nine cases). The inputs to the artificial neural network will be the active and reactive powers of the several nine cases. By using the testing process, the artificial neural network is going to predict the voltage magnitudes and thermal lines. And the results are compared with the results of Newton-Raphson power flow in terms of accuracy. In addition, the testing process is use to determine the power system operating statuses (normal state, alert state, emergency state and extreme emergency state). These operating statuses are identified according to the limits of the bus voltage values and thermal line values as shown below in table 4.6.

Table 4.13: Power system's operating statuses

Operating Statuses	Voltage Magnitude (p.u.) Limit	Desired Output for Voltage Magnitude Limit	Thermal Line (TH) Limit (%)	Desired Output for Thermal Line Limit
Normal State	0.91 < |V| < 1.0	"NS"	< 80%	0
Alarm State	1.0 ≤ |V| < 1.1 or 0.85 < |V| ≤ 0.91	"AS"	80% - 99%	1
Emergency State	1.1 ≤ |V| < 1.15 or 0.8 ≤ |V| ≤ 0.85	"ES"	100% - 109%	2
Extreme Emergency State	1.15 ≤ |V| < 1.2 or 0.8 > |V|	"EES"	> 110 %	3

By using this table (4.6), the outputs of the artificial neural network (the voltage magnitudes and thermal lines) are going to classify under four operating statuses (normal alert state, emergency state and extreme emergency state) to help the system operator to operate any power system at properly and safely and to avoid the dangerous situations that lead to the collapse or the total blackout for that system. In addition, the outputs of the artificial neural network can be used to reveal the most susceptible areas for emergency situations and to forecast the vulnerable areas in the power system.

The testing process will implement by using MATLAB's program. The procedures of the testing process are shown below in figure 4.7.

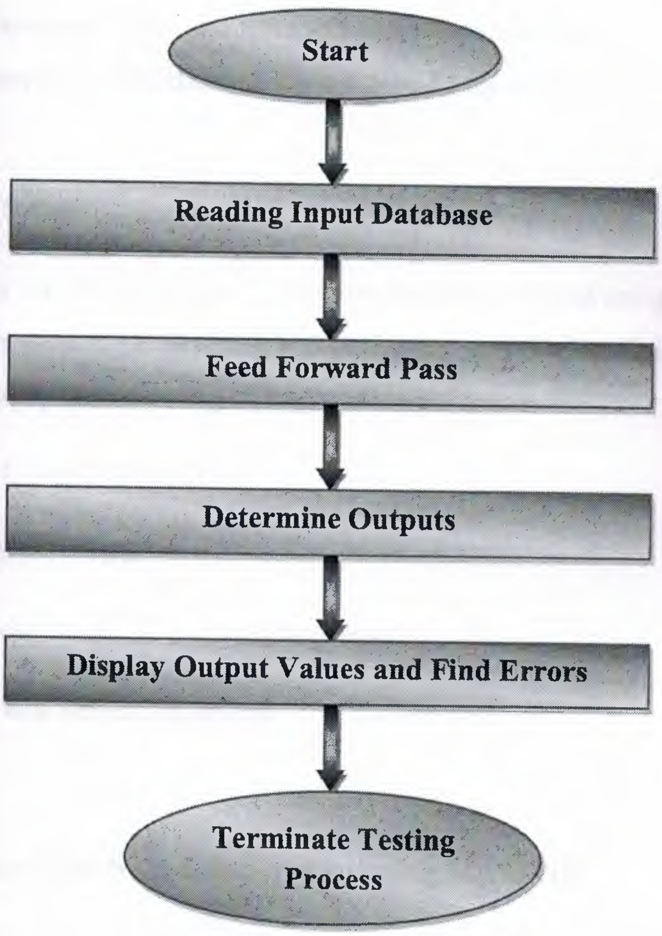

Figure 4.7: Flow chart of the testing process.

With the end of the testing process, the desired outputs and operating statuses will be calculated. In addition, the performance of the artificial neural network is calculated.

CHAPTER FIVE

EXPERIMENTAL RESULTS AND DISCUSSION

Overview

presents the training and the testing results of the artificial neural network for the static security assessment. At the end of the training and testing process, magnitudes per unit, power system's operating statuses, values of the thermal errors between ANN and NR method will be calculated at each case. In percentages of classification accuracy (CA) for every case in the training and process.

Experimental Setup

Bus System was implemented by Newton-Raphson method using Power World 's program version 12. Training and testing the specified artificial neural network performed by using the following characteristics as:

Intel (R) Core (TM) i3 CPU.

memory (RAM): 3GB

Type: Window 7 with 32-bit Operating system

LAB software tool version (R2011a)

5.3 Training the Artificial Neural Network by using MATLAB

generated database by the Newton-Raphson method using Power World Simulator's are used in the training process. Enter the inputs (the active and reactive powers first nine cases) and the outputs (the voltage magnitudes and the thermal limits of the cases) to the artificial neural network by using MATLAB's program.

appropriate values of the momentum factor (α), the learning rate coefficient size (η), the Mean Square Error, number of iteration (epochs), transfer function and a number the hidden layers are selected. In addition, the numbers of neurons in every hidden layer determined as shown below in table 5.1.

Table 5.1: Values for Training Parameters

Desired Mean Square Error	0.000001
Learning Rate (η)	0.04
Momentum Factor (α)	0.3
Maximum Iteration (Epochs)	300000
Type of the transfer function	Sigmoid function
Number of Hidden Layers	4
Number of Neurons at the first Hidden Layer	30
Number of Neurons at the second Hidden Layer	100
Number of Neurons at the third Hidden Layer	30
Number of Neurons at the fourth Hidden Layer	50

These training parameters were selected because they produced the best mean square error and the best results. Four hidden layers have been selected with their neurons in each hidden layer according to the characteristics of data base and the degree of their complexity where these layers with their neurons provided the best predicted results.

Results of the Training and the Discussions

At the end of the training process, the training performance of the artificial neural network was calculated as shown in figure 5.1. In addition, the rest of the parameters were determined as shown below in table 5.2.

Table 5.2: Results of training

Best Mean Square Error	$2.8 * 10^{-6}$ at epoch 300000
Number of Input Neurons	24
Number of Output Neurons	15
Learning Rate	1.0484 at epoch 300000
Number of Iteration to get Best Mean Square Error	300000

Square Error (MSE) performance for these layers and the neurones is for the process is shown below in figure 5.1.

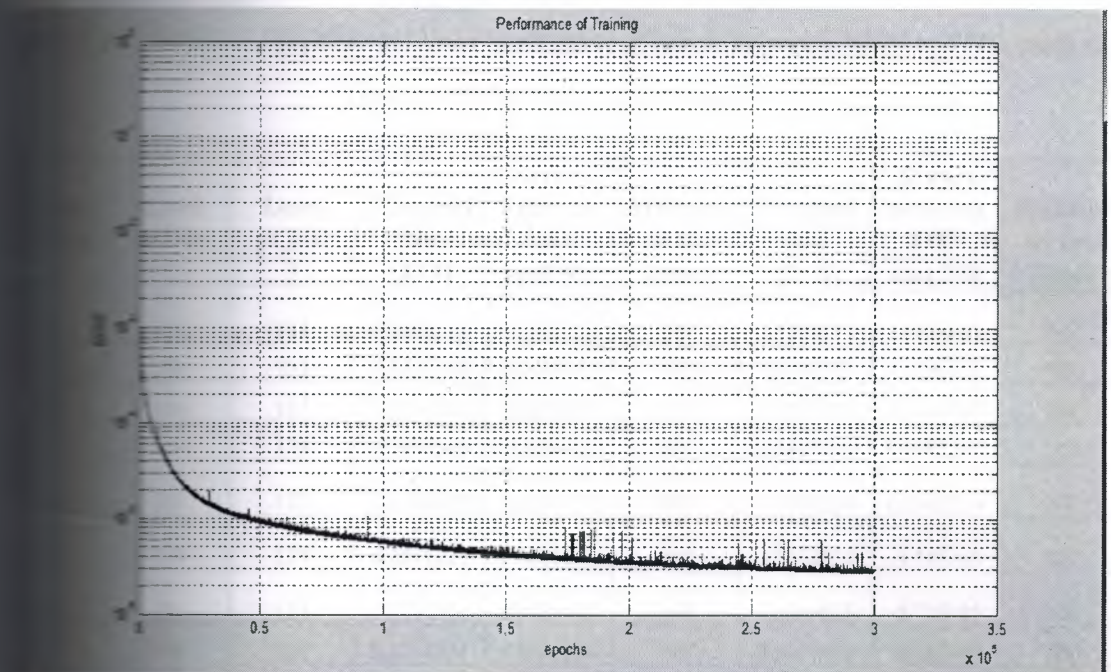

Figure 5.1: Training performance of the neural network.

Mean Square Error (MSE) at epoch 300000 is $2.8 * 10^{-6}$ which is satisfactorily . This reflects the correct choice of the training parameters for providing a good forecast the power system's operating statuses.

on of the training results (the voltage magnitudes and the thermal lines) and g statuses (normal state, alert state, emergency state and extreme emergency were determined. In addition, the errors between the estimated training results and Raphson technique were calculated in terms of accuracy as shown below in the

system's operating statuses is considered as a normal state "NS" when the voltage limit is ($0.91 < |V| < 1.0$) and the thermal line limit is (< 80%).

magnitude limit consider as an alert state "AS" when the voltage magnitude ($1.0 \leq |V| < 1.1$ or $0.85 < |V| \leq 0.91$) and the thermal line limit is (80% - 99%).

magnitude limit consider as an emergency state "AS" when the voltage limit is ($1.1 \leq |V| < 1.15$ or $0.80 \leq |V| \leq 0.85$) and the thermal line limit is (100%

[illegible] magnitude limit consider as an extreme emergency state "EES" when the [illegible]gnitude limit is (1.15 ≤ |V| < 1.2 or 0.8 >|V|) and the thermal line limit is [illegible].

[illegible] 5.3.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case1)

[illegible]	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.3505252	-0.0005252	'NS'	0.5500251	-2.51E-05	'NS'
[illegible]	108	133	0.3297847	0.0002153	'NS'	0.549593	0.000407	'NS'
[illegible]	106	131	0.3094563	0.0005437	'NS'	0.5497093	0.0002907	'NS'
[illegible]	104	129	0.2899338	6.62E-05	'NS'	0.5497764	0.0002236	'NS'
[illegible]	102	127	0.2707077	-0.0007077	'NS'	0.5502329	-0.0002329	'NS'
[illegible]	100	125	0.2517225	-0.0017225	'NS'	0.5500514	-5.14E-05	'NS'
[illegible]	98	123	0.2334405	-0.0034405	'NS'	0.5500977	-9.77E-05	'NS'
[illegible]	96	121	0.2154724	0.0045276	'NS'	0.5500863	-8.63E-05	'NS'
[illegible]	94	119	0.1973909	0.0026091	'NS'	0.5494854	0.0005146	'NS'
[illegible]	92	117	0.1801468	-0.0001468	'NS'	0.5495965	0.0004035	'NS'
[illegible]	90	115	0.1624721	-0.0024721	'NS'	0.550171	-0.000171	'NS'
[illegible]	Load at Bus 7	Load at Bus 9	Thermal line (3- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (4-5)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.2806102	-0.0006102	'NS'	0.3105016	-0.0005016	'NS'
[illegible]	108	133	0.2798584	0.0001416	'NS'	0.2935128	-0.0035128	'NS'
[illegible]	106	131	0.2793308	0.0006692	'NS'	0.276429	0.003571	'NS'
[illegible]	104	129	0.2792728	0.0007272	'NS'	0.2592222	0.0007778	'NS'
[illegible]	102	127	0.2795147	0.0004853	'NS'	0.2422159	-0.0022159	'NS'
[illegible]	100	125	0.2792484	0.0007516	'NS'	0.2254147	-0.0054147	'NS'
[illegible]	98	123	0.2800275	-2.75E-05	'NS'	0.2087196	0.0012804	'NS'
[illegible]	96	121	0.2807281	-0.0007281	'NS'	0.193162	-0.003162	'NS'
[illegible]	94	119	0.2817693	-0.0017693	'NS'	0.1769675	0.0030325	'NS'
[illegible]	92	117	0.2836639	-0.0036639	'NS'	0.1615521	-0.0015521	'NS'
[illegible]	90	115	0.2857252	0.0042748	'NS'	0.1481931	0.0018069	'NS'
[illegible]	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines

[illegible]	110	135	0.3896416	0.0003584	'NS'	0.2496347	0.0003653	'NS'
[illegible]	108	133	0.3944245	-0.0044245	'NS'	0.243446	-0.003446	'NS'
[illegible]	106	131	0.3987104	0.0012896	'NS'	0.238091	0.001909	'NS'
[illegible]	104	129	0.4046497	-0.0046497	'NS'	0.2332339	-0.0032339	'NS'
[illegible]	102	127	0.4097727	0.0002273	'NS'	0.2290503	0.0009497	'NS'
[illegible]	100	125	0.4150258	-0.0050258	'NS'	0.2245268	0.0054732	'NS'
[illegible]	98	123	0.4214957	-0.0014957	'NS'	0.2205718	-0.0005718	'NS'
[illegible]	96	121	0.4262347	0.0037653	'NS'	0.2172677	0.0027323	'NS'
[illegible]	94	119	0.4321513	-0.0021513	'NS'	0.2135697	-0.0035697	'NS'
[illegible]	92	117	0.4387307	0.0012693	'NS'	0.2103366	-0.0003366	'NS'
[illegible]	90	115	0.4417904	-0.0017904	'NS'	0.2078859	0.0021141	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
[illegible]	110	135	0.5487771	0.0012229	'NS'	0.5421103	-0.0021103	'NS'
[illegible]	108	133	0.5402988	-0.0002988	'NS'	0.5487568	0.0012432	'NS'
[illegible]	106	131	0.5332185	-0.0032185	'NS'	0.5552163	0.0047837	'NS'
[illegible]	104	129	0.5250694	0.0049306	'NS'	0.5623683	-0.0023683	'NS'
[illegible]	102	127	0.518265	0.001735	'NS'	0.5693174	0.0006826	'NS'
[illegible]	100	125	0.5115806	-0.0015806	'NS'	0.5766744	0.0033256	'NS'
[illegible]	98	123	0.5029461	-0.0029461	'NS'	0.5840972	-0.0040972	'NS'
[illegible]	96	121	0.4958435	0.0041565	'NS'	0.5910653	-0.0010653	'NS'
[illegible]	94	119	0.4891612	0.0008388	'NS'	0.5983824	0.0016176	'NS'
[illegible]	92	117	0.4826969	-0.0026969	'NS'	0.6057817	0.0042183	'NS'
[illegible]	90	115	0.4773375	0.0026625	'NS'	0.6132913	-0.0032913	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
[illegible]	110	135	0.4396952	0.0003048	'NS'
[illegible]	108	133	0.4230675	-0.0030675	'NS'
[illegible]	106	131	0.4084687	0.0015313	'NS'
[illegible]	104	129	0.3923028	-0.0023028	'NS'
[illegible]	102	127	0.3787964	0.0012036	'NS'
[illegible]	100	125	0.3636223	-0.0036223	'NS'
[illegible]	98	123	0.3497343	0.0002657	'NS'
[illegible]	96	121	0.3369494	0.0030506	'NS'

[illegible]	94	119	0.3233204	-0.0033204	'NS'
[illegible]	92	117	0.3110103	-0.0010103	'NS'
[illegible]	90	115	0.2978378	0.0021622	'NS'

Table 5.3.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case1)

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
[illegible]	110	135	0.9869775	2.25E-05	'NS'	0.9745836	-0.0005836	'NS'
[illegible]	108	133	0.9872057	-0.0002057	'NS'	0.9752385	-0.0012385	'NS'
[illegible]	106	131	0.987392	-0.000392	'NS'	0.9757531	-0.0007531	'NS'
[illegible]	104	129	0.9875611	-0.0005611	'NS'	0.9761304	-0.0011304	'NS'
[illegible]	102	127	0.9876278	-0.0006278	'NS'	0.9763179	-0.0013179	'NS'
[illegible]	100	125	0.9877945	-0.0007945	'NS'	0.9763857	-0.0013857	'NS'
[illegible]	98	123	0.9877661	-0.0007661	'NS'	0.9762731	-0.0002731	'NS'
[illegible]	96	121	0.9876903	-0.0006903	'NS'	0.9759055	9.45E-05	'NS'
[illegible]	94	119	0.987533	-0.000533	'NS'	0.9752826	0.0007174	'NS'
[illegible]	92	117	0.9872132	-0.0002132	'NS'	0.9745095	0.0014905	'NS'
[illegible]	90	115	0.9868238	0.0001762	'NS'	0.9734658	0.0025342	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
[illegible]	110	135	1.0012827	0.0017173	'AS'	0.9827505	0.0002495	'NS'
[illegible]	108	133	1.0015874	0.0014126	'AS'	0.9834817	-0.000482	'NS'
[illegible]	106	131	1.0018991	0.0011009	'AS'	0.9841398	-0.0001398	'NS'
[illegible]	104	129	1.0022273	0.0007727	'AS'	0.9846216	-0.0006216	'NS'
[illegible]	102	127	1.0025375	0.0014625	'AS'	0.9849638	-0.0009638	'NS'
[illegible]	100	125	1.0028355	0.0011645	'AS'	0.9852257	-0.0002257	'NS'
[illegible]	98	123	1.0031551	8.45E-04	'AS'	0.9851921	-0.000192	'NS'
[illegible]	96	121	1.0033922	0.0006078	'AS'	0.9850859	-8.59E-05	'NS'
[illegible]	94	119	1.0035837	0.0004163	'AS'	0.9848121	0.0011879	'NS'
[illegible]	92	117	1.0037682	0.0002318	'AS'	0.9842412	0.0017588	'NS'
[illegible]	90	115	1.0037889	0.0002111	'AS'	0.9836485	0.0023515	'NS'
Load at Bus	**Load at Bus**	**Load at Bus**	**| V8 |**	**Errors between**	**Statuses of the**	**| V9 |**	**Errors between**	**Statuses of the**

7	9	(P.U.)	ANN and NR	Buses	(P.U.)	ANN and NR	Buses
110	135	0.9973498	-0.0023498	'NS'	0.9551582	0.0018418	'NS'
108	133	0.9972926	-0.0022926	'NS'	0.9560716	0.0009284	'NS'
106	131	0.9971479	-0.0021479	'NS'	0.9567135	0.0002865	'NS'
104	129	0.9968984	-0.0008984	'NS'	0.9572819	-0.0002819	'NS'
102	127	0.9966152	-0.0006152	'NS'	0.9576201	-0.0006201	'NS'
100	125	0.9963055	-0.0003055	'NS'	0.9581794	-0.0011794	'NS'
98	123	0.995893	0.000107	'NS'	0.9582057	-0.0002057	'NS'
96	121	0.995546	0.000454	'NS'	0.9582731	-0.0002731	'NS'
94	119	0.9952425	0.0007575	'NS'	0.9583923	-0.0003923	'NS'
92	117	0.9948755	0.0011245	'NS'	0.9580517	-5.17E-05	'NS'
90	115	0.9946702	0.0013298	'NS'	0.9580461	-4.61E-05	'NS'

...the tables 5.3.1 and 5.3.2, the values of the thermal lines, voltage magnitudes per ... power system's operating statuses and the errors between ANN and NR method were ...mined.

...formance of the feed forward back propagation neural network will be calculated ... classification accuracy (CA) using the error between ANN and NR method. The ...age of classification accuracy (CA) is determined by using equation (5.1).

$$\text{...fication accuracy (\%)} = \frac{\text{NO.of samples classified correctly}}{\text{total number of samples in each case}} * 100 \qquad (5.1)$$

...errors for the values of the thermal lines per unit < 0.019 (selected threshold) and the ... for the values of the voltage magnitudes < 0.019 (selected threshold), then the value ... thermal line and the voltage magnitude per unit is correctly predicted.

...errors for the values of the thermal lines per unit > 0.019 and the errors for the values ... voltage magnitudes > 0.019, then the value of the thermal line and the voltage ...itude per unit is not predicted. These values of the thresholds were selected according ... limits of the statues (normal state, alert state, emergency state and extreme ...gency state) for IEEE-9 bus system.

[illegible] accuracy for case1 at training stage (%) = (165 / 165) * 100 = 100 %.

[illegible] Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case4 (outage the line (4-5)))

[illegible]	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.3592865	7.13E-04	'NS'	0.5486795	1.32E-03	'NS'
[illegible]	108	133	0.3409765	-0.0009765	'NS'	0.5507969	-0.0007969	'NS'
[illegible]	106	131	0.321347	-1.35E-03	'NS'	0.5514868	-1.49E-03	'NS'
[illegible]	104	129	0.3005038	-5.04E-04	'NS'	0.5510634	-1.06E-03	'NS'
[illegible]	102	127	0.2799744	2.56E-05	'NS'	0.5496012	0.0003988	'NS'
[illegible]	100	125	0.2596425	0.0003575	'NS'	0.5487958	1.20E-03	'NS'
[illegible]	98	123	0.2388961	0.0011039	'NS'	5.48E-01	1.97E-03	'NS'
[illegible]	96	121	0.2195005	0.0004995	'NS'	0.5492389	7.61E-04	'NS'
[illegible]	94	119	0.2011487	-0.0011487	'NS'	0.5518257	-1.83E-03	'NS'
[illegible]	92	117	0.1824728	-0.0024728	'NS'	0.5567058	-0.0067058	'NS'
[illegible]	90	115	0.161803	-0.001803	'NS'	0.5647418	-1.47E-02	'NS'

[illegible]	Load at Bus 7	Load at Bus 9	Thermal line (3- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (4- 5)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.3009903	-0.0009903	'NS'	-6.65E-05	6.65E-05	'NS'
[illegible]	108	133	2.99E-01	5.44E-04	'NS'	0.0001189	-0.0001189	'NS'
[illegible]	106	131	0.2977719	0.0022281	'NS'	-7.88E-05	7.88E-05	'NS'
[illegible]	104	129	0.2962817	0.0037183	'NS'	3.22E-05	-3.22E-05	'NS'
[illegible]	102	127	0.2938819	-0.0038819	'NS'	-0.0010265	1.03E-03	'NS'
[illegible]	100	125	0.2920867	-0.0020867	'NS'	-0.0022136	0.0022136	'NS'
[illegible]	98	123	0.2907484	-7.48E-04	'NS'	-0.0011351	1.14E-03	'NS'
[illegible]	96	121	0.2900926	-9.26E-05	'NS'	-0.0004966	4.97E-04	'NS'
[illegible]	94	119	0.2890221	0.0009779	'NS'	0.0005908	-0.0005908	'NS'
[illegible]	92	117	0.28848	1.52E-03	'NS'	0.0033136	-3.31E-03	'NS'
[illegible]	90	115	0.291331	-0.001331	'NS'	0.0213757	-0.0213757	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.712126	-0.002126	'NS'	0.2094224	5.78E-04	'NS'
[illegible]	108	133	0.6980984	0.0019016	'NS'	0.199893	1.07E-04	'NS'

[illegible]	106	131	0.6835434	-0.0035434	'NS'	0.1897675	0.0002325	'NS'
[illegible]	104	129	0.6685391	0.0014609	'NS'	0.1807081	-7.08E-04	'NS'
[illegible]	102	127	0.6531885	-0.0031885	'NS'	0.1708503	-0.0008503	'NS'
[illegible]	100	125	0.6386848	-8.68E-03	'NS'	0.1621184	-0.0021184	'NS'
[illegible]	98	123	0.6223251	-0.002325	'NS'	0.1574355	0.0025645	'NS'
[illegible]	96	121	0.6075287	0.0024713	'NS'	0.1530995	-0.0030995	'NS'
[illegible]	94	119	0.5915998	-0.0015998	'NS'	0.1484835	1.52E-03	'NS'
[illegible]	92	117	0.5737565	0.0062435	'NS'	0.1448143	-4.81E-03	'NS'
[illegible]	90	115	0.5440236	0.0259764	'NS'	0.1535037	-1.35E-02	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.8914926	-0.0014926	'AS'	0.2697485	0.0002515	'NS'
[illegible]	108	133	0.8549386	0.0050614	'AS'	0.2904657	-0.0004657	'NS'
[illegible]	106	131	0.8216877	0.0083123	'AS'	0.3106417	-0.0006417	'NS'
[illegible]	104	129	0.7907562	-0.0007562	'NS'	0.3305621	-0.0005621	'NS'
[illegible]	102	127	0.7621597	-0.0021597	'NS'	0.3521873	-0.0021873	'NS'
[illegible]	100	125	0.7347299	0.0052701	'NS'	0.3737691	-0.0037691	'NS'
[illegible]	98	123	0.7068758	0.0031242	'NS'	0.397006	0.002994	'NS'
[illegible]	96	121	0.678922	0.001078	'NS'	0.4194575	0.0005425	'NS'
[illegible]	94	119	0.6503932	-0.0003932	'NS'	0.4422903	-2.29E-03	'NS'
[illegible]	92	117	0.6220012	-0.0020012	'NS'	0.4647114	0.0052886	'NS'
[illegible]	90	115	0.5746541	0.0153459	'NS'	0.4839839	0.0160161	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
[illegible]	110	135	0.7091267	0.0008733	'NS'
[illegible]	108	133	0.6709519	-0.0009519	'NS'
[illegible]	106	131	0.6337167	-0.0037167	'NS'
[illegible]	104	129	0.5978009	0.0021991	'NS'
[illegible]	102	127	0.5614629	-0.0014629	'NS'
[illegible]	100	125	0.5266275	-0.0066275	'NS'
[illegible]	98	123	0.4915749	-0.0015749	'NS'
[illegible]	96	121	0.4566653	0.0033347	'NS'
[illegible]	94	119	0.4209778	-0.0009778	'NS'
[illegible]	92	117	0.3837537	0.0062463	'NS'

[illegible]	90	115	0.3424019	0.0175981	'NS'

Table 5.3.4: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case4 (outage the line (4-5)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
[illegible]	110	135	0.9867206	1.28E-03	'NS'	0.8945238	-2.52E-03	'AS'
[illegible]	108	133	0.9875292	0.0004708	'NS'	0.8961605	- 0.0011605	'AS'
[illegible]	106	131	0.9881582	-1.58E-04	'NS'	0.8979594	1.04E-03	'AS'
[illegible]	104	129	0.9885709	4.29E-04	'NS'	0.9000085	1.99E-03	'AS'
[illegible]	102	127	0.9890795	-7.95E-05	'NS'	0.9026991	0.0023009	'AS'
[illegible]	100	125	0.9894266	-0.000427	'NS'	0.9055782	1.42E-03	'AS'
[illegible]	98	123	0.9896136	- 0.0006136	'NS'	9.09E-01	8.06E-04	'AS'
[illegible]	96	121	0.9897215	-0.000721	'NS'	0.9128159	1.84E-04	'NS'
[illegible]	94	119	0.9899355	- 0.0009355	'NS'	0.9168748	-1.87E-03	'NS'
[illegible]	92	117	0.9900183	- 0.0020183	'NS'	0.921017	-0.003017	'NS'
[illegible]	90	115	0.9894417	- 0.0014417	'NS'	0.9256829	-5.68E-03	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
[illegible]	110	135	0.9857583	- 0.0027583	'NS'	0.9685872	0.0034128	'NS'
[illegible]	108	133	9.86E-01	-1.95E-03	'NS'	0.9701785	0.0028215	'NS'
[illegible]	106	131	0.986208	-0.001208	'NS'	0.9719411	0.0020589	'NS'
[illegible]	104	129	0.9865164	- 0.0005164	'NS'	0.9738393	0.0011607	'NS'
[illegible]	102	127	0.9870243	-2.43E-05	'NS'	0.9756811	3.19E-04	'NS'
[illegible]	100	125	0.9876246	0.0003754	'NS'	0.9774294	- 0.0014294	'NS'
[illegible]	98	123	0.988326	6.74E-04	'NS'	0.9792452	-2.25E-03	'NS'
[illegible]	96	121	0.9891527	0.0008473	'NS'	0.9807796	-2.78E-03	'NS'
[illegible]	94	119	0.9901476	- 0.0001476	'NS'	0.9820302	- 0.0030302	'NS'
[illegible]	92	117	0.991207	-2.07E-04	'NS'	0.9830613	-4.06E-03	'NS'
[illegible]	90	115	0.9921071	- 0.0001071	'NS'	0.9843415	- 0.0043415	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
[illegible]	110	135	0.9886934	0.0013066	'NS'	0.9572355	1.76E-03	'NS'
[illegible]	108	133	0.9898733	0.0011267	'NS'	0.9593471	-3.47E-04	'NS'

96	106	131	0.9910368	-3.68E-05	'NS'	0.9604132	-0.0004132	'NS'
94	104	129	0.992097	-9.70E-05	'NS'	0.960744	-7.44E-04	'NS'
92	102	127	0.9930143	-0.0010143	'NS'	0.9608716	-0.0008716	'NS'
90	100	125	0.9937166	-7.17E-04	'NS'	0.9605852	0.0004148	'NS'
88	98	123	0.9942047	-0.0012047	'NS'	0.9606259	0.0003741	'NS'
86	96	121	0.9944493	-0.0004493	'NS'	0.9607122	0.0002878	'NS'
84	94	119	0.9945255	-0.0005255	'NS'	0.9613294	-3.29E-04	'NS'
82	92	117	0.9944717	-0.0004717	'NS'	0.962688	-2.69E-03	'NS'
80	90	115	0.9945002	-0.0005002	'NS'	0.9648898	-4.89E-03	'NS'

Classification accuracy for case4at training stage (%) = (164 / 165) * 100 = 99.3939 %.

From these tables of case4, the comparison of estimated and actual bus voltages will be obtained by ANN-based algorithm and traditional NR power flow method at the maximum increase of load level as shown below in figure 5.2.

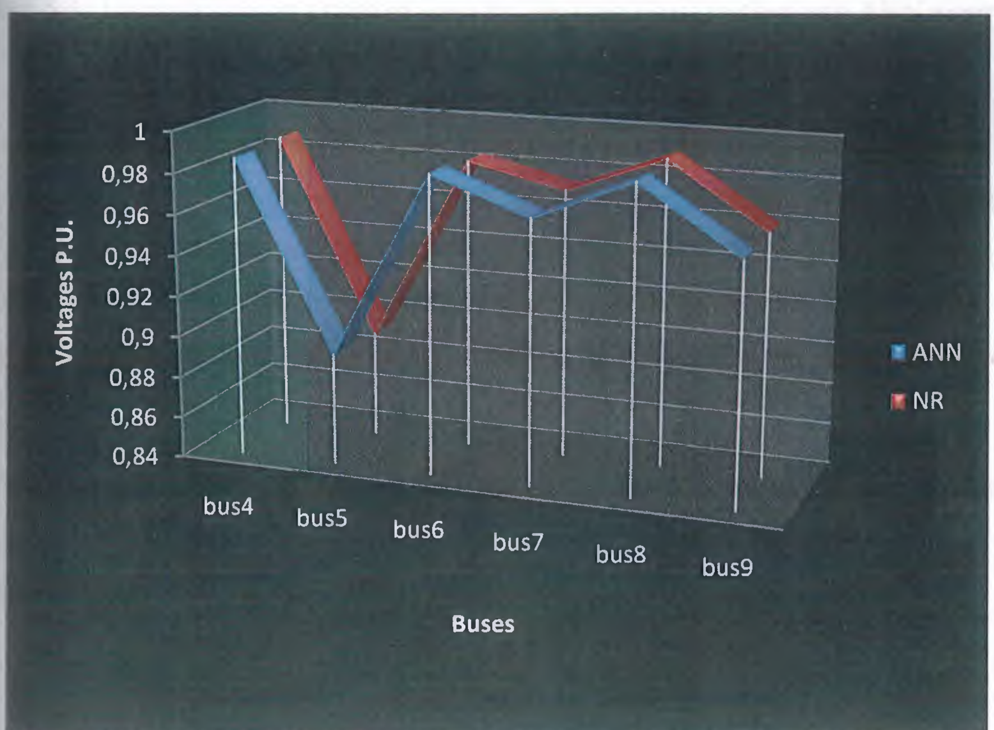

Figure 5.2: Estimation of bus voltages by NR load flow method and ANN algorithm atthe maximum increase of load level for training of case4.

Also from these tables of case4, the comparison between the NR Load Flow and ANN-based algorithm results for thermal lines at the maximum increase of load level as shown below in figure 5.3.

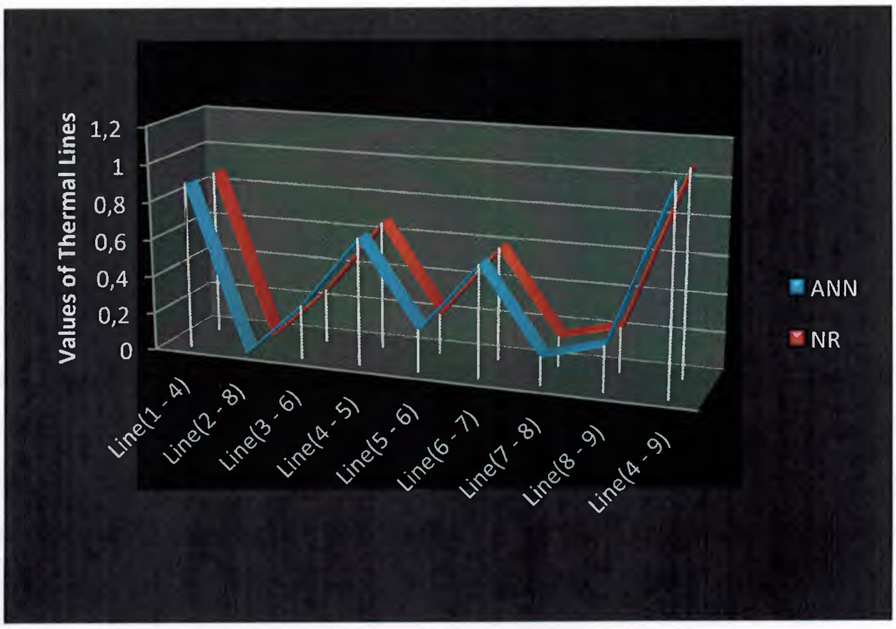

Figure 5.3: Thermal lines in different lines by NR load Flow method and ANN algorithm at the maximum increase of load level for training of case4.

From these both figures (5.2 and 5.3), the estimated bus voltages and thermal lines by used artificial neural network were compared with the actual bus voltages and thermal lines by used Newton-Raphson power flow analysis to prove the ability of prediction where the errors between these two techniques were very small. Because of these small errors between these two methods, ANN demonstrated on its high ability to predict the thermal lines and bus voltages to be uses for real time application.

The classification accuracy (CA %) of the nine trained cases by using feed forward back propagation neural network will be calculated as shown below in the table 5.3.5 and equation 5.2:

Table 5.3.5: The classification accuracy (CA %) of the nine trained cases.

(CA %) Case1	**(CA %) Case2**	**(CA %) Case3**	**(CA %) Case4**	**(CA %) Case5**
100 %.	96.3636 %.	98.7878 %.	99.3939 %.	100 %.
(CA %) Case6	**(CA %) Case7**	**(CA %) Case8**	**(CA %) Case9**	
100 %.	100 %.	100 %.	98.7878 %.	

$$\text{Total Classification Accuracy (\%)} = \frac{\text{Classification Accuracy for each case}}{\text{total number of cases}} \tag{5.2}$$

CA_{TOTAL} (%) = 893.3331 (%) / 9 = 99.25923333 %.

This percentage indicates that the artificial neural network trained well and the correct choice of the training parameters. Because of this excellent percentage, the artificial neural network will be able to predict its outputs (voltage magnitudes per unit, values of the thermal lines, operating statuses and errors between ANN and NR method) in proper way during the testing stage on specific cases differ from the cases used in the training stage.

The outputs of the artificial neural network (the voltage magnitudes and thermal lines) were classified under specified operating statuses: secure state (normal state) and insecure states (alert state, emergency state and extreme emergency state) to help the system operator to operate the power system at properly and safely and to avoid the dangerous situations that lead to the collapse or the total blackout for that system. The insecure statuses (alert state, emergency state and extreme emergency state) constitute a potential risk on the electrical system, so the insecure statuses will analyze and calculate very carefully as shown below in figure 5.4 and 5.5 respectively:

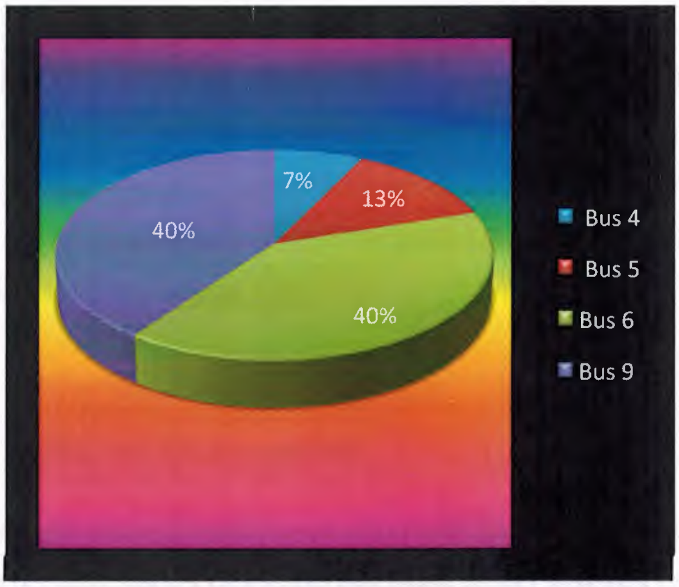

Figure 5.4: Total percentages of the insecure situations at different buses.

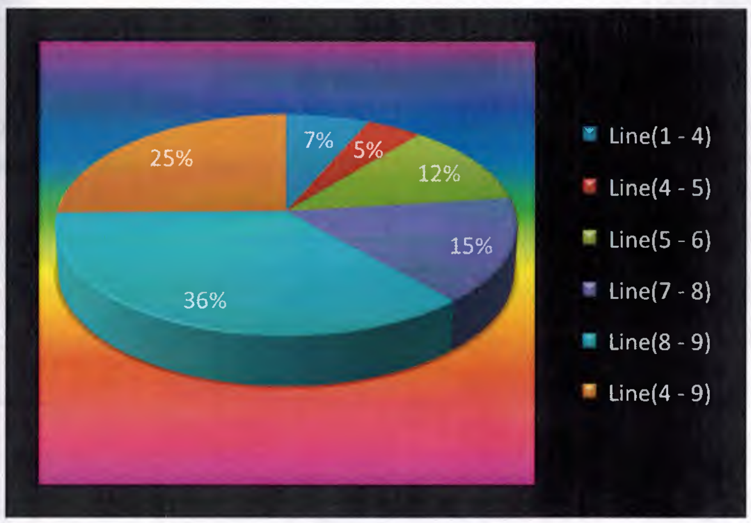

Figure 5.5: Total percentages of the insecure situations at different lines.

In these figures, the vulnerable areas and the most falling in the insecure situations as a result of exposure to serious disturbances (contingencies) are (bus4, bus5, bus6 and bus9) and (line(1-4), line(4-5), line(5-6), line(7-8), line(8-9) and line(4-9)). Therefore, these figures is used to warn the system operator to take the preventive necessary actions with the required speed to prevent the electrical system from sliding into more serious cases that lead to the collapse of parts or the whole system.

Testing the Artificial Neural Network by using MATLAB

The generated database by the Newton-Raphson method using Power World Simulator's programs are used in the testing process. Enter the inputs (891 * patterns for active powers and 891 * patterns for reactive powers of the different nine cases) and the final results of training parameters at best mean square error to the artificial neural network by using commands of the MATLAB's program.

Results of the Testing and the Discussions

At the end of the testing process, the estimated outputs of the artificial neural network (voltage magnitudes per unit, values of the thermal lines, power system's operating statuses and errors between artificial neural network (ANN) and Newton-Raphson (NR) technique) will be calculated as shown in these tables below:

Table 5.6.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case2 (outage the line (2-8)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.8880299	-8.03E-03	'AS'	-0.0023265	2.33E-03	'NS'
93	103	128	0.8402215	-0.0002215	'AS'	-0.0016993	0.0016993	'NS'
89	99	124	0.7909955	-9.95E-04	'NS'	-0.0007511	7.51E-04	'NS'
85	95	120	0.7460146	3.99E-03	'NS'	-0.0005872	5.87E-04	'NS'
81	91	116	0.70099	-9.90E-04	'NS'	0.0026893	-0.0026893	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.2928586	-0.0028586	'NS'	6.76E-01	4.06E-03	'NS'
93	103	128	0.292209	-0.002209	'NS'	0.6353013	4.70E-03	'NS'
89	99	124	0.2886115	0.0013885	'NS'	0.5989953	1.00E-03	'NS'
85	95	120	0.2835512	-3.55E-03	'NS'	0.5610951	-0.0010951	'NS'
81	91	116	0.2791108	0.0008892	'NS'	0.5193264	6.74E-04	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN**	**Statuses of the Lines**

				and NR			and NR	
97	107	132	0.2271825	-0.0071825	'NS'	0.5993128	0.0006872	'NS'
93	103	128	2.16E-01	-5.85E-03	'NS'	0.5831633	-0.0031633	'NS'
89	99	124	0.2052845	0.0047155	'NS'	0.5691061	0.0008939	'NS'
85	95	120	0.2010454	-0.0010454	'NS'	0.5571275	0.0028725	'NS'
81	91	116	0.1983597	-0.0083597	'NS'	0.543798	-3.80E-03	'NS'
Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.1524651	7.53E-03	'NS'	0.2425155	-2.52E-03	'NS'
93	103	128	0.1450814	0.0049186	'NS'	0.2295489	4.51E-04	'NS'
89	99	124	0.1383583	0.0016417	'NS'	0.2223053	-0.0023053	'NS'
85	95	120	0.1317602	-1.76E-03	'NS'	0.2124501	-2.45E-03	'NS'
81	91	116	0.1156208	0.0043792	'NS'	0.209129	-0.009129	'NS'
Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines			
97	107	132	1.0827844	-0.0027844	'ES'			
93	103	128	1.0323664	-0.0023664	'ES'			
89	99	124	0.9845105	0.0054895	'AS'			
85	95	120	0.9401082	-0.0001082	'AS'			
81	91	116	0.8859183	0.0040817	'AS'			

Table 5.6.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case2 (outage the line (2-8))).

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9787121	-1.71E-03	'NS'	0.9654186	-1.42E-03	'NS'
93	103	128	0.9806891	-0.0016891	'NS'	0.9679297	-0.0009297	'NS'
89	99	124	0.9822585	-1.26E-03	'NS'	0.9701839	-1.84E-04	'NS'
85	95	120	0.9830406	-4.06E-05	'NS'	0.9719111	1.09E-03	'NS'
81	91	116	0.9833817	1.62E-03	'NS'	0.9736086	0.0013914	'NS'
Load at Bus 5	Load at Bus 7	Load at Bus 9	| V6 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V7 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9950651	-0.0030651	'NS'	9.54E-01	-3.82E-04	'NS'

93	103	128	0.994864	-0.001864	'NS'	0.9574247	-4.25E-04	'NS'
89	99	124	0.9943649	0.0006351	'NS'	0.9603057	-3.06E-04	'NS'
85	95	120	0.9936945	0.0023055	'NS'	0.9629748	2.52E-05	'NS'
81	91	116	0.9930129	0.0039871	'NS'	0.9655374	3.05E-02	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V8 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V9 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9607758	-0.0017758	'NS'	0.9383615	0.0006385	'NS'
93	103	128	9.63E-01	-1.01E-03	'NS'	0.9410327	0.0009673	'NS'
89	99	124	0.9655331	0.0004669	'NS'	0.9446105	0.0013895	'NS'
85	95	120	0.9679516	0.0010484	'NS'	0.9490341	-3.41E-05	'NS'
81	91	116	0.9701013	0.0018987	'NS'	0.9543398	-2.34E-03	'NS'

Classification accuracy for case2 at testing stage (%) = (74 / 75) * 100 = 98.66667 %.

From these tables of case2, the comparison of estimated and actual bus voltages will be estimated by ANN-based algorithm and traditional NR power flow method as well as the comparison between the NR Load Flow and ANN-based algorithm results for thermal lines at the maximum increase of load level as shown below in figure 5.6 and 5.7 respectively:

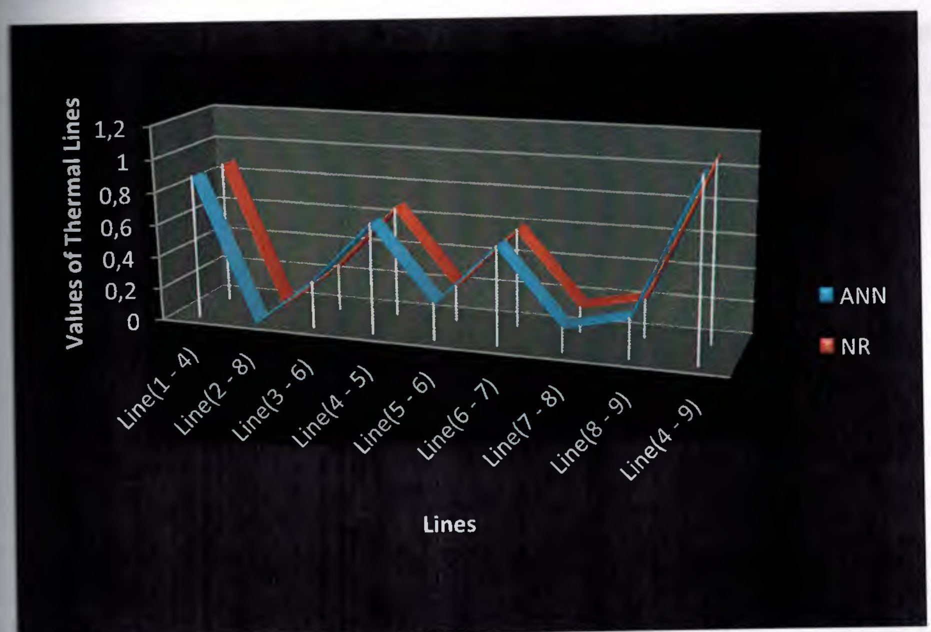

Figure 5.6: Thermal lines in different lines by NR load Flow method and ANN algorithm at the maximum increase of load level for testing of case2.

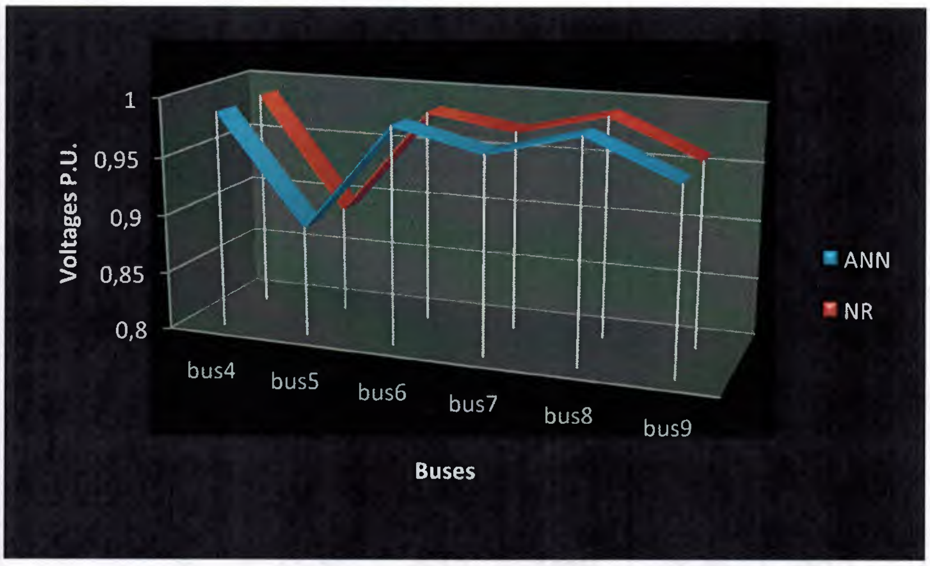

Figure 5.7: Estimation of bus voltages by NR load flow method and ANN algorithm at the maximum increase of load level for testing of case2.

The estimated results obtained from the ANN technique was compared with NR power flow analysis in terms of accuracy. As shown from these figures, the obtained estimated outcomes from the ANN are approximately matching of the results of NR technique and that demonstrates the reliability of artificial neural network in the field of the static security assessment.

Table 5.6.3: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case9 (outage the line (4-9)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.3411931	-1.19E-03	'NS'	0.634674	-1.47E-02	'NS'
93	103	128	0.2974166	-0.0074166	'NS'	0.6156348	-0.0056348	'NS'
89	99	124	0.2520061	-2.01E-03	'NS'	0.605739	4.26E-03	'NS'
85	95	120	0.2089985	1.00E-03	'NS'	0.5969542	3.05E-03	'NS'
81	91	116	0.1611838	-1.18E-03	'NS'	0.5904782	-0.0004782	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.2953426	-0.0053426	'NS'	6.80E-01	2.40E-04	'NS'
93	103	128	0.2899816	1.84E-05	'NS'	0.5882053	1.79E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line	Errors between ANN and NR	Statuses of the Lines	Thermal line	Errors between ANN and NR	Statuses of the Lines
89	99	124	0.2843009	-0.004300	'NS'	0.4976458	2.35E-03	'NS'
85	95	120	0.2806079	-0.0006079	'NS'	0.4096443	0.0003557	'NS'
81	91	116	0.2793825	0.0006175	'NS'	0.331319	8.68E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.1704014	-4.01E-04	'NS'	0.5916351	1.84E-02	'NS'
93	103	128	1.61E-01	-1.20E-03	'NS'	0.5612823	-0.0012823	'NS'
89	99	124	0.1731007	-0.0031007	'NS'	0.5091249	0.0008751	'NS'
85	95	120	0.2001142	-1.14E-04	'NS'	0.4543046	0.0056954	'NS'
81	91	116	0.2457937	0.0042063	'NS'	0.4084279	1.57E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.1569826	-6.98E-03	'NS'	1.1254884	1.45E-02	'ES'
93	103	128	0.1786647	0.0013353	'NS'	1.0916699	-1.67E-03	'ES'
89	99	124	0.2128286	-0.0028286	'NS'	1.0458613	0.0041387	'ES'
85	95	120	0.2421638	-2.16E-03	'NS'	1.0009054	-9.05E-04	'ES'
81	91	116	0.2743141	0.0056859	'NS'	0.9585014	0.0014986	'AS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**			
97	107	132	0.0016181	-0.0016181	'NS'			
93	103	128	0.0005793	-0.0005793	'NS'			
89	99	124	0.0002327	-0.0002327	'NS'			
85	95	120	0.0002812	-0.0002812	'NS'			
81	91	116	-0.0011778	0.0011778	'NS'			

Table 5.6.4: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case9 (outage the line (4-9)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9988861	1.14E-04	'NS'	0.9769206	3.08E-03	'NS'
93	103	128	0.9996171	0.0003829	'NS'	0.981368	0.000632	'NS'
89	99	124	1.0001421	-1.42E-04	'AS'	0.9844338	[illegible]	[illegible]
85	95	120	1.0002362	-2.36E-04	'AS'	0.9849107	[illegible]	[illegible]

81	91	116	0.999822	1.78E-04	'NS'	0.9837491	0.0012509	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9953472	-0.0023472	'NS'	9.51E-01	-3.00E-03	'NS'
93	103	128	0.9959265	-0.0019265	'NS'	0.9530758	-1.08E-03	'NS'
89	99	124	0.996669	-0.000669	'NS'	0.955458	-4.58E-04	'NS'
85	95	120	0.9973808	-0.0003808	'NS'	0.9581733	0.0008267	'NS'
81	91	116	0.9980451	-4.51E-05	'NS'	0.9612111	-2.11E-04	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9515041	-0.0035041	'NS'	0.779472	-0.007472	'EES'
93	103	128	9.53E-01	-9.63E-04	'NS'	0.7856612	-0.001661	'EES'
89	99	124	0.9555184	-0.000518	'NS'	0.7937982	0.0002018	'EES'
85	95	120	0.9586735	-0.0006735	'NS'	0.8028797	0.0001203	'ES'
81	91	116	0.9614504	-0.0004504	'NS'	0.8126439	-6.44E-04	'ES'

Classification accuracy for case9 at testing stage (%) = (75 / 75) * 100 = 100 %.

The classification accuracy (CA %) of the nine tested cases by using feed forward back propagation neural network will be calculated as shown below in the table 5.6.5:

Table 5.6.5: The classification accuracy of the nine tested cases.

(CA %) Case1	**(CA %) Case2**	**(CA %) Case3**	**(CA %) Case4**	**(CA %) Case5**
60 %.	98.66667 %.	58.66667 %.	98.66667 %.	98.66667 %.
(CA %) Case6	**(CA %) Case7**	**(CA %) Case8**	**(CA %) Case9**	
100 %.	100 %.	100 %.	100 %.	

Total Classification Accuracy for testing stage (%) = 860.66668 (%) / 9 = 90.51852 %.

This percentage shows the ability of the artificial neural network to determine the estimated voltage magnitudes at various buses and the estimated values of the thermal lines at various transmission lines for different probable disturbances (outage the transmission lines with changing loads). In addition, the percentage of the Classification Accuracy for total nine tested cases can be considered as a good percentage when compared with the other published results of works in this field.

The total spent time to carry out the testing process by ANN was 0.013 second while the spent time by Newton-Raphson power flow analysis was 0.0627 second. Because of these results, the ANN is faster than NR method in predicting the security level of that system. This time indicates the ability of the artificial neural network to identify power system's operating statuses (normal state, alert state, emergency state and extreme emergency state). The testing time is considered a short period, which can enable the system operator to take the preventive necessary actions to prevent the electrical system from sliding into more serious cases that lead to the collapse of parts or the whole system. The most susceptible areas by dangerous contingencies that lead to the insecure statuses will be analyzed and presented in figures 5.8 and 5.9 respectively:

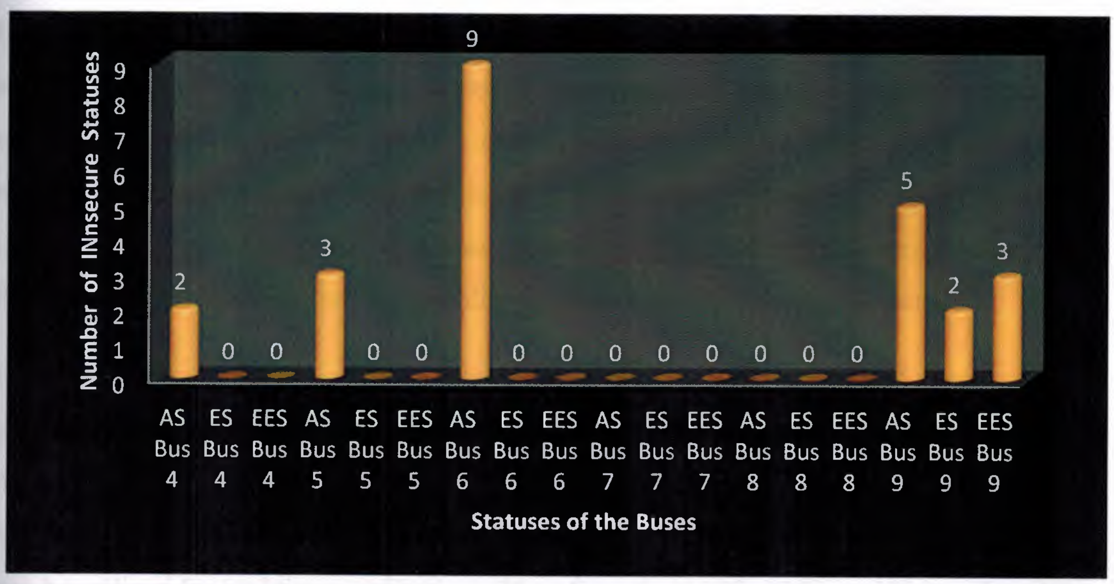

Figure 5.8: Number of Insecure Statuses of testing stage for voltage magnitudes at different buses.

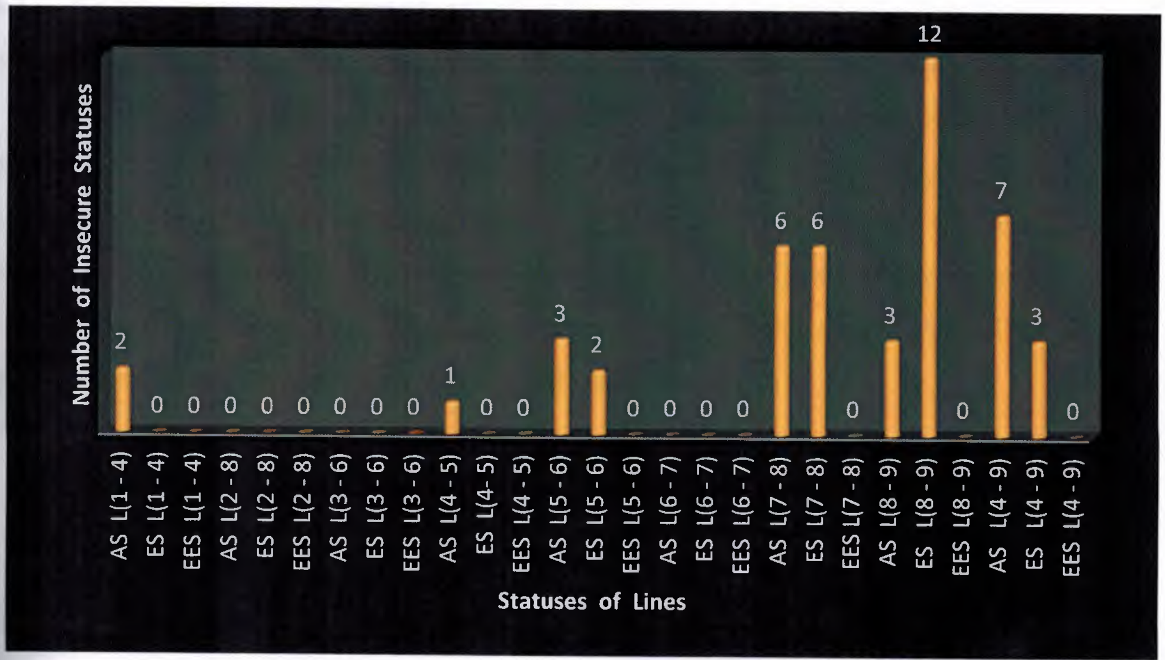

Figure 5.9: Number of Insecure Statuses of training stage for values of the thermal lines at different lines.

In these figures, the numbers of insecure statuses for voltage magnitudes at different buses and the values of the thermal lines at various lines were calculated to help the system operator to reveal the most susceptible areas (buses and lines) for unsafe situations. In addition, to warn the system operator to take rapid and preventive action which it helps to take the operating system back to the secure position and to avoid remaining the system at the unsafe situations that lead to the collapse or the shutdown for that system.

Because of the high accuracy prediction of the training process and a good accuracy prediction of the testing process by using Artificial Neural Network (ANN) technique in determining the security level of the IEEE 9-bus system. Besides that, the average time required ANN is faster than the average time required by NR method and this technique can be utilized for real time application. Therefore, the Artificial Neural Network (ANN) proved of its high potential in the field of the static security assessment to be like a protective shield for warning the system operator from the unsafe instances and to operate the power system at a safe position to ensure arrival of electricity to consumers with high quality and without interruptions. The prediction of classification accuracy at the testing process is considered a good percentage according to [4].

In [4], six transmission lines separated in all cases while eight transmission lines were cutting in all scenarios of this thesis. Each outage of these transmission lines contained (11 * 12) values of real powers and (11 * 12) values of reactive powers at the input layer. As well as, (11 * 12) values of thermal limits and (9 * 11) values of voltage magnitudes at the output layer where all these values are obtained from the change in the loads of IEEE-9 bus system. Due to these reasons, the average time required by feed forward back propagation neural network and the value of mean square error increased in this system. As well as, the percentage of classification accuracy decreased also.

CHAPTER SIX

CONCLUSIONS AND SUGGESTION FOR FUTURE WORK

6.1 Conclusions

An artificial neural network approach was proposed to assess the static security of IEEE 9-bus test system. Newton-Raphson power flow by using Power World Simulator's program was applied to collect the data to be used in the training and testing of the selected neural network. The power flow was solved for different kinds of the popular disturbances and the outcomes were compared with system restrictions (the magnitudes of bus voltage and thermal limits of transmission lines) to determine the current status of the power system.

- Feed forward back propagation neural network was used to overcome the problems that associated with traditional methods in a static security assessment.
- Feed forward back propagation neural network proved the high ability by predicting the bus voltages and line flows for various operating conditions as well as the most famous probable of N-1 contingences with $2.8 * 10^{-6}$ the best Mean Square Error, where it reflected the correct choice of the training parameters for providing a good security to forecast the power system's operating statuses. In addition, the obtained results were a high percentage (99.25923333 %) for total Training Classification Accuracy and an acceptable percentage (90.51852 %) for total Testing Classification Accuracy. These percentages are deemed good when compared to the comparable outcomes from published works.
- The testing time required by Back Propagation Neural Network to identify power system's operating statuses and the estimated power flow was 0.013 for IEEE 9-bus test system, which is considered as a very short period because the rate of time by using Newton-Raphson technique was 0.0627. Such a short period enables the system operator to take the preventive necessary actions very quickly to prevent the electrical system from sliding into more serious cases that lead to the collapse of parts or the whole system.

- Back Propagation Neural Network detected and determined the most susceptible areas for insecure statues to warn the system operator from these weak areas. Furthermore, the rapid detection on these vulnerable areas is going to help the system operator to take the operating system back to the secure position and to avoid remaining the system at the unsafe situations that lead to the collapse or the shutdown for that system.

- Because of these results, an artificial neural network proved the reliability to assess the static security and it works well in supplying the current power system's operating status.

- This system is going to assist the trainees in the electrical stations to gain the required experience through the identification on the most popular N-1 contingency and its impact on the status of the power system. In addition, this will lead to help the engineers in maintaining the power system at a safe operating point.

- At the end of this thesis, an intelligent system was established for IEEE 9-bus system to help the system operator to operate the power system at a correct manner to keep the operating system under a secure position and avoiding the emergency situations that lead to the collapse or the blackout for that system. In addition, this system can be implemented for real time application to guarantee access a continuous supply of power to the customers without interruptions.

6.2 Suggestion for Future Work

Future work could be expanded in these fields and directions:

- To improve the accuracy for the status of the power system, the number of the hidden layer and the neurons in each hidden layer need to be investigated further.
- Expand this technique to the large power system.
- This subject is considered an excellent start to study the dynamic security assessment as well as this technique is represented the backbone to search in the field of the power system state estimation.

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APPENDIX A

Results of IEEE 9-Bus system by Newton-Raphson method using Power World Simulator's program.

Table A.1.1: Real powers in MW (testing data for case1):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 - 7)
97	107	132	93	163	85	41.1	56.2	27.5
93	103	128	81	163	85	35.2	58	25.6
89	99	124	69	163	85	29.4	59.8	23.8
85	95	120	57.1	163	85	23.6	61.5	21.9
81	91	116	45.2	163	85	17.8	63.3	20.1

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	80.3	82.8	51.9
93	103	128	78.1	84.9	45.7
89	99	124	75.9	87.1	39.6
85	95	120	73.7	89.3	35.5
81	91	116	71.5	91.5	27.4

Table A.1.2: Reactive powers in MVAR (testing data for case1):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	25.2	15.9	7.7	12.2	17.8	23.6
93	103	128	24.4	15.4	8.2	13	17	23.6
89	99	124	24	15	8.6	13.7	16.3	23.7
85	95	120	23.8	14.6	8.9	14.4	15.6	23.8
81	91	116	23.8	14.3	9.3	15	15	23.9

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	11.4	15.3	34.7
93	103	128	11.4	14.6	35.4
89	99	124	11.3	13.9	36.1
85	95	120	11.2	13.3	36.7
81	91	116	11.1	12.7	37.3

Table A.1.3: Thermal lines (testing data for case1):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	32	55	28	28	39	24
93	103	128	28	55	28	25	40	23
89	99	124	24	55	28	22	42	22
85	95	120	21	55	28	18	43	22
81	91	116	17	55	28	15	44	21

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	54	55	41
93	103	128	52	57	38
89	99	124	51	58	36
85	95	120	49	60	33
81	91	116	48	61	31

Table A.1.4: Voltage magnitudes at various buses (testing data for case1):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.987	0.975	1.003	0.984	0.995	0.957
93	103	128	0.987	0.975	1.004	0.984	0.996	0.957
89	99	124	0.987	0.976	1.004	0.985	0.996	0.958
85	95	120	0.987	0.976	1.004	0.985	0.996	0.958
81	91	116	0.987	0.976	1.004	0.986	0.996	0.958

Table A.2.1: Real powers in MW (training data for case2):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	267.1	0	85	106.5	4.4	89.3
98	108	133	260.8	0	85	103.3	3.4	88.3
96	106	131	254.4	0	85	100.2	2.4	87.3
94	104	129	248.1	0	85	97.1	1.5	86.4
92	102	127	241.9	0	85	94	0.5	85.4
90	100	125	235.6	0	85	91	0.5	84.4
88	98	123	229.3	0	85	87.9	1.5	83.4
86	96	121	223	0	85	84.8	2.5	82.5
84	94	119	216.8	0	85	81.8	3.4	81.5
82	92	117	210.6	0	85	78.7	4.4	80.5
80	90	115	204.3	0	85	75.6	5.4	79.6

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	22.5	22.5	160.6
98	108	133	21.4	21.4	157.4
96	106	131	20.3	20.3	154.2
94	104	129	19.3	19.3	151
92	102	127	18.2	18.2	147.8
90	100	125	17.1	17.1	144.6
88	98	123	16.1	16.1	141.4
86	96	121	15	15	183.2
84	94	119	13.9	13.9	135
82	92	117	12.8	12.8	131.9
80	90	115	11.8	11.8	128.7

Table A.2.2: Reactive powers in MVAR (training data for case2):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	65.1	0	18.8	7.6	33.7	25
98	108	133	61.8	0	17.3	7.7	33.2	24.6
96	106	131	58.7	0	15.9	7.8	32.6	24.2
94	104	129	55.7	0	14.5	7.9	32.1	23.7
92	102	127	52.8	0	13.2	8	31.5	23.3
90	100	125	50	0	11.9	8.1	31	22.9
88	98	123	47.3	0	10.6	8.2	30.5	22.5
86	96	121	44.7	0	9.4	8.2	30	22.2
84	94	119	42.2	0	8.2	8.3	29.5	21.8
82	92	117	39.8	0	7	8.3	29	21.5
80	90	115	37.5	0	5.9	8.3	28.5	21.1

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	10	29.1	29.1
98	108	133	10.4	29	28.2
96	106	131	10.8	28.9	27.2
94	104	129	11.3	28.7	26.4
92	102	127	11.7	28.6	25.5
90	100	125	12.1	28.5	24.7
88	98	123	12.5	28.3	23.9
86	96	121	12.8	28.2	23.1
84	94	119	13.2	28	22.3
82	92	117	13.5	27.9	22.1
80	90	115	13.9	27.8	22.2

Table A.2.3: Thermal lines (training data for case2):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	92	0	29	71	23	61
98	108	133	89	0	29	69	22	60
96	106	131	87	0	29	67	22	59
94	104	129	85	0	29	65	21	59
92	102	127	83	0	29	63	21	58
90	100	125	80	0	29	61	21	57
88	98	123	78	0	29	59	20	57
86	96	121	76	0	29	57	20	56
84	94	119	74	0	28	55	20	55
82	92	117	71	0	28	53	20	55
80	90	115	69	0	28	51	19	54

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	16	25	112
98	108	133	16	24	109
96	106	131	15	24	107
94	104	129	15	23	104
92	102	127	14	23	102
90	100	125	14	22	100
88	98	123	14	22	97
86	96	121	13	21	95
84	94	119	13	21	93
82	92	117	12	21	90
80	90	115	12	20	88

Table A.2.4: Voltage magnitudes at various buses (training data for case2):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.975	0.962	0.99	0.951	0.956	0.936
98	108	133	0.976	0.963	0.991	0.953	0.958	0.938
96	106	131	0.977	0.965	0.992	0.955	0.96	0.94
94	104	129	0.978	0.966	0.993	0.956	0.962	0.941
92	102	127	0.98	0.968	0.994	0.958	0.963	0.943
90	100	125	0.981	0.969	0.994	0.96	0.965	0.945
88	98	123	0.982	0.971	0.995	0.961	0.967	0.947
86	96	121	0.983	0.972	0.996	0.963	0.968	0.948
84	94	119	0.984	0.973	0.996	0.964	0.97	0.95
82	92	117	0.985	0.974	0.997	0.965	0.971	0.952
80	90	115	0.985	0.976	0.998	0.967	0.973	0.953

Table A.3.1: Real powers in MW (training data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	186.6	163	0	98	3.7	3.8
98	108	133	180.5	163	0	94.9	4.6	4.7
96	106	131	174.3	163	0	91.9	5.5	5.6
94	104	129	168.2	163	0	88.9	6.4	6.5
92	102	127	162.1	163	0	85.9	7.4	7.4
90	100	125	156	163	0	82.9	8.3	8.3
88	98	123	149.9	163	0	79.9	9.2	9.3
86	96	121	143.8	163	0	76.9	10.1	10.2
84	94	119	137.7	163	0	73.9	11	11.1
82	92	117	131.6	163	0	71	11.9	12
80	90	115	125.5	163	0	68	12.8	12.9

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	115	48	88.7
98	108	133	113.9	49.1	85.5
96	106	131	112.8	50.2	82.4
94	104	129	111.7	51.3	79.3
92	102	127	110.6	52.4	76.2
90	100	125	109.5	53.6	73
88	98	123	108.3	54.7	69.9
86	96	121	107.2	55.8	66.8
84	94	119	106.1	56.9	63.7
82	92	117	105	58	60.6
80	90	115	103.9	59.1	57.5

Table A.3.2: Reactive powers in MVAR (training data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	33.3	19.9	0	4.7	28.6	25.7
98	108	133	31.5	19	0	5	28.4	26
96	106	131	29.8	18.1	0	5.4	28.1	26.4
94	104	129	28.1	17.3	0	5.7	27.9	26.7
92	102	127	26.6	16.5	0	6	27.7	27
90	100	125	25.1	15.7	0	6.3	27.5	27.3
88	98	123	23.7	14.9	0	6.6	27.2	27.6
86	96	121	22.4	14.2	0	6.8	27	27.8
84	94	119	21.1	13.5	0	7	26.8	28.1
82	92	117	20	12.8	0	7.2	26.6	28.4

80	90	115	18.9	12.2	0	7.4	26.4	28.6

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	9.3	23.5	26.5
98	108	133	9	23.1	26.9
96	106	131	8.6	22.6	27.4
94	104	129	8.3	22.2	27.8
92	102	127	8	21.8	28.2
90	100	125	7.7	21.4	28.6
88	98	123	7.4	21	29
86	96	121	7.2	20.6	29.4
84	94	119	6.9	20.3	29.7
82	92	117	6.6	19.9	30.1
80	90	115	6.4	19.5	30.5

Table A.3.3: Thermal lines (training data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	63	55	0	65	19	17
98	108	133	61	55	0	63	19	18
96	106	131	59	55	0	61	19	18
94	104	129	57	55	0	59	19	18
92	102	127	55	55	0	57	19	19
90	100	125	53	55	0	55	19	19
88	98	123	51	55	0	53	19	19
86	96	121	48	55	0	51	19	20
84	94	119	46	55	0	50	19	20
82	92	117	44	55	0	48	19	21
80	90	115	42	54	0	46	20	21

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	77	35	61
98	108	133	76	36	59
96	106	131	75	36	57
94	104	129	74	37	56
92	102	127	74	37	54
90	100	125	73	38	52
88	98	123	72	38	50
86	96	121	72	39	48
84	94	119	71	40	47
82	92	117	70	40	45
80	90	115	69	41	43

Table A.3.4: Voltage magnitudes at various buses (training data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.987	0.971	0.993	0.978	0.993	0.958
98	108	133	0.987	0.972	0.994	0.979	0.993	0.959
96	106	131	0.988	0.974	0.995	0.98	0.994	0.96
94	104	129	0.989	0.975	0.996	0.981	0.994	0.961
92	102	127	0.989	0.976	0.998	0.982	0.995	0.961
90	100	125	0.99	0.977	0.998	0.982	0.995	0.962
88	98	123	0.99	0.978	0.999	0.983	0.996	0.963
86	96	121	0.991	0.979	1	0.984	0.996	0.963
84	94	119	0.991	0.98	1.001	0.985	0.997	0.964
82	92	117	0.991	0.981	1.002	0.986	0.997	0.965
80	90	115	0.992	0.982	1.003	0.987	0.998	0.965

Table A.3.5: Real powers in MW (testing data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	177.4	163.01	0	93.4	5.1	5.1
93	103	128	165.1	163.01	0	87.4	6.9	7
89	99	124	152.9	163.01	0	81.4	8.7	8.8
85	95	120	140.7	163.01	0	75.4	10.5	10.6
81	91	116	128.5	163	0	69.5	12.4	12.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	113.3	49.7	84
93	103	128	111.1	51.9	77.7
89	99	124	108.9	54.1	71.5
85	95	120	106.7	56.3	65.3
81	91	116	104.5	58.5	59.1

Table A.3.6: Reactive powers in MVAR (testing data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	30.6	18.5	0	5.2	28.3	26.2
93	103	128	27.3	16.9	0	5.9	27.8	26.8
89	99	124	24.4	15.3	0	6.4	27.4	27.4
85	95	120	21.7	13.8	0	6.9	26.9	28

81	91	116	19.4	12.5	0	7.3	26.5	28.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	8.8	22.8	27.1
93	103	128	8.2	22	28
89	99	124	7.6	21.2	28.8
85	95	120	7	20.4	29.5
81	91	116	6.5	19.7	30.3

Table A.3.7: Thermal lines (testing data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	60	55	0	62	19	18
93	103	128	56	55	0	58	19	18
89	99	124	52	55	0	54	19	19
85	95	120	47	55	0	51	19	20
81	91	116	43	54	0	47	19	21

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	76	36	58
93	103	128	74	37	55
89	99	124	73	38	51
85	95	120	71	39	47
81	91	116	70	40	44

Table A.3.8: Voltage magnitudes at various buses (testing data for case3):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.988	0.973	0.995	0.979	0.994	0.96
93	103	128	0.989	0.975	0.997	0.981	0.995	0.961
89	99	124	0.99	0.978	0.999	0.983	0.996	0.962
85	95	120	0.991	0.98	1.001	0.985	0.997	0.964
81	91	116	0.992	0.981	1.002	0.986	0.997	0.965

Table A.4.1: Real powers in MW (training data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	105.3	163	85	0	100	20
98	108	133	98.9	163	85	0	98	17.8
96	106	131	92.5	163	85	0	96	15.6
94	104	129	86.2	163	85	0	94	13.4
92	102	127	79.9	163	85	0	92	11.1
90	100	125	73.6	163	85	0	90	8.9
88	98	123	67.4	163	85	0	88	6.8
86	96	121	61.2	163	85	0	86	4.6
84	94	119	55.1	163	85	0	84	2.4
82	92	117	49	163	85	0	82	0.2
80	90	115	42.9	163	85	0	80	2

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	131.7	31.3	105.3
98	108	133	127.3	35.7	98.9
96	106	131	123	40	92.5
94	104	129	118.7	44.3	86.2
92	102	127	114.4	48.6	79.9
90	100	125	110.1	52.9	73.6
88	98	123	105.8	57.2	67.4
86	96	121	101.5	61.5	61.2
84	94	119	97.2	65.8	55.1
82	92	117	93	70	49
80	90	115	88.8	74.2	42.9

Table A.4.2: Reactive powers in MVAR (training data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	24.4	24.5	30.7	0	30	24.9
98	108	133	23.5	23.4	28.9	0	30	24.4
96	106	131	22.7	22.4	27.2	0	30	24
94	104	129	22	21.5	25.6	0	30	23.7
92	102	127	21.5	20.6	24	0	30	23.3
90	100	125	21.1	19.9	22.6	0	30	22.9
88	98	123	20.9	19.3	21.1	0	30	22.6
86	96	121	20.7	18.7	19.8	0	30	22.3
84	94	119	20.8	18.2	18.5	0	30	21.9
82	92	117	20.9	17.8	17.2	0	30	21.6

80	90	115	21.1	17.5	16.1	0	30	21.3

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	10.1	25.9	24.1
98	108	133	10.6	24.9	25.1
96	106	131	11	23.9	26.1
94	104	129	11.3	22.9	27.1
92	102	127	11.7	21.9	28.1
90	100	125	12.1	20.8	29.1
88	98	123	12.4	19.8	30.2
86	96	121	12.7	18.8	31.2
84	94	119	13.1	17.8	32.2
82	92	117	13.4	16.8	33.2
80	90	115	13.7	15.8	34.2

Table A.4.3: Thermal lines (training data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	36	55	30	0	71	21
98	108	133	34	55	30	0	70	20
96	106	131	32	55	30	0	68	19
94	104	129	30	55	30	0	67	18
92	102	127	28	55	29	0	65	17
90	100	125	26	55	29	0	63	16
88	98	123	24	55	29	0	62	16
86	96	121	22	55	29	0	61	15
84	94	119	20	55	29	0	59	15
82	92	117	18	55	29	0	58	14
80	90	115	16	55	29	0	57	14

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	89	27	71
98	108	133	86	29	67
96	106	131	83	31	63
94	104	129	79	33	60
92	102	127	76	35	56
90	100	125	74	37	52
88	98	123	71	40	49
86	96	121	68	42	46
84	94	119	65	44	42
82	92	117	62	47	39
80	90	115	59	50	36

Table A.4.4: Voltage magnitudes at various buses (training data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.988	0.892	0.983	0.972	0.99	0.959
98	108	133	0.988	0.895	0.984	0.973	0.991	0.959
96	106	131	0.988	0.899	0.985	0.974	0.991	0.96
94	104	129	0.989	0.902	0.986	0.975	0.992	0.96
92	102	127	0.989	0.905	0.987	0.976	0.992	0.96
90	100	125	0.989	0.907	0.988	0.976	0.993	0.961
88	98	123	0.989	0.91	0.989	0.977	0.993	0.961
86	96	121	0.989	0.913	0.99	0.978	0.994	0.961
84	94	119	0.989	0.915	0.99	0.979	0.994	0.961
82	92	117	0.988	0.918	0.991	0.979	0.994	0.96
80	90	115	0.988	0.92	0.992	0.98	0.994	0.96

Table A.4.5: Real powers in MW (testing data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	95.7	163.01	85	0	97	16.7
93	103	128	83	163.01	85	0	93	12.2
89	99	124	70.5	163.01	85	0	89	7.8
85	95	120	58.1	163.01	85	0	85	3.5
81	91	116	45.9	163	85	0	81	0.9

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	125.2	37.8	95.7
93	103	128	116.5	46.5	83
89	99	124	107.9	55.1	70.5
85	95	120	99.4	63.6	58.1
81	91	116	90.9	72.1	45.9

Table A.4.6: Reactive powers in MVAR (testing data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	23	22.9	28	0	30	24.2
93	103	128	21.7	21	24.8	0	30	23.5
89	99	124	21	19.6	21.8	0	30	22.8
85	95	120	20.7	18.4	19.1	0	30	22.1
81	91	116	21	17.6	16.7	0	30	21.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	10.8	24.4	25.6
93	103	128	11.5	22.4	27.6
89	99	124	12.2	20.3	29.6
85	95	120	12.9	18.3	31.7
81	91	116	13.5	16.3	33.7

Table A.4.7: Thermal lines (testing data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	33	55	30	0	69	20
93	103	128	29	55	30	0	66	18
89	99	124	25	55	29	0	63	16
85	95	120	21	55	29	0	60	15
81	91	116	17	55	29	0	58	14

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	84	30	65
93	103	128	78	34	58
89	99	124	72	39	51
85	95	120	66	43	44
81	91	116	61	48	38

Table A.4.8: Voltage magnitudes at various buses (testing data for case4):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.988	0.897	0.985	0.973	0.991	0.959
93	103	128	0.989	0.903	0.987	0.975	0.992	0.96
89	99	124	0.989	0.909	0.988	0.977	0.993	0.961
85	95	120	0.989	0.914	0.99	0.978	0.994	0.961
81	91	116	0.988	0.919	0.992	0.98	0.994	0.96

Table A.5.1: Real powers in MW (training data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	107.2	163	85	102.1	0	85
98	108	133	101.3	163	85	100.1	0	85
96	106	131	95.4	163	85	98	0	85
94	104	129	89.5	163	85	95.9	0	85
92	102	127	83.6	163	85	93.8	0	85
90	100	125	77.8	163	85	91.7	0	85
88	98	123	71.9	163	85	89.7	0	85
86	96	121	66.1	163	85	87.6	0	85
84	94	119	60.2	163	85	85.5	0	85
82	92	117	54.3	163	85	83.5	0	85
80	90	115	48.6	163	85	81.4	0	85

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	26.6	136.4	5
98	108	133	24.5	138.5	1.2
96	106	131	22.5	140.5	2.6
94	104	129	20.5	142.5	6.4
92	102	127	18.5	144.5	10.2
90	100	125	16.5	146.5	14
88	98	123	14.5	148.5	17.8
86	96	121	12.5	150.5	21.5
84	94	119	10.5	152.5	25.3
82	92	117	8.5	154.6	29.1
80	90	115	6.5	156.5	32.8

Table A.5.2: Reactive powers in MVAR (training data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	67.9	32.7	5.9	30	0	14.4
98	108	133	67.5	32.9	5.8	30	0	14.4
96	106	131	67.2	33.1	5.8	30	0	14.4
94	104	129	66.9	33.3	5.7	30	0	14.3
92	102	127	66.8	33.5	5.7	30	0	14.3
90	100	125	66.7	33.8	5.7	30	0	14.3
88	98	123	66.7	34.1	5.7	30	0	14.3
86	96	121	66.8	34.4	5.7	30	0	14.3
84	94	119	67	34.8	5.7	30	0	14.3
82	92	117	67.3	35.1	5.7	30	0	14.3

80	90	115	67.6	35.5	5.8	30	0	14.4

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	20.6	8.5	45.3
98	108	133	20.6	8.7	46.1
96	106	131	20.6	8.9	46.8
94	104	129	20.7	9.1	47.6
92	102	127	20.7	9.4	48.3
90	100	125	20.7	9.7	49
88	98	123	20.7	10	49.8
86	96	121	20.7	10.4	50.5
84	94	119	20.7	10.7	51.2
82	92	117	20.7	11.1	51.9
80	90	115	20.6	11.6	52.6

Table A.5.3: Thermal lines (training data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	42	55	28	71	0	57
98	108	133	41	55	28	69	0	57
96	106	131	39	55	28	68	0	57
94	104	129	37	55	28	66	0	57
92	102	127	36	55	28	65	0	57
90	100	125	34	55	28	63	0	57
88	98	123	33	56	28	62	0	57
86	96	121	31	56	28	61	0	57
84	94	119	30	56	28	59	0	57
82	92	117	29	56	28	58	0	57
80	90	115	28	56	28	57	0	57

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	22	93	30
98	108	133	21	94	31
96	106	131	20	95	31
94	104	129	19	97	32
92	102	127	18	98	33
90	100	125	18	99	34
88	98	123	17	101	35
86	96	121	16	102	37
84	94	119	15	104	38
82	92	117	15	105	40
80	90	115	14	106	41

Table A.5.4: Voltage magnitudes at various buses (training data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.963	0.916	0.998	0.972	0.985	0.928
98	108	133	0.963	0.917	0.998	0.972	0.985	0.927
96	106	131	0.963	0.917	0.998	0.972	0.985	0.927
94	104	129	0.963	0.918	0.998	0.973	0.984	0.927
92	102	127	0.963	0.918	0.998	0.973	0.984	0.926
90	100	125	0.963	0.919	0.998	0.973	0.984	0.926
88	98	123	0.962	0.919	0.998	0.973	0.984	0.925
86	96	121	0.962	0.92	0.998	0.973	0.984	0.925
84	94	119	0.962	0.92	0.998	0.973	0.984	0.924
82	92	117	0.962	0.92	0.998	0.973	0.983	0.924
80	90	115	0.961	0.92	0.998	0.972	0.983	0.923

Table A.5.5: Real powers in MW (testing data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	98.3	163.01	85	99	0	85
93	103	128	86.6	163.01	85	94.9	0	85
89	99	124	74.8	163.01	85	90.7	0	85
85	95	120	63.1	163.01	85	86.6	0	85
81	91	116	51.5	163.01	85	82.4	0	85

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	23.5	139.5	0.7
93	103	128	19.5	143.5	8.3
89	99	124	15.5	147.5	15.9
85	95	120	11.5	151.5	23.4
81	91	116	7.5	155.5	30.9

Table A.5.6: Reactive powers in MVAR (testing data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	67.3	33	5.8	30	0	14.4
93	103	128	66.8	33.4	5.7	30	0	14.3
89	99	124	66.7	33.9	5.7	30	0	14.3
85	95	120	66.9	34.6	5.7	30	0	14.3
81	91	116	67.4	35.3	5.8	30	0	14.3

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)

97	107	132	20.6	8.8	46.4
93	103	128	20.7	9.3	47.9
89	99	124	20.7	9.8	49.4
85	95	120	20.7	10.5	50.8
81	91	116	20.7	11.3	52.2

Table A.5.7: Thermal lines (testing data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	40	55	28	68	0	57
93	103	128	36	55	28	66	0	57
89	99	124	33	56	28	63	0	57
85	95	120	31	56	28	60	0	57
81	91	116	28	56	28	58	0	57

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	21	95	31
93	103	128	19	97	32
89	99	124	17	100	35
85	95	120	16	103	37
81	91	116	15	106	41

Table A.5.8: Voltage magnitudes at various buses (testing data for case5):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.963	0.917	0.998	0.972	0.985	0.927
93	103	128	0.963	0.918	0.998	0.973	0.984	0.927
89	99	124	0.963	0.919	0.998	0.973	0.984	0.926
85	95	120	0.962	0.92	0.998	0.973	0.984	0.925
81	91	116	0.962	0.92	0.998	0.972	0.983	0.923

Table A.6.1: Real powers in MW (training data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	102.9	163	85	17.9	82.2	0
98	108	133	96.8	163	85	15.9	82.2	0
96	106	131	90.8	163	85	13.9	82.2	0
94	104	129	84.8	163	85	11.9	82.2	0
92	102	127	78.7	163	85	9.8	82.2	0
90	100	125	72.7	163	85	7.8	82.2	0
88	98	123	66.7	163	85	5.8	82.2	0
86	96	121	60.7	163	85	3.8	82.2	0
84	94	119	54.7	163	85	1.8	82.2	0
82	92	117	48.7	163	85	0.2	82.2	0
80	90	115	42.7	163	85	2.2	82.2	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	111.2	51.8	85
98	108	133	109.2	53.8	81
96	106	131	107.1	55.9	76.9
94	104	129	105.1	57.9	72.9
92	102	127	103.1	59.9	68.9
90	100	125	101	62	64.9
88	98	123	99	64	60.9
86	96	121	96.9	66.1	56.9
84	94	119	94.9	68.1	52.9
82	92	117	92.9	70.1	48.9
80	90	115	90.8	72.2	44.9

Table A.6.2: Reactive powers in MVAR (training data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	32.7	43.8	10.6	18	12	0
98	108	133	32.1	43.1	10.8	18.1	11.9	0
96	106	131	31.4	42.5	11	18.3	11.7	0
94	104	129	30.9	41.9	11.2	18.4	11.6	0
92	102	127	30.4	41.4	11.3	18.6	11.4	0
90	100	125	30	40.9	11.5	18.7	11.5	0
88	98	123	29.7	40.4	11.6	18.8	11.6	0
86	96	121	29.5	39.9	11.7	18.9	11.7	0
84	94	119	29.3	39.5	11.8	19	11.8	0
82	92	117	29.2	39.1	11.9	19.1	11.9	0

80	90	115	29.2	38.7	12	19.2	12	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	35	18.1	31.9
98	108	133	35	17.5	32.5
96	106	131	35	17	33
94	104	129	35	16.4	33.6
92	102	127	35	15.9	34.1
90	100	125	35	15.4	34.6
88	98	123	35	14.8	35.2
86	96	121	35	14.3	35.7
84	94	119	35	13.8	36.2
82	92	117	35	13.3	36.7
80	90	115	35	12.8	37.2

Table A.6.3: Thermal lines (training data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	36	56	29	17	57	0
98	108	133	34	56	29	16	57	0
96	106	131	32	56	29	15	57	0
94	104	129	30	56	29	15	57	0
92	102	127	28	56	29	14	57	0
90	100	125	26	56	29	14	57	0
88	98	123	24	56	29	13	57	0
86	96	121	22	56	29	13	57	0
84	94	119	21	56	29	13	57	0
82	92	117	19	56	29	13	57	0
80	90	115	17	56	29	13	57	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	77	36	60
98	108	133	76	37	58
96	106	131	74	38	55
94	104	129	73	39	53
92	102	127	72	41	51
90	100	125	71	42	49
88	98	123	69	43	47
86	96	121	68	44	45
84	94	119	67	46	43
82	92	117	66	47	41
80	90	115	64	48	39

Table A.6.4: Voltage magnitudes at various buses (training data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.983	0.97	1.005	0.943	0.978	0.95
98	108	133	0.983	0.97	1.005	0.944	0.978	0.95
96	106	131	0.983	0.971	1.005	0.944	0.979	0.951
94	104	129	0.983	0.971	1.005	0.945	0.979	0.951
92	102	127	0.984	0.971	1.005	0.946	0.979	0.951
90	100	125	0.984	0.972	1.005	0.946	0.98	0.951
88	98	123	0.984	0.972	1.006	0.947	0.98	0.952
86	96	121	0.984	0.972	1.006	0.948	0.98	0.952
84	94	119	0.984	0.972	1.006	0.948	0.981	0.952
82	92	117	0.984	0.973	1.006	0.949	0.981	0.952
80	90	115	0.984	0.973	1.006	0.949	0.981	0.952

Table A.6.5: Real powers in MW (testing data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	93.8	163.01	85	14.9	82.2	0
93	103	128	81.7	163.01	85	10.8	82.2	0
89	99	124	69.7	163.01	85	6.8	82.2	0
85	95	120	57.7	163.01	85	2.8	82.2	0
81	91	116	45.7	163.01	85	1.2	82.2	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	108.2	54.8	78.9
93	103	128	104.1	58.9	70.9
89	99	124	100	63	62.9
85	95	120	95.9	67.1	54.9
81	91	116	91.9	71.7	46.9

Table A.6.6: Reactive powers in MVAR (testing data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	31.7	42.8	10.9	18.2	11.8	0
93	103	128	30.6	41.7	11.2	18.5	11.5	0
89	99	124	29.9	40.6	11.5	18.8	11.5	0
85	95	120	29.4	39.7	11.8	19	11.8	0

81	91	116	29.2	38.9	12	19.1	12	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	35	17.2	32.7
93	103	128	35	16.2	33.8
89	99	124	35	15.1	34.9
85	95	120	35	14	35.9
81	91	116	35	13	37

Table A.6.7: Thermal lines (testing data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	33	56	29	16	57	0
93	103	128	29	56	29	14	57	0
89	99	124	25	56	29	13	57	0
85	95	120	22	56	29	13	57	0
81	91	116	18	56	29	13	57	0

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	75	38	57
93	103	128	73	40	52
89	99	124	70	42	48
85	95	120	67	45	43
81	91	116	65	48	40

Table A.6.8: Voltage magnitudes at various buses (testing data for case6):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.983	0.97	1.005	0.944	0.979	0.951
93	103	128	0.983	0.971	1.005	0.946	0.979	0.951
89	99	124	0.984	0.972	1.005	0.947	0.98	0.952
85	95	120	0.984	0.972	1.006	0.948	0.981	0.952
81	91	116	0.984	0.973	1.006	0.949	0.981	0.952

Table A.7.1: Real powers in MW (training data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	112.9	163	85	131.6	28.5	113
98	108	133	106.5	163	85	127.2	26.3	110.9
96	106	131	100.1	163	85	122.9	24.2	108.8
94	104	129	93.8	163	85	118.5	22	106.7
92	102	127	87.4	163	85	114.2	19.9	104.6
90	100	125	81.1	163	85	109.9	17.7	102.5
88	98	123	74.8	163	85	105.6	15.6	100.4
86	96	121	68.6	163	85	101.3	13.4	98.3
84	94	119	62.3	163	85	97	11.3	96.2
82	92	117	56	163	85	92.7	9.2	94.1
80	90	115	49.8	163	85	88.5	7.1	92

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	0	163	18.8
98	108	133	0	163	20.8
96	106	131	0	163	22.8
94	104	129	0	163	24.8
92	102	127	0	163	26.7
90	100	125	0	163	28.7
88	98	123	0	163	30.7
86	96	121	0	163	32.7
84	94	119	0	163	34.7
82	92	117	0	163	36.7
80	90	115	0	163	38.7

Table A.7.2: Reactive powers in MVAR (training data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	49.2	27.2	40.3	4.9	34.9	35
98	108	133	48	26.9	38.8	4.4	34.4	35
96	106	131	46.8	26.7	37.2	4	33.9	35
94	104	129	45.7	26.5	35.8	4.5	33.4	35
92	102	127	44.8	26.3	34.4	5	32.9	35
90	100	125	43.9	26.1	33	5.5	32.4	35
88	98	123	43.1	26	31.7	5.9	31.9	35
86	96	121	42.4	25.8	30.4	6.3	31.4	35
84	94	119	41.8	25.7	29.1	6.7	30.9	35
82	92	117	41.2	25.6	27.9	7	30.4	35

80	90	115	40.8	25.5	26.8	7.3	29.9	35

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	0	10.1	56.5
98	108	133	0	9.9	56.7
96	106	131	0	9.7	56.9
94	104	129	0	9.5	57
92	102	127	0	9.3	57.2
90	100	125	0	9.1	57.3
88	98	123	0	9	57.4
86	96	121	0	8.8	57.5
84	94	119	0	8.7	57.6
82	92	117	0	8.6	57.7
80	90	115	0	8.5	57.8

Table A.7.3: Thermal lines (training data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	41	55	31	90	30	80
98	108	133	39	55	31	87	29	77
96	106	131	37	55	31	84	28	75
94	104	129	35	55	31	81	27	74
92	102	127	33	55	31	76	26	72
90	100	125	31	55	30	73	25	71
88	98	123	29	55	30	70	24	69
86	96	121	27	55	30	68	23	68
84	94	119	25	55	30	65	22	67
82	92	117	23	55	30	62	21	66
80	90	115	21	55	30	59	21	64

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	0	110	40
98	108	133	0	110	40
96	106	131	0	110	41
94	104	129	0	110	42
92	102	127	0	110	42
90	100	125	0	110	43
88	98	123	0	110	44
86	96	121	0	110	44
84	94	119	0	110	45
82	92	117	0	110	46
80	90	115	0	110	47

Table A.7.4: Voltage magnitudes at various buses (training data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.974	0.954	0.978	0.918	0.988	0.931
98	108	133	0.974	0.956	0.979	0.92	0.988	0.932
96	106	131	0.975	0.957	0.979	0.922	0.989	0.932
94	104	129	0.975	0.958	0.98	0.923	0.989	0.932
92	102	127	0.976	0.959	0.981	0.925	0.989	0.933
90	100	125	0.976	0.96	0.982	0.927	0.989	0.933
88	98	123	0.976	0.961	0.983	0.928	0.989	0.934
86	96	121	0.976	0.962	0.983	0.93	0.989	0.934
84	94	119	0.977	0.963	0.984	0.931	0.989	0.934
82	92	117	0.977	0.964	0.985	0.933	0.989	0.934
80	90	115	0.977	0.965	0.986	0.934	0.989	0.935

Table A.7.5: Real powers in MW (testing data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	103.3	163.01	85	125.1	25.3	109.8
93	103	128	90.6	163.01	85	116.4	20.9	105.6
89	99	124	78	163.01	85	107.7	16.6	101.4
85	95	120	65.4	163.01	85	99.1	12.4	97.2
81	91	116	52.9	163.01	85	90.6	8.1	93

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	0	163	21.8
93	103	128	0	163	25.8
89	99	124	0	163	29.7
85	95	120	0	163	33.7
81	91	116	0	163	37.7

Table A.7.6: Reactive powers in MVAR (testing data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	47.3	26.8	38	4.1	34.1	35
93	103	128	45.2	26.4	35.1	4.8	33.1	35
89	99	124	43.5	26.1	32.3	5.7	32.1	35
85	95	120	42	25.8	29.8	6.5	31.1	35
81	91	116	41	25.5	27.4	7.1	30.2	35

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)

97	107	132	0	9.8	56.8
93	103	128	0	9.4	57.1
89	99	124	0	9	57.3
85	95	120	0	8.7	57.6
81	91	116	0	8.5	57.8

Table A.7.7: Thermal lines (testing data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	38	55	31	86	28	76
93	103	128	34	55	31	78	26	73
89	99	124	30	55	30	72	24	70
85	95	120	26	55	30	66	22	67
81	91	116	22	55	30	61	21	65

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	0	110	41
93	103	128	0	110	42
89	99	124	0	110	43
85	95	120	0	110	45
81	91	116	0	110	46

Table A.7.8: Voltage magnitudes at various buses (testing data for case7):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.975	0.956	0.979	0.921	0.989	0.932
93	103	128	0.975	0.959	0.981	0.924	0.989	0.933
89	99	124	0.976	0.961	0.982	0.928	0.989	0.933
85	95	120	0.977	0.963	0.984	0.931	0.989	0.934
81	91	116	0.977	0.964	0.985	0.933	0.989	0.935

Table A.8.1: Real powers in MW (training data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	110.1	163	85	27.4	127.6	50
98	108	133	104.4	163	85	31.1	129.4	52
96	106	131	98.6	163	85	34.8	131.1	53.9
94	104	129	92.9	163	85	38.4	132.9	55.9
92	102	127	87.2	163	85	42.1	134.6	57.8
90	100	125	81.5	163	85	45.7	136.3	59.8
88	98	123	75.8	163	85	49.4	138	61.7
86	96	121	70.1	163	85	53	139.7	63.7
84	94	119	64.4	163	85	56.6	141.4	65.6
82	92	117	58.8	163	85	60.2	143.1	67.6
80	90	115	53.1	163	85	63.8	144.8	69.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	163	0	137.5
98	108	133	163	0	135.5
96	106	131	163	0	133.4
94	104	129	163	0	131.3
92	102	127	163	0	129.3
90	100	125	163	0	127.2
88	98	123	163	0	125.1
86	96	121	163	0	123.1
84	94	119	163	0	121
82	92	117	163	0	119
80	90	115	163	0	116.9

Table A.8.2: Reactive powers in MVAR (training data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	84.9	23.6	20.4	29.9	0.9	33.6
98	108	133	84.7	23.6	20.8	30.7	0.7	33.6
96	106	131	84.6	23.6	21.2	31.5	1.5	33.7
94	104	129	84.5	23.6	21.6	32.4	2.4	33.7
92	102	127	84.6	23.6	22.1	33.2	3.2	33.7
90	100	125	84.7	23.6	22.6	34	4	33.6
88	98	123	84.9	23.6	23.2	34.8	4.8	33.6
86	96	121	85.2	23.6	23.7	35.6	5.6	33.6
84	94	119	85.6	23.7	24.3	36.3	6.3	33.6
82	92	117	86	23.7	24.9	37.1	7.1	33.5

80	90	115	86.6	23.8	25.5	37.9	7.9	33.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	6.7	0	56.7
98	108	133	6.6	0	56.1
96	106	131	6.6	0	55.5
94	104	129	6.6	0	54.9
92	102	127	6.6	0	54.3
90	100	125	6.6	0	53.8
88	98	123	6.6	0	53.2
86	96	121	6.7	0	52.7
84	94	119	6.7	0	52.2
82	92	117	6.8	0	51.7
80	90	115	6.8	0	51.2

Table A.8.3: Thermal lines (training data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	46	55	29	27	91	41
98	108	133	45	55	29	29	92	42
96	106	131	43	55	29	31	94	43
94	104	129	42	55	29	34	95	44
92	102	127	40	55	29	36	96	45
90	100	125	39	55	29	38	97	46
88	98	123	38	55	29	41	99	47
86	96	121	37	55	29	43	100	49
84	94	119	36	55	29	45	101	50
82	92	117	35	55	30	48	103	51
80	90	115	34	55	30	50	104	52

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	110	0	104
98	108	133	110	0	103
96	106	131	110	0	101
94	104	129	110	0	100
92	102	127	110	0	98
90	100	125	110	0	97
88	98	123	110	0	95
86	96	121	110	0	94
84	94	119	110	0	92
82	92	117	110	0	91
80	90	115	110	0	90

Table A.8.4: Voltage magnitudes at various buses (training data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.953	0.935	0.989	0.973	0.99	0.889
98	108	133	0.953	0.935	0.989	0.973	0.991	0.889
96	106	131	0.953	0.934	0.989	0.974	0.991	0.889
94	104	129	0.953	0.934	0.989	0.974	0.991	0.89
92	102	127	0.953	0.933	0.988	0.974	0.991	0.89
90	100	125	0.952	0.933	0.988	0.973	0.991	0.89
88	98	123	0.952	0.932	0.988	0.973	0.991	0.891
86	96	121	0.952	0.931	0.987	0.973	0.99	0.891
84	94	119	0.951	0.931	0.987	0.973	0.99	0.891
82	92	117	0.951	0.93	0.987	0.973	0.99	0.891
80	90	115	0.951	0.929	0.986	0.973	0.99	0.891

Table A.8.5: Real powers in MW (testing data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	101.5	163	85	32.9	130.3	53
93	103	128	90	163	85	40.3	133.7	56.9
89	99	124	78.6	163	85	47.5	137.1	60.8
85	95	120	67.3	163	85	54.8	140.6	64.7
81	91	116	55.9	163	85	62	144	68.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	163	0	134.4
93	103	128	163	0	130.3
89	99	124	163	0	126.2
85	95	120	163	0	122
81	91	116	163	0	117.9

Table A.8.6: Reactive powers in MVAR (testing data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	84.6	23.6	21	31.1	1.1	33.6
93	103	128	84.5	23.6	21.9	32.8	2.8	33.7
89	99	124	84.8	23.6	22.9	34.4	4.4	33.6
85	95	120	85.3	23.6	24	35.9	5.9	33.6
81	91	116	86.3	23.7	25.2	37.5	7.5	33.5

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	6.6	0	55.7
93	103	128	6.6	0	54.6
89	99	124	6.6	0	53.5
85	95	120	6.7	0	52.4
81	91	116	6.8	0	51.5

Table A.8.7: Thermal lines (testing data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	44	55	29	30	93	42
93	103	128	41	55	29	35	96	45
89	99	124	39	55	29	39	98	47
85	95	120	36	55	29	44	101	49
81	91	116	34	55	30	49	103	52

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	110	0	102
93	103	128	110	0	99
89	99	124	110	0	96
85	95	120	110	0	93
81	91	116	110	0	90

Table A.8.8: Voltage magnitudes at various buses (testing data for case8):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.953	0.935	0.989	0.973	0.991	0.889
93	103	128	0.953	0.934	0.988	0.974	0.991	0.89
89	99	124	0.952	0.932	0.988	0.973	0.991	0.89
85	95	120	0.952	0.931	0.987	0.973	0.99	0.891
81	91	116	0.951	0.93	0.986	0.973	0.99	0.891

Table A.9.1: Real powers in MW (training data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	112.1	163.06	85	112.1	9.9	94.8
98	108	133	105.1	163.06	85	105.1	5.2	90.2
96	106	131	98.3	163.05	85	98.3	0.6	85.6
94	104	129	91.5	163.05	85	91.5	4	81
92	102	127	84.8	163.05	85	84.8	8.5	76.5
90	100	125	78.1	163.05	85	78.1	12.9	72
88	98	123	71.5	163.05	85	71.5	17.4	67.5
86	96	121	65	163.04	85	65	21.7	63.1
84	94	119	58.5	163.04	85	58.5	26.1	58.7
82	92	117	52.1	163.04	85	52.1	30.4	54.3
80	90	115	45.8	163	85	45.8	34.6	50

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	17.2	145.8	0
98	108	133	19.7	143.4	0
96	106	131	22.1	140.9	0
94	104	129	24.5	138.5	0
92	102	127	26.9	136.1	0
90	100	125	29.3	133.8	0
88	98	123	31.7	131.4	0
86	96	121	34	129	0
84	94	119	36.3	126.7	0
82	92	117	38.6	124.4	0
80	90	115	40.8	122.2	0

Table A.9.2: Reactive powers in MVAR (training data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	6.6	96.6	17.5	3.2	26.8	30
98	108	133	5.4	93.2	15.6	4.2	25.8	30.5
96	106	131	4.3	90	13.9	5.3	24.7	30.9
94	104	129	3.4	87	12.2	6.3	23.7	31.3
92	102	127	2.7	84.1	10.8	7.4	22.6	31.7
90	100	125	2.1	81.4	9.4	8.5	21.5	32.1
88	98	123	1.7	78.9	8.2	9.5	20.5	32.5
86	96	121	1.4	76.5	7.1	10.6	19.4	32.9
84	94	119	1.3	74.2	6.1	11.7	18.3	33.2
82	92	117	1.3	72	5.2	12.7	17.3	33.6

80	90	115	1.4	70	4.5	13.8	16.9	33.9

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	8.1	82.3	0
98	108	133	8.5	79.7	0
96	106	131	8.9	77.2	0
94	104	129	9.3	74.9	0
92	102	127	9.7	72.7	0
90	100	125	10	70.7	0
88	98	123	10.3	68.7	0
86	96	121	10.6	66.8	0
84	94	119	10.9	65	0
82	92	117	11.1	63.3	0
80	90	115	11.4	61.7	0

Table A.9.3: Thermal lines (training data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
100	110	135	37	63	29	75	19	65
98	108	133	35	63	29	70	18	62
96	106	131	33	62	29	66	16	60
94	104	129	31	62	29	61	16	57
92	102	127	28	61	29	57	16	54
90	100	125	26	61	29	52	17	52
88	98	123	24	60	28	48	18	49
86	96	121	22	60	28	43	19	47
84	94	119	20	60	28	39	21	44
82	92	117	17	59	28	35	23	42
80	90	115	15	59	28	32	26	40

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
100	110	135	13	118	0
98	108	133	14	115	0
96	106	131	16	113	0
94	104	129	17	110	0
92	102	127	19	108	0
90	100	125	21	106	0
88	98	123	22	103	0
86	96	121	24	101	0
84	94	119	25	99	0
82	92	117	27	97	0

80	90	115	28	95	0

Table A.9.4: Voltage magnitudes at various buses (training data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
100	110	135	0.998	0.978	0.991	0.945	0.945	0.764
98	108	133	0.999	0.979	0.992	0.947	0.947	0.77
96	106	131	0.999	0.98	0.993	0.949	0.949	0.776
94	104	129	0.999	0.981	0.994	0.951	0.951	0.782
92	102	127	1	0.982	0.995	0.953	0.953	0.787
90	100	125	1	0.983	0.996	0.955	0.955	0.792
88	98	123	1	0.984	0.996	0.956	0.956	0.797
86	96	121	1	0.984	0.997	0.958	0.958	0.802
84	94	119	1	0.985	0.998	0.959	0.959	0.806
82	92	117	1	0.985	0.998	0.961	0.961	0.81
80	90	115	1	0.985	0.999	0.962	0.962	0.814

Table A.9.5: Real powers in MW (testing data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	101.9	163	85	101.9	3.1	88
93	103	128	88.3	163	85	88.3	6.1	78.9
89	99	124	74.9	163	85	74.9	15	69.9
85	95	120	61.8	163	85	61.8	23.8	61
81	91	116	49	163	85	49	32.4	52.1

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	20.7	142.3	0
93	103	128	25.6	137.4	0
89	99	124	30.4	132.6	0
85	95	120	35.1	127.9	0
81	91	116	39.7	123.3	0

Table A.9.6: Reactive powers in MVAR (testing data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)

97	107	132	4.9	91.8	14.8	4.7	25.3	30.7
93	103	128	3.1	85.7	11.6	6.9	23.1	31.5
89	99	124	1.9	80.3	8.8	9	21	32.3
85	95	120	1.3	75.4	6.6	11.1	18.9	33.1
81	91	116	1.3	71	4.8	13.2	16.8	33.8

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	8.7	78.7	0
93	103	128	9.5	74	0
89	99	124	10.2	69.8	0
85	95	120	10.8	66	0
81	91	116	11.3	62.5	0

Table A.9.7: Thermal lines (testing data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (1 - 4)	line (2 - 8)	line (3 - 6)	line (4 - 5)	line (5 - 6)	line (6 – 7)
97	107	132	34	62	29	68	17	61
93	103	128	29	61	29	59	16	56
89	99	124	25	61	28	50	17	51
85	95	120	21	60	28	41	20	46
81	91	116	16	59	28	34	25	41

Load at Bus 5	Load at Bus 7	Load at Bus 9	line (7 - 8)	line (8 - 9)	line (4 - 9)
97	107	132	15	114	0
93	103	128	18	109	0
89	99	124	21	105	0
85	95	120	24	100	0
81	91	116	28	96	0

Table A.9.8: Voltage magnitudes at various buses (testing data for case9):

Load at Bus 5	Load at Bus 7	Load at Bus 9	V4(P.U.)	V5(P.U.)	V6(P.U.)	V7(P.U.)	V8(P.U.)	V9(P.U.)
97	107	132	0.999	0.98	0.993	0.948	0.948	0.772
93	103	128	1	0.982	0.994	0.952	0.952	0.784
89	99	124	1	0.983	0.996	0.955	0.955	0.794
85	95	120	1	0.984	0.997	0.959	0.958	0.803
81	91	116	1	0.985	0.998	0.961	0.961	0.812

APPENDIX B

Results of IEEE 9-Bus system using ANN method by MATLAB program.

Table B.2.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case2 (outage the line (2-8)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.9192811	7.19E-04	'AS'	-0.0001435	1.43E-04	'NS'
98	108	133	0.8984193	-0.0084193	'AS'	-0.0020362	0.0020362	'NS'
96	106	131	0.876505	-0.006505	'AS'	-0.0026314	0.0026314	'NS'
94	104	129	0.8521855	-2.19E-03	'AS'	-0.0016672	0.0016672	'NS'
92	102	127	0.8279813	0.0020187	'AS'	-0.0012292	0.0012292	'NS'
90	100	125	0.8030207	-0.0030207	'AS'	-0.0005734	5.73E-04	'NS'
88	98	123	0.7797151	0.0002849	'NS'	1.92E-05	-1.92E-05	'NS'
86	96	121	0.6938134	0.0661866	'NS'	0.0021261	-2.13E-03	'NS'
84	94	119	0.7349579	0.0050421	'NS'	-0.0008239	0.0008239	'NS'
82	92	117	0.7128679	-0.0028679	'NS'	0.0004612	-0.0004612	'NS'
80	90	115	0.6914139	-0.0014139	'NS'	0.0048632	-0.0048632	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2909647	-0.0009647	'NS'	0.7095949	0.0004051	'NS'
98	108	133	0.2925325	-0.0025325	'NS'	0.6867551	0.0032449	'NS'
96	106	131	0.2930192	-0.0030192	'NS'	0.6651845	0.0048155	'NS'
94	104	129	0.2926205	-0.0026205	'NS'	0.6460127	0.0039873	'NS'
92	102	127	0.2914525	-0.0014525	'NS'	0.6257081	0.0042919	'NS'
90	100	125	0.289586	0.000414	'NS'	0.6081532	0.0018468	'NS'
88	98	123	0.2872966	2.70E-03	'NS'	0.5905767	-0.0005767	'NS'
86	96	121	0.2339113	0.0560887	'NS'	0.5447497	2.53E-02	'NS'
84	94	119	0.2823447	-0.0023447	'NS'	0.5505874	-0.0005874	'NS'

82	92	117	0.2800502	-5.02E-05	'NS'	0.528602	0.001398	'NS'
80	90	115	0.2782576	0.0017424	'NS'	0.5078264	0.0021736	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.2307382	-0.0007382	'NS'	0.6101434	-0.0001434	'NS'
98	108	133	0.2283632	-0.0083632	'NS'	0.6028347	-0.0028347	'NS'
96	106	131	0.2247384	-0.0047384	'NS'	0.5951477	-0.0051477	'NS'
94	104	129	0.218353	-0.008353	'NS'	0.5869516	0.0030484	'NS'
92	102	127	0.2129509	-0.002951	'NS'	0.5787903	0.0012097	'NS'
90	100	125	0.2073625	0.0026375	'NS'	0.5718715	-0.0018715	'NS'
88	98	123	0.2037401	-0.0037401	'NS'	0.565937	0.004063	'NS'
86	96	121	0.3201399	-0.1201399	'NS'	0.5207254	0.0392746	'NS'
84	94	119	0.2001098	-0.0001098	'NS'	0.5539019	-0.0039019	'NS'
82	92	117	0.2003293	-0.0003293	'NS'	0.5480288	1.97E-03	'NS'
80	90	115	0.1984334	-0.0084334	'NS'	0.5409658	-9.66E-04	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.1591778	0.0008222	'NS'	0.2501484	-0.0001484	'NS'
98	108	133	0.1535733	0.0064267	'NS'	0.2449253	-0.0049253	'NS'
96	106	131	0.1506645	-0.0006645	'NS'	0.2382938	0.0017062	'NS'
94	104	129	0.1472254	0.0027746	'NS'	0.2312282	-0.0012282	'NS'
92	102	127	0.144581	-0.004581	'NS'	0.2272191	0.0027809	'NS'
90	100	125	0.1408302	-0.0008302	'NS'	0.223175	-0.003175	'NS'
88	98	123	0.1380118	0.0019882	'NS'	0.2176255	0.0023745	'NS'
86	96	121	0.2613738	-0.1313738	'NS'	0.0090588	0.2009412	'NS'
84	94	119	0.1284468	0.0015532	'NS'	0.2100488	-4.88E-05	'NS'
82	92	117	0.1203333	-0.0003333	'NS'	0.2112644	-0.0012644	'NS'
80	90	115	0.1108505	0.0091495	'NS'	0.2071374	-0.0071374	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	1.1197637	0.0002363	'ES'
98	108	133	1.0932987	-0.0032987	'ES'
96	106	131	1.0693057	0.0006943	'ES'

94	104	129	1.0449005	-0.0049005	'ES'
92	102	127	1.0210988	-0.0010988	'ES'
90	100	125	0.9963371	0.0036629	'ES'
88	98	123	0.9745851	-0.0045851	'AS'
86	96	121	1.1087825	-0.1587825	'ES'
84	94	119	0.9271057	0.0028943	'AS'
82	92	117	0.9003849	-0.000385	'AS'
80	90	115	0.8728738	0.0071262	'AS'

Table B.2.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case2 (outage the line (2-8)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.97702	-2.02E-03	'NS'	0.963298	-1.30E-03	'NS'
98	108	133	0.9781962	-0.0021962	'NS'	0.9647803	-0.0017803	'NS'
96	106	131	0.9792451	-0.0022451	'NS'	0.9660286	-0.0010286	'NS'
94	104	129	0.9802456	-2.25E-03	'NS'	0.9674068	-0.0014068	'NS'
92	102	127	0.9811503	-0.0011503	'NS'	0.9684897	-0.0004897	'NS'
90	100	125	0.9819482	-0.0009482	'NS'	0.9696626	-6.63E-04	'NS'
88	98	123	0.9824964	-0.0004964	'NS'	9.71E-01	2.79E-04	'NS'
86	96	121	0.9836517	-0.0006517	'NS'	0.9754853	-3.49E-03	'NS'
84	94	119	0.9831553	0.0008447	'NS'	0.9722761	0.0007239	'NS'
82	92	117	0.9833559	0.0016441	'NS'	0.9730756	0.0009244	'NS'
80	90	115	0.9832663	0.0017337	'NS'	0.9739872	0.0020128	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9951423	-0.0051423	'NS'	0.951998	-0.000998	'NS'
98	108	133	0.9950909	-0.0040909	'NS'	0.9536402	-0.0006402	'NS'
96	106	131	0.9950289	-0.0030289	'NS'	0.9552028	-0.0002028	'NS'
94	104	129	0.9949244	-0.0019244	'NS'	0.9566675	-0.0006675	'NS'
92	102	127	0.9947918	-0.0007918	'NS'	0.9580548	-5.48E-05	'NS'
90	100	125	0.9945394	-0.0005394	'NS'	0.9595634	0.0004366	'NS'
88	98	123	0.9942129	7.87E-04	'NS'	0.9609988	1.24E-06	'NS'

86	96	121	0.9936087	0.0023913	'NS'	0.9645955	-1.60E-03	'NS'
84	94	119	0.9935153	0.0024847	'NS'	0.9635539	0.0004461	'NS'
82	92	117	0.9931612	3.84E-03	'NS'	0.9649487	5.13E-05	'NS'
80	90	115	0.9928941	0.0051059	'NS'	0.9661364	0.0008636	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V8 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V9 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9594493	-0.0034493	'NS'	0.9370666	-0.0010666	'NS'
98	108	133	0.9602418	-0.0022418	'NS'	0.9379285	7.15E-05	'NS'
96	106	131	0.9612975	-0.0012975	'NS'	0.9389417	0.0010583	'NS'
94	104	129	0.9623879	-0.0003879	'NS'	0.9405646	0.0004354	'NS'
92	102	127	0.9636727	-0.0006727	'NS'	0.9419478	0.0010522	'NS'
90	100	125	0.9649203	7.97E-05	'NS'	0.9436201	0.0013799	'NS'
88	98	123	0.9661465	0.0008535	'NS'	0.9457819	0.0012181	'NS'
86	96	121	0.9684365	-0.0004365	'NS'	0.9580974	-0.0100974	'NS'
84	94	119	0.968439	0.001561	'NS'	0.9506027	-0.0006027	'NS'
82	92	117	0.9696209	0.0013791	'NS'	0.9528407	-8.41E-04	'NS'
80	90	115	0.9705698	0.0024302	'NS'	0.9556983	-2.70E-03	'NS'

Classification accuracy for case2 at training stage (%) = (157 / 165) * 100 = 95.1515 %.

Table B.3.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case3 (outage the line (3-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.6282481	1.75E-03	'NS'	0.5496737	3.26E-04	'NS'
98	108	133	0.6109275	-0.0009275	'NS'	0.5498624	0.0001376	'NS'
96	106	131	0.5926371	-0.0026371	'NS'	0.549934	6.60E-05	'NS'
94	104	129	0.5712337	-1.23E-03	'NS'	0.5500292	-2.92E-05	'NS'
92	102	127	0.5497958	0.0002042	'NS'	0.5498761	0.0001239	'NS'
90	100	125	0.5266772	0.0033228	'NS'	0.5494694	5.31E-04	'NS'
88	98	123	0.5035406	0.0064594	'NS'	5.49E-01	1.17E-03	'NS'
86	96	121	0.4814876	-0.0014876	'NS'	0.5490119	9.88E-04	'NS'
84	94	119	0.461368	-0.001368	'NS'	0.5499632	3.68E-05	'NS'

82	92	117	0.4388749	0.0011251	'NS'	0.5523484	-0.0023484	'NS'
80	90	115	0.4181155	0.0018845	'NS'	0.5569099	-0.0169099	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	-0.0008025	0.0008025	'NS'	0.6493054	0.0006946	'NS'
98	108	133	2.50E-05	-2.50E-05	'NS'	0.6297562	0.0002438	'NS'
96	106	131	0.0003901	-0.0003901	'NS'	0.6085615	0.0014385	'NS'
94	104	129	0.0005762	-0.0005762	'NS'	0.5903669	-0.0003669	'NS'
92	102	127	0.0004818	-0.0004818	'NS'	0.5692074	7.93E-04	'NS'
90	100	125	0.0001113	-0.0001113	'NS'	0.5504543	-0.0004543	'NS'
88	98	123	-0.0002454	2.45E-04	'NS'	0.5328801	-2.88E-03	'NS'
86	96	121	-0.0006689	0.0006689	'NS'	0.514492	-4.49E-03	'NS'
84	94	119	-0.0003911	0.0003911	'NS'	0.4990532	0.0009468	'NS'
82	92	117	-0.000457	4.57E-04	'NS'	0.4949156	-1.49E-02	'NS'
80	90	115	0.000735	-0.000735	'NS'	0.4974538	-0.0374538	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.1890372	0.0009628	'NS'	0.1720352	-0.0020352	'NS'
98	108	133	0.1903587	-0.0003587	'NS'	0.1763639	3.64E-03	'NS'
96	106	131	0.1927053	-0.0027053	'NS'	0.1805858	-0.0005858	'NS'
94	104	129	0.1903927	-0.0003927	'NS'	0.1837193	-0.0037193	'NS'
92	102	127	0.1911547	-0.0011547	'NS'	0.1871898	0.0028102	'NS'
90	100	125	0.189486	5.14E-04	'NS'	0.190365	-0.000365	'NS'
88	98	123	0.1880582	0.0019418	'NS'	0.1939135	-0.0039135	'NS'
86	96	121	0.18894	0.00106	'NS'	0.1974477	0.0025523	'NS'
84	94	119	0.190428	-0.000428	'NS'	0.2000242	-2.42E-05	'NS'
82	92	117	0.1802145	0.0097855	'NS'	0.2017839	8.22E-03	'NS'
80	90	115	0.1645728	0.0354272	'NS'	0.2015052	8.49E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.7692626	0.0007374	'NS'	0.3527065	-0.0027065	'NS'
98	108	133	0.7580651	0.0019349	'NS'	0.3567756	0.0032244	'NS'
96	106	131	0.749872	0.000128	'NS'	0.361289	-0.001289	'NS'

94	104	129	0.742666	-0.002666	'NS'	0.3675133	0.0024867	'NS'
92	102	127	0.7363288	0.0036712	'NS'	0.3731162	-0.0031162	'NS'
90	100	125	0.7297928	0.0002072	'NS'	0.3807924	-0.0007924	'NS'
88	98	123	0.7231035	-0.0031035	'NS'	0.3887891	-0.0087891	'NS'
86	96	121	0.7153779	0.0046221	'NS'	0.3946452	-0.0046452	'NS'
84	94	119	0.7093544	0.0006456	'NS'	0.3996093	3.91E-04	'NS'
82	92	117	0.7028293	-0.0028293	'NS'	0.4037684	-0.0037684	'NS'
80	90	115	0.6959525	-0.0059525	'NS'	0.4040525	0.0059475	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.6080291	0.0019709	'NS'
98	108	133	0.5908557	-0.0008557	'NS'
96	106	131	0.5744588	-0.0044588	'NS'
94	104	129	0.5562667	0.0037333	'NS'
92	102	127	0.5387051	0.0012949	'NS'
90	100	125	0.5203614	-0.0003614	'NS'
88	98	123	0.5028364	-0.0028364	'NS'
86	96	121	0.4857343	-0.0057343	'NS'
84	94	119	0.4702421	-0.0002421	'NS'
82	92	117	0.4513169	-0.0013169	'NS'
80	90	115	0.4294267	0.0005733	'NS'

Table B.3.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case3 (outage the line (3-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9869835	1.65E-05	'NS'	0.9715347	-5.35E-04	'NS'
98	108	133	0.9874399	-0.0004399	'NS'	0.9723688	-0.0003688	'NS'
96	106	131	0.9879257	7.43E-05	'NS'	0.9733355	6.64E-04	'NS'
94	104	129	0.9885057	4.94E-04	'NS'	0.9744951	5.05E-04	'NS'
92	102	127	0.9890066	-6.60E-06	'NS'	0.9756404	0.0003596	'NS'

90	100	125	0.9896098	0.0003902	'NS'	0.976817	1.83E-04	'NS'
88	98	123	0.9902825	-0.0002825	'NS'	9.78E-01	-1.49E-04	'NS'
86	96	121	0.9908579	0.0001421	'NS'	0.9792642	-2.64E-04	'NS'
84	94	119	0.9915821	-0.0005821	'NS'	0.9805085	-5.08E-04	'NS'
82	92	117	0.9920117	-0.0010117	'NS'	0.9814324	-0.0004324	'NS'
80	90	115	0.9924348	-0.0004348	'NS'	0.9820765	-7.65E-05	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.996037	-0.003037	'NS'	0.9773094	0.0006906	'NS'
98	108	133	9.96E-01	-2.24E-03	'NS'	0.9785879	0.0004121	'NS'
96	106	131	0.9964806	-0.0014806	'NS'	0.9797355	0.0002645	'NS'
94	104	129	0.9966261	-0.0006261	'NS'	0.9808338	0.0001662	'NS'
92	102	127	0.9968202	0.0011798	'NS'	0.9819349	6.51E-05	'NS'
90	100	125	0.9969399	0.0010601	'NS'	0.9829893	-0.000989	'NS'
88	98	123	0.9970013	2.00E-03	'NS'	0.9839329	-9.33E-04	'NS'
86	96	121	0.9971067	0.0028933	'NS'	0.9848075	-8.08E-04	'NS'
84	94	119	0.9971636	0.0038364	'NS'	0.9853992	-0.0003992	'NS'
82	92	117	0.9970351	4.96E-03	'NS'	0.9861648	-1.65E-04	'NS'
80	90	115	0.9968336	0.0061664	'NS'	0.9868813	0.0001187	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9947161	-0.0017161	'NS'	0.9579323	6.77E-05	'NS'
98	108	133	0.9945644	-0.0015644	'NS'	0.9587754	2.25E-04	'NS'
96	106	131	0.994407	-0.000407	'NS'	0.9596466	0.0003534	'NS'
94	104	129	0.9943394	-0.0003394	'NS'	0.9609337	6.63E-05	'NS'
92	102	127	0.9942816	0.0007184	'NS'	0.9616942	-0.0006942	'NS'
90	100	125	0.9942863	7.14E-04	'NS'	0.9624934	-0.0004934	'NS'
88	98	123	0.9942753	0.0017247	'NS'	0.9632921	-0.0002921	'NS'
86	96	121	0.9942596	0.0017404	'NS'	0.9635114	-0.0005114	'NS'
84	94	119	0.9942178	0.0027822	'NS'	0.9635071	4.93E-04	'NS'
82	92	117	0.9944087	0.0025913	'NS'	0.9639767	1.02E-03	'NS'
80	90	115	0.9946687	0.0033313	'NS'	0.96424	7.60E-04	'NS'

Classification accuracy for case3 at training stage (%) = (160 / 165) * 100 = 96.9696 %.

Table B.4.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case5 (outage the line (5-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.4198816	1.18E-04	'NS'	0.548436	1.56E-03	'NS'
98	108	133	0.406529	0.003471	'NS'	0.5505159	-0.0005159	'NS'
96	106	131	0.3896724	3.28E-04	'NS'	0.5512741	-1.27E-03	'NS'
94	104	129	0.3722079	-2.21E-03	'NS'	0.5523938	-2.39E-03	'NS'
92	102	127	0.3567961	3.20E-03	'NS'	0.5531385	-0.0031385	'NS'
90	100	125	0.3423682	-0.0023682	'NS'	0.5542213	-4.22E-03	'NS'
88	98	123	0.3290221	0.0009779	'NS'	5.55E-01	4.68E-03	'NS'
86	96	121	0.3163382	-0.0063382	'NS'	0.5567291	3.27E-03	'NS'
84	94	119	0.3029206	-0.0029206	'NS'	0.5581207	1.88E-03	'NS'
82	92	117	0.2901087	-0.0001087	'NS'	0.5598001	0.0001999	'NS'
80	90	115	0.2785483	0.0014517	'NS'	0.5615814	-1.58E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (3- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (4- 5)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.2797305	0.0002695	'NS'	0.7092112	0.0007888	'NS'
98	108	133	2.83E-01	-3.06E-03	'NS'	0.6901056	-0.0001056	'NS'
96	106	131	0.282354	-0.002354	'NS'	0.6745193	0.0054807	'NS'
94	104	129	0.281019	-0.001019	'NS'	0.6620877	-0.0020877	'NS'
92	102	127	0.279901	9.90E-05	'NS'	0.6473134	2.69E-03	'NS'
90	100	125	0.2793522	0.0006478	'NS'	0.6321903	-0.0021903	'NS'
88	98	123	0.2793932	6.07E-04	'NS'	0.6172615	2.74E-03	'NS'
86	96	121	0.279796	0.000204	'NS'	0.603552	6.45E-03	'NS'
84	94	119	0.2799032	9.68E-05	'NS'	0.5913494	-0.0013494	'NS'
82	92	117	0.2801679	-1.68E-04	'NS'	0.5806036	-6.04E-04	'NS'
80	90	115	0.2805243	-0.0005243	'NS'	0.5683541	0.0016459	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.0007942	-0.000794	'NS'	0.5698638	1.36E-04	'NS'
98	108	133	0.0005067	-0.0005067	'NS'	0.5704261	-4.26E-04	'NS'
96	106	131	0.0005767	-0.0005767	'NS'	0.571165	-0.001165	'NS'
94	104	129	-7.43E-05	7.43E-05	'NS'	0.569822	1.78E-04	'NS'

92	102	127	8.59E-05	-8.59E-05	'NS'	0.5702729	-0.0002729	'NS'
90	100	125	0.0005585	-5.58E-04	'NS'	0.5705659	-0.0005659	'NS'
88	98	123	0.0012104	-0.0012104	'NS'	0.5704624	-0.0004624	'NS'
86	96	121	0.0010818	-0.0010818	'NS'	0.5705226	-0.0005226	'NS'
84	94	119	0.0004094	-0.0004094	'NS'	0.5699256	7.44E-05	'NS'
82	92	117	-0.0004057	0.0004057	'NS'	0.5691549	8.45E-04	'NS'
80	90	115	0.0009909	-0.0009909	'NS'	0.5704423	-4.42E-04	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2196361	0.0003639	'NS'	0.9307502	-0.0007502	'AS'
98	108	133	0.1953813	0.0146187	'NS'	0.9404827	-0.0004827	'AS'
96	106	131	0.1885215	0.0114785	'NS'	0.9546331	-0.0046331	'AS'
94	104	129	0.1860369	0.0039631	'NS'	0.9681181	0.0018819	'AS'
92	102	127	0.1820964	-0.0020964	'NS'	0.982981	-0.002981	'AS'
90	100	125	0.1761967	0.0038033	'NS'	0.9978131	-0.0078131	'ES'
88	98	123	0.1685658	0.0014342	'NS'	1.0117858	-0.0017858	'ES'
86	96	121	0.1603331	-0.0003331	'NS'	1.0251948	-0.0051948	'ES'
84	94	119	0.1525127	-0.0025127	'NS'	1.0388035	1.20E-03	'ES'
82	92	117	0.1456687	0.0043313	'NS'	1.0503299	-0.0003299	'ES'
80	90	115	0.1397116	0.0002884	'NS'	1.0608315	-0.0008315	'ES'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2999097	9.03E-05	'NS'
98	108	133	0.306185	0.003815	'NS'
96	106	131	0.3131178	-0.0031178	'NS'
94	104	129	0.3194826	0.0005174	'NS'
92	102	127	0.3289029	0.0010971	'NS'
90	100	125	0.3397272	0.0002728	'NS'
88	98	123	0.3520424	-0.0020424	'NS'
86	96	121	0.3652262	0.0047738	'NS'
84	94	119	0.380016	-1.60E-05	'NS'
82	92	117	0.3952595	0.0047405	'NS'
80	90	115	0.4121335	-0.0021335	'NS'

Table B.4.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR (results of the training for case5 (outage the line (5-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9594537	3.55E-03	'NS'	0.9180777	-2.08E-03	'NS'
98	108	133	0.9592194	0.0037806	'NS'	0.9181953	-0.0011953	'NS'
96	106	131	0.9595923	3.41E-03	'NS'	0.9179667	-9.67E-04	'NS'
94	104	129	0.960183	2.82E-03	'NS'	0.9180836	-8.36E-05	'NS'
92	102	127	0.9607878	2.21E-03	'NS'	0.9180194	-1.94E-05	'NS'
90	100	125	0.9614157	0.0015843	'NS'	0.9180808	9.19E-04	'NS'
88	98	123	0.9620351	-3.51E-05	'NS'	9.18E-01	7.19E-04	'NS'
86	96	121	0.9627014	-0.0007014	'NS'	0.9186773	1.32E-03	'NS'
84	94	119	0.9634848	-0.0014848	'NS'	0.919019	9.81E-04	'NS'
82	92	117	0.9642914	-0.0022914	'NS'	0.9195596	0.0004404	'NS'
80	90	115	0.9650874	-0.0040874	'NS'	0.9198864	1.14E-04	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V6 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V7 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9989953	-0.0009953	'NS'	0.9742715	-0.0022715	'NS'
98	108	133	9.99E-01	-7.53E-04	'NS'	0.9742905	-0.0022905	'NS'
96	106	131	0.9984011	-0.0004011	'NS'	0.9741005	-0.0021005	'NS'
94	104	129	0.9980733	-7.33E-05	'NS'	0.9738826	-0.0008826	'NS'
92	102	127	0.9976946	3.05E-04	'NS'	0.973514	-5.14E-04	'NS'
90	100	125	0.997328	0.000672	'NS'	0.9730718	-7.18E-05	'NS'
88	98	123	0.9969872	1.01E-03	'NS'	0.9725583	4.42E-04	'NS'
86	96	121	0.9966428	0.0013572	'NS'	0.9720449	9.55E-04	'NS'
84	94	119	0.9963005	1.70E-03	'NS'	0.9714937	0.0015063	'NS'
82	92	117	0.9959888	2.01E-03	'NS'	0.9709148	2.09E-03	'NS'
80	90	115	0.9957017	0.0022983	'NS'	0.9700993	0.0019007	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V8 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V9 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9876325	-0.0026325	'NS'	0.9269705	1.03E-03	'NS'
98	108	133	0.986994	-0.001994	'NS'	0.9276554	-6.55E-04	'NS'
96	106	131	0.9864096	-0.001409	'NS'	0.9277486	-0.000749	'NS'
94	104	129	9.86E-01	-1.75E-03	'NS'	0.9276753	-6.75E-04	'NS'
92	102	127	9.85E-01	-1.13E-03	'NS'	0.9271028	-0.001103	'NS'

90	100	125	0.9844855	-4.86E-04	'NS'	0.9262749	-0.0002749	'NS'
88	98	123	0.9838425	0.0001575	'NS'	0.9254197	-0.0004197	'NS'
86	96	121	0.9831554	0.0008446	'NS'	0.9244219	0.0005781	'NS'
84	94	119	0.982507	0.001493	'NS'	0.9236174	3.83E-04	'NS'
82	92	117	0.9818346	0.0011654	'NS'	0.9230468	9.53E-04	'NS'
80	90	115	0.9812492	0.0017508	'NS'	0.9228267	1.73E-04	'NS'

Classification accuracy for case5 at training stage5 (%) = *(163 /165) * 100* = 98.7878 %.

Table B.6.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case6 (outage the line (6-7)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.3607249	-7.25E-04	'NS'	0.5612726	-1.27E-03	'NS'
98	108	133	0.3395228	0.0004772	'NS'	0.5604807	-0.0004807	'NS'
96	106	131	0.3197654	2.35E-04	'NS'	0.5597855	2.14E-04	'NS'
94	104	129	0.3005141	-5.14E-04	'NS'	0.5591547	8.45E-04	'NS'
92	102	127	0.2808526	-8.53E-04	'NS'	0.5593392	0.0006608	'NS'
90	100	125	0.263056	-0.003056	'NS'	0.5586674	1.33E-03	'NS'
88	98	123	0.2452942	-0.0052942	'NS'	5.59E-01	1.13E-03	'NS'
86	96	121	0.2276178	-0.0076178	'NS'	0.5594694	5.31E-04	'NS'
84	94	119	0.2098518	0.0001482	'NS'	0.5599259	7.41E-05	'NS'
82	92	117	0.192819	-0.002819	'NS'	0.5608459	-0.0008459	'NS'
80	90	115	0.1784677	-0.0084677	'NS'	0.5635646	-3.56E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (3- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (4- 5)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.2895584	0.0004416	'NS'	0.1662457	0.0037543	'NS'
98	108	133	2.89E-01	6.92E-04	'NS'	0.1576239	0.0023761	'NS'
96	106	131	0.2898811	0.0001189	'NS'	0.1512141	-0.0012141	'NS'
94	104	129	0.2897922	0.0002078	'NS'	0.1450014	0.0049986	'NS'
92	102	127	0.2905843	-0.0005843	'NS'	0.1406931	-6.93E-04	'NS'
90	100	125	0.2901924	-0.0001924	'NS'	0.1375829	0.0024171	'NS'
88	98	123	0.2898561	1.44E-04	'NS'	0.1341141	-4.11E-03	'NS'

86	96	121	0.2898191	0.0001809	'NS'	0.132066	-2.07E-03	'NS'
84	94	119	0.2900038	-3.82E-06	'NS'	0.1289966	0.0010034	'NS'
82	92	117	0.2904872	-4.87E-04	'NS'	0.1269077	3.09E-03	'NS'
80	90	115	0.291387	-0.001387	'NS'	0.137766	-0.007766	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.5698515	0.0001485	'NS'	0.0066551	-6.66E-03	'NS'
98	108	133	0.5697327	0.0002673	'NS'	0.0021531	-2.15E-03	'NS'
96	106	131	0.5706085	-0.0006085	'NS'	-0.0003773	0.0003773	'NS'
94	104	129	0.570865	-0.000865	'NS'	-0.0024794	2.48E-03	'NS'
92	102	127	0.5711787	-0.0011787	'NS'	-0.003054	0.003054	'NS'
90	100	125	0.570398	-3.98E-04	'NS'	-0.0031253	0.0031253	'NS'
88	98	123	0.5698497	0.0001503	'NS'	-0.0026667	0.0026667	'NS'
86	96	121	0.5690147	0.0009853	'NS'	-0.0009984	0.0009984	'NS'
84	94	119	0.5702555	-0.0002555	'NS'	0.0012661	-1.27E-03	'NS'
82	92	117	0.5709962	-0.0009962	'NS'	0.0044035	-4.40E-03	'NS'
80	90	115	0.557529	0.012471	'NS'	0.0080125	-8.01E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.7707269	-0.0007269	'NS'	0.3533152	0.0066848	'NS'
98	108	133	0.7573631	0.0026369	'NS'	0.3684456	0.0015544	'NS'
96	106	131	0.7432122	-0.0032122	'NS'	0.3825326	-0.0025326	'NS'
94	104	129	0.7312108	-0.0012108	'NS'	0.3970745	-0.0070745	'NS'
92	102	127	0.7174706	0.0025294	'NS'	0.4101983	-0.0001983	'NS'
90	100	125	0.706097	0.003903	'NS'	0.4245566	-0.0045566	'NS'
88	98	123	0.6945464	-0.0045464	'NS'	0.4386335	-0.0086335	'NS'
86	96	121	0.6821899	-0.0021899	'NS'	0.450117	-0.010117	'NS'
84	94	119	0.6696925	0.0003075	'NS'	0.4600083	-8.28E-06	'NS'
82	92	117	0.6563111	0.0036889	'NS'	0.4670013	0.0029987	'NS'
80	90	115	0.6393082	0.0006918	'NS'	0.4671681	0.0128319	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.6037944	-0.0037944	'NS'
98	108	133	0.5774806	0.0025194	'NS'

96	106	131	0.5536815	- 0.0036815	'NS'
94	104	129	0.5301889	-0.000189	'NS'
92	102	127	0.5079319	0.0020681	'NS'
90	100	125	0.4868119	0.0031881	'NS'
88	98	123	0.4661199	0.0038801	'NS'
86	96	121	0.4471382	0.0028618	'NS'
84	94	119	0.4301966	- 0.0001966	'NS'
82	92	117	0.4141294	- 0.0041294	'NS'
80	90	115	0.3899111	8.89E-05	'NS'

Table B.6.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case6 (outage the line (6-7)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9836696	-6.70E-04	'NS'	0.9685046	1.50E-03	'NS'
98	108	133	0.9835117	- 0.0005117	'NS'	0.9689683	0.0010317	'NS'
96	106	131	0.9831487	-1.49E-04	'NS'	0.9696641	1.34E-03	'NS'
94	104	129	0.9828978	1.02E-04	'NS'	0.9703648	6.35E-04	'NS'
92	102	127	0.9823878	1.61E-03	'NS'	0.9712251	- 0.0002251	'NS'
90	100	125	0.9822128	0.0017872	'NS'	0.9720876	-8.76E-05	'NS'
88	98	123	0.9820055	0.0019945	'NS'	9.73E-01	-9.17E-04	'NS'
86	96	121	0.9816903	0.0023097	'NS'	0.9737716	-1.77E-03	'NS'
84	94	119	0.9813415	0.0026585	'NS'	0.9744788	-2.48E-03	'NS'
82	92	117	0.98093	0.00307	'NS'	0.9751238	- 0.0021238	'NS'
80	90	115	0.9803499	0.0036501	'NS'	0.9761715	-3.17E-03	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	1.0045472	0.0004528	'AS'	0.944712	-0.001712	'NS'
98	108	133	1.00E+00	2.48E-04	'AS'	0.9445454	0.0005454	'NS'
96	106	131	1.0049774	2.26E-05	'AS'	0.9445987	- 0.0005987	'NS'
94	104	129	1.0051646	- 0.0001646	'AS'	0.9448603	0.0001397	'NS'
92	102	127	1.0053877	- 0.0003877	'AS'	0.9453135	6.86E-04	'NS'
90	100	125	1.005538	-0.000538	'AS'	0.9459501	4.99E-05	'NS'

88	98	123	1.0056987	3.01E-04	'AS'	0.9468077	1.92E-04	'NS'
86	96	121	1.0058614	0.0001386	'AS'	0.9477512	2.49E-04	'NS'
84	94	119	1.0060357	-3.57E-05	'AS'	0.9487786	- 0.0007786	'NS'
82	92	117	1.0062163	-2.16E-04	'AS'	0.9498241	-8.24E-04	'NS'
80	90	115	1.0063489	-0.00035	'AS'	0.9504111	-0.001411	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9779124	8.76E-05	'NS'	0.9472697	2.73E-03	'NS'
98	108	133	0.9780211	-2.11E-05	'NS'	0.9492537	7.46E-04	'NS'
96	106	131	0.9781346	0.0008654	'NS'	0.9502541	0.0007459	'NS'
94	104	129	0.9783252	0.0006748	'NS'	0.9513487	-3.49E-04	'NS'
92	102	127	0.9784928	0.0005072	'NS'	0.9518709	- 0.0008709	'NS'
90	100	125	0.9787168	1.28E-03	'NS'	0.9523406	- 0.0013406	'NS'
88	98	123	0.9790051	0.0009949	'NS'	0.9527515	- 0.0007515	'NS'
86	96	121	0.9792238	0.0007762	'NS'	0.9528656	- 0.0008656	'NS'
84	94	119	0.9794052	0.0015948	'NS'	0.952512	-5.12E-04	'NS'
82	92	117	0.9795173	0.0014827	'NS'	0.9519097	9.03E-05	'NS'
80	90	115	0.9793844	0.0016156	'NS'	0.9520878	-8.78E-05	'NS'

Classification accuracy for case6 at training stage (%) = (162 /165) * 100 = 98.8181 %.

Table B.7.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case7 (outage the line (7-8)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.4021832	7.82E-03	'NS'	0.5462893	3.71E-03	'NS'
98	108	133	0.3889382	0.0010618	'NS'	0.5490289	0.0009711	'NS'
96	106	131	0.3723078	-2.31E-03	'NS'	0.5516084	-1.61E-03	'NS'
94	104	129	0.3517077	-1.71E-03	'NS'	0.5509773	-9.77E-04	'NS'
92	102	127	0.3304021	-4.02E-04	'NS'	0.550247	-0.000247	'NS'
90	100	125	0.3085061	0.0014939	'NS'	0.5492884	7.12E-04	'NS'
88	98	123	0.2874434	0.0025566	'NS'	5.49E-01	1.05E-03	'NS'
86	96	121	0.2671857	0.0028143	'NS'	0.5487642	1.24E-03	'NS'
84	94	119	0.2483681	0.0016319	'NS'	0.5486941	1.31E-03	'NS'
82	92	117	0.2302162	-	'NS'	0.5495323	0.0004677	'NS'

				0.0002162				
80	90	115	0.2130163	-0.0030163	'NS'	0.5508359	-8.36E-04	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.3141566	-0.0041566	'NS'	0.8976283	0.0023717	'AS'
98	108	133	3.12E-01	-2.03E-03	'NS'	0.8711689	-0.0011689	'AS'
96	106	131	0.3096134	0.0003866	'NS'	0.8420463	-0.0020463	'AS'
94	104	129	0.3075555	0.0024445	'NS'	0.8025902	0.0074098	'AS'
92	102	127	0.3057286	0.0042714	'NS'	0.7653718	-5.37E-03	'NS'
90	100	125	0.304056	-0.004056	'NS'	0.7291651	0.0008349	'NS'
88	98	123	0.3027752	-2.78E-03	'NS'	0.6969612	3.04E-03	'NS'
86	96	121	0.3015029	-0.0015029	'NS'	0.6675803	1.24E-02	'NS'
84	94	119	0.3009212	-0.0009212	'NS'	0.6418023	0.0081977	'NS'
82	92	117	0.3003947	-3.95E-04	'NS'	0.6191231	8.77E-04	'NS'
80	90	115	0.3003312	-0.0003312	'NS'	0.5997382	-0.0097382	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2984668	0.0015332	'NS'	0.7816371	1.84E-02	'NS'
98	108	133	0.290229	-0.000229	'NS'	0.7696441	3.56E-04	'NS'
96	106	131	0.2786948	0.0013052	'NS'	0.7544957	-0.0044957	'NS'
94	104	129	0.2707252	-0.0007252	'NS'	0.7388602	1.14E-03	'NS'
92	102	127	0.2607217	-0.0007217	'NS'	0.7234249	-0.0034249	'NS'
90	100	125	0.249983	1.70E-05	'NS'	0.708195	0.001805	'NS'
88	98	123	0.2390164	0.0009836	'NS'	0.6944302	-0.0044302	'NS'
86	96	121	0.2289997	0.0010003	'NS'	0.6813795	-0.0013795	'NS'
84	94	119	0.2189948	0.0010052	'NS'	0.6703202	-3.20E-04	'NS'
82	92	117	0.2105137	-0.0005137	'NS'	0.659967	3.30E-05	'NS'
80	90	115	0.2034198	0.0065802	'NS'	0.6513558	-1.14E-02	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	1.35E-05	-1.35E-05	'NS'	1.1028275	-0.002827	'ES'
98	108	133	-0.0006257	0.0006257	'NS'	1.1014478	-0.0014478	'ES'
96	106	131	0.0011715	-0.0011715	'NS'	1.0969321	0.0030679	'ES'
94	104	129	-5.20E-05	5.20E-05	'NS'	1.0993266	0.0006734	'ES'

92	102	127	-0.0008276	0.0008276	'NS'	1.1003585	-0.0003585	'ES'
90	100	125	-0.0016842	0.0016842	'NS'	1.1017848	-0.0017848	'ES'
88	98	123	-0.0022812	0.0022812	'NS'	1.1024188	-0.0024188	'ES'
86	96	121	-0.0014436	0.0014436	'NS'	1.1021798	-0.0021798	'ES'
84	94	119	0.0012467	0.0012467	'NS'	1.101948	-1.95E-03	'ES'
82	92	117	-0.0001821	0.0001821	'NS'	1.1006097	-0.0006097	'ES'
80	90	115	0.0004264	-0.0004264	'NS'	1.0989717	0.0010283	'ES'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
100	110	135	0.3936462	0.0063538	'NS'
98	108	133	0.4004733	-0.0004733	'NS'
96	106	131	0.4093383	0.0006617	'NS'
94	104	129	0.4154915	0.0045085	'NS'
92	102	127	0.4228803	-0.0028803	'NS'
90	100	125	0.4300088	-8.85E-06	'NS'
88	98	123	0.4368215	0.0031785	'NS'
86	96	121	0.4448843	-0.0048843	'NS'
84	94	119	0.4523201	-0.0023201	'NS'
82	92	117	0.4591196	0.0008804	'NS'
80	90	115	0.4657734	0.0042266	'NS'

Table B.7.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case7 (outage the line (7-8)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
100	110	135	0.9728791	1.12E-03	'NS'	0.9522965	1.70E-03	'NS'
98	108	133	0.9732728	0.0007272	'NS'	0.9545176	0.0014824	'NS'
96	106	131	0.9737397	1.26E-03	'NS'	0.9567446	2.55E-04	'NS'
94	104	129	0.9743211	6.79E-04	'NS'	0.9586794	-6.79E-04	'NS'
92	102	127	0.9748973	1.10E-03	'NS'	0.9602781	-0.0012781	'NS'
90	100	125	0.975508	0.000492	'NS'	0.9615238	-1.52E-03	'NS'
88	98	123	0.9760797	-7.97E-05	'NS'	9.62E-01	-1.32E-03	'NS'

86	96	121	0.9766483	-0.0006483	'NS'	0.9626829	-6.83E-04	'NS'
84	94	119	0.9771188	-0.0001188	'NS'	0.9626876	3.12E-04	'NS'
82	92	117	0.9775575	-0.0005575	'NS'	0.9623365	0.0016635	'NS'
80	90	115	0.9779029	-0.0009029	'NS'	0.9616186	3.38E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.984162	-0.006162	'NS'	0.9184357	-0.0004357	'NS'
98	108	133	9.84E-01	-4.81E-03	'NS'	0.9199603	3.97E-05	'NS'
96	106	131	0.9834768	0.0044768	'NS'	0.9219152	8.48E-05	'NS'
94	104	129	0.9833778	-0.0033778	'NS'	0.9236981	-0.0006981	'NS'
92	102	127	0.9833248	-0.0023248	'NS'	0.9255649	-5.65E-04	'NS'
90	100	125	0.9833143	-0.0013143	'NS'	0.9274804	-0.0004804	'NS'
88	98	123	0.9833196	-3.20E-04	'NS'	0.9293622	-1.36E-03	'NS'
86	96	121	0.9833407	-0.0003407	'NS'	0.9311999	-1.20E-03	'NS'
84	94	119	0.9833915	0.0006085	'NS'	0.9329749	-0.0019749	'NS'
82	92	117	0.983431	1.57E-03	'NS'	0.9347857	-1.79E-03	'NS'
80	90	115	0.9834764	0.0025236	'NS'	0.9366006	-0.0026006	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9894985	-0.0014985	'NS'	0.9284587	2.54E-03	'NS'
98	108	133	0.9892677	-0.0012677	'NS'	0.9310833	9.17E-04	'NS'
96	106	131	0.9889364	6.36E-05	'NS'	0.9333074	-0.0013074	'NS'
94	104	129	0.9887332	0.0002668	'NS'	0.9331306	-1.13E-03	'NS'
92	102	127	0.9884882	0.0005118	'NS'	0.9329863	1.37E-05	'NS'
90	100	125	0.9882191	7.81E-04	'NS'	0.9327506	0.0002494	'NS'
88	98	123	0.987947	0.001053	'NS'	0.9327183	0.0012817	'NS'
86	96	121	0.9877657	0.0012343	'NS'	0.9328926	0.0011074	'NS'
84	94	119	0.9876055	0.0013945	'NS'	0.9332741	7.26E-04	'NS'
82	92	117	0.9875237	0.0014763	'NS'	0.9341358	-1.36E-04	'NS'
80	90	115	0.9875107	0.0014893	'NS'	0.9355227	-5.23E-04	'NS'

Classification accuracy for case7 at training stage (%) = (162 / 165) * 100 = 98.8181 %.

Table B.8.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case8 (outage the line (8-9)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.4601921	-1.92E-04	'NS'	0.5505705	-5.70E-04	'NS'
98	108	133	0.448698	0.001302	'NS'	0.5486713	0.0013287	'NS'
96	106	131	0.4320222	-2.02E-03	'NS'	0.5495519	4.48E-04	'NS'
94	104	129	0.4168749	3.13E-03	'NS'	0.55042	-4.20E-04	'NS'
92	102	127	0.4030811	-3.08E-03	'NS'	0.5502646	-0.0002646	'NS'
90	100	125	0.3905076	-0.0005076	'NS'	0.550378	-3.78E-04	'NS'
88	98	123	0.3789385	0.0010615	'NS'	5.50E-01	3.60E-04	'NS'
86	96	121	0.3680366	0.0019634	'NS'	0.5498501	1.50E-04	'NS'
84	94	119	0.3589658	0.0010342	'NS'	0.5492989	7.01E-04	'NS'
82	92	117	0.3505405	-0.0005405	'NS'	0.549484	0.000516	'NS'
80	90	115	0.3433647	-0.0033647	'NS'	0.5506812	-6.81E-04	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2915653	-0.0015653	'NS'	0.2702437	-0.0002437	'NS'
98	108	133	2.89E-01	6.80E-04	'NS'	0.2897024	0.0002976	'NS'
96	106	131	0.2889885	0.0010115	'NS'	0.3117103	-0.0017103	'NS'
94	104	129	0.2893043	0.0006957	'NS'	0.335383	0.004617	'NS'
92	102	127	0.2895299	0.0004701	'NS'	0.3585326	1.47E-03	'NS'
90	100	125	0.2904719	-0.0004719	'NS'	0.3822842	-0.0022842	'NS'
88	98	123	0.2917734	-1.77E-03	'NS'	0.405167	4.83E-03	'NS'
86	96	121	0.2931617	-0.0031617	'NS'	0.4308186	-8.19E-04	'NS'
84	94	119	0.2954513	-0.0054513	'NS'	0.4538867	-0.0038867	'NS'
82	92	117	0.2982083	1.79E-03	'NS'	0.4787862	1.21E-03	'NS'
80	90	115	0.3012126	-0.0012126	'NS'	0.504728	-0.004728	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.910567	-0.000567	'AS'	0.4105002	-5.00E-04	'NS'
98	108	133	0.9246071	-0.0046071	'AS'	0.4201066	-1.07E-04	'NS'
96	106	131	0.9358948	0.0041052	'AS'	0.4287283	0.0012717	'NS'
94	104	129	0.9477791	0.0022209	'AS'	0.4394208	5.79E-04	'NS'

92	102	127	0.9610457	-0.0010457	'AS'	0.4506249	-0.0006249	'NS'
90	100	125	0.9737827	-3.78E-03	'AS'	0.4624358	-0.0024358	'NS'
88	98	123	0.9882001	0.0017999	'AS'	0.4743409	-0.0043409	'NS'
86	96	121	1.0009931	-0.0009931	'ES'	0.4872156	0.0027844	'NS'
84	94	119	1.0158805	-0.0058805	'ES'	0.4989127	1.09E-03	'NS'
82	92	117	1.0291674	0.0008326	'ES'	0.5112271	-1.23E-03	'NS'
80	90	115	1.0418432	-0.0018432	'ES'	0.523227	-3.23E-03	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	1.0981064	0.0018936	'ES'	0.0017103	-0.0017103	'NS'
98	108	133	1.1013405	-0.0013405	'ES'	-0.0017206	0.0017206	'NS'
96	106	131	1.0999254	7.46E-05	'ES'	-0.0004265	0.0004265	'NS'
94	104	129	1.0986293	0.0013707	'ES'	0.0010624	-0.0010624	'NS'
92	102	127	1.0990243	0.0009757	'ES'	0.0007469	-0.0007469	'NS'
90	100	125	1.0994752	0.0005248	'ES'	0.0001094	-0.0001094	'NS'
88	98	123	1.1011225	-0.0011225	'ES'	0.0001448	-0.0001448	'NS'
86	96	121	1.1000927	-9.27E-05	'ES'	0.0005583	-0.0005583	'NS'
84	94	119	1.1004135	-0.0004135	'ES'	-0.000602	6.02E-04	'NS'
82	92	117	1.0990015	0.0009985	'ES'	-0.0002364	0.0002364	'NS'
80	90	115	1.0953161	0.0046839	'ES'	0.0002947	-0.0002947	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	1.0385112	0.0014888	'ES'
98	108	133	1.0293412	0.0006588	'ES'
96	106	131	1.0135673	-0.0035673	'ES'
94	104	129	0.9976112	0.0023888	'ES'
92	102	127	0.9826898	-0.0026898	'AS'
90	100	125	0.9676671	0.0023329	'AS'
88	98	123	0.9530337	-0.0030337	'AS'
86	96	121	0.9388156	0.0011844	'AS'
84	94	119	0.925279	-0.005279	'AS'
82	92	117	0.9106478	-0.0006478	'AS'
80	90	115	0.8958996	0.0041004	'AS'

Table B.8.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case8 (outage the line (8-9)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9520616	9.38E-04	'NS'	0.934428	5.72E-04	'NS'
98	108	133	0.9520428	0.0009572	'NS'	0.934525	0.000475	'NS'
96	106	131	0.952178	8.22E-04	'NS'	0.9345222	-5.22E-04	'NS'
94	104	129	0.9523718	6.28E-04	'NS'	0.9343429	-3.43E-04	'NS'
92	102	127	0.9525417	4.58E-04	'NS'	0.9339071	-0.0009071	'NS'
90	100	125	0.9527051	-0.0007051	'NS'	0.9333175	-3.18E-04	'NS'
88	98	123	0.9528898	-0.0008898	'NS'	9.32E-01	-4.67E-04	'NS'
86	96	121	0.9530945	-0.0010945	'NS'	0.931426	-4.26E-04	'NS'
84	94	119	0.9532791	-0.0022791	'NS'	0.9300216	9.78E-04	'NS'
82	92	117	0.9535495	-0.0025495	'NS'	0.9284777	0.0015223	'NS'
80	90	115	0.9538583	-0.0028583	'NS'	0.9265925	2.41E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9887596	0.0002404	'NS'	0.9734383	-0.0004383	'NS'
98	108	133	9.89E-01	3.93E-04	'NS'	0.9734863	-0.0004863	'NS'
96	106	131	0.9883569	0.0006431	'NS'	0.973628	0.000372	'NS'
94	104	129	0.9880968	0.0009032	'NS'	0.9737383	0.0002617	'NS'
92	102	127	0.9878701	0.0001299	'NS'	0.9737489	2.51E-04	'NS'
90	100	125	0.9876468	0.0003532	'NS'	0.9736996	-0.0006996	'NS'
88	98	123	0.9874543	5.46E-04	'NS'	0.9735377	-5.38E-04	'NS'
86	96	121	0.9872565	-0.0002565	'NS'	0.97333	-3.30E-04	'NS'
84	94	119	0.9870831	-8.31E-05	'NS'	0.9729606	3.94E-05	'NS'
82	92	117	0.9869106	8.94E-05	'NS'	0.9724876	5.12E-04	'NS'
80	90	115	0.986754	-0.000754	'NS'	0.971901	0.001099	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9915245	-0.0015245	'NS'	0.8890602	-6.02E-05	'AS'
98	108	133	0.9911691	-0.0001691	'NS'	0.8889117	8.83E-05	'AS'
96	106	131	0.9908367	0.0001633	'NS'	0.8895472	-0.0005472	'AS'

94	104	129	0.9905405	0.0004595	'NS'	0.8900415	-4.15E-05	'AS'
92	102	127	0.990291	0.000709	'NS'	0.890322	-0.000322	'AS'
90	100	125	0.9901019	8.98E-04	'NS'	0.8905086	-0.0005086	'AS'
88	98	123	0.9899695	0.0010305	'NS'	0.8902993	0.0007007	'AS'
86	96	121	0.9899296	7.04E-05	'NS'	0.8905637	0.0004363	'AS'
84	94	119	0.9899842	1.58E-05	'NS'	0.8901849	8.15E-04	'AS'
82	92	117	0.9901037	-0.000104	'NS'	0.8901492	8.51E-04	'AS'
80	90	115	0.9903465	-0.000346	'NS'	0.8903105	6.89E-04	'AS'

Classification accuracy for case8 at training stage (%) = (165 / 165) * 100 = 100 %.

Table B.9.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the training for case9 (outage the line (4-9)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.3703913	-3.91E-04	'NS'	0.6612272	-3.12E-02	'NS'
98	108	133	0.3491001	0.0008999	'NS'	0.6441735	-0.0141735	'NS'
96	106	131	0.3331196	-3.12E-03	'NS'	0.6258888	-5.89E-03	'NS'
94	104	129	0.3092375	7.62E-04	'NS'	0.6189061	1.09E-03	'NS'
92	102	127	0.2848001	-4.80E-03	'NS'	0.6140217	-0.0040217	'NS'
90	100	125	0.2621071	-0.0021071	'NS'	0.6091084	8.92E-04	'NS'
88	98	123	0.2406066	-0.0006066	'NS'	6.04E-01	-4.14E-03	'NS'
86	96	121	0.219215	0.000785	'NS'	0.5994894	5.11E-04	'NS'
84	94	119	0.1962507	0.0037493	'NS'	0.5959065	4.09E-03	'NS'
82	92	117	0.1728154	-0.0028154	'NS'	0.5924119	-0.0024119	'NS'
80	90	115	0.1497415	0.0002585	'NS'	0.5889475	1.05E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.2996031	-0.0096031	'NS'	0.7456332	0.0043668	'NS'
98	108	133	2.97E-01	-6.77E-03	'NS'	0.703495	-0.003495	'NS'
96	106	131	0.2940768	-0.0040768	'NS'	0.6526994	0.0073006	'NS'
94	104	129	0.2913523	-0.0013523	'NS'	0.609526	0.000474	'NS'
92	102	127	0.2883404	0.0016596	'NS'	0.5663177	3.68E-03	'NS'
90	100	125	0.2854692	0.0045308	'NS'	0.5209943	-	'NS'

							0.0009943	
88	98	123	0.2828959	-2.90E-03	'NS'	0.4756938	4.31E-03	'NS'
86	96	121	0.2812232	- 0.0012232	'NS'	0.431403	-1.40E-03	'NS'
84	94	119	0.2801811	-0.000181	'NS'	0.3901553	-0.000155	'NS'
82	92	117	0.2794997	5.00E-04	'NS'	0.3505422	-5.42E-04	'NS'
80	90	115	0.2797507	0.0002493	'NS'	0.3184895	0.0015105	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.1922041	- 0.0022041	'NS'	0.5875454	6.25E-02	'NS'
98	108	133	0.1769	0.0031	'NS'	0.5911041	2.89E-02	'NS'
96	106	131	0.1628915	- 0.0028915	'NS'	0.5862071	0.0137929	'NS'
94	104	129	0.1610572	-0.001057	'NS'	0.5690095	9.90E-04	'NS'
92	102	127	0.1633049	- 0.0033049	'NS'	0.5474972	- 0.0074972	'NS'
90	100	125	0.1693104	6.90E-04	'NS'	0.5208401	- 0.0008401	'NS'
88	98	123	0.1797119	0.0002881	'NS'	0.4938726	- 0.0038726	'NS'
86	96	121	0.192051	-0.002051	'NS'	0.4661646	0.0038354	'NS'
84	94	119	0.2094792	0.0005208	'NS'	0.4399678	3.22E-05	'NS'
82	92	117	0.2321712	- 0.0021712	'NS'	0.4178519	2.15E-03	'NS'
80	90	115	0.2592717	0.0007283	'NS'	0.4022722	-2.27E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
100	110	135	0.1796839	- 0.0496839	'NS'	1.1158921	0.0641079	'ES'
98	108	133	0.1614048	- 0.0214048	'NS'	1.1284993	0.0215007	'ES'
96	106	131	0.1558593	0.0041407	'NS'	1.1188161	0.0111839	'ES'
94	104	129	0.170133	-0.000133	'NS'	1.1012249	- 0.0012249	'ES'
92	102	127	0.1886318	0.0013682	'NS'	1.0798951	0.0001049	'ES'
90	100	125	0.206454	0.003546	'NS'	1.0566579	0.0033421	'ES'
88	98	123	0.2224351	- 0.0024351	'NS'	1.0335725	- 0.0035725	'ES'
86	96	121	0.2369621	0.0030379	'NS'	1.0116786	- 0.0016786	'ES'
84	94	119	0.2515162	- 0.0015162	'NS'	0.989815	1.85E-04	'AS'
82	92	117	0.2675687	0.0024313	'NS'	0.9693464	0.0006536	'AS'
80	90	115	0.2797077	0.0002923	'NS'	0.9508322	- 0.0008322	'AS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**			
100	110	135	0.0077154	-	'NS'			

				0.0077154	
98	108	133	0.0002271	- 0.0002271	'NS'
96	106	131	0.0020852	- 0.0020852	'NS'
94	104	129	-0.00012	0.00012	'NS'
92	102	127	-0.000722	0.000722	'NS'
90	100	125	- 0.0011798	0.0011798	'NS'
88	98	123	0.0002965	- 0.0002965	'NS'
86	96	121	0.000234	-0.000234	'NS'
84	94	119	-0.000744	0.000744	'NS'
82	92	117	- 0.0009416	0.0009416	'NS'
80	90	115	0.0001026	-0.000103	'NS'

Table B.9.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case9 (outage the line (4-9)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.997946	5.40E-05	'NS'	0.9746447	3.36E-03	'NS'
98	108	133	0.9986783	0.0003217	'NS'	0.976153	0.002847	'NS'
96	106	131	0.9990819	-8.19E-05	'NS'	0.9780128	1.99E-03	'NS'
94	104	129	0.9994851	-4.85E-04	'NS'	0.9803849	6.15E-04	'NS'
92	102	127	0.9998234	1.77E-04	'NS'	0.9825165	- 0.0005165	'NS'
90	100	125	1.0000681	-6.81E-05	'AS'	0.9840817	-1.08E-03	'NS'
88	98	123	1.000261	-0.000261	'AS'	9.85E-01	-8.89E-04	'NS'
86	96	121	1.0002719	- 0.0002719	'AS'	0.9850936	-1.09E-03	'NS'
84	94	119	1.0001473	- 0.0001473	'AS'	0.9848863	1.14E-04	'NS'
82	92	117	0.9999689	3.11E-05	'NS'	0.9841834	0.0008166	'NS'
80	90	115	0.9998932	0.0001068	'NS'	0.9833939	1.61E-03	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9954012	- 0.0044012	'NS'	0.9494775	- 0.0044775	'NS'
98	108	133	9.95E-01	-3.32E-03	'NS'	0.9505218	- 0.0035218	'NS'
96	106	131	0.9954895	-0.002489	'NS'	0.9513877	-0.002387	'NS'
94	104	129	0.9957994	- 0.0017994	'NS'	0.9525093	- 0.0015093	'NS'

92	102	127	0.9961333	-0.0011333	'NS'	0.9536322	-6.32E-04	'NS'
90	100	125	0.9965197	-0.0005197	'NS'	0.9548189	0.0001811	'NS'
88	98	123	0.9968667	-8.67E-04	'NS'	0.9561012	-1.01E-04	'NS'
86	96	121	0.9972213	-0.0002213	'NS'	0.9574357	5.64E-04	'NS'
84	94	119	0.9975779	0.0004221	'NS'	0.9588765	0.0001235	'NS'
82	92	117	0.9978787	1.21E-04	'NS'	0.9604499	5.50E-04	'NS'
80	90	115	0.9981278	0.0008722	'NS'	0.9618677	0.0001323	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 5**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
100	110	135	0.9509805	-0.0059805	'NS'	0.775178	-1.12E-02	'EES'
98	108	133	0.9513149	-0.004315	'NS'	0.7783251	-8.33E-03	'EES'
96	106	131	0.9518999	-0.0029	'NS'	0.7807767	-0.004777	'EES'
94	104	129	0.9526183	-0.0016183	'NS'	0.7840951	-2.10E-03	'EES'
92	102	127	0.9535533	-0.0005533	'NS'	0.7878405	-0.0008405	'EES'
90	100	125	0.9548484	1.52E-04	'NS'	0.7917786	0.0002214	'EES'
88	98	123	0.956338	-0.000338	'NS'	0.796108	0.000892	'EES'
86	96	121	0.9579425	5.75E-05	'NS'	0.8005309	0.0014691	'ES'
84	94	119	0.9594611	-0.0004611	'NS'	0.8052623	7.38E-04	'ES'
82	92	117	0.9608817	0.0001183	'NS'	0.8100501	-5.01E-05	'ES'
80	90	115	0.9618604	0.0001396	'NS'	0.815418	-1.42E-03	'ES'

Classification accuracy for case9 at training stage (%) = (154 / 165) * 100 = 93.3333 %.

Table B.1.1.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case1).

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.3195191	4.81E-04	'NS'	0.5494836	5.16E-04	'NS'
93	103	128	0.2982165	-0.0582165	'NS'	0.5488578	0.0011422	'NS'
89	99	124	0.2638602	-5.39E-02	'NS'	0.5414309	8.57E-03	'NS'
85	95	120	0.2135248	-4.35E-02	'NS'	0.5446177	5.38E-03	'NS'
81	91	116	0.1194402	1.61E-01	'NS'	0.5326296	0.0173704	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.2795387	0.0004613	'NS'	2.85E-01	-5.04E-03	'NS'

93	103	128	0.3157175	-0.0357175	'NS'	0.2629413	-4.29E-02	'NS'
89	99	124	0.3119297	-0.0319297	'NS'	0.2271694	-4.72E-02	'NS'
85	95	120	0.3111504	-0.0311504	'NS'	0.1675675	-0.0175675	'NS'
81	91	116	0.2175934	0.0624066	'NS'	0.1531675	9.68E-02	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.3964766	-0.0064766	'NS'	0.2409887	-0.0009887	'NS'
93	103	128	3.83E-01	3.67E-02	'NS'	0.2843162	-0.0643162	'NS'
89	99	124	0.3954494	0.0345506	'NS'	0.2744012	-0.0544012	'NS'
85	95	120	0.4278672	0.0121328	'NS'	0.2471949	-0.0371949	'NS'
81	91	116	0.3734362	0.0265638	'NS'	0.1266421	1.03E-01	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.5375157	2.48E-03	'NS'	0.5521811	-2.18E-03	'NS'
93	103	128	0.3004405	0.2095595	'NS'	0.546202	3.38E-02	'NS'
89	99	124	0.2769795	0.2130205	'NS'	0.5677526	0.0322474	'NS'
85	95	120	0.2923999	1.88E-01	'NS'	0.5808238	2.92E-02	'NS'
81	91	116	1.0202622	-0.5002622	'ES'	0.6542643	-0.0842643	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.4168324	-0.0068324	'NS'
93	103	128	0.281366	0.078634	'NS'
89	99	124	0.2634497	0.0665503	'NS'
85	95	120	0.2513029	0.0586971	'NS'
81	91	116	0.6211442	-0.2411442	'NS'

Table B.1.1.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case1)

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9872936	-2.94E-04	'NS'	0.9754874	-4.87E-04	'NS'

93	103	128	0.9830115	0.0039885	'NS'	0.9725477	0.0024523	'NS'
89	99	124	0.9837789	3.22E-03	'NS'	0.9729905	3.01E-03	'NS'
85	95	120	0.9837894	3.21E-03	'NS'	0.9731857	2.81E-03	'NS'
81	91	116	0.9924674	-5.47E-03	'NS'	0.9733304	0.0016696	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	1.0017274	0.0012726	'AS'	9.84E-01	1.86E-04	'NS'
93	103	128	1.0019511	0.0020489	'AS'	0.9858679	-1.87E-03	'NS'
89	99	124	1.0023692	0.0016308	'AS'	0.9858989	-8.99E-04	'NS'
85	95	120	1.0039959	4.06E-06	'AS'	0.9843325	0.0006675	'NS'
81	91	116	0.9982552	0.0057448	'NS'	0.9837489	2.51E-04	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9972354	-0.0022354	'NS'	0.9562469	0.0007531	'NS'
93	103	128	9.96E-01	-1.90E-04	'NS'	0.9630469	-0.0060469	'NS'
89	99	124	0.995664	0.000336	'NS'	0.9633897	-0.0053897	'NS'
85	95	120	0.994308	0.001692	'NS'	0.9603014	-0.0023014	'NS'
81	91	116	0.9931952	0.0028048	'NS'	0.9527645	4.24E-03	'NS'

Classification accuracy for case1 at testing stage (%) = (42 / 75) * 100 = 56 %.

Table B.3.3.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case3 (outage the line (3-6))).

Load at Bus 5	Load at Bus 5	Load at Bus 5	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.5550344	4.50E-02	'NS'	0.5769383	-2.69E-02	'NS'
93	103	128	0.5064507	0.0535493	'NS'	0.5712214	-0.0212214	'NS'
89	99	124	0.45749	6.25E-02	'NS'	0.5646028	-1.46E-02	'NS'
85	95	120	0.4113799	5.86E-02	'NS'	0.5593406	-9.34E-03	'NS'
81	91	116	0.3708696	5.91E-02	'NS'	0.5618222	-0.0218222	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**

97	107	132	0.0034446	0.0034446	'NS'	5.60E-01	6.03E-02	'NS'
93	103	128	-0.0066561	0.0066561	'NS'	0.5421591	3.78E-02	'NS'
89	99	124	-0.0109299	0.0109299	'NS'	0.5200635	1.99E-02	'NS'
85	95	120	-0.0155327	0.0155327	'NS'	0.5003023	0.0096977	'NS'
81	91	116	-0.0180936	0.0180936	'NS'	0.5016319	-3.16E-02	'NS'

Load at Bus 5	Load at Bus 5	Load at Bus 5	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.2416611	-0.051661	'NS'	0.1783164	0.0016836	'NS'
93	103	128	2.32E-01	-4.19E-02	'NS'	0.1842488	-0.0042488	'NS'
89	99	124	0.2286693	-0.0386693	'NS'	0.1936588	-0.0036588	'NS'
85	95	120	0.2274369	-0.0374369	'NS'	0.2072563	-0.0072563	'NS'
81	91	116	0.2056501	-0.0156501	'NS'	0.2250997	-1.51E-02	'NS'

Load at Bus 5	Load at Bus 5	Load at Bus 5	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.953596	-1.94E-01	'AS'	0.3813418	-2.13E-02	'NS'
93	103	128	0.9491573	-0.2091573	'AS'	0.4040419	-3.40E-02	'NS'
89	99	124	0.9244066	-0.1944066	'AS'	0.4280338	-0.0480338	'NS'
85	95	120	0.8808452	-1.71E-01	'AS'	0.4525323	-6.25E-02	'NS'
81	91	116	0.824305	-0.124305	'AS'	0.4707905	-0.0707905	'NS'

Load at Bus 5	Load at Bus 5	Load at Bus 5	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.5313769	0.0486231	'NS'
93	103	128	0.5243086	0.0256914	'NS'
89	99	124	0.5202178	-0.0102178	'NS'
85	95	120	0.5197341	-0.0497341	'NS'
81	91	116	0.5140916	-0.0740916	'NS'

Table B.3.3.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the training for case3 (outage the line (3-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses

97	107	132	0.9962073	-8.21E-03	'NS'	0.9947224	-2.17E-02	'NS'
93	103	128	0.9956177	-0.0066177	'NS'	0.9957799	-0.0207799	'NS'
89	99	124	0.9946365	-4.64E-03	'NS'	0.9951823	-1.72E-02	'NS'
85	95	120	0.9929231	-1.92E-03	'NS'	0.9924528	-1.25E-02	'NS'
81	91	116	0.99036	1.64E-03	'NS'	0.9873447	-0.0063447	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9991133	-0.0041133	'NS'	9.73E-01	6.02E-03	'NS'
93	103	128	0.999237	-0.002237	'NS'	0.9751998	5.80E-03	'NS'
89	99	124	0.9994063	-0.0004063	'NS'	0.9777078	5.29E-03	'NS'
85	95	120	0.9995447	0.0014553	'NS'	0.9803126	0.0046874	'NS'
81	91	116	0.999314	0.002686	'NS'	0.9826924	3.31E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9895358	0.0044642	'NS'	0.9663693	-0.0063693	'NS'
93	103	128	9.90E-01	4.92E-03	'NS'	0.9689925	-0.0079925	'NS'
89	99	124	0.9909129	0.0050871	'NS'	0.9706799	-0.0086799	'NS'
85	95	120	0.9923057	0.0046943	'NS'	0.9713882	-0.0073882	'NS'
81	91	116	0.99433	0.00267	'NS'	0.9725932	-7.59E-03	'NS'

Classification accuracy for case3 at testing stage (%) = (36 / 75) * 100 = 48 %.

Table B.4.4.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case4 (outage the line (4-5)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.3311228	-1.12E-03	'NS'	0.5512541	-1.25E-03	'NS'
93	103	128	0.2903975	-0.0003975	'NS'	0.5504487	-0.0004487	'NS'
89	99	124	0.248844	1.16E-03	'NS'	0.5483473	1.65E-03	'NS'
85	95	120	0.210108	-1.08E-04	'NS'	0.5502769	-2.77E-04	'NS'
81	91	116	0.1722164	-2.22E-03	'NS'	0.5606283	-0.0106283	'NS'
Load	**Load**	**Load**	**Thermal**	**Errors**	**Statuses**	**Thermal**	**Errors**	**Statuses**

at Bus 5	at Bus 7	at Bus 9	line (3- 6)	between ANN and NR	of the Lines	line (4- 5)	between ANN and NR	of the Lines
97	107	132	0.2984876	0.0015124	'NS'	8.03E-05	-8.03E-05	'NS'
93	103	128	0.2950114	0.0049886	'NS'	-0.000581	5.81E-04	'NS'
89	99	124	0.2915552	-0.0015552	'NS'	-0.0016384	1.64E-03	'NS'
85	95	120	0.289344	0.000656	'NS'	-0.000147	0.000147	'NS'
81	91	116	0.290441	-0.000441	'NS'	0.0113752	-1.14E-02	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.6908624	-0.0008624	'NS'	0.1946333	0.0053667	'NS'
93	103	128	6.61E-01	-8.23E-04	'NS'	0.1754633	0.0045367	'NS'
89	99	124	0.6302199	-0.0002199	'NS'	0.1600278	-2.78E-05	'NS'
85	95	120	0.5994735	0.0005265	'NS'	0.1504593	-0.0004593	'NS'
81	91	116	0.5603582	0.0196418	'NS'	0.149539	-9.54E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.8383439	1.66E-03	'AS'	0.3010103	-1.01E-03	'NS'
93	103	128	0.7763716	0.0036284	'NS'	0.3414238	-1.42E-03	'NS'
89	99	124	0.7209235	-0.0009235	'NS'	0.385363	0.004637	'NS'
85	95	120	0.6650707	-5.07E-03	'NS'	0.4312654	-1.27E-03	'NS'
81	91	116	0.5989367	0.0110633	'NS'	0.4741391	0.0058609	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.6521256	-0.0021256	'NS'
93	103	128	0.5791152	0.0008848	'NS'
89	99	124	0.5087977	0.0012023	'NS'
85	95	120	0.4384504	0.0015496	'NS'
81	91	116	0.3638466	0.0161534	'NS'

Table B.4.4.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case4 (outage the line (4-5)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9878884	1.12E-04	'NS'	0.8970459	-4.59E-05	'AS'

93	103	128	0.9888464	0.0001536	'NS'	0.9013103	0.0016897	'AS'
89	99	124	0.9894924	-4.92E-04	'NS'	0.9073741	1.63E-03	'AS'
85	95	120	0.9898573	-8.57E-04	'NS'	0.9149208	-9.21E-04	'NS'
81	91	116	0.9896434	-1.64E-03	'NS'	0.9231372	-0.0041372	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V6 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V7 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.986074	-0.001074	'NS'	9.71E-01	1.95E-03	'NS'
93	103	128	0.9867671	0.0002329	'NS'	0.9747647	2.35E-04	'NS'
89	99	124	0.9879587	4.13E-05	'NS'	0.9783981	-1.40E-03	'NS'
85	95	120	0.9896621	0.0003379	'NS'	0.9814401	-0.0034401	'NS'
81	91	116	0.9916145	0.0003855	'NS'	0.983737	-3.74E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V8 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V9 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9904595	0.0005405	'NS'	0.9600122	-0.0010122	'NS'
93	103	128	9.93E-01	-5.95E-04	'NS'	0.9608479	-0.0008479	'NS'
89	99	124	0.9939653	-0.0009653	'NS'	0.9606457	0.0003543	'NS'
85	95	120	0.994506	-0.000506	'NS'	0.9610367	-3.67E-05	'NS'
81	91	116	0.994491	-0.000491	'NS'	0.9635612	-3.56E-03	'NS'

Classification accuracy for case4 at testing stage (%) = (70 / 75) * 100 = 93.3333 %.

Table B.5.5.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case5 (outage the line (5-6)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.3986733	1.33E-03	'NS'	0.5512231	-1.22E-03	'NS'
93	103	128	0.3643896	-0.0043896	'NS'	0.5529346	-0.0029346	'NS'
89	99	124	0.335432	-5.43E-03	'NS'	0.5546358	5.36E-03	'NS'
85	95	120	0.3090737	9.26E-04	'NS'	0.5572856	2.71E-03	'NS'
81	91	116	0.2833524	-3.35E-03	'NS'	0.5615458	-0.0015458	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**

97	107	132	0.2835727	-0.0035727	'NS'	6.82E-01	-1.71E-03	'NS'
93	103	128	0.2804199	-0.0004199	'NS'	0.6549094	5.09E-03	'NS'
89	99	124	0.2792476	0.0007524	'NS'	0.6246611	5.34E-03	'NS'
85	95	120	0.2795411	0.0004589	'NS'	0.597631	0.002369	'NS'
81	91	116	0.2803887	-0.0003887	'NS'	0.5752842	4.72E-03	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.0002826	-0.0002826	'NS'	0.5708766	-0.0008766	'NS'
93	103	128	3.90E-07	-3.90E-07	'NS'	0.5701082	-0.0001082	'NS'
89	99	124	0.0007713	-0.0007713	'NS'	0.5703817	-0.0003817	'NS'
85	95	120	0.0004776	-0.0004776	'NS'	0.5700401	-4.01E-05	'NS'
81	91	116	-0.0003217	0.0003217	'NS'	0.5693268	6.73E-04	'NS'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.1881774	2.18E-02	'NS'	0.9472319	2.77E-03	'AS'
93	103	128	0.1847979	0.0052021	'NS'	0.9754939	-5.49E-03	'AS'
89	99	124	0.1723244	-0.0023244	'NS'	1.0049908	-0.0049908	'ES'
85	95	120	0.1568918	3.11E-03	'NS'	1.0324999	-2.50E-03	'ES'
81	91	116	0.1430617	0.0069383	'NS'	1.0561109	0.0038891	'ES'

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.3093172	0.0006828	'NS'
93	103	128	0.3235555	-0.0035555	'NS'
89	99	124	0.3459365	0.0040635	'NS'
85	95	120	0.3726959	-0.0026959	'NS'
81	91	116	0.4030501	0.0069499	'NS'

Table B.5.5.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case5 (outage the line (5-6)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V4 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V5 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9592976	3.70E-03	'NS'	0.9181388	-1.14E-03	'NS'

93	103	128	0.9604925	0.0025075	'NS'	0.9181092	- 0.0001092	'NS'
89	99	124	0.9617317	1.27E-03	'NS'	0.9181285	8.72E-04	'NS'
85	95	120	0.96313	-1.13E-03	'NS'	0.9187696	1.23E-03	'NS'
81	91	116	0.9647507	-2.75E-03	'NS'	0.9198978	0.0001022	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9985906	- 0.0005906	'NS'	9.74E-01	-2.25E-03	'NS'
93	103	128	0.9978847	0.0001153	'NS'	0.973717	-7.17E-04	'NS'
89	99	124	0.9971562	0.0008438	'NS'	0.9728217	1.78E-04	'NS'
85	95	120	0.9964582	0.0015418	'NS'	0.9718009	0.0011991	'NS'
81	91	116	0.9958326	0.0021674	'NS'	0.9705444	1.46E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9866827	- 0.0016827	'NS'	0.9277047	- 0.0007047	'NS'
93	103	128	9.85E-01	-1.42E-03	'NS'	0.9273251	- 0.0003251	'NS'
89	99	124	0.984178	-0.000178	'NS'	0.925913	8.70E-05	'NS'
85	95	120	0.9828422	0.0011578	'NS'	0.9240158	0.0009842	'NS'
81	91	116	0.9814614	0.0015386	'NS'	0.922731	2.69E-04	'NS'

Classification accuracy for case5 at testing stage (%) = (74 / 75) * 100 = 98.667 %.

Table B.6.6.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case6 (outage the line (6-7))).

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.3296712	3.29E-04	'NS'	0.5600024	-2.43E-06	'NS'
93	103	128	0.2901185	- 0.0001185	'NS'	0.5591533	0.0008467	'NS'
89	99	124	0.2541805	-4.18E-03	'NS'	0.5593748	6.25E-04	'NS'
85	95	120	0.2197559	2.44E-04	'NS'	0.5593797	6.20E-04	'NS'
81	91	116	0.1862802	-6.28E-03	'NS'	0.5621544	- 0.0021544	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**

97	107	132	0.2896342	0.0003658	'NS'	1.54E-01	6.39E-03	'NS'
93	103	128	0.2902879	-0.0002879	'NS'	0.1426911	-2.69E-03	'NS'
89	99	124	0.2902823	-0.0002823	'NS'	0.1364742	-6.47E-03	'NS'
85	95	120	0.2898993	0.0001007	'NS'	0.1306452	-0.000645	'NS'
81	91	116	0.2907017	-0.0007017	'NS'	0.1328261	-2.83E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.5705955	-0.0005955	'NS'	0.0006516	-0.0006516	'NS'
93	103	128	5.71E-01	-1.25E-03	'NS'	-0.0028327	0.0028327	'NS'
89	99	124	0.5691563	0.0008437	'NS'	-0.0027643	0.0027643	'NS'
85	95	120	0.5693863	0.0006137	'NS'	3.88E-05	-3.88E-05	'NS'
81	91	116	0.5637179	0.0062821	'NS'	0.0058867	-5.89E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.7506291	-6.29E-04	'NS'	0.3754641	4.54E-03	'NS'
93	103	128	0.7240656	0.0059344	'NS'	0.4038907	-3.89E-03	'NS'
89	99	124	0.699376	0.000624	'NS'	0.4312875	-0.0112875	'NS'
85	95	120	0.6763047	-6.30E-03	'NS'	0.4555012	-5.50E-03	'NS'
81	91	116	0.6501731	-0.0001731	'NS'	0.4667817	0.0132183	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.5655972	0.0044028	'NS'
93	103	128	0.5190558	0.0009442	'NS'
89	99	124	0.4757842	0.0042158	'NS'
85	95	120	0.4390388	-0.0090388	'NS'
81	91	116	0.4035492	-0.0035492	'NS'

Table B.6.6.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case6 (outage the line (6-7)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.983347	-3.47E-04	'NS'	0.9692529	7.47E-04	'NS'
93	103	128	0.9826246	0.0003754	'NS'	0.9708079	0.0001921	'NS'

89	99	124	0.9820303	1.97E-03	'NS'	0.9725556	-5.56E-04	'NS'
85	95	120	0.9815801	2.42E-03	'NS'	0.9740941	-2.09E-03	'NS'
81	91	116	0.9806965	3.30E-03	'NS'	0.9756797	-0.0026797	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	1.0048685	0.0001315	'AS'	9.45E-01	-5.28E-04	'NS'
93	103	128	1.0052879	-0.0002879	'AS'	0.9450773	9.23E-04	'NS'
89	99	124	1.0056287	-0.0006287	'AS'	0.9463747	6.25E-04	'NS'
85	95	120	1.0059302	6.98E-05	'AS'	0.9482338	-0.0002338	'NS'
81	91	116	1.0062527	-0.0002527	'AS'	0.950075	-1.07E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9780746	0.0009254	'NS'	0.9497541	0.0012459	'NS'
93	103	128	9.78E-01	6.12E-04	'NS'	0.9515698	-0.0005698	'NS'
89	99	124	0.9788662	0.0011338	'NS'	0.9526745	-0.0006745	'NS'
85	95	120	0.9793325	0.0016675	'NS'	0.9525947	-0.0005947	'NS'
81	91	116	0.9794713	0.0015287	'NS'	0.9517856	2.14E-04	'NS'

Classification accuracy for case6 at testing stage (%) = (73 / 75) * 100 = 97.3333 %.

Table B.7.7.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case7 (outage the line (7-8)))

Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (1- 4)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (2- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.3809256	-9.26E-04	'NS'	0.550702	-7.02E-04	'NS'
93	103	128	0.3409752	-0.0009752	'NS'	0.5501492	-0.0001492	'NS'
89	99	124	0.2976874	2.31E-03	'NS'	0.5485558	1.44E-03	'NS'
85	95	120	0.257195	2.81E-03	'NS'	0.5487836	1.22E-03	'NS'
81	91	116	0.2214536	-1.45E-03	'NS'	0.5506147	-0.0006147	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**Thermal line (3- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN and NR**	**Statuses of the Lines**

97	107	132	0.3107894	-0.000789	'NS'	8.57E-01	3.18E-03	'AS'
93	103	128	0.3066649	0.0033351	'NS'	0.7821837	-2.18E-03	'NS'
89	99	124	0.303566	-0.003566	'NS'	0.7111183	8.88E-03	'NS'
85	95	120	0.3012178	0.0012178	'NS'	0.6527307	0.0072693	'NS'
81	91	116	0.2998094	0.0001906	'NS'	0.6104874	-4.87E-04	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (5- 6)	Errors between ANN and NR	Statuses of the Lines	Thermal line (6- 7)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.2849352	-0.0049352	'NS'	0.7619739	-0.0019739	'NS'
93	103	128	2.67E-01	-6.77E-03	'NS'	0.7309382	-0.0009382	'NS'
89	99	124	0.2446075	-0.0046075	'NS'	0.7010868	-0.0010868	'NS'
85	95	120	0.2249757	-0.0049757	'NS'	0.6751729	-0.0051729	'NS'
81	91	116	0.206788	0.003212	'NS'	0.654974	-4.97E-03	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (7- 8)	Errors between ANN and NR	Statuses of the Lines	Thermal line (8- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.0001723	-1.72E-04	'NS'	1.099112	8.88E-04	'ES'
93	103	128	-0.0009783	0.0009783	'NS'	1.1009782	-9.78E-04	'ES'
89	99	124	-0.0027076	0.0027076	'NS'	1.1032249	-0.0032249	'ES'
85	95	120	-0.0017157	1.72E-03	'NS'	1.1025626	-2.56E-03	'ES'
81	91	116	0.0021654	-0.0021654	'NS'	1.0977804	0.0022196	'ES'

Load at Bus 5	Load at Bus 7	Load at Bus 9	Thermal line (4- 9)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.4044037	0.0055963	'NS'
93	103	128	0.4186701	0.0013299	'NS'
89	99	124	0.4337269	-0.0037269	'NS'
85	95	120	0.4478412	0.0021588	'NS'
81	91	116	0.4638064	-0.0038064	'NS'

Table B.7.7.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case7 (outage the line (7-8)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses

97	107	132	0.9734956	1.50E-03	'NS'	0.9556555	3.44E-04	'NS'
93	103	128	0.9746107	0.0003893	'NS'	0.959551	-0.000551	'NS'
89	99	124	0.9757829	2.17E-04	'NS'	0.9619652	-9.65E-04	'NS'
85	95	120	0.9768869	1.13E-04	'NS'	0.9627156	2.84E-04	'NS'
81	91	116	0.9777833	-7.83E-04	'NS'	0.9620234	0.0019766	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V6 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V7 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.9836305	-0.0046305	'NS'	9.21E-01	7.06E-05	'NS'
93	103	128	0.9833743	-0.0023743	'NS'	0.9245823	-5.82E-04	'NS'
89	99	124	0.9833253	-0.0013253	'NS'	0.928452	-4.52E-04	'NS'
85	95	120	0.9833826	0.0006174	'NS'	0.9320767	-0.0010767	'NS'
81	91	116	0.9834255	0.0015745	'NS'	0.9357133	-2.71E-03	'NS'
Load at Bus 5	**Load at Bus 7**	**Load at Bus 9**	**| V8 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**	**| V9 | (P.U.)**	**Errors between ANN and NR**	**Statuses of the Buses**
97	107	132	0.989104	-0.000104	'NS'	0.9323641	-0.0003641	'NS'
93	103	128	9.89E-01	3.58E-04	'NS'	0.9328423	0.0001577	'NS'
89	99	124	0.988072	0.000928	'NS'	0.9326607	0.0003393	'NS'
85	95	120	0.987702	0.001298	'NS'	0.9329204	0.0010796	'NS'
81	91	116	0.987552	0.001448	'NS'	0.9349124	8.76E-05	'NS'

assification accuracy for case7 at testing stage (%) = (75 / 75) * 100 = 100 %.

Table B.8.8.1: Values of the thermal lines, statuses and errors between ANN and NR method (results of the testing for case8 (outage the line (8-9)))

Load at Bus 5	Load at Bus 5	Load at Bus 5	Thermal line (1- 4)	Errors between ANN and NR	Statuses of the Lines	Thermal line (2- 8)	Errors between ANN and NR	Statuses of the Lines
97	107	132	0.4408637	-8.64E-04	'NS'	0.548648	1.35E-03	'NS'
93	103	128	0.4094583	0.0005417	'NS'	0.5501799	-0.0001799	'NS'
89	99	124	0.3843839	5.62E-03	'NS'	0.5499621	3.79E-05	'NS'
85	95	120	0.36319	-3.19E-03	'NS'	0.5491861	8.14E-04	'NS'
81	91	116	0.3469644	-6.96E-03	'NS'	0.550365	-0.000365	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (3- 6)**	**Errors between ANN**	**Statuses of the Lines**	**Thermal line (4- 5)**	**Errors between ANN**	**Statuses of the Lines**

				and NR			and NR	
97	107	132	0.2894298	0.0005702	'NS'	3.00E-01	7.37E-05	'NS'
93	103	128	0.28944	0.00056	'NS'	0.346531	3.47E-03	'NS'
89	99	124	0.2910677	-0.0010677	'NS'	0.39375	-3.75E-03	'NS'
85	95	120	0.2942412	0.0042412	'NS'	0.4413793	0.0013793	'NS'
81	91	116	0.2997218	0.0002782	'NS'	0.4915659	-1.57E-03	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (5- 6)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (6- 7)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	0.9311835	-0.0011835	'AS'	0.4243829	-0.0043829	'NS'
93	103	128	9.55E-01	5.42E-03	'AS'	0.444652	0.005348	'NS'
89	99	124	0.9811323	-0.0011323	'AS'	0.4683713	0.0016287	'NS'
85	95	120	1.0090623	0.0009377	'ES'	0.4927884	-0.0027884	'NS'
81	91	116	1.035155	-0.005155	'ES'	0.5172829	2.72E-03	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (7- 8)**	**Errors between ANN and NR**	**Statuses of the Lines**	**Thermal line (8- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**
97	107	132	1.1011661	-1.17E-03	'ES'	-0.0010257	1.03E-03	'NS'
93	103	128	1.0996193	0.0003807	'ES'	0.0014982	-1.50E-03	'NS'
89	99	124	1.100281	-0.000281	'ES'	0.0003745	-0.0003745	'NS'
85	95	120	1.1006235	-6.24E-04	'ES'	-0.0005191	5.19E-04	'NS'
81	91	116	1.0974916	0.0025084	'ES'	-0.0002595	0.0002595	'NS'
Load at Bus 5	**Load at Bus 5**	**Load at Bus 5**	**Thermal line (4- 9)**	**Errors between ANN and NR**	**Statuses of the Lines**			
97	107	132	1.0216272	-0.0016272	'ES'			
93	103	128	0.9894248	0.0005752	'AS'			
89	99	124	0.9601849	-0.0001849	'AS'			
85	95	120	0.9320892	-0.0020892	'AS'			
81	91	116	0.9031357	-0.0031357	'AS'			

Table B.8.8.2: Voltage Magnitudes per unit, statuses and errors between ANN and NR method (results of the testing for case8 (outage the line (8-9)))

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V4 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V5 | (P.U.)	Errors between ANN and NR	Statuses of the Buses

97	107	132	0.9521224	8.78E-04	'NS'	0.9345222	4.78E-04	'NS'
93	103	128	0.952462	0.000538	'NS'	0.9341889	0.0001889	'NS'
89	99	124	0.952799	-7.99E-04	'NS'	0.9329262	-9.26E-04	'NS'
85	95	120	0.9531527	-1.15E-03	'NS'	0.9307224	2.78E-04	'NS'
81	91	116	0.9536892	-2.69E-03	'NS'	0.9275689	0.0024311	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V6 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V7 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9884782	0.0005218	'NS'	9.74E-01	-5.49E-04	'NS'
93	103	128	0.9879889	1.11E-05	'NS'	0.9737347	2.65E-04	'NS'
89	99	124	0.9875505	0.0004495	'NS'	0.9736301	-6.30E-04	'NS'
85	95	120	0.9871766	-0.0001766	'NS'	0.9731506	-0.0001506	'NS'
81	91	116	0.986833	-0.000833	'NS'	0.9722092	7.91E-04	'NS'

Load at Bus 5	Load at Bus 7	Load at Bus 9	| V8 | (P.U.)	Errors between ANN and NR	Statuses of the Buses	| V9 | (P.U.)	Errors between ANN and NR	Statuses of the Buses
97	107	132	0.9909938	6.21E-06	'NS'	0.8889665	3.35E-05	'AS'
93	103	128	9.90E-01	6.03E-04	'NS'	0.8901123	-0.0001123	'AS'
89	99	124	0.9900247	0.0009753	'NS'	0.8904187	-0.0004187	'AS'
85	95	120	0.9899457	5.43E-05	'NS'	0.8903058	0.0006942	'AS'
81	91	116	0.9902124	-0.0002124	'NS'	0.8902254	7.75E-04	'AS'

assification accuracy for case8 at testing stage (%) = (75 / 75) * 100 = 100 %.

APPENDIX C

MATLAB SOURSE CODE

The neural network part of the used program:

```
clc
clear;
target_tr=[];
target_test=[];
input_tr=[];
input_tr_re=[];
input_test=[];
input_test_re=[];
for n=1:9
   t=strcat(['a',num2str(n)]);
   load(t);clear('t');
   t_tr=[v_out_tr' ; ther_out_tr'./100];
   t_test=[v_out_test' ; ther_out_test'./100];

   input_tr=[input_tr in_tr'];
   input_tr_re=[input_tr_re in_tr_re'];
   input_test=[input_test in_test'];
   input_test_re=[input_test_re in_test_re'];

   target_tr=[target_tr t_tr]; target_test=[target_test t_test];
   clear('t_tr','t_test');


end
clear('n');


input_tr_final=[input_tr;input_tr_re];
input_test_final=[input_test;input_test_re];



net=newff((input_tr_final),target_tr,[30 100 30
50],{'tansig','tansig','logsig','logsig'},'traingdx');



net.trainparam.epochs=20000;
net.trainparam.goal=0.000001;
net.trainparam.lr=0.04;
net.trainparam.mc=0.3;
```

```
t_s,tr]=train(net,input_tr_final,target_tr);

ult;
sim(net_s,input_tr_final);
sim(net_s,input_test_final);
_error=target_test-b; save('test_error','test_error');
n_error=target_tr-a; save('train_error','train_error');
e_test=test_error.^2;  save('mse_test','mse_test');

iche;
ssify;

che_d_erreur;
```