POWER SYSTEM ON LINE CONTINGENCY ANALYSIS USING SOFT COMPUTING

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

By
MUSTAPHA BALA JIBRIL

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

NICOSIA, 2018

MUSTAPHA BALA JIBRIL
POWER SYSTEM ON-LINE CONTINGENCY ANALYSIS
USING SOFT COMPUTING
NEU
2018

POWER SYSTEM ON LINE CONTINGENCY ANALYSIS USING SOFT COMPUTING

A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES

OF

NEAR EAST UNIVERSITY

By
MUSTAPHA BALA JIBRIL

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

NICOSIA, 2018

Mustapha BALA JIBRIL: POWER SYSTEM ON LINE CONTINGENCY USING SOFT COMPUTING.

Approval of Director of Graduate School of Applied Sciences

Prof. Dr. Nadire ÇAVUŞ

We certify this thesis is satisfactory for the award of the degree of Masters of Science in Electrical Electronics Engineering

Examining Committee in Charge:

Prof. S. H. Hosseini	Committee Chairman, Department of Electrical Electronic Engineering, Tabriz.
Prof. Mehrdad Tarafdar Hagh	Supervisor, Department of Electrical Electronic Engineering, NEU
Assist. Prof. Dr. Lida Ebrahim Vafaei	Department of Mechanical Engineering, NEU

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that I have fully cited and referenced all material and results that are not original to this work, as required by these rules and conduct.

Name, Last name:

Signature:

Date:

ACKNOWLEGMENTS

I take this opportunity to express my sincere appreciation to my supervisor Prof. Mehrdad Tarafdar Hagh for his guidance and encouragement throughout the course of this thesis and also the staffs of Electrical Electronics Engineering department Near East University, especially the Head of Department Prof. Dr. Bülent Bilgehan and my adviser, Dr. Sartan Kaymak.

To my parents Late Alh. Bala Jibril and Haj. Hauwa Mustapha, whose constant prayers, love, support, and guidance have been my source of strength and inspiration throughout these years, words alone can’t express how grateful I am for the support you gave me. May your soul continue to rest in perfect peace (Father).

I take this opportunity to express my profound gratitude and deep regards to my friends and my entire family for their consistent support and help amid my study.

Lastly, I am obliged to thank my sponsor, (Kano State Government) who made my dreams reality.

To my parents...

ABSTRACT

Power System Security and Contingency evaluation are one of the most important tasks in power systems. In operation, contingency analysis assists engineers to operate the power system at a secure operating point where equipment are loaded within their safe limits and power is delivered to customers with acceptable quality standards. In this regard, An Adaptive Neuro-Fuzzy Inference System (ANFIS) and Artificial Neural Network (ANN) approach for contingency analysis of the power system is proposed using voltage and line flow contingency screening. An AC load flow is performed for each contingency case. The offline results of full AC load flow calculations are used to construct two types of performance indices, namely the power flow performance index (PI_flow) and the voltage performance index (PIv), which reflect the degree of severity of the contingencies. The results of off-line load flow calculations are used to to estimate performance indices (PI_flow, PIV). ANN and ANFIS are trained to measure the accuracy of both algorithms which compare with the Neuton Raphson method. The contingencies are transmitted to the "classification module" for the classification of contingencies. The accuracy of the proposed algorithm is tested on a standard IEEE 6-bus system. The proposed methodology was implemented using the MATLAB toolbox. In general, the training capability was able to select unknown contingencies that have a high range of operating conditions and changes in the network topology. The proposed approach for contingency analysis was found to be appropriate for screening and ranking of fast voltage and line flow contingencies.

Keywords: Contingency analysis; Evaluation; Screening; Ranking; Artifitial Neural network; Adaptive Neuro Fuzzy Inference system; Performance Index; Voltage and flow ranking

ÖZET

Güç Sistem Güvenliği ve Durumsallık analizi Durum sistemlerinde en önemli görevlerden biridir. Operasyonda, olumsallık analizi mühendislerin güç sistemini ekipmanın güvenli limitleri dahilinde yüklendiği ve gücün kabul edilebilir kalite standartlarına sahip müşterilere ulaştırıldığı güvenli bir çalışma noktasında çalıştırmasına yardımcı olur. Bu bağlamda, gerilim ve hat akışı durum tespiti kullanılarak güç sistemindeki beklenmedik durum için Adaptive Neuro-Fuzzy Inference System (ANFIS) ve Yapay Sinir Ağı (YSA) yaklaşımı önerilmiştir. Çevrim dışı yük akışı hesaplarının sonuçları, performans endekslerini tahmin etmek için kullanılır (PI_flow, PIV). Tam AC yük akışı hesaplarının çevrimdışı sonuçları, iki tip performans endeksi oluşturmak için kullanılır: güç akış performans endeksi (PI_flow) ve şarta bağlılık derecelerinin derecesini yansıtan voltaj performans endeksi (PIv). Çevrim dışı yük akışı hesaplamalarının sonuçları, Performans İndekslerini (PI_flow, PIV) tahmin etmek için, Neuton Raphson yöntemiyle karşılaştırılan her iki algoritmanın doğruluğunu ölçmek üzere tir. Durumsallık, olasılıkların sınıflandırılması için "sınıflandırma modülüne" iletilir. Önerilen algoritmanın doğruluğu standart bir IEEE 6-bus sistemi üzerinde test edilmiştir. Önerilen metodoloji MATLAB araç kutusu kullanılarak uygulandı. Genel olarak, eğitim kapasitesi, çok çeşitli çalışma koşullarına ve ağ topolojisindeki değişikliklere sahip olan bilinmeyen olasılıkları seçebilmiştir. durum için önerilen yaklaşım, hızlı gerilim ve hat akışı olasılıklarının taranması ve sıralanması için uygun bulunmuştur.

Anahtar Kelimeler: Durumsallık analizi; Değerlendirme; Tarama; Sıralama; Yapay Sinir Ağı; Uyarlamalı Nöro Bulanık Çıkarım sistemi; Performans Endeksi; Gerilim ve akış sıralaması;.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATION

ANN:	Artificial Neural Network
NR:	Newton Raphson
ANFIS:	Adaptive Neuro Fuzzy Inference System
RBFNN:	Radial basis function Neural network.
NN:	Neural Networks
PIp:	Active Power Performance Index
PIv:	Voltage Performance index
PI:	Performance Index
HANN:	Hybrid Artificial Neural Network
FFNN:	artificial neural network Feed-Forward (FFNN)
VA:	Voltage Amplitude
MDT:	Multi-path Decision Tree
FMLP:	Fuzzified Multi Layer Perceptron

CHAPTER 1

INTRODUCTION

1.1 Overview

Power system security encompass practices planned to maintain the system running when the components stop or fail to respond. Contingency analysis also called What if? The analysis gives an answer to the following question; Are there any components with parameters that would be out of limit due to outage of another component? The outcomes of this analysis permit the systems to be operated and defensively. Contingency analysis should be used by planning the working condition of the system in others to measure the performance of the power system and the requirement for further expansion of the transmission lines due to load growth, loss of power or increase in generation.

Contingency assessment and power system safety are the most vital tasks faced by engineers in the operation and planning of bulk power systems. Contingency analysis is used in planning power system to inspect the nature by which the performance of the systems and when the requirement for further expansion of transmission line due to the high increase in load or the need for power expansion of production. In the operation of power, engineers were help by running this analysis to control the energy system at a safe operational range at which components are charged to their protected cut-off limits. Power is passed to consumers with standard, adequate and acceptable qualities. The objective in this analysis is to discover the voltage violation or the overload growth within the range of the equipment and the appropriate actions necessary to overcome these infringementS. Contingency identification and the determination of appropriate corrective measure frequently include calculation of full flow demand. This analysis is very vital and play a significant part of evaluating the safety and security of the power system. Given that, the contingency set has several probable failures leading to the composition of its occurrence, some among the few resulted outcome for the contingency can cause transmission line failures and bus voltage limit violations or overloads at the electrical power system operation. These critical outcome are to be identify and notified speedily for a more accurate assessment, as such, if possible, corrective action to be taken. Contingency selection is the technique for notifying critical contingencies to the operational engineers. The classical contingency selection method focuses on the outcome of a complete alternative current load flow clarification. So many methods were created for contingency analysis, but Performance Index (PI) was the most famous technique among all. This technique uses a system-wide scalar performance index in the process to measure how severe each case will be, by computing the PI values calculations. In other to obtain the best and perfect classification, individual PI value should be determined from the outcome of the complete alternative current demand flow (Srivastava et al., 2011).

1.2 States In Security Analysis

Four states of power system analysis:

a. **Optimal dispatch:** This is a condition whereby the system economic setup is optimal with respect to profitable operation and prior to any contingency. However, it might not be safeguarded.
b. **Post contingency:** This is a system condition, subsequent to the existence of a eventuality, it is expected that, at this condition security violation has occurred, such as, bus voltage exceeded the maximum limit, otherwise a transformer or line is exceeded its limit.
c. **Secure dispatch:** This is a system condition whereby the power system has zero eventuality, but with corrective measures taken on the parameters that are operating to come with maximum justification in the security destructions.
d. **Secure post-contingency:** This is where operating condition possibilities are connected to the base working condition with restorative, corrective and accurate measures.

The security analysis process has been demonstrated with the above mention instances. Suppose that two generators are operating in the system, with a circuit that has two lines and a load bus, and the operation must be by the two generators, each contribute to the load as presented in Figure 1 (a) and neglecting the losses, it assumes that the system as illustrated, is in an economic dispatch, namely 500 MW is designated for the first unit and the 700 MW for the second unit as the optimal distribution. Furthermore, considering the double line circuit with the maximum of 400MW asserted to each circuit, the overloading problem in the base working condition will be overcome. With that, the condition will be referred as optimal dispatch.

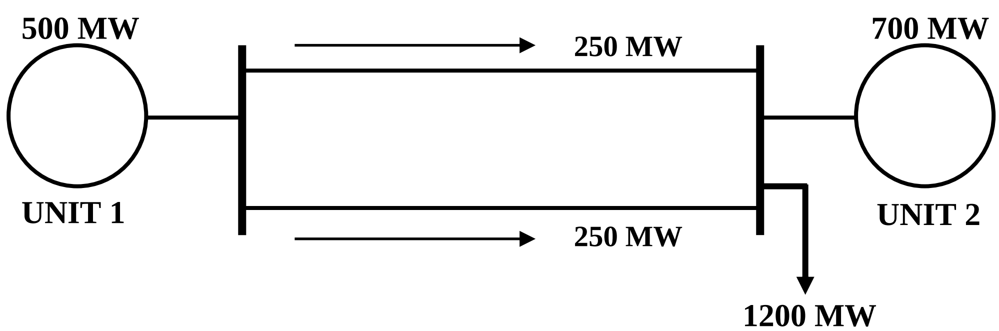


Figure 1(a): Optimal Dispatch

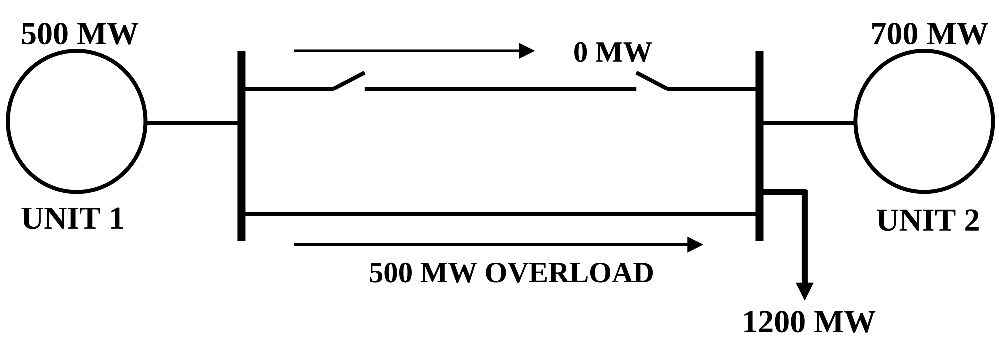


Figure 1(b): Post Contingency State

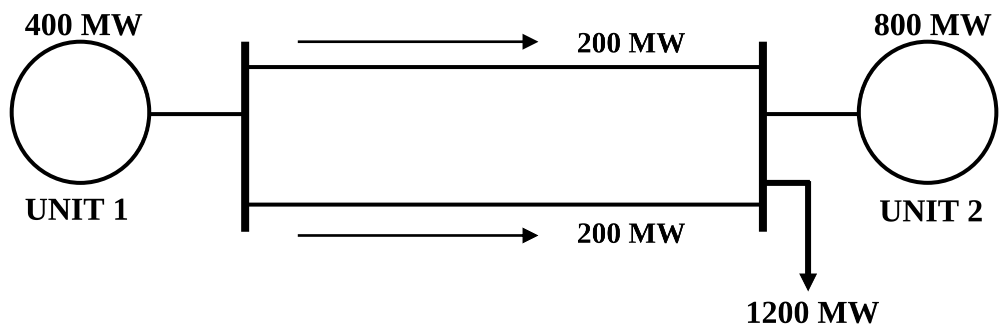


Figure 1(c): Secure Dispatch

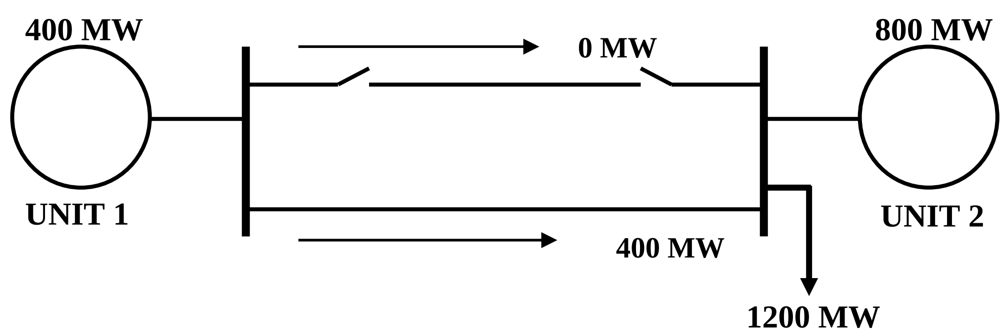


Figure 1(d): Secure Post Contingency State

Figure 1: Different working states of the power system technique

Considering that, a fault has been that postulated in one of the two transmission lines then it can be believed that a line contingency has happened and this translates into a change of power flow in the former line which causes the violation limit of the other transmission line.

Figure 1(b) shows the result of the flow, and with this, the state of the electric power system is in post contingency condition.

Considering other remaining circuits that are overloaded, to avoid the above condition, some security measures have to be considered. Unit 1 has to be lowered from its initial value of 500MW to 400MW and unit 2 generation will be raised from 700 MW to 800 MW. This secured system of dispatch is demonstrated in Figure 1(c). Repeating this contingency analysis, power flows post-contingency situation is illustrated in figure 1(d).

Therefore, when the generation is regulated at unit 1 as well as second unit (2), the overloading in another line is prevented and thus the power system remains secure. These adjustments are refered as “security corrections”. The programs that can regulate and make adjustments in order to control the basic or pre-contingency operation to avoid contingency infringement under the situations of post-contingency, as such, they are referred to as “limited optimal power flow security constrained”. These programs can get account of several contingencies with calculations to adjust the voltages and generator MW, transformer taps etc. Collectively along with the work of systematic observation, emergency examination and corrective performance analysis process form a set of complex tools safe operation of the power system. (Wood and Wollenberg, 2013).

1.3 Motivation/Objective of the Work

It is said that, Electrical power system is in a safe condition when the system point of operation is maintained within its suitable ranges, taking into consideration that there will conceivable outcomes of changes in the system (contingencies) and its surroundings. Evaluation in power system is needed for safety and to have a system that will be sufficiently safe, secured, continuous and reliable even when the contingencies are within realistic case. It is a significant task for operational engineers to forecast these instability / contingencies (outages) and initiate preventive control activities as efficiently as possible in order to maintain system continuity, reliability and stability for the power supply.

The objective of this research is to achieve a dependable, trustworthy and secure system by which the emergency classification of the contingency is performed. Ranking of the contingency is performed by computing the performance indices for unavailability of the critical transmission line by utilizing the traditional load flow techniques, i.e. The decoupled fast charge flow method and the prediction using flexible figuring techniques. The objective is to identify the contingency and rank them in accordance with their value by running the prediction using ANN and ANFIS to compare the performance of the methods used.

1.4 Definition of Problem

It is said that, Electrical power system is in a safe condition when the system point of operation is maintained within its suitable ranges, taking into consideration that there will conceivable outcomes of changes in the system (contingencies) and its surroundings.

There is requirement for the assessment of power system safety in order maintained a system that will be adequately protected, sufficiently reliable, safe and that can continuously be running even under the case of contingency that are credible. It is an imperative task for the operating engineers to forecast such interuptions/contingencies and to start protective activities to keep under regulated action as economically as conceivable to maintained the integration and stability of the power supply system scheme. Conventional techniques are time consuming, with that, they are not continuously appropriate for online usage. Additionally, a lot of IP-based analytical methods go through the difficulty of false alarm and / or misclassification. An effective contingency can be categorized as non-critical contingency, which is referred to as Mis-classification. When a inactive contingency is categorized as critical, then a false alerm has happen. A system that is speedy and fast with the ability to avoid fake alarm most be needed.

1.5 Significant of Research

Nowadays, continuous delivery of electrical energy is vital due to the societal reliability on the sector. In power system, system security is the bedrock of power survival and since contingency analysis add security, reliability and customer service as well as protecting the power system from harm.

Some of the methods lack versatility due to some set back that are rule based system and system specific even though they are fast. With recent advances in soft computing learning techniques, Artifitial Neural Network (ANN) based and Adaptive neuro fuzzy imfrence (ANFIS) system technique for contingency screening and ranking will be a good option. Furthermore, by using the hybrid of ANN and fuzzy (ANFIS) a more reliable system would be obtained.

1.6 Methodology

In conducting the research, the contingency selection technique will be grounded on the performance index (PI) which might signify either a line overload or a bus voltage drop limit violation, the performance Index will be calculated using traditional method.

A huge amount of patterns will be generated at random for an individual bus within a wide range of load difference. In each pattern, a full AC load flow will be carried out in order to calculate the line flows before failure and the voltages at the terminals of the line or the possibly the generator, and so also the equivalent to the unavailability of line and generator to calculate the voltage indices and flow performance. The recommended technique will be planned and tested using Artificial Neural Network (ANN) and Adaptive Neuro Fuzzy inference System (ANFIS) on a Windows environment using MATLAB.

The accuracy of the recommended method will be illustrated by contingency screening and ranking in the 6-bus system. The functioning of the recommended technique will be compared with the traditional Newton Raphson method.

1.6 Organization of Thesis

This thesis report consists of five chapters. Chapter one gave a brief overview of Artificial Neural network, Adaptive Neuro Fuzzy Inference System, objectives and organization of the thesis. Chapter two reviewed about the researches that have been done related to the soft computing. Meanwhile, chapter three discuss about data collection, design and simulation for AC load. Chapter four explain about the result and interpretation Finally, chapter five gives conclusion and future work this thesis work.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This section explains some review of the related work for the energy system analysis activity. The contingency analysis with the use of Newton Raphson has been exermine. Furthermore, the use of alternating current flow for contingency analysis has been presented in detail. The contingency analysis algorithm using the Newton Raphson method was developed with the main objective of making contingency selection for line contingencies for various test bus systems.

2.2 Overview

Contingency assessment in bulk power system security is among the most essential tasks faced by planners and operators of the systems. Contingency analysis is used in power planning to analyze the accomplishment of a power system and the requirment for further expansion of transmission line due to expansion or load growth of the power system production. Contingency evaluation used the conventional method for contingency analysis methods which has a drawback compare to modern methods which can be implied using ANN and ANFIS. This section will explain some review of the related work for the task of power system analysis.

Contingency analysis is used in planning the power system to analyze the operational performance of the system and the need for further expansion of transmission line as a result in the expansion or high load demand of the power system production.

2.3 Power System Contingency Analysis

Briefly, contingency is defined as any effect or disturbance in the network, while the contingency analysis is defined as the study of the failure in any elements such as Generator, Transformer and transmission lines by examining the resulting effects on the network power flows and bus voltages of the rest of the system. It is an extremely important tool to investigate the behavior of the system in the event of an unexpected or planned system failure in order to detect the vulnerability of the network.

2.3.1 Outages of the System Elements

Most of the system outages are probably considered as the result of elements overload besides specific technical and operational failure. Contingencies preferably exist as the result of the single or multiple outages of the system elements such as: Transformer, generator and network transmission lines where each of these elements has its specific outage characteristics such as:

a) ***Generator:*** Overload due to intake demand, temperature limit and technical failure.

b) ***Transmission line*****:** Line overload will cause a challenge of thermal limit, voltage drop limit and steady state stability limit.

c) ***Transformers:*** outage of the system transformer will depend on the challenge of the thermal limit and any other technical failure.

2.3.2 Modelling Contingency Analysis

Contingency Analysis is a hybrid of two words, i.e Contingency and Analysis. Contingency in power system termed use as a disturbance resulting in the outage of one or more element, such(s) as generators, transmission lines, transformers and circuit breakers. However, Contingency Analysis is the study of the power system element outage, which can reveals its influence to the line flow overload and bus voltage profile in the system. It is a useful measure for power system security assessment, particularly to reveal which system element outage leads to the line flow overloads and bus voltage margin's violation. Performance index is used to evaluate and rank contingency impact on the remaining system elements in such way as to identify which critical system element outage sabotages its operational status (Mudasingwa and Mangoli, 2015).

The contingency analysis includes the simulation of every contingency going on the base case model of the power system, three main challenges involved in this technique. Firstly is the challenges of developing the suitable power system model, secondly is the difficulty in the choice of the case to be considered and thirdly is the challenge in computing the energy flow and the bus voltages that involve enormous waste of time inside the system of the energy management (Amit and Sanjay, 2011).

2.3.3 Contingency Analysis

The contingency analysis is among the firstly spoken about issues when assessing the security of every power system for the reason that with the present difficult infrastructure and without wide-ranging power plant, it is observable that many much active power systems are un-able to adapt through the raise in the demand. Contingency analysis would remain implemented to unforeseen and critical measure which might happen in the power system and to protect the occurrence of other relevant cascaded unrequited incidences. The contingency analysis of a model is chosen to be in power system which implies the simulation of the separate contingencies. Toward achieving this, an easier way has to be taken into account. It includes three important steps as follows:

1. ***Contingency creation:*** This stands as the initial stage of the analysis. It comprises the overall likely contingencies which can happen in the system. The procedure includes the creation of contingency lists.
2. ***Contingency selection:*** it is middle stage and the procedure that comprises the selection of contingencies that are more serious after the result that can be taken to the violations of the bus voltage as well as the power limitation. With such procedure, the list of the contingencies reduced to a minimum by eliminating the less severe contingency and taking

into account the more serious contingencies. For this procedure, Index calculations are used to detect the contingencies.

3. ***Contingency evaluation:*** As the final stage and the most significant stage, it comprises all the required and control actions so that the required security actions that are needed to moderate the impact of the most serious contingencies during feeding the system.

The performance index (PI) is the technique utilized to quantify and to classify such contingencies within the range of their severity. To calculate these performance indices different iterative technique can take place and applied.

2.4 Power Flow Solution

Power flow studies also essential in the process of planning and by controlling the present condition of power system and it involve the future planning of its expansion. Determination of the reactive as well as active power flow designed for individual line with the computations of the phase angle with the magnitude of the voltages on individual bus is a challenging task. At the moment of resolving the current power flow difficulty, its assume that the power system is considered to one-phase model and it operate in equilibrium conditions. Four parameters are associated with each bus involves the reactive power Q, the phase angle (δ), the voltage amplitude | V |, and the real power P. The buses in the system are classified into three categories:

1. ***Slack Bus:*** This bus can as well be referred to as a swing bus. It can also be utilized as a situation in which only amplitude and the phase angle of the voltages are categorized. The bus detect the variation that is stuck between the magnitude of the loads with the power been generated by which the losses are caused in the systems.
2. ***Load Buses:*** In this buses, voltage as well as phase angle magnitude of the bus voltage are not undefined while the active as well the reactive power are define. They can be referred as P-Q buses.
3. ***Regulated Buses:*** They can be called generator buses moreover can also be reffered to as voltage-controlled buses. As such, specified on these buses are the voltage magnitude and

the real power. Voltages and the reactive power of the phase angle are to be detected. These buses can be reffered to as P-V buses.

Iterative method can be use to solve the load flow drawback in power flow that generate the non linear algebraic condition using numerical formulation technique.

2.4.1 Concept of Power Flow Iterative Techniques

The power flow analysis information is determined using three common techniques named as Newton Raphson, Gauss Seidel and Fast-Decoupled solution method. Among these methods each one has its merits and drawbacks depending on the four paramount features; speed of solution, accuracy of the method, convergence of the method for the solution and computational memory required for the applied technique (Mudasingwa and Mangoli, 2015).

2.4.2 Newton Raphson Load Flow Method

The Newton-Raphson technique as one among the popular technique for the load flow solutions, for the reason that it has numerous advantages. It has powerful convergence features compared to other alternative processes and has a low calculation. The ordered sparse elimination program is used to solve sparse network equations with less time requirement.The NR method is conveniently in place of large networks, as computer storage needs are judicious and add to almost linearly with the size of the problem. The method is very sensitive to good starting conditions. Using an appropriate starting condition greatly reduces the calculation time, as well as ensuring faster convergence. There is no obligation to determine the acceleration factors, and the iteration is not affected by the choice of the slack bus, and network changes require a much smaller computational effort.Generality and flexibility are the great advantages of NR method, therefore, it allows a simple and effective participation of the interpretation needs, such as on the change of the load and on the phase displacement devices, area interchanges, functional loads and remote voltage control. The NR load flow is the central method for several recent methods developed to optimize the operation of the power system, its sensitivity analysis, system status evaluations, linear network modeling, safety evaluation and analysis of transient stability, it is appropriate for online network calculation. The NR formulation is also needed for the system with large angles along the entire line and with a control device that influences reactive and real power.

Now, taking a typical bus in to consideration for the supply of the system, the current that inputs the bus *I* is given by the equation:

The Y bus admittance matrix of the power flow are formulated in a poler form as follows:

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2.1}$$

Poler form express as:

$$I_i = \sum_{j=1}^{n} /Y_{ij}//V_j/ \angle \theta_{ij} + \delta_j \tag{2.2}$$

Active and reactive power of the current in bus I is expressed as:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.3}$$

Putting for *Ii* from equation (2.3) into (2.2), we obtain:

$$P_i - jQ_i = /V_i/\angle -\delta_i \sum_{j=1}^{n} /Y_{ij}//V_j/ < \theta_{ij} + \delta_j \tag{2.4}$$

Real and imaginary part of the power are separated:

$$P_i = \sum_{j=1}^{n} /V_{ij}//V_j//V_i/ \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.5}$$

$$Q_i = \sum_{j=1}^{n} /V_{ij}//V_j//V_i/ \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.6}$$

By using Taylor's series using initial estimate to expand equation (3.5) and (3.6) and neglecting the higher order terms, equition (2.7) is obtained

$$\frac{\begin{matrix}\Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)}\end{matrix}}{\begin{matrix}\Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)}\end{matrix}} = \left[\frac{\begin{matrix}\frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} \cdots \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial P_2^{(k)}}{\partial /v_2/} \cdots \frac{\partial P_2^{(k)}}{\partial /v_n/} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} \quad \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} \quad \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}}\end{matrix}}{\begin{matrix}\frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} \cdots \frac{\partial Q_2^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial Q_2^{(k)}}{\partial /v_2/} \cdots \frac{\partial Q_2^{(k)}}{\partial /v_n/} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} \quad \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} & \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} \quad \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}}\end{matrix}}\right]\left[\frac{\begin{matrix}\partial \delta_2^{(k)} \\ \vdots \\ \partial \delta_n^{(k)}\end{matrix}}{\begin{matrix}\Delta /v_2^{(k)}/ \\ \vdots \\ \Delta /v_n^{(k)}/\end{matrix}}\right] \quad (2.7)$$

The Jacobian matrix provides the linearized relation between small changes in $\Delta\delta_i^{(k)}$ and the voltage magnitude $\Delta\left[V_i^k\right]$ with minor changes in real and reactive power ΔP_i^k and ΔQ_i^k.

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix}J_1 & J_2 \\ J_3 & J_4\end{bmatrix}\left[\begin{matrix}\Delta P \\ \Delta /V/\end{matrix}\right] \quad (2.8)$$

The diagonal and off diagonal elements of J_1 are

$$\frac{\delta P_i}{\partial \delta_i} = \sum_{j\neq 1}^{n} /Y_{ij}//V_j//V_i/ \sin(\theta_{ij} - \delta_i + \delta_j) \quad (2.9)$$

$$\frac{\delta P_i}{\partial \delta_i} = -/V_i//V_j//Y_{ij}/ \sin(\theta_{ij} - \delta_i + \delta_j) \; i \neq j \quad (2.10)$$

Similarly, the diagonal element and the off diagonal elements for J_2, J_3 and J_4 can found:

The power residual values are the gap between scheduled and calculated values in terms of ΔP_i^k and ΔQ_i^k and are given as follows:

$$\Delta P_i^k = P_i^{sch} - P_i^{(k)} \quad (2.11)$$

$$\Delta Q_i^k = Q_i^{sch} - Q_i^{(k)} \tag{2.12}$$

By utilising the standard numerical values of power residuals and the Jacobian matrix, $\delta_i^{(k)}$and $/V_i^{(k)}/$ are generated from the equation (2.8) for a perticuler circle to be completed and the different values are generated as presented to another circle shown below (Scott et al 1984).
The new generated values are estimated for bus voltages as follows:

$$\delta_i^{(k+1)} = \delta_i^{(k)} - \Delta\delta_i^{(k)} \tag{2.13}$$

$$/V_i^{(k+1)}/ = /V_i^{(k)}/ - \Delta/V_i^{(k)}/ \tag{2.14}$$

2.4.3.1 An approach to Newton raphson technique Algorithm for Contingency Analysis:

Solution to Newton raphson technique Algorithm for Contingency Analysis solution is as follows:

Step 1: The line and bus data of the system will be interpreted as provided.

Step 2: Considereing the base case, the load flow analysis is excuted by neglecting the line contingency.

Step 3: Simulation of either line outage, i.e removal of a line and schedule to continue to the subsquint stage.

Step 4: Load flow analysis is performed for this particular outage, so the calculation of the active power flow is performed in the remaining lines and the Pmax value is detected.

Step 5: The active power performance index (PI_P) is detected, and this indicates the violation of the active power limit of the system model used.

Step 6: Hence, for the individual line contingency; the voltages of all the load buses are considered.

Step 7: Subsequently the voltage performance index (PI_V) is calculated which demonstrates the violation of the voltage boundary taking place all the load busses due to line contingencies.

Step 8: Calculation of the summation of the performance index is performed by adding PI_P and PI_V for each system line outage.

Step 9: Steps 3 through 8 for the sum of the line breaks are repeated to get PI_P and PI_V for all line breaks.

Step 10: Therefore the contingencies are classified and rank on the basis of the severity which are calculated on the basis of the values of the performance indices obtained.

Step 11: Perform the power flow analysis of the mainly severe emergency case and get the results.

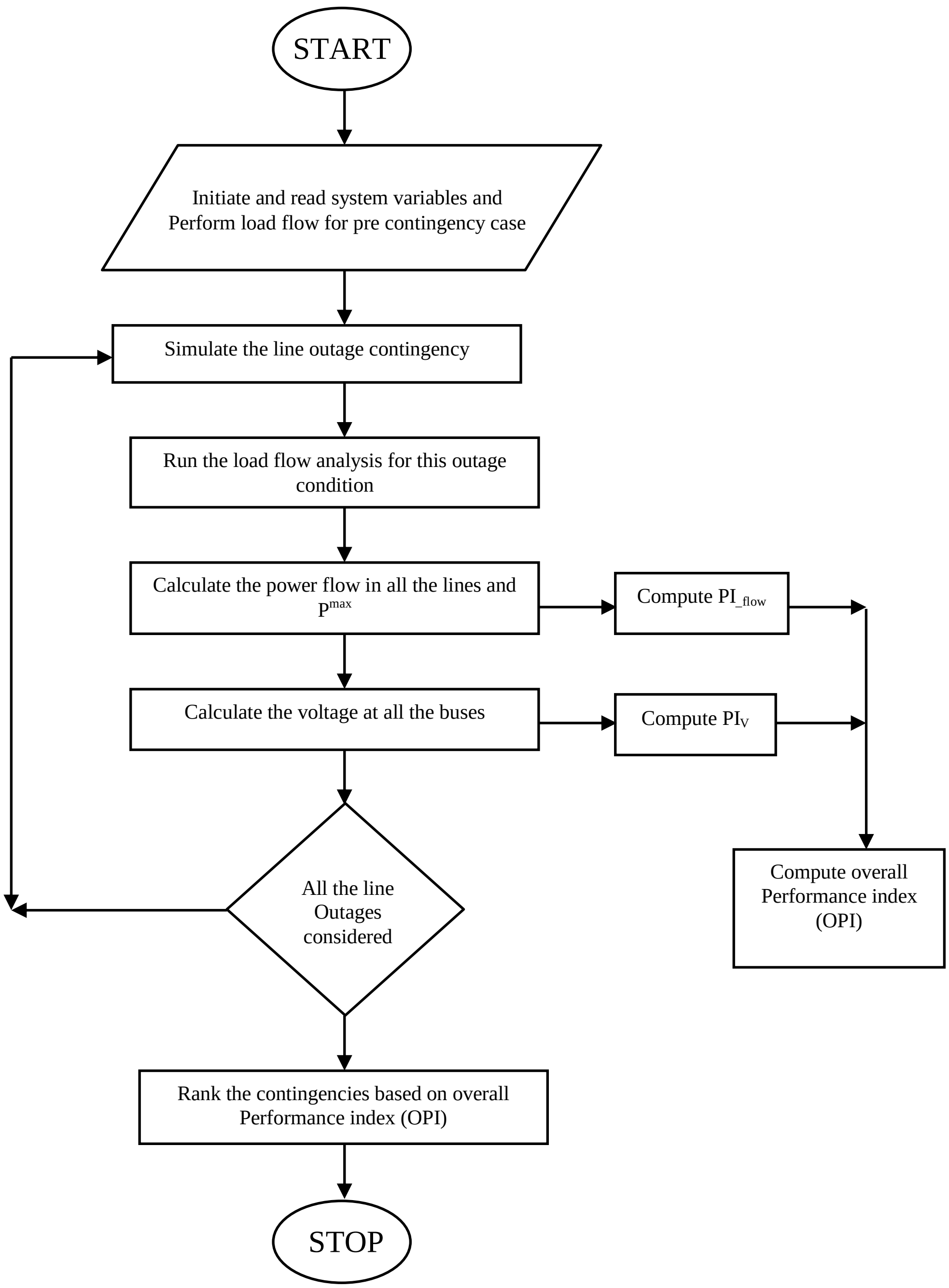


Figure 2.1: Flow chart Algorithm

2.5 Techniques for Power System Contingency Analysis

Electrical power plays a big role in the growth of the economy of any country, more especially in the industrial sector. Therefore, There is a need to put emphasis on maintaining electrical power system security in terms of generation, transmission and supply for reliability. Power system security incorporates system monitoring installed capacity at the utility dispatching center, protective measures put in place along the system network and contingency analysis to necessitate scheduled maintenance outage, abrupt element(s) outage and system expansion plan.

A secure power system is likely to be reliable in terms of economic income for the utility, continuity of supply and technically vibrant in all system elements to withstand system post contingency.

The power system security analysis is implemented to create several control approaches to assure security and existence of system during emergency circumstances and to hence operation at its possible lowest price. To have a secure power system, its elements must operate within their prescribed operating conditions such as voltage variation limits, thermal limits, reactive power limits so as to maximize the avoidance of any hazardous event (Shaikh and Ramanshu 2014).

It is also useful to have a power system security assessment under contingency analysis by calculating the system operating indices for both pre and post contingency in order to have pre defensive system operating mechanisms to withstand system emergency conditions. This can be done using the following techniques:

i. AC load flow
ii. DC load flow
iii. Artificial Neural Network
iv. Adaptive Neuro Fuzzy Inference system (ANFIS)

The techniques mentioned above were used to determine the severity effect of contingency and rank/screen the effect according to its degree of implication of the power network and to optimize the network performance as efficient and reliable.

2.5.1 DC Load Flow

Direct current (DC) power flow is a common model for power system contingency analysis due to its robust simplicity for computational time in order to reveal the only real power flow in the system network branches. Meanwhile, the full AC load flow is accurate to look at all necessary information required, such as system voltage profile, real and reactive power and power losses within the system network branches, but it is constrained by the rate of computational time to reveal necessary information.

It is also noted that such DC load flow simplification technique is not always justifiable to give realistic values due to its weak standards to consider power flow controlling devices. Thus, it is basically fast with minimum accuracy compared to full AC load flow.
DC load flow specifically has a shorter computational time due to the impact of linearization of power flow solution with respect to the following assumptions:

- Voltage angle difference between two buses is considerably small so that its approximate sine is equal to that angle and its cosine is one.
- All voltage magnitudes are approximately equated to be 1.00p.u.
- The system is an ideal network, i.e lossless network branches.
- The tap settings are ignored.

The above assumptions inspired DC load flow to have some specific advantages over the full AC load flow under Newton Raphson method.

- The system impedance matrix is less about half the size of the full problem.
- The problem is simplified to be non-iterative, just requiring a simple calculation in order to have the final solution.

- Impedance matrix is independent of the system network, hence it is calculated once throughout the whole calculation to have a final solution.

The above so called DC flow advantages undermined it in such a way that system network gains a flat voltage profile while in the actual practice of power system, voltage keeps changing with insecure voltage limits in accordance of power network perceptions like end users demand and power generation concepts.

Thus, this gives an emphasis to use full AC load flow technique in the concept of actual practice load flow solution which later applied to contingency analysis for a better approximate solution of the network. The content indicates the usefulness of full AC load flow for contingency analysis in comparison with the DC load flow under sensitivity factor method. It is important to apply sensitivity factor for studying thousands of possible outages due to its quick calculation of possible lines overloads. This model is mostly recommended to be applied when line loading is a major challenge for the study case because it is able to approximate change in the line flows for changes in generation on the network recovery by the DC load flow solution.

There are many ways in which sensitivity factors are being used for contingency analysis, but mainly are grouped into two classes.

i. Generation shift factor
ii. Line outage distribution factor

The generation shift factor is presented as:

$$a_{li} = \frac{\Delta P_l}{\Delta P_i} \tag{2.14}$$

Where, l = line index

i = bus index

ΔP_l= Change in real power flow on line l with respect to the change of real power on bus i.
ΔP_i= change of real power generated at bus i.
It is noted that real power generated change at bus i, is virtually recovered from reference bus real power change. i.e Loss in real power generated is equivalent to its change as:

$$\Delta P_i = -\Delta P_i^o \tag{2.15}$$

Thus power flow on each line in power networks, should be determined by anticipating factor "a" as:

$$P_l = P_l^O + a_{li}\Delta_i \tag{2.16}$$

For l = 1... n

Where;

P_l = Post real power flow on line l under generator outage
P_l^O = Pre real power flow on line l

Thus, when the post outage real power flowing in the line l is about to violate the prescribed limits, the system operator on duty should be attentively able to know what is going wrong in the network.

The line distribution factors: This is used for the line outage contingency analysis under usage of DC load flow.
The line outage distribution factor has the following definition:

$$d_{n,m} = \frac{\Delta P_n}{P_m^o} \tag{2.17}$$

Where,

$d_{n,m}$= Line outage distribution factor for monitoring line *n* under the outage of line *m*

ΔP_n= Post change in real power flow on line *n*

P_m^O= Pre real power flow in line *m*

If both cases power flow on lines n and m before the outage of line *m* are well known, the post real power flow in line *n* can be determined by the line outage distribution factor as:

$$P_n = P_n^O + d_{n,m} P_m^O \tag{2.18}$$

Where,

P_n^O *and* P_m^O are pre outage flows of line *n* and *m* respectively.

P_n = Post real power flow on line *n* under line m outage.

Hence, before calculating the line outage distribution factors, it is advisable to introduce a fast technique for load flow solution in order to monitor all lines in the network for overload under the outage of each particular line. Thereafter, line outage distribution factor will facilitate to examine if post line real power flow is bound within the line limits factors i.e $-P_n^{max}$ as well as P_m^{max}. This is a worthy note point that, line flow can be either negative or positive.

2.5.2 AC Load Flow Contingency Analysis

AC load flow facilitates to make an analysis of the system behavior due to its paramount outputs revealed on the system buses and network corridors such as voltage magnitude and phase angles, real and reactive power besides corridors losses. On the system buses, voltage magnitudes and phase angles are determined in order to justify any change due to system element failure and this gives immediate significance to know what is going on the system corridors. In other words, it gives information of both real and reactive power in the system network corridors and voltage magnitudes on the system buses. Thus, the AC load flow method reveals the system overloads and voltage bounds violation accurately, but it takes a long time to give online information for any system failure since it performs Y-bus for each iteration to give a finite solution. Therefore the total time to compute consecutive line outages will be too long. Similarly, checking the entire system operation will also be time-consuming. In most cases of models applied in power systems have the conflict of accuracy and computational speed; here it is recommended to use AC load flow when the predominate factor is the accuracy.

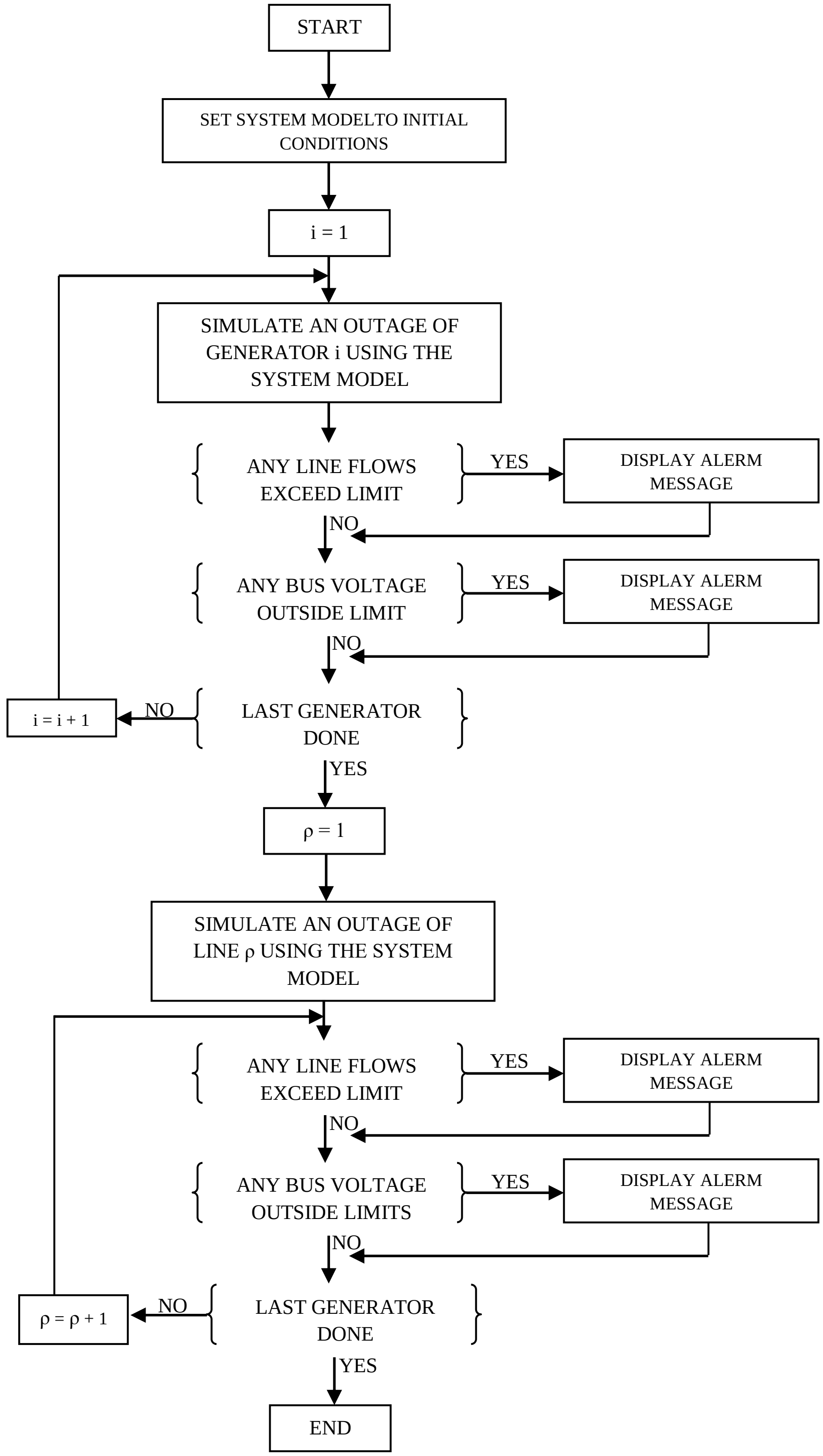


Figure 2.2: Full AC power flow contingency analysis procedure

2.5.3 Artificial Neural Network

Artificial Neural Networks (ANN) are widely used for pattern recognition and classification owing to the certain fact by which they can minimize complex systems that are challenging to models by utilizing traditional modelling approach i.e numerical modeling (Abdulkadir et al., 2017).

The Neural Network is a group of interconnected neurons based on a mathematical model for processing and transmitting information. The neurons (nodes) receive an input signal, then process and produce an output. Each of the input signals x_i is associated with a weight w_i which strengthen or deplete the input signal.

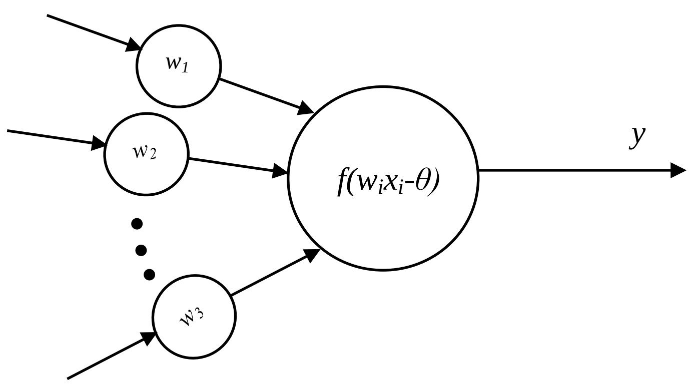


Figure 2.3: The ANN model

The model of neuron shown above is expressed as

$$y = f(\sum_{i=1}^{n} w_i x_i - \theta) \tag{2.19}$$

Where;

f = is the activation (transfer) function,

x_i = is input signals,

w_i = depicts the weights and

θ is the bias.

The desired output can be obtained by updating the weights. The process of updating the weights of a neuron is referred as learning or training. Learning rules are used to govern the neuron weights updating process and the procedure of utilizing the learning rules to update the weights is known as learning algorithm. Based on the learning procedure, neural networks are categorized as supervised or unsupervised or hybrid.

In supervised learning, the neural network is provided with inputs and the desired outputs. The main concern is to obtain a set of weights that drastically reduces the error between the network output and the desired output. Unsupervised learning uses only input, the network updates its weights so that similar input yields corresponding output. Hybrid learning combines supervised and unsupervised learning.

Neural network gains vast popularity over the last few decades, particularly in the field of system identification, modelling and control applications. The most common applications are future extraction, pattern recognition, classification and prediction (Gaya et al., 2017).

2.5.4 Adaptive Neuro Fuzzy Inference system (ANFIS)

Generally, ANFIS is a multilayer feed forward network in which each node performs a particular function (node function) on incoming signals. For simplicity, consider two inputs 'x' and 'y' and one output 'z'. Suppose that the rule base contains two fuzzy if-then rules of Takagi and Sugeno type (Jang, 1993).

Rule 1: IF x is A1 and y is B1 THEN f1 = P1x +Q1y + R1

Rule 2: IF x is A2 and y is B2 THEN f2 = P2x +Q2y + R2

The integration of fuzzy logic and neural network formed Adaptive Neuro Fuzzy System. ANFIS is an adaptive network of Sugeono fuzzy model type, it consists of layers and nodes (Abba, et al 2017).

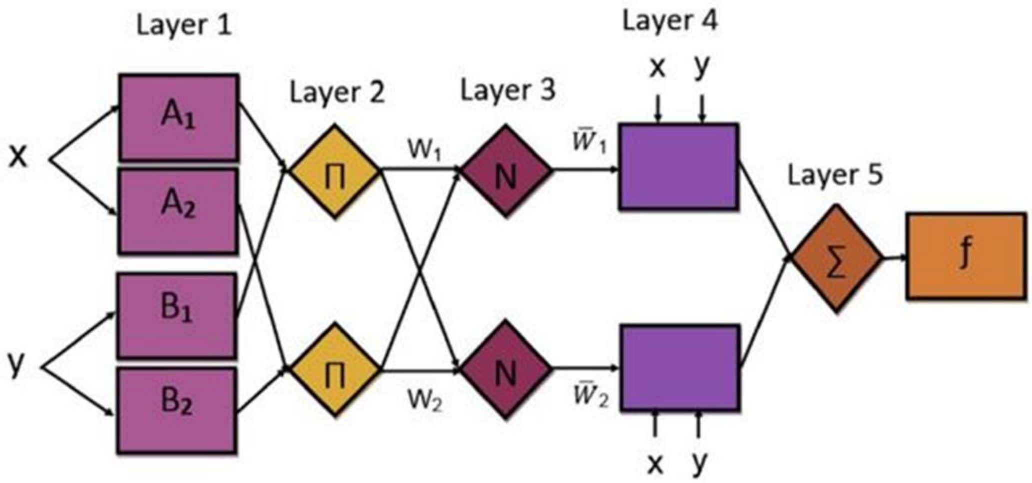


Figure 2.4: ANFIS Architecture

In Figure 2.4, the parameters with square nodes are variable nodes which are updated during the learning process, while the circuler nodes are fixed. In ANFIS mapping, once the input-output data of a given function to be approximated is presented. The nodes in the layers perform certain function based on the incoming signals (input) and parameters associated with nodes. The accuracy between ANFIS model with the required model are minimized by upgrading the parameters using hybrid learning algorithm until the desired output is met. Least square technique in the hybrid learning algorithm used to optimize the consequent parameters, while premise parameters are updated using gradient descent process (Pandiarajan and Babulal, 2014).

2.6 Review of the related work

2.6.1 An ANN-Based Ward Equivalent Approach for Power System Security Assessment

This research work presents a new Hybrid Artificial Neural Network (HANN) and an extended ward equivalent approach for the rapid assessment of on-line voltage safety of power systems. The method upholds the desirable properties of the in-room equivalence approach and can update the on-line parameters of the equivalent model as the external system topology changes. Simulation tests of the method are performed on a 59 bus system. (Chung and Ying 2001).

2.6.2 Efficient ANN Method for Post-Contingency Status Evaluation

The Radial Based Neural Network (RBFNN) architecture was used for accurate and fast post-contingent information assessment, grading and emergency screening. The bus voltage amplitude was estimated for the contingency analysis based on the desired voltage while the MW, MVA and Mvar line flows are obtained for contingency analysis based on the power flow. However, knowledge of the voltage amplitudes and angles of all the buses in the system was adequite to obtained the quantities. Hence, two neural networks; one for the amplitude of the voltage and the other for the estimation of the voltage angle corresponding to the normal, in addition to each contingent condition wes used in the research. The estimate was used to calculate two types of performance index (PI) for contingency ranking and screening. These IPs are compared to those obtained by power flow analysis. The method has been tested on the IEEE 14 and 30 bus test systems. RNAs have been designed for forecasting under normal conditions as well as for each eventuality. In this work, only single line breaks are taken into account and the RBFNNs are designed to estimate the amplitude and angle of the post-contingency bus voltage for each eventual eventuality of the test systems (Rakesh and Shiv, 2010).

2.6.3 Supervised Learning Approach to Online Contingency Screening and Ranking

This work presents a supervised learning method for accurate and rapid assessment in contingency analysis for power system safety. The severity of the contingency was measured by two scalar performance indices (PI): voltage reactive power performance index, PIVQ and performance index of the MVA line, PIMVA. In this work, the artificial neural network Feed-Forward (FFNN) was used which uses the pattern recognition approach for safety assessment and contingency analysis. This work has been tested on the New England IEEE-39 bus which has 10 generators, 12 transformers, 46 transmission lines. The accuracy of test results for unknown pattern, highlights the relevance of the approach for online applications at the Energy Management Center (Kusum and Niazi, 2012).

2.6.4 Online Static Security Assessment Module Using Artificial Neural Networks

In this paper, the Multi-Layer Feed-Forward Artificial Neural Network (MLFFN) and the Radial Basic Function Network (RBFN) are presented to implement the online module for the evaluation of the static security of the system. The approach has been tested on an IEEE 118 bus test system that demonstrates its effectiveness in evaluating the online static safety of the power system. The comparison of the ANN models with the Newton Raphson load flow analysis model in terms of accuracy and computational speed indicates that the model is efficient and reliable in the rapid assessment of the safety level of electrical systems (Sunitha et al., 2013).

2.6.5 Power Flow Based Contingency Analysis Using Fuzzy Logic

This article presents a contingency assessment using a new method in which the performance indices (PI) obtained from the changes in the amplitude of the bus voltage and the apparent power of the transmission line are taken into account with masking effect. The general classification of the severity of the contingencies is obtained by the fuzzy logic. To do this, a three stages approach was used: at the intial stage, the performance indices are obtained by power flow; at the middle stage, the masking effect is suppressed; The general classification based on fuzzy logic is obtained at the last stage. The approach was tested on an IEEE 14 bus system (Krishnakumar et al., 2012).

2.6.6 Power System Contingency Ranking using Fuzzy Logic Based Approach

This research presents a fuzzy logic approach to classify contingencies using the composite index based on the fuzzy inference engine operated in parallel. The artificial neural network Feed-Forward (FFNN)and the bus Voltage Amplitude (VM) of the load buses were expressed in fuzzy notation. In addition, they were evaluated using Fuzzy rules to obtain the overall criticality index. The eventualities were classified according to the descending order of the criticality index, then the comparison of the rankings obtained with the method of the index of the stability of the fast tension (FVSI). The fuzzy logic approach was tested on an IEEE-30 bus system and an IEEE-14 bus system. Contingencies were classified using a composite index that gives exceptionally valuable information on the impact of the contingency on the whole system and assist to take important control measures to minimize the possibility of the contingency. The algorithm was based on fuzzy logic with simple and efficient class contingencies (Abdelaziz et al., 2013).

2.6.7 Contingency Ranking In Power Systems Employing Fuzzy Based Analysis

This article presents an approach using fuzzy logic that evaluates the severity of conventional contingency and eliminates the masking effect in the technique. The level of system safety in each bus voltage and line power flow has been compared and its corresponding tolerable maximum and minimum values. The approach has been tested on IEEE test systems with 5 buses and 14 buses. Lower-ranked eventualities are more severe than higher eventualities. The ranking of contingencies on the bases of real power and tension is calculated using the Fuzzy performance index and conventional. Therefore, transmission failure analysis requires strategies to forecast these voltages and flows to ensure they are within their appropriate ranges. (Manjula et al., 2012).

2.6.8 Power security assessment for multiple contingencies using multiway decision tree.

In this paper, an approach to figure out the operating safety of the power system use for numerous contingencies with a Multi-path Decision Tree (MDT). This method presents the use of topologies (contingencies) as categorical attributes. In this approach, The interpretation is to improve with respect to the operational condition of the electrical power system, since the operational engineer can clearly observe the critical variables for the individual topology, therefore, the MDT rules can be utilized to make the decision easier by MDT. This approach was used to assess the security of the northern part of the Brazilian Electrical Interconnect System (BIPS) and the rules was tested with real day data, demonstrating good performance, with a simple set of rules and clear. (Werbeston et al., 2017).

2.6.9 A least square support vector machine-based approach for contingency classification and ranking in a large power system.

This article presents an effective supervised learning approach for assessing the static safety of a large power grid. The supervised learning approach uses the least-squares support vector (LS-SVM) machine to classify contingencies and predict the severity level of the system. The severity of the contingency was measured by two scalar performance indices (PI): the MVA line performance index (PIMVA) and the voltage reactive power performance index (PIVQ). SVM works in two stages. Stage I is the estimation of the two standard indices (PIMVA and PIVQ) which is carried out in different operating scenarios and the emergency classification of stage II is carried out on the basis of the values of the PIs. The effectiveness of the methodology is demonstrated on the New England IEEE 39-bus system (Bhanu et al., 2016).

2.6.10 A Comprehensive Approach to Single and Double Line Contingency Screening.

This paper illustrates line contingency screening of single line outage and double line outages efficiently using the limiting principle with distinctive reference to vector/matrix computing environments. Those outcomes acquired in both the minor and moderate scale actual scheme show the strength of the limiting principle. The principal was tested on a well-known 14 IEEE bus test system and 118 IEEE bus test systems (Mario, 2016).

2.6.11 Contingency Analysis of South Bandung Electric Power System.

In this work, a simulation using the Newton Raphson Power Flow method was used to measure the contingency analysis of the power system. The analysis serves as a solution to network operation planning by identifying the weak components to minimize the impact of failures that cause the release of components. The system was tested in a South Bandung power system IBT 500/150 KV peak load the data used which need to maneuver at any circumstances (Fauziah and Mulyadi, 2017).

2.6.12 Voltage Contingency Ranking of a Practical Power Network Using Hybrid Neuro-Fuzzy System.

This paper presents a simple fuzzy-neural multi-output network for contingency ranking in the power system. A fuzzy total performance index formed by combining i) voltage violations and ii) voltage stability. The margins are used in the composite ranking of the contingencies. The approach was very effective in dealing with contingencies that bordered on two severity classes. The performance of the method was tested on a practical Indian power system with 69 buses (Chaturvedi et al., 2008).

2.6.13 Voltage Contingency Ranking Using Fuzzified Multilayer Perceptron.

This paper presents trained back-propagation algorithm using Fuzzified Multi-Layer Perceptron (FMLP) to a achieve the ranking analysis of the on line voltage contingency. These analysis ware found to rank and also classify the contingencies accurately and with the best result for an unknown load category. The efficiency of the analysis was tested on standard IEEE 30-bus test system and 75-bus Indian system (Manjaree et al., 2001).

2.6.14 Multi-criteria contingency ranking method for voltage stability

This paper presents voltage stability contingency ranking procedure for the Multi-criteria system. The method selects the most severe contingency and coming up with a very good capture ratio. The simulation was tested on IEEE 14-bus, 20-branch system (Mauricio and Carlos, 2009).

2.6.15 Contingency Analysis of Power System uses Voltage and Active Power Performance Index

In this article, the Newton Raphson method was used to calculate the effectiveness of the voltage performance and active power indices. The idea of changing the active power flow through the lines and voltages on the buses for a specific line outage is provided by these indices. Adding up the two indices yields the value of the performance index that assigns severity to each row. The indices of all lines outage contingencies ware tested on IEEE 5-bus and 6-bus system (Satyanarayana et al., 2016).

CHAPTER 3

INTRODUCTION

This chapter covers the existing method of the data collection, design and simulation procedures for AC load flow.

3.1 Methodology

AC load flow under Newton Raphson model in MATLAB environment was used to compute voltage magnitude and phase angle for each system bus, real and reactive power flow in the network branches. Newton Raphson technique is chosen from other conventional models due to its successful iterative accuracy and convergence for the solution. A sequential line outage is applied to test if the system is designed with enough redundancy to withstand the influence of a such disturbance. Using Performance Indices (PIs), contingency ranking is applied to reveal the effect of each transmission line outage in the system operational status.

Therefore, assess such influence by referring to the power ratings of the system transmission lines and buses voltage limits. In doing so, ranking was done sequentially according to the highest value of PI as the first critical sub-outage and lowest value as the minor hazard subjected to the network.

Block diagram in figure 3.1 is a modified complete AC load flow which display the results in a matrix form and gives the line flows to the flow screening module and bus voltages to the voltage-screening module. While figure 3.2a and 3.2b shows the flow chart for the line and generator outages respectively.

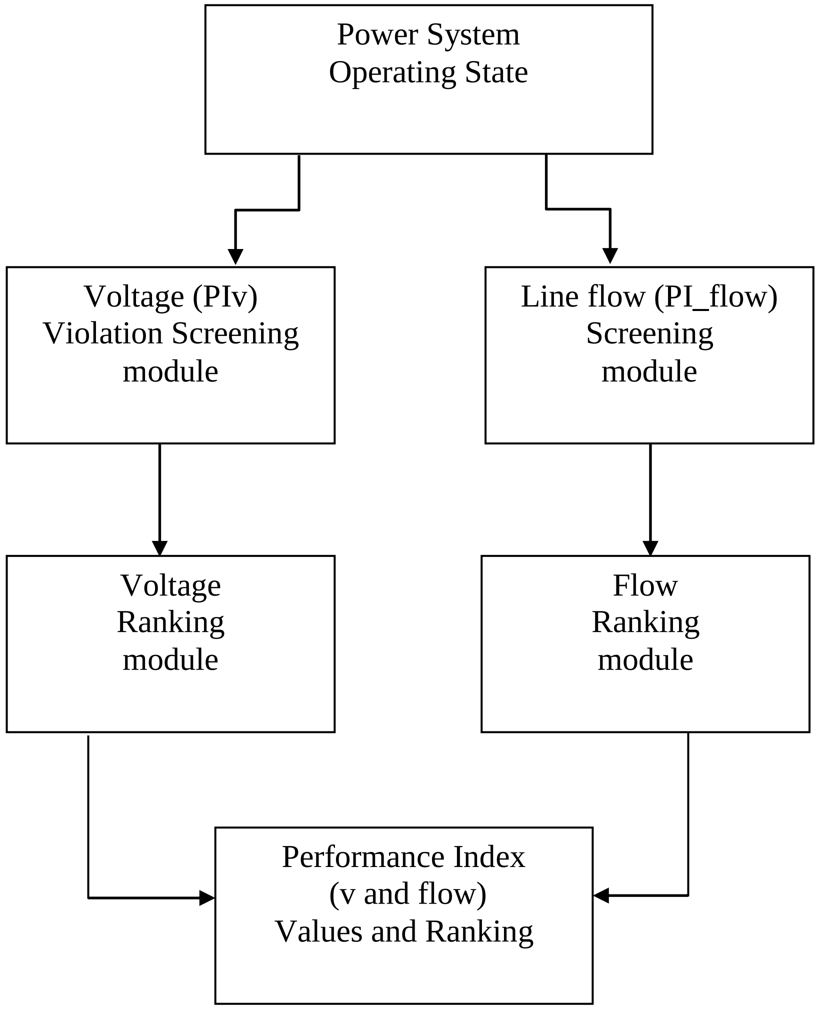


Figure 3.1: Block diagram of the approach to contingency analysis

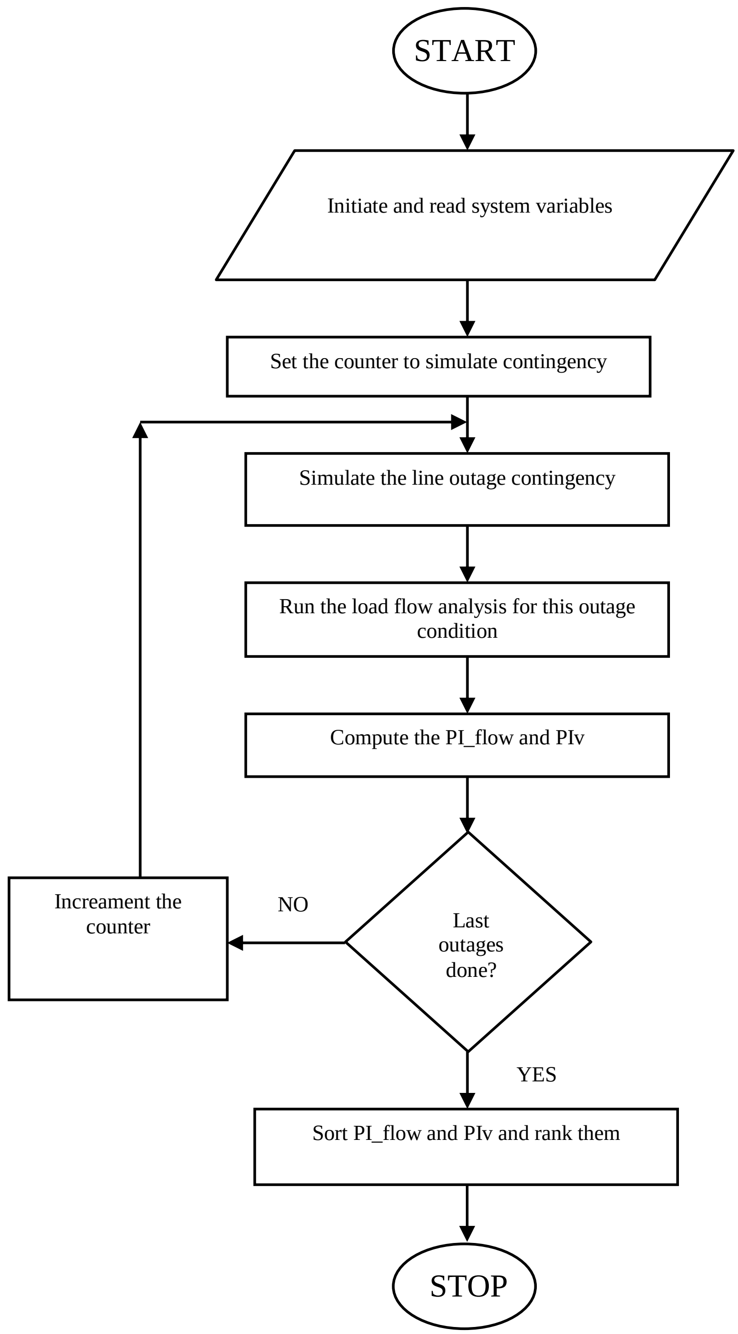


Figure 3.2: A flow chart for line outage contingency selection technique

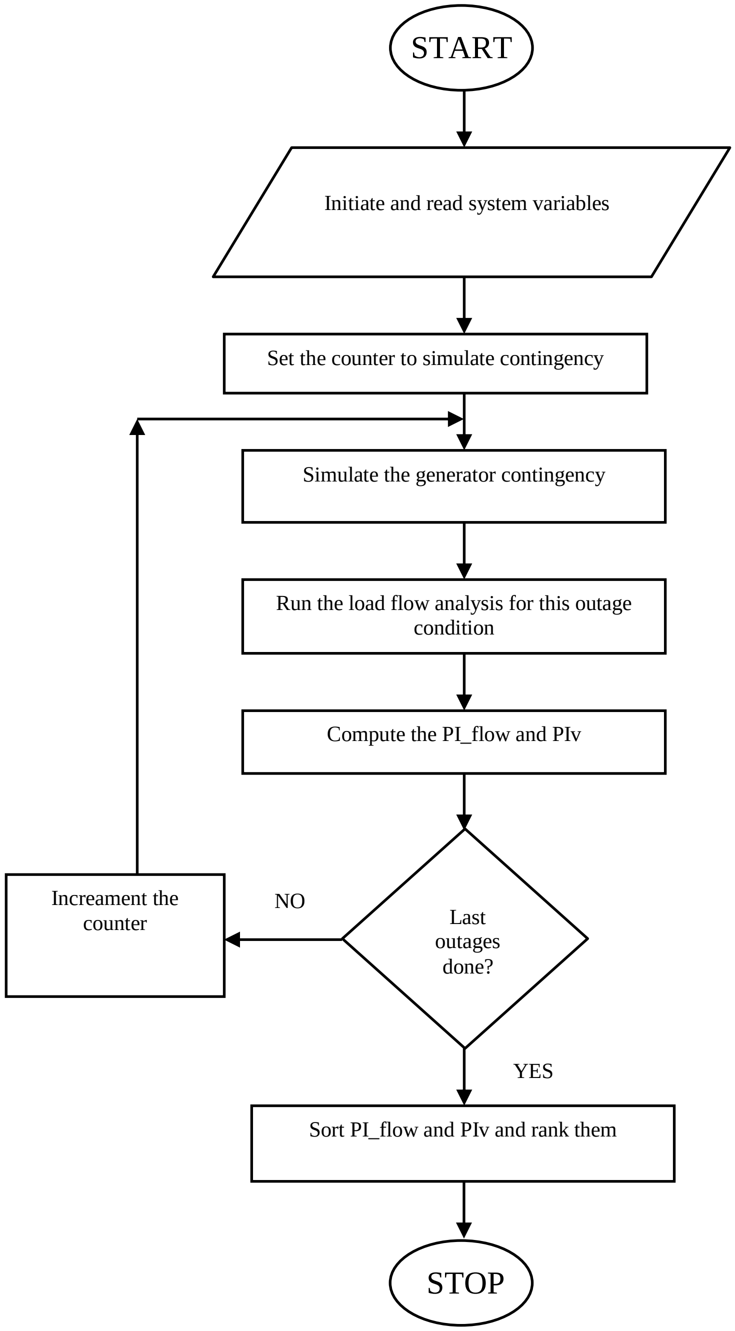


Figure 3.3: A flow chart for generator outage contingency selection technique

3.1.1 Voltage screening module

One of the main points of voltage screening is to calculate the amount of effect in a particuler outage of the power system and with the idea of performance index the scenario can be achieved. Buses limit violation are only considered during the calculation of the performance index (PIv) and as such it is considered as the network output. The input to the Artifial Neural Network (ANN) and the Adaptive Neuro Fuzzy inference system (ANFIS) are considered to be the contingent element of the Pre-contingency voltage. The PIv corresponds to bus voltage magnitude violations. It's mathematically given by equation 3.1.

$$PI\_volt_i = \sum_{\substack{all\ buses \\ j}} \left(\frac{V_j^{min}}{V_{j,i}}\right)^{n_{PIV}} + \sum_{\substack{all\ buses \\ j}} \left(\frac{V_{j,i}}{V_j^{max}}\right)^{n_{PIV}} \tag{3.1}$$

Where,

$V_{j,i}$ = *voltage on bus j with line i out.*

With n as a big number, if the flow is within the line limit, the PI values will be a small number and it will be big if either or more lines are overloaded. When a line or branch is taken out, there are several techniques employed to obtained the values of PI. A formula n-1 can exactly be use to calculate the PI values. That is, a PI value can be tabulated, one for each line in the network, can be calculated quite quickly.

3.1.2 Flow screening module

Classification of the contingencies as either critical or noncritical are done in the Flow screening module. This module is a train algorithm for the flow screening. As such, the line limit violation flow are calculated within performance index (PI_flow) only and it is the network output. The flows of pre-contingency lines of the contingent element are choosen as input characteristics for network training. The PI values calculated from the voltage and flow screening modules are passed to the voltage and flow ranking modules respectively for the contingencies ranking. PI_flow reflects the violation of the active energy flow of the line and is given by equation 3.2.

$$PI\_flow_i = \sum_{\substack{all\ branches \\ l, l \neq i}} \left(\frac{P_{flow\ l,i}}{P_l^{max}}\right)^{n_{PI\ flow}} \qquad (3.2)$$

Where,

For i = 1……..N_{lines}

$P_{flow\ l,i}$ *is the flow on line l with line i out*

If n_{PI_flow} is a large number, the PI will be a small number if all flows are within limits, and it will be larger if one or more lines are overloaded. Here the value of n has been kept unity.

3.1.3 Voltage ranking module

The critical contingencies are screened by the voltage screening module and are transmitted to the voltage ranking module for the contingencies ranking.

3.1.4 PI_flow ranking module

Critical contingencies are screened at the flow screening module which are transmitted onto the flow ranking module to rank the contingencies.

3.2 Contingency Ranking

In power system security analysis, contingency ranking is practiced in order to identify the contingency effect on the system during operation and to experience which critical contingencies violate the bounds of the system operational conditions. In this study, contingency ranking is done to identify which critical branch(s) outage that leads the power system network to be under stress in terms of real power ratings and voltage magnitudes. Also, active power performance index (PI_P) was considered in order to rank the contingency.

3.2.1 Single line diagram of the case study

In the given single line diagram below, bus one (1) is considered as the slack (reference) bus in computing load flow solutions of the network.

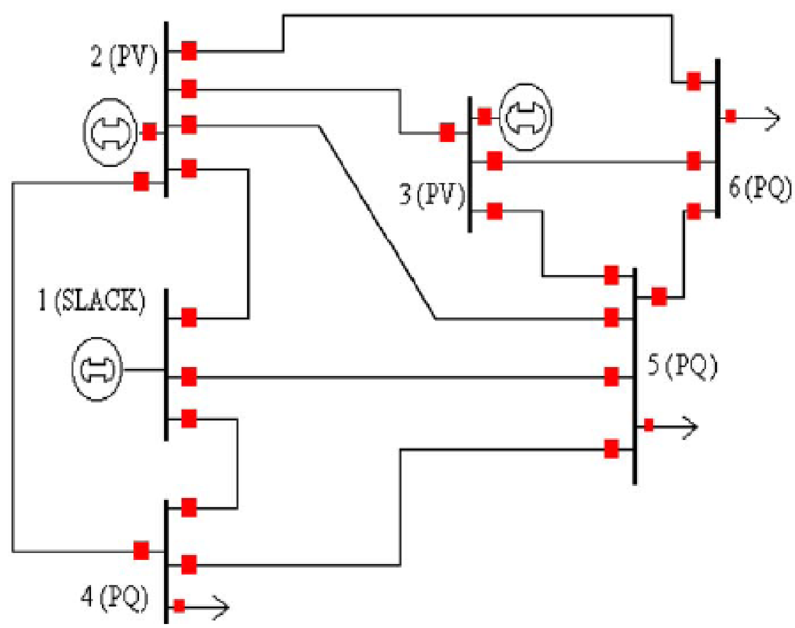


Figure 3.4: Single line diagram for standard IEEE 6-Bus power system

3.2.2 Generation of training data for ANN and ANFIS

Once the input and output parameters are completely selected, prepation for the training is next schedule for the selected data set. Some among the system variables change at the moment of operation. Among the system variables include:

1. Topology of the power system,
2. Total load,
3. Total generation,
4. Capacitor/reactor at different locations,

5. Transformer taps,
6. Phase shifter angles.

Basically, changes in the parameters above are to be considered during the data generation. With this, for the purpose of simplifying the variation and to maintain the data set for training at a minimum length, ideally, at the moment of generating the training data, only the entire load on the system was varied. For the screenind and ranking of flow contingencies, 208 training patterns showing 16 load scenarios were generated in the interval of 5% of their base load and for the screenind and ranking of voltage contingencies, 208 training plan were generated with increment of 5% of their base case load.

The set of contingencies has different types of outages or interruptions (line and generator). Many among the cases in the contingency can contribute to overloading of the transmission line and violations of the bus voltage limit during the operation of the power system. A complete AC load flow is applied to select an individual eventualities with the contingency set and apply the obtained flow results to the PI_flow block (program to calculate the flow performance index) and complete bus voltages apply to the PIv block (program to calculate the voltage performance index) and continuesly, complete AC load flow was repeated with the same procedure to all contingencies within the set of the contingency. With this, large data need to be generated for the overall system, the condition of operation used in load ranged from 75% to 175% in 5% increments for each contingency within the set of the contingency.

3.3 Data Collection

The data used in this research were gathered using the standard IEEE 6-Bus system in a Matlab environment. Enormous numbers of data are generated with variation on individual bus at different load scale with their ranges. A complete AC load flow is done at individual load case in order to calculate the flows of the line before failure wth the voltages at the terminals of the contingent line or the generator, as well as the unavailabilities of line and generator to calculate the voltage and flow performance indices. The AC load flow using the Newton Raphson technique under MATLAB software applied to obtain a load flow solution for both available demand and load increase conditions. They are used to reveal the impact of each transmission line outage to the standard IEEE 6-Bus power system. They are also necessary to give out the post outage information of which critical branch in the system and load bus voltage profile in the entire network. Therefore, this helps to plan and put in place the measures for maintaining the power system network security.

3.4 Selection of training and testing patterns

In this case, the data to be trained and tested are generated in a scenario by which the load patterns are altered with 5% increment of the normal base case, which are randomly selected in a step. With these variation patterns, it is normal to achieve it in a great power system. Thus, the state of the system will be stated by each variable model at each step. With full AC load, a solution was done in order to obtain the accurate performance index (PI) that tally with each among the 25 contingency solution. A code was used in MATLAB to automatically generate the training and testing data for the models automatically. In this process, 75% of the patterns are used for training while the remaining 25% are used to test the model accuracy for both ANN and ANFIS performance of the training. Table 3.0 and 3.1 shows the training statistics for ANFIS and ANN on a standard IEEE 6-bus system.

3.5 Data Normalization

Data normalization is one of the vital aspect in the process of training both the ANN and ANFIS. Therefore, un-normalized data can lead to the risk were the simulated neurons can reach saturation conditions. As a result, when the simulated neurons reach their saturation level, then the variation in input result can lead to a very narrow difference or even no variation in the output result. With this, the learning is affected and can give an undesired output result. One among the best way to normalize is to scale the values in the range of 0 and 1 in oder to reduce redundancy and increase integrity of the data. The formula in equation 4.1

is used and all the parameters are defined. Generally, in this thesis, all the data used are normalized by this procedure as training parameters.

$$\boldsymbol{X_i} = \frac{(x_i - x_{min})}{(x_{\max} - x_{\min})} \tag{4.1}$$

Where,

X_i = is normalize quantity, x_i = is un-normalized quantity, x_{min} = Minimum value of the total quantity and x_{max} = Maximum value of the total quantity respectively (Abba, and Elkiran, 2017).

Table 3.1: General Features of ANN During the calibration

No.	ANN feature	Parameters
1	Input	13
2	Output	1
3	Hidden layers	1
4	Hidden neurons	7
5	Iteretions step	100
6	Momentum factor	0.97
7	Learning rate	0.005
8	Sum squared error	0.005
9	Training patterns	75%
10	Testing data	25%

Table 3.2: General Features of ANFIS During the calibration

No.	ANFIS feature	Parameters
1	Input	13
2	Output	1
3	MFs	Guassian (22 22 22)
4	Optim.Method	Hybrid
5	Generated FIS	Sub-clustering
6	Error Tolerence	0.0005
7	Avg. Training Error	0.0102129
8	Avg. Training Error	0.0102129
9	Training patterns	75%
10	Testing data	25%

CHAPTER 4

RESULTS AND INTERPRETATION

4.1 Result Discussion

The flow charts of figures (3.1), (3.2) and (3.3) are considered to provide results of load flow and contingency analysis for the standard IEEE 6-Bus power system, referring to the scenarios of available load demand and a 5% load increase on PQ buses in the system network. By considering the available load demand condition, AC load flow under Newton Raphson model are used to determine the magnitude and phase angle of voltage and power flow in each transmission line.

Equations (3.1) and (3.2) are used to reveal the sequential severity influence of each transmission line outage as well as the generator outages. From equation (3.1), the flow rate (PIF) of each branch is provided. While (3.2) is the voltage flow rating (PIV) in the branch after contingency, and is determined by using load flow power equations. Finally, each line is considered as outage in the network and also outages of generator 2 and generator 3 are considered under both available load demand and load growth scenarios, to reveal and analyze its impact by relating pre and post-voltage profile of each system bus. Computed results are shown in table 4.0.

Table 4.1: Load Flow Outputs for single line outage (N-1).

S/N	(flow on line\With line out)	(1-2)	(1-4)	(1-5)	(2-3)	(2-4)	(2-5)	(2-6)	(3-5)	(3-6)	(4-5)	(5-6)	Gen 2 out	Gen 3 out	Pmax
1	(1-2)	0.00	56.38	48.01	28.36	12.04	25.43	25.49	26.07	29.28	28.73	28.90	91.20	75.74	38
2	(1-4)	60.65	0.00	59.87	43.49	63.84	42.63	42.64	42.82	43.76	42.25	43.65	0.00	84.35	57
3	(1-5)	47.23	51.49	0.00	36.03	31.99	39.82	39.75	38.99	34.84	36.90	35.33	71.08	0.00	38
4	(2-3)	0.02	1.52	9.28	0.00	7.04	6.44	15.17	-4.71	20.06	3.63	3.14	10.35	39.86	38
5	(2-4)	16.21	66.42	27.01	33.56	0.00	37.70	37.62	36.79	32.26	30.34	32.79	63.29	20.31	57
6	(2-5)	10.13	12.95	27.09	16.16	23.00	0.00	21.80	20.65	14.36	16.78	15.10	8.16	39.92	28.5
7	(2-6)	22.77	24.59	33.73	27.74	31.09	30.39	0.00	22.44	51.82	27.07	26.96	23.01	60.47	85.5
8	(3-5)	15.75	17.51	26.37	18.02	23.81	23.12	14.60	0.00	39.89	19.91	18.43	12.48	6.75	66.5
9	(3-6)	44.19	43.97	42.87	41.94	43.19	43.27	60.52	55.25	0.00	43.67	44.67	32.18	11.07	76
10	(4-5)	4.27	-6.17	14.28	4.45	-8.75	7.73	7.66	7.01	3.42	0.00	3.85	9.28	24.95	19
11	(5-6)	4.67	3.07	-4.97	1.96	-2.65	-2.02	11.11	-6.06	19.82	0.89	0.00	6.96	0.30	38
	PI_flow	**3.41**	**6.20**	**5.10**	**3.25**	**3.55**	**3.31**	**3.98**	**3.80**	**3.91**	**3.22**	**3.21**	**11.21**	**11.61**	

Bus\ Line	(1-2)	(1-4)	(1-5)	(2-3)	(2-4)	(2-5)	(2-6)	(3-5)	(3-6)	(4-5)	(5-6)	Gen 2 out	Gen 3 out	Vmax	Vmin
1	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05
2	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	1.05	0.96	1.05	1.05	1.05
3	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	1.07	0.94	1.07	1.07
4	0.99	0.95	0.99	0.99	0.89	0.99	0.99	0.98	0.99	0.99	0.99	0.87	0.98	1.05	0.95
5	0.99	0.98	0.96	0.99	0.97	0.96	0.98	0.96	0.96	0.99	0.98	0.94	0.90	1.05	0.95
6	1.00	1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.89	1.00	1.01	0.97	0.92	1.05	0.95
PI_v	**11.71**	**11.52**	**11.71**	**11.71**	**11.72**	**11.71**	**11.71**	**11.71**	**11.72**	**11.71**	**11.71**	**11.74**	**11.74**		

Table 4.2: Full AC power flow for each contingency.

			PI_flow			PI_V		
Contingency	**From**	**To**	**NR**	**ANN**	**ANFIS**	**NR**	**ANN**	**ANFIS**
1	1	2	0.01848	0.0248	0.0183	0.132906	0.1336	0.1327
2	1	4	0.119212	0.1199	0.1188	3.3E-06	0.0079	0.0007
3	1	5	0.081466	0.0776	0.0818	0.137474	0.1355	0.1381
4	2	3	0.004671	0.0195	0.0048	0.132803	0.1296	0.1333
5	2	4	2.23E-09	0.0156	0.0001	0.167178	0.1726	0.1678
6	2	5	0.005425	0.0183	0.0049	0.13684	0.1349	0.1372
7	2	6	0.026048	0.0295	0.0263	0.135151	0.1339	0.1345
8	3	5	0.011205	0.0189	0.0112	0.138494	0.1358	0.1388
9	3	6	0.014583	0.0239	0.0143	0.171855	0.1698	0.1474
10	4	5	0.003487	0.0155	0.0037	0.132796	0.1328	0.1324
11	5	6	0.002348	0.0179	0.0022	0.133256	0.1344	0.1334
12	Gen 2		0.222218	0.2304	0.2222	0.209849	0.2253	0.2081
13	Gen 3		0.222798	0.2247	0.2171	0.200113	0.2	0.1993

4.3 Simulation results

Figure 3.4 shows a standard IEEE 6-bus system which was chosen to portray the application of ANN and ANFIS with single line outage and generator outage respectively to obtain the system performance indices under variable load request levels. The network has 6 buses, where 11 of them are transmission lines while 3 are generator buses. The sum of 18 cases at base variable load levels ware tested in order to generate enough data for the training of Artifictial Neural Network and Adaptive Neuro Fuzzy Inference System. With different load cases, a sum of 208 (contingencies) ware generated while the load flow case was chosen under different scenarios using a generator and line outages. Using the generated data, training of the ANN and ANFIS was done, as well after the training, testing of the trained network model was done using new data sets on the load flow cases that are excluded in the set of data used during training time. Table 4.0 shows PIF and PIV Load Flow Outputs for single line and generator outage that were screened and rank accordingly at the first loading conditions for the system.

Table 4.3 : PI_flow screening and ranking

			PI_flow			Ranking		
Contingency	**From**	**To**	**NR**	**ANN**	**ANFIS**	**NN**	**ANN**	**ANFIS**
1	1	2	0.01848	0.0248	0.0183	6	6	6
2	1	4	0.119212	0.1199	0.1188	3	3	3
3	1	5	0.081466	0.0776	0.0818	4	4	4
4	2	3	0.004671	0.0195	0.0048	10	8	10
5	2	4	2.23E-09	0.0156	0.0001	13	12	13
6	2	5	0.005425	0.0183	0.0049	9	10	9
7	2	6	0.026048	0.0295	0.0263	5	5	5
8	3	5	0.011205	0.0189	0.0112	8	9	8
9	3	6	0.014583	0.0239	0.0143	7	7	7
10	4	5	0.003487	0.0155	0.0037	11	13	11
11	5	6	0.002348	0.0179	0.0022	12	11	12
12	Gen 2		0.222218	0.2304	0.2222	2	1	1
13	Gen 3		0.222798	0.2247	0.2171	1	2	2

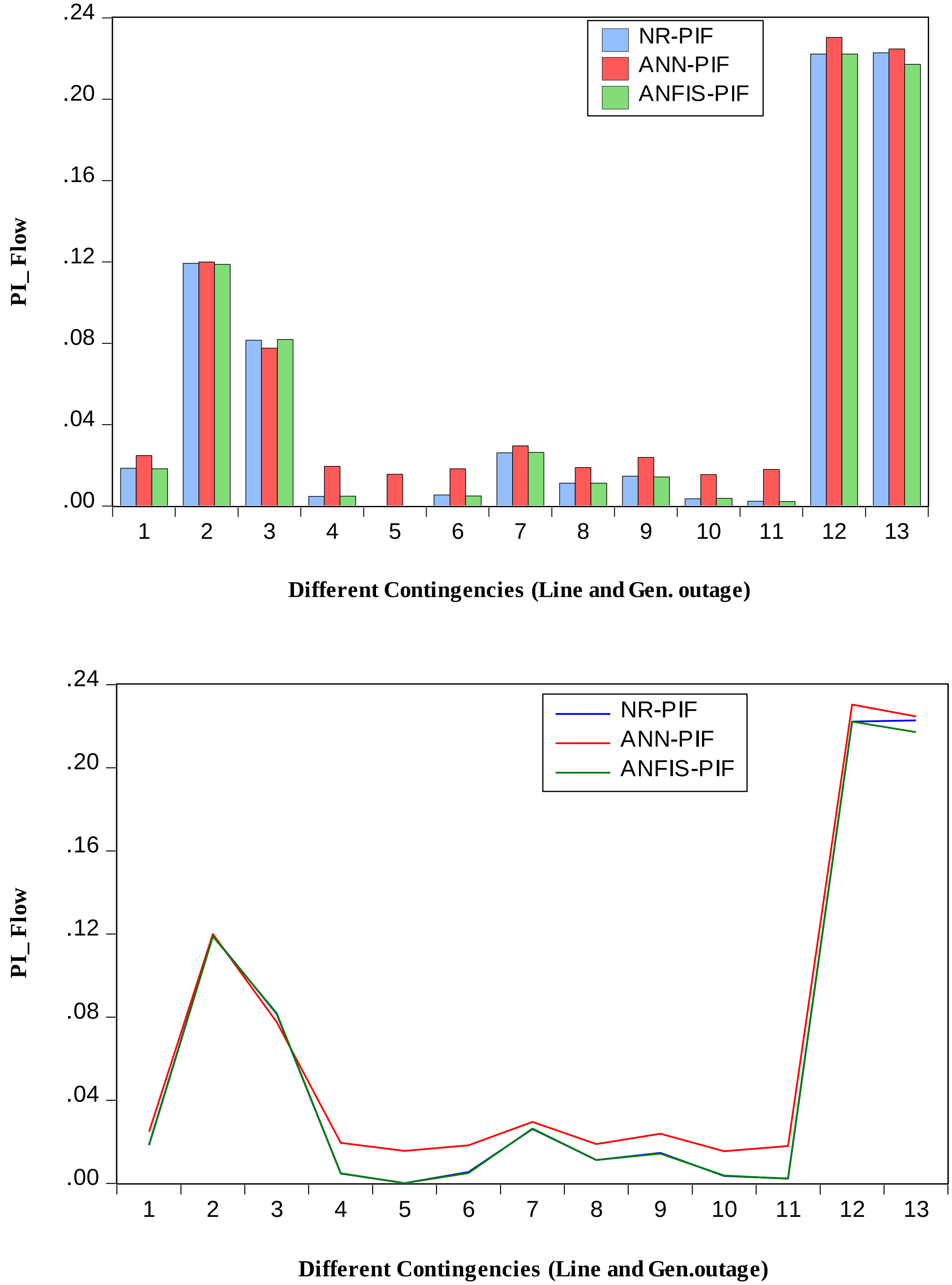
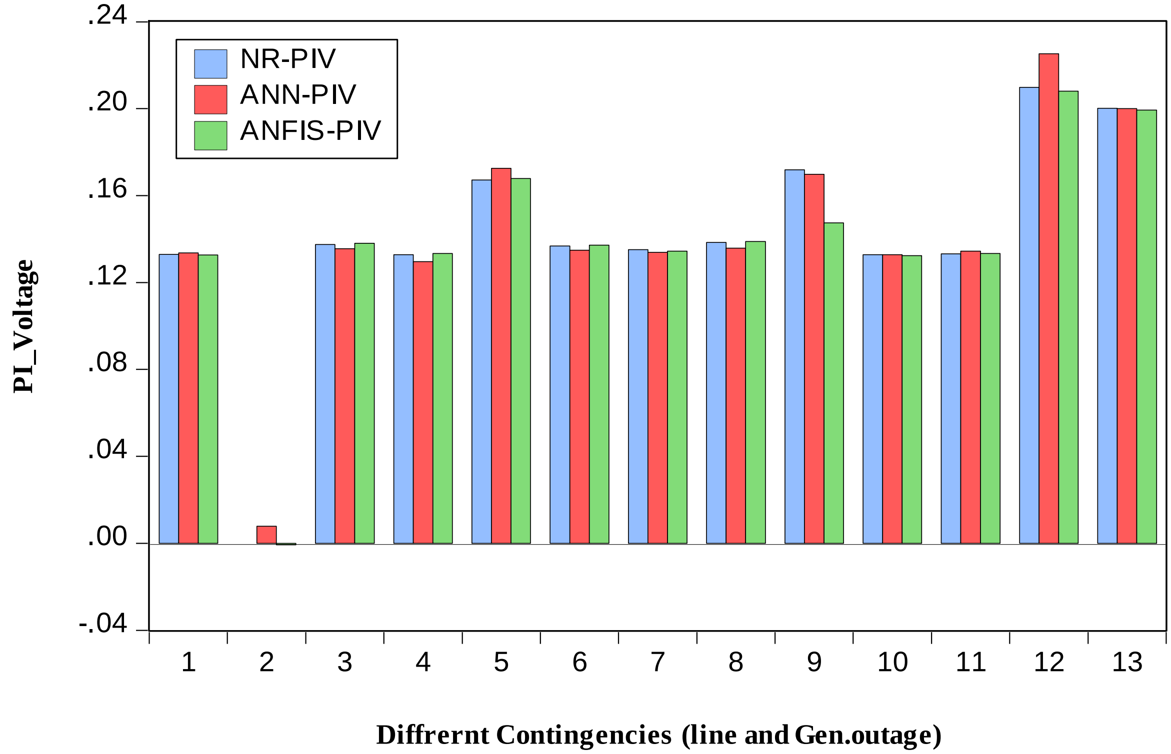


Figure 4.1 : PI_Flow Comparison result between traditional NR-method, ANFIS and ANN.

Table 4.4 : PI_V screening and ranking

				PI_V			Ranking	
Contingency	**From**	**To**	**NR**	**ANN**	**ANFIS**	**NR**	**ANN**	**ANFIS**
1	1	2	0.132906	0.1336	0.1327	10	10	11
2	1	4	-3.3E-06	0.0079	0.0007	13	13	13
3	1	5	0.137474	0.1355	0.1381	6	6	6
4	2	3	0.132803	0.1296	0.1333	11	12	10
5	2	4	0.167178	0.1726	0.1678	4	3	3
6	2	5	0.13684	0.1349	0.1372	7	7	7
7	2	6	0.135151	0.1339	0.1345	8	9	8
8	3	5	0.138494	0.1358	0.1388	5	5	5
9	3	6	0.171855	0.1698	0.1474	3	4	4
10	4	5	0.132796	0.1328	0.1324	12	11	12
11	5	6	0.133256	0.1344	0.1334	9	8	9
12	Gen 2		0.209849	0.2253	0.2081	1	1	1
13	Gen 3		0.200113	0.2	0.1993	2	2	2



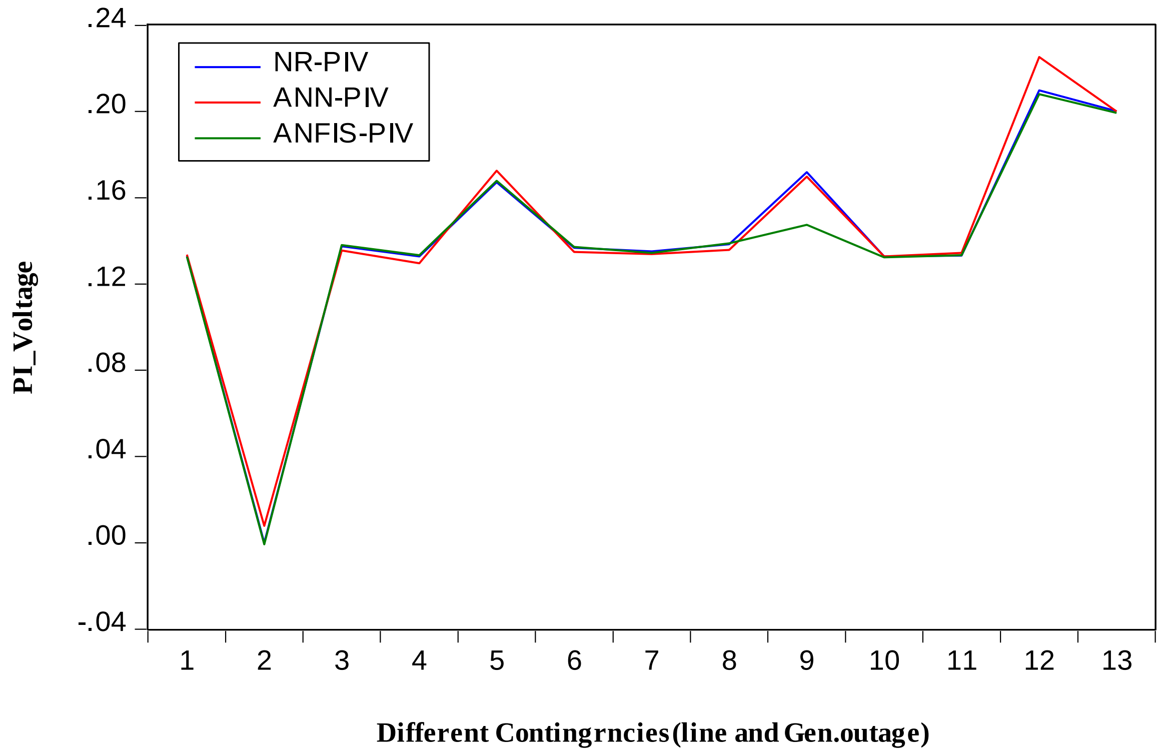


Figure 4.2 : PI_V Comparison result bewteen traditional NR-method, ANFIS and ANN.

4.4 Observation

It can be observed from Table 3.3 and 3.4 that Adaptive Neuro Fuzzy Inference System (ANFIS) gives out a better result as compared in the columns of tables that correspond to the contingency ranking load condition as it is nearer to the same obtained by the Analytical technique (NR) compared to Artificial Neural Network (ANN).

The voltage and flow performance index values displayed nearest result for both methods i.e ANFIS and NR, as such those with most severe contingencies have a greater performance index value. Also, both the techniques have the same sequence in their contingency ranking grade except in place of contingencies 1 and 2, which display a close value result of the performance indices, so they have less effect as seen on the system, which can be ignored. Figure 4.1 displays the closest comparison with PIv results of the NR-technique with Artifial Neural Network and ANFIS methods.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Introduction

This chapter presents the note points for conclusion and recommendations for policy and technical aspects to maintain steady state operation of the case study network.

5.2 Conclusion

The analytical technique for analyzing contingency have several computations of performance indices, therefore, performing complete AC load flow for the overall contingencies with the approach, is tedious and required more time to execute. With this, ANFIS approach to this technique can be more suitable which consist of screening and training module for different contingencies that tally with the voltage violation in the buses and power flow violation in the lines. Accurate result was obtained from the screening module where performance indices (PI_flow, PIv) for the unknown load variation patterns are obtained when compared with analytical technique. Ranking module was used to rank the screened performance indices according to the severity of the contingencies. ANFIS approach demonstrated on the standard IEEE 6-bus system for contingency technique has been tested and give better results.

According to the simulation results obtained in the above table, it was observed that:

(i) ANFIS approach to this technique provides speed computation in the process of generating variable load data for voltage and flow performance index respectively.

(ii) Effect of masking is avoided in the contingencies, if the performance indices are properly constructed.

(iii) Once the training and evaluation of the network is done, it provides speed contingency screening and less calculations as compared to other techniques.

(iv) ANFIS approach to contingency analysis for online applications is a good assessment tool appropriated for power system management.

5.3 Future work

The work done in this research uses Newton Raphson method to generate the data on a standard IEEE 6-Bus system, under different loading conditions which are further utilized to train ANN and ANFIS for further compairism of their performances. In line with the study made, further work can be suggested by using different algorithms and on different standard IEEE bus system.

REFERENCES

Abdelaziz, A.Y., Tahaa, A.T.M., Mostafaa, M. A., and Hassanb, A. M. (2013). Power System Contingency Ranking using Fuzzy Logic Based Approach. *International Journal of Intelligent Systems and Applications in Engineering (IJISAE), 1*(2), 24–28.

Abdulkadir, R.A., Khalipha, A. I., and Jibril, M.B., (2017). Simulation of Back Propagation Neural Network for Iris Flower Classification. *American Journal of Engineering Research, 6*(1), pp 200–205.

Abba, S. I., Hadi, S. J., & Abdullahi, J. (2017). River Water Modelling Prediction Using Multi-Linear Regression, Artificial Neural Network, and Adaptive Neuro-Fuzzy Inference System Techniques. *Procedia Computer Science,* 120, 75-82.

Abba, S. I., & Elkiran, G. (2017). Effluent Prediction of Chemical Oxygen Demand from the Astewater Treatment Plant Using Artificial Neural Network Application. *Procedia Computer Science,* 120, 156-163.

Amit, K. R., and Sanjay, K. (2011). Contingency Analysis in Power System. Thesis of Master of Engineering in Power Systems & Electric Drives, Thapar University, Patiala.

Chaturvedi K.T., Manjaree P., Srivastava L., and Bhatele R.P(2008). Voltage Contingency Ranking of a Practical Power Network Using Hybrid Neuro-Fuzzy System. *Joint International Conference on Power System Technology and IEEE Power India Conference,* 1-5.

Fauziah, D., and Mulyadi, Y., (2017), Contingency Analysis of South Bandung Electric Power System. *1st Annual Applied Science and Engineering Conference,* 012053.

Gaya, M.S., Zango, M.U., Yusuf, L.A., Mamunu, M., Bashir, M., Ashiru, S., Aminu T., Wahab, N.A., and Khairi, M.T.M., (2017). Estimation of Turbidity in Water Treatment Plant using Hammerstein-Wiener and Neural Network Technique. *Indonesian Journal of Electrical Engineering and Computer Science, 5*(3), pp. 666 – 672.

Jang, J.S., (1993). Adaptive network based fuzzy inference system. *IEEE Transaction on System, Man and Cybernetics, 23*(3), pp. 665-685.

Kusum, V., and Niazi, K.R. (2012). Supervised Learning Approach to Online Contingency Screening and Ranking in Power Systems. *Journal of Electrical Power and Energy Systems,* 38, 97–104.

Krishnakumar B., Subaashirn M., Ganesh K. E., and Arthi R., (2012). Power Flow Based Contingency Analysis Using Fuzzy Logic. *International Conference on Modeling Optimization and Computing, 38*, 3603–3613.

Manjula, B. G., Suma, A. P., Kulkarni, A. D., Narendra K., and Ananthapadmanabha, T. (2012). Contingency Ranking In Power Systems Employing Fuzzy Based Analysis. *International Journal of Electronics and Electrical Engineering Systems, 4*(1), 1–6.

Mario, M., (2016). A Comprehensive Approach To Single And Double Line Contingency Screening. *International Journal For Computation And Mathematics In Electrical And Electronic Engineering, 35*(5), 1672-1684.

Mudasingwa, A., and Mangoli, M.K., (2015) Power flow and contingency analysis: "Case of Rwanda high voltage power system". www.icastorindia.org, *ICASTAR Journal of Engineering, 8*(1).

Manjaree P., Laxmi S., and Jaydev S., (2001). Voltage Contingency Ranking Using Fuzzified Multilayer Perceptron. *Electric Power Systems Research, 59*(1), 65–73.

Mauricio D., and Carlos A. C., (2009). Multi-criteria contingency ranking method for voltage stability. *Electric Power Systems Research,* 79, 220–225.

Pandiarajan, K., and Babulal, C.K., (2014). An ANFIS Approach for Overload Alleviation in Electric Power System. *Journal of Electrical Systems, 10*(2), 179 – 193.

Rakesh, K.M., and Shiv, P.S. (2010). Efficient ANN Method for Post-Contingency Status Evaluation. *Journal of Electrical Power and Energy Systems*, 32, 54–62.

Srivastava, L., Singh, S.N., and Sharma, J. (2011). A Hybrid Neural Network Model for Fast Voltage Contingency Screening and Ranking, Electric Power Energy. *In proceedings of the 2nd International Conference on Advances in Communication, Network and Computing* (pp.35–42). Bangalore, India.

Sunitha, R., Sreerama K. R., and Abraham, T. M., (2013). Online Static Security Assessment Module Using Artificial Neural Networks. *Journal of IEEE Transactions on Power Systems, 28*(4).

Soni, B. P., Saxena, A., & Gupta, V. (2016). A least square support vector machine-based approach for contingency classification and ranking in a large power system. *Cogent Engineering, 3*(1), 1137201.

Satyanarayana B., Deepak J., and Khyati D. M., (2016). Contingency Analysis of Power System uses Voltage and Active Power Performance Inde. *1st IEEE International Conference on Power Electronics. Intelligent Control and Energy Systems, 978*(1), 4673-8587.

Shaikh, F.A., and Ramanshu, J. (2014). New Techniques for Prevention of Power System Collapse. *International Journal of Electrical and Electronics Engineering, 1*(3), 123–128.

Scott, B., Alsac O., and Monticelli, A.J., (1984). Security analysis and optimization, *Proceedings of the IEEE, 75*(12), pp.1623-1644.

Swarup, K. S., and Sudhakar G., (2006). Neural Network Approach to Contingency Screening and Ranking in Power Systems. *Neurocomputing, 70*, pp.105–18.

T. S. Chung, Ying Fu (2001) An ANN-Based Ward Equivalent Approach for Power System Security Assessment, *Electric Power Components and Systems, 29*(1), 55-69.

Wood, A.J., and Wollenberg. (2013). Power Generation, Operation and Control 3rd Edition. New Jersey: John Wiley & Sons Ltd.

Werbeston D. O., João P.A., Ubiratan H. B., Daniel A. M., and Benedito G. R., (2017). Power System Security Assessment For Multiple Contingencies Using multi-way Decision Tree. *International Journal of Electronics and Electrical Engineering Systems*, 148, 264–272.

Yousu, C., Kurt G., and Erin F., (2017). Contingency Analysis Post-Processing With Advanced Computing and Visualization. *IFAC Conference Papers On Line, 50*(1), 55–60.

APPENDICES

APPENDIX 1

STANDARD IEEE 6-BUS DATA

```
function mpc = case6ww
%CASE6WW  Power flow data for 6 bus, 3 gen case from Wood &
Wollenberg.
%   Please see CASEFORMAT for details on the case file format.
%
%   This is the 6 bus example from pp. 104, 112, 119, 123-124, 549 of
%   "Power Generation, Operation, and Control, 2nd Edition",
%   by Allen. J. Wood and Bruce F. Wollenberg, John Wiley & Sons, NY,
Jan 1996.

%   MATPOWER

%% MATPOWER Case Format : Version 2
mpc.version = '2';

%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;

%% bus data
%     bus_i type  Pd    Qd    Gs    Bs    area  Vm    Va    baseKV
      zone  Vmax  Vmin
mpc.bus = [
      1     3     0     0     0     0     1     1.05  0     230   1
      1.05  1.05;
      2     2     0     0     0     0     1     1.05  0     230   1
      1.05  1.05;
      3     2     0     0     0     0     1     1.07  0     230   1
      1.07  1.07;
      4     1     70    70    0     0     1     1          0 230   1
      1.05  0.95;
      5     1     70    70    0     0     1     1          0 230   1
      1.05  0.95;
      6     1     70    70    0     0     1     1          0 230   1
      1.05  0.95;
];

%% generator data
%     bus   Pg    Qg    Qmax  Qmin  Vg    mBase status     Pmax  Pmin  Pc1
      Pc2   Qc1min      Qc1max      Qc2min      Qc2max      ramp_agc
      ramp_10     ramp_30     ramp_q      apf
mpc.gen = [
```

```
    1     0     0     100   -100  1.05  100   1     200   50    0     0
    0     0     0     0     0     0     0     0     0;
    2     50    0     100   -100  1.05  100   1     150   37.5  0     0
    0     0     0     0     0     0     0     0     0;
    3     60    0     100   -100  1.07  100   1     180   45    0     0
    0     0     0     0     0     0     0     0     0;
];

%% branch data
%   fbus  tbus  r     x     b     rateA rateB rateC ratio angle status
    angmin     angmax
mpc.branch = [
    1     2     0.1       0.2         0.04    40    40    40    0     0
    1     -360  360;
    1     4     0.05  0.2       0.04    60    60    60    0     0     1
    -360  360;
    1     5     0.08  0.3       0.06    40    40    40    0     0     1
    -360  360;
    2     3     0.05  0.25  0.06  40    40    40    0     0     1     -
360   360;
    2     4     0.05  0.1       0.02    60    60    60    0     0     1
    -360  360;
    2     5     0.1         0.3   0.04  30    30    30    0     0     1
    -360  360;
    2     6     0.07   0.2  0.05  90    90    90    0     0     1     -
360   360;
    3     5     0.12   0.26 0.05  70    70    70    0     0     1     -
360   360;
    3     6     0.02   0.1  0.02  80    80    80    0     0     1     -
360   360;
    4     5     0.2         0.4   0.08  20    20    20    0     0     1
    -360  360;
    5     6     0.1         0.3   0.06  40    40    40    0     0     1
    -360  360;
];

%%-----  OPF Data  -----%%
%% generator cost data
%   1     startup    shutdown   n     x1    y1    ...   xn    yn
%   2     startup    shutdown   n     c(n-1)      ...   c0
mpc.gencost = [
    2     0     0     3     0.00533    11.669     213.1;
    2     0     0     3     0.00889    10.333     200;
    2     0     0     3     0.00741    10.833     240;
];
```

APPENDIX 2

GENERATOR OUTAGE CODE

```
function [gennew, genout] = genout(gen)
%GENOUT Displays available generators to be taken out of service
%   Input, the generator matrix
%   Outputs, the gen matrix with the outaged generator removed, the
outage
%   generator

%---------------------------------------------------------------------
------
% Plan for Generator Out of Service
%---------------------------------------------------------------------
------

% Print the Generator Data

%   Generator Data Format
%       1   bus number
%   (-)     (machine identifier, 0-9, A-Z)
%       2   Pg, real power output (MW)
%       3   Qg, reactive power output (MVAR)
%       4   Qmax, maximum reactive power output (MVAR)
%       5   Qmin, minimum reactive power output (MVAR)
%       6   Vg, voltage magnitude setpoint (p.u.)
%   (-)     (remote controlled bus index)
%       7   mBase, total MVA base of this machine, defaults to
baseMVA
%   (-)     (machine impedance, p.u. on mBase)
%   (-)     (step up transformer impedance, p.u. on mBase)
%   (-)     (step up transformer off nominal turns ratio)
%       8   status, 1 - machine in service, 0 - machine out of
service
%   (-)     (% of total VARS to come from this gen in order to hold V
at
%               remote bus controlled by several generators)
%       9   Pmax, maximum real power output (MW)
%       10  Pmin, minimum real power output (MW)

D = size(gen);
fprintf('\n');
fprintf('\n');


fprintf('\n=============================================================
```

```
================================================================================
========');
    fprintf('\n|     Generator Setup Data
|');

fprintf('\n=============================================================
================================================================================
=========');
    fprintf('\n Bus Number # \t Pg real power output (MW) \t Qg
reactive power output (MVAR) \t Qmax     \t Qmin     \t Pmax     \t
Pmin     \t Status');
    fprintf('\n ------------ \t ------------------------- \t --------
---------------------- \t -------- \t -------- \t -------- \t ------
-- \t --------');
for i=1:D(1)
    fprintf('\n \t%1.0f \t\t\t\t\t%6f \t\t\t\t\t%6f \t\t\t\t\t%6f
\t%6f \t%6f \t%6f \t%6f', gen(i,1), gen(i,2), gen(i,3), gen(i,4),
gen(i,5), gen(i,9), gen(i,10), gen(i,8));
end;
fprintf('\n');
fprintf('\n');

% Ask for a generator to be taken out of service and perform error
checking

genout = -1;
while genout <= 1 || genout > 3
genout = input('Enter the Generator number to be taken out of
service:');
fprintf('\n');
fprintf('Your have chosen Generator number: ');
fprintf('%1.0f', genout);
fprintf(' to be out of service.');

    if genout >=2 && genout <= 3

    else
        fprintf('\n');
        fprintf('Your have chosen an invalid Generator number: ');
        fprintf('\n');
        genout = input('Enter the Generator number to be taken out of
service:');
        fprintf('\n');
        fprintf('Your have chosen Generator number: ');
        fprintf('%1.0f', genout);
        fprintf(' to be out of service.');
    end;
end;

% Make a new generator data based on the outaged generator
```

```
gennew = gen;
gennew(genout,:)=[];

% gennew now contains the eliminated branch
```

APPENDIX 3

LINE FLOW OUTAGE CODE

```
function [baseMVA, bus, gen, branch, area, gencost] = wscc9bus
%WSCC9BUS    Defines the power flow data in a format similar to PTI.
%   [baseMVA, bus, gen, branch, area, gencost] = wscc9bus
%   The format for the data is similar to PTI format except where
noted.
%   An item marked with (+) indicates that it is included in this
data
%   but is not part of the PTI format. An item marked with (-) is one
that
%   is in the PTI format but is not included here.
%
%   Bus Data Format
%       1   bus number (1 to 29997)
%       2   bus type
%               PQ bus          = 1
%               PV bus          = 2
%               reference bus   = 3
%               isolated bus    = 4
%       3   Pd, real p  ower demand (MW)
%       4   Qd, reactive power demand (MVAR)
%       5   Gs, shunt conductance (MW (demanded?) at V = 1.0 p.u.)
%       6   Bs, shunt susceptance (MVAR (injected?) at V = 1.0 p.u.)
%       7   area number, 1-100
%       8   Vm, voltage magnitude (p.u.)
%       9   Va, voltage angle (degrees)
%   (-)     (bus name)
%       10  baseKV, base voltage (kV)
%       11  zone, loss zone (1-999)
%   (+) 12  maxVm, maximum voltage magnitude (p.u.)
%   (+) 13  minVm, minimum voltage magnitude (p.u.)
%
%   Generator Data Format
%       1   bus number
%   (-)     (machine identifier, 0-9, A-Z)
%       2   Pg, real power output (MW)
%       3   Qg, reactive power output (MVAR)
%       4   Qmax, maximum reactive power output (MVAR)
%       5   Qmin, minimum reactive power output (MVAR)
%       6   Vg, voltage magnitude setpoint (p.u.)
%   (-)     (remote controlled bus index)
%       7   mBase, total MVA base of this machine, defaults to
baseMVA
%   (-)     (machine impedance, p.u. on mBase)
%   (-)     (step up transformer impedance, p.u. on mBase)
```

```
%   (-)      (step up transformer off nominal turns ratio)
%       8   status, 1 - machine in service, 0 - machine out of
service
%   (-)      (% of total VARS to come from this gen in order to hold V
at
%                remote bus controlled by several generators)
%       9   Pmax, maximum real power output (MW)
%       10  Pmin, minimum real power output (MW)
%
%   Branch Data Format
%       1   f, from bus number
%       2   t, to bus number
%   (-)      (circuit identifier)
%       3   r, resistance (p.u.)
%       4   x, reactance (p.u.)
%       5   b, total line charging susceptance (p.u.)
%       6   rateA, MVA rating A (long term rating)
%       7   rateB, MVA rating B (short term rating)
%       8   rateC, MVA rating C (emergency rating)
%       9   ratio, transformer off nominal turns ratio ( = 0 for
lines )
%            (taps at 'from' bus, impedance at 'to' bus, i.e. ratio =
Vf / Vt)
%       10  angle, transformer phase shift angle (degrees)
%   (-)      (Gf, shunt conductance at from bus p.u.)
%   (-)      (Bf, shunt susceptance at from bus p.u.)
%   (-)      (Gt, shunt conductance at to bus p.u.)
%   (-)      (Bt, shunt susceptance at to bus p.u.)
%       11  initial branch status, 1 - in service, 0 - out of service
%
% (+) Area Data Format
%       1   i, area number
%       2   price_ref_bus, reference bus for that area
%
% (+) Generator Cost Data Format
%       NOTE: If gen has n rows, then the first n rows of gencost
contain
%       the cost for active power produced by the corresponding
generators.
%       If gencost has 2*n rows then rows n+1 to 2*n contain the
reactive
%       power costs in the same format.
%       1   model, 1 - piecewise linear, 2 - polynomial
%       2   startup, startup cost in US dollars
%       3   shutdown, shutdown cost in US dollars
%       4   n, number of cost coefficients to follow for polynomial
%            (or data points for piecewise linear) total cost function
%       5 and following, cost data, piecewise linear data as:
%                   x0, y0, x1, y1, x2, y2, ...
%           and polynomial data as, e.g.:
%                   c2, c1, c0
```

```
%           where the polynomial is c0 + c1*P + c2*P^2
%
% << this file modified [2005-Sep-02 13:51:27] by AJF >>

%%-----  Power Flow Data  -----%%
%% system MVA base
baseMVA = 100.0000;

%% bus data
%    bus_i type  Pd    Qd    Gs    Bs    area  Vm    Va    baseKV
     zone  Vmax  Vmin
bus = [
     1     3     0     0     0     0     1     1.05  0     230   1
     1.05  1.05;
     2     2     0     0     0     0     1     1.05  0     230   1
     1.05  1.05;
     3     2     0     0     0     0     1     1.07  0     230   1
     1.07  1.07;
     4     1     49    49    0     0     1     1        0  230   1
     1.05  0.95;
     5     1     49    49    0     0     1     1        0  230   1
     1.05  0.95;
     6     1     49    49    0     0     1     1        0  230   1
     1.05  0.95;
];

%% generator data
gen = [
     1     0     0     100   -100  1.05  100   1     200   50    0     0
     0     0     0     0     0     0     0     0     0;
     2     50    0     100   -100  1.05  100   1     150   37.5  0     0
     0     0     0     0     0     0     0     0     0;
     3     60    0     100   -100  1.07  100   1     180   45    0     0
     0     0     0     0     0     0     0     0     0;
];

%%  original generator data
%gen = [
%   1    71.6000   27.0000    50.0000    -30.0000   1.0400   100.0000
1   250.0000   10.0000;
%   2   163.0000    6.7000   100.0000    -70.0000   1.0250   100.0000
1   300.0000   10.0000;
%   3    85.0000  -10.9000    50.0000    -30.0000   1.0250   100.0000
1   270.0000   10.0000;
%];


%% branch data
branch = [
     1     2     0.1       0.2        0.04   40    40    40    0     0
     1     -360  360;
```

```
     1     4     0.05  0.2       0.04   60    60    60    0     0     1
     -360  360;
     1     5     0.08  0.3       0.06   40    40    40    0     0     1
     -360  360;
     2     3     0.05  0.25  0.06  40    40    40    0     0     1     -
360  360;
     2     4     0.05  0.1       0.02   60    60    60    0     0     1
     -360  360;
     2     5     0.1        0.3   0.04  30    30    30    0     0     1
     -360  360;
     2     6     0.07   0.2  0.05  90    90    90    0     0     1     -
360  360;
     3     5     0.12   0.26 0.05  70    70    70    0     0     1     -
360  360;
     3     6     0.02   0.1  0.02  80    80    80    0     0     1     -
360  360;
     4     5     0.2        0.4   0.08  20    20    20    0     0     1
     -360  360;
     5     6     0.1        0.3   0.06  40    40    40    0     0     1
     -360  360;
];

%%-----  OPF Data  -----%%
%% area data
area = [
   1   5;
];
% Annual Costs for Coal Steam Plants

gencost = [
     2     0     0     3     0.00533    11.669     213.1;
     2     0     0     3     0.00889    10.333     200;
     2     0     0     3     0.00741    10.833     240;
];
%% generator cost data
%gencost = [
%   2   1500.00   0.00   3   0.1100  5.0   150;
%   2   2000.00   0.00   3   0.0850  1.2   600;
%   2   3000.00   0.00   3   0.1225  1.0   335;
%];

return;
```