DEVELOPMENT OF A SENSITIVITY INDEX BASED TECHNIQUE FOR UNIFIED POWER FLOW CONTROLLER PLACEMENT WITH CONTINGENCY ANALYSIS ON NIGERIA 330kV TRANSMISSION NETWORK

BY

SAMBO, KURUTSI

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A DISSERTATION SUBMITTED TO THE DEPARTMENT OF ELECTRICAL ENGINEERING, AHMADU BELLO UNIVERSITY, ZARIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF SCIENCE (M.Sc.) DEGREE IN ELECTRICAL ENGINEERING.

FEBRUARY, 2018.

DECLARATION

I declare that the work in this dissertation entitled "DEVELOPMENT OF A SENSITIVITY INDEX BASED TECHNIQUE FOR UNIFIED POWER FLOW CONTROLLER PLACEMENT WITH CONTINGENCY ANALYSIS ON NIGERIA 330kV TRANSMISSION NETWORK" has been carried out by me in the Department of Electrical Engineering. The information derived from literatures has been duly acknowledged in the text and lists of references were provided. No part of this dissertation was previously presented for another degree or diploma in this institution or another.

Sambo Kurutsi ______________________ ______________________

Signature Date

CERTIFICATION

This Dissertation entitled “DEVELOPMENT OF A SENSITIVITY INDEX BASED TECHNIQUE FOR UNIFIED POWER FLOW CONTROLLER PLACEMENT WITH CONTINGENCY ANALYSIS ON NIGERIA 330kV TRANSMISSION NETWORK” by SAMBO KURUTSI meets the regulations governing the award of degree of Master of Science (M.Sc.) in Electric Engineering of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

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Chairman, Supervisory Committee Signature Date

Prof. B. Jimoh ____________________ __________________
Member, Supervisory Committee Signature Date

Dr. Y. Jibril ____________________ __________________
Head of Department Signature Date

Prof. S. Z. Abubakar __________________ ________________
Dean. School of Postgraduate Studies Signature Date

DEDICATION

This research work is dedicated to God Almighty and to my beloved mother Late Mrs. Tani Luka Sambo

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ABSTRACT

Power system network is designed to operate in a prescribed voltage and frequency for stability and for better power quality. Unexpected contingencies leads to instability related problems in the system. This research develops a sensitivity index based technique with contingency analysis for Unified Power Flow Controller (UPFC) placement for Nigeria 330kV power transmission system. The research employed Newton Raphson power flow method considering multiple contingency analyses which include double line outages, line and load outages, double load outages and load increments. The identification of the severity of the violated bus voltages was achieved through the use of Active Power Performance Index (APPI) and Reactive Power Performance Index (RPPI). The contingency cases were addressed through the sizing and placement of UPFC on the network and simulated in Matlab R2013a environment. The analyses shows that the predominately violated buses and the sizes of the UPFC placed are Maiduguri bus (-183 MVar), Birni Kebbi bus (99 MVar) Oshogbo bus (-84MVar), Jos bus (-28 MVar), Gombe bus (-13 MVar) and Kano bus (21 MVar). The result shows 1.3% (694.6233MVar) reduction in the total reactive power loss as compared with base case of (703.7499MVar) after the placement of UPFC and a total voltage improvement of 3.11% (31.9298pu) as compared to the base case voltage deviation of (32.9541pu). The developed approach was analyzed on IEEE 30 bus network with a transmission line power loss reduction of (0.00166pu) and a voltage improvement of 0.83% (30.6753pu) as compared to the work of Reddy *et al.*, (2014) with power loss of (0.02116pu) and a voltage of (30.4214pu).

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LIST OF ACRONYMS

ACRONYMS	**DEFINITION**
AC	Alternating Current
APPI	Active Power Performance Index
FACTS	Flexible Alternating Current Transmission System
FDNR	Fast Decouple Newton-Raphson
GS	Gauss-Seidel
IEEE	Institute of Electrical Electronics Engineering
MATLAB	Matrix Laboratory
MVar	Mega Voltage Ampere Reactive
MW	Mega Watt
NCC	National Control Centre
NR	Newton Raphson
p.u.	Per Unit
PHCN	Power Holding Company of Nigeria
P_{max}	Maximum Power
PQ	Active and Reactive Power
PV	Active Power and Voltage
R/X	Resistance/Reactance
RPPI	Reactive Power Performance Index
UPFC	Unified Power Flow Controller
V	Voltage magnitude
δ	Phase angle

CHAPTER ONE

INTRODUCTION

1.1 Background To The Study

An electric power system is a network of electrical components deployed to supply, transfer, and use electric power (Pai, 2012). Electric power system is design for efficiency, reliability, ease of operation, and to meet consumer needs at minimum cost. Power system stability refers to that property of the power system which enables the system to maintain an equilibrium operating point under normal conditions and to attain a state of equilibrium after being subjected to a disturbance (Aman *et al*., 2014).

Power systems are subjected to a wide range of small or larger disturbances during operation. Small disturbances are changes in loading conditions which occur continually. Small or larger disturbances could be faults, load changes, generator outages, line outages, voltage collapse or some combination of these. The power system must adjust to these changing conditions and continue to operate satisfactorily and within the desired bounds of voltage and frequency. The power system should be designed to survive both small and large types of disturbances (Tziouvaras & Hou, 2004).

One of the key concerns in transmission of electricity is power loss in transmission lines often referred to as line loss or transmission loss which is dissipated as heat due to the resistance of the conductors. The smaller the surface area of the conductors, the smaller the loss due to heat dissipation, hence, high voltages require less surface area, resulting in reduced line loss. With high-voltage lines, the voltage can be stepped up at the generating station, transmitted through the transmission grid to a load center, and there stepped down to the lower voltages required by distribution lines (Bergen, 2009).

Secure operation of power systems have become a critical issue nowadays, as they are heavily loaded and are being operated in ways not been originally designed (Kavitha & Neela, 2016). Security is a term used to reflect a power system's ability to meet its load without unduly stressing its apparatus or allowing variables to stray from prescribed range under certain contingencies (Rohini *et al*., 2015). Moreover any of the unexpected contingencies may collapse the system suddenly. To overcome this situation it is essential to have the study of contingency analysis and to trace the critical contingencies in advance; so that necessary supporting FACTS devices can be installed (Kavitha & Neela, 2016). In order to provide proper security in power system during contingencies FACTS devices is widely used.

Since, power system operation is affected by stability related problems, leading to unpredictable system behavior, FACTS technology opens up new opportunities for controlling power and hence, enhancing the usable capacity of transmission lines. The possibility that current through a line can be controlled enables a large potential of increasing the capacity of existing lines with larger conductors, and use of one of the FACTS Controllers to enable corresponding power to flow through such lines under normal and contingency conditions (Zhang *et al*., 2012). UPFC is a versatile FACTS device. The choice of this FACTS device in this research is due to its capability of providing active, reactive and bus voltage control under normal and network contingencies conditions without violating the operating limits. Since UPFC can be installed in different locations, its effectiveness will be different; hence, it is highly important to determine the optimal location of this device in the power system for voltage stability margin improvement, increase in power transmission capacity and for power blackout prevention (Shaheen *et al*., 2011).

Power flow analysis which is the backbone of power system analysis and design is necessary for planning, operation, economic scheduling and exchange of power between utilities (Wane & Verma, 2013). The principle of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. The conventional techniques used for solving the load flow problems are iterative. These techniques are Newton-Raphson (NR), Gauss-Seidel (GS) and Fast Decouple Newton-Raphson (FDNR) methods. These techniques are difficult and take a lot of time to perform hence, MATLAB R2013 programming software is used for solving problem speedily.

Contingency analysis and selection for the placement of this FACTS device is performed using Newton-Raphson and two kinds of performance indices namely, active power performance index and reactive power performance index respectively. Hence, the impacts of this FACTS placement to mitigate power losses and to increase loadability during these contingencies are investigated on Nigerian 330kV transmission network.

1.2 Motivation

Electrical power system is expected to be stable and reliable at all times. Violations of bus voltages arising as a result of equipments straying from its operating limit due to disturbance in form of outage of lines, outage of generators and load variations is a major concern in power system. The reason of incorporating FACTS devices (UPFC) into power system network with contingencies is for voltage stability and a mean to increase the line loadability thereby making the system stable and reliable. APPI and RPPI are sensitivity indices used in the selection and ranking of the violated voltage buses. The impact of the UPFC creates voltage stability and increase in the line loadability of the network.

1.3 Statement Of Problem

Multiple contingencies describe a set of single contingencies which occur one at a time that is; the outage of equipment could spur to the outage of another on the same network. Multiple contingencies related problems on power system such as sudden drop or addition of heavy load or line outages can violate the power quality constraint of the network. In cases of sudden load variations, the system is considered insecure and the loadability of the network is severely affected. Several literatures have been reviewed to shows different techniques carried out for solving and analyzing contingency on power system network through the placements of FACTS devices. Due to the limitations attached to some of these methods is the reason for the choice of sensitivity indices used in this research. APPI and RPPI used in this research help to quantify and rank the contingency identified according to the level of their severity. The ranking from the indices was used for the placement of the UPFC to mitigate the effects of the contingencies hence, reducing the degree of the line overload and stabilizing the bus voltages of the network.

1.4 Aim And Objectives

The aim of this research is to develop a sensitivity index based technique for the placement of UPFC with contingency analysis on Nigerian 330kV transmission network.

The objectives of the research are to:

i. Adopt Newton Raphson power flow algorithm for power flow analysis on Nigerian 330kV transmission network.
ii. Implement sensitivity index based technique for UPFC placement with contingency analysis on the Nigerian 330kV transmission network.
iii. Make a comparative assessment of the result of the proposed method with that of the work of Reddy *et al*., (2014) in term of voltage profile.

1.5 Methodology

The methodology used to carry out this research work is as follows:

i. The adoption of Newton Raphson method for power flow analysis.
ii. Implementation of a sensitivity index based technique for contingency ranking and for determination of UPFC device placement using APPI and RPPI.
iii. Implementation analysis of the proposed method is performed on Nigerian 330kV transmission network to improve the network voltage profile and the lines transfer capabilities.
iv. Comparison of the result of the proposed method with that of the work of Reddy *et al*., (2014) using charts of voltage profile.

1.6 Significance Of Research

The significance of this research is to analyze a sensitivity index based technique for the placement of UPFC with contingency analysis on Nigerian transmission network. The placement of the UPFC will help in the improvement of the performance of the power system by mitigating voltage instability arising from various forms of disturbances and in the increment of the network line transfer capability. Although, most of the placements of these FACTS has been majorly considered by researchers in networks under single line contingency to improve the power quality of the network, hence, most of these research works considered the uniformly distribution of load ignoring the presence and location of priority load in the network which this research seeks to considered.

1.7 Scope And Limitation Of The Research

This research covers the development of sensitivity index for the placement of UPFC with contingency analysis on Nigerian 330kV transmission network. The various contingency considered in this research includes the line outages, load outages, line and load outages and load increment. The placement of UPFC on the network helps to mitigate the effect of the contingency on the bus voltages. Hence, the voltage profile improvement results to an increase in the line loadability of the network. However, the contingency analysis performed in this research did not investigate the extreme of contingency which could involve the outage of generators leading to blackout in the network.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature review encompasses the overview of fundamental concept and the review of similar works.

2.2 Overview Of Fundamental Concept

In this section, fundamental concepts to the research work are reviewed.

2.2.1 Electrical Power System

Power system is the largest and most complex infrastructure and has been operating for the past 100 years using the same fundamental principles (Monti & Ponci, 2015). An electric power system is a network of electrical components deployed to supply, transfer, and use electric power (Pai, 2012). The power system consists of generation, transmission and distribution of electric power (Patel *et al*., 2015). Electric supply system comprises of the following three principal components: power stations, transmission lines and distribution lines. Technology governing the power system has, so far, allowed an improvement of their performance, but it has not revolutionized the basic principles. The electrical grid has no structural way to store energy; hence, it is necessary that at every instant the amount of power generated to be equal to the power absorbed by the loads (Monti & Ponci, 2015).

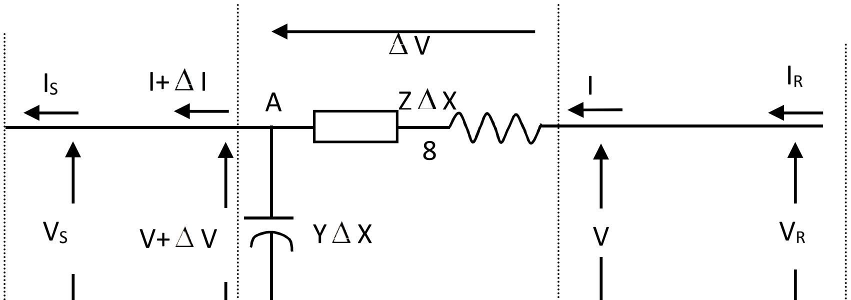
2.2.2 Transmission Line Network

Transmission of electric power normally implies the bulk transfer of power by high voltage links between main load centers (Rajput, 2006). Transmission lines are set of conductors which carry electric power from generating plants to the substations that deliver power to customers. At a generating plant, electric power is “stepped up” to several thousand volts by a transformer and delivered to the transmission line. At numerous substations on the transmission system, step down transformers lower the voltage and deliver it to distribution lines.

Transmission lines are normally operated with a balanced 3-phase load; the analysis can therefore proceed on a per phase basis. A transmission line on a per phase basis can be regarded as a two-port network wherein the sending-end voltage V_s and current I_s are related to the receiving end voltage V_R and current I_R through ABCD constants as given in equation (2.1) (Kothari & Nagrath, 2008).

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{2.1}$$

The following identity holds for ABCD constants AD – BC = 1. ABCD can be determined easily by short and medium transmission lines because the distributed effect of the line parameter are small hence, it is sufficient to consider the lumped parameter model for the lines. However, for long transmission line exact analysis has to be carried out by considering the distribution of resistance, inductance and capacitance parameters and then ABCD parameters can be determined (Kothari & Nagrath, 2008).



A long transmission line of length greater than 250km is supplied with a sending end voltage and current (V_S and I_S) respectively, whereas the V_R and I_R are the values of voltage and current obtained from the receiving end. Considering an element of infinitely small length Δx at a distance x from the receiving end as shown in Figure 2.1. (Kothari & Nagrath, 2008):

Nomenclature:

V is the value of voltage just before entering the element Δx.

I is the value of current just before entering the element Δx.

V+ΔV is the voltage leaving the element Δx.

I+ΔI is the current leaving the element Δx.

ΔV is the voltage drop across element Δx.

zΔx is series impedance of element Δx

yΔx is shunt admittance of element Δx

Z and Y are the values of total impedance and admittance of the long transmission line.

The voltage drop across the infinitely small element Δx is given by equation (2.2)

$$\Delta V = Iz\Delta x$$

$$or\ I_Z = \frac{\Delta V}{\Delta x} \tag{2.2}$$

$$or\ I_Z = \frac{dV}{dx}$$

Now to determine the current ΔI, we apply KCL to node A as stated in equation (2.3)

$$\Delta I = (\mathrm{V}+\Delta \mathrm{V})\,\mathrm{y}\,\Delta x = \mathrm{Vy}\,\Delta x + \Delta \mathrm{V}\,\mathrm{y}\,\Delta x \tag{2.3}$$

Since the terms ΔV and yΔx are the product of two infinitely small values, it can be ignored for the sake of easier calculation. Therefore, it can be rewritten as stated in equation (2.4) (Kothari & Nagrath, 2008):

$$\frac{dI}{dx} = Vy \tag{2.4}$$

Differentiating both sides of equation (2.2) with respect to x gives equation (2.5),

$$\frac{d^2V}{dx^2} = z\frac{dI}{dx} \tag{2.5}$$

Substituting $\frac{dI}{dx} = Vy$ from equation (2.4) gives equation (2.6)

$$\frac{d^2V}{dx^2} = zyV \text{ or } \frac{d^2V}{dx^2} - zyV = 0 \tag{2.6}$$

The solution of the above second order differential equation is given by equation (2.7):

$$V = A_1 e^{x\sqrt{yz}} + A_2 e^{-x\sqrt{yz}} \tag{2.7}$$

Differentiating equation (2.7) with respect to x and comparing with equation (2.2) give equation (2.8)

$$I = \frac{dV}{dx} = \frac{\sqrt{yz}\,A_1 e^{x\sqrt{yz}}}{\sqrt{\frac{z}{y}}} - \frac{\sqrt{yz}\,A_2 e^{-x\sqrt{yz}}}{\sqrt{\frac{z}{y}}} \tag{2.8}$$

The characteristic impedance Z_c and propagation constant δ is given by equation (2.9)

$$Z_c = \sqrt{\frac{z}{y}}\ \Omega \text{ and } \delta = \sqrt{yz} \tag{2.9}$$

The voltage and current equation can be expressed in terms of characteristic impedance and propagation constant and are given as (2.10) and (2.11).

$$V = A_1 e^{\delta x} + A_2 e^{-\delta x} \tag{2.10}$$

$$I = \frac{A_1}{Z_c} e^{\delta x} + \frac{A_2}{Z_c} e^{-\delta x} \tag{2.11}$$

Substituting x = 0, V = V_R and I = I_R into equation (2.10) and (2.11) respectively gives equation (2.12) and (2.13).

$$V_R = A_1 + A_2 \tag{2.12}$$

$$I_R = \frac{A_1}{Z_c} - \frac{A_2}{Z_c} \tag{2.13}$$

Solving equation (2.12) and (2.13) gives the values of A_1 and A_2 as stated in equation (2.14)

$$A_1 = \frac{V_R + Z_c I_R}{2} \text{ and } A_2 = \frac{V_R - Z_c I_R}{2} \tag{2.14}$$

Now by applying another extreme condition at x = l, then, V = V_S and I = I_S respectively. Now to determine V_S and I_S, x is substituted by l and then putting the values of A_1 and A_2 in equation (2.10) and (2.11) gives equation (2.15) and (2.16) (Kothari & Nagrath, 2008):

$$V_S = (V_R + Z_c I_R) e^{\frac{\delta l}{2}} + (V_R - Z_c I_R) e^{-(\frac{\delta l}{2})} \tag{2.15}$$

$$I_S = \left(\frac{V_R}{Z_c} + I_R\right) e^{\frac{\delta l}{2}} - \left(\frac{V_R}{Z_c} - I_R\right) e^{\frac{-\delta l}{2}} \tag{2.16}$$

Using trigonometric and exponential operators

$$\sinh \delta l = \frac{e^{\delta l} - e^{-\delta l}}{2} \ \ and \ \ \cosh \delta l = \frac{e^{\delta l} + e^{-\delta l}}{2}$$

Where δ is the propagation constant at any distance *l*

Therefore, equation (2.15) and (2.16) can be re-written after introducing hyperbolic function as given in equation (2.17) and (2.18) (Kothari & Nagrath, 2008):

$$V_S = V_R \cosh \delta l + Z_c I_R \sinh \delta l \tag{2.17}$$

$$I_S = \frac{V_R \cosh \delta l}{Z_c} + I_R \sinh \delta l \tag{2.18}$$

Thus comparing with the general circuit parameters equation, the ABCD parameters of a long transmission line is given as (Kothari & Nagrath, 2008):

$$\begin{aligned} A &= \cosh \delta l \\ B &= Z_c \sinh \delta l \\ C &= \frac{\sinh \delta l}{Z_c} \\ D &= \cosh \delta l \end{aligned}$$

2.2.3 Power System Stability

When a disturbance occurs in the system, there is a tendency for the system to develop forces to restore it to the original stable state by maintaining synchronism and equilibrium. This tendency of the system is known as stability. The load on the system may change gradually or suddenly. Sudden changes of load may be due to quick switching operations or sudden faults followed by tripping of lines etc. whether or not the system will behave well and continue to supply the load and keep various synchronous machines in step under various conditions is a study by itself and are known as system stability (Sivanagaraju & Reddy, 2007).

There are two kinds of stability – steady state and transient. The steady state stability limit of a generator or system is the maximum power, P_{max} that can be transmitted for a change in load which occur slowly enough to allow for a similar change in excitation to bring the terminal voltage back to normal. Transient stability is determined by considering the effect of moment of inertial of the moving parts of the machine, of governor operation, of voltage regulators, of the performance of the plants under transient conditions, etc. under transient conditions, there is tendency for synchronous machines to swing or oscillate around the relative angular displacement. Whether or not a machine can come back to a steady condition after a temporary swing decides the transient stability of the system and the machine (Sivanagaraju & Reddy, 2007).

2.2.3 Power System Operating States

Power system may be identified to be operating in a number of states. The three states are defined in Figure 2.2 as follows (Toshi & Anil, 2014):

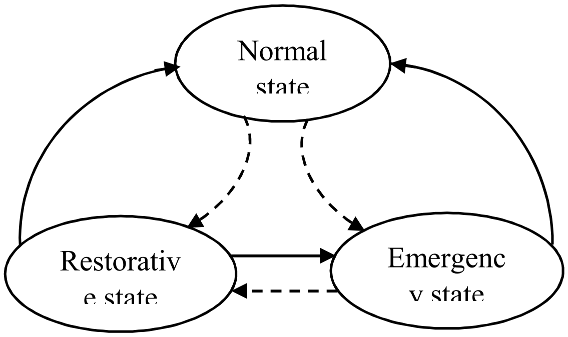


Figure 2.2: Power System Operating States (Toshi & Anil, 2014)

i. *Preventive state:* The preventive state is actually the normal state. The term preventive was used to stress the security aspect of the normal operation. Normal operating condition usually means that all the apparatus are running within their prescribed limits, and all the system variables are within acceptable ranges. The system should also continue to operate normally even in the case of credible contingencies. The operator should envisage such contingencies (disturbances) and take preventive control actions (as economically as possible) such that the system integrity and quality of power supply is maintained.

ii. *Emergency state*: The power system enters an emergency state when some of the components operating limits are violated; some of the states wander outside the acceptable ranges, or when the system frequency starts to decrease. The control objective in the emergency state is to relieve system stress by appropriate actions.

iii. *Restorative state*: Restorative state is the condition when some parts (or whole) of the system has lost power. The control objective in this state is to steer the system to a normal state again by taking appropriate actions.

2.3 Power System Buses

The system buses are divided into three categories: they are as follows (Naik, 2014):

a. *Slack Bus:* This bus is also known as swing bus. This bus is used as reference where the magnitude and phase angle of the voltages are only specified. This bus finds the difference between the scheduled loads and generated power which are caused by the losses in the networks.

b. *Load Buses*: The magnitude of bus voltage and the phase angle of the bus voltage are unknown. The active and the reactive power are specified. These buses are also known as P-Q buses.

c. *Regulated Buses*: These are also known as generator buses, or voltage controlled buses. Real power and voltage magnitude are specified at these buses. The phase angle of the voltages and the reactive powers are to be determined. These buses are known as P-V buses.

2.4 Power Flow Studies

The power flow studies are very common in power system analysis. The Power flow studies helps in determining the present state of a system. Hence, they are necessary for control and planning of an existing power system and also for planning its future expansion. Power flow calculation iteratively decided the power that is flowing through the lines, the power that is being consumed by the loads and generated by the generators, the losses arising during the transfer of power from source to load and so on. In several systems, the most important quantity is known as the voltage at different points all over the networks. As soon as the voltage and angles are computed, the real and reactive power flow in each line can be computed. Based on the variation among power flow in the transmitting and receiving ends, the losses in the transmission lines can also be calculated (Kailay & Brar, 2016). Determining of active and reactive power flow for each line and calculation of magnitude and phase angle of voltages at each bus is a challenging thing. Four quantities are associated with each bus; these four quantities are voltage magnitude (|V|), phase angle (δ), real power (P) and reactive power (Q) (Kailay & Brar, 2016).

2.4.1 Power Flow Methods

The mathematical formulation of the power flow or the load flow problem results into nonlinear algebraic equations which can only be solved by iterative techniques. There are various iterative techniques (Naik, 2014). These include:

i. Gauss Seidel power flow solution
ii. Fast decoupled power flow solution
iii. Newton Raphson load flow solution

Compared with Newton-Raphson method in solving nonlinear power flow problems, Gauss-Seidel method is simpler and consumes less time in computation. However, for a larger system, Gauss-Seidel will take more iterations and more time to converge. Slow rate of convergence, large numbers of iterations, increase of numbers of iteration directly with the increase in the number of buses and effect of convergence due to choice of slack bus are other drawbacks of using Gauss-Seidel method. In view of these disadvantages, Gauss-Seidel method is used only for system having small number of buses. Therefore, in practice, Newton-Raphson is mainly used to solve power flow problems. Many advantages are attributed to the Newton-Raphson (NR) approach. Its convergence characteristics are relatively more powerful compared to other alternative processes and the reliability of Newton-Raphson approach is comparatively good, since it can solve cases that lead to divergence with other popular processes. Failures do occur on some ill-conditional problems (Jagpreet & Rajni., 2016).

2.4.2 Newton-Raphson Iterative Method

Given a set of non linear equations, (Hadi, 1999) ,

$$\begin{aligned} y_1 &= f_1(\mathrm{x}_1, \mathrm{x}_2, \ldots.., \mathrm{x}_n) \\ y_2 &= f_2(\mathrm{x}_1, \mathrm{x}_2, \ldots.., \mathrm{x}_n) \\ \ldots. & \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ y_n &= f_n(\mathrm{x}_1, \mathrm{x}_2, \ldots.., \mathrm{x}_n) \end{aligned} \tag{2.19}$$

And the initial estimate for the solution vector

$$\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots\ldots\ldots \mathrm{x}_n^{(0)}$$

Assuming $\Delta \mathrm{x}_1, \Delta \mathrm{x}_2, \ldots\ldots\ldots, \Delta \mathrm{x}_n$ are the corrections required for $\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots\ldots\ldots \mathrm{x}_n^{(0)}$ so that the equations (2.19) are solved i.e.,

$$\begin{aligned} y_1 &= f_1(\mathrm{x}_1^{(0)} + \Delta \mathrm{x}_1, \mathrm{x}_2^{(0)} + \Delta \mathrm{x}_2, \ldots\ldots\ldots \mathrm{x}_n^{(0)} + \Delta \mathrm{x}_n) \\ y_2 &= f_2(\mathrm{x}_1^{(0)} + \Delta \mathrm{x}_1, \mathrm{x}_2^{(0)} + \Delta \mathrm{x}_2, \ldots\ldots\ldots \mathrm{x}_n^{(0)} + \Delta \mathrm{x}_n) \\ \ldots.. & \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ y_n &= f_n(\mathrm{x}_1^{(0)} + \Delta \mathrm{x}_1, \mathrm{x}_2^{(0)} + \Delta \mathrm{x}_2, \ldots\ldots\ldots \mathrm{x}_n^{(0)} + \Delta \mathrm{x}_n) \end{aligned} \tag{2.20}$$

Each equation of the set (2.20) can be expanded by Taylor's series for a function of two or more variables. For example, the following is obtained for the first equation (Hadi, 1999) .

$$
\begin{aligned}
y_1 &= f_1(\mathrm{x}_1^{(0)} + \Delta\,\mathrm{x}_1, \mathrm{x}_2^{(0)} + \Delta\,\mathrm{x}_2, \ldots\ldots\ldots \mathrm{x}_n^{(0)} + \Delta\,\mathrm{x}_n) \\
y_1 &= f_1(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) + \Delta\,\mathrm{x}_1 \left.\frac{\partial f_1}{\partial x_1}\right|_0 + \Delta\,\mathrm{x}_2 \left.\frac{\partial f_1}{\partial x_2}\right|_0 + \Delta\,\mathrm{x}_n \left.\frac{\partial f_1}{\partial x_n}\right|_0 + \psi_1
\end{aligned}
$$

Where ψ_1 is a function of higher powers of $\Delta\,\mathrm{x}_1, \Delta\,\mathrm{x}_2, \ldots\ldots\ldots, \Delta\,\mathrm{x}_n$ and second, third …, derivatives of the function f1. Neglecting ψ_1, the linear set of equations resulting is as follows (Hadi, 1999):

$$
\begin{aligned}
y_1 &= f_1(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) + \Delta\,\mathrm{x}_1 \left.\frac{\partial f_1}{\partial x_1}\right|_0 + \Delta\,\mathrm{x}_2 \left.\frac{\partial f_1}{\partial x_2}\right|_0 + \Delta\,\mathrm{x}_n \left.\frac{\partial f_1}{\partial x_n}\right|_0 \\
y_2 &= f_2(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) + \Delta\,\mathrm{x}_1 \left.\frac{\partial f_2}{\partial x_1}\right|_0 + \Delta\,\mathrm{x}_2 \left.\frac{\partial f_2}{\partial x_2}\right|_0 + \Delta\,\mathrm{x}_n \left.\frac{\partial f_2}{\partial x_n}\right|_0 \\
\ldots\ldots &\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
y_n &= f_n(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) + \Delta\,\mathrm{x}_1 \left.\frac{\partial f_n}{\partial x_1}\right|_0 + \Delta\,\mathrm{x}_2 \left.\frac{\partial f_n}{\partial x_2}\right|_0 + \Delta\,\mathrm{x}_n \left.\frac{\partial f_n}{\partial x_n}\right|_0
\end{aligned}
\tag{2.21}
$$

$$
\begin{bmatrix}
y_1 - f_1(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) \\
y_2 - f_2(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)}) \\
\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
y_n = f_n(\mathrm{x}_1^{(0)}, \mathrm{x}_2^{(0)}, \ldots \mathrm{x}_n^{(0)})
\end{bmatrix}
=
\begin{bmatrix}
\left.\frac{\partial f_1}{\partial x_1}\right|_0 & \left.\frac{\partial f_1}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_1}{\partial x_n}\right|_0 \\
\left.\frac{\partial f_2}{\partial x_1}\right|_0 & \left.\frac{\partial f_2}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_2}{\partial x_n}\right|_0 \\
\ldots\ldots & \ldots\ldots & \ldots\ldots & \ldots\ldots \\
\left.\frac{\partial f_n}{\partial x_1}\right|_0 & \left.\frac{\partial f_n}{\partial x_2}\right|_0 & \cdots & \left.\frac{\partial f_n}{\partial x_n}\right|_0
\end{bmatrix}
\begin{bmatrix}
\Delta\,\mathrm{x}_1 \\
\Delta\,\mathrm{x}_2 \\
\ldots\ldots \\
\Delta\,\mathrm{x}_n
\end{bmatrix}
\tag{2.22}
$$

Or $$D = JR \tag{2.22}$$

Where J is the Jacobain for the functions f_i and R is the change vector $\Delta\,\mathrm{x}_i$. Equation (2.22) may be written in iterative form as (Hadi, 1999):

$$\mathrm{D}^{(\mathrm{k})} = J^{(\mathrm{k})} R^{(\mathrm{k})}$$

Hence, $R^{(\mathrm{k})} = J^{(\mathrm{k})-(1)}\mathrm{D}^{(\mathrm{k})}$ (2.23)

The new values for $\mathrm{x}_i\mathrm{s}$ are calculated from

$$\mathrm{x}_i^{(\mathrm{k+1})} = \mathrm{x}_i^{(\mathrm{k})} + \Delta\mathrm{x}_i^{(\mathrm{k})} \tag{2.24}$$

Load flow using Newton-Raphson can be formulated as (Hadi, 1999):

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2.25}$$

Expressing in polar form;

$$I_i = \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{2.26}$$

Where $I_i = \dfrac{p_i - jQ_i}{V_i}$

$$p_i - jQ_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{2.27}$$

Separating the real part and the imaginary part gives equation (2.28) and (2.29)

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.28}$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.29}$$

Expanding equations (2.28) and (2.29) in Taylor-series and neglecting higher order terms gives equation (2.30)

$$\begin{bmatrix} \Delta P_2^{(\mathrm{p})} \\ \vdots \\ \Delta P_n^{(\mathrm{p})} \\ \hline \Delta Q_2^{(\mathrm{p})} \\ \vdots \\ \Delta Q_n^{(\mathrm{p})} \end{bmatrix} = \left[\begin{array}{cc|cc} \left(\frac{\partial P_2}{\partial \delta_2}\right)^{(p)} \cdots & \left(\frac{\partial P_2}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial P_2}{\partial |V_2|}\right)^{(p)} \cdots & \left(\frac{\partial P_2}{\partial \delta_n}\right)^{(p)} \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{\partial P_n}{\partial \delta_2}\right)^{(p)} \cdots & \left(\frac{\partial P_n}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial P_n}{\partial |V_2|}\right)^{(p)} \cdots & \left(\frac{\partial P_n}{\partial |V_n|}\right)^{(p)} \\ \hline \left(\frac{\partial Q_2}{\partial \delta_2}\right)^{(p)} \cdots & \left(\frac{\partial Q_2}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial Q_2}{\partial |V_2|}\right)^{(p)} \cdots & \left(\frac{\partial Q_2}{\partial \delta_n}\right)^{(p)} \\ \vdots & \vdots & \vdots & \vdots \\ \left(\frac{\partial Q_n}{\partial \delta_2}\right)^{(p)} \cdots & \left(\frac{\partial Q_n}{\partial \delta_n}\right)^{(p)} & \left(\frac{\partial Q_n}{\partial |V_2|}\right)^{(p)} \cdots & \left(\frac{\partial Q_n}{\partial |V_n|}\right)^{(p)} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(\mathrm{p})} \\ \vdots \\ \Delta \delta_n^{(\mathrm{p})} \\ \hline \Delta |V_2|^{(\mathrm{p})} \\ \vdots \\ \Delta |V_n|^{(\mathrm{p})} \end{bmatrix} \tag{2.30}$$

In the above equation, bus-1 is assumed to be the slack bus.

The Jacobian matrix gives the linearized relationship between small changes in phase angle ($\Delta\, \delta_i^{(\mathrm{k})}$) and voltage magnitude $\Delta[\, V_i^k\,]$ with small changes in real and reactive power $\Delta\, P_i^k$ and $\Delta\, Q_i^k$ (Hadi, 1999).

Equation (2.30) can be written in short form as thus (Hadi, 1999):

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \tag{2.31}$$

The diagonal and off diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.32}$$

$$\frac{\partial Q_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j)\ \mathrm{j} \neq \mathrm{i} \tag{2.33}$$

Similarly we can find the diagonal and off diagonal elements for J_2, J_3 and J_4.

The terms ΔP_i^k and ΔQ_i^k are the difference between the scheduled and calculated values which are known as power residuals, and is given by (Hadi, 1999):

$$\Delta P_i^k = P_i^{sch} - P_i^{(k)} \tag{2.34}$$

$$\Delta Q_i^k = Q_i^{sch} - Q_i^{(k)} \tag{2.35}$$

Using the values of power residuals and Jacobian matrix, $\delta_i^{(\mathrm{k})}$ and V_i^k are calculated from equation (2.30) to complete particular iteration and the new values calculated as shown in equation (2.36) and (2.37) below are used for next iteration (Hadi, 1999).

The new estimates for bus voltages are

$$\delta_i^{(\mathrm{k+1})} = \delta_i^{(\mathrm{k})} + \Delta\delta_i^{(\mathrm{k})} \tag{2.36}$$

$$\left|V_i^{(\mathrm{k+1})}\right| = \left|V_i^{(\mathrm{k})}\right| + \Delta\left|V_i^{(\mathrm{k})}\right| \tag{2.37}$$

2.4.3 Algorithm for Newton Raphson Method

The procedure for Newton Raphson load flow method is described as follows (Naik, 2014):

1. P_i and Q_i are specified for the load buses, the values of voltage magnitudes and phase angles are set equal to the values of slack bus values, 1.0 and 0.0 i.e, V_i=1.0 and δ_i=0.0. for voltage-regulated buses, where V_i and P_i^{sch} are specified, phase angle are set equal to the slack bus angle, or 0,i.e., $\delta i = 0$.
2. For load buses P_i^k and Q_i^k are calculated from the equations. And ΔP_i^k and ΔQ_i^k are calculated.
3. From voltage controlled buses P_i^k and Q_i^k are calculated from equations respectively.
4. The elements of Jacobian matrix (J_1, J_2, J_3 and J_4) are calculated.

5. Computation of new voltage and phase angles
6. The process is repeated until the residuals ΔP_i^k and ΔQ_i^k is less than the specified accuracy.

2.5 Contingency Analysis

Contingency refer to disturbances such as transmission element outages, generator outages or load variations which may cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the operating constraints. Contingency analysis is the study of the outage of elements such as transmission lines, transformers and generators, and investigation of the resulting effects on line power flows and bus voltages of the remaining system (Gasim *et al.*, 2012).

Contingency happens as unexpected opening of the power transmission lines, generators tripping condition, sudden changes in power generation or unexpected changes in loads. Contingency analysis offers tools for analyzing, creating, managing, and reporting lists of contingencies and violations.

Generally, once the current working state of a system is known, contingency analysis can be broken down into the following steps (Patel *et al.*, 2015):

a. Contingency Definition: it is the first step of contingency analysis. It consists of all set of possible contingencies that may occur in a power system. This process comprises of creating contingency list.
b. Contingency Selection: it is the second step and it is the process which involves selection of severe contingencies from the list that may lead to bus voltage and power limit violations. Here in this process contingency list is minimized by elimination of least severe

contingency and taking into account of most severe ones. The severity of contingencies is found by index calculation for this process.

c. Contingency Evaluation: it is the third step and the most important one as it involves necessary control action and necessary security actions which are needed in order to mitigate the effects of most severe contingencies in a power system. Finally, in the contingency evaluation, the selected contingencies are ranked in order of their security, till no violation of operating limits is observed (Patel *et al*., 2015).

2.5.1 Contingency Selection

Contingency selection is the second step and it is the process which involves selection of severe contingencies from the list that may lead to bus voltage and power limit violations. Here in this process contingency list is minimized by elimination of least severe contingency and taking into account of most severe ones. The severity of contingencies is found by index calculation for this process (Patel *et al*., 2015).

Since contingency analysis process involves the prediction of the effect of individual contingency cases, the above process becomes very tedious and time consuming when the power system network is large. In order to alleviate the above problem contingency screening or contingency selection process is used. Practically it is found that all the possible outages does not cause the overloads or under voltage in the other power system equipment. The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection (Roy *et al*., 2011).

2.5.2 Contingency Evaluation

The contingencies are selected by calculating a kind of severity indices known as Performance Indices (PI). PI is the method which is used for quantifying the severity and ranking those contingencies in the order of their severity. These indices are calculated using the conventional power flow algorithms for individual contingencies in an off line mode. Based on the values obtained the contingencies are ranked in a manner where the highest value of PI is ranked first. The analysis is then done starting from the contingency that is ranked one and is continued till no severe contingencies are found (Roy *et al.*, 2011).

Finally, in the contingency evaluation, the selected contingencies are ranked in order of their security, till no violation of operating limits is observed (Patel *et al.*, 2015).

There are two kinds of performance indices which are of great use, these are:

i. Active Power Performance Index (APPI)

APPI reflects the violation of line active power flow. It provides a measure of the severity of the line overloads for a given state in a power system and is given by equation (2.38) (Naik *et al.*, 2015):

$$APPI = M\sum_{i=1}^{L}\left(\frac{P_i}{P_i^{\max}}\right)^n \tag{2.38}$$

P_i is active power flow in line i,

$P_i^{\max}$ is maximum active power flow in line i,

n is the specified exponent

L is the total number of transmission lines in the system.

M is the weighting factor

The value of maximum power flow in each line is calculated using the formula in equation (2.39) (Naik *et al.*, 2015):

$$P_i^{\max} = \frac{V_i \times V_j}{X} \tag{2.39}$$

V_i is voltage at bus i is obtain from Newton Raphson load flow solution

V_j is voltage at bus j is obtain from Newton Raphson load flow solution

X is reactance of the line connecting bus "i" and bus "j"

ii. Reactive Power Performance Index (RPPI)

RPPI is another performance index parameter which is corresponding to bus voltage magnitude violations. It mathematically given by equation (2.40) (Naik *et al.*, 2015):

$$RPPI = \sum_{i=1}^{N_{pq}} \left[\frac{2(V_i - V_{inom})}{(V_{i\max} - V_{i\min})} \right]^2 \tag{2.40}$$

V_i is voltage of bus i

V_{imax} and V_{imin} are maximum and minimum voltage limits

V_{inom} is average of V_{imax} and V_{imin}

N_{pq} is total number of load buses in the system

The bus voltages are influenced by the reactive power produced by the generating units and RPPI gives the severity of abnormal voltages until the reactive power lie in the limits. Under contingency case the reactive power may approach the limits, and in this scenario the AC load flow computes the bus voltages by considering the reactive power limits and thus voltage violation is observed from their actual voltage at the generator buses (Abdulrazzaq, 2015).

For calculation of RPPI it is required to know the maximum and minimum voltage limits, generally a margin of ± 5% is kept for assigning the limits. Performance indices are useful for performing the contingency selection (Gasim *et al.*, 2012).The flow chat of contingency selection is represented in Figure 2.3.

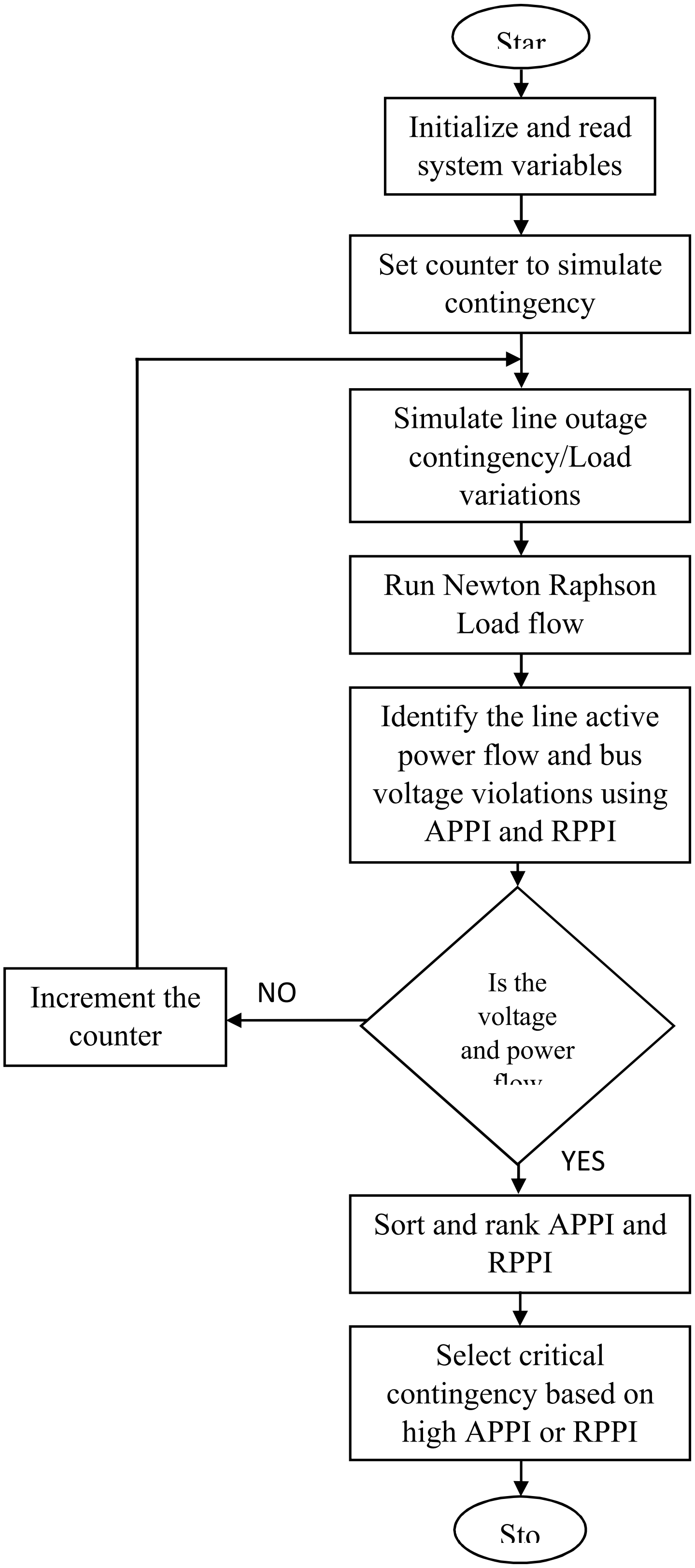


Figure 2.3: Flow Chart for Contingency Selection Naik, (2014).

2.5.3 Percentage Improvement

The formula for calculating the percentage improvement for the APPI and RPPI is given by equation (2.41) and (2.42).

$$APPI = \frac{APPI\ before\ placement\ of\ UPFC - APPI\ after\ placement\ of\ UPFC}{APPI\ before\ placement\ of\ UPFC} \times 100\% \qquad (2.41)$$

Equation (2.41) indicates the percentage reduction in the degree of the total lines overload in the network.

$$RPPI = \frac{RPPI\ before\ placement\ of\ UPFC - RPPI\ after\ placement\ of\ UPFC}{RPPI\ before\ placement\ of\ UPFC} \times 100\% \qquad (2.42)$$

Equation (2.42) indicates the percentage reduction in the severity of the bus voltages violation in the network.

2.6 Conventional Methods Of Voltage Regulation

In order to keep load bus voltage constant, many conventional compensating devices such as listed below can be used. In general, these can be referred as VAR compensators (Theraja, 1999)

1. **Static Capacitors**. Compensation of transmission lines utilizes both series and shunt capacitors to cancel a portion of the inductive reactance of the transmission line, so by means of compensation it can improve the power transmission capability of the line. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. Series and shunt compensation has been applied mostly to long transmission lines and other locations where the transmission distances, are great and where large power transfers over these distances are required (Joshi & Kothari, 2014). However, they have short service life ranging from 8 to 10 years, easily damaged if the

voltage exceeds the rated value and once the capacitors are damaged, their repair is uneconomical.

2. **Synchronous Motor**. A synchronous motor takes a leading current when over-excited and therefore, behaves as a capacitor. An over-excited synchronous motor running on no load is known as synchronous condenser. When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralizes the lagging reactive component of the load. Thus the power factor is improved. However, there are considerable losses in the motor, the motor produces noise, except in sizes above 500kVA, the cost is greater than that of the static capacitors of the same rating and the general maintenance cost is high.
3. **Tap Changing Transformer**. The tap changing in the power transformer is mainly done for keeping the output voltage within the prescribed limit. Power transformers are provided with on-load tap changer. The tap setting arrangement is mainly used for changing the turn ratio of the transformer to regulate the system voltage while the transformer is delivering the load. The main feature of an on-load tap changer is that during its operation the main circuit of the switch should not be opened. Thus, no part of the switch should get the short circuit.
4. **Buck-Boost Transformer**. Buck-boost transformers are used situations where the line voltage is consistently below or above the rated load voltage. Their main function is to adjust a line voltage by a small amount (normally 5% to 27%) to match the load voltage (Suzette, 2012). They are commonly used in applications that require boosting of line voltage and in applications where the nominal voltage is above or below the prescribed voltage level. Buck-Boost transformers do not compensate for fluctuating voltages; they will always increase or decrease the voltage by a constant percentage of the source voltage.

2.7 Flexible AC Transmission Systems (Facts) Devices

According to IEEE in (Hingorani & Gyugyi, 2000), FACTS is defined as an alternating current transmission systems incorporating power electronics based and other static controllers to enhance controllability and power transfer capability.

FACTS technology opens up new opportunities for controlling power and enhancing the usable capacity of transmission lines (Zhang *et al*., 2012).These opportunities arise through the ability of FACTS Controllers to control the interrelated parameters that govern the operation of transmission systems including series impedance, shunt impedance, current, voltage, phase angle, and the damping of oscillations at various frequencies below the rated frequency. These constraints cannot be overcome, while maintaining the required system reliability, by mechanical means without lowering the useable transmission capacity. By providing added flexibility, FACTS Controllers can enable a line to carry power closer to its thermal rating (Hingorani & Gyugyi, 2000).

FACTS-devices can be utilized to increase the transmission capacity, the stability margin and dynamic behavior or serve to ensure improved power quality. Their main capabilities are reactive power compensation, voltage control and power flow control. Due to their controllable power electronics, FACTS device provide always a fast controllability in comparison to conventional devices like switched compensation or phase shifting transformers (Hingorani & Gyugyi, 2000).

Several FACTS-devices have been introduced for various applications worldwide. In most of the applications the controllability is used to avoid cost intensive or landscape requiring extensions of power systems, for instance like upgrades or additions of substations and power lines. The basic applications of FACTS-devices are: power flow control, increase of transmission capability, voltage control, reactive power compensation, stability improvement, power quality improvement and flicker mitigation (Zhang *et al*., 2012).

2.7.1 Types of FACTS Controllers

FACTS controllers can be broadly divided into four categories (Patel *et al.*, 2015), which include,

i. Series Controllers
ii. Shunt Controllers
iii. Combined Series-Series Controllers
iv. Combined Series-Shunt Controllers.

i. *Series Controllers:* These devices are connected in series with the lines to control the reactive and capacitive impedance there by controlling or damping various oscillations in a power system. In principle, all series controllers inject voltage in series with the line. As long as the voltage is in phase quadrature with the line current, the series controller only supplies or consumes variable reactive power. Examples are Static Synchronous Series Compensator (SSSC), Thyristor controlled Series Capacitor (TCSC), Thyristor-Controlled Series Reactor (TCSR). They can be effectively used to control current and power flow in the system and to damp system's oscillations. The symbolic representation of series FACTS controllers is given in Figure 2.4.

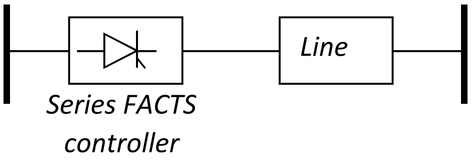


Figure 2.4: Symbolic of Series Compensation Controller (Patel *et al.*, 2015)

ii. *Shunt Controllers*: As in the case of series controllers, the shunt controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt controllers inject current into the system at the point of connection. Even a variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt controller only supplies or consumes reactive power. Any other phase relationship will involve handling of real power as well. The reactive power injected can be varied by varying the Static Synchronous Generator (SSG), Static VAR Compensator (SVC). Shunt controllers include Static Compensator (STATCOM), shunt-connected thyristor-controlled reactor (TCR), shunt-connected thyristor-switched reactor (TSR), shunt-connected thyristor-switched capacitor (TSC), and shunt-connected thyristor-switched resistor (TCBR). The symbolic representation of shun FACTS controllers is given in Figure 2.5.

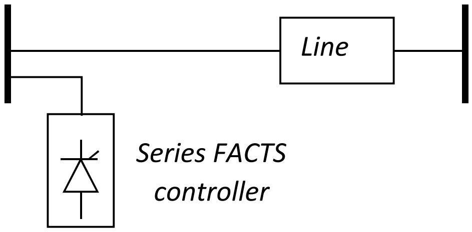


Figure 2.5: Symbolic of Shunt Compensation Controller (Patel *et al.*, 2015)

ii. *Combined Series-Series Controllers*: This controller may have two configurations consisting of series controllers in a coordinated manner in a transmission system with multi lines or an independent reactive power controller for each line of a multiline system. An example of this type of controller is the Interline Power Flow Controller (IPFC), which helps in balancing both the real and reactive power flows on the lines. The symbolic representation of series-series FACTS controllers is given in Figure 2.6.

iii.

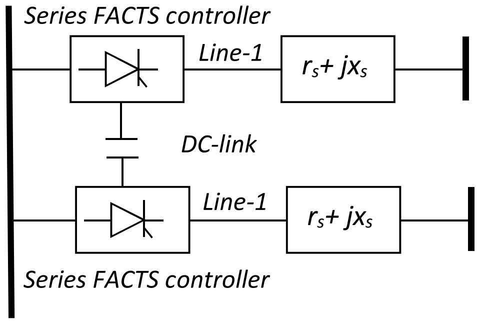


Figure 2.6: Symbolic of Series-Series Compensation Controller (Patel *et al.*, 2015)

iv. *Combined Series-Shunt Controllers*: In this type of controller there are two unified controllers a shunt controller to inject current into the system and a series controller to inject series voltage. Examples of such controllers are UPFC and Thyristor Controlled Phase-Shifting Transformer (TCPST). The symbolic representation of series-shun FACTS controllers is given in Figure 2.7.

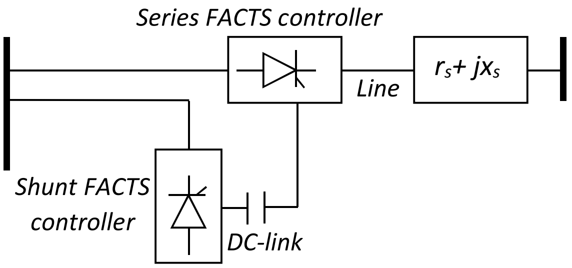


Figure 2.7: Symbolic of Series-Shunt Compensation Controller (Patel *et al.*, 2015)

2.7.2 Role of FACTS Controllers in Power System Operation

Due to the voltage, current, impedance, real power, and reactive power interrelation, each controller has multiple attributes of what they can do in terms of controlling the voltage, power flow, stability and so on. These controllers can have multiple open loop and closed loop controls to accomplish multiple benefits **(**Georgilakis & Vernados, 2011). Table 2.1 presents the role of FACTS controllers in power system operation.

Table 2.1: Role of FACTS Controllers in Power System Operation **(**Georgilakis & Vernados, 2011)

Operating Problem	Corrective Action	FACTS Controllers
Voltage limits:		
Low voltage at heavy load	Supply reactive power	STATCOM, SVC
High voltage at low load	Absorb reactive power	STATCOM, SVC

High voltage following an outage	Absorb reactive power; prevent overload	STATCOM, SVC
Low voltage following an outage	Supply reactive power; prevent overload	STATCOM, SVC
Thermal limits:		
Transmission circuit overload	Reduce overload	TCSC, UPFC
Tripping of parallel circuits	Limit circuit loading	TCSC, UPFC
Loop flows:		
Parallel line load sharing	Adjust series reactance	UPFC, TCSC
Post-fault power flow sharing	Rearrange network or use thermal limit actions	TCSC, UPFC
Power flow direction reversal	Adjust phase angle	UPFC

2.7.3 FACTS Controllers

Control of compensating reactive power in weak zones of power system ensures the improvement of voltage stability. Traditional means such as capacitor banks are a source of reactive power. There are similarly numerous universal controllers such as tap changing transformers which are capable to stabilize power system (Meddeb *et al*., 2016). Nonetheless, the limitation and the slow response of such means, give FACTS devices the opportunity to be most used universally in stability study.

i. *SVC*

SVC which is one of the most installed FACTS systems in world's networks is able to provide adjustable reactive power in order to improve voltage profile (Nandi & Chakraborty, 2014). Indeed, in case of reactive power excess, SVC absorbs the increased quantity, which decreases bus voltage where it is connected. Otherwise, it acts like a capacitor and produces the reactive required to increase voltage magnitude.

ii. *TCSC*

TCSC is an important device in the FACTS family. It can be modeled as an integrated adjustable reactance in series with transmission line. This structure allows it to adjust line impedance and therefore control powers transmitted through lines. In contrast to shunt compensators, TCSC will be more effective because thyristors can offer flexible adjustment, and more advanced control theories can be easily applied (Meddeb *et al*., 2016).

iii. *UPFC*

UPFC is a hybrid compensator i.e. it is designed by combining the series compensator and shunt compensator coupled with a common DC capacitor. It can control the three control parameters (phase angle, line impedance and bus voltage) either individually or in appropriate combinations at its series-connected output while maintaining reactive power support at its shunt-connected input device to enhance the transmission capacity of lines and control the power flow (Meddeb *et al*., 2016).

UPFC consists of two converters: one connected in series with the transmission line through a series inserted transformer and the other one connected in shunt with the transmission line through a shunt transformer. The DC terminal of the two converters is connected together with a DC capacitor. The series converter control to inject voltage magnitude and phase angle in series with the line to control the active and reactive power flows on the transmission line. Hence the series converter will exchange active and reactive power with the line (Sarkar, 2013).The shun Converter is used to generate a voltage source at the fundamental frequency with variable amplitude ($0 \leq V_T \leq V_{Tmax}$) and phase angle ($0 \leq Ø_T \leq 2\pi$), which is added to the AC transmission line by the series connected boosting transformer. Thus, UPFC can be used for direct bus and line voltage control, series compensation, phase shifter, and their combinations. With these features, UPFC is probably the most powerful and versatile FACTS controller which combines the properties of TCSC, TCPR and SVC. It is only FACTS controller having the unique ability to simultaneously control all three parameters of power flow i.e. voltage, line impedance and phase angle. The symbolic representation of the UPFC basic circuit arrangement is given in Figure 2.8.

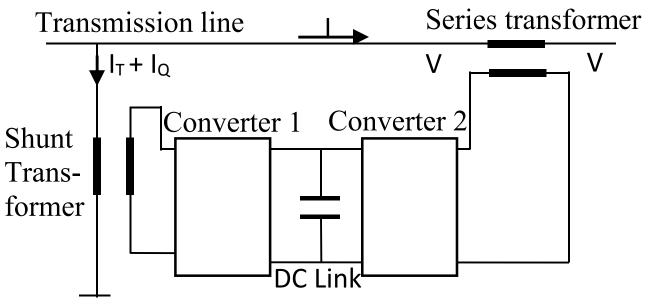


Figure 2.8: The UPFC Basic Circuit Arrangement (Singh & Erlich, 2005)

The equivalent circuit of UPFC placed in line-k connected between bus-i and bus-j is shown in Figure 2.9.

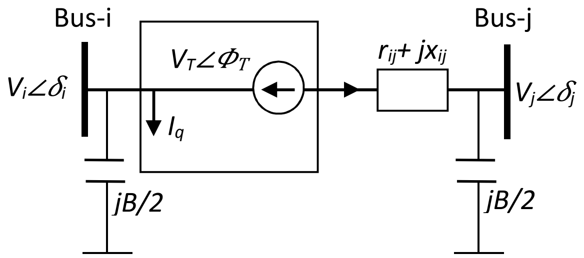


Figure 2.9: Equivalent Circuit of UPFC (Singh & Erlich, 2005)

V_T is the series injected voltage magnitude of the UPFC

Φ_T is the series injected phase angle of the UPFC

V_i is bus voltage at node i

V_j is bus voltage at node j

δ_{ij} is the voltage angle of the transmission line

g_{ij} is conductance of i,j

b_{ij} is susceptance of i,j

I_q is the reactive current flowing in the shunt transformer to improve the voltage of the bus where UPFC is connected

Based on the basic principle of UPFC and network theory, the active and reactive power flows in the line, from bus-i to bus-j, having UPFC can be written as (Singh & Erlich, 2005):

$$\begin{aligned} P_{ij} = {} & (\mathrm{V}_i^2 + \mathrm{V}_T^2)\,\mathrm{g}_{ij} + 2V_i V_T g_{ij} \cos(\phi_T - \delta_i) - V_j V_T [\mathrm{g}_{ij}\cos(\phi_T - \delta_i) + \mathrm{b}_{ij}\sin(\phi_T - \delta_i)] - \\ & \mathrm{V}_i V_j (g_{ij} \cos\delta_{ij} + b_{ij} \sin\delta_{ij}) \end{aligned} \tag{2.43}$$

$$\begin{aligned} Q_{ij} = {} & -V_i I_q - V_i^2 (b_{ij} + \frac{B}{2}) - V_i V_T [\mathrm{g}_{ij}\sin(\phi_T - \delta_i) + \mathrm{b}_{ij} \cos(\phi_T - \delta_i)] - \\ & V_i V_T (\mathrm{g}_{ij} \sin\delta_{ij} - b_{ij} \cos\delta_{ij}) \end{aligned} \tag{2.44}$$

Similarly, the active and reactive power flows in the line, from bus-*j* to bus-*i*, having UPFC can be rewritten as:

$$\begin{aligned} P_{ji} = {} & V_j^2 g_{ij} - V_j V_T [\mathrm{g}_{ij}\cos(\phi_T - \delta_j) - \mathrm{b}_{ij}\sin(\phi_T - \delta_j)] - \\ & V_i V_j \left(g_{ij} \cos\delta_{ij} - b_{ij} \sin\delta_{ij}\right) \end{aligned} \tag{2.45}$$

$$\begin{aligned} Q_{ji} = {} & -V_j^2 (b_{ij} + \frac{B}{2}) - V_j V_T [\mathrm{g}_{ij}\sin(\phi_T - \delta_j) - \mathrm{b}_{ij}\cos(\phi_T - \delta_j)] + \\ & V_i V_j \left(g_{ij} \sin\delta_{ij} + b_{ij} \cos\delta_{ij}\right) \end{aligned} \tag{2.46}$$

The real power and reactive power injections at bus-i where the UPFC is being placed with consideration of the system loading (λ) can be written as:

$$P_i = P_{Gi} - P_{Di}^0 (1 + \lambda) = \sum_{j \in N_b} P_{ij} \tag{2.47}$$

$$Q_i = Q_{Gi} - Q_{Di}^0 (1 + \lambda) = \sum_{j \in N_b} Q_{ij} \tag{2.48}$$

Where P_{Di}^0 and Q_{Di}^0 are the initial real and reactive power demands

P_{Gi} and Q_{Gi} are the real and reactive power generated at bus-*i* respectively

N_b is the number of system buses

2.8 Line Loadability

Loadability of a transmission line is defined as the optimum power transfer capability of a transmission line under a specified set of operating criteria. Three major line-loading limits are (Patel *et al*., 2015):

a. the thermal limit,
b. the voltage-drop limit, and
c. the steady-state stability limit.

The maximum temperature of a conductor determines its thermal limit. Conductor temperature affects the conductor sag between towers and the loss of conductor tensile strength due to annealing. If the temperature is too high, prescribed conductor-to-ground clearances may not be met, or the elastic limit of the conductor may be exceeded such that it cannot shrink to its original length when cooled. Conductor temperature depends on the current magnitude and its time duration, as well as on ambient temperature, wind velocity, and conductor surface conditions. The loadability of short transmission lines (less than 80 km in length) is usually determined by the conductor thermal limit or by ratings of line terminal equipment such as circuit breakers. For longer line lengths (up to 300 km), line loadability is often determined by the voltage-drop limit. For line lengths over 300 km, steady-state stability becomes a limiting factor (Patel *et al*., 2015).

2.8.1 Maximum Loadability Formulation

The maximum loadability is obtained by the following formulation (Singh & Erlich, 2005).

$$\text{Objective function} = \text{Max } \{\text{Loadability } (\lambda)\} \tag{2.49}$$

Subject to the following constraints:

i. Equality constraints**:** Power flow equations corresponding to both real and reactive powers as defined in (2.47) and (2.48) must satisfy.

ii. Inequality constraints: These include the operating limits on the various power system variables and the parameters of UPFC as given below.

$$Q_{gi}^{\min} \leq Q_i \leq Q_{gi}^{\max} \quad \text{i=1,2,3.....N}_b \tag{2.50}$$

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad \text{i=1,2,3.....N}_b \tag{2.51}$$

$$\delta_i^{\min} \leq \delta_i \leq \delta_i^{\max} \quad \text{i=1,2,3.....N}_b \tag{2.52}$$

$$0 \leq V_T \leq V_{T\max}; 0 \leq \phi_T \leq 2\pi; I_q^{\min} \leq I_q \leq I_q^{\max} \tag{2.53}$$

Equation (2.50) represents the limits on the reactive power generations. The limits on the bus voltage magnitude and angle are given by equation (2.51) and (2.52), respectively. Equation (2.53) includes limitation of the UPFC parameters (Singh & Erlich, 2005).

2.9 Review Of Related Works

The review of similar works gives an overview of methods used by other researcher in the placement of FACTS devices and in analyzing contingency in electrical power system network. They are stated as thus:

Sutha & Kamaraj, (2008) proposed an optimal location of multi type FACTS devices for multiple contingencies using Particle Swarm Optimization (PSO). The application of PSO algorithm to find the optimal location of multi type FACTS devices in a power system is to eliminate or alleviate the line over loads. The optimizations were performed on the following parameters namely: the location of the devices, their types, their settings and installation cost of the devices for single and multiple contingencies. TCSC, SVC and UPFC were considered and modeled for steady state analysis. The effectiveness of the proposed method was tested for IEEE 6 bus and IEEE 30 bus systems. The result of the work shows that the system security margin cannot be improved further after placing certain optimal number of multi type FACTS devices. However, the combination of three different FACTS devices for the purpose of mitigating contingencies for both single and double line on the same network is not cost effective since UPFC can perform the function of both TCSC and SVC when being installed on a network.

Shaheen *et al*., (2011) proposed a new approach based on Differential Evolution (DE) technique to find out the optimal placement and parameter setting of UPFC for enhancing power system security under single line contingencies. A contingency analysis and ranking process was performed to determine the most severe line outage contingencies considering line overloads and bus voltage limit violations as a Performance Index. DE technique was applied to find out the optimal location and parameter setting of UPFC under the determined contingency scenarios. The proposed approach was tested on an IEEE 14-bus and IEEE 30-bus power systems. Although DE performs superiorly in trying to improve a candidate solution with regard to a given measure of quality and makes few or no assumptions about problem being optimized however, DE do not guarantee an optimal solution on a problems that are continuous or changes over time.

Aghaei *et al*., (2012) proposed a new formulation to determine a security margin in the presence of TCSC and SVC using the Sequential Quadratic Problem (SQP) method. The SQP is proposed to overcome the divergence of the problem near the critical states during the convergence of the Newton-Raphson method in its iterations. To improve voltage stability margin in load domain, TCSC and the SVC model are mathematically employed in the optimization process. Voltage stability margin in the load domain measures the distance from the present operating point to the voltage collapse point, in terms of the load increment. However, using voltage stability margin in term of load increment creates an associate threat due to temperature rise which will also spur the risk of line tripping and system stress due to thermal overload.

Roy & Jain, (2013) proposed a transmission line contingency analysis in power system using Fast Decoupled Newton Raphson method for IEEE-14 bus test system. Contingency selection by calculating two kinds of performance indices; voltage performance index (PIV) and Line performance index (PIF) for single transmission line outage. The ranking of most severe contingency has been done based on the values of performance indices (PIF and PIV). Based on the results of PIF and PIV the most severe transmission line contingency were identified. For cases where there is high resistance/reactance ratio or heavy loading or low voltage at some buses during contingency, FDNR do not converge because it is an approximation method.

Reddy *et al*., (2014) proposed the application of Particle Swarm Optimization (PSO) to find the placement location and sizing of Unified Power Flow Controller (UPFC) device to minimize the voltage stability index and load voltage deviation to improve voltage stability in the power system. Load flow analysis for the determination of power system state variables was done based on the

Equivalent-Current-Inject (ECI) using the Norton Equivalent theorem. The proposed method shows that the voltage support was provided by UPFC with ECI model, and its optimal location and capacity was determined using PSO. However, the use of Equivalent-Current-Inject model is only effective in distribution network where there is high considerable flow of current but less effective in transmission network where high voltages are transmitted with minimal current.

Sayyed *et al.*, (2014) proposed Contingency analysis and improvement of power system security by locating series FACTS devices "Thyristor controlled phase angle regulator (TCPAR)" at optimal location. The contingency conditions were analyzed using line outage distribution factor (LODF). According to the severity of contingency, a real power flow performance index (PI) sensitivity based approach was used to decide optimal location of the series FACTS device (TCPAR) which was utilized to stabilize the system. However, the use of active power performance index does not determine the out of limit bus voltages since it is employed to measure only the line overload.

Eseosa & Samuel, (2014) proposed the impact of UPFC in the Nigeria 330kV integrated power network which comprises of 52 buses. UPFC was incorporated into Newton-Raphson power flow program developed in Matlab programming software environment. The power flow study without FACTS devices shows high power losses but with the introduction of UPFC into the weak buses identified, there was real power loss reduction and reactive power loss saving. However, Nigeria 330kV transmission network in service are not upto 52 buses as claimed in the work. Hence, the analysis makes the result to lack credence since some of the claimed buses were not incorporated into the national grid.

Das & Mohan, (2014) proposed an optimal allocation of FACTS device with multiple objectives using Genetic Algorithm. Genetic Algorithm (GA) was used for optimal location and optimal sizing of TCSC for a purpose of maximizing the system loadability and minimizing the system losses. Although, this method has been applied to obtain promising results, however, when considering a large network, the requested run time of GA will be very long and this will warrant other methods to perform better in terms of placement and sizing of FACTS in an event of contingency.

Ravindra *et al*., (2015) proposed a power system security analysis under transmission line outage condition. The transmission line outage leads to collapse condition. To avoid this type of uncontrolled condition, the power system security needs to be analyzed under transmission line outage condition. The most critical transmission lines are identified using line collapse proximity index values and the system severity is analyzed in terms of transmission line loadings. Although, Voltage collapse proximity indicators provides information of each bus voltage and its proximity to the voltage collapse limits. However, as the operating condition of a power system continuously changes, it is difficult to use these methods to provide real time information due to the significant computational requirements of such methods.

Kavitha & Neela, (2016) proposed an optimal placement of multi-type FACTS Devices under single line contingencies for enhancement of power system security in cost effective manner. The proposed work introduced Biogeography based optimization (BBO) technique to find out the optimal location and parameter setting of the Multi-FACTS devices to enhance system security under single line contingencies. The objective function of the paper comprises of line loadings, voltage deviations at the load buses and cost of the FACTS device. The performance of the algorithm has been validated by comparing the results with the results obtained through the application of Particle Swarm Optimization (PSO) and Weight Improved Particle Swarm Optimization (WIPSO) techniques. The result given from the application of BBO proved that BBO gives a better result as compared with PSO and WIPSO. The method in this work make use of line loading to ensure uniformly distributed loading which helps to ensure system security but ignored the presence of priority load in the system and this could lead to loss of load at critical areas of the network where more power is needed.

Zobeidi *et al*., (2016) stated that stressed power system, due to the increased loading or severe contingencies leads to situation where the system no longer remains in the secure operating region, hence, proposed a reduction of total system reactive power losses method to find optimal placement of FACTS devices in the power system. Optimal placement of TCSC devices is achieved using the reactive power loss sensitivity index based approach and LODF (Line Outage Distribution Factor). The method proposed was tested in two different systems of IEEE 6 bus and IEEE 25 bus systems. However, TCSC are versatile devices that controls the reactive power injection at a bus using power electronics switching components however, its corrective actions are limited when considering multiple line outages leading to blackout.

Malathy & Shunmugalatha, (2016) proposed an improvement of maximum loadability (ML) during single contingency by optimal placement and settings of multi-type FACTS devices like SVC, TCSC and UPFC in transmission network. The devices are located in the system by using Contingency Severity Index (CSI) and Fast Voltage Stability Index (FVSI) respectively which facilitates the enhancement of socio-economic benefits by minimizing the Installation Cost (IC) of FACTS devices and overloading. The problem was tested using IEEE 30 bus system and optimized using Differential Evolution (DE) algorithm. However, optimization work of DE algorithm was not clearly stated in the result since the location and placement of the FACTS devices was clearly stated in the results to be done using Contingency Severity Index (CSI) and Fast Voltage Stability Index (FVSI).

Sharmila, (2016) proposed an optimal location of TCSC and SVC devices to enhance power system security based on contingency ranking. In the author's ranking approach, line outage case has been considered and the ranking is given based on the severity measured using transmission lines overload and bus voltage limit violations as the performance indices. Single contingency analysis for the considered test system was performed on a modified IEEE-30 bus. The computation of performance indices are calculated based on load flow analysis carried out using Newton Raphson method. However, contingency in a power system is caused by the outages of generators which the author failed to consider. Generator outage condition is the most critical one because it results to loss of generation leading to sudden and large changes in both the configuration and the state of the entire system.

Kailay & Brar, (2016) proposed FACTS based power system optimization by using Newton Raphson technique. The load flow calculation of the power system network was modified to include FACTS controller. Aspects of modeling and implementation of the STATCOM which is a shunt connected FACTS controllers was presented with the help of MATLAB programming using Newton Raphson load flow technique. The load flow analysis was performed on IEEE 5 bus system and the technique exhibits very strong convergence characteristics irrespective of the size of the network. However, the claim that the work can be implemented on any network is not substantial since it was only implemented on a small network of 5-bus IEEE network.

Sookananta, (2016) proposed sensitivity index and the Differential Evolution technique applications on the determination of FACTS placement**.** The proposed methods were compared with that of GA which is the most commonly used technique for FACTS device placement. From the result obtained, it shows that among the techniques considered, the use of PI sensitivity index is the fastest in terms of optimal allocation of FACTS devices in comparison to DE and GA. However, in terms of sizing, DE performs better than GA and sensitivity index.

The literatures reviewed shows different techniques carried out for contingency analysis and FACTS device placement for the purpose of increasing the line loadability and voltage stability. The voltage profiles of the networks used in various studies were identified through the use of various load flow techniques. Due to the limitations attached to some of these methods is the reason for the choice of sensitivity indices used in this research. APPI and RPPI used in this research help to quantify and rank the contingency identified according to the level of their severity. Some of the authors that performed contingency analysis did not go further to mitigate the effect of such contingency through the placement of FACTS devices. FACTS devices (UPFC) placement in the event of contingency analysis performed in this research facilitate in mitigating the severity of bus voltage violation and line overload which was analyzed in this research work. Again, some authors that did the placement of FACTS devices did not perform contingency analysis which has an effect of changing the configuration of the entire system when being ignored. Hence, this research work develops a sensitivity index based technique for the placement of UPFC with consideration of contingency analysis to improve the voltage profile and line loadability on Nigeria 330kV transmission network. This approach through the use of UPFC compensates the network during contingency and keeps the voltages in the network within its prescribed range for normal system operation.

CHAPTER THREE

MATERIALS AND METHOD

3.1 Introduction

This chapter gives the detailed procedures (materials and methods) used in achieving the research work, and are discussed below.

3.2 Materials

The materials employed for the actualization of this research are as follows:

3.2.1 Simulation platform

All simulations analyses were carried out in MATLAB 2013a software using Dell PC with the following specifications:

a) Processor: Intel(R) Pentium (R) CPU 2127U @ 1.90GHz

b) Installed Memory (RAM): 4.00GB

c) System type: 64-bit Operating system, x64-based processor

d) Operating System: Windows 8 pro single language.

Details of the program developed are provided in appendix B.

3.3 Nigeria Network Description

The Nigerian power network like many practical systems in developing countries consists of a few generating stations mostly sited in remote locations near the raw fuel sources which are usually connected to the load centers by long transmission lines. Generation, transmission, distribution and marketing of electricity in Nigeria are the statutory functions of Power Holding Company of Nigeria (PHCN). Presently, the national electricity grid consists of nine generating stations comprising three (3) hydro and six (6) thermal with a total installed generating capacity of 6500MW. The thermal stations are mainly in the southern part of the country located at Afam, Okpai, Delta, Ughelli, Egbin and Sapele. The hydroelectric power stations are located at Kainji, Jebba and Shiroro.

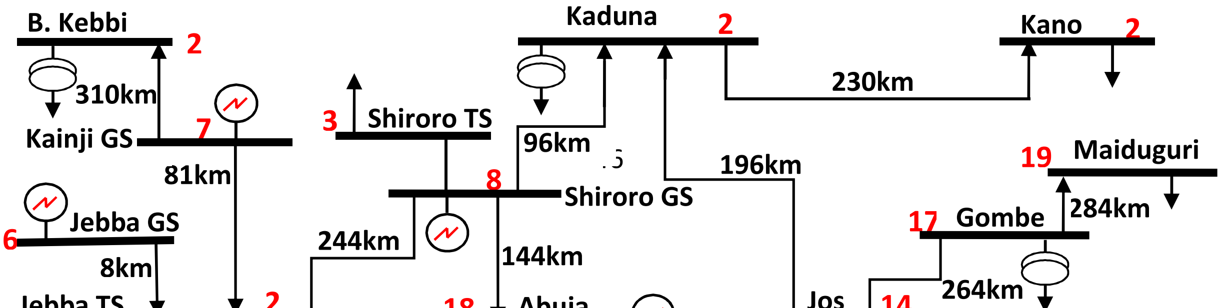
The high voltage transmission in Nigeria is separated into two; the 330kV high voltage transmission and the 132kV high voltage transmission. The 330kV transmission is from the generating stations to the sub-transmission system. The sub-transmission system which works at 132kV is the National Control Centre (NCC) which is at Oshogbo. This 132kV system disseminates voltages at diverse levels. These voltages are 33kV, 11kV and 415/240V distribution levels (Ibe & Okedu, 2009).

The transmission network is made up of 5000km of 330kV lines, 6000km of 132kV lines, 23km of 330/132kV sub-stations and 91km of 132/33kV substations. The distribution sector is comprised of 23,753km of 33kV lines 19,226km of 11kV lines, 679km of 33/11kV sub-stations. There are also 1790 distribution transformers and 680 injection substations (Momoh *et al*., 2003). Although, the installed capacity of the existing power stations is 6500MW the maximum load ever recorded was 4,000MW.

The present installed generating capacity is about 6000MW and the maximum generation of 4000MW for a population of about 160 million. This indeed is grossly inadequate to meet the demand of electricity consumers. The current projected capacity that needs to be injected into the system is estimated at 10,000MW which is hoped to come in through the independent power producers (IPPs) as soon as the deregulation of electricity supply industry is successfully achieved (Ogbuefi & Madueme, 2015).

2.3.1 Nigeria 330kV 31 Bus Transmission Network

The single-line diagram of the existing 330kV Nigeria transmission network used as the case study is as shown in Figure 3.1



In order to evaluate the proposed method, the parameters of the Nigerian 330kV transmission network were considered. The One Line Diagram in Figure (2.9) of the PHCN 330kV Interconnected Network was adopted from the work of Ogbuefi & Madueme, (2015). Transmission line data for the 330kV network which includes resistance and reactance of the lines is given in Table 3.1 and the real and reactive power on each bus of the network are given in the Table 3.2

Table 3.1: Transmission Line Data for 330KV Lines (Ogbuefi & Madueme, 2015)

Bus Name	Shun

SN	From	To	Length (km)	R (P.U)	X (P.U)	$\frac{y}{2}$(P.U)
1.	Akamgbe	Ik-West	17	0.0006	0.0051	0.065
2.	Ayede	Oshogbo	115	0.0041	0.0349	0.437
3.	Ik-West	Egbin	62	0.0022	0.0172	0.257
4.	Ik-West	Benin	280	0.0101	0.0799	1.162
5.	Oshogbo	Jebba	249	0.0056	0.4770	0.597
6.	Oshogbo	Benin	251	0.0089	0.0763	0.954
7.	Jebba TS	Jebba GS	8	0.0030	0.0022	0.033
8.	Jebba TS	Shiroro	244	0.0087	0.0742	0.927
9.	Jebba TS	Kainji	81	0.0022	0.0246	0.308
10.	Kainji	B.Kebbi	310	0.0111	0.9420	1.178
11.	Shiroro	Kaduna	96	0.0034	0.0292	0.364
12.	Kaduna	Kano	320	0.0082	0.0899	0.874
13.	Jos	Gombe	265	0.0095	0.0810	1.010
14	Benin	Ajaokuta	195	0.0070	0.056 0	0.745
15.	Benin	Sapele	50	0.0018	0.0139	0.208
16.	Benin	Onitsha	137	0.0049	0.0416	0.521
17.	Onitsa	N.Heaven	96	0.0034	0.0292	0.0355
18.	Onitsha	Alaoji	138	0.0049	0.0419	0.5240
19.	Alaoji	Afam	25	0.0090	0.0070	0.104
20.	Sapele	Aladja	63	0.0023	0.0190	0.239
21.	Delta	Aladja	30	0.0011	0.0088	0.171
22.	Kainji GS	Jebba TS	81	0.0022	0.0246	0.308
23.	Ayede	lk West	137	0.0049	0.0416	0.521
24.	Egbin TS	Aja	27.5	0.0022	0.0172	0.257
25	Egbin TS	Aja	27.5	0.0022	0.0172	0.257
26.	Kaduna	Jos	197	0.007	0.0599	0.748
27.	Jos	Makurdi	275	0.0029	0.0246	0
28.	Oshogbo	lk West	252	0.0049	0.0341	0.521
29.	Benin	Delta	107	0.0022	0.0190	0.239
30.	Onitsha	Okpai	80	0.0090	0.0070	0.104
31.	Geregu	Ajokuta	5	0.0022	0.0172	0.257
32.	Shiroro	Kaduna	96	0.0034	0.0292	0.364
33.	Gombe	Maiduguri	413	2.2869	16.63992	0.529
34.	N.Haven	Makurdi	549	2.0854	15.6925	0.880

Table 3.2: Bus Data (Ogbuefi & Madueme, 2015)

B No	Bus Name	Generation		Load		V (volts)	Angle (Degree)	Remark
		P(MW)	Q(MVar)	P(MW)	Q(MVar)			

1.	Egbin	-	-	0.0000	0.0000	1.02	0.0000	Slack
2.	Delta Ps	55.000	28.160	-	-	1.0000	0.0000	PV Bus
3.	Okpai	220.000	112.700	-	-	1.0000	0.0000	PV Bus
4.	Sapele	75.000	38.420	-	-	1.0000	0.0000	PV Bus
5.	Afam	479.000	245.390	-	-	1.0000	0.0000	PV Bus
6.	Jebba	322,000	164.960	-	-	1.0000	0.0000	PV Bus
7.	Kainji	323.000	165.490	-	-	1.0000	0.0000	PV Bus
8.	Shiroro	280.000	143.440	-	-	1.0000	0.0000	PV Bus
9.	Geregu	200.000	102.440	-	-	1.0000	0.0000	PV Bus
10.	Oshogbo	-	-	120.370	61.650	1.0000	0.0000	Load Bus
11.	Benin	-	-	160.560	82.240	1.0000	0.0000	Load Bus
12.	Ikj-West	-	-	334.000	171.110	1.0000	0.0000	Load Bus
13.	Ayede	-	-	176.650	90.490	1.0000	0.0000	Load Bus
14.	Jos	-	-	82.230	42.129	1.0000	0.0000	Load Bus
15.	Onitsha	-	-	130.510	66.860	1.0000	0.0000	Load Bus
16.	Akamgba	-	-	233.379	119.560	1.0000	0.0000	Load Bus
17.	Gombe	-	-	74.480	38.140	1.0000	0.0000	Load Bus
18.	Abuja(katamkpe)	-	-	200.000	102.440	1.0000	0.0000	Load Bus
19.	Maiduguri	-	-	10.000	5.110	1.0000	0.0000	Load Bus
20.	Egbin TS	-	-	0.000	0.000	1.0000	0.0000	Load Bus
21.	Aladja	-	-	47.997	24.589	1.0000	0.0000	Load Bus
22.	Kano	-	-	252.450	129.330	1.0000	0.0000	Load Bus
23.	Aja	-	-	119.990	61.477	1.0000	0.0000	Load Bus
24.	Ajaokuta	-	-	63.220	32.380	1.0000	0.0000	Load Bus
25.	N.Heaven	-	-	113.050	57.910	1.0000	0.0000	Load Bus
26.	Alaoji	-	-	163.950	83.980	1.0000	0.0000	Load Bus
27.	Jebba TS	-	-	7.440	3.790	1.0000	0.0000	Load Bus
28.	B.Kebbi	-	-	69.990	35.850	1.0000	0.0000	Load Bus
29.	Kaduna	-	-	149.77	76.720	1.0000	0.0000	Load Bus
30.	ShiroroTS	-	-	73.070	37.430	1.0000	0.0000	Load Bus
31	Makurdi	-	-	80.000	61.220	1.0000	0.0000	Load Bus

3.3 Methodology

The methodology used in carrying out the research work as listed in chapter one sub-section (1.5) are discussed as follows:

3.3.1 Power Flow Analysis

The power flow analysis using Newton Raphson method was carried out through the following outlined steps to obtain the unspecified parameters:

i. Read the network parameters.
ii. Classify the buses into slack bus, generator bus and load bus.
iii. Identify slack bus and set voltage magnitudes and phase angles data to be equal to the slack bus value.
iv. Compute active ($P_i^{(p)}$) and reactive power ($Q_i^{(p)}$) of load buses using equations (2.28) and (2.29).
v. Real and reactive power mismatch $\Delta P_i^{(p)}$ and $\Delta Q_i^{(p)}$ are calculated using equations (2.34) and (2.35).
vi. Compute elements of Jacobian matrix J_1 J_2 J_3 and J_4 using equations (2.32) and (2.33).
vii. New voltage magnitude and phase angles are computed using equations (2.36) and (2.37) to obtain the power flow during normal and contingencies problems.
viii. Continue until scheduled errors of active power and reactive power deviation are within specified tolerance.
ix. Calculate power flows in all the lines.
x. Print the voltage magnitude.
xi. Stop.

3.3.2 Contingency Analysis

Contingency analysis was performed in consideration of cases where elements such as line and load are removed or load variations are considered to determine its effect on the network. In this research work, multiple contingency (N-2) is considered. The steps involved in carrying out the contingency analysis are as follows:

i. Read the system bus data and line data
ii. Without considering the contingency, calculate base case power flow using Newton Raphson technique
iii. Simulate element outage by removing one line, load or line and load variation on the network and proceed to the next step
iv. Using Newton Raphson Power Flow technique calculate the active power flow in the lines and voltage magnitude of each bus
v. Calculate APPI and RPPI using equation (2.38) and (2.40)
vi. Repeat (ii) to (v) until all contingencies are specified
vii. Rank the contingencies in order of severity based on RPPI
viii. Perform Newton Raphson power flow for the most severe contingency case
ix. Print the line overloads and voltage violations.

3.2.3 Contingency Selection

This subsection gives the flow chart of the process of identifying the contingencies that actually lead to the violation of the operational limits in Figure 3.1.

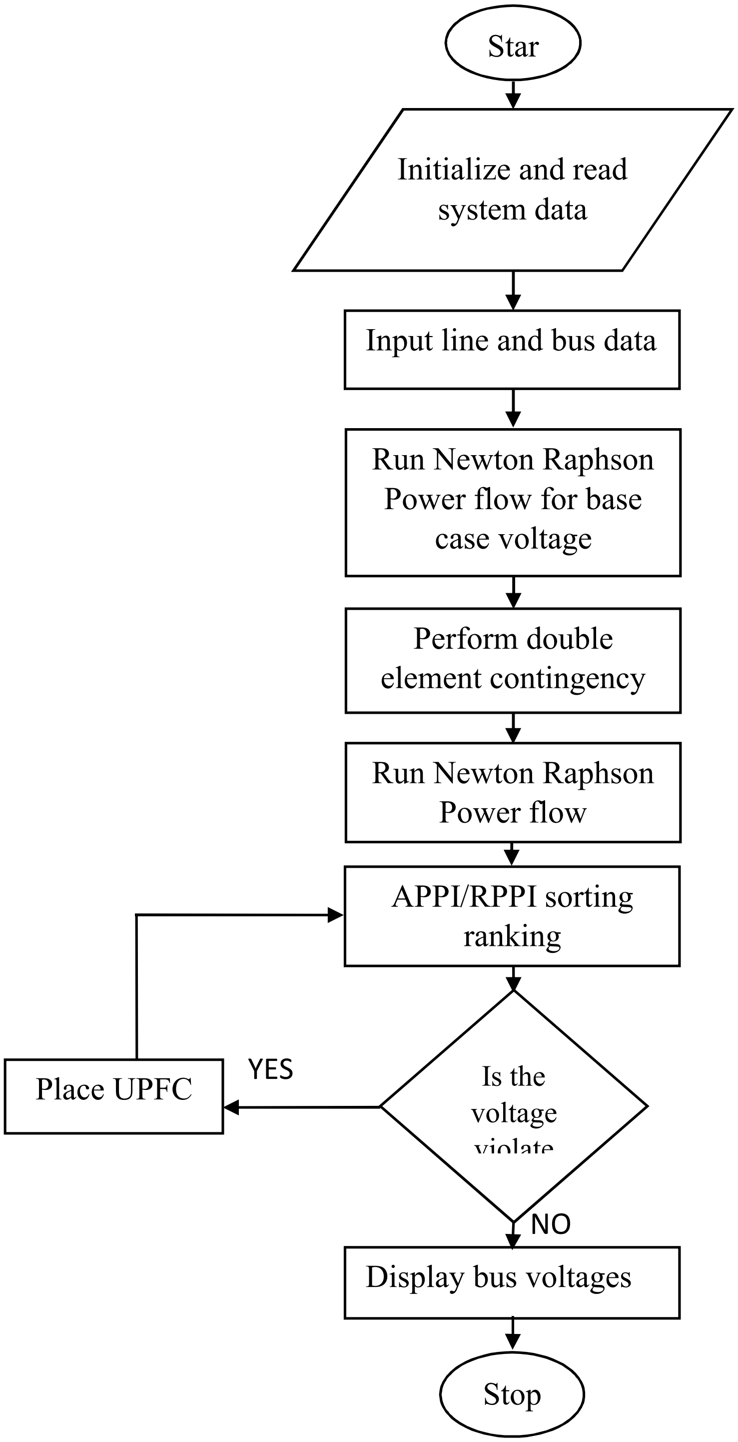


Figure 3.1: Flow Chart for Contingency Analysis

3.2.4 Sens

Implementation analysis of a sensitivity index based technique for contingency ranking and for determination of UPFC device placement is achieved using:

i. Active power performance index (APPI) given by equation (2.38)
ii. Reactive power performance index (RPPI) given by equation (2.40)

The choice of APPI and RPPI in this research over other sensitivity indices is for the purpose of contingency ranking; hence, APPI measures the degree of line overload while RPPI measures the out of limit bus voltage violation in the event of various contingencies that occurs in the network.

3.2.5 Implementation of the Proposed Method

The implementation of the proposed method was done using Matlab R2013a environment. The data obtained from Nigeria 330kV transmission network was used for the analysis. The analysis was achieved based on power flow performed on various cases of contingencies that occurs on the network and the placement of FACTS devices was done to mitigate the impact of the contingency by stabilizing the bus voltages of the entire network and improving the lines transfer capability. The analysis of the 330kV Nigerian transmission network was carried out using the network parameters which are resistance and reactance of the lines interconnecting the buses in the network and the real and reactive power on each bus of the network.

3.2.6 Performance Evaluation

In this subsection, the evaluation of the results obtained in this research was done using the percentage improvement equation stated in subsection 2.5.3 and the voltage profile serving as the performance metric. Impact of UPFC placement in an event of contingency that occurs in the network is seen in the voltage profile improvement. The values of the voltages are shown on the plot for pre and post contingency following the placement of UPFC on the network. The results in chapter four shows that voltage deviations are found to be within an acceptable range of ±5% nominal voltage tolerance and were compared with the base case voltage and with the work of Reddy *et al*., (2014)**.**

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the results obtained. The results and the performance of the proposed method are shown after it was implemented on 31-bus Nigerian transmission network system. The performance of the method in the placement of UPFC was discussed. All simulations were carried out on Matlab R2013a software environment.

The Nigeria 330kV transmission network is discussed in chapter three. The single line diagram of the Nigerian Transmission Network is also shown in Figure 3.1. The bus and line data is given in Table 3.1 and 3.2. In carrying out the analysis on this bus, the following case scenarios were considered; the pre-contingency (also referred to as base case), and the contingency analysis respectively.

4.2 Results

The results of all the analyses carried out are presented and discussed in this section**.**

4.2.1 Pre-Contingency Analysis (Base Case)

Power flow was performed to determine the initial steady state of the network which is being referred to as the pre-contingency analysis of the network. The power flow is performed using Newton Raphson power flow technique as discussed in subsection 2.4.2. Subsection 3.3.1 provides the procedure used in carrying out the pre-contingency analysis.

Table 4.1: Pre Contingency and Post Contingency

Bus No	Bus Name	Base Case Voltage	RPPI Before UPFC	RPPI Ranking	Voltage After UPFC	RPPI After UPFC
1	Egbin	1.0200	0.4000	29	1.0200	0.4000
2	Delta Ps	1.0300	1.0000	12	1.0500	1.0000
3	Okpai	1.0500	1.0000	12	1.0500	1.0000
4	Sapele	1.0500	1.0000	12	1.0500	1.0000
5	Afam	1.0500	1.0000	12	1.0500	1.0000
6	Jebba	1.0300	0.6000	23	1.0100	0.2000
7	Kainji	1.0300	0.6000	23	1.0100	0.2000
8	Shiroro	1.0500	1.0000	12	1.0300	0.6000
9	Geregu	1.0500	1.0000	12	1.0500	1.0000
10	Oshogbo	1.0737	1.2893	8	1.0626	1.2520
11	Benin	1.0616	1.2304	9	1.0604	1.2089
12	Ikj-West	1.0372	0.5205	25	1.0256	0.5124
13	Ayede	1.0557	0.9041	20	1.0440	0.8794
14	Jos	1.1848	3.6956	4	1.0645	1.2903
15	Onitsha	1.0458	0.9151	19	1.0396	0.7921
16	Akamgba	1.0306	0.4728	28	1.0234	0.4681
17	Gombe	1.3836	7.6716	2	1.0527	1.0544
18	Abuja(katamkpe)	1.0451	0.9027	21	1.0245	0.4899
19	Maiduguri	1.3942	7.8830	1	1.0329	0.6572
20	Egbin TS	1.0303	0.5027	26	1.0250	0.4994
21	Aladja	1.0371	0.9845	18	1.0492	0.9845
22	Kano	1.0138	0.2780	31	0.9602	0.7952
23	Aja	1.0217	0.3289	30	1.0163	0.3255
24	Ajaokuta	1.0606	1.2122	10	1.0604	1.2071
25	N.Heaven	1.0809	1.6167	7	1.0490	0.9799
26	Alaoji	1.0384	0.7674	22	1.0281	0.5625
27	Jebba TS	1.0246	0.4917	27	1.0043	0.0862
28	B.Kebbi	0.7020	5.9593	3	0.9561	0.8778
29	Kaduna	1.0918	1.8370	6	1.0355	0.7094
30	ShiroroTS	1.0569	1.1384	11	1.0365	0.7307
31	Makurdi	1.1237	2.4732	5	1.0585	1.1699
			38.7567			20.5870

From Table 4.1, the base case voltage was obtained after the power flow method was performed. RPPI ranking shows the bus numbers that violate the prescribed voltage limit according to their severity. After the use of the proposed method followed by the placement of UPFC, the UPFC voltages shows that the identified violated buses were being aligned to the operating voltage limit.

4.2.2. Contingency Analysis

The contingency analyses considered in this research were however grouped and analyzed into the following case scenarios. This includes: line outage, line and load outage, load outage and load increment accordingly.

4.2.2.1 Case 1: Line outage contingency analysis

This section describes the scenario of line outage contingency. The level of the contingency considered is the (n-2) contingency analysis where two line outages occur in the network. The (n-2) contingency analysis was performed considering double line outages that will not cause a split in the network, thereby making any part of the network to be isolated. The resultant effect of this case scenario is shown in Table 4.1.

Table 4.2: Line Outage Contingency Analysis

Line outages	Violated Buses	RPPI Ranking	Voltages (pu) before UPFC Placement	UPFC size (MVar)	Voltage(pu) after UPFC Placement
4, 19	Maiduguri	1	1.3941	-196	1.0329
	Gombe	2	1.3836		1.0527
	B.Kebbi	3	0.7020	99	0.9561
	Jos	4	1.1848	- 49	1.0645
	Makurdi	5	1.1237		1.0585
	Kano	6	1.0139	20	0.9602
4, 37	Maiduguri	1	1.3941	-185	1.0329
	Gombe	2	1.3836		1.0527
	B.Kebbi	3	0.7020	99	0.9561
	Jos	4	1.1848	-25	1.0645
	Kano	5	1.0139	66	0.9602
	Ajaokuta	6	1.0606	-61	1.0604
	Osogbo	7	1.0645	-87	1.0626
	Benin	8	1.0615	-76	0.9497
19, 37	Maiduguri	1	1.4484	-184	0.9978
	B.Kebbi	2	0.7020	99	0.9561
	Jos	3	1.2282	-18	1.0429
	Kano	4	0.7912	66	0.9511
	Ajaokuta	5	1.0570	-47	1.0338
	Osogbo	6	1.0564	-14	1.0498

In Table 4.2, the numerical values were obtained from Newton Raphson load analysis performed in Matlab R2013a. In the event of the contingencies in line 4 and 19, the buses that deviate from the prescribed nominal voltage were identified and ranked using RPPI. In the outages of line 4 and 19, Maiduguri, Gombe, B.Kebbi, Jos and Makurdi buses were being ranked based on RPPI as the buses whose voltages deviate from the prescribed nominal voltage limit of ±5%. With the placement of UPFC in the network, the voltages that deviate from the prescribed nominal voltage limit of ±5% were kept within an acceptable range for a stable system operation.

Maiduguri bus is ranked highest following the RPPI ranking with an overvoltage of 1.3941pu. The placement of UPFC consumed -196MVar from the network causing the violated bus voltage to be 1.0329pu. Consequently, due to the interconnection of the network, the placement of the UPFC in Maiduguri bus also salvaged the voltage violation in Gombe bus which is being ranked second most severe in the network as seen in Table 4.2. Birni Kebbi Bus is identified as a weak bus with an undervoltage value of 0.7020pu. The value of UPFC placed on the bus was +99MVar which improved the voltage to an acceptable value of 0.9561pu by reactive power injection. The placement of UPFC consumed -49MVar in Jos which brought down the value from 1.1848pu to 1.0645pu. The placement of UPFC in Jos salvaged the problem of overvoltage in Makurdi without further placement of UPFC in the bus. Hence, considering the outages of line 4 and 19, four UPFCs were placed in the network which allows for stability in the network by keeping all the bus voltages within the acceptable limit. Tabular presentation following the double line outages of 4,37 and 19,37 as shown in Table 4.2.

The total APPI before the placement of UPFCs for the outages of line 4 and 19 is given by an index of 278.4336 but after the placement of the UPFCs on the violated buses, the total APPI is reduced to an index value of 264.5650 as shown in Table A2 in Appendix. These values show a 5% reduction in the degree of the total lines overload hence, increasing the line loadability in the network. Still, during the aforementioned case scenario, the total RPPI value also reduced from 20.5870 to 38.7567 after the placement of UPFCs indicating a 47% reduction in the severity of the bus voltage violation in the network.

In the outages of line 4 and 37, after the placement of the various UPFCs, there was 7% reduction in the degree of the total line overload and 65% reduction in the severity of the bus voltages violation in the network. For the line outage of 19 and 37, the placement of the UPFCs resulted to a 7.5% reduction in the degree of the total line overload on the network and 61.4% reduction in the severity of the bus voltages violation in the network. The placement of UPFC on the network has great impact in restoring the network from abnormal state during contingency to a stable state. Figure 4.1 represent voltage profile of line outage contingency analysis.

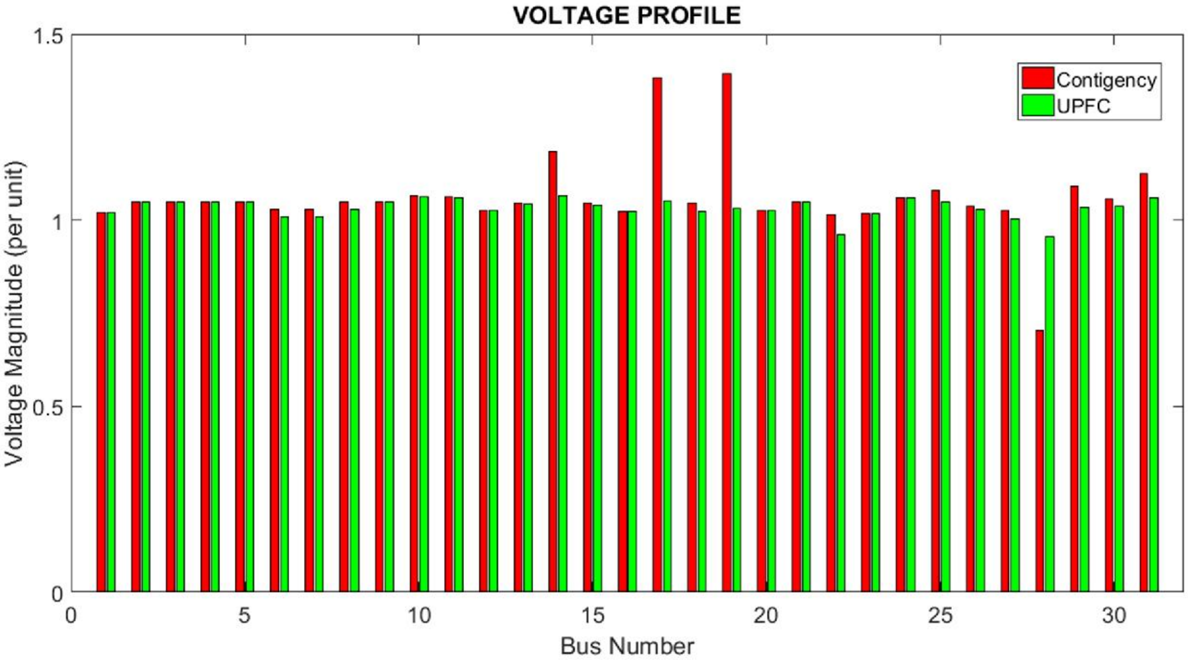


Figure 4.1: Voltage Profile of Line Outage Contingency Analysis

In Figure 4.1, the bar chart shows the voltage profile of the network before and after the placement of UPFC during contingency. The voltage magnitude after contingency is indicated by red colour and the voltage magnitude after the placement of UPFC is indicated by green colour.

The bars that exceed the range of (1.0500 - 0.9500)pu indicates violation hence the placement of UPFC help to keep the voltages within the prescribed range as shown in Figure 4.1. Similar explanation also goes to the remaining figures showing voltage profile for the double line outages of 4,37 and 19,37. Figure 4.2 indicate the RPPI before and after the placement of UPFC.

Figure 4.2: RPPI of Line Outage Contingency Analysis

The red colour bar in figure 4.2 shows the severity of voltage violation during the aforementioned case scenario. The placement of UPFC helped to reduce the level of the severity and is indicated by the green colour bar on the chart in Figure 4.2. Similar explanation also applies to the remaining RPPI figures for the contingency cases discussed in this chapter.

Figure 4.3 shows the APPI bar chart indicating the placement of UPFC before and after the line outage contingency.

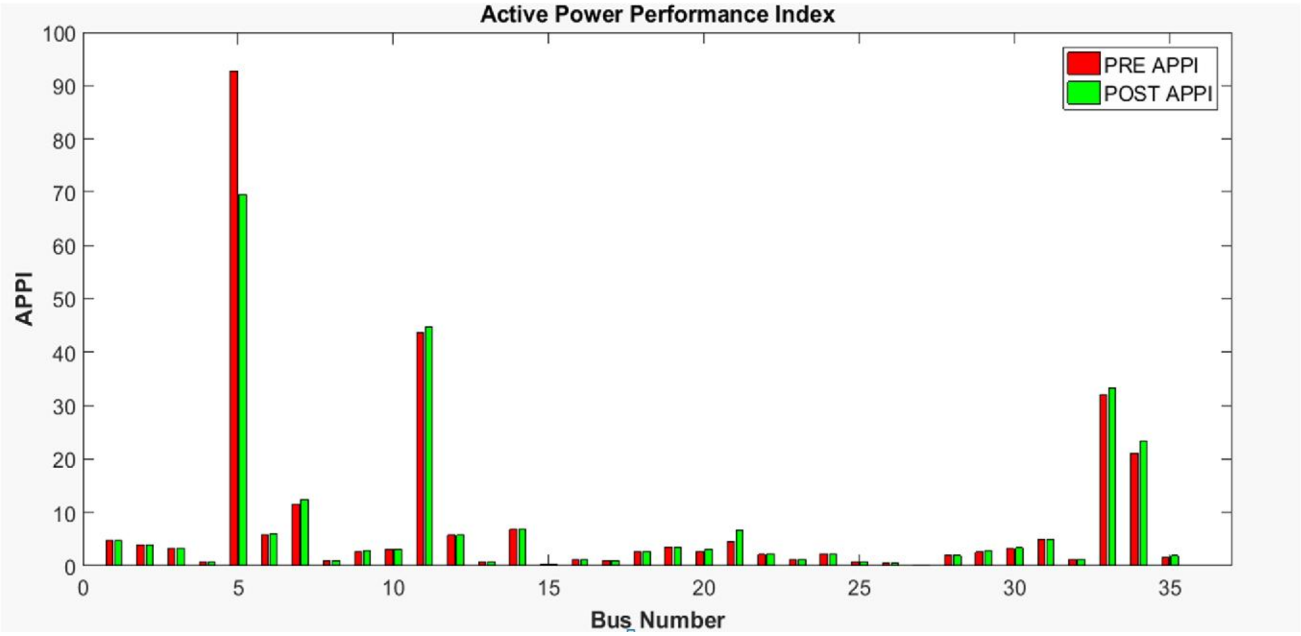


Figure 4.3: APPI of Line Outage Contingency Analysis

The red colour bar shows the severity of line overload in the network. The placement of UPFC helps to reduce the level of the severity and is indicated by the green colour bar as seen in the chart. Similar explanation also applies to the remaining APPI figures for the contingency cases discussed in this chapter.

4.2.2.2. Case 2: Line and Load Outages

In this section, line and load contingency analysis is performed. The load outage contingency was performed considering the buses with the heaviest load and the line outage was performed such that the line outage will not isolate any part of the network. The resultant effect of this case scenario is shown in Table 4.3.

Table 4.3: Load and Line Outage Contingency Analysis

Line/Load outages	Violated Buses	RPPI Ranking	Violated voltages (pu)	UPFC size (MVar)	UPFC Voltage (pu)
4, 11	Maiduguri	1	1.3948	-183	1.0341
	B.Kebbi	2	0.7020	99	0.9561
	Jos	3	1.1853	-52	1.0644
	Osogbo	4	1.0768	-107	1.0501
	Kano	5	1.0144	21	0.9617
19, 11	Maiduguri	1	1.3934	-183	1.0333
	B.Kebbi	2	0.7020	99	0.9561
	Jos	3	1.1842	-50	1.0639
	Kano	4	1.0141	20	0.9599
37, 11	Maiduguri	1	1.4512	-185	0.9832
	B.Kebbi	2	0.7020	99	0.9561
	Jos	3	1.2305	-25	1.0351
	Kano	4	0.7912	66	0.9511
	Osogbo	5	1.0741	63	1.0496
	Ajaokuta	6	1.0633	-58	1.0499

The numerical values of Table 4.3 were obtained from Newton Raphson load analysis performed in Matlab R2013a. Table 4.3 shows that, in an outage of line 4 and load 11, the following were ranked as the most severe buses based on RPPI and these buses include Maiduguri, B.Kebbi, Jos, Osogbo and Kano. Maiduguri bus was ranked as a violated bus with an overvoltage value of 1.3948pu. Jos and Osogbo also experienced an overvoltage with values 1.1853pu and 1.0768pu. Birni Kebbi bus had an undervoltage value of 0.7020pu but with the placement of various UPFCs as seen in Table 4.3, all the violated voltages were kept within an acceptable range. However, due to the placement of UPFCs in the previous buses, Kano bus which was initially stable became violated. This further required the placement of UPFC to stabilize the network. The total APPI before and after the placement of UPFCs is given by an index of 285.9539 and 273.8864 respectively. These values indicate that during the aforementioned case scenario there was a 4.2% reduction in the degree of the total line overload in the network. Similarly, with the total Pre-RPPI (i.e. before the placement of UPFC) and Post-RPPI (i.e. after the placement of UPFC) indices are given by 40.3191and 20.7678. This shows 48.5% reduction in the severity of the bus voltages violation in the network.

In the outage of line 19 and load 11, the contingency analysis report is detailed in the Table 4.3. Hence, the total APPI during and after the placement of various UPFCs is given by 291.9915 and 278.0963 indices. This shows that there is 4.8% reduction in the degree of the total line overload of the network. Also, the total RPPI before and after the placement of UPFCs is given by 36.8791 and 18.7311 respectively. These indices indicate that during the outage of the line 19 and load 11, there is a 49.2% reduction in the severity of the bus voltages violation in the network.

Similarly, the contingency analysis report of line 37 and load 11 is detailed in the Table 4.3. Following the outages of line 37 and load 11, there is 6.7% reduction in the degree of total line overload and 63.8% reduction in the severity of the bus voltages violation in the network before and after the placement of the various UPFCs.

The pictorial representation of the voltage profile following the load and line outage contingency is shown in Figure 4.4. The RPPI of the load and line outage contingencies is shown in Figure 4.5. Figure 4.6 shows the APPI of the load and line outage contingencies.

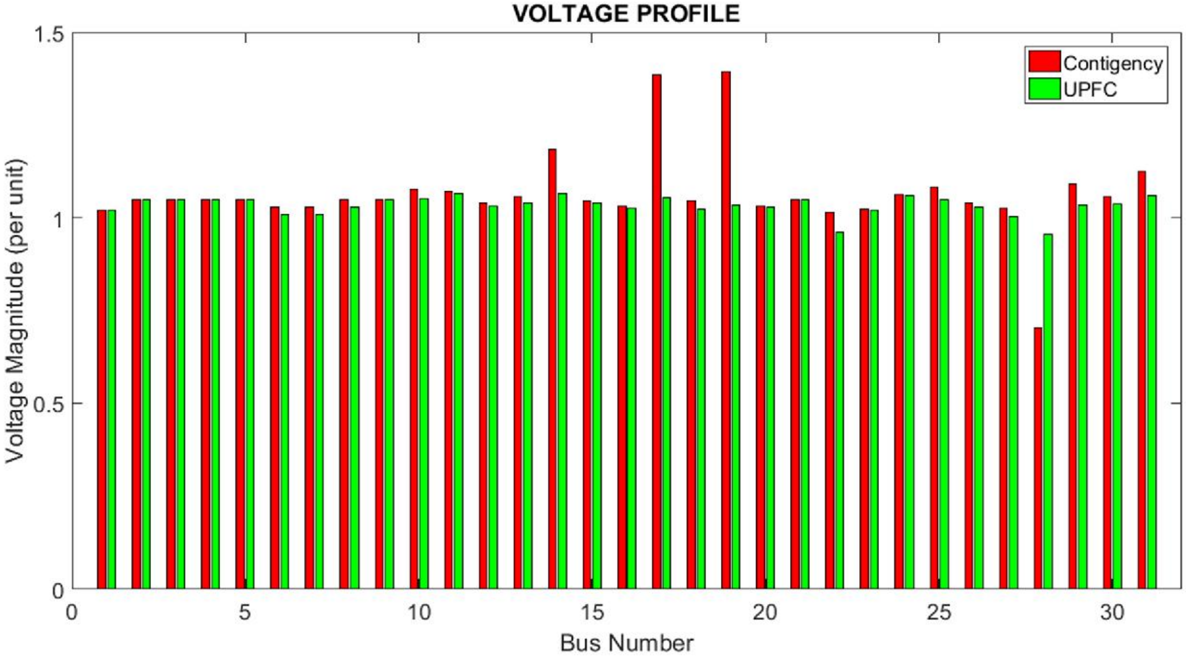


Figure 4.4: Voltage Profile Load and Line Outage Contingency Analysis

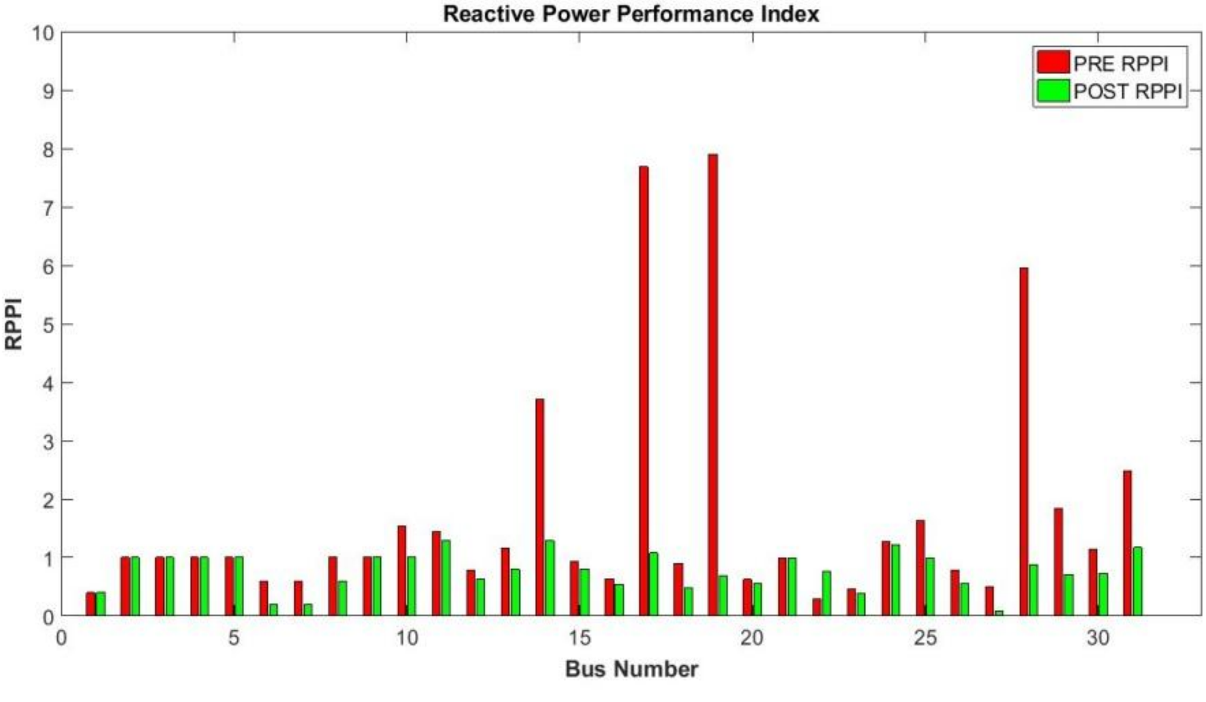


Figure 4.5: RPPI Load and Line Outage Contingency Analysis

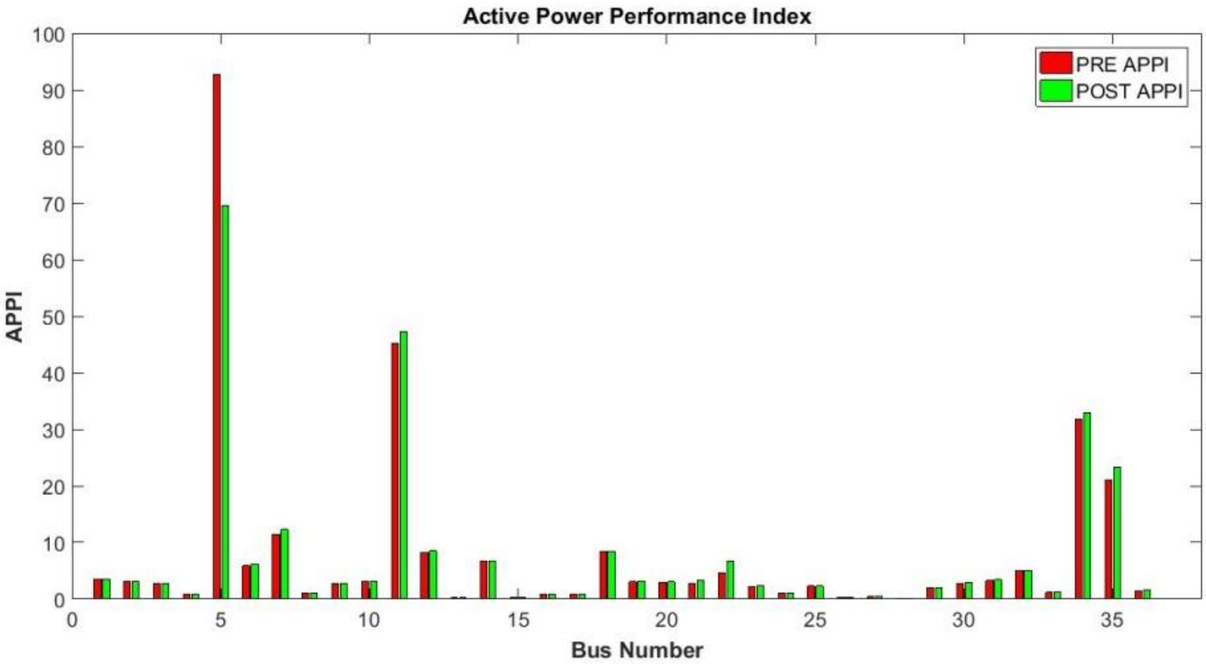


Figure 4.6: APPI Load and Line Outage Contingency Analysis

4.2.2.3. Case 3: Load Increment

This section describes the scenario of load increment that occurs on the network. This level of disturbance can be analyzed in a situation where two load buses experience an addition of load that have an impact on the general network stability. A 20% load increment is added to the load buses selected for contingency analysis to be performed. Load increment on the load buses specified in Table 4.4 shows voltage violations on certain buses in the network. The resultant effect of these disturbances is shown in Table 4.4.

Table 4.4: Load Increment Contingency Analysis

Load Increment	Violated Buses	RPPI Ranking	Violated voltages (pu)	UPFC size (MVar)	UPFC Voltage (pu)
11,22	Maiduguri	1	1.3594	-183	1.0193
	Gombe	2	1.3491	-13	1.0395
	B.Kebbi	3	0.7020	99	1.0453
	Jos	4	1.1570	-28	0.9621
	Kano	5	0.8835	46	0.9617
	Osogbo	6	1.0706	-84	1.0499
	Benin	7	1.0520	16	1.0500
11,26	Maiduguri	1	1.3931	-183	1.0193
	Gombe	2	1.3836	-13	1.0395
	B.Kebbi	3	0.7020	99	0.9561
	Jos	4	1.1848	-28	1.0453
	Kano	5	1.0136	46	0.9621
	Osogbo	6	1.0783	-84	1.0499
	Benin	7	1.0738	16	1.0506
	Alaoji	8	1.0377	17	1.0279
22, 26	Maiduguri	1	1.4681	-183	1.0193
	Gombe	2	1.4569	-13	1.0395
	B.Kebbi	3	0.7020	99	0.9561
	Jos	4	1.2441	-28	1.0453
	Osogbo	5	1.0741	-84	0.9511

The numerical values of Table 4.4 were obtained from Newton Raphson load analysis performed in Matlab R2013a. In table 4.4, when there is 20% load increment on load bus 11 and 22, Maiduguri, Gombe, B.Kebbi, Jos, Kano, Osogbo and Benin are ranked based on RPPI as buses with voltage violations in the network. The placement of various UPFCs helped to salvage the situations by keeping the voltages in an acceptable range for the stability of the system. Based on the aforementioned case scenario, Maiduguri, Gombe and Jos are ranked to have violated the acceptable nominal voltage. After the placement of UPFCs to solve the voltage violations of Maiduguri, Gombe and Jos, there was slight voltage violation above normal in Osogbo and Benin in an attempt to compensate for the severed cases ranked by RPPI. This further required the placement of UPFCs which helped to salvage the situations. On the other hand, Birni Kebbi and Kano are ranked to be violated in the network with an undervoltage of 0.7020 and 0.8835. The placement of the various UPFCs as indicated in the Table 4.4 shows an improvement in all the violated buses in the network hence making the bus voltages in entire network normal.

The total APPI before and after the placement of UPFCs is given by 284.4995 and 264.7672. The total RPPI before and after the placement of UPFCs is also given by 30.7855 and 18.5933 respectively. These indices indicate that, for the aforementioned case scenario there is 7% reduction in the degree of lines overload based on APPI value and 40% voltage improvement on the buses in the network base on RPPI value.

Similarly, for 20% load increment on bus 11 and 26 following the contingency analysis as specified in Table 4.4, there is 4.4% reduction in the degree of lines overload based on APPI and 54.8% voltage improvement of the buses in the network after the placement of various UPFCs based on RPPI. Again, considering 20% load increment on load bus 22 and 26, the resultant effect of these contingencies is specified in Table 4.4. Based on the total APPI values for before and after the placement of the various UPFCs, there is 2.3% reduction in the degree of lines overload in the network and 66.5% voltage improvement of the buses in the network based on total RPPI values before and after the placement of the various UPFCs. The pictorial representation of the voltage profile following the load increment contingency is shown in Figure 4.7. The RPPI of the load increment contingencies is shown in Figure 4.8. Figure 4.9 shows the APPI of the load increment contingencies.

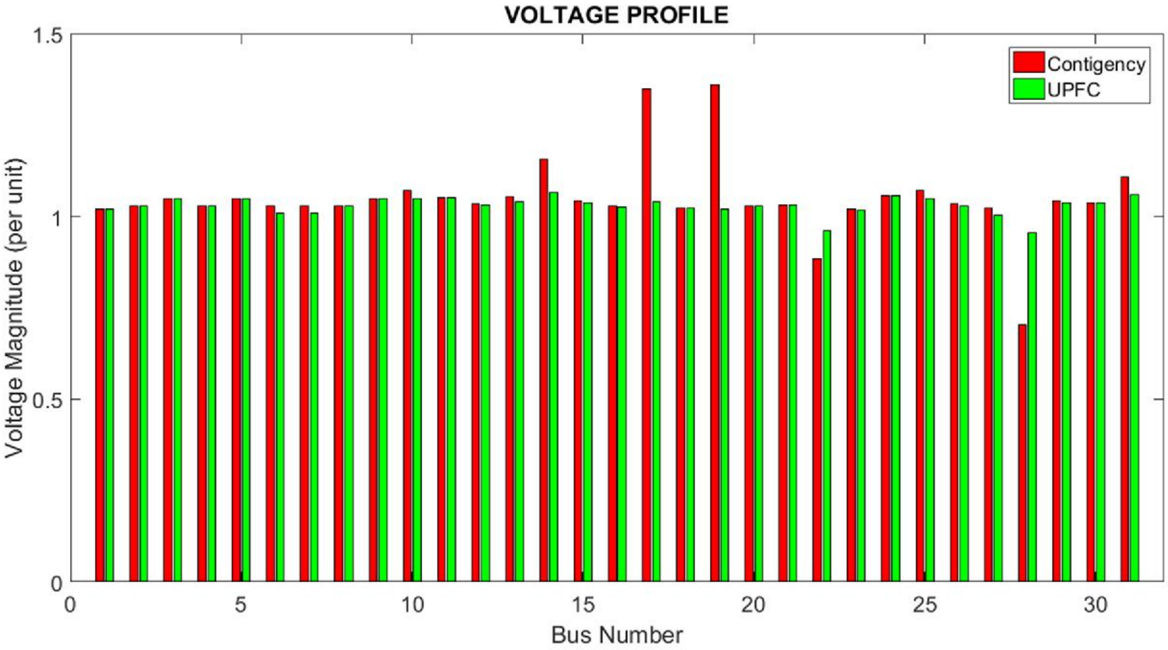


Figure 4.7: Voltage Profile Load Outage Contingency Analysis

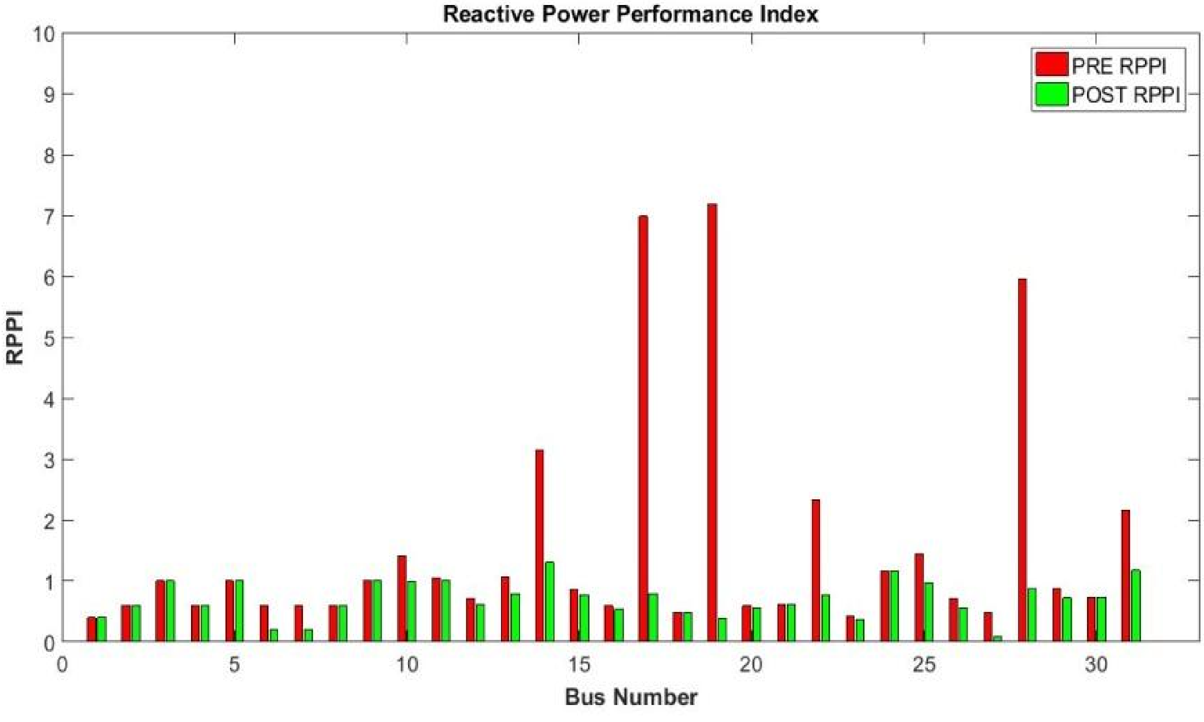


Figure 4.8: RPPI Load and Line Outage Contingency Analysis

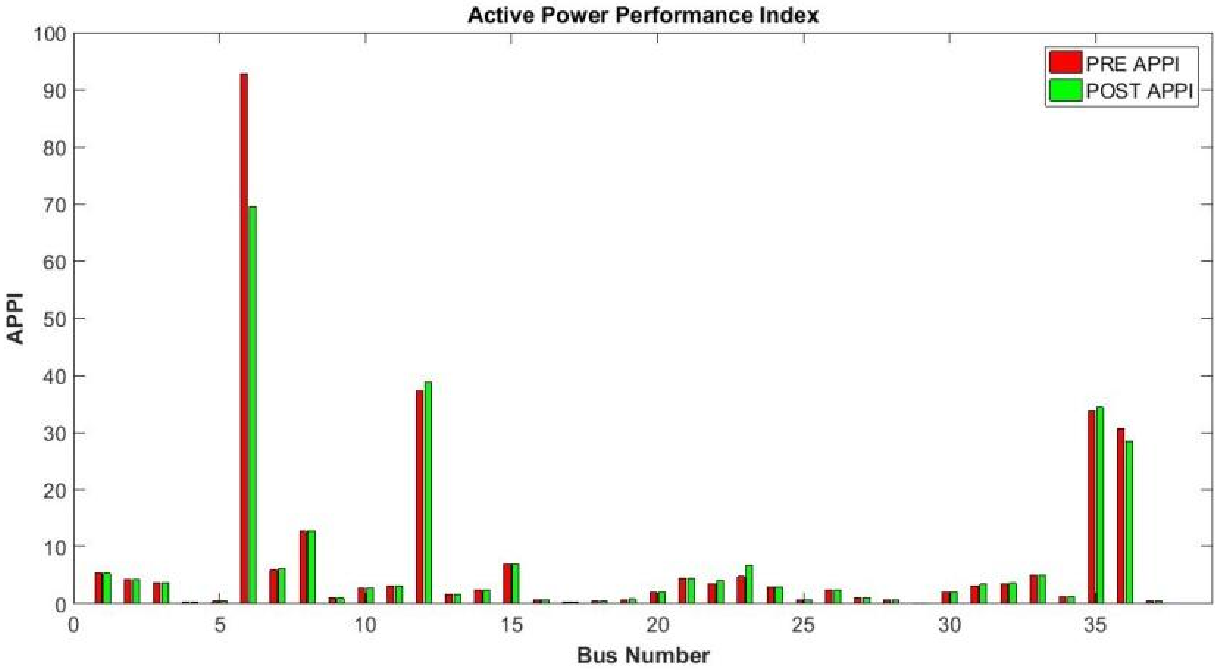


Figure 4.9: APPI Load and Line Outage Contingency Analysis

4.2.2.4. Case 4: Load Outage

Load outage is another form of contingency that occurs in electric power network. This section describes the scenario of load outage contingencies that occurs in the network. This level of disturbance can be analyzed in a situation whereby two load buses experiences an outage such that the impact of the outages has an effect on the general network stability. The load outage contingency was performed considering the buses with the heaviest load and the resultant effect of this case scenario is shown in Table 4.5.

Table 4.5: Load Outage Contingency Analysis

Load outages	Violated Buses	RPPI Ranking	Violated voltages (pu)	UPFC size (MVar)	UPFC Voltage (pu)
11, 22	Maiduguri	1	1.4318	-183	1.0193
	Gombe	2	1.4209	-13	1.0395
	B.Kebbi	3	0.7020	99	0.9561
	Kano	4	1.2454		0.9621
	Jos	5	1.2149	-28	1.0653
	Osogbo	6	1.0670	-84	1.0499
11, 26	Maiduguri	1	1.3989	-183	1.0193
	Gombe	2	1.3883	-13	1.0395
	B.Kebbi	3	0.7020	99	0.9561
	Jos	4	1.1886	-28	1.0653
	Makurdi	5	1.1278		1.0586
	Kano	6	1.0167	21	0.9621
	Osogbo	7	1.0763	-84	1.0499
22, 26	Maiduguri	1	1.4681	-183	1.0193
	Gombe	2	1.4569	-13	1.0395
	B.Kebbi	3	0.7020	99	0.9561
	Kano	4	1.2568		0.9621
	Jos	5	1.2441	-28	1.0653
	Makurdi	6	1.1746		1.0586
	Osogbo	7	1.0678	-84	1.0499

In Table 4.4, the outage of load bus 11 and 22 creates instability in the network resulting to voltage violation in Maiduguri, Gombe, B.Kebbi, Kano, Jos and Osogbo as ranged based on RPPI. In the outage of the aforementioned contingency, the most severed bus was found to be Maiduguri bus. Birni Kebbi bus ranked the weakest bus with a voltage violation of 0.7020pu while Gombe, Kano and Jos buses were found to be violated as the result of the outages. Hence, following the placement of UPFCs on the network, all the violated buses where kept within an acceptable voltage range. The total APPI values before and after the placement of UPFCs are given by 307.5407 and

296.9623 respectively. This index shows 3.5% reduction in the degree of lines overload, thereby, increasing the line loadability of the network of the network. The total RPPI values before and after the placement of UPFCs are also given by 48.1787 and 18.5933. This index shows 61.4% reduction in the severity of the bus voltages violation in the network.

The analysis of the load outage of load bus 11 and 22 is shown in table 4.5. The total APPI before and after the placement of various UPFCs is given by 306.2964 and 296.0891. This index shows 3.3% reduction in the degree of lines overload in the network thereby, increasing the lines loadability. The total RPPI values before and after the placement of UPFCs is given by 42.0496 and 18.5933. These indices indicate 55.8% reduction in the severity of the bus voltages violation in the network.

Figure 4.10 shows the voltage profile of the load outage contingency considered. The RPPI and APPI of the load outage contingency considered in shown in Figures 4.11 and 4.12.

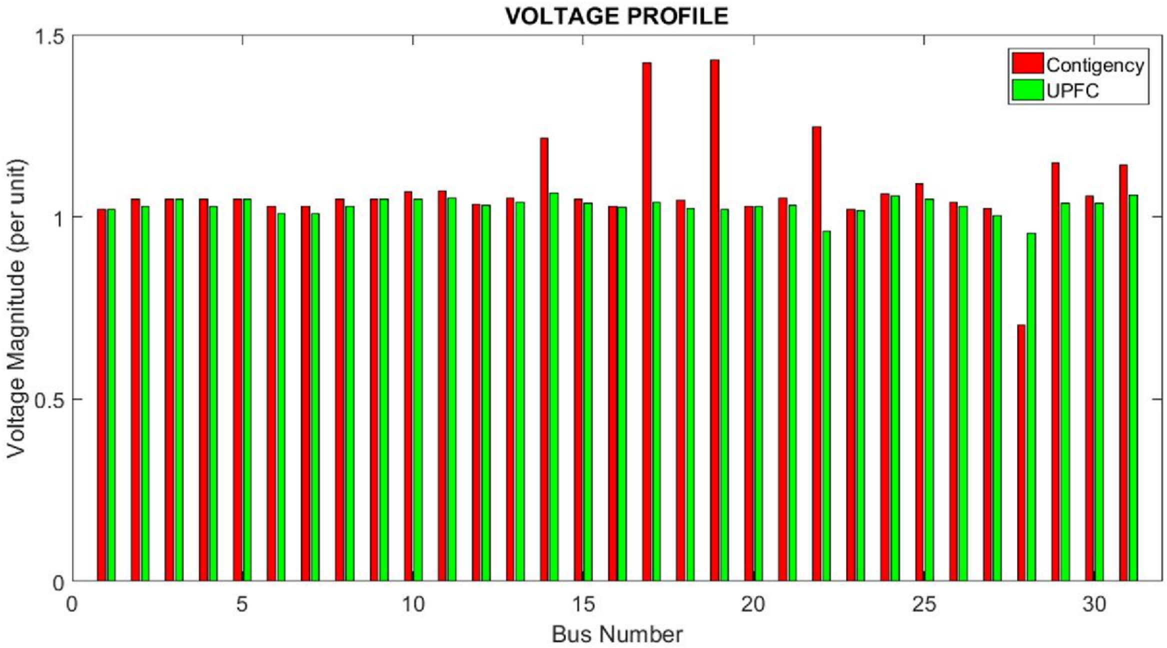


Figure 4.10: Voltage Profile of Load Outage Contingency Analysis

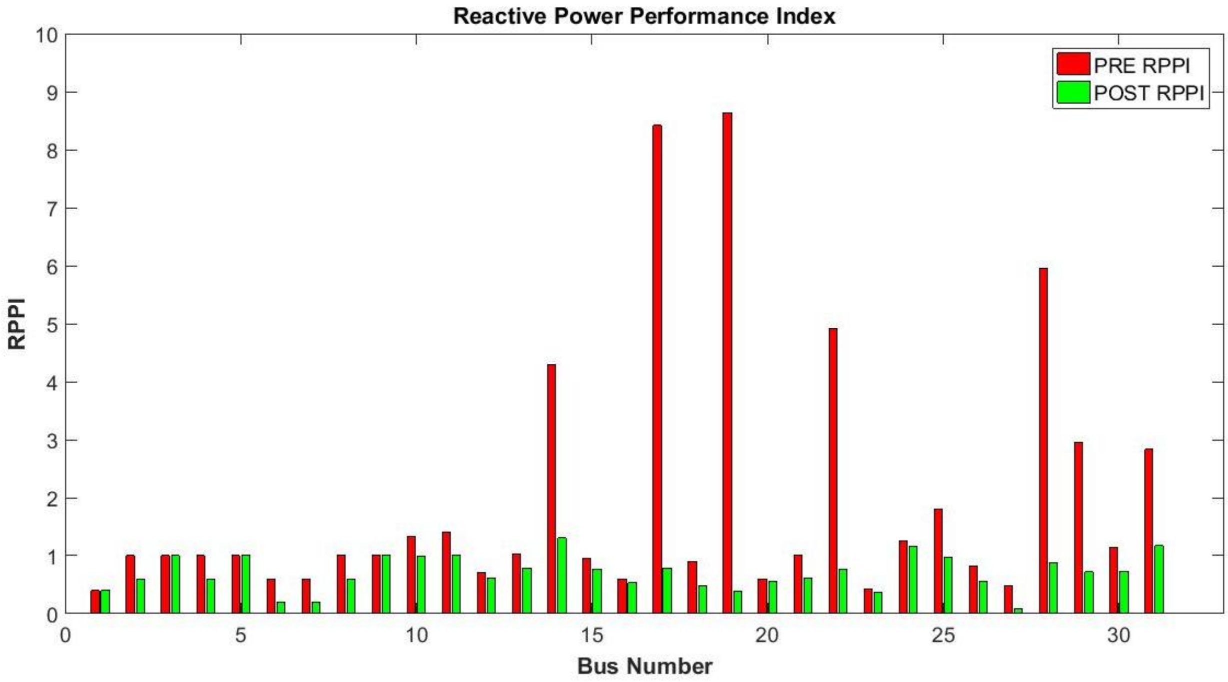


Figure 4.11: RPPI Load Outage Contingency Analysis

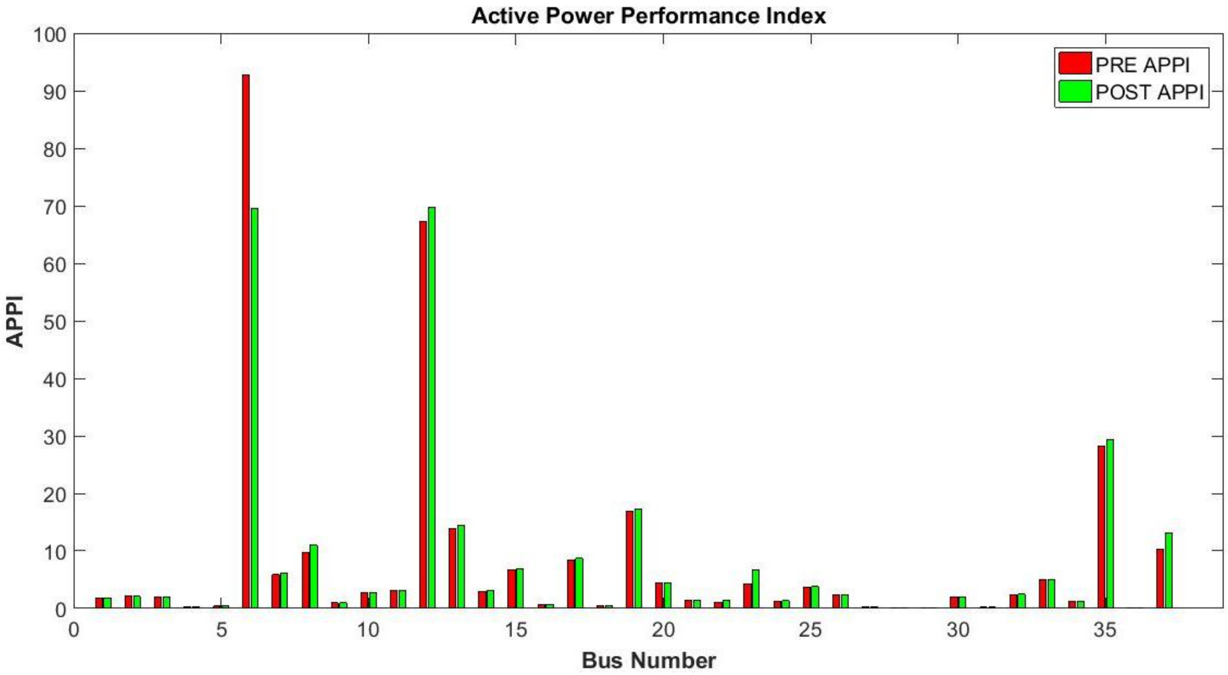


Figure 4.12: APPI Load Outage Contingency Analysis

The placement of UPFC following the aforementioned case scenarios performed the function of compensating the violated bus voltages by either injecting or absorbing reactive power in the network therefore keeping the network voltages of the various buses at a prescribed range for stability of the entire network, therefore increased the lines transfer capabilities of the network.

Table A7 in Appendix A shows the values of the active and reactive power loss reductions with UPFC compensation. The total reactive power loss in the network after the placement of various sizes of UPFCs were sum to be 694.6233MVar and the base case reactive power loss to be 703.7499MVar resulting to a percentage power loss reduction of 1.3% and a total voltage improvement of 3.11% (32.9541pu) as compared to the base case voltage deviation of (31.9298pu).

4.2.3 Priority Load

Following the various case scenarios discussed in Section 4.2, the predominately violated buses on Nigerian 330kV Transmission Network as ranked based on RPPI were identified to be Maiduguri, Birni Kebbi, Gombe, Oshogbo, Jos and Kano. Kano was identified as the priority load being one of the commercial cities in Nigeria. In the event of various contingency cases discussed, the placement of UPFC helped in aligning the bus voltages of the priority load bus and other violated load buses to be within the acceptable nominal range of voltage for better power quality in the network.

4.3 Comparative Assessment

The comparative assessment of this work was done using the base case voltage of the Nigerian Transmission Network and with the work of Reddy *et al.*, (2014) in terms of voltage profile as the performance metric.

4.3.1 Comparative Assessment of the Proposed Method with the Base Case

The base case data were obtained from Newton Raphson power flow run in Matlab R2013a. In the proposed method, the placement of UPFC was performed using sensitivity index through the use of RPPI and APPI. Table 4.6 shows the comparison between the base case voltage and the proposed method. Also, Figure 4.13 shows the graph of the comparison between the base case voltage and the proposed method.

Table 4.6: Comparison between the Base Case Voltage and the Proposed Method

Bus No	Bus Name	Base Case (BC) voltage before the placement of UPFC	Voltage after placement of UPFC
1	Egbin	1.0200	1.0200
2	Delta Ps	1.0300	1.0300
3	Okpai	1.0500	1.0500
4	Sapele	1.0500	1.0300
5	Afam	1.0500	1.0500
6	Jebba	1.0300	1.0100
7	Kainji	1.0300	1.0100
8	Shiroro	1.0500	1.0300
9	Geregu	1.0500	1.0500
10	Oshogbo	**1.0737**	**1.0499**
11	Benin	1.0616	1.0506
12	Ikj-West	1.0372	1.0309
13	Ayede	1.0557	1.0393
14	Jos	**1.1848**	**1.0653**
15	Onitsha	1.0458	1.0385
16	Akamgba	1.0306	1.0267
17	Gombe	**1.3836**	**1.0395**
18	Abuja(katamkpe)	1.0451	1.0245
19	Maiduguri	**1.3942**	**1.0193**
20	Egbin TS	1.0303	1.0274
21	Aladja	1.0371	1.0308
22	Kano*	1.0138	0.9621
23	Aja	1.0217	1.0188
24	Ajaokuta	1.0606	1.0580
25	N.Heaven	1.0809	1.0488
26	Alaoji	1.0384	1.0279
27	Jebba TS	1.0246	1.0043
28	B.Kebbi	**0.7020**	**0.9561**
29	Kaduna	1.0918	1.0360
30	ShiroroTS	1.0569	1.0365
31	Makurdi	1.1237	1.0586

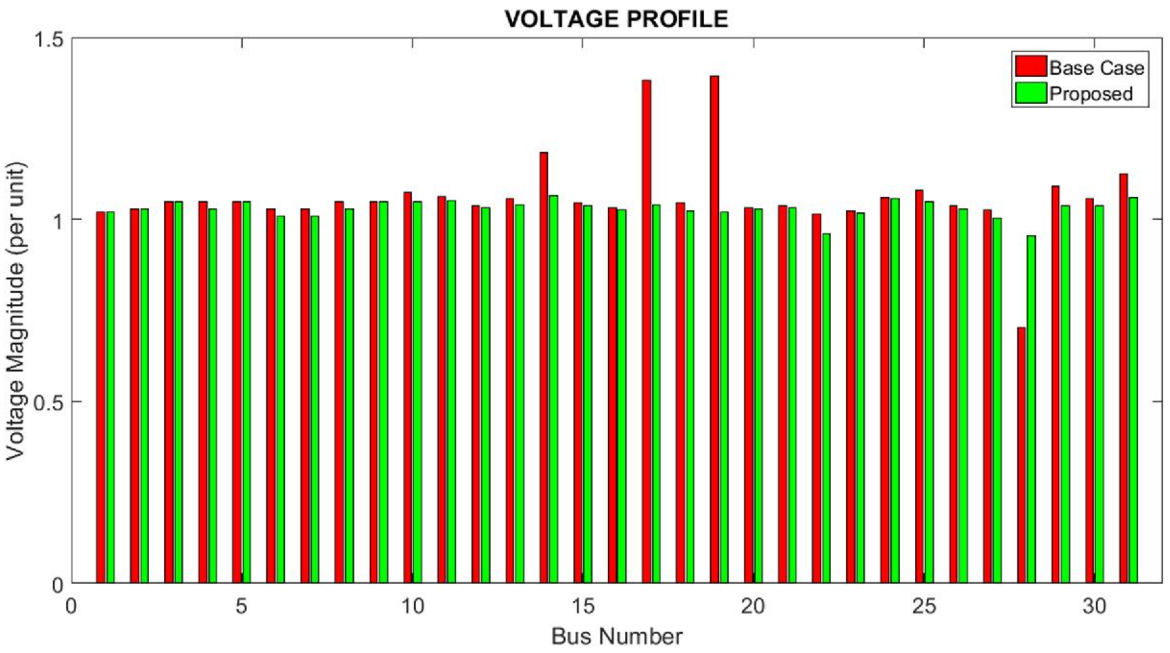


Figure 4.13: Voltage Comparison between the Base Case and the Proposed Method

In Figure 4.13, the bars with red colour represent the base case voltage magnitude gotten from Newton Raphson power flow. The green colour bars represent the voltage magnitude of the proposed method. The bars that exceed or fall below the prescribed range of ±5% (1.050 – 0.950)pu of Nigerian transmission voltage of 330kV is referred to as the violated voltages. It is observed from figure 4.13, after the placement of UPFC following the result obtained from Newton Raphson, the voltage magnitude of the proposed method falls within the acceptable nominal voltage range of ±5%. The proposed method shows a 3.11% voltage magnitude improvement as compare to the base case voltage.

4.3.2 Comparative Assessment of the Proposed Method with the Work of Reddy *et al.,* (2014)

The result of the proposed method was compared with the work of Reddy et al., (2014). The performance metric for the comparison was voltage profile. The comparison was done on the same test bed of IEEE 30 bus system. Figure 4.14 was obtained from Matlab 2013a plot of voltages for each bus.

From figure 4.14, it was observed that after the placement of UPFC as seen from the work of Reddy *et al*., (2014), there was a significant improvement in the voltage magnitude result over the base case voltage; but some of the bus voltages did not fall with the acceptable tolerance limit of ±5%. In the proposed method however, all the bus voltages falls within the acceptable range of ±5% tolerance limit after the placement of UPFC.

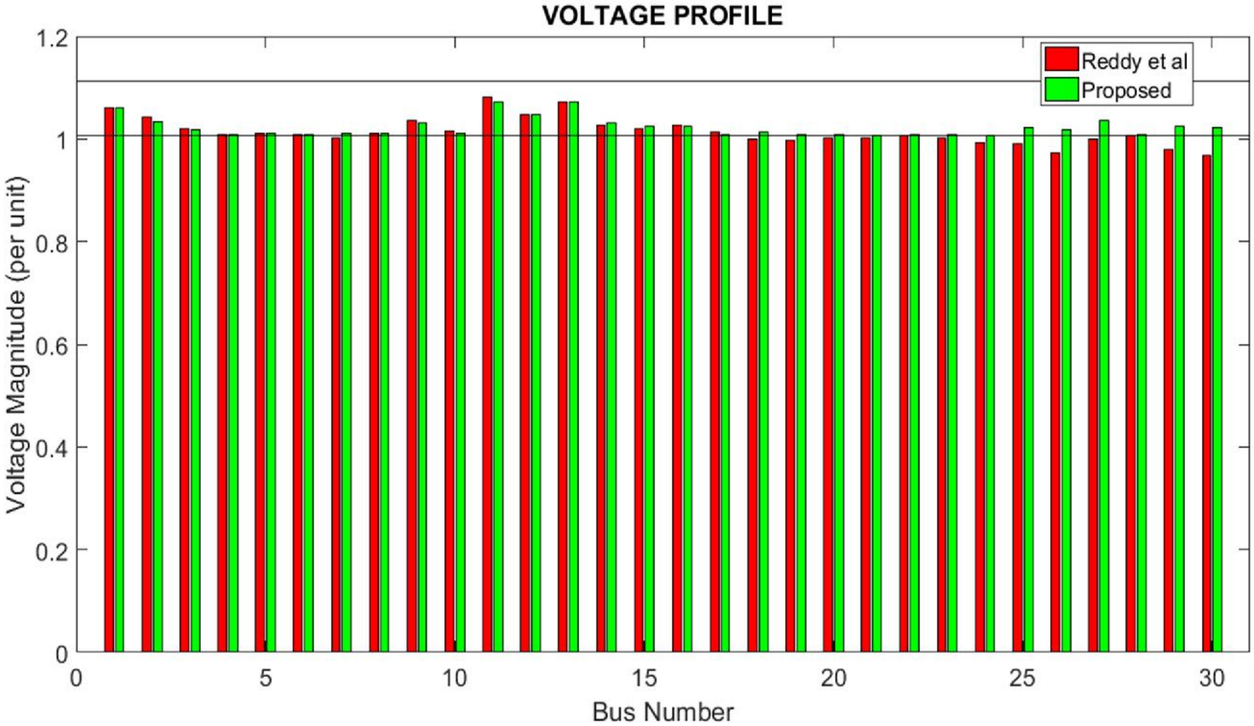


Figure 4.14: Voltage Profile Comparison of the Proposed Method with the Work of Reddy *et al*., (2014)

Figure 4.14 shows that the proposed approach as analyzed on IEEE 30 bus network proffers a voltage improvement of 0.83% (30.6753pu) and a transmission power loss reduction of (0.00166pu) as compared to the work of Reddy *et al*., (2014) with power loss of (0.02116pu) and a voltage of (30.4214pu). Table 4.7 shows the voltage profile comparison of the proposed method with the work of Reddy *et al*., (2014) as analyzed on IEEE 30-Bus network

Table 4.7: Voltage Profile Comparison of the Proposed Method with the Work of Reddy *et al*., (2014) using IEEE Bus-30 Network

Bus No.	Reddy et al (2014)	Proposed Method
1	1.0600	1.0600
2	1.0430	1.0330
3	1.0189	1.0180
4	1.0094	1.0085
5	1.0100	1.0100
6	1.0086	1.0092
7	1.0014	1.0104
8	1.0100	1.0100
9	1.0366	1.0311
10	1.0166	1.0100
11	1.0820	1.0720
12	1.0466	1.0480
13	1.0710	1.0710
14	1.0276	1.0310
15	1.0194	1.0245
16	1.0266	1.0247
17	1.0142	1.0090
18	1.0000	1.0128
19	0.9972	1.0090
20	1.0012	1.0085
21	1.0028	1.0073
22	1.0060	1.0092
23	1.0029	1.0084
24	0.9917	1.0071
25	0.9914	1.0233
26	0.9732	1.0170
27	1.0000	1.0357
28	1.0056	1.0097
29	0.9796	1.0245
30	0.9679	1.0224

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Introduction

The summary of the research work and conclusion are presented in this chapter. Suggestions are also presented.

5.2 Summary

Multiple contingency analyses were considered in this research. The multiple contingency analyses considered in this research include double line outages, line and load outages, double load outages and load increments leading to voltage violations. The identification of the severity of the violated bus voltages was achieved through the use of APPI and RPPI following the various contingency cases on the Nigerian 330kV transmission network. The contingency cases were addressed through the placement of various UPFCs in the network and the predominantly violated buses are Maiduguri, Birni Kebbi, Oshogbo, Jos, Gombe and Kano. The total base case reactive power loss obtained in the network is 703.7499MVar and after the placement of UPFCs following the (N-2) contingency, the reactive power loss results to 694.6233MVar. The percentage power loss reduction as compare to the base case reactive power loss is 1.3%. The voltage improvement of 3.11% over the base case voltage was reported. The proposed method was also validated on IEEE 30-bus network showing a voltage improvement of 0.83% as compared to the work of Reddy *et al.,* (2014).

5.3 Conclusion

The development of a sensitivity index based technique for placement of UPFC device with multiple contingency analyses on Nigerian 330kV transmission network was presented. The research work has achieved its aim using the outlined objectives and the results have shown significant improvement over the base case and other current method.

5.3 Significant Contributions

The significant contributions of this research work are as follows:

1. The used of sensitivity index based technique on Nigerian 330kV transmission network with contingency analysis to improve its loadability through the placement of UPFC was analyzed.
2. The proposed method proffers a 1.3% reactive power loss reduction in the network as a result of the placement of UPFC as compare to the total base case reactive power loss.
3. The proposed method proffers a voltage improvement of 3.11% over the base case voltage.
4. The proposed method proffers a voltage profile improvement of 0.83% over the method of Reddy *et al*., (2014).

5.4 Recommendations

1. Base on the impact of UPFC as seen in this research, the device can be installed on every critical bus on the Nigeria 330kV transmission network to enhance its voltage stability and its line transfer capability.
2. To avoid switching problems attach to other conventional means of regulating voltages on the Nigeria 330kV network, UPFC can be used to overcome such limitations.

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Appendix A

Table A1: Contingency analysis of line 4 and 19 outages showing voltage improvement

Bus No	Bus Name	Base Case (BC) _V	Line Outage (LO)_V	Pre-RPPI	RPPI Ranking	Post UPFC_V	Post RPPI
1	Egbin	1.0200	1.0200	0.4000	29	1.0200	0.4000
2	Delta Ps	1.0300	1.0500	1.0000	12	1.0500	1.0000
3	Okpai	1.0500	1.0500	1.0000	12	1.0500	1.0000
4	Sapele	1.0500	1.0500	1.0000	12	1.0500	1.0000
5	Afam	1.0500	1.0500	1.0000	12	1.0500	1.0000
6	Jebba	1.0300	1.0300	0.6000	23	1.0100	0.2000
7	Kainji	1.0300	1.0300	0.6000	23	1.0100	0.2000
8	Shiroro	1.0500	1.0500	1.0000	12	1.0300	0.6000
9	Geregu	1.0500	1.0500	1.0000	12	1.0500	1.0000
10	Oshogbo	1.0737	1.0645	1.2893	8	1.0626	1.2520
11	Benin	1.0616	1.0615	1.2304	9	1.0604	1.2089
12	Ikj-West	1.0372	1.0260	0.5205	25	1.0256	0.5124
13	Ayede	1.0557	1.0452	0.9041	20	1.0440	0.8794
14	Jos	1.1848	1.1848	3.6956	4	1.0645	1.2903
15	Onitsha	1.0458	1.0458	0.9151	19	1.0396	0.7921
16	Akamgba	1.0306	1.0236	0.4728	28	1.0234	0.4681
17	Gombe	1.3836	1.3836	7.6716	2	1.0527	1.0544
18	Abuja(katamkpe)	1.0451	1.0451	0.9027	21	1.0245	0.4899
19	Maiduguri	1.3942	1.3941	7.8830	1	1.0329	0.6572
20	Egbin TS	1.0303	1.0251	0.5027	26	1.0250	0.4994
21	Aladja	1.0371	1.0492	0.9845	18	1.0492	0.9845
22	Kano	1.0138	1.0139	0.2780	31	0.9602	0.7952
23	Aja	1.0217	1.0164	0.3289	30	1.0163	0.3255
24	Ajaokuta	1.0606	1.0606	1.2122	10	1.0604	1.2071
25	N.Heaven	1.0809	1.0808	1.6167	7	1.0490	0.9799
26	Alaoji	1.0384	1.0384	0.7674	22	1.0281	0.5625
27	Jebba TS	1.0246	1.0246	0.4917	27	1.0043	0.0862
28	B.Kebbi	0.7020	0.7020	5.9593	3	0.9561	0.8778
29	Kaduna	1.0918	1.0919	1.8370	6	1.0355	0.7094
30	ShiroroTS	1.0569	1.0569	1.1384	11	1.0365	0.7307
31	Makurdi	1.1237	1.1237	2.4732	5	1.0585	1.1699
				38.7567			20.5870

Table A2: Contingency analysis of line 4 and 19 outages

Line No	APPI before UPFC placement	APPI Ranking	APPI after UPFC Placement
1	4.7308	10	4.7327
2	3.9189	12	3.9198
3	3.3351	14	3.3357
4	-	-	-
5	0.8347	30	0.8347
6	92.7666	1	69.4639
7	5.8929	7	6.1309
8	11.5290	5	12.3928
9	0.9584	28	0.9962
10	2.6564	18	2.7625
11	3.1141	16	3.1149
12	43.7388	2	44.7000
13	5.7653	8	5.7813
14	0.7468	32	0.7484
15	6.8088	6	6.8173
16	0.3390	34	0.3393
17	1.1004	27	1.1081
18	0.9438	29	0.9448
19	-	-	-
20	2.7259	17	2.7339
21	3.5637	13	3.5693
22	2.6537	19	3.1354
23	4.5343	11	6.6326
24	2.1546	22	2.2332
25	1.1725	25	1.1912
26	2.2844	21	2.2979
27	0.8086	31	0.8091
28	0.5806	33	0.5808
29	0.0809	35	0.1435
30	2.0023	23	2.0030
31	2.6122	20	2.8572
32	3.2677	15	3.4004
33	5.0092	9	5.0591
34	1.1351	26	1.1810
35	32.0254	3	33.3062
36	21.0109	4	23.3930
37	1.6320	24	1.9153
	278.4336	105.1517	264.5650

Table A3: Contingency analysis of line 4 and 37 Showing Bus Voltages improvement

Bus No	Bus Name	Base Case (BC) _V	Line Outage (LO)_V	Pre-RPPI	RPPI Ranking	Post UPFC_V	Post RPPI
1	Egbin	1.0200	1.0200	0.4000	28	1.0200	0.4000

2	Delta Ps	1.0300	1.0500	1.0000	13	1.0500	1.0000
3	Okpai	1.0500	1.0500	1.0000	13	1.0500	0.6000
4	Sapele	1.0500	1.0500	1.0000	13	1.0500	0.6000
5	Afam	1.0500	1.0500	1.0000	13	1.0500	1.0000
6	Jebba	1.0300	1.0300	0.6000	24	1.0100	0.2000
7	Kainji	1.0300	1.0300	0.6000	24	1.0100	0.2000
8	Shiroro	1.0500	1.0500	0.2000	30	1.0300	0.2000
9	Geregu	1.0500	1.0500	1.0000	13	1.0500	0.6000
10	Oshogbo	1.0737	1.0645	1.4479	8	1.0626	0.8819
11	Benin	1.0616	1.0615	1.3536	9	1.0604	0.9497
12	Ikj-West	1.0372	1.0260	0.7456	21	1.0256	0.5861
13	Ayede	1.0557	1.0452	1.1003	12	1.0440	0.7049
14	Jos	1.1848	1.1848	4.6008	4	1.0645	0.7017
15	Onitsha	1.0458	1.0458	0.9734	19	1.0396	0.4473
16	Akamgba	1.0306	1.0236	0.6133	22	1.0234	0.5143
17	Gombe	1.3836	1.3836	8.7916	2	1.0527	0.1001
18	Abuja(katamkpe)	1.0451	1.0451	0.0768	31	1.0245	0.0768
19	Maiduguri	1.3942	1.3941	9.0126	1	1.0329	0.3367
20	Egbin TS	1.0303	1.0251	0.6072	23	1.0250	0.5339
21	Aladja	1.0371	1.0492	0.9845	18	1.0492	0.5804
22	Kano	1.0138	1.0139	4.1753	5	0.9602	0.9776
23	Aja	1.0217	1.0164	0.4352	27	1.0163	0.3606
24	Ajaokuta	1.0606	1.0606	1.2415	10	1.0604	0.6737
25	N.Heaven	1.0809	1.0808	1.8544	7	1.0490	0.6944
26	Alaoji	1.0384	1.0384	0.8454	20	1.0281	0.4412
27	Jebba TS	1.0246	1.0246	0.4658	26	1.0043	0.0684
28	B.Kebbi	0.7020	0.7020	5.9593	3	0.9561	0.8778
29	Kaduna	1.0918	1.0919	1.1128	11	1.0355	0.2478
30	ShiroroTS	1.0569	1.0569	0.3228	29	1.0365	0.3228
31	Makurdi	1.1237	1.1237	2.9575	6	1.0585	0.7635
				33.9829			11.7618

Table A4: Contingency analysis following line 4 and 37 outages

Line No	APPI before UPFC Placement	APPI Ranking	APPI after UPFC

			Placement
1	4.7633	9.	4.8002
2	3.9391	11.	3.9581
3	3.3529	14.	3.3649
4	-	-	-
5	0.8347	28.	0.8676
6	92.7666	1.	69.4639
7	5.9003	7.	6.1363
8	12.8986	5.	12.3337
9	1.0363	26.	1.0363
10	2.8761	18.	2.8761
11	3.1098	16.	3.2573
12	58.2089	2.	60.9705
13	2.0106	22.	2.1049
14	1.1770	24.	1.2183
15	6.7586	6.	7.0781
16	0.3370	34.	0.3502
17	0.5511	33.	0.5762
18	0.9384	27.	0.9565
19	0.7798	30.	0.8010
20	2.4781	20.	2.5938
21	3.7407	12.	3.8417
22	3.1264	15.	4.1078
23	4.2261	10.	7.1937
24	2.8318	19.	3.0674
25	0.5976	31.	0.6251
26	2.2781	21.	2.3821
27	0.8212	29.	0.8316
28	0.5852	32.	0.5902
29	0.0748	35.	0.1581
30	1.9817	23.	1.9961
31	2.9586	17.	3.4546
32	3.3584	13.	3.6168
33	4.9904	8.	5.0891
34	1.1365	25.	1.1820
35	30.9220	4.	31.5343
36	31.5961	3.	25.1335
37	-	-	-
	299.9428		279.5479

Table A5: Contingency Analysis of Line 19 and 37 Outages Showing Voltage Improvement

Bus No	Bus Name	Base Case (BC) _V	Line Outage (LO)_V	Pre-RPPI	RPPI Ranking	Post UPFC_V	Post RPPI
1	Egbin	1.0200	1.0200	0.4000	27	1.0200	0.4000

2	Delta Ps	1.0300	1.0300	0.6000	19	1.0300	0.6000
3	Okpai	1.0500	1.0500	1.0000	11	1.0300	0.6000
4	Sapele	1.0500	1.0300	0.6000	19	1.0300	0.6000
5	Afam	1.0500	1.0500	1.0000	11	1.0500	1.0000
6	Jebba	1.0300	1.0300	0.6000	19	1.0100	0.2000
7	Kainji	1.0300	1.0300	0.6000	19	1.0100	0.2000
8	Shiroro	1.0500	1.0100	0.2000	30	1.0100	0.2000
9	Geregu	1.0500	1.0500	1.0000	11	1.0300	0.6000
10	Osogbo	1.0737	1.0564	1.1276	9	1.0498	0.9958
11	Benin	1.0616	1.0465	0.9306	14	1.0403	0.8056
12	Ikj-West	1.0372	1.0240	0.4794	24	1.0224	0.4482
13	Ayede	1.0557	1.0397	0.7931	17	1.0352	0.7041
14	Jos	1.1848	1.2282	4.5643	4	1.0429	0.8590
15	Onitsha	1.0458	1.0461	0.9211	15	1.0219	0.4380
16	Akamgba	1.0306	1.0223	0.4469	26	1.0214	0.4281
17	Gombe	1.3836	1.4373	8.7463	2	1.0189	0.3778
18	Abuja(katamkpe)	1.0451	1.0038	0.0768	31	1.0038	0.0768
19	Maiduguri	1.3942	1.4484	8.9670	1	0.9978	-0.0449
20	Egbin TS	1.0303	1.0242	0.4834	23	1.0235	0.4697
21	Aladja	1.0371	1.0308	0.6151	18	1.0308	0.6151
22	Kano	1.0138	0.7912	4.1753	5	0.9511	-0.9776
23	Aja	1.0217	1.0155	0.3092	29	1.0148	0.2952
24	Ajaokuta	1.0606	1.0570	1.1408	8	1.0338	0.6757
25	N.Heaven	1.0809	1.0912	1.8247	7	1.0365	0.7292
26	Alaoji	1.0384	1.0415	0.8309	16	1.0225	0.4507
27	Jebba TS	1.0246	1.0232	0.4641	25	1.0034	0.0690
28	B.Kebbi	0.7020	0.7020	5.9593	3	0.9561	0.8778
29	Kaduna	1.0918	0.9444	1.1128	10	0.9876	0.2478
30	ShiroroTS	1.0569	1.0161	0.3228	28	1.0161	0.3228
31	Makurdi	1.1237	1.1462	2.9249	6	1.0422	0.8444
				30.7216			11.8573

Table A6: Contingency Analysis of Line 19 and 37 Outages

Line No	APPI before UPFC Placement	APPI Rank	APPI after UPFC Placement

1	4.7937	9	4.8010
2	3.9580	11	3.9616
3	3.3636	14	3.3658
4	0.2146	34	0.2146
5	0.4024	33	0.4024
6	92.7666	1	69.4639
7	5.9008	7	6.1362
8	12.8986	5	12.3337
9	1.0363	25	1.0363
10	2.8761	19	2.8761
11	3.1246	16	3.2570
12	59.1064	2	60.6486
13	3.0071	17	3.0442
14	0.9172	26	0.9243
15	6.9330	6	7.1315
16	0.6850	28	0.6891
17	0.4727	32	0.4868
18	0.5200	31	0.5231
19	-	-	-
20	2.6849	21	2.7134
21	3.6818	12	3.7033
22	3.1348	15	4.0601
23	4.2379	10	7.0402
24	2.8296	20	3.0496
25	0.6120	29	0.6381
26	2.2838	22	2.3831
27	0.8321	27	0.8342
28	0.5908	30	0.5917
29	0.0750	35	0.1536
30	2.0062	23	2.0089
31	2.9662	18	3.4346
32	3.3708	13	3.6149
33	4.9939	8	5.0868
34	1.1366	24	1.1820
35	30.9246	4	31.5336
36	31.5961	3	25.1335
37	-	-	-
	300.9338		278.450

Table A7: Active and Reactive Power Loss with UPFC Compensation

Line No	Base case P Loss	UPFC PL	Base Case Q Loss	UPFC QL

1	2.0974	1.8137	16.3979	14.1795
2	1.6586	1.5090	12.5706	11.4366
3	1.2386	1.1271	9.3871	8.5422
4	0.0843	0.0482	0.6746	0.3981
5	0.1084	1.2143	0.8958	0.0000
6	1.2143	1.3159	103.0546	103.0546
7	1.3159	7.1744	14.7137	14.7145
8	7.2287	0.1538	62.0818	61.6156
9	0.1538	0.6965	1.1659	1.1659
10	0.6965	0.9489	5.2785	5.2785
11	0.9491	0.5428	7.4200	7.4187
12	0.5152	0.5785	43.8833	46.2311
13	0.2804	0.6831	2.4037	4.9591
14	0.7169	1.1603	4.9888	4.7537
15	1.1604	0.1454	9.2829	9.2824
16	0.1888	0.1204	1.4577	1.1227
17	0.1268	0.1573	1.0768	1.0219
18	0.6474	0.3586	5.5911	0.0000
19	0.1594	0.5345	1.2611	1.3586
20	0.2874	2.4402	2.4465	3.0526
21	0.6069	6.5537	5.1523	4.5375
22	2.4236	0.7719	20.5585	20.6999
23	6.5538	0.0627	55.8795	55.8788
24	0.7644	7.6020	6.5652	6.6291
25	0.0646	0.1820	0.5528	0.5357
26	7.6060	0.0819	5.9158	5.9127
27	0.2841	0.1042	2.4153	1.5472
28	0.0818	0.3326	0.6955	0.6963
29	0.1042	2.7244	0.7594	0.7594
30	0.3287	3.0880	2.5700	2.6000
31	2.7085	32.3825	20.5277	20.6480
32	3.0825	3.8696	23.3618	23.4040
33	32.3898	17.6405	25.1921	25.1864
34	3.8950	5.2080	2.8563	2.8377
35	17.8066	1.8248	151.8679	150.4514
36	5.2090	-	57.1080	57.0976
37	1.8393	-	15.7395	15.6152

Appendix B

m-file: Matlab Code for the developed contingency analysis and UPFC placement

```
% Contingency Analysis for generator outage and line outage
close all;
clear all;
clc;
nbus = 31;                % IEEE-6, IEEE-14, IEEE-30, 31-NGR, IEEE-57..
mul_cont=2;               % type of contingency double, triple so on
line_2rem=[4 19 37];      % line to remove (outage)
load_2rem=[11 12 22 26 29]; % load to remove (outage)
loadwl_2rem=[12 22 26];   % load to remove combo with line (outage)
n=0.5;                    % PIp multiplier
rtp=2*n;                  % raised to power
busd = busdatas(nbus);    % Calling busdatas..
lined = linedatas(nbus);  % Get linedats..
bus = busd(:,1);          % Bus Number..
type = busd(:,2);         % Type of Bus 1-Slack, 2-PV, 3-PQ..
pv = find(type == 2);     % PV Buses..
pq = find(type == 3);            % PQ Buses..
npv = length(pv);               % No. of PV buses..
npq = length(pq);               % No. of PQ buses..
nbr = length(lined);            % No. of lines(branches)
sbus = size(busd);


% L_lim=(rand(nbr,1))*1e2;          % Creating the line limit, randomly
%L_lim=lined(:,7);

n=zeros(nbr,1);                 % creating the number set for each line
for i=1:nbr
   n(i)=i;
end

m=zeros(nbus,1);                 % creating the number set for each bus
for i=1:nbus
   m(i)=i;
end

%%%%%%%%%%%%%%%%  Base case result   %%%%%%%%%%%%%%%%%%%%%%%
[PF_Result_BC, LF_Result_BC]=nrlfppg(0,0,0);

disp('################################################################################################');
disp('------------------------------------------------------------------------------------------------');
disp('                         Newton Raphson Loadflow Analysis ');
disp('------------------------------------------------------------------------------------------------');
disp('| Bus    |    V     | Angle  |     Injection      |     Generation      |         Load      |');
disp('| No     |   pu     | Degree |    MW  |   MVar   |    MW   | Mvar     |     MW    | MVar |');
disp('------------------------------------------------------------------------------------------------');
PF_Result_BC
disp('------------------------------------------------------------------------------------------------');

disp('----------------------------------------------------------------------------------------------------------');
disp('                         Line FLow and Losses ');
disp('----------------------------------------------------------------------------------------------------------');
disp('  |From |    To     |   P   |   Q    | From    | To    |    P    |  Q    |      Line Loss      |');
disp('  |Bus  |    Bus    |  MW   |  MVar  | Bus     | Bus   |   MW    | MVar  |     MW    |    MVar  |');
disp('----------------------------------------------------------------------------------------------------------');
LF_Result_BC
disp('----------------------------------------------------------------------------------------------------------');
```

```
%%%%%%%%%%%%%%%%%%    contigency for line data   %%%%%%%%%%%%%%%%%%%%%%
    dou_ln_cont=nchoosek(line_2rem,mul_cont);
    sz_dou_ln_cont=size(dou_ln_cont);
    Ttl_cont=zeros(sz_dou_ln_cont(1),5);
    upfc_sz=zeros(1,sz_dou_ln_cont(1));
    for i=3;%:sz_dou_ln_cont(1)
      nbus = 31;
      info=sprintf('THE OUTAGE OF LINES %d . ',dou_ln_cont(i,:));
      disp(info);
      llined=lined;
      sz_line=size(llined);
      new_line=zeros(sz_line(1),sz_line(2)+1);
      new_line(:,1)=n;
      new_line(:,2:end)=llined;
      llined=new_line;
      pre_cont_llined=llined;
      llined([dou_ln_cont(i,:)],:)=[];
      post_cont_llined=llined;

      llined=post_cont_llined(:,2:end);
      [PF_Result, LF_Result]=nrlfppg(llined,0,0);


disp('########################################################################################');
    disp('-------------------------------------------------------------------------------------');
    disp('                          Newton Raphson Loadflow Analysis ');
    disp('-------------------------------------------------------------------------------------');
    disp('| Bus    |    V     | Angle |    Injection      |    Generation     |        Load      |');
    disp('| No     |   pu     | Degree |   MW   |  MVar   |    MW   | Mvar    |     MW     | MVar |');
    disp('-------------------------------------------------------------------------------------');
    PF_Result;
    PF_Result_PREUPFC=PF_Result
    disp('-------------------------------------------------------------------------------------');

    disp('-----------------------------------------------------------------------------------------------');
    disp('                          Line FLow and Losses ');
    disp('-----------------------------------------------------------------------------------------------');
    disp('  |From |     To     |   P    |    Q     | From     | To     |    P     |  Q     |      Line Loss      |');
    disp('  |Bus |     Bus    |  MW    |   MVar   | Bus      | Bus  |    MW    | MVar   |     MW    |    MVar  |');
    disp('-----------------------------------------------------------------------------------------------');
    LF_Result;
    LF_Result_PREUPFC=LF_Result
    disp('-----------------------------------------------------------------------------------------------');

    %%%%%%%%%%%%%%%%%%     contigency ranking         %%%%%%%%%%%%%%%%%%%%%%
    %%%  active power PI
    for r=1:length(LF_Result(1:end-1,1))
      vi=PF_Result(LF_Result(r,1),2);
      vp=PF_Result(LF_Result(r,2),2);
      zip=abs(llined(r,3)+llined(r,4).*1i);
      rip=llined(r,3);
%          pi_max=((vi*vp)/zip)-(rip*vp/zip^2);
      pi_max=(vi*vp)/zip;

      max_pi_d1=abs(LF_Result(r,3));
      max_pi_d2=abs(LF_Result(r,7));
```

```
    if max_pi_d1>max_pi_d2
        max_pi=max_pi_d1;
    else
        max_pi=max_pi_d2;
    end
    PIp(r)=(max_pi/pi_max).^(rtp);
end
PIp=abs(PIp);
PIp_sorted=sort(PIp,'descend');
[~,rnk]=ismember(PIp,PIp_sorted);
rank_PIp=rnk';

%%%   reactive power PI
vi_nom=1.0;
vi_max=1.05*vi_nom;
vi_min=0.95*vi_nom;

for s=1:length(PF_Result(1:end-1,1));
    PIv(s)=(2*(PF_Result(s,2)-vi_nom))/(vi_max-vi_min);
end
PIv=abs(PIv);
PIv_sorted=sort(PIv,'descend');
[~,rnk]=ismember(PIv,PIv_sorted);
rank_PIv=rnk';

RPPI=zeros(length(PF_Result(1:end-1,1)),3);
RPPI(:,1)=PF_Result(1:end-1,1);
size(RPPI);
size(PIv);
RPPI(:,2)=PIv(1:length(PF_Result(1:end-1,1)));
RPPI(:,3)=rank_PIv(1:length(PF_Result(1:end-1,1)));
RPPI_PRE_tbl=RPPI;
ttl_RPPI=sum(RPPI(:,2));
ttl_RPPI_pre(i)=ttl_RPPI;

%%%   APPI table   %%%
APPI=zeros(length(post_cont_llined),5);
APPI(:,1:3)=post_cont_llined(:,1:3);
APPI(:,4)=PIp;
APPI(:,5)=rank_PIp;
APPI_PRE_tbl=APPI;
ttl_APPI=sum(APPI(:,4));
ttl_APPI_pre(i)=ttl_APPI;

%%% upfc injection bus
upfc_ulim=+300;
upfc_llim=-300;
stp_sz=1;           % step size
pre_upfc_busd=busd;
upfc_busd=pre_upfc_busd;
PF_Result_upfc=PF_Result;
for j=1:5
    for t=1:length(PF_Result)-1
        if RPPI(t,3)==1
            if PF_Result(t,2)>1.05 || PF_Result(t,2)<0.95
                upfc_size=zeros(1,upfc_ulim);
                if PF_Result(t,2)<0.95
```

```
                            for s_sz=1:stp_sz:upfc_ulim
                                upfc_size(s_sz)=s_sz;
                                if PF_Result_upfc(t,2)<=vi_min
                                upfc_busd(t,8)=upfc_busd(t,8)-stp_sz;
                                [PF_Result_upfc, LF_Result_upfc]=nrlfppg(llined,upfc_busd,nbus);
                                if PF_Result_upfc(t,2)==vi_min
                                    break
                                end
                                end
                            end

                        elseif PF_Result(t,2)>1.05
                            for s_sz=-1:-stp_sz:upfc_llim
                                upfc_size(s_sz*-1)=s_sz;
                                if PF_Result_upfc(t,2)>vi_max
                                upfc_busd(t,8)=upfc_busd(t,8)+stp_sz;
                                [PF_Result_upfc, LF_Result_upfc]=nrlfppg(llined,upfc_busd,nbus);
                                PF_Result_upfc;
                                if PF_Result_upfc(t,2)==vi_max
                                    break
                                end
                                end
                            end
                        end
                    end
                end
                PF_Result=PF_Result_upfc;
                        %%%   reactive power PI
                            vi_nom=1.0;
                            vi_max=1.05*vi_nom;
                            vi_min=0.95*vi_nom;

                            for s=1:length(PF_Result(1:end-1,1));
                                PIv(s)=(2*(PF_Result(s,2)-vi_nom))/(vi_max-vi_min);
                            end
                            PIv=abs(PIv);
                            PIv_sorted=sort(PIv,'descend');
                            [~,rnk]=ismember(PIv,PIv_sorted);
                            rank_PIv=rnk';

                            RPPI=zeros(length(PF_Result(1:end-1,1)),3);
                            RPPI(:,1)=PF_Result(1:end-1,1);
                            size(RPPI);
                            size(PIv);
                            RPPI(:,2)=PIv(1:length(PF_Result(1:end-1,1)));
                            RPPI(:,3)=rank_PIv(1:length(PF_Result(1:end-1,1)));
            end
        end

disp('#####################################################################################');
        disp('------------------------------------------------------------------------------------------');
        disp('                            Newton Raphson Loadflow Analysis ');
        disp('------------------------------------------------------------------------------------------');
        disp('| Bus     |    V     |  Angle  |     Injection      |     Generation      |         Load      |');
        disp('| No      |   pu     |  Degree |    MW   |   MVar   |    MW   |  Mvar    |     MW    |  MVar |');
        disp('------------------------------------------------------------------------------------------');
        PF_Result;
```

```
        PF_Result_POSTUPFC=PF_Result
        disp('-----------------------------------------------------------------------------------------------');

        disp('---------------------------------------------------------------------------------------------------------');
        disp('                              Line FLow and Losses ');
        disp('---------------------------------------------------------------------------------------------------------');
        disp('  |From |    To     |   P   |   Q    | From     | To    |    P    |  Q    |      Line Loss      |');
        disp('  |Bus  |    Bus    |  MW   |  MVar  | Bus      | Bus   |   MW    | MVar  |    MW    |   MVar  |');
        disp('---------------------------------------------------------------------------------------------------------');
        LF_Result;
        LF_Result_POSTUPFC=LF_Result
        disp('---------------------------------------------------------------------------------------------------------');

        upfc_tbl=zeros(length(PF_Result_POSTUPFC)-1,2);
        upfc_tbl(:,1)=m;
        for yu=1:length(PF_Result_POSTUPFC)-1
           if PF_Result_PREUPFC(yu,9)~=PF_Result_POSTUPFC(yu,9)
              if PF_Result_PREUPFC(yu,9)<PF_Result_POSTUPFC(yu,9)&&PF_Result_PREUPFC(yu,9)>0
                 upfsz=PF_Result_POSTUPFC(yu,9)-PF_Result_PREUPFC(yu,9);
                 upfc_tbl(yu,2)=upfsz;
              elseif PF_Result_PREUPFC(yu,9)>PF_Result_POSTUPFC(yu,9)&& PF_Result_POSTUPFC(yu,9)>0
                 upfsz=PF_Result_POSTUPFC(yu,9)-PF_Result_PREUPFC(yu,9);
                 upfc_tbl(yu,2)=upfsz;
              elseif PF_Result_PREUPFC(yu,9)>PF_Result_POSTUPFC(yu,9)&& PF_Result_POSTUPFC(yu,9)<0
                 upfsz=PF_Result_POSTUPFC(yu,9)-PF_Result_PREUPFC(yu,9);
                 upfc_tbl(yu,2)=upfsz;
              end
           end
        end

        upfc_tbl=upfc_tbl(1:end-1,:);
        upfc_tbl(:,2)=upfc_tbl(:,2)*-1;
        lut=length(upfc_tbl);
        %%%  UPFC location and sizes

        upsl=find(upfc_tbl(:,2)==0);
        upfc_tbl(upsl,:)=[];
        upfc_tbl;

%          PF_Result_PREUPFC(upfc_tbl(:,1),2)
%          PF_Result_POSTUPFC(upfc_tbl(:,1),2)

              %%%%%%%%%%%%%%%%%%     contigency ranking          %%%%%%%%%%%%%%%%%%%%
              %%%  active power PI
        for r=1:length(LF_Result(1:end-1,1))
           vi=PF_Result(LF_Result(r,1),2);
           vp=PF_Result(LF_Result(r,2),2);
           zip=abs(llined(r,3)+llined(r,4).*1i);
           rip=llined(r,3);
%             pi_max=((vi*vp)/zip)-(rip*vp/zip^2);
           pi_max=(vi*vp)/zip;

           max_pi_d1=abs(LF_Result(r,3));
           max_pi_d2=abs(LF_Result(r,7));
           if max_pi_d1>max_pi_d2
              max_pi=max_pi_d1;
           else
```

```
            max_pi=max_pi_d2;
         end
         PIp(r)=(max_pi/pi_max).^(rtp);
      end
      PIp=abs(PIp);
      PIp_sorted=sort(PIp,'descend');
      [~,rnk]=ismember(PIp,PIp_sorted);
      rank_PIp=rnk';

      %%%   reactive power PI
      vi_nom=1.0;
      vi_max=1.05*vi_nom;
      vi_min=0.95*vi_nom;

      for s=1:length(PF_Result(1:end-1,1));
         PIv(s)=(2*(PF_Result(s,2)-vi_nom))/(vi_max-vi_min);
      end
      PIv=abs(PIv);
      PIv_sorted=sort(PIv,'descend');
      [~,rnk]=ismember(PIv,PIv_sorted);
      rank_PIv=rnk';

      RPPI=zeros(length(PF_Result(1:end-1,1)),3);
      RPPI(:,1)=PF_Result(1:end-1,1);
      RPPI(:,2)=PIv;
      RPPI(:,3)=rank_PIv;
      RPPI_POST_tbl=RPPI;
      ttl_RPPI=sum(RPPI(:,2));
      ttl_RPPI_post(i)=ttl_RPPI;

            %%%   APPI table   %%%
%                 post_cont_llined=llined;
            APPI=zeros(length(post_cont_llined),5);
            APPI(:,1:3)=post_cont_llined(:,1:3);
            APPI(:,4)=PIp;
            APPI(:,5)=rank_PIp;
            APPI_POST_tbl=APPI;
            ttl_APPI=sum(APPI(:,4));
            ttl_APPI_post(i)=ttl_APPI;

      dou_ln_cont=dou_ln_cont(i,:);
      end

      dou_ln_cont

      upfc_sz_lo=upfc_tbl

      APPI_PRE_tbl
      APPI_PRE_tblc4=APPI_PRE_tbl(:,4)
      APPI_PRE_tblc5=APPI_PRE_tbl(:,5)
      ttl_APPI_pre

      RPPI_PRE_tbl
      RPPI_PRE_tblc2=RPPI_PRE_tbl(:,2)
      RPPI_PRE_tblc3=RPPI_PRE_tbl(:,3)
      ttl_RPPI_pre
```

```
APPI_POST_tbl
APPI_POST_tblc4=APPI_POST_tbl(:,4)
APPI_POST_tblc5=APPI_POST_tbl(:,5)
ttl_APPI_post

RPPI_POST_tbl
RPPI_POST_tblc2=RPPI_POST_tbl(:,2)
RPPI_POST_tblc3=RPPI_POST_tbl(:,3)
ttl_RPPI_post

BC_PL=LF_Result_BC(end,end-1)
LO_PL=LF_Result_PREUPFC(end,end-1)
UPFC_PL=LF_Result_POSTUPFC(end,end-1)

BC_QL=LF_Result_BC(end,end)
LO_QL=LF_Result_PREUPFC(end,end)
UPFC_QL=LF_Result_POSTUPFC(end,end)

BC_V=PF_Result_BC(:,2)
LO_V=PF_Result_PREUPFC(:,2)
UPFC_V=PF_Result_POSTUPFC(:,2)

BC_PL_ln=LF_Result_BC(1:end-1,end-1)
LO_PL_ln=LF_Result_PREUPFC(1:end-1,end-1)
UPFC_PL_ln=LF_Result_POSTUPFC(1:end-1,end-1)

BC_QL_ln=LF_Result_BC(1:end-1,end)
LO_QL_ln=LF_Result_PREUPFC(1:end-1,end)
UPFC_QL_ln=LF_Result_POSTUPFC(1:end-1,end)
```

m-file: Matlab Code for Newton Raphson Power Flow

```
function[PF_Result, LF_Result]= nrlfppg(llined,lbusd,nnbus)
% Program for Newton-Raphson Load Flow Analysis..
%     clear all;
%     clc;
%%%%%%%%%%%%%%%%%%%% WITHOUT CONTIGENCY %%%%%%%%%%%%%%%%%%%%
%   REMOVE THE INSERT COMMENT SYMBOL (%) FROM THE NEXT TWO LINES
%     llined=0;
%     lbusd=0;
%     nnbus=0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
nbus = nnbus;                  % IEEE-6, IEEE-14, IEEE-30, IEEE-57..
   if llined==0
      lined = linedatas(nbus);    % Get linedats..
   else lined=llined;
   end
   linedata=lined;

   if lbusd==0
   busd = busdatas(nbus);          % Get busdats..
   else busd=lbusd;
   end
   busdata=busd;

   if nnbus==0
```

```
   nbus = nbus;                   % Get nbus..
   else nbus=nnbus;
   end
   nbus;

Y = ybusppg(nbus,linedata); % Calling ybusppg.m to get Y-Bus Matrix..
% busd = busdatas(nbus);      % Calling busdatas..
BMva = 100;                  % Base MVA..
bus = busd(:,1);            % Bus Number..
type = busd(:,2);           % Type of Bus 1-Slack, 2-PV, 3-PQ..
V = busd(:,3);              % Specified Voltage..
del = busd(:,4);            % Voltage Angle..
Pg = busd(:,5)/BMva;        % PGi..
Qg = busd(:,6)/BMva;        % QGi..
Pl = busd(:,7)/BMva;        % PLi..
Ql = busd(:,8)/BMva;        % QLi..
Qmin = busd(:,9)/BMva;      % Minimum Reactive Power Limit..
Qmax = busd(:,10)/BMva;     % Maximum Reactive Power Limit..
P = Pg - Pl;                % Pi = PGi - PLi..
Q = Qg - Ql;                % Qi = QGi - QLi..
Psp = P;                    % P Specified..
Qsp = Q;                    % Q Specified..
G = real(Y);                % Conductance matrix..
B = imag(Y);                % Susceptance matrix..

pv = find(type == 2 | type == 1);   % PV Buses..
pq = find(type == 3);               % PQ Buses..
npv = length(pv);                   % No. of PV buses..
npq = length(pq);                   % No. of PQ buses..

Tol = 1;
Iter = 1;
while (Tol > 1e-5)   % Iteration starting..

   P = zeros(nbus,1);
   Q = zeros(nbus,1);
   % Calculate P and Q
   for i = 1:nbus
      for k = 1:nbus
         P(i) = P(i) + V(i)* V(k)*(G(i,k)*cos(del(i)-del(k)) + B(i,k)*sin(del(i)-del(k)));
         Q(i) = Q(i) + V(i)* V(k)*(G(i,k)*sin(del(i)-del(k)) - B(i,k)*cos(del(i)-del(k)));
      end
   end

   % Checking Q-limit violations..
   if Iter <= 7 && Iter > 2    % Only checked up to 7th iterations..
      for n = 2:nbus
         if type(n) == 2
            QG = Q(n)+Ql(n);
            if QG < Qmin(n)
               V(n) = V(n) + 0.01;
            elseif QG > Qmax(n)
               V(n) = V(n) - 0.01;
            end
         end
       end
   end
```

```
% Calculate change from specified value
dPa = Psp-P;
dQa = Qsp-Q;
k = 1;
dQ = zeros(npq,1);
for i = 1:nbus
    if type(i) == 3
        dQ(k,1) = dQa(i);
        k = k+1;
    end
end
dP = dPa(2:nbus);
M = [dP; dQ];       % Mismatch Vector

% Jacobian
% J1 - Derivative of Real Power Injections with Angles..
J1 = zeros(nbus-1,nbus-1);
for i = 1:(nbus-1)
    m = i+1;
    for k = 1:(nbus-1)
        n = k+1;
        if n == m
            for n = 1:nbus
                J1(i,k) = J1(i,k) + V(m)* V(n)*(-G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
            end
            J1(i,k) = J1(i,k) - V(m)^2*B(m,m);
        else
            J1(i,k) = V(m)* V(n)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
        end
    end
end

% J2 - Derivative of Real Power Injections with V..
J2 = zeros(nbus-1,npq);
for i = 1:(nbus-1)
    m = i+1;
    for k = 1:npq
        n = pq(k);
        if n == m
            for n = 1:nbus
                J2(i,k) = J2(i,k) + V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
            end
            J2(i,k) = J2(i,k) + V(m)*G(m,m);
        else
            J2(i,k) = V(m)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
        end
    end
end

% J3 - Derivative of Reactive Power Injections with Angles..
J3 = zeros(npq,nbus-1);
for i = 1:npq
    m = pq(i);
    for k = 1:(nbus-1)
        n = k+1;
        if n == m
```

```
                for n = 1:nbus
                    J3(i,k) = J3(i,k) + V(m)* V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
                end
                J3(i,k) = J3(i,k) - V(m)^2*G(m,m);
            else
                J3(i,k) = V(m)* V(n)*(-G(m,n)*cos(del(m)-del(n)) - B(m,n)*sin(del(m)-del(n)));
            end
        end
    end

    % J4 - Derivative of Reactive Power Injections with V..
    J4 = zeros(npq,npq);
    for i = 1:npq
        m = pq(i);
        for k = 1:npq
            n = pq(k);
            if n == m
                for n = 1:nbus
                    J4(i,k) = J4(i,k) + V(n)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
                end
                J4(i,k) = J4(i,k) - V(m)*B(m,m);
            else
                J4(i,k) = V(m)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
            end
        end
    end

    J = [J1 J2; J3 J4];     % Jacobian Matrix..

    X = inv(J)*M;           % Correction Vector
    dTh = X(1:nbus-1);      % Change in Voltage Angle..
    dV = X(nbus:end);       % Change in Voltage Magnitude..

    % Updating State Vectors..
    del(2:nbus) = dTh + del(2:nbus);    % Voltage Angle..
    k = 1;
    for i = 2:nbus
        if type(i) == 3
            V(i) = dV(k) + V(i);        % Voltage Magnitude..
            k = k+1;
        end
    end

    Iter = Iter + 1;
    Tol = max(abs(M));                  % Tolerance..

end
[PF_Result, LF_Result]=loadflow(nbus,V,del,BMva,llined, lbusd);             % Calling Loadflow.m..
```