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Contingency Analysis In Presence Of SVC Controller Of Sudan National Grid For Electricity

تحليل الحالات الطارئة في الشبكة القومية للكهرباء بوجود معوض القدرة الرد فعليه

A Thesis Submitted In Partial Fulfillment For The Requirement Of The Degree Of M.Sc In Electrical Engineering (Power) .

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الآيـــــــــة

قال تعالى :

{يَرْفَعِ اللَّهُ الَّذِينَ آمَنُوا مِنْكُمْ وَالَّذِينَ أُوتُوا الْعِلْمَ دَرَجَاتٍ وَاللَّهُ بِمَا تَعْمَلُونَ خَبِيرٌ }

صدق الله العظيم

Dedication

To

My Dearest Parents who are the part of my soul and whose love, affection and confidence enabled me to achieve this goal.

To

My Friends who have encouraged me to complete this work.

To

Naima izzaldin who have supported me with good ideas throughout the project.

ACKNOWLEDGEMENT

*To the **Almighty God** who have granted me all these graces to fulfill this work and who blessed and supported me by this power in all my life. Without this guidance I would have never reached this position where I am writing this page. To him I extend my heartfelt thanks.*

*I would like to present my greatest appreciation to my honorable supervisor **Dr. Mohamed Osman**, He is not only a great professor with deep vision but also very kind person. I sincerely thank for his exemplary guidance and encouragement. Without his encouragement and guidance, this project would not have materialized.*

*I wish to thank all my friends for their support, specially my colleagues **Eng.Hafeez El-haj** , **Eng.Mohamed Mowafi** , **Naiema izzaldeen** , for their help and encouragement me during all the period of research. I would also thank them for his valuable suggestions and discussions.*

*A special thanks to my **M.Sc. fellows** at **SUST**, **Bachelor** classmates, **SUST** students. I enjoyed every moment working together in the academic and occupational period.*

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ABSTRACT

Maintaining power system security of large power system is one of the challenging tasks to have secure operation point. The security assessment is an essential task as it gives the knowledge about the system state in the event of a contingency.

Contingency analysis technique is being widely used to predict the effect of outages like buses, transmission lines, generators and inter-bus transformers, these may cause transmission line over loading and bus voltage limits violations.

At the present load in Sudanese National Grid is expected to increase around (1700 MW), The main motivation of this work focuses on the contingencies of transmission line outage by simulated the network on NEPLAN Program to analyze the contingency (N-1) to have a good margins for critical event which may occur in the transmission lines and added SVC to violated buses to keep it in permissible limits and take a necessary actions which keep the power system secure and reliable.

Lastly, the results was discussed the results of in case of pre-contingency, post contingency and after add SVC, also conclusion and recommendation are made.

المستخلص

الحفاظ على أمان منظومة القدرة في منظومات القدرة الكبيرة أحد المهام الصعبة التي تتسم بنقطة تشغيل آمنة. التقييم الأمن هو مهمة أساسية لأنه يعطي المعرفة حول حالة النظام في حالة حدوث طارئ .

يتم استخدام تقنية تحليل الحالات الطارئة على نطاق واسع للتنبؤ بتأثير انقطاع التيار مثل البسبارات وخطوط النقل والمولدات والمحولات بين البسبارات ، وقد تتسبب هذه في حدوث خط نقل فوق حدود تحميل وحدود البسبار .

من المتوقع أن يزيد الحمل الحالي في الشبكة القومية السودانية حوالي (1700 ميقاواط) ، والهدف الأساسي لهذا العمل هو تحليل الحالات الطارئة لانقطاع خطوط النقل وذلك من خلال محاكاة الشبكة على برنامج NEPLAN لتحليل الحالات الطارئه والحصول على نتائج للحدث المهم الذي قد يحدث في خطوط النقل وكذلك لمعرفة المكان المناسب لإضافة معوض القدرة الرد فعلية الساكن إلى البسبارات المتأثره بخروج الخط لإبقائها في الحدود المسموح بها ، وذلك لإتخاذ الإجراءات اللازمة التي تحافظ على نظام الطاقة آمنًا وموثوقًا به.

وأخيرا ، تمت مناقشة النتائج في حالة ما قبل الطوارئ ، وحالة ما بعد الطوارئ وبعد إضافة SVC ، وعمل خلاصة لهذا العمل مع التوصيات .

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LIST OF ABBREVIATIONS

EMS	Energy Management System
AVC	Static Var Compensator

C.A	Contingency analysis
NR	Newton Rapson
FACTs	Flexible Ac Transmission System
AC	Alternating Current
SSSC	Static Synchronous Series Compensator
TCSC	Thyristor Control Series Compensator
STATCOM	Static Synchronous Compensator
IPFC	Interline Power Flow Controller
TCPST	Thyristor Controlled Phase Shifting Transformer
UPFC	Unified Power Flow Controller
TCR	Thyristor Controlled Reactor
VSC	Voltage Source Converter
LQP	Line Stability Index
GUT	Graphical User Interfaces
NGS	National Grid Of Sudan
PSO	Piratical Swarm Optimizations

CHAPTER ONE

INTRODUCTION

1.1 Overview :

It is well known that power system is a complex network consisting of numerous equipment's like generators, transformers, transmission lines, circuit breakers etc. Failure of any of these equipment's during its operation harms the reliability of the system and hence leading to outages. Thus one of the major agenda of power system planning and its operation is to study the effect of outages in terms of its severity. Installation of redundant generation capacity or transmission lines is essential in order to make the system run even when any of its components fails. But, power system being dynamic in nature does not guarantee that it will be 100 % reliable. Further, such arrangement may not be cost effective. Hence, a detailed security assessment is essential to deal with the possible failures in the system, its consequences and its remedial actions. This assessment is known as Power system security assessment.

Power system security involves system monitoring where the real time parameters of the system are monitored by using the telemetry systems or by the SCADA systems. It then involves the most important function of contingency analysis where the simulation is being carried out on the list of "credible" outage cases so as to give the operators an indication of what might happen to the power system in an event of unscheduled equipment outage. This analysis forewarns the system operator, and allows deciding some remedial action before the outage event.

For a power system to be secure, it must have continuity in supply without a loss of load. For this security analysis is performed to develop various control strategies to guarantee the avoidance and survival of emergency conditions and to operate the system at lowest cost. Whenever the pre specified operating limits of the power system gets violated the system is said to be in emergency condition. These violations of the limits result from contingencies occurring in the system. Thus, an important part of the security analysis revolves around the power system to withstand the effect of contingencies. The system security assessment process is carried out by calculating system operating limits in the pre- contingency and post contingency operating states at an operation control center or at the Energy Management System (EMS) of the utility company. The contingency analysis is time consuming as it involves the computation of complete AC load flow calculations following every possible outage events like outages occurring at various generators and transmission lines. This makes the list of various contingency cases very lengthy and the process very tedious. In order to mitigate the above problem, automatic contingency screening approach is being adopted which identifies and ranks only those outages which actually causes the limit violation on power flow or voltages in the lines. The contingencies are screened according to the severity index or performance index where a higher value of these indices denotes a higher degree of severity.

1.2 Problem statement :

sometimes, outage of generator due to failure of the auxiliary equipment or removal of a transmission line for maintenance purpose or due to storm and other effects may happens , the system frequency may drops and leads to load shedding or uncontrolled operation and sometimes leads to system collapse condition . This happens mainly due to the overloading of the transmission lines . this research presents to evaluation of improvement the power transmitted and voltage magnitude in the network system by using SVC controller considering normal and contingency condition based on Sudan national grid for more security .

1.3 Objective :

The main objective of this research is to improve the voltage profile and transmitted power in the lines, also to identify the effect of outage of transmission lines under contingency condition for more security system to meet the demand continuously without any failures.

1.4 Methodology :

Investigation of power system security under transmission lines outage condition and presence of SVC controller . The most critical lines in a given system will be identified using line collapse proximity index values , and the severity of contingency will be analyzed in terms of transmission line loadings and bus voltage magnitude violations , The proposed methodology will be implement on Sudan national grid .

1.5 Thesis Layout :

The work carried out in this thesis has been summarized in five chapters, **Chapter One** deliberates on the overview of the research, states in security analysis , problem statement , objectives of work and organization of the thesis. **Chapter Two** present the literature review include the various methods for contingency analysis, contingency ranking , Basic type of FACTS of controllers , SVC modeling and enhancement the voltage level by added SVC . In **Chapter Three** describes the N-X contingency analysis . **Chapter Four** describes the network at base case , loading on transmission line , voltage at buses after contingency occurrence and also after added SVC to violated buses to improve the security level of the system and discussed results for various cases in the systems .The conclusions and the scope of further work or recommendation are detailed in **Chapter Five** .

CHAPTER TWO

CONTINGENCY ANALYSIS

2.1 Introduction:

Contingencies are defined as potentially harmful disturbances that occur during the steady state operation of a power system. Load flow constitutes the most important study in a power system for planning, operation and expansion. The purpose of load flow study is to compute operating conditions of the power system under steady state. These operating conditions are normally voltage magnitudes and phase angles at different buses, line flows (MW and Mvar), real and reactive power supplied by the generators and power loss .

In a modern Energy Management power system security monitoring and analysis form an integral part but the real time implementation is a challenging task for the power system engineer. A power system which is operating under normal mode may face contingencies such as sudden loss of line or generator, sudden increase or decrease of power demand. These contingencies cause transmission line overloading or bus voltage violations. In electrical power systems voltage stability is receiving special attention these days. During the past two and half decades it has become a major threat to the operation of many systems. The transfer of power through a transmission network is accompanied by voltage drops between the generation and consumption points. In normal operating conditions, these drops are of the order of few percents of the nominal voltage. One of the principle tasks of power system operators is to check that under different operating conditions and/or following credible contingencies (e.g.: tripping of a single line) all bus voltages remain within bounds. In such circumstances, however in the seconds or minutes following a disturbance, voltages may experience large progressive falls, which are so prominent that the system integrity is endangered and power cannot be delivered to the customers. This catastrophe is referred to as voltage instability and its calamitous result as a voltage collapse .

Large violations in transmission line flow can result in line outage which may lead to cascading effect of outages and cause over load on the other lines. If such over load results from a line outage there is an immediate need for the control action to be initiated for line over load alleviation. Therefore, contingency analysis is one of the most important tasks to be met by the power system planners and operation engineers. But on line contingency analysis is difficult because of the conflict between the accuracy in solution of the power system problem and the speed required to simulate all the contingencies. The simulation of contingency is complex since it results in change in configuration of the system [2].

2.2 Modelling Contingency Analysis :

Since contingency analysis involves the simulation of each contingency on the base case model of the power system, three major difficulties are involved in this analysis.

First is the difficulty to develop the appropriate power system model. Second is the choice of which contingency case to consider and third is the difficulty in computing the power flow and bus voltages which leads to enormous time consumption in the Energy Management System. It is therefore apt to separate the on-line contingency analysis into three different stages namely contingency definition, selection and evaluation. Contingency definition comprises of the set of possible contingencies that might occur in a power system, it involves the process of creating the contingency list. Contingency selection is a process of identifying the most severe contingencies from the contingency list that leads to limit violations in the power flow and bus voltage magnitude, thus this process eliminates the least severe contingencies and shortens the contingency list. It uses some sort of index calculations which indicates the severity of contingencies. On the basis of the results of these index calculations the contingency cases are ranked. Contingency evaluation is then done which involves the necessary security actions or necessary control to function in order to mitigate the effect of contingency [2].

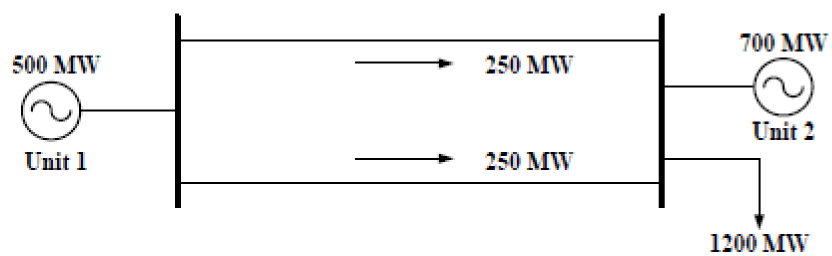
2.3 States in security analysis :

Security analysis involves the power system to operate into four operating states [1**] :**

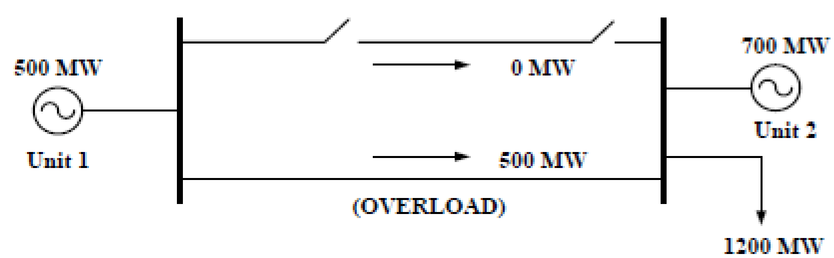
- **Optimal dispatch:** In this state the power system is in prior to any contingency. It is optimal with respect to economic operation, but it may not be secure.
- **Post contingency:** It is the state of the power system after a contingency has occurred, it is being assumed that this condition has a security violation such as line or transformer are beyond its flow limit, or a bus voltage is outside the limit.
- **Secure dispatch:** It is the state of the system with no contingency, but with corrections to the operating parameters to account for security violations.

- **Secure post-contingency:** This is the state where the contingency is applied to the base operating condition with corrections.

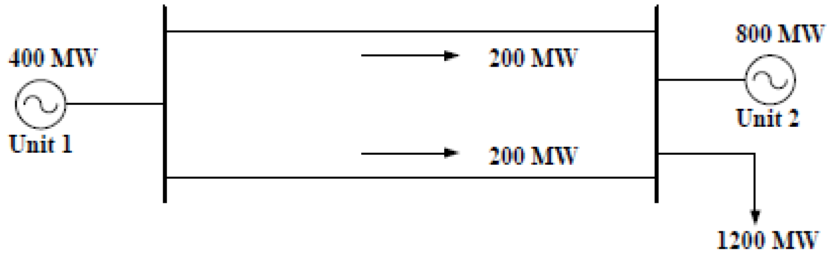
The concept of security analysis has been illustrated with a following example. Suppose a power system consisting of two generators, a load, and a double circuit line, is to be operated with both generators supplying the load as shown in Fig. 1.1(a) and ignoring the losses it is assumed that the system as shown is in economic dispatch i.e. 500 MW is allotted for unit 1 and the 700 MW for unit 2 as the optimum dispatch. Further, it is asserted that each circuit of the double circuit line can carry a maximum of 400 MW, so that there is no loading problem in the base-operating condition. This condition is being referred to as the optimal dispatch.



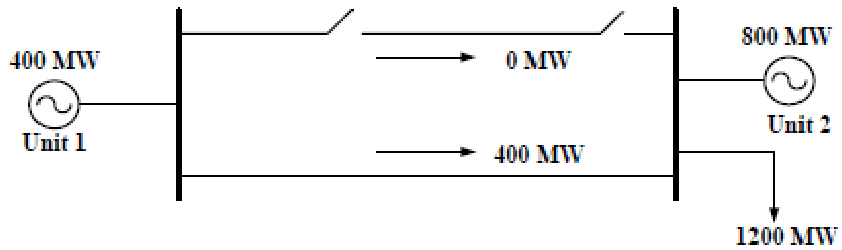
(a) Optimal Dispatch



(b) Post Contingency State



(c) Secure Dispatch



(d) Secure Post Contingency State

Fig. 2.1 Various operating states of Power System

Now, a failure in one of the two transmission lines has been postulated and it can be said that a line contingency has occurred and this results in change in power flows in the other line causing the transmission line limit to get violated. The resulting flows have been shown Fig. 1.1(b), this sate of power system is being said to be post contingency state. Now there is an overload on the remaining circuit. If the above condition is to be avoided, the following security corrections have been done. The generation of unit 1 has been lowered from 500 MW to 400 MW and the generation of unit 2 is raised from 700 MW to 800 MW. This secure dispatch is illustrated in Fig. 1.1(c). Now, if the same contingency analysis is to done, the post-contingency condition power flows is illustrated in Fig. 1.1(d) Thus by adjusting the generation on unit 1 and unit 2, the overloading in other line is prevented and thus the power system remains secure. These adjustments are called "security corrections." Programs which can make control adjustments to the base or Pre contingency operation to prevent violations in the post-contingency conditions are called "security-constrained optimal power flows". These programs can take account of many contingencies and calculate adjustments to generator MW, generator voltages, transformer taps etc. Together with the function of system monitoring, contingency analysis and the corrective actions the analysis procedure forms a set of complex tools that can lead to the secure operation of a power system.

2.4 Contingency Analysis using Sensitivity Factors:

The problem of studying thousands of possible outages becomes very difficult to solve if it is desired to present the results quickly. One of the easiest ways to provide a quick calculation of possible overloads is to use sensitivity factors [1]. These factors show the approximate change in line flows for changes in generation on the network configuration and are derived from the DC load flow**.** These factors can be derived in a variety of ways and basically come down to two types:

- Generation Shift Factors.
- Line Outage Distribution Factors.

2.4.1 Generation Shift Factors:

The generation shift factors represent the change in flow due to increment injection at a generator bus, and corresponding with draws at the swing bus. And they are designated a_{li} and have the following definition:

$$a_{lt} = \frac{\Delta f_l}{\Delta p_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where:

l= line index

i=bus index

Δf_l = change in megawatt power flow on line l when a change in generation ΔP_i occurs at bus i

ΔP_i = change in generation at bus i

It is assumed that the change in generation ΔPi is exactly compensated by an opposite change in generation at the reference bus, and that all other generators remain fixed. The a_{li} factor then represents the sensitivity of the flow on line l due to a change in generation at bus ***i***. If the generator was generating Pi_o MW and it was lost, it is represented by ΔPi, as the new

$$\Delta P_i = -P_i^{\circ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.2)$$

power flow on each line in the network could be calculated using a pre calculated set of ***"a"*** factors as follows:

$$f_l = f_l^{\circ} + a_{li}\Delta P_i \ for\ l = 1 \ldots L \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2.3)$$

Where:

f_l = flow on line *l* after the generator on bus *i* fails

f_l^0 = flow before the failure

The outage flow *fl* on each line can be compared to its limit and those exceeding their limit are flagged for alarming. This would tell the operations personal that the loss of the generator on bus *i* would result in an overload on line *l*. The generation shift sensitivity factors are linear estimates of the change in flow with a change in power at a bus. Therefore, the effects of simultaneous changes on several generating buses can be calculated using superposition.

2.4.2 Line outage distribution factors:

The line outage distribution factors are used in a similar manner, only they apply to the testing for overloads when transmission circuits are lost. By definition, the line outage distribution factor has the following meaning:

$$d_{l,k} = \frac{\Delta f_l}{f_k^{\circ}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.4)}$$

Where :

$d_{l,k}$ = line outage distribution factor when monitoring line *l* after an outage on line *k*

Δf_l = change in MW flow on line *l*

f_k^0 = original flow on line *k* before it was outaged i.e., opened

If one knows the power on line *l* and line *k***,** the flow on line *l* with line *k* out can be determined using ***"d"*** factors.

$$f_i = f_l^{\circ} + d_{l,k} f_k^{\circ} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2.5)}$$

Where :

f_l^0 and f_k^0 = pre outage flows on lines l and k, respectively

f_l = flow on line l with line k out

By pre calculating the line outage distribution factors, a very fast procedure can be set up to test all lines in the network for overload for the outage of a particular line.

Furthermore, this procedure can be repeated for the outage of each line in turn, with overloads reported to the operations personnel in the form of alarm messages. The generator and line outage procedures can be used to program a digital computer to execute a contingency analysis study of the power system. It is to be noted that a line flow can be positive or negative so that we must check f_l against $-f_{lmax}$ as well as f_{lmax}. It is assumed that the generator output for each of the generators in the system is available and that the line flow for each transmission line in the network is also available and the sensitivity factors have been calculated and stored.

2.5 Contingency selection:

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's. The process of identifying the contingencies that actually leads to the violation of the operational limits is known as contingency selection. The contingencies are selected by calculating a kind of severity indices known as Performance indices PI (v) 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.

There are two kind of performance index which are of great use, these are active power performance index (PI_P) and reactive power performance index (PI_V). PI_P reflects the violation of line active power flow and is given by eq. 2.6.

$$PI_P = \sum_{i=1}^{L} (\frac{Pi}{Pimax})^{2n} \quad \text{.....(2.6)}$$

Where:

Pi = Active Power flow in line *i*,

Pi_{max} = Maximum active power flow in line *i*,

n is the specified exponent,

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

If *n* is a large number, the PI will be a small number if all flows are within limit, and it

will be large if one or more lines are overloaded. Here the value of n has been kept unity.

The value of maximum power flow in each line is calculated using the formula :

$$P_i^{max} = \frac{V_i * V_j}{x} \qquad \text{……..………………………… (2.7)}$$

Where :

Vi= Voltage at bus i obtained from FDLF solution

Vj= Voltage at bus j obtained from FDLF solution

X = Reactance of the line connecting bus „i" and bus „j"

Another performance index parameter which is used is reactive power performance index

corresponding to bus voltage magnitude violations. It mathematically given by eq.2.8 :

$$PI_V = \sum_{i=1}^{Npq} \left[\frac{2(Vi - Vinom)}{Vimax - Vimin}\right]^2 \text{…………………..……….. (2.8)}$$

Where:

Vi: Voltage of bus i

Vimax and Vimin : are maximum and minimum voltage limits

Vinom: is average of Vimax and Vimin

Npq : is total number of load buses in the system

CHAPTER THREE

PLACEMENT AND SIZING OF FACTS

3.1 Introduction

Flexible AC Transmission System (FACTS) is defined as ’a power electronic based system and other static equipment that provide control of one or more AC transmission system parameters'[3-4]. Also defined as ‘Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability’ [6]. There are two main objectives of FACTS devices which are increasing the power transfer capability of transmission system and limit power flow over designated lines. In current power market, control of active and reactive power flow in a transmission line becomes a necessity aspect. Entry of more power generation companies has increased the need for enhanced secured operation of power systems, which are facing the threat of voltage instability leading to voltage collapse and also for minimization of active power loss leading to reduction in electricity cost. This achieved by load compensation which consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation of large fluctuating loads. And also achieved by voltage support at a given terminal of the transmission line [7-8].

3.2 Reactive Power Controller :

Power flow control has traditionally relied on generator control, voltage regulation by means of tap-changing and phase-shifting transformers, and reactive power plant compensation switching. Phase-shifting transformers have been used for the purpose of regulating active power in alternating current (AC) transmission networks [3].

Series reactors are used to reduce power flow and short-circuit levels at designated locations of the network. Conversely, series capacitors are used to shorten the electrical length of lines, hence increasing the power flow. In general, series compensation is switched on and off according to load and voltage conditions. For instance, in longitudinal power systems, series capacitive compensation is bypassed during minimum loading in order to avoid transmission line overvoltage due to excessive capacitive effects in the system. Conversely, series capacitive compensation is fully utilized during maximum loading, aiming at increasing the transfer of power without subjecting transmission lines to overloads [3].

3.3 Compensator classification :

The compensator in Terms of Connection can be classified with regard to their connection in the network as.

1. Series controllers,

2. Shunt Compensator.

3. Combined series-series Compensator.

4. Combined shunt-series Compensator.

3.3.1 Series Compensator:

Series controllers, in FACTS technology, are used to inject voltage in series with the line. In simplest form, a variable impedance multiplied by the current flow through it represents an injected series voltage in the line. If the series voltage in phase quadrature with the line current, the series controller only supplied or absorbs variable reactive power. Real power is involved for any other phase relationship between the injected voltage and the line current. The symbolic representation of series FACTS controller is shown in Figure 3.1 [9].

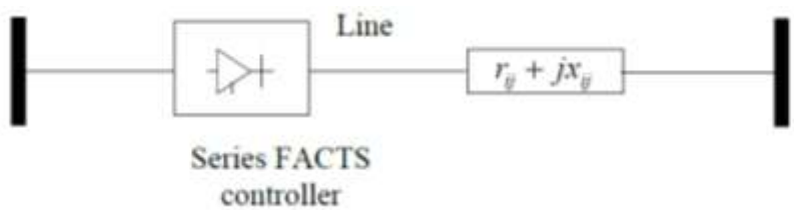


Figure 3.1: The symbolic of series compensation.

The symbolic of series controller are effective line parameters by connecting a variable reactance in series with the line. This increase the transmission line capability which in turn reduces transmission line net impedance. Example of Series compensator are Static Synchronous Series Compensator (SSSC) and Thyristor Control Series Compensator (TCSC) [8].

3.3.2 Shunt Compensator:

Similar to series controller, shunt Compensator have variable impedance or variable source or combination of both. All shunt connected FACTS device inject current into the bus at the point of connection. The shunt impedance may be variable to vary the injected current. As long as this injected current is in phase quadrature with the line voltage, the shunt controller only supplies or absorbs variable reactive power. Any other phase relationship of the generated current with line voltage will involve real power flow [9].

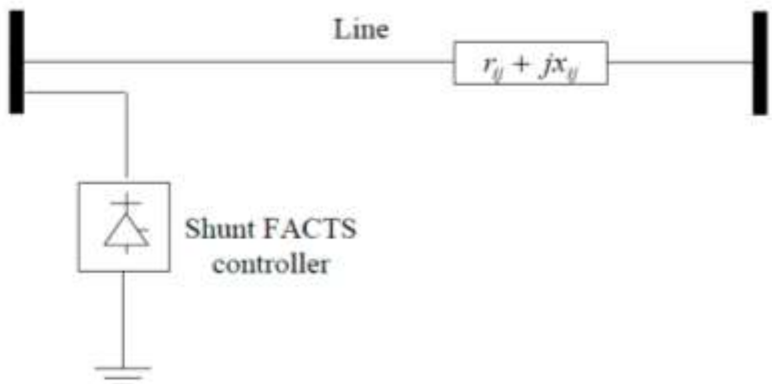


Figure 3.2: The symbolic of shunt compensation.

The operational pattern is same with an ideal synchronous machine that generates balanced three phase voltages with controllable amplitude and phase angle. The characteristics enables shunt compensators to be represented in positive sequence power flow studies with zero active power generation and reactive limits. Examples are Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC) [8].

3.3.3 Series-Series Compensator:

It is the combination of two or more static synchronous compensators coupled through a common dc link to enhance bi-directional flow of real power between the ac terminals of SSSC and are controlled to provide independent reactance compensation for the adjustment of real power flow in each line and maintain the desired distance of reactive power flow among the power lines. Example of series – series compensator is Interline Power Flow Controller (IPFC) [8].

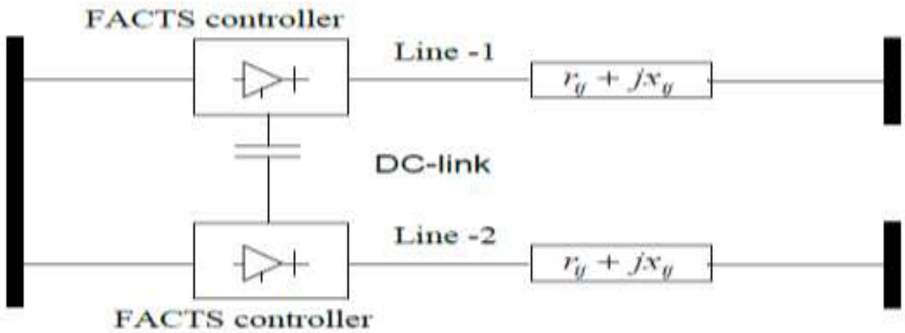


Figure 3.3: The symbolic of series- series compensation.

3.3.4 Series-Shunt Compensator:

It allows the simultaneous control of active power flow, reactive power flow and voltage magnitude at the series shunt compensator terminals. The active power control takes place between the series converter and the AC system, while the shunt converter generates or absorbs reactive power so as to provide voltage magnitude at the point of connection of the device and the AC system. Example of the series-shunt compensator is the unified power flow controller (UPFC) and thyristor controlled phase shifting Transformer (TCPST) [8].

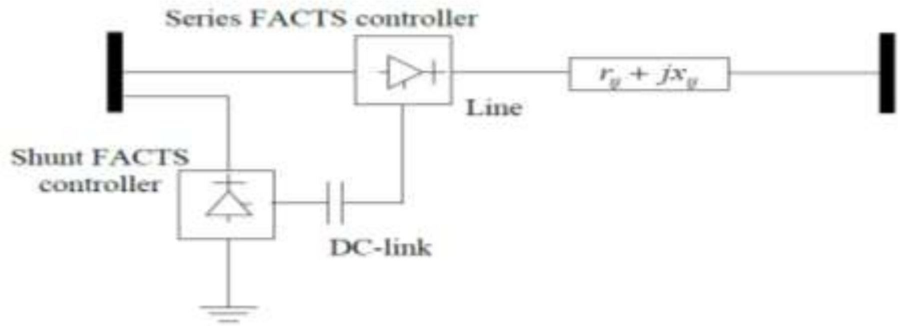


Figure 3.4: The symbolic of series- shunt compensation.

3.5 Classification of FACTS Controllers Based on Power Electronic Devices:

Depending on the power electronic devices used in the control, the FACTS controllers can be classified as following :

A. **Variable impedance type include (SVC , TCSC) :**

I. Static VAR Compensator (SVC):

The SVC consists of a TCR in parallel with a bank of capacitors. From an operational point of view, the SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response. Generally they are two configurations of the SVC [3].

II. Shunt Variable susceptance model

The SVC consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching circuits. From the operational point of view, the SVC can be considered as a variable shunt reactance that adjusts automatically according to the system operative conditions. Depending on the nature of the equivalent SVC's reactance, i.e., capacitive or inductive, the SVC draws either capacitive or inductive current from the network. Suitable control of this equivalent reactance allows voltage magnitude regulation at the SVC point of connection. The most popular configuration for continuously controlled SVC is the combination of either fix capacitor and thyristor controlled reactor or thyristor switched capacitor and thyristor controlled reactor. For steady-stale analysis, both configurations can be modeled along similar lines [10]. A changing susceptance B_{svc} represents the fundamental frequency equivalent susceptance of all shunt modules making up the SVC as shown in Figure 2.5. Is used to derive the SVC nonlinear power equations and the linearized equations required by Newton's method with reference to Fig 2.5,

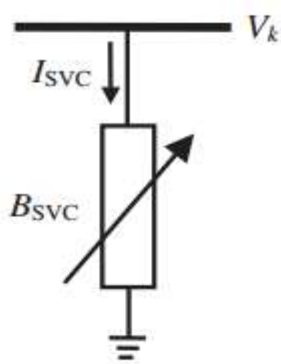


Figure (3.5) : SVC susceptance model.

The current drawn by the SVC is :

$$I_{SVC} = j\, B_{SVC}\, V_k \qquad (3.1)$$

And the reactive power drawn by the SVC, which is also the reactive power injected at bus k, is

$$Q_{SVC} = Q_k = -V_k^2 B_{SVC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.2)$$

The linearized equation is given by Equation, where the equivalent susceptance B_{SVC} is taken to be the state variable:

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \end{bmatrix}^{(i)} = \begin{bmatrix} 0 & 0 \\ 0 & Qk \end{bmatrix}^{(i)} \begin{bmatrix} \Delta\theta_k \\ \Delta B_{svc}/B_{svc} \end{bmatrix}^{(i)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

At the end of iteration (i), the variable shunt susceptance B_{SVC} is updated according to:

$$B_{svc}{}^{(i)} = B_{svc}{}^{(i-1)} + \left(\frac{\Delta B_{svc}}{B_{svc}}\right)^{(i)} Bsvc^{(i-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.4)$$

Where, V_K =voltage at bus k

B_{svc}= Susceptance

Q_{svc}= reactive power drawn by SVC.

The changing susceptance represents the total SVC susceptance necessary to maintain the nodal voltage magnitude at the specified value.

Once the level of compensation has been computed then the thyristor firing angle can be calculated. However, the additional calculation requires an iterative solution because the SVC susceptance and thyristor firing angle are nonlinearly related [3].

III. **Firing angle model**.

The equivalent reactance X_{SVC}, which is function of a changing firing angle α, is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance as shown in Figure 2.6. This model provides information on the SVC firing angle required to achieve a given level of compensation [10].

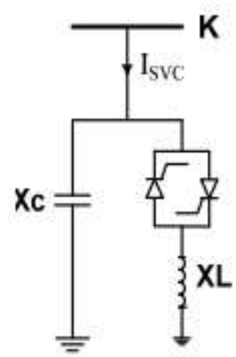


Figure (3.6) : SVC firing angle model.

$$I_{svc} = j\, B_{svc}\, V_k$$

The fundamental frequency TCR equivalent reactance X_{TCR}

$$X_{TCR}=\frac{\pi X_L}{\sigma - sin\sigma} \qquad \text{(3.5)}$$

Where

$\sigma = 2(\pi - \alpha)$, X_L=wL

And in terms of firing angle

$$X_{TCR} = \frac{\pi X_L}{2(\pi-\alpha)+\sin(2\alpha)} \qquad \text{(3.6)}$$

σ and α are conduction and firing angles respectively. At α=90, TCR conducts fully and the equivalent reactance X_{TCR} becomes X_L, while at α=180, TCR is blocked and its equivalent reactance becomes infinite. The SVC effective reactance X_{SVC} is determined by the parallel combination of X_C and X_{TCR}

$$X_{SVC} = \frac{\pi X_C X_L}{X_C[X_C[2((\pi-\alpha)+sin2\alpha]-\pi X_L} \qquad \text{(3.7)}$$

Where X_c=1/ωC

$$Q_K = -V_k{}^2 \left\{\frac{X_C[X_C[2((\pi-\alpha)+sin2\alpha]-\pi X_L}{\pi X_C X_L}\right\} \text{……………………. (3.8)}$$

The proposed model takes firing angle as the state variable in power flow formulation. From equation (3.8) the SVC linearized power flow equation can be written as

$$\begin{bmatrix}\Delta P_k \\ \Delta Q_k\end{bmatrix}^{(i)} = \begin{bmatrix}0 & 0 \\ 0 & \frac{2V_k{}^2}{\pi X_L}[\cos(2\alpha)-1]\end{bmatrix}^{(i)} \begin{bmatrix}\Delta\theta_k \\ \Delta\alpha\end{bmatrix}^{(i)} \text{……………. (3.9)}$$

At the end of iteration i, the variable firing angle αis updated according to

$$\alpha^{(i)} = \alpha^{(i-1)} + \Delta\alpha^{(i)} \text{…………………………………….. (3.10)}$$

IV. **SVC V-I Characteristic:**

- The linear control domain, in which the voltage control system is provided with appropriate reactive power resources, and the set-point can be defined anywhere on the AB characteristic. This domain is bounded by the reactive current Q_{Cmax}, supplied by the capacitors, and by the reactive current Q_{Lmax} absorbed by the reactor, that is $Q_{Cmax} \leq Q \leq Q_{Lmax}$.

  In practice, a SVC uses droop control of the voltage at the regulated bus, with a slope of about 5%. The droop control means that the voltage at the regulated bus is controlled within a certain interval [V_{min}, V_{max}], instead of a constant voltage value V_{ref}.

- The high voltages domain (BC), resulted from the limitation in the inductive reactive power, i.e. $Q > Q_{Lmax}$. The SVC is, in this case, is out of the control area and it behaves like a fixed inductive susceptance.
- The low voltages domain (OA), resulted from the limitation in the capacitive reactive power, i.e. $Q < Q_{Cmax}$. The SVC is, in this case,

is out of the control area and it behaves like a fixed capacitive susceptance [11].

The typical steady-state control law of a SVC used here is depicted in Figure3.3, and may be represented by the following voltage-current characteristic:

$$V_k = V_{ref} + X_{SL} \cdot I_{SVC} \quad (3.11)$$

Where V_k and I_{SVC} stand for controlling bus voltage and SVC current [12].

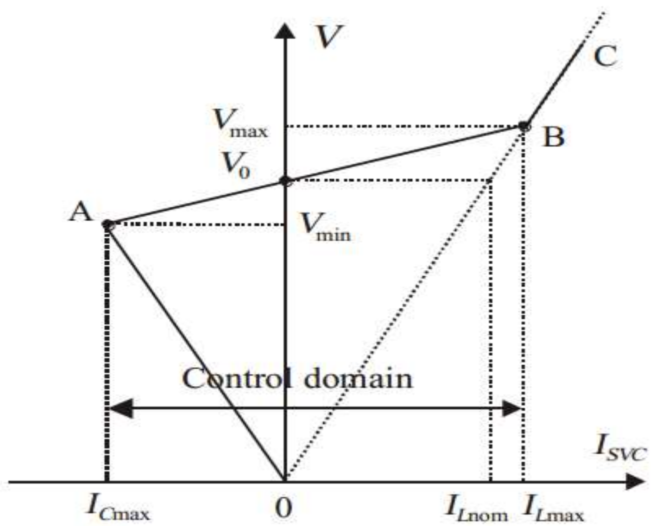


Figure (3.7) : The V-I Characteristic Curve of SVC

The reason for including the SVC voltage current slope in power flow studies is compelling. The slope can be represented by connecting the SVC models to an auxiliary bus coupled to the high voltage bus by an inductive reactance consisting of the transformer reactance and the SVC slope, in per unit (p.u) on the SVC base. A simpler representation assumes that the SVC slope, accounting for voltage regulation is zero. This assumption may be acceptable as long as the SVC is operating within the limits, but may lead to gross errors if the SVC is operating close to its reactive limits [13-15].

V. Thyristor Controlled Series Compensator (TCSC) :

It is designed based on the thyristor based FACTS technology that has the ability to control the line impedance with a thyristor-controlled capacitor placed in series with the transmission line. It is used to increase the transmission line capability by installing a series capacitor that reduces the net series impedance thus allowing additional power to be transferred [15].

TCSC is a series compensation component which consists of a series capacitor bank shunted by thyristor controlled reactor Figure 3.8 shows the main circuit of a TCSC. The basic idea behind power flow control with the TCSC is to decrease or increase the overall lines effective series transmission impedance, by adding a capacitive or inductive reactive correspondingly. Thyristor Controlled Series Capacitor (TCSC) is one of the most effective FACTS devices which offer smooth and flexible control of the line impedance with much faster response compared to the traditional control devices. TCSC can also enhance the stability, improve the dynamic characteristics of power system, and increase the transfer capability of the transmission system by reducing the transfer reactance between the buses at which the line is connected. However, to achieve the above mentioned benefits, the TCSC should be properly installed in the network with appropriate parameter settings.

For this reason, some performance indices must be satisfied, following factors can be considered in the optimal installation of TCSC, the topology of the system, the stability margin improvement, the power transmission capacity increasing, and the power blackout prevention [17].

B. Variable Source Converter (VSC) – base include (SSSC , STATCOM , IPFC and UPFC) :

VI. Static Synchronous Series Compensator (SSSC) :

Static Synchronous Series Compensator is based on solid-state voltage source converter designed to generate the desired voltage magnitude independent of line current. SSSC consists of a converter, DC bus (storage unit) and coupling transformer. The dc bus uses the inverter to synthesize an ac voltage waveform that is inserted in series with transmission line through the transformer with an appropriate phase angle and line current. If the injected voltage is in phase with the line current it exchanges a real power and if the injected voltage is in quadrature with line current it exchanges a reactive power. Therefore, it has the ability to exchange both the real and reactive power in a transmission line [16].

VII. Static Synchronous Compensator (STATCOM)

It is designed based on Voltage source converter (VSC) electronic device with Gate turn off thyristor and dc capacitor coupled with a step down transformer tied to a transmission line. It converts the dc input voltage into ac output voltages to compensate the active and reactive power of the system. The STATCOM has better characteristics than SVC and it is used for voltage control and reactive power compensation. STATCOM placed on a transmission network improve the voltage stability of a power system by controlling the voltage in transmission and distribution systems, improves the damping power oscillation in transmission system, and provides the desired reactive power compensation of a power system [16].

VIII. Unified Power Flow Controller (UPFC)

It is designed by combining the series compensator (SSSC) and shunt compensator (STATCOM) coupled with a common DC capacitor. It provides the ability to simultaneously control all the transmission parameters of power systems, i.e. voltage, impedance and phase angle. it 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 [16].

3.6 Optimal placement of FACTS :

In power systems, appropriate placement of FACTS is becoming important. Improperly placed FACTS controllers fail to give the optimum performance and can even be counterproductive. Therefore, proper placement of these devices must be examined. This chapter investigates the optimal location of SVC and TCSC device in Sudanese grid to get the maximum possible benefit of maximum power transfer and enhance bus voltage under steady state conditions. There are many indices which use the elements of the admittance matrix and some system variables such as bus voltages and power flow through lines such as VCPI, L-index, L_{mn}, LQP, NVSI and FVSI. Some of these indices use the concept of the maximum power transfer that can be transmitted to the load bus in a simple two bus power system. These indices require less computational effort and are suitable for quickly diagnosing the power system voltage stability. These indices should be use on-line or off-line to help operators in real time operation of power system or in designing and planning operations. In this thesis used line indices to find the optimal location of FACTS devices. Three different types of indices are used in Sudanese electrical network to identify the weakest line in the network.

3.6.1 Line stability index (LQP) :

Line stability index LQP can be obtained from the equation

$$LQP=4\left(\frac{X}{V_i^2}\right)\left(\frac{X}{V_i^2}P_i^2+Q_j\right) \qquad (3.8)$$

To maintain a secure condition LQP indices should be maintained less than 1. Table 3.1 represent indices LQP [19].

Table 3.1: LQP :

Index	Formulation	Relative Variable	Assumption	Critical value
LQP	$4\left(\frac{X}{V_i^2}\right)\left(\frac{X}{V_i^2}P_i^2+Q_j\right)$	P Q V X	R/X<<1	1.00

3.7 FACTS implementation :

In this thesis SVC have been implemented in Sudanese grid, there is some condition must be taken into account before installing FACTS devices in the system.

3.7.1 SVC placement Criteria :

The previous indices FVSI, LQP and NVSI used to find the optimal location for the SVC and TCSC in the system. The weakest bus selected by line indices, the SVC connected to bus bar which gives the best improvement of the system. Equations (2.1 to 2.11) is used to set parameter of SVC to improve the voltage profile at the candidate buses to flat profile. The injected reactive power from SVC is modified adapted until the system reached the desired improvement in the voltage and power losses.

The SVC parameter limits must be set correctly to allow the power flow software to converges toward the solution; if these parameters does not specified correctly, the power flow program will not converges to the solution.

3.8 Software Development :

NEPLAN is one of the most intelligent planning, optimization and simulation tool. It is all operations can be assessed by means of graphical user interfaces (GUIs). In this thesis, NEPLAN software environment is used to simulate the system and to introduce SVC and TCSC devices in the system and to obtain the power flow results.

3.8.1 NEPLAN SVC model & parameter :

Description of the Model :

For Load Flow calculations, a regulated VAR compensator can be described as follows :

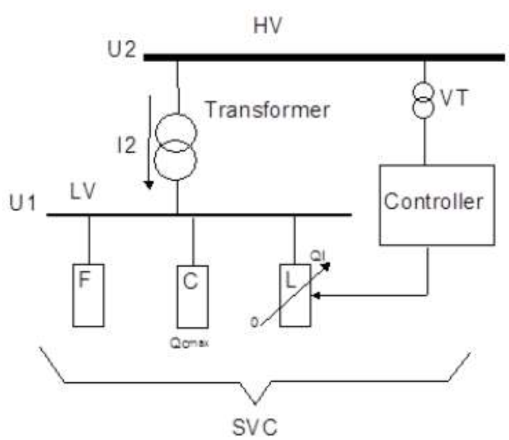


Figure 3.8 : NEPLAN Model of a SVC.

F: filter

C: fixed capacitor

L: thyristor controlled reactor

There are three modes:

Capacitive mode (V_2 <= Vmin):

$I_2 = B_{cap} * V_1$ with $B_{cap} = - B_{c0}$ and $B_{c0} = Qc_{max} / V_{2n}^2$; Qc_{max}**:** input value

- **Inductive mode (V2 >= Vmax):**

I2 = B_{ind} * V_1 with $B_{ind} = B_{L0} - B_{c0}$ and $B_{L0} = (Q_{cmax} + Q_{Lmax}) / V_{2n}^2$;

Q_{cmax}, Q_{Lmax}: input values

- **Linear control range, normal mode (Vmin <= V_2 >= Vmax):**

  $I_2 = (V_2 - Vref)/Xsl$ for $Xsl \neq 0$; Xsl : input value

  $V_2 = Vref$ for $Xsl = 0$

SVC – Parameters :

Name	Name of element.
U ref	Reference voltage for the regulation.
X sl	Slope admittance.
Qc max	Maximum capacitive reactive power in Mvar.
Ql max	Maximum inductive reactive power in Mvar.

CHAPTER FOUR

SIMULATION AND RESULTS

4-1 Background:

In this thesis the case study is a part of National grid of Sudan. It consists of 84 bus interconnects the generation plant to end user (loads) through transmission line with different levels of voltage: 500, 220, 110 and 66 kV which forms the main part of the transmission system, its transfer power from generation plants to different areas of NGS, Data of the network of the national grid are obtained from the National grid control center. This data is taken at normal load condition the total loading level of the system is 1553.3 MW and 1083.3 MVAr, and the total power generated is 1603.517 MW, 227.008 MVAr. A single line diagram of the partial Sudanese electrical grid is depicted in Figure (4.1).

The sudan national grid depends mainly on Merowe hydro plants , Khartoum north(1 and 2) thermal plants and Garri to supplying the load , Hydroelectricity is sudan largest source of on grid power , accounting for 68% of generation in 2011 , followed by diesel and heavy fuel oil (27%) and biomass and waste (5%) , Up to the year 2002, the combined grid - connected generating capacity in Sudan was 728 MW. This was far lower than the required rate and the government decided to increase it to avoid blackouts. The design capacity of generation in the national network amounted to 1234.6 MW up to the end of 2002 :

1. 342.8 MW which were from hydro generation.
2. 180 MW from steam generation.
3. 45.2 MW from diesel generation.

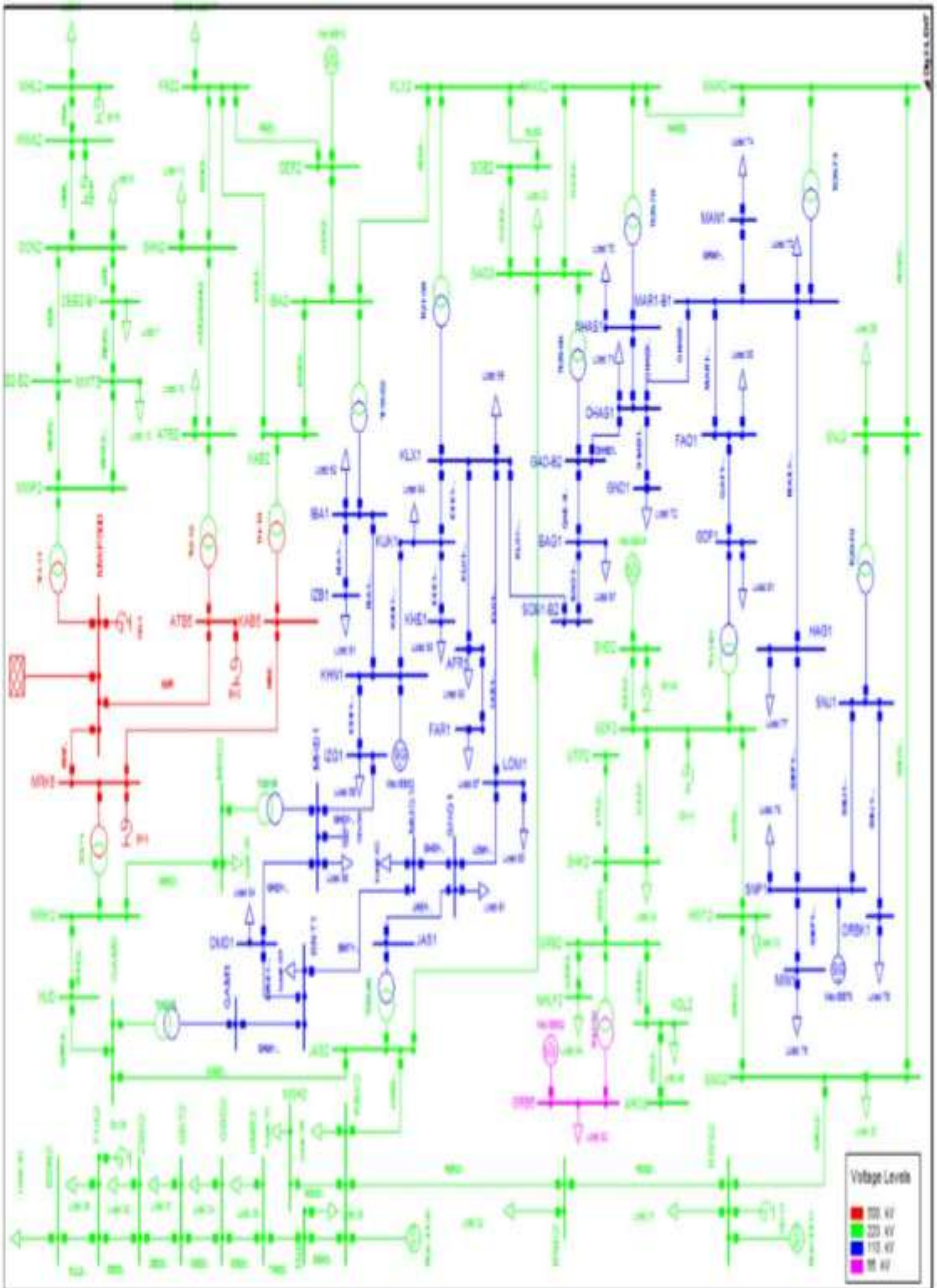
4. 65 MW from gas generation.

5. 450 MW from mixed generation.

Construction of Merowe Dam project was intended to roughly double Sudan's power generation in addition to increasing the national network security. the Merowe dam project is a multipurpose scheme for hydro power generation with a largest generation capacity at 1250 MW , but the hydro plants has some restrictions like autumn season in which all hydro plants in remote areas (due to suitable place) , from the central of load . The cost of hydro generations is cheapest than thermal generation . The new plant is joined to grid after Merowe Dam.

Table 4.1 : Represent all the plants, types of generation, and total capacity at 2016 .

PLANT	Type of generation unit	No. of generation unit	Max capacity per MW
Marawi	hydro	10	1250
Garri1,2	combined	12	400
Garri4	Steam	2	120
Kosti	Steam	4	500
KHN	steam	6	380
Roseries	hydro	7	280
Jabel Awlyaa	hydro	40	32
Algirba	hydro	2	4
Sennar	hydro	2	15
Kassala	diesel	1	7.5
ETH	-	-	100
Total Capacity			**3088.5**



4.2 Contingency (Outage) Analysis in NEPLAN :

With the "Analysis - Contingency Analysis - Contingency Modes" menu option, the user can define all elements and nodes (single mode outage) that have to be disconnected during the contingency analysis. Common mode outages can also be defined to disconnect several nodes and/or several elements at the same time. Each element or node is disconnected, one by one, and the load flow is calculated. In the case of a common mode, several elements/nodes are disconnected.

After the analysis is completed the user can display the results by selecting the menu option "Analysis – Contingency Analysis – Show results". The outages are listed in order of decreasing number of voltage and current violations and every row in the table of results contains the:

1. Outages element
2. Name of the element or node violating limits
3. Type of the element or node violating limits
4. Value of the variable violating limits after the outage under consideration (the variable is voltage for nodes and current/apparent power for elements) in %
5. Value of the corresponding to point number four above the variable at the base case in % .

4.3 Types of Violations:

Line contingency and generator contingency are generally most common type of contingencies. These contingencies mainly cause two types of violations.

A. Low Voltage Violations :

This type of violation occurs at the buses. This suggests that the voltage at the bus is less than the specified value. The operating range of voltage at any bus is generally 0.95-1.05 p.u. Thus if the voltage falls below 0.95 p.u then the bus is said to have low voltage. If the voltage rises above the 1.05 p.u then the bus is said to have a high voltage problem. It is known that in the power system network generally reactive power is the reason for the voltage problems. Hence in the case of low voltage problems reactive power is supplied to the bus to increase the voltage profile at the bus. In the case of the high voltage reactive power is absorbed at the buses to maintain the system normal voltage.

B. Line MVA Limits Violations:

This type of contingency occurs in the system when the MVA rating of the line exceeds given rating. This is mainly due to the increase in the amplitude of the current flowing in that line. The lines are designed in such a way that they should be able to withstand 125% of their MVA limit. Based on utility practices, if the current crosses the 80-90 % of the limit, it is declared as an alarm situation .

4.4 Results :

The bus data and line data specification for 84 buses in the network and 163 lines, have been given in APPENDIX (1), the results of voltage buses per unit and line loading on transmission line in the base case given in the Table (4.2) .

Table (4.2) : Represent the bus voltage in normal case :

No.	Bus name	voltage			No.	Bus name	voltage		
		kV	P.U	Angle °			kV	P.U	Angle °
1	1	515	1.03	0	43	43	218.862	0.995	-27.2
2	2	502.947	1.01	-4.5	44	44	217.23	0.987	-27.7
3	3	479.971	0.96	-10.4	45	45	218.067	0.991	-27.8
4	4	481.443	0.96	-11	46	46	218.041	0.991	-27.8
5	5	239.395	1.09	-6.5	47	47	218.861	0.995	-22.4
6	6	238.665	1.08	-6.2	48	48	218.957	0.995	-27.2
7	7	221.899	1.01	-4.6	49	49	220	1.000	-25.6
8	8	228.033	1.04	-4.6	50	50	108.738	0.989	-29.6
9	9	232.689	1.06	-5.6	51	51	105.617	0.960	-28.4
10	10	209.562	0.95	-2.2	52	52	106.479	0.968	-27.9
11	11	206.639	0.94	-1.2	53	53	110	1.000	-29.1
12	12	219.185	1.00	-11.7	54	54	109.028	0.991	-29.4
13	13	219.94	1.00	-16	55	55	107.643	0.979	-29.1
14	14	219.874	1.00	-22.2	56	56	106.714	0.970	-28.8
15	15	215.607	0.98	-23.1	57	57	106.406	0.967	-29.6
16	16	215.324	0.98	-19	58	58	106.666	0.970	-29.5
17	17	219.522	1.00	-18.7	59	59	107.361	0.976	-29.2
18	18	220	1.00	-18.8	60	60	107.097	0.974	-29.3
19	19	216.134	0.98	-21	61	61	107.184	0.974	-29.3
20	20	219.995	1.00	-22.9	62	62	106.759	0.971	-29.4
21	21	214.691	0.98	-21.9	63	63	106.904	0.972	-29.3
22	22	214.483	0.97	-23.7	64	64	106.461	0.968	-29.3
23	23	214.133	0.97	-23.7	65	65	109.563	0.996	-28.3
24	24	214.582	0.98	-22.4	66	66	111.794	1.016	-27.6
25	25	212.437	0.97	-25.5	67	67	106.116	0.965	-27.7
26	26	211.244	0.96	-26.3	68	68	106.919	0.972	-28.6
27	27	217.615	0.99	-23.4	69	69	106.629	0.969	-27.4
28	28	220	1.00	-23	70	70	108.215	0.984	-27.4
29	29	214.592	0.98	-26	71	71	107.652	0.979	-27.7
30	30	218.19	0.99	-25.4	72	72	107.234	0.975	-28
31	31	220	1.00	-20.9	73	73	112.734	1.025	-29.2
32	32	222.55	1.01	-22.1	74	74	111.575	1.014	-30.1
33	33	220.061	1.00	-26	75	75	114.126	1.038	-27.7
34	34	224.745	1.02	-25.5	76	76	114.149	1.038	-27.6
35	35	224.073	1.02	-24.6	77	77	111.798	1.016	-28.8
36	36	222.837	1.01	-23.9	78	78	112.2	1.020	-27.4
37	37	225.673	1.03	-26.1	79	79	106.63	0.969	-28.4

38	38	225.532	1.03	-26.4	80	80	110.165	1.002	-29.6
39	39	226.04	1.03	-26.8	81	81	111.686	1.015	-28
40	40	226.506	1.03	-26.9	82	82	66	1.000	-28.4
41	41	219.473	1.00	-26.6	83	83	215.989	0.982	-23.9
42	42	217.272	0.99	-27.6	84	84	106.524	0.968	-26.5

he table (4.2) represent the buses voltage in normal case and all the buses below their limits in this case .

Table (4.3): Shows Power flow results at base case:

Line No.	**Line Name**	**P MW**	**Q Mvar**	**P Loss MW**	**Q Loss Mvar**	**Loading %**
1	MWP51_MRK51	673.035	-68.691	24.2705	-356.987	6.78
2	MWP5-ATB5	-318.743	-171.181	2.7228	-225.213	14.37
3	MRK5_KAB5	-259.062	78.155	0.3394	-31.567	11.24
4	WHL21-WAW21	9.017	-54.373	0.0167	-94.2222	5.38
5	DEB2 B1-D0N2	-7.617	34.604	0.417	-17.8306	10.44
6	DON2_WAW21	9.357	-92.449	0.3405	-72.7176	4.65
7	DEB1 B2_ DON2	-25.74	21.889	0.2493	-39.8201	4.98
8	MWT2-DEB2-B1	25.915	-39.897	0.3804	-16.444	15.18
9	MWP-MWT2	43.087	-34.886	0.1722	-3.4893	17.83
10	MWP2-DEB2-B2	26.896	-59.37	0.9074	-18.7496	20.96
11	ATB22-SHN22	162.243	-64.904	2.7061	-43.171	9.21
12	SHN21-FRZ21	126.273	-42.348	1.3006	-39.6843	6.99
13	MRK12_MHD12	191.621	-54.313	0.5714	-5.7537	10.46
14	MRK21_HUD21	197.742	133.604	0.3585	-2.112	25.08
15	KAB22-FRZ22	-77.285	-159.163	0.8007	-11.1059	9.5
16	KAB22-IBA22	336.348	-98.07	2.6461	0.5247	18.82
17	GER21_IBA21	219.221	53.48	2.1734	-13.5475	11.84
18	FRZ21-GER21	-33.221	157.811	0.0911	-1.5705	8.46
19	IBA22_KLX22	355.944	68.011	1.3303	0.6984	19.42
20	KLX21_SOB21	164.105	-31.226	0.2308	-1.3723	26.51
21	GAM22-JAS22	-81.028	-33.016	0.1954	-13.1454	4.71
22	JAS22_MSH22	-20.3	-59.648	0.1514	-37.588	3.39
23	GAD21_NHAS21	117.204	-16.495	0.8116	-26.4626	9.4
24	JAS21_GAD21	-13.558	-20.847	0.0101	-13.5007	1.34
25	SOB22_GAD22	163.874	-29.854	0.7531	-4.5704	26.43
26	HAS22_MAR22	55.418	-3.42	0.1566	-14.5598	4.43
27	MAR21_SNJ21	-23.748	-55.367	0.1822	-20.7902	4.83
28	MSH21_NRBK21	-27.44	-47.594	0.1115	-41.6013	2.92
29	NRBK21_TND21	44.823	-75.394	0.3172	-32.3646	4.6
30	NRBK21 - RNK21	-34.079	-47.365	0.1564	-64.7873	3.06
31	SNJ22_SNG22	-60.848	-63.981	0.2856	-11.873	6.95

32	SNG22_HWT22	30.076	-50.879	0.1261	-35.1091	3.12
33	SNG12_ ROS12	-103.238	-6.814	1.5462	-40.3975	8.02
34	RNK21_ROS21	34.882	-63.045	0.2442	-68.0076	3.78
35	HWT22 _ GDF22	28.404	-16.728	0.0632	-43.479	1.73
36	OBD21_DBT21	19.8	-22.737	0.0678	-18.2482	6.2
37	UMR21_OBD21	39.712	-42.328	0.1551	-51.3691	5.98
38	TND21_UMR21	43.498	-48.59	0.1562	-31.3782	3.38
39	DBT21_ZBD21	13.482	-8.428	0.016	-13.7181	3.25
40	ZBD22_FUL22	10.106	-18.474	0.0218	-24.8031	4.31
41	FUL21_BBN21	3.365	-14.074	0.0046	-16.5766	2.96
42	GDF21_SH21	42.876	-11.572	0.0964	-29.2476	2.33
43	GDF21_SHD21	-37.857	-0.692	0.1432	-13.2638	3.98
44	GRB21_ KSL21	16.706	-35.299	0.0376	-28.8282	2.07
45	GRB22_NHLF22	12.034	-10.92	0.0051	-18.9413	0.86
46	SHK21_UTB21	0.001	-11.034	0.0006	-11.0335	1.16
47	SHK22_ GRB22	42.107	16.195	0.1129	-23.947	2.38
48	KSL22_ARO22	0.002	-17.149	0.0023	-17.1491	0.91
49	HUD22_GAM22	197.383	135.716	1.1544	-6.1998	25.29
50	IBA12-IZB12	68.208	39.875	0.2019	-0.1173	8.52
51	IBA12-KHN12	-83.765	195.03	1.5045	5.6211	22.28
52	KHN11_IZG11	37.849	149.648	0.7975	2.0409	16.2
53	KUK11-KHE11	82.003	53.162	0.0862	0.0347	20.69
54	KUK11-KHN11	-121.676	-135.402	0.2404	1.5685	20.08
55	MHD12-IZG12	-37.138	101.045	0.2698	0.3287	11.55
56	MHD22_OMD22	80.125	-0.196	0.1756	-0.1627	8.67
57	AFR12_FAR12	50.314	33.029	0.048	-0.2255	6.51
58	KLX11_SOB11	-8.835	19.394	0.1386	-0.1433	39.87
59	KLX12_LOM12	86.11	52.338	0.0884	0.0711	10.82
60	KLX11_AFR11	67.691	41.315	0.1742	-0.1919	8.52
61	KUK11_KLX11	5.155	-61.643	0.2068	-0.1209	10.65
62	SHG22_LOM22	0.678	-5.751	0.0007	-0.7337	0.62
63	MUG11_SHG11	22.11	27.322	0.0405	-0.8721	3.78
64	SHG12_JAS12	-86.348	-72.399	1.4115	1.8411	12.13
65	BNT11_MUG11	-53.396	-14.372	0.034	-0.2196	5.98
66	OMD11_BNT11	-1.363	-54.464	0.0512	-0.3208	5.91
67	BNT11_GAM11	115.005	101.679	1.092	2.7965	16.17
68	BAG11_GAD B2	-45.722	-4.459	0.1954	0.1446	29.39
69	SOB11_BAG11	-8.973	19.537	0.2587	-0.2398	40.4
70	GAD1 B2_OHAS1	-0.554	-4.224	0.0227	-2.4795	8.03
71	NHAS11_OHAS11	-36.05	1.456	0.195	0.0782	7.73
72	OHAS1_MAR1	-3.477	-22.082	0.7618	-0.8901	41.72
73	OHAS12_GND12	27.863	13.017	0.0417	-1.2361	3.29
74	MAR 11_HAG11	0.562	6.835	0.0531	-1.1322	12.21

75	MAR1 B2_ FAO1	6.535	3.181	0.1202	-2.2482	12.94
76	MAN1_MAR1	-10.886	-4.058	0.0693	-2.3111	11.99
77	ORBK2_SNJ1	-0.336	-1.476	0.0004	-3.3467	2.68
78	SNJ1_SNP1	20.117	21.366	0.2342	-0.0611	51.96
79	HAG12_SNP12	-7.085	3.93	0.1243	-1.886	14.56
80	SNP1_MIN1	14.97	8.031	0.5891	-1.5206	30.46
81	GDF1_FAO1	4.708	-3.873	0.1014	-4.9825	8.5
82	ATB-POR	-53	-17.589	2.1616	-48.7546	17.56
	Total			60.6007	-1826.746	

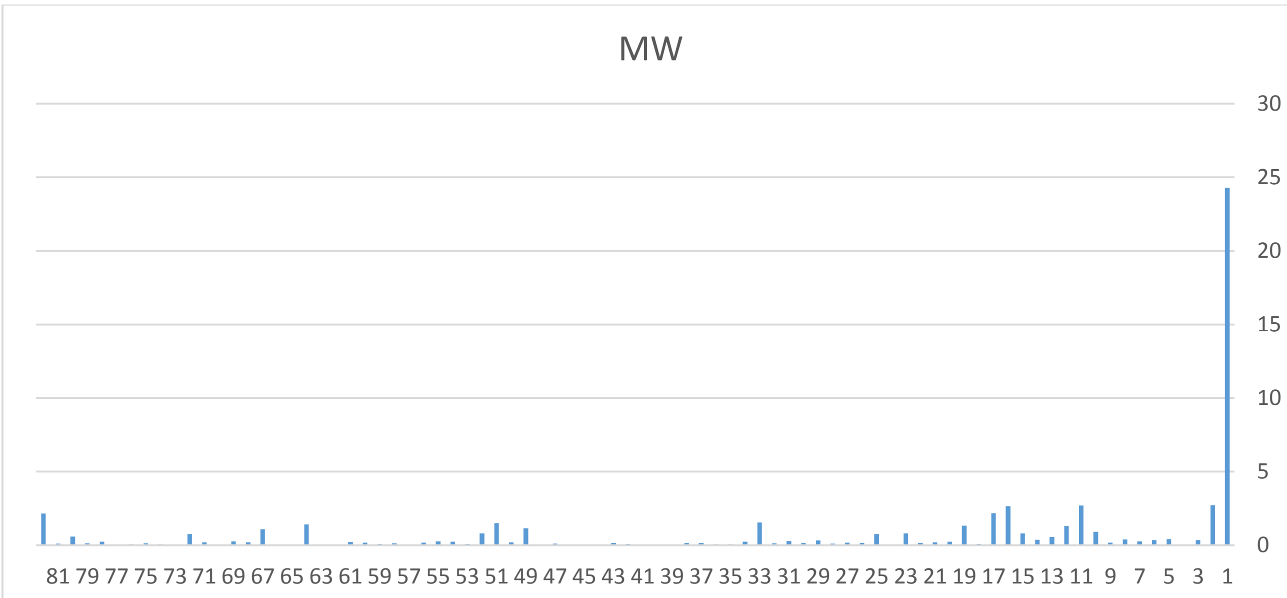


Fig (4.2) : Active Power losses At base case

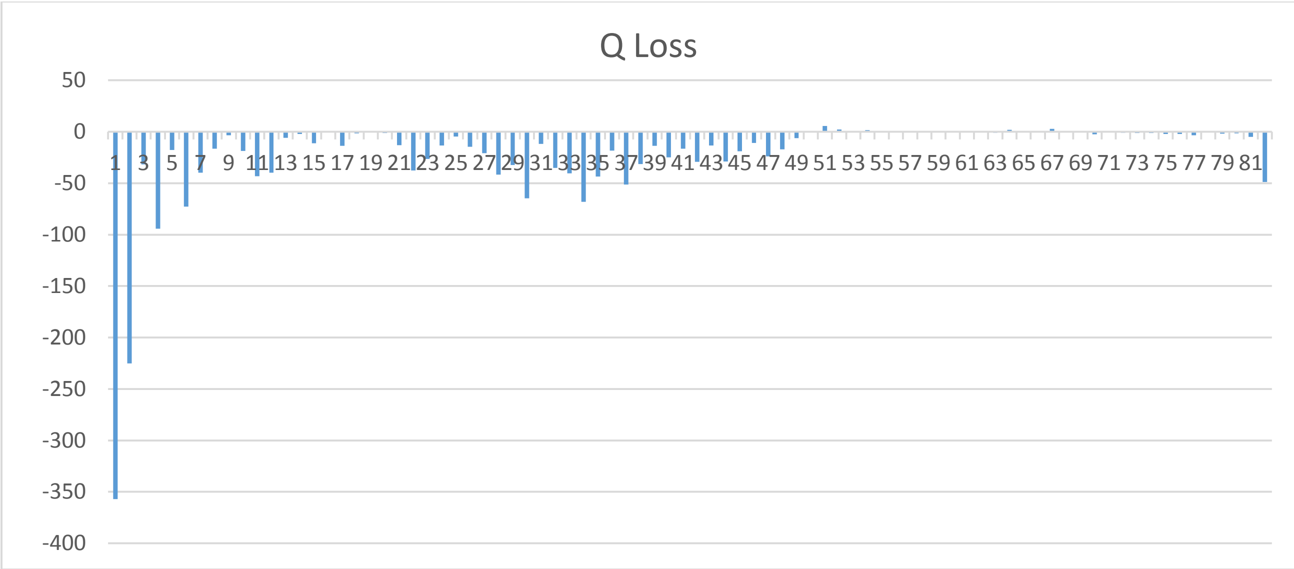


Figure (4.3): reactive Power Losses at base case

Figure (4.2) & (4.3) above explained the active power MW losses and the reactive power losses in the base case .

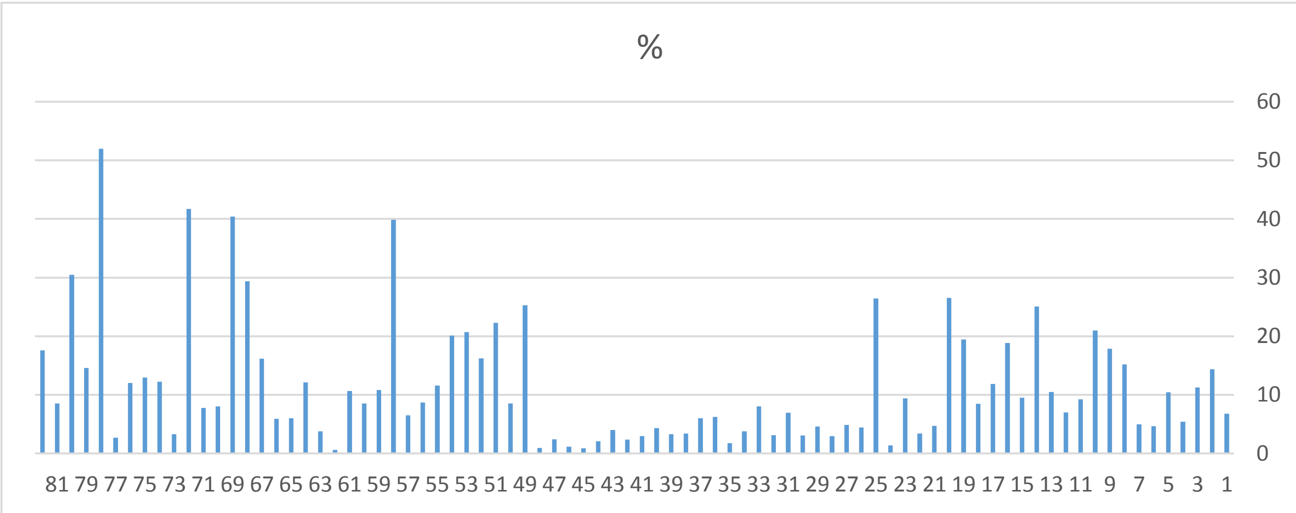


Figure (4.5) : shows the lines loading in normal case

Figure (4.5) above showing the lines loading in normal case and all of lines under 80% of allowed limits.

Table (4.4) : Represent the Line stability indices with system loading :

Line	**Line**	**λ =1**	**Line**	**Line**	**λ =1**
No.	**name**	**LQP**	**No.**	**name**	**LQP**
1	BAG11_GAD B2	0.002546	42	NHAS11_OHAS11	-0.00055
2	ATB-POR	-0.31472	43	OHAS12_GND12	-0.02181
3	WHL21-WAW21	-0.84375	44	OHAS1_MAR1	0.164661
4	DEB2 B1-D0N2	-1.07301	45	JAS22_MSH22	0.056353
5	MWP-MWT2	0.066628	46	MSH21_NRBK21	0.015345
6	ATB22-SHN22	0.158602	47	HAS22_MAR22	-0.0342
7	MWP2-DEB2-B2	0.421394	48	MAN1_MAR1	0.011761
8	MWT2-DEB2-B1	0.232838	49	MAR21_SNJ21	0.083786
9	DON2_WAW21	0.07515	50	MAR 11_HAG11	-0.03678
10	DEB1 B2_ DON2	-0.25836	51	HAG12_SNP12	-0.04546
11	MWP5-ATB5	-0.02884	52	SNJ1_SNP1	-0.04502
12	MWP51_MRK51	-0.10129	53	ORBK2_SNJ1	-0.02358
13	MRK5_KAB5	-0.01908	54	SNP1_MIN1	-0.08337
14	SHN21-FRZ21	0.04092	55	MAR1 B2_ FAO1	-0.04891
15	FRZ21-GER21	-0.01839	56	SNJ22_SNG22	0.107643
16	KAB22-IBA22	0.106046	57	SNG12_ ROS12	-0.07733
17	IBA12-IZB12	-0.04527	58	RNK21_ROS21	-0.01574
18	IBA12-KHN12	-0.02756	59	SNG22_HWT22	0.045185
19	KUK11-KHE11	-0.01525	60	NRBK21_TND21	0.092421
20	MHD12-IZG12	-0.07526	61	UMR21_OBD21	-0.02396
21	KUK11-KHN11	0.065371	62	OBD21_DBT21	0.008884
22	KHN11_IZG11	-0.15803	63	DBT21_ZBD21	-0.0073
23	MRK12_MHD12	0.027641	64	ZBD22_FUL22	-0.01577
24	AFR12_FAR12	-0.01404	65	FUL21_BBN21	-0.00415
25	KLX11_AFR11	-0.03591	66	TND21_UMR21	0.034517
26	KUK11_KLX11	0.12755	67	NRBK21 - RNK21	0.07567
27	KLX12_LOM12	-0.01344	68	HWT22 _ GDF22	-0.06157
28	SHG22_LOM22	0.006425	69	GRB21_ KSL21	0.011223
29	MUG11_SHG11	-0.02626	70	SHK22_ GRB22	-0.0608

30	BNT11_MUG11	-0.00599	71	GDF21_SH21	-0.03011
31	MHD22_OMD22	-0.00018	72	KSL22_ARO22	1.24E-14
32	OMD11_BNT11	0.033002	73	GRB22_NHLF22	-0.00995
33	BNT11_GAM11	-0.14038	74	MRK21_HUD21	-0.01347
34	KLX21_SOB21	0.003468	75	HUD22_GAM22	-0.04361
35	SOB22_GAD22	0.010303	76	KAB22-FRZ22	0.136114
36	SOB11_BAG11	-0.05011	77	SHK21_UTB21	2.47E-14
37	KLX11_SOB11	-0.02725	78	GER21_IBA21	-0.04999
38	SHG12_JAS12	0.30045	79	IBA22_KLX22	-0.02046
39	JAS21_GAD21	0.003771	80	GDF21_SHD21	-0.01577
40	GAD21_NHAS21	-0.02026	81	GDF1_FAO1	-0.02328
41	GAD1 B2_OHAS1	0.018536	82	GAM22-JAS22	0.019627

Table (4.4) showing and represent the Line stability indices with system loading in base case .

Table (4.5) : shows the ranking of lines severity :

Rank	**Line No.**	**Line name**	**LQP**
1	4	DEB2 B1 –DON2	**1.073**
2	3	WHL21 – WAW21	0.843
3	7	MWP2 – DEB B2	0.421
4	2	ATB -POR	0.314
5	38	SHG12 –JAS 12	0.3
6	10	DEB1 B2 – DON2	0.258
7	8	MWT2 – DEB2 B1	0.232
8	44	OHS1 –MAR1	0.164
9	6	ATB 22 – SHN 22	0.158
10	22	KHN 11- IZG 11	0.15

11	33	BNT 11 – GAM 11	0.14
12	26	KUK11 – KLX 11	0.127

The result in table (4.5) showing the ranking of lines severity during the base case depend on the LQP result . .

Table (4.6) : Show the violation Buses and lines Under contingency :

Contingency Line Name	Violated Bus	P.U in Base Case	P.U After Contingency	U kV	Un kV
MWP2-DEB2-B2	9	1.0477	1.1654	256.388	220
DEB2 B1-D0N2	9	1.0477	1.1249	247.478	220
MWP-MWT2	9	1.0477	1.1079	243.738	220
MWP2-DEB2-B2	8	1.0269	1.1648	256.256	220
BNT11_GAM11	65	0.9964	1.1141	122.551	110
MWP2-DEB2-B2	6	1.0746	1.196	263.12	220
DEB2 B1-D0N2	6	1.0746	1.1542	253.924	220
MWP-MWT2	6	1.0746	1.1367	250.074	220
MWT2-DEB2-B1	6	1.0746	1.1136	244.992	220
DEB1 B2_ DON2	6	1.0746	1.1107	244.354	220
KHN11_IZG11	55	0.9787	0.8974	98.714	110
KUK11-KHN11	54	0.9914	0.8918	98.098	110
IBA12-KHN12	51	0.9659	0.8439	92.829	110
KUK11-KHN11	50	0.9888	0.8888	97.768	110
MWP2-DEB2-B2	5	1.0778	1.2005	264.11	220
DEB2 B1-D0N2	5	1.0778	1.1583	254.826	220
MWP-MWT2	5	1.0778	1.1406	250.932	220
MWT2-DEB2-B1	5	1.0778	1.1172	245.784	220
DEB1 B2_ DON2	5	1.0778	1.1143	245.146	220

The table shows the buses under contingency and the comparative results of the buses between normal case and after contingency .

Table (4.7) : shows the buses after adding SVC :

Bus name	voltage			Bus name	voltage		
	kV	P.U	Angle °		kV	P.U	Angle °
1	515	1.03	0	43	219.122	0.996	-27.1
2	502.95	1.0059	-4.5	44	217.452	0.9884	-27.6

3	479.949	0.9599	-10.3	45	218.291	0.9922	-27.8
4	481.39	0.9628	-11	46	218.265	0.9921	-27.8
5	220.524	1.0024	-5.2	47	218.931	0.9951	-22.4
6	220	1	-4.8	48	219.216	0.9964	-27.1
7	216.974	0.9862	-3.9	49	220	1	-25.5
8	218.862	0.9948	-3.6	50	109.519	0.9956	-29.6
9	220.115	1.0005	-4.6	51	108.522	0.9866	-28.6
10	217.367	0.988	-2.1	52	108.172	0.9834	-28
11	212.527	0.966	-1.1	53	110	1	-29
12	219.178	0.9963	-11.7	54	109.497	0.9954	-29.4
13	219.926	0.9997	-16	55	107.72	0.9793	-29
14	219.947	0.9998	-22.1	56	106.842	0.9713	-28.7
15	215.668	0.9803	-23.1	57	106.763	0.9706	-29.6
16	215.115	0.9778	-19	58	107.022	0.9729	-29.5
17	219.498	0.9977	-18.7	59	107.715	0.9792	-29.1
18	220	1	-18.7	60	107.408	0.9764	-29.3
19	215.739	0.9806	-21	61	107.379	0.9762	-29.3
20	220.086	1.0004	-22.9	62	106.997	0.9727	-29.4
21	214.282	0.974	-21.9	63	107.156	0.9741	-29.3
22	214.414	0.9746	-23.6	64	106.663	0.9697	-29.2
23	214.057	0.973	-23.7	65	110	1	-28.3
24	214.251	0.9739	-22.3	66	111.258	1.0114	-27.5
25	212.736	0.967	-25.5	67	106.306	0.9664	-27.6
26	211.887	0.9631	-26.3	68	107.215	0.9747	-28.6
27	217.579	0.989	-23.4	69	106.801	0.9709	-27.4
28	220	1	-23	70	108.394	0.9854	-27.3
29	215.783	0.9808	-26	71	107.842	0.9804	-27.7
30	218.996	0.9954	-25.4	72	107.425	0.9766	-28
31	220	1	-20.8	73	113.038	1.0276	-29.2
32	222.55	1.0116	-22.1	74	111.884	1.0171	-30.1
33	220.645	1.0029	-26	75	113.59	1.0326	-27.6
34	224.745	1.0216	-25.5	76	113.619	1.0329	-27.5
35	224.073	1.0185	-24.5	77	111.994	1.0181	-28.8
36	222.837	1.0129	-23.8	78	112.2	1.02	-27.6
37	225.673	1.0258	-26.1	79	106.63	0.9694	-28.6
38	225.532	1.0251	-26.4	80	110.437	1.004	-29.6
39	226.04	1.0275	-26.8	81	111.864	1.0169	-27.9
40	226.506	1.0296	-26.9	82	66	1	-28.4
41	219.775	0.999	-26.5	83	215.979	0.9817	-23.9
42	217.494	0.9886	-27.5	84	106.519	0.9684	-26.5

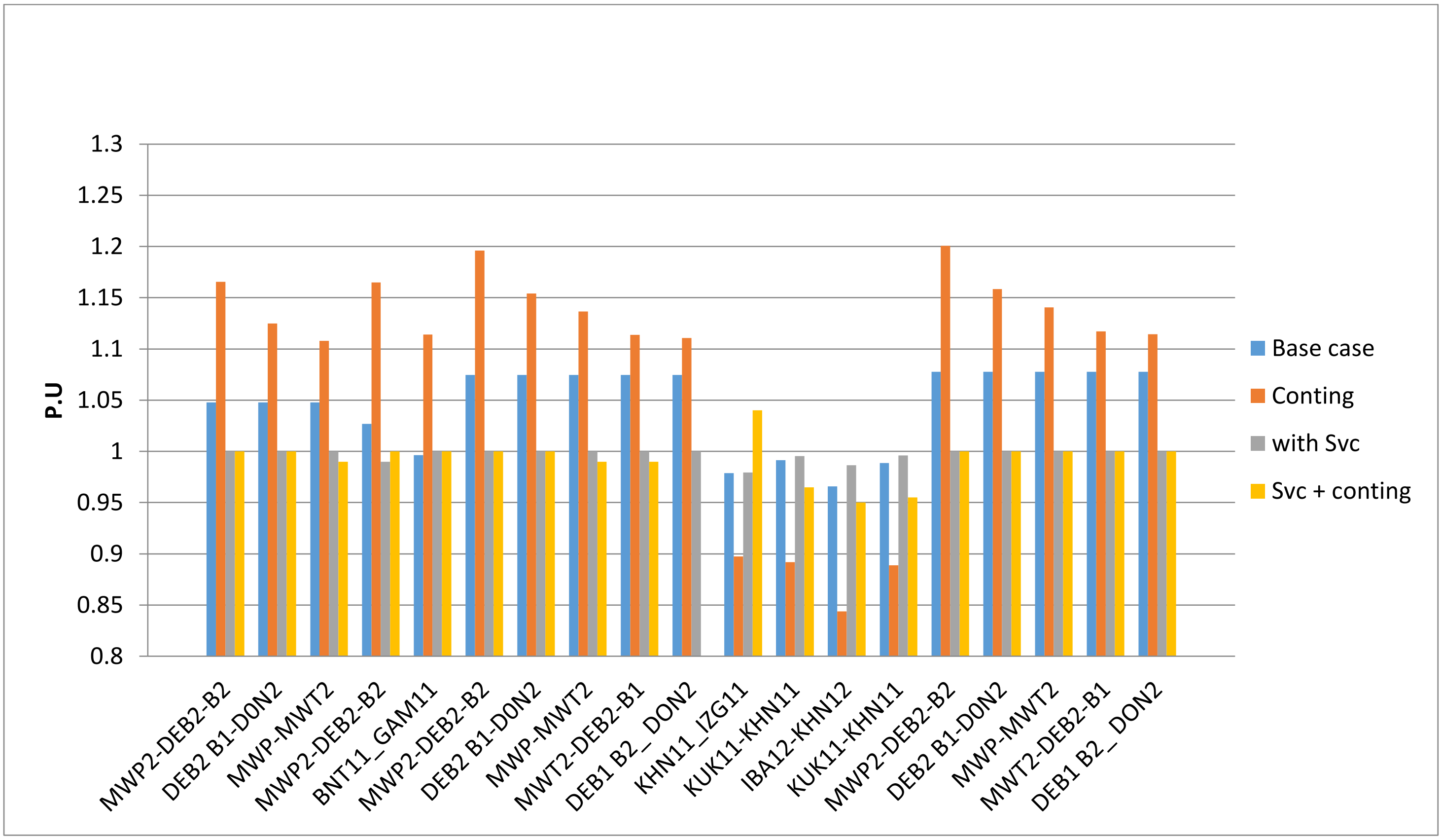


Fig (4.6) : comparative between three cases

Contingency	Violated Bus	Base Case	C.A	With Svc	Svc + C.A	U kV	Un kV
MWP2-DEB2-B2	9	1.0477	1.1654	1	1	256.388	220
DEB2 B1-D0N2	9	1.0477	1.1249	1	1	247.478	220
MWP-MWT2	9	1.0477	1.1079	1	0.99	243.738	220
MWP2-DEB2-B2	8	1.0269	1.1648	0.99	1	256.256	220
BNT11_GAM11	65	0.9964	1.1141	1	1	122.551	110
MWP2-DEB2-B2	6	1.0746	1.196	1	1	263.12	220
DEB2 B1-D0N2	6	1.0746	1.1542	1	1	253.924	220
MWP-MWT2	6	1.0746	1.1367	1	0.99	250.074	220
MWT2-DEB2-B1	6	1.0746	1.1136	1	0.99	244.992	220

DEB1 B2_ DON2	6	1.0746	1.1107	1	1	244.354	220
KHN11_IZG11	55	0.9787	0.8974	0.9793	1.04	98.714	110
KUK11-KHN11	54	0.9914	0.8918	0.9954	0.965	98.098	110
IBA12-KHN12	51	0.9659	0.8439	0.9866	0.95	92.829	110
KUK11-KHN11	50	0.9888	0.8888	0.996	0.955	97.768	110
MWP2-DEB2-B2	5	1.0778	1.2005	1	1	264.11	220
DEB2 B1-D0N2	5	1.0778	1.1583	1	1	254.826	220
MWP-MWT2	5	1.0778	1.1406	1	1	250.932	220
MWT2-DEB2-B1	5	1.0778	1.1172	1	1	245.784	220
DEB1 B2_ DON2	5	1.0778	1.1143	1	1	245.146	220

The table shows the buses under contingency and the comparative results of the buses between normal case and after contingency and during contingency in presence of SVC controller by graphical representation above .

Table (4.8) : shows comparative between three cases :

Depend on the table (4.8) : Its clear that during contingency analysis in presence of SVC controller all results in allowed limit (0.95 to 1.05) . so the system is going to be stable during this case .

4.4 Discussions:

- At the time of lines outage: (MWP2-DEB2 B2), (DEB2 B1-D0N2),(MWP-MWT2) The system is get unstable condition and occurs violation at Bus number 9 ,and corresponding to this outages it's become overloading and out of limit range (0.95 to 1.05 P.U) and by improving the system by adding facts devises used to maintain a system as stable, the location of the facts devises found sensitivity value analysis and improved the value due the limit and become (1 P.U) .

- Corresponding of line outage (MWP2-DEB2-B2) its occurs overloading in bus number 8 and for (BNT11 –GAM11) Also effect in bus number 65 and by adding Svc to near bus which selected by index LQP it become due the limit again .
- At the time of lines outage: (MWP2-DEB2 B2), (DEB2 B1-D0N2),(DEB1 B2_ DON2), (MWP-MWT2),(DEB1 B2_ DON2) The system is get unstable condition and occurs violation at Bus number 9 ,and corresponding to this outages it's become overloading and out of limit range (0.95 to 1.05 P.U) and by improving the system by adding SVC And improved the value due the limit and become (1 P.U) .
- Due the contingency of lines (KHN11- IZG11), (KUK11-KHN11), (IBA12-KHN12), (KUK11-KHN11) the system is unstable and the bus number 55,54,51,50 respectively are in the critical minimum state limit according to the result obtained in the table (4.6) and its observed the minimum voltage due this outage.
- Bus number 5 is overloading corresponding to the contingencies of lines : (MWP2-DEB2-B2), (DEB2 B1-D0N2), (MWP-MWT2), (MWT2-DEB2-B1) and (DEB1 B2_ DON2) , and the system become unstable and out of voltage limits and after adding SVC to the near bus which selected by the index its improved and come due the voltage limits .
- Following shunt capacitors have been added to improve the security level of the network as follows:

Table (4.9) : shows the shunt capacitors have been added to the network :

Bus name	Q Mvar
1	132.613
2	128.449
3	229.561
5	30.143
6	30
7	19.454
8	19.794
9	20.021
12	29.762
31	15
39	15.835
41	29.913
49	30
56	-14.119
73	0

These shunt capacitor have been added to increase the reactive power production so that the reactive power and related overloading of transmission line are reduced to improve the voltage performance of the system, the optimal location for a SVC installation has been found as :

Table (4.10) : Represent the Location of the Static Var Compensation :

At Bus	**Vref %**	**Mvar (± 500)**

6	100%	48.351
10	100%	-78.097
50	100%	-94.297
51	100%	-79.942
65	100%	-26.212
66	100%	46.215

1. The reactive power range of ± 500 Mvar is only to be able to calculate without limitation , how much reactive power is actually needed in the studied loading levels and contingencies to control the voltage to the desired value .

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion :

This work outlines mathematical models for the simulation of transmission line outages so as to carry out a load flow based contingency analysis. The method has been applied to National Sudan's Grid and gives good results in determining the network weaknesses. Result of contingencies analysis shows that which lines is the most severe after contingency and ranked based on LQP Index.

Many techniques are used to optimize the location of FACTS devices. And in this thesis the results shows that the voltage profile during the line outage was enhanced at all buses after added SVC , and power losses are considerably decreased by considering the objectives such as minimization of power losses when compared with the base case .

5.2 Recommendation :

The NGS mainly depends on Merowe Dam and Rosieres Dam which is considered as semi radial system and this thesis shows the improvement of Sudanese National Grid performance with the use of SVC under the critical lines outage . some recommendations are given for future research in this area:

1. It is strongly recommended to make NGS as a ring network to improve the voltages and to avoid critical cases when losing or during outages of single transmission lines .
2. Also it is recommend building up new transmission lines for Khartoum state so that the existing system could be improved , upgrading by expanding the sizes of conductors by adding SVCs to the NGS weak nodes is also necessary to keep the voltages within the given reference values at normal operation.
3. Can be use the new generation of FACTS such as STATCOM, SSSC, UPFC and IPFC to improve performance and prevent sudden instability.
4. Use a new optimization methods to select the optimal placement of FACTS devices such as Genetics Algorithm GA, Particle Swarm Optimization PSO and other Artificial Intelligence.
5. Control schemes and intelligent controllers can be considered for FACTS devices .
6. To perform an economic balance to conclude whether it is economically viable to invest on FACTS, i.e. to calculate the money losses due to the under exploitation of the transmission lines and the saved and invested money on FACTS.

APPENDICES

Appendix (1) :

BUS DATA:

Bus number	Type*	Pg MW	Qg MVAr	Pd MW	Qd MVAr	Bs MVAr	Base KV
1	3	0	0	0	0	-125	500
2	1	0	0	0	0	-125	500
3	1	0	0	0	0	-250	500
4	1	0	0	0	0	0	500
5	1	0	0	14.36	11.483	-30	220
6	1	0	0	0	0	-40	220
7	1	0	0	33.456	23.961	0	220
8	1	0	0	0	0	0	220
9	1	0	0	50.32	46.148	0	220
10	1	0	0	29.808	20.496	0	220
11	1	0	0	0	0	0	220
12	1	0	0	101.338	70.734	0	220
13	1	0	0	33.264	20.615	0	220
14	1	0	0	0	0	0	220
15	1	0	0	0	0	0	220
16	1	0	0	0	0	0	220
17	1	0	0	13.574	8.661	0	220
18	2	186	0	0	0	0	220
19	1	0	0	0	0	0	220
20	1	0	0	60.883	37.732	0	220
21	1	0	0	0	0	0	220
22	1	0	0	0	0	0	220
23	1	0	0	14.112	8.746	0	220
24	1	0	0	0	0	0	220
25	1	0	0	0	0	0	220
26	1	0	0	0	0	0	220
27	1	0	0	6.989	25.534	0	220
28	2	85	0	46.704	32.357	0	220
29	1	0	0	16.464	8.842	0	220
30	1	0	0	12.029	5.585	0	220
31	2	148	0	8.333	5.76	-15	220
32	1	0	0	0.403	22.385	0	220
33	1	0	0	1.546	0.958	0	220
34	1	0	0	19.757	31.778	0	220
35	1	0	0	3.629	25.117	0	220
36	1	0	0	1.008	5.56	0	220
37	1	0	0	6.25	3.939	0	220
38	1	0	0	3.36	23.764	0	220
39	1	0	0	6.72	4.568	-15	220
40	1	0	0	3.36	2.503	0	220
41	1	0	0	0	0	-30	220
42	1	0	0	0	0	0	220
43	1	0	0	0.672	12.515	0	220
44	1	0	0	12.029	8.021	0	220
45	1	0	0	0	0	0	220
46	1	0	0	16.666	10.678	0	220
47	1	0	0	0	0	0	220

48	1	0	0	0	0	0	220
49	2	38	0	0	0	-30	220
50	1	0	0	81.917	53.127	0	110
51	1	0	0	68.006	39.992	0	110
52	1	0	0	41.328	17.854	0	110
53	2	76	0	0	0	0	110
54	1	0	0	44.621	20.718	0	110
55	1	0	0	74.189	46.562	0	110
56	1	0	0	12.634	8.128	15	110
57	1	0	0	50.266	33.255	0	110
58	1	0	0	17.203	8.477	0	110
59	1	0	0	40.387	18.165	0	110
60	1	0	0	85.344	58.018	0	110
61	1	0	0	64.915	40.06	0	110
62	1	0	0	75.466	42.566	0	110
63	1	0	0	59.069	30.588	0	110
64	1	0	0	81.312	54.43	0	110
65	1	0	0	0	0	0	110
66	1	0	0	0	0	0	110
67	1	0	0	36.49	24.236	0	110
68	1	0	0	0	0	0	110
69	1	0	0	0	0	0	110
70	1	0	0	24.73	12.738	0	110
71	1	0	0	11.088	5.864	0	110
72	1	0	0	27.821	14.253	0	110
73	1	0	0	56.717	26.986	0	110
74	1	0	0	10.886	4.058	0	110
75	1	0	0	0.336	1.476	0	110
76	1	0	0	0	0	0	110
77	1	0	0	7.594	4.037	0	110
78	2	7	0	4.704	2.238	0	110
79	1	0	0	14.381	9.552	0	110
80	1	0	0	11.021	6.539	0	110
81	1	0	0	18.614	12.315	0	110
82	2	2	0	15.254	8.604	0	66

*1 = PQ, 2 = PV, 3 = Slack

Line data at MVAbase = 1000.

X+	To bus	R p.u.	X p.u.	B p.u.	rating MVA	ratio
67	69	0.086281	0.10438	9.81E-05	93.5	1
6	5	0.283781	1.279132	4.07E-02	213.84	1
11	10	0.054252	0.287679	4.74E-03	187	1
9	7	0.218861	1.16054	1.91E-02	187	1
12	13	0.096901	0.436777	5.56E-02	213.84	1
10	7	0.218421	1.158209	1.91E-02	187	1
11	8	0.272988	1.447553	2.38E-02	187	1
9	6	0.114897	0.461302	6.59E-02	275	1
9	8	0.218861	1.16054	1.91E-02	187	1
2	1	0.02651	0.261317	2.43E-01	1064	1
1	3	0.019376	0.190992	7.11E-01	1064	1

4	3	0.004122	0.040627	3.78E-02	1064	1
13	17	0.079597	0.319576	4.57E-02	275	1
18	17	0.003461	0.013895	1.99E-03	275	1
16	19	0.020764	0.093595	1.19E-02	213.84	1
52	51	0.030455	0.122273	1.09E-03	137.5	1
54	50	0.00886	0.03557	3.18E-04	137.5	1
53	52	0.033223	0.133388	1.19E-03	137.5	1
55	56	0.022149	0.088926	7.94E-04	137.5	1
54	53	0.00714	0.056157	3.25E-04	132	1
53	55	0.033223	0.133388	1.19E-03	137.5	1
14	20	0.014535	0.058357	8.34E-03	275	1
59	58	0.030455	0.122273	1.09E-03	137.5	1
58	57	0.03876	0.15562	1.39E-03	137.5	1
59	54	0.052488	0.228653	1.05E-03	85.8	1
59	60	0.008306	0.033347	2.98E-04	137.5	1
60	61	0.021595	0.086702	7.74E-04	137.5	1
61	62	0.030455	0.122273	1.09E-03	137.5	1
62	63	0.010521	0.04224	3.77E-04	137.5	1
64	63	0.016335	0.065583	5.86E-04	137.5	1
56	64	0.025748	0.10376	9.23E-04	137.5	1
65	63	0.045682	0.183409	1.64E-03	137.5	1
21	24	0.007851	0.041632	2.74E-03	187	1
24	23	0.025909	0.137386	9.05E-03	187	1
68	67	0.517686	0.626281	5.88E-04	31.57	1
59	68	0.287603	0.347934	3.27E-04	31.57	1
61	66	0.107975	0.433512	3.87E-03	137.5	1
23	22	0.024917	0.100041	1.43E-02	275	1
23	25	0.067521	0.358037	2.36E-02	187	1
69	71	2.214545	2.679091	2.52E-03	31.57	1
71	70	0.013843	0.055579	4.96E-04	137.5	1
71	72	0.041529	0.166736	1.49E-03	137.5	1
71	73	1.581818	1.913636	1.80E-03	31.57	1
22	27	0.10223	0.410447	5.87E-02	275	1
27	28	0.074198	0.297901	4.26E-02	275	1
25	26	0.043182	0.228977	1.51E-02	187	1
74	73	0.566653	1.559645	2.40E-03	55	1
26	29	0.06595	0.349711	2.30E-02	187	1
73	77	1.006612	1.217769	1.14E-03	31.57	1
77	78	1.72562	2.087603	1.96E-03	31.57	1
76	78	0.287603	0.347934	3.27E-04	31.57	1
75	76	2.760992	3.340165	3.14E-03	31.57	1
78	79	1.984463	2.400744	2.26E-03	31.57	1
73	80	2.041983	2.470331	2.32E-03	31.57	1
29	30	0.039256	0.208161	1.37E-02	187	1

30	31	0.139752	0.741054	4.88E-02	187	1
31	32	0.096901	0.38905	5.56E-02	275	1
30	33	0.062293	0.250103	3.57E-02	275	1
28	36	0.076829	0.308461	4.41E-02	275	1
35	34	0.174421	0.700289	2.50E-02	275	1
34	37	0.123202	0.494649	1.77E-02	275	1
37	38	0.091364	0.366818	1.31E-02	275	1
38	39	0.164731	0.661384	2.36E-02	275	1
39	40	0.10936	0.43907	1.57E-02	275	1
36	35	0.054195	0.21759	3.11E-02	275	1
28	32	0.11282	0.452965	6.47E-02	275	1
33	41	0.069215	0.277893	3.97E-02	275	1
42	46	0.065754	0.263998	3.77E-02	275	1
41	43	0.005707	0.022912	3.27E-03	275	1
43	42	0.04845	0.194525	2.78E-02	275	1
42	44	0.033825	0.135806	1.94E-02	275	1
46	45	0.030288	0.121606	1.74E-02	275	1
14	47	0.006229	0.02501	3.57E-03	275	1
47	15	0.01938	0.07781	1.11E-02	275	1
16	17	0.026302	0.105599	1.51E-02	275	1
43	48	0.01938	0.07781	1.11E-02	275	1
18	19	0.041529	0.166736	2.38E-02	275	1
19	21	0.00969	0.038905	5.56E-03	275	1
41	49	0.134277	0.539112	7.71E-02	275	1
81	80	4.400331	5.019917	5.21E-03	40.7	1
22	15	0.01938	0.087355	1.11E-02	213.84	1
25	70	0	0.511333	0	300	0.905
59	21	0	0.596	0	300	0.922
52	19	0	0.643333	0	450	0.905
12	2	0	0.393333	0	600	0.905
16	4	0	0.56	0	600	0.915
3	14	0	0.56	0	900	0.911
41	81	0	1.2	0	200	0.975
42	82	0	1.253	0	200	0.905
26	73	0	0.7045	0	200	0.918
69	23	0	1.34	0	150	0.905
29	76	0	1.424545	0	110	0.945
56	20	0	0.844667	0	450	0.975
15	65	0	0.858	0	300	0.925
1	11	0	0.243778	0	900	0.967
22	66	0	0.866667	0	150	0.913

Appendix (2) :

BUS NO.	BUS NAME	BUS NO.	BUS NAME
1	MARWI	43	SHWAK -2
2	ATBRA – 1	44	NEW HALFA 2
3	MARKYAT-1	45	AROMA -2
4	KABASHI	46	U - ATBRA
5	WADI HALFA	47	HUD
6	WAWA	48	U - ATBRA-2
7	DEBA	49	SHD-2
8	DEBA -B1	50	KHE-1
9	DONGLA	51	IZBA-1
10	MARWI -T1	52	EID BABEKR
11	MARWI -T2	53	KHN- 1
12	ATBRA -2	54	KUKU-1
13	SHANDI -2	55	IZERGAB
14	MARKYAT-2	56	MAHDIA-1
15	GAMOEIA -2	57	FERZYON 1
16	KABASHI -2	58	AFRA-1
17	FREZION-2	59	KILO 10-1
18	GARI -2	60	LOMIAN
19	IZBA -2	61	SHAGRA
20	MHADIA -2	62	MUGROS
21	KILO 10 -2	63	BANT
22	JABEL AWLYAA	64	OMDBAKER
23	GIAD -2	65	GAMOEIA -1
24	SOBA- 2	66	JABL AWLYAA
25	NEW HOUSE -2	67	BAGEER
26	MARKYAT-2	68	SOBA1-B1
27	MASHKOR-2	69	GIAD -B2
28	RABK-2	70	NEW HOUSE
29	SNJA -2	71	OHAS-1
30	SNG -2	72	GNB -1
31	ROSERIS -2	73	MARKYAT1 B1
32	AL RNK-2	74	MANSOR
33	HAWATA -2	75	ORBEEK -1
34	OBYED -2	76	SNJA-1
35	UM ROWABA -2	77	HAGR ALASL
36	TANDLTI -2	78	SENAR P-1
37	DEBA -T2	79	MARINGAN
38	ZREEBA	80	FAO -1
39	FULA -2	81	GDARIF -1
40	BABNOSA-2	82	GERBA -6
41	GDARIF -2	83	PORT SUD-2
42	GRBA-2	84	PORT SUD-1

Appendix (3) :

Line No.	Line name	Length km	R(1) Ohm/...	X(1) Ohm/...	Un kV	R	X	Pi	Qj	Vi
1	BAG11_GAD B2	3	0.348	0.421	110	1.044	1.263	-45.702	5.44	106.116
2	ATB-POR	448.92	0.076	0.403	220	34.11792	180.91476	-53	-31.182	215.989
3	WHL21-WAW21	205	0.067	0.302	220	13.735	61.91	9.017	-40.523	108.48
4	DEB2 B1-D0N2	139.38	0.076	0.403	220	10.59288	56.17014	-7.584	-53.716	105.77
5	MWP-MWT2	34.55	0.076	0.403	220	2.6258	13.92365	43.567	50.463	206.639
6	ATB22-SHN22	140	0.067	0.302	220	9.38	42.28	162.308	21.87	219.185
7	MWP2-DEB2-B2	173.85	0.076	0.403	220	13.2126	70.06155	27.663	62.95	206.639
8	MWT2-DEB2-B1	139.1	0.076	0.403	220	10.5716	56.0573	26.29	44.72	209.562
9	DON2_WAW21	166	0.067	0.302	220	11.122	50.132	9.365	20.21	232.689
10	DEB1 B2_ DON2	139.38	0.076	0.403	220	10.59288	56.17014	-25.781	-62.95	232.689
11	MWP5-ATB5	236.7	0.028	0.276	500	6.6276	65.3292	-318.807	-54.17	502.947
12	MWP51_MRK51	346	0.076	0.403	500	26.296	139.438	673.614	-286.72	515
13	MRK5_KAB5	36.8	0.028	0.276	500	1.0304	10.1568	-259.97	-111.78	481.343
14	SHN21-FRZ21	115	0.067	0.302	220	7.705	34.73	126.334	2.79	219.94
15	FRZ21-GER21	5	0.067	0.302	220	0.335	1.51	-33.372	-147.36	220
16	KAB22-IBA22	30	0.067	0.302	220	2.01	9.06	337.272	113.444	215.324
17	IBA12-IZB12	11	0.067	0.302	110	0.737	3.322	68.21	-39.99	106.479
18	IBA12-KHN12	12	0.067	0.302	110	0.804	3.624	-83.965	-25.12	110
19	KUK11-KHE11	3.2	0.067	0.269	110	0.2144	0.8608	82.003	-53.13	109.028
20	MHD12-IZG12	8	0.067	0.269	110	0.536	2.152	-36.819	-101.57	107.648
21	KUK11-KHN11	4.5	0.0384	0.302	110	0.1728	1.359	-121.54	141.93	109.28
22	KHN11_IZG11	12	0.067	0.269	110	0.804	3.228	38.177	-148.48	110
23	MRK12_MHD12	21	0.067	0.302	220	1.407	6.342	191.39	47.906	219.94
24	AFR12_FAR12	4.5	0.067	0.269	110	0.3015	1.2105	50.314	-33.26	106.666
25	KLX11_AFR11	9.5	0.067	0.269	110	0.6365	2.5555	67.69	-41.51	107.361
26	KUK11_KLX11	14.6	0.087	0.379	110	1.2702	5.5334	5.33	66.41	107.361
27	KLX12_LOM12	3	0.067	0.269	110	0.201	0.807	86.55	-48.52	107.361
28	SHG22_LOM22	7.8	0.067	0.269	110	0.5226	2.0982	1.11	8.78	107.097
29	MUG11_SHG11	11	0.067	0.269	110	0.737	2.959	22.25	-25.62	107.184
30	BNT11_MUG11	3.8	0.067	0.269	110	0.2546	1.0222	-53.25	-16.95	106.759
31	MHD22_OMD22	9.3	0.067	0.269	110	0.6231	2.5017	80.212	-1.62	106.714
32	OMD11_BNT11	5.9	0.067	0.302	110	0.3953	1.7818	-1.276	52.48	106.461
33	BNT11_GAM11	16.5	0.067	0.269	110	1.1055	4.4385	114.78	-99.79	109.563
34	KLX21_SOB21	10	0.038	0.2015	220	0.38	2.015	-163.854	18.66	214.691
35	SOB22_GAD22	33	0.038	0.2015	220	1.254	6.6495	163.629	13.97	214.582
36	SOB11_BAG11	18	0.348	0.421	110	6.264	7.578	-8.971	-18.95	106.919
37	KLX11_SOB11	10	0.348	0.421	110	3.48	4.21	-8.842	-18.68	107.361
38	SHG12_JAS12	39	0.067	0.269	110	2.613	10.491	-86.062	75.49	107.184
39	JAS21_GAD21	36	0.067	0.302	220	2.412	10.872	-13.95	3.93	214.133

40	GAD21_NHAS21	80.7	0.067	0.302	220	5.4069	24.3714	117.341	-16.85	214.133
41	GAD1 B2_OHAS1	80.7	0.348	0.421	110	28.0836	33.9747	-0.508	1.55	106.629
42	NHAS11_OHAS11	5	0.348	0.421	110	1.74	2.105	-36.087	-0.996	107.652
43	OHAS12_GND12	15	0.067	0.302	110	1.005	4.53	27.87	-14.25	107.652
44	OHAS1_MAR1	55	0.348	0.421	110	19.14	23.155	-3.392	20.58	107.652
45	JAS22_MSH22	100	0.067	0.302	220	6.7	30.2	-20.292	21.19	214.483
46	MSH21_NRBK21	107.2	0.067	0.302	220	7.1824	32.3744	-27.43	5.097	217.615
47	HAS22_MAR22	60.3	0.076	0.403	220	4.5828	24.3009	55.515	-17.54	212.437
48	MAN1_MAR1	65.3	0.105	0.289	110	6.8565	18.8717	-10.886	1.76	111.575
49	MAR21_SNJ21	84	0.076	0.403	220	6.384	33.852	-22.73	27.22	211.244
50	MAR 11_HAG11	35	0.348	0.421	110	12.18	14.735	-0.265	-7.93	112.734
51	HAG12_SNP12	60	0.348	0.421	110	20.88	25.26	-7.911	-5.75	111.798
52	SNJ1_SNP1	10	0.348	0.421	110	3.48	4.21	21.184	-34.98	114.149
53	ORBK2_SNJ1	96	0.348	0.421	110	33.408	40.416	-0.336	-1.9	114.126
54	SNP1_MIN1	69	0.348	0.421	110	24.012	29.049	14.97	-9.55	112.2
55	MAR1 B2_ FAO1	71	0.348	0.421	110	24.708	29.891	6.56	-5.3	112.734
56	SNJ22_SNG22	50	0.076	0.403	220	3.8	20.15	-60.851	59.88	214.592
57	SNG12_ ROS12	178	0.076	0.403	220	13.528	71.734	-103.27	-28.9	218.19
58	RNK21_ROS21	172	0.067	0.302	220	11.524	51.944	34.865	-4.97	220
59	SNG22_HWT22	90	0.067	0.302	220	6.03	27.18	30.057	19.27	218.19
60	NRBK21_TND21	84	0.067	0.302	220	5.628	25.368	44.823	43.03	220
61	UMR21_OBD21	126	0.067	0.302	220	8.442	38.052	39.73	-9.1	224.073
62	OBD21_DBT21	89	0.067	0.269	220	5.963	23.941	19.8	4.5	224.745
63	DBT21_ZBD21	66	0.067	0.269	220	4.422	17.754	13.482	-5.3	225.673
64	ZBD22_FUL22	119	0.067	0.269	220	7.973	32.011	10.106	-6.33	225.532
65	FUL21_BBN21	79	0.067	0.269	220	5.293	21.251	3.365	-2.5	226.04
66	TND21_UMR21	78.3	0.067	0.302	220	5.2461	23.6466	43.498	17.22	222.837
67	NRBK21 - RNK21	163	0.067	0.302	220	10.921	49.226	-34.062	17.42	220
68	HWT22 _ GDF22	110	0.067	0.302	220	7.37	33.22	28.37	-23.1	220.61
69	GRB21_ KSL21	74.4	0.067	0.269	220	4.9848	20.0136	16.71	6.5	217.277
70	SHK22_ GRB22	62.54	0.067	0.302	220	4.19018	18.88708	42.105	-39.25	218.862
71	GDF21_SH21	75.12	0.067	0.302	220	5.03304	22.68624	42.88	-16.85	219.473
72	KSL22_ARO22	43.87	0.067	0.0302	220	2.93929	1.324874	0.002	0	218.041
73	GRB22_NHLF22	48.87	0.067	0.302	220	3.27429	14.75874	12.034	-8	217.272
74	MRK21_HUD21	9	0.0335	0.1345	220	0.3015	1.2105	197.64	-135.5	219.874
75	HUD22_GAM22	28	0.0335	0.1345	220	0.938	3.766	197.28	-141.73	218.861
76	KAB22-FRZ22	38	0.067	0.302	220	2.546	11.476	-77.305	136	215.324
77	SHK21_UTB21	28	0.0335	0.1345	220	0.938	3.766	0.001	0	218.862
78	GER21_IBA21	60	0.067	0.302	220	4.02	18.12	219.37	-51.4	220
79	IBA22_KLX22	14	0.067	0.302	220	0.938	4.228	356.277	-68	216.134
80	GDF21_SHD21	70.12	0.067	0.302	220	4.69804	21.17624	-37.86	-9.6	219.473
81	GDF1_FAO1	153	0.348	0.421	110	53.244	64.413	4.68	-1.24	111.686
82	GAM22-JAS22	37	0.067	0.302	220	2.479	11.174	-81.16	18.6	214.48

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