Sudan University of Science and Technology

College of Engineering

Electrical Engineering Department

Contingency Analysis with Embedded SVC FACTS Controller (Case Study (SNG))

تحليل حالات الطوارئ بتضمين متحكم القدرة الرد فعلية الساكنة

دراسة حالة للشبكة السودانية القومية

A project Submitted in Partial Fulfillment for Requirements of the Degree of B.Sc. (Honor) In Electrical Engineering

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الآيات الكريمة

قال تعالى:

{ اقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ (1) خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ (2) اقْرَأْ
وَرَبُّكَ الْأَكْرَمُ (3) الَّذِي عَلَّمَ بِالْقَلَمِ (4) عَلَّمَ الْإِنْسَانَ مَا لَمْ يَعْلَم (5) }

صدق الله العظيم

سورة العلق الآيات من(1) الى (5)

DEDICTATION

To our parents the reason of what we became today, Thanks for your great patience support and Continuous care. To our friends and colleagues whom are always with us and force source to go forward.

ACKNOWLEDGEMENTS

Before all, greater thank and grace to Allah firstly and lastly, who always Inspire and guide us.

We wish to express our sincerest thanks, gratitude and indebtedness to **Dr. Mohammed Osman** for his guidance, supervision and moral support throughout the entire period of this work. His initiatives, encouragement, patience and invaluable suggestions are very gratefully acknowledged without which this work would not have been possible.

We are highly grateful to school of electrical Engineering for providing all necessary support.

ABSTRACT

In the past many wide spread blackouts have been occurred in interconnected power systems du to transient state of power system insecurity such as outages and cascade outages which may lead to complete blackout. The contingency analysis is used to predict which contingencies make system violations and rank the contingencies according to their relative severity. Contingency Analysis is useful both in the network design stages and for programmed maintenance or network expansion works to detect network weakness. Contingency analysis is a well-known function in modern energy management systems, the goal of this power system analysis function is to give operator information about the static security. Contingency analysis of a power system is a major activity in power system planning and operation, in general an outage of a transmission line or transformer may lead to overloads in other branches or a sudden system voltage rise or drop. Contingency analysis is used to calculate violation.

In this project the contingency analysis is done to Sudanese National Grid (SNG) as case study to determine and analyze the effect of equipment outage for a single outage (N-1) on bus voltage profile and rank the most severe equipment affect the voltage profile according to Bus Voltage Security Index ($PI_{V\ /\ Vsp}$) descending ranking. Static var compensator is used to decrease the voltage violation during outages and it gave better results.

المستخلص

حدثت العديد من حالات إنقطاع التيار الكهربائي في الماضي في أنظمة الطاقة المترابطة للحالات العابرة من إنعدام الأمن في نظام الطاقة مثل الإنقطاعات والإنقطاعات المتتالية التي قد تؤدي إلى التعتيم التام. تحليل الطوارئ (الأحداث) يستخدم للتنبؤ بأي من هذه الأحداث سوف يؤدي إلى الإنحراف في قيم الجهود عن القيم الطبيعية وترتيبها بناءً على خطورتها , و هذا التحليل مفيد جدا في مراحل التصميم و الصيانة المبرمجة (الدورية) وعمليات التوسعة في الشبكة وتحديد العناصر الضعيفة بغرض المعالجة (زيادة سعة خطوط النقل و زيادة مقننات المحولات مع زيادة في مقننات أجهزة الحماية).تحليل الطوارئ هو وظيفة معروفة في أنظمة إدارة الطاقة الحديثة , والهدف من وظيفة تحليل نظم الطاقة هو إعطاء معلومات للمشغل عن الأمان.يعتبر تحليل نظام القوى نشاطا رئيسيا في تخطيط نظام الطاقة وتشغيلة , وبشكل عام انقطاع أو خروج خط نقل أو محول من الخدمة , وهذا قد يؤدي زيادة الحمولة في فروع اخرى أو قد يؤدي إلى إرتفاع او إنخفاض مفاجئ للجهد في النظام .

أجريت الدراسة على الشبكة القومية السودانية وتحليل حالات الطوارئ وذلك عند خروج معدة وتأثيرها على جهود البسبارات وترتيب المعدات الأكثر تأثيرا باستخدام مؤشر جهد البسبار وترتيبها ترتيبا تنازليا من الأخطر الى الأقل خطورة, كما تم إستخدام معوض القدرة الردية الإستاتيكي لتحسن أداء الشبكة عند حدوث حالات خروج المعدات الذي أعطى نتائج جيدة.

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LIST OF ABBREVIATIONS

AFR	Afraa
ARO	Arooma
ATB	Atbara
BAG	Bagair
BNT	Bant
DEB	Debba
DON	Dongla
ETAP	Electrical Transient And Analysis Program
FACTS	Flexible Alternating Current Transmission System
FAO	Alfao
FAR	Faroog
GAD	Giad
GAM	Gamoiea
GDF	Algadaref
GND	Gneed
GRB	Grba
HAG	AlhagAbdellah
HWT	Awata
IBA	Eid Babiker
IZB	Izbah
IZG	Izrgab
JAS	Japal Substation
KHE	Khortoum Earth
KHN	Khortoum North
KLX	Kilo 10
KSL	Kasala

KUK	Helat Kuku
MAN	Managel
MAR	Marinjan
MHD	Mahdiea
MRK	Mrkheiat
MSH	Mshkoor
MUG	Mugran
MWP	Marwei plant
MWT	Marwei Town
OBD	Alobied
$PI_{S / Ssp}$	Branch Overloading Security Index
$PI_{V / Vsp}$	Bus Voltage Security Index
$PI_{\Delta P}$	Real Power Flow Change Index
$PI_{\Delta Q}$	Reactive Power Flow Change Index
RBK	Rabak
RNK	Alrank
SNG	Sudanese National Grid
SHG	Shagara
SIG	Sengah
SNJ	SennarJuntion
SNP	Sennar Plant
SVC	Static Var Compensator
TCSC	Thyristor-controlled Series Compensation
TND	Tndelti
UBFC	Unified power flow controlled
UMR	Umrawaba
WHL	WadiHalfa
WWA	Wawa

LIST OF SYMPOLES

Z	Impedance, Ω
Y	Admittance, S
I	Bus Current, A
V	Bus Voltage, V
P	Active Power, MW
Q	Reactive Power, $MVAr$
δ	Power Angle, Degree
J	Jacobean Matrix

CHAPTER ONE

INTRODUCTION

1.1 General Concepts:

A power system is in normal state if all the system is healthy no equipment such as generators, transformers and transmission lines etc is overloaded, all bus voltages and system frequency are within specified limits etc.

It is well known that power system is a complex network consisting of numerous equipments like generators, transformers, transmission lines, circuit breakers etc. Failure of any of these equipments during its operation harms the reliability of the system and hence leading to outages. 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 contingency analysis is time consuming as it involves the computation of complete AC load flow calculations following every possible outage event like outages occurring at various generators and transmission lines.

In the past many widespread blackout have occurred in interconnected power systems, it is necessary to ensure that power system should be operated most economically. Most power systems are designed with enough redundancy so that they can withstand all major failure or outage events, and the overriding factor in the operation of the power systems is the desire to maintain system security.

System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken off-line or a transmission line may be damaged by a storm and taken out. And the system must be operated at all times in such a way that the system will not be left in a dangerous condition. System security can be broken down into two major functions:

1. System monitoring.
2. contingency analysis.

The Probabilities of changes in the system and its environment called contingencies, some contingencies (such as line outage, generator or transformer outage etc.) make the system unsecure and if the system is unsecure then these contingencies may cause blackouts.

Contingency analysis is the most important task for planning Contingency analysis is used to study the performance of power system and to assess transmission expansion due to the load growth or generation expansion.

1.2 Problem statement:

Power system is in emergency state if there are one or more problems due to equipment or outages such as outage of transmission line or outage of transformer or loss of generating unit, so we must've to perfume analytical program which is ETAP to analyze the condition of the system changes.

1.3 Project objectives:

(1) Study the contingency analysis and perform a single (N-1) contingency analysis simulation. for bulk power system network (SNG).

(2) Contingency Ranking indices of the system.

(3) Ameliorate and improve the busbar's voltage by embedding SVC compensator.

1.4 Methodology:

(1) Applying the load flow to the network by using (Fast-decoupled) method under transient state.

(2) Screening contingencies on the network and ranking the most sever contingencies by using (ETAP) software.

(3) Installing SVC for the network and Screening contingencies on the network and ranking the most sever contingencies using (ETAP) software.

1.5 Project outlines:

Chapter one: represent the general concept, project objectives, statement of the problem, methodology and the layout of the project.

Chapter two: represent an introduction to the power system, security and contingencies.

Chapter three: represent an introduction to the power flow, fast-decoupled power flow method, contingency analysis, contingency ranking, and SVC modeling.

Chapter four: represent the results and simulation of the Sudanese National Grid by using ETAP program.

Chapter five: represent the project conclusion and the recommendation.

CHAPTER TWO

CONTINGENCY ANALYSIS AND FACTS DEVICES

2.1 Definition:

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.

2.2 Power System Security:

Up until now we have been mainly concerned with minimizing the cost of operating a power system. An overriding factor in the operation of a power system is the desire to maintain system security. System security involves practices designed to keep the system operating when components fail. For example, a generating unit may have to be taken offline because of auxiliary equipment failure. By maintaining proper amounts of spinning reserve, the remaining units on the system can make up the deficit without too low a frequency drop or need to shed any load. Similarly, a transmission line may be damaged by a storm and taken out by automatic relaying. If, in committing and dispatching generation, proper regard for transmission flows is maintained, the remaining transmission lines can take the increased loading and still remain within limit.

All equipment in a power system is designed such that it can be disconnected from the network. The reasons for these disconnections are generally divided into two categories: scheduled outages and forced outages.

Scheduled outages: are typically done to perform maintenance or replacement of the equipment, and, as its name implies, the time of disconnect is scheduled by operators to minimize the impact on the reliability of the system.

Forced outages: are those that happen at random and may be due to internal component failures or outside influences such as lightning, wind storms, ice buildup, etc. Because the specific times at which forced outages occur are unpredictable, the system must be operated at all times in such a way that the system will not be left in a dangerous condition should any credible outage event occur. Since power system equipment is designed to be operated within certain limits, most pieces of equipment are protected by automatic devices that can cause equipment to be switched out of the system if these limits are violated. If a forced outage occurs on a system that leaves it operating with limits violated on other components, the event may be followed by a series of further actions that switch other equipment out of service. If this process of cascading failures continues, the entire system or large parts of it may completely collapse. This is usually referred to as a system blackout. An example of the type of event sequence that can cause a blackout might start with a single line being opened due to an insulation failure; the remaining transmission circuits in the system will take up the flow that was flowing on the now-opened line. If one of the remaining lines is now too heavily loaded, it may open due to relay action, thereby causing even more load on the remaining lines. This type of process is often termed a cascading outage. Most power systems are operated such that any single initial failure event will not leave other components heavily overloaded, specifically to avoid cascading failures[1].

2.3 Functions that are carried out in an energy control center:

System security can be said to comprise of three major functions that are carried out in an energy control center:

1. System monitoring.
2. Contingency analysis.
3. Corrective action analysis.

2.3.1 System Monitoring:

System monitoring supplies the power system operators or dispatchers with pertinent up-to-date information on the conditions of the power system on real time basis as load and generation change. Telemetry systems rneasure monitor and transmit the data, voltages, currents, current flows and the status of circuit breakers and switches in every substation in a transrnission network. Further, other critical and important information such as frequency, generator outputs and transformer tap position scan also be telemetered. Digital computers in a control center then processes the telemetered data and place them in a data base form and inform the operators in case of an overload or out of limit voltage. Important data are also displayed on large size monitors. Alarms or warnings may be given if required.

2.3.2 Contingency Analysis:

The second major security function is contingency analysis. Modern Operation computers have contingency analysis programs stored in them. These foresee possible system troubles(outages)before they occur. They study outage events and alert the operators to any potential overloads or serious voltage violation.

2.3.3 Corrective action analysis:

The third major security function, corrective action analysis, permits the operator to change the operation of the power system if a contingency analysis program predicts a serious problem in the event of the occurrence of a certain outage. Thus, this provides preventive and post-contingency control. A simple example of corrective action is the shifting of generation from one station to another. This may result in change in power flows and causing a change in loading on overloaded lines.

2.4 Contingencies Analysis:

In general terms, contingency analysis can be defined as the evaluation of the security degree of a power system. Contingency analysis is generally related to the analysis of abnormal system conditions. This is a crucial problem, both in planning and in daily operation. A common criterion is to consider contingencies as a single outage of any system element (generator, transmission line, transformer or reactor) and evaluate the post-contingency state. This is known as the N−1 security criterion. Other contingencies to be considered are simultaneous outages of double-circuit lines that share towers in a significant part of the line path. Contingency analyses are used to determine the state of the network after an outage of one (N−1) or multiple elements (N−k). Therefore, a load flow must be performed for each selected contingency. This chapter deals with the most basic but typically used contingency analysis, deterministic contingency analysis.

2.5 Contingency Analysis: Detection of Network Problems:

2.5.1 Generation Outages:

When a generator suffers a forced outage, it causes changes in other generators as well as changes in the transmission system.

Effect on Other Generations: When a generator fails, its power output is lost, and the result is an imbalance between total load plus losses and total generation. This imbalance results in a drop-in frequency, which must be restored. To restore frequency back to its nominal value (50Hz or 60Hz), other generators must make up the loss of power from the outage generator. The proportion of the lost power made up by each generator is strictly determined by its governor droop characteristic.

Effects on Transmission: When generation is lost, much of the made-up power will come from tie lines, and this can mean line flow limit or bus voltage limit violations. In summary, the system must monitor two things to be sure generator outages do not cause problems when one is lost: check spinning reserve at all times to be sure it is adequate and model generator outages and their effect on transmission flows and voltages.

2.5.2 Transmission Outages:

When a transmission line or transformer fails and is disconnected, the flow on that line goes to zero and all flows nearby will be affected. The result can be a line flow limit or bus voltage limit violation. There is no way to know which line or transformer outage is going to cause the worst violations. The operators therefore usually want to check as many of them as possible, as often as possible. Thus, the operators may seek to model and calculate the outage effects from an outage of every line and transformer in the system.

2.5.3 Double Outages:

An even more difficult analysis is to check all pairs of possible simultaneous outages, which is denoted (n− 2). Thus, all pairs of generators, and all pairs of transmission lines as well as pairs of single generator outages plus a possible single transmission-line outage at the same time would have to be analyzed. This (n − 2) analysis is much more difficult because of the extremely large number of cases to model. The usual practice is to only study a few of the (n− 2) cases that are known by experience to be the most serious cases [2].

2.6 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 do 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. The contingencies are selected by calculating a kind of severity indices known as performance indices (PI) [3]. 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 found.

2.7 FACTS-Devices and Applications:

Flexible AC Transmission Systems, called FACTS, got in the recent years a well-known term for higher controllability in power systems by means of power electronic devices. Several FACTS-devices have been introduced for various applications worldwide. A number of new types of devices are in the stage of being introduced in practice. Even more concepts of configurations of FACTS-devices are discussed in research and literature. 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. FACTS-devices provide a better adaptation to varying operational conditions and improve the usage of existing installations. The basic applications of FACTS-devices are:

- Power flow control.
- Increase of transmission capability.
- Voltage control.
- Reactive power compensation.
- Stability improvement.

• Power quality improvement.

• Power conditioning.

• Flicker mitigation.

• Interconnection of renewable and distributed generation and storages.

The influence of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices work electrically as fast current, voltage or impedance controllers. The power electronic allows very short reaction times down to far below one second. [4]

CHAPTER THREE

CONTINGENCY ANALYSIS USING AC LOAD FLOW SOLUTION AND SVC

3.1 Contingency Analysis Using AC Load Flow Solution:

The calculation made with the help of network sensitivity factors for contingency analysis are faster, but there are many power systems where voltage magnitudes are the critical factor in assessing contingencies. The method gives rapid analysis of the MW flows in the system, but cannot give information about MVAR flows and bus voltages. In systems where VAR flows predominate, such as underground cables, an analysis will not be adequate to indicate overloads. Hence the method of contingency analysis using AC power flow is preferred as it gives the information about MVAR flows and bus voltages in the system. When AC power flow is to be used to study each contingency case, the speed of solution for estimating the MW and MVAR flows for the contingency cases are important, if the solution of post contingency state comes late, the purpose of contingency analysis fails. The method using AC power flow will determine the overloads and voltage limit violations accurately. It does suffer drawback, that the time such a program takes to execute might be too long. If the list of outages can be too long. However, the AC power flow program for contingency analysis by the Fast-Decoupled Power Flow (FDPF) [5] provides a fast solution to the contingency analysis since it has the advantage of matrix alteration formula that can be incorporated and can be used to simulate the problem of contingencies involving transmission line outages without reinverting the system Jacobian matrix for all iterations. Hence to model the contingency analysis problem the AC power flow method using FDLF has been extensively chosen.

3.2 Introduction to Load Flow:

In a three-phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide a systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system.

Network equations can be formulated in variety of forms. However, node voltage method is commonly used for power system analysis. The network equations which are in the nodal admittance form results in complex linear simultaneous algebraic equations in terms of node currents. The load flow result gives the bus magnitude and phase angle and hence the power flow through the transmission lines, line losses and power injection at all the busses.

3.2.1 Bus Classifications:

There are four quantities of interest associated with each bus:

1. Real power, **P.**
2. Reactive power, **Q.**
3. Voltage magnitude, **|V|.**
4. Voltage angle, **δ.**

At every bus of the system two of these four quantities will be specified and the remaining two will be unknowns. Each of the system buses may be classified in accordance with which of the two quantities are specified. The following classifications are typical:

Slack bus—The slack bus for the system is a single bus for which the voltage magnitude and angle are specified. The real and reactive power are unknowns. The bus selected as the slack bus must have a source of both real and reactive power, since the injected power at this bus must ‘‘swing’’ to take up the ‘‘slack’’ in the solution. The best choice for the slack bus (since, in most power systems, many buses have real and reactive power sources) requires experience with the particular system under study. The behavior of the solution is often influenced by the bus chosen. (In the earlier discussion, the last bus was selected as the slack bus for convenience.)

Load bus (P–Q bus)—A load bus is defined as any bus of the system for which the real and reactive powers are specified. Load buses may contain generators with specified real and reactive power outputs; however, it is often convenient to designate any bus with specified injected complex power as a load bus.

Voltage-controlled bus (P–V bus)—Any bus for which the voltage magnitude and the injected real power are specified is classified as a voltage controlled (or P–V) bus. The injected reactive power is a variable (with specified upper and lower bounds) in the power flow analysis. (A P–V bus must have a variable source of reactive power such as a generator or a capacitor bank.)

Table 3.1: Bus Classification

Bus type	Specified quantities	Unknown quantities
Slack bus	$\|V\|$, δ	P, Q
Load bus	P, Q	$\|V\|$, δ
Voltage bus	P, $\|V\|$	Q, δ

3.2.2 Bus Admittance Matrix:

In order to obtain the bus-voltage equations, consider the simple 4-bus power system as shown in figure below

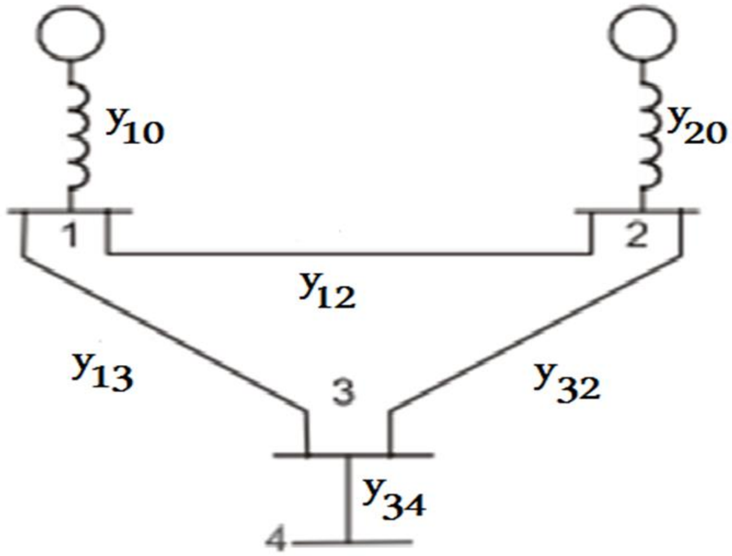

Figure (3.1): the impedance diagram of sample 4-bus power system

for simplicity resistance of the line are neglected and the impedances shown in above figure are expressed in per-unit on common MVA base

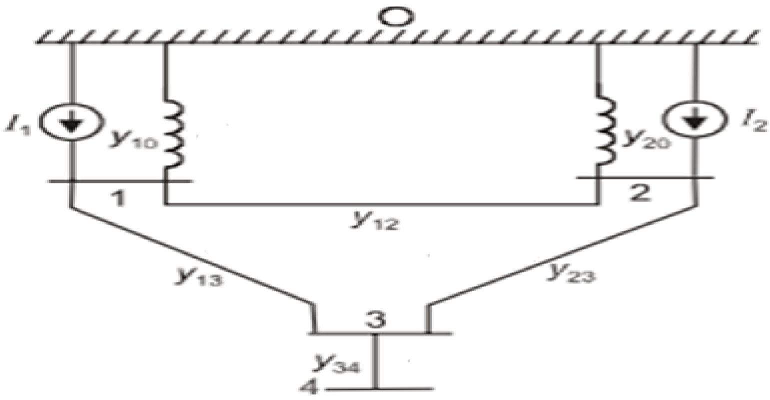

Figure (3.2): The admittance diagram of figure (3.1)

Applying KCL to the independent nodes 1, 2, 3, 4 we have,

$I_1 = y_{10}V_1 + y_{12}\ (V_1 - V_2) + y_{13}\ (V_1 - V_3)$

$I_2 = y_{20}V_2 + y_{12}\ (V_2 - V_1) + y_{23}\ (V_2 - V_3)$

$0 = y_{23}\ (V_3 - V_2) + y_{13}\ (V_3 - V_1) + y_{34}\ (V_3 - V_4)$

$0 = y_{34}\ (V_4 - V_3)$

Rearranging the above equations, we get

$I_1 = (y_{10} + y_{12} + y_{13}) V_1 - y_{12}V_2 - y_{13}V_3$

$I_2 = -y_{12}V_1 + (y_{20} + y_{12} + y_{23}) V_2 - y_{23}V_3$

$0 = -y_{13}V_1 - y_{23}V_2 + (y_{13} + y_{23} + y_{34}) V_3 - y_{34}V_4$

$0 = -y_{34}V_3 + y_{34}$

Let,

$Y_{11} = (y_{10} + y_{12} + y_{13})$

$Y_{22} = (y_{20} + y_{21} + y_{23})$

$Y_{33} = (y_{31} + y_{32} + y_{34})$

$Y_{44} = y_{43}$

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

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

$Y_{23} = Y_{32} = -y_{23}$

$Y_{34} = Y_{43} = -y_{43}$

The node equations reduce to

$I_1 = Y_{11}V_1 + Y_{12}V_2 + Y_{13}V_3 + Y_{14}V_4$

$I_2 = Y_{21}V_1 + Y_{22}V_2 + Y_{23}V_3 + Y_{24}V_4$

$I_3 = Y_{31}V_1 + Y_{32}V_2 + Y_{33}V_3 + Y_{34}V_4$

$I_4 = Y_{41}V_1 + Y_{42}V_2 + Y_{43}V_3 + Y_{44}V_4$

Above equations can be written in matrix form,

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & Y_{23} & Y_{24} \\ Y_{31} & Y_{32} & Y_{33} & Y_{34} \\ Y_{41} & Y_{42} & Y_{43} & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \qquad (3.1)$$

Or in general

$$I_{bus} = Y_{bus}V_{bus} \qquad (3.2)$$

$V_{bus} \equiv vector\ of\ bus\ voltages$

I_{bus} ≡vector of the injected currents

Y_{bus} ≡admittance matrix

Diagonal element of Y matrix:

$$Y_{ii} = \sum_{k=0}^{n} y_{ik} \ , j \neq i \quad (3.3)$$

Off-diagonal element of Y matrix:

$Y_{ik} = Y_{ki} = -y_{ik}$ (3.4)

$\mathrm{V_{bus}} = \mathrm{Y_{bus}^{-1}} \ \mathrm{I_{bus}}$ (3.5)

3.2.3 BUS LOADING EQUATIONS:

Consider i- th bus of a power system as shown infigure(3.3) transmission lines arerepresented by their equivalent p models π models. yi0 is the total charging admitance at bus i.

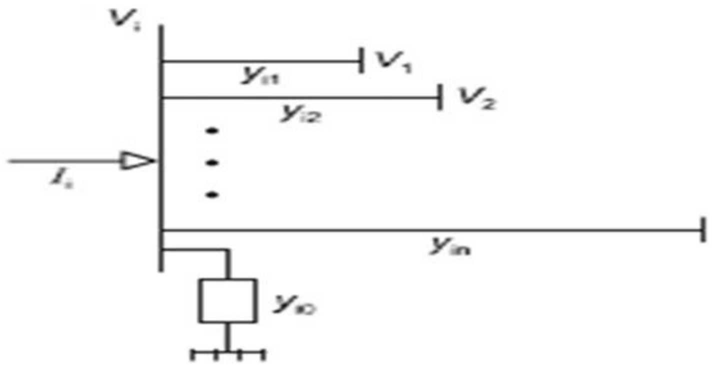

Figure (3.3): i-th bus of a power system

Net injected current **I**i into the bus i can be written as:

$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$

$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i \ - y_{i1}V_1 - y_{i1}V_2 - \cdots - y_{i1}V_n$

Let us define

$Y_{ii} = y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in}$

$Y_{i1} = -y_{i1}$

$Y_{i2} = -y_{i2}$

$\vdots$

$Y_{in} = -y_{in}$

$I_i = Y_{ii}V_i + Y_{i1}V_1 + Y_{i2}V_2 + \cdots + Y_{in}V_n$……………... (3.7)

Or

$$I_i = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.8)}$$

The real and reactive power injected at the bus i is

$$Pi - jQi = V_i * I_i$$

$$I_i = \frac{P_i - jQ_i}{v_i^*}$$

(3.9)

From eqns. (3.9) and (3.10) we get

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k \ldots\ldots\ldots \qquad \text{(3.10)}$$

$$Y_{ii}V_i = \frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{v_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \ldots\ldots\ldots\ldots \qquad \text{(3.11)}$$

3.2.4 Calculation of Net Injected Power:

From eqn. (3.11), we get

$$\frac{P_i - jQ_i}{v_i^*} = Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k$$

$$P_i - jQ_i = v_i^*\left[Y_{ii}V_i + \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \ldots\ldots\ldots\ldots\ldots\ldots \qquad \text{(3.12)}$$

$$\therefore P_i - jQ_i = |V_i|^2|Y_{ii}|\cos\theta_{ii} + j|V_i|^2|Y_{ii}|\sin\theta_{\text{ii}}$$

$$+ \sum_{\substack{k=1 \\ k\neq i}}^{n} |Y_{ik}||V_i||V_k|\cos(\theta_{ik} + \delta_k - \delta_i)$$

$$+ \text{j}\sum_{\substack{k=1 \\ k\neq i}}^{n} |Y_{ik}||V_i||V_k|\sin(\theta_{ik} + \delta_k - \delta_i) \qquad (3.13)$$

separating real and imaginary part of equation (3.14)

$$P_i = \sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\cos(\theta_{ik} + \delta_k - \delta_i) \dots\dots\dots\dots\dots\dots \qquad (3.14)$$

And

$$Q_i = -\sum_{k=1}^{n}|Y_{ik}||V_i||V_k|\sin(\theta_{ik} + \delta_k - \delta_i) \dots\dots\dots\dots\dots \qquad (3.15)$$

3.2.5 Fast Decoupled Power Flow Solution:

The fast-decoupled power flow algorithm simplifies the procedure presented for the Newton–Raphson algorithm by exploiting the strong coupling between real power and bus voltage phase angles and reactive power and bus voltage magnitudes commonly seen in power systems. The Jacobian matrix is simplified by approximating as zero the partial derivatives of the real power equations with respect to the bus voltage magnitudes. Similarly, the partial derivatives of the reactive power equations with respect to the bus voltage phase angles are approximated as zero.

$$\begin{bmatrix}\Delta P \\ \Delta Q\end{bmatrix} = \begin{bmatrix} J1 & 0 \\ 0 & J4\end{bmatrix}\begin{bmatrix}\Delta\delta \\ \Delta|\text{V}|\end{bmatrix} \dots\dots\dots\dots \text{(3.16)}$$

Or

$$\Delta P = J1.\Delta\delta$$

$$\Delta Q = J1.\Delta|\text{V}$$

(3.17)

For voltage-controlled buses, voltage magnitudes are known. Therefore, if m buses of the system are voltage controlled, $J1$ is of the order (n-1) ×(n-1) and $J4$ is of the order (n-1-m) ×(n-1-m)

Now the diagonal elements of $J1$ are

$$\frac{\partial Pi}{\partial \delta i} = \sum_{\substack{k=1 \\ k \neq i}}^{n} |\mathrm{Vi}|\,|\mathrm{Vk}|\,|\mathrm{Yik}| \sin \theta\mathrm{ik} - \delta\mathrm{i} + \delta\mathrm{k}) \ldots\ldots\ldots\ldots \quad (3.18)$$

Off-diagonal elements of $J1$ are

$$\frac{\partial P}{\partial \delta k} = -|\mathrm{Vi}|\,|\mathrm{Vk}|\,|\mathrm{Yik}| \sin(\theta\mathrm{ik} - \delta\mathrm{i} + \delta\mathrm{k}) \;\; k \neq i \ldots\ldots\ldots \quad (3.19)$$

The diagonal elements of $J4$ are

$$\frac{\partial Qi}{\partial |\mathrm{Vi}|} = -2|\mathrm{Vi}|\,|\mathrm{Yii}| \sin\theta\mathrm{ii} - \sum_{\substack{k=1 \\ k \neq i}}^{n} |\mathrm{Vi}|\,|\mathrm{Yik}| \sin(\theta\mathrm{ik} - \delta\mathrm{i} + \delta\mathrm{k}) \quad (3.20)$$

$$\frac{\partial Qi}{\partial |\mathrm{Vi}|} = -|\mathrm{Vi}|\,|\mathrm{Yik}| \sin(\theta\mathrm{ik} - \delta\mathrm{i} + \delta\mathrm{k}) k \neq \mathrm{i} \quad (3.21)$$

The terms $\Delta P^{(p)}$ and $\Delta Q^{(p)}$ are the difference between the scheduled and calculated values at bus i known as power residuals, given by

$$\Delta P^{(p)} = P_{\mathrm{i}}^{\mathrm{scheduled}} - P_{\mathrm{i}}^{(p)}{}_{(\mathrm{calculated})} \quad (3.22)$$

$$\Delta Q_{\mathrm{i}}^{(p)} = Q_{\mathrm{i}}^{\mathrm{scheduled}} - Q_{\mathrm{i}}^{(p)}{}_{(\mathrm{calculated})} \quad (3.23)$$

The new estimates for bus voltage magnitude and angles are

$$|\mathrm{Vi}|^{(p+1)} = |\mathrm{Vi}|^{(p)} + \Delta|\mathrm{Vi}|^{(p)} \quad (3.24)$$

3.3 ETAP Overview:

"ETAP" is an abbrev for "Electrical Transient Analysis Program ". ETAP is full spectrum analytical engineering software company specializing in analysis simulation, monitoring, control, optimization, and automation of electrical power system. ETAP software offers the most comprehensive and integrated suite of power system enterprise solution that spans from model to operation.

3.3.1 Contingency Analysis:

Contingency Analysis represents an important tool to study the effect of elements outages in power system security during operation and planning. It investigates, evaluates, filters and prioritizes the impacts on an electric power system whenever typically unplanned problems or outages occur. The ETAP Contingency Analysis module allows users to evaluate the impact of N-1 and N-2 contingencies, determine system performance indices, and compare results against safe operating limits for each element in the power system based on user-defined component outage and failure scenarios. For accurate results, AC load flow is run for each contingency. The ETAP user friendly interface allows running base and contingency load flows to see the outage effects on OLV.

To access the various contingency analysis related functions within ETAP, click on the icon 

change Toolbar and select “Contingency Analysis”.

The toolbar consists of many functions as shown in figure (3.4) to run the program you have to press “run contingency analysis” after choosing the equipment to be out, the toolbar also provides the base load flow.

You can see the report summary by clicking on “report summary” it gives quick information, also you can print the report from “report manager”.

Performance index icon gives the performance indices list.

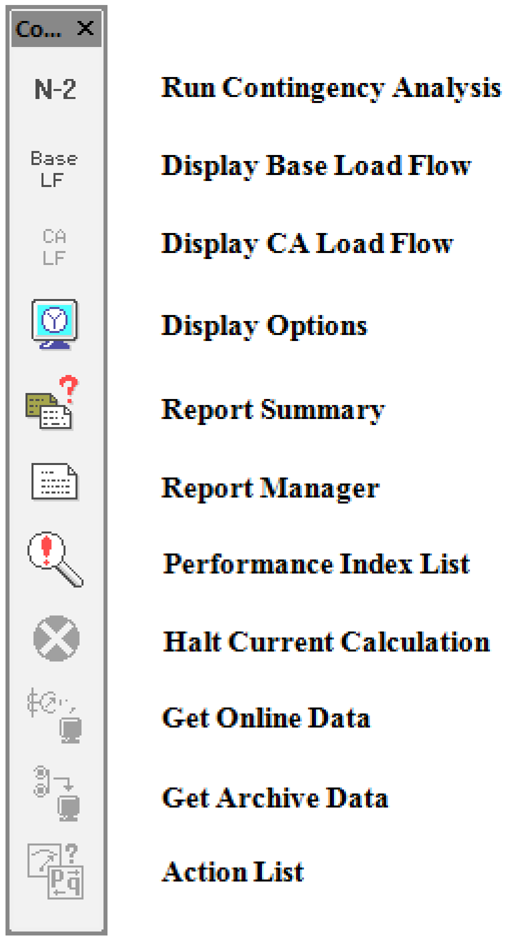

Figure (3.4) The Contingency Analysis Toolbar, with all the related functions

3.3.2 Performance Index Calculation:

Performance Index is used for outage ranking. An index may indicate the severity of the outage. Performance index is a number and it has no unit. Therefore, we can add different indices as well as different weights and they are calculated from ETAP as follow:

Bus Voltage Security Index (*PI*$_{V/Vsp}$)

Bus Voltage Security Index is calculated based on the bus voltage difference before and after the contingency. Smaller values represent smaller differences.

$$PI_{V/Vsp} = \left[\sum_{n=1}^{N} \left(\left(V_{n\_PostCon} - V_{n\_Spec} \right) / V_{limit} \right)^2 \right] / N \qquad 3.25$$

For $PI_{V/Vsp}$ based on Equipment Rating

$V_{n\_PostCon}$	Post contingency bus voltage for Bus n in percentage value.
V_{n_Spec}	Specified bus voltage base for Bus n in percentage value, 100% in this case.
V_{limit}	Limit for bus voltage critical alert. $V_{limit} = \lvert V_{critical} - 100\% \rvert$
N	Number of buses in the system.

For $PI_{V/Vsp}$ based on Base Case

$V_{n\_PostCon}$	Post contingency bus voltage for Bus n in percentage value.
V_{n_Spec}	Specified bus voltage base for Bus n in percentage value, base case in this case.
V_{limit}	Limit for bus voltage critical alert. $V_{limit} = V_{Crit\_Dev}$, which is the critical voltage deviation alert in percentage value. V_{Crit_Dev} is collected from the Alert page

Real Power Flow Change Index ($PI_{\Delta P}$)

Real Power Flow Change Index is calculated based on the real power flow difference before and after the contingency. Smaller values represent smaller differences.

$$PI_{\Delta P} = \left[\sum_{n=1}^{N} \left(\left(P_{n\_PostCon} - P_{n\_Base}\right)/P_{n\_Base}\right)^2\right]/N \qquad 3.26$$

$P_{n\_PostCon}$	Post contingency real power flow for Branch n.
P_{n_Base}	Base case real power flow for Branch n.
N	Number of branches in the system.

Reactive Power Flow Change Index (*$PI_{\Delta Q}$*)

Reactive Power Flow Change Index is calculated based on the reactive power flow difference before and after the contingency. Smaller values represent smaller differences.

$$PI_{\Delta Q} = \left[\sum_{n=1}^{N} \left(\left(Q_{n\_PostCon} - Q_{n\_Base}\right)/Q_{n\_Base}\right)^2\right]/N \qquad 3.28$$

$Q_{n\_PostCon}$ Post contingency reactive power flow for Branch n.

Q_{n_Base} Base case reactive power flow for Branch n.

N Number of branches in the system.

Branch Overloading Security Index (*$PI_{S/Ssp}$*)

Branch Overloading Security Index is calculated based on the branch overloading condition after the contingency. Smaller values represent less overloading violations

$$PI_{S/Ssp} = \left[\sum_{n=1}^{N} \left(S_{n\_PostCon}/S_{Limit}\right)^2\right]/N \qquad 3.29$$

For $PI_{S/Ssp}$ based on Equipment Rating

$S_{n\_PostCon}$ Post contingency branch load flow for Branch n, MVA for transformers and Amps for other branches.

S_{Limit} Branch overloading limit, in this case **S_{Limit} = Ampacity * S_{Crit_Alert}.**

N Number of branches in the system.

For $PI_{S / Ssp}$ based on Base Case

$S_{n\_PostCon}$	Post contingency branch load flow for Branch n, MVA for transformers and Amps for other branches.
S_{Limit}	Branch overloading limit in this case $S_{limit} = S_{Base} * (1 + S_{Crit\_Dev})$.
N	Number of branches in the system.

3.4 Static Var Compensator (SVC):

Electrical loads both generate and absorb reactive power. Since the transmitted load varies considerably from one hour to another, the reactive power balance in a grid varies as well. The result can be unacceptable voltage amplitude variations or even a voltage depression, at the extreme a voltage collapse. A rapidly operating Static Var Compensator (SVC) can continuously provide the reactive power required to control dynamic voltage oscillations under various system conditions and thereby improve the power system transmission and distribution stability. Installing an SVC at one or more suitable points in the network can increase transfer capability and reduce losses while maintaining a smooth voltage profile under different network conditions. In addition, an SVC can mitigate active power oscillations through voltage amplitude modulation. SVC installations consist of a number of building blocks. The most important is the Thyristor valve, i.e. stack assemblies of series connected anti-parallel Thyristors to provide controllability. Air core reactors and high voltage AC capacitors are the reactive power elements used together with the Thyristor valves. The step-up connection of this equipment to the transmission voltage is achieved through a power transformer. The Thyristor valves together with auxiliary systems are located indoors in an SVC building, while the air core reactors and capacitors, together with the power transformer are located outdoors.

In principle the SVC consists of Thyristor Switched Capacitors (TSC) and Thyristor Switched or Controlled Reactors (TSR / TCR). The coordinated control of a combination of these branches varies the reactive power as shown in Figure (3.5) The first commercial SVC was installed in 1972 for an electric arc furnace. On transmission level the first SVC was used in 1979. Since then it is widely used and the most accepted FACTS-device. A recent installation is shown in Figure (3.5)

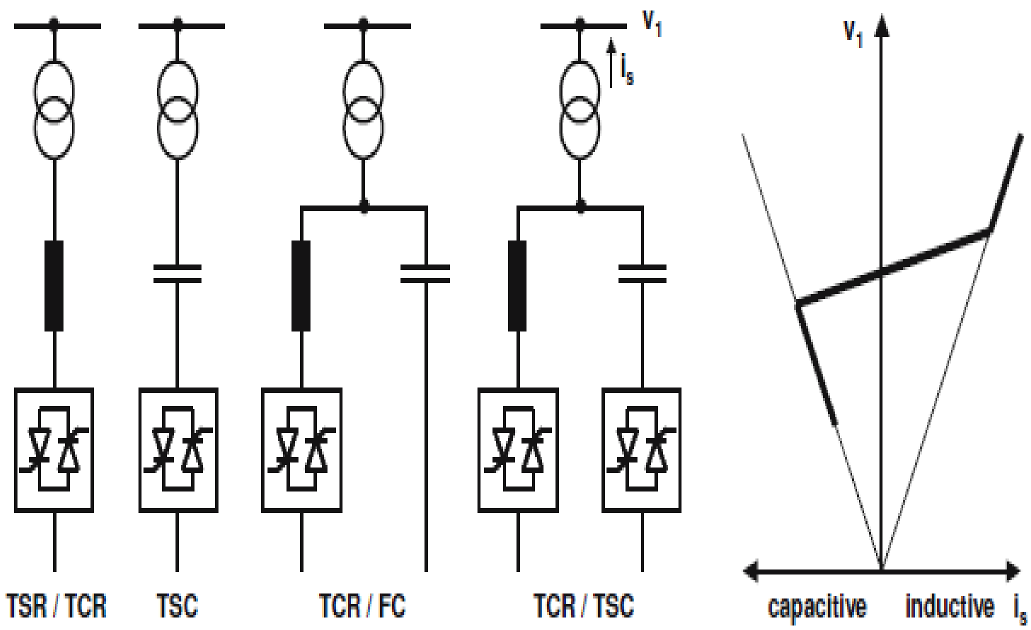

Fig. (3.5) SVC building blocks and voltage / current characteristic

3.4.1 Static Var Compensator ETAP Model

The Static Var Compensator Control model can be accessed from the SVC Editor, Model page. It is imperative that you model this control when performing Transient Stability Studies to determine the dynamic response of the SVC under different conditions the model is shown in figure (3.6) below for type 3

SVC Control Model - Type3

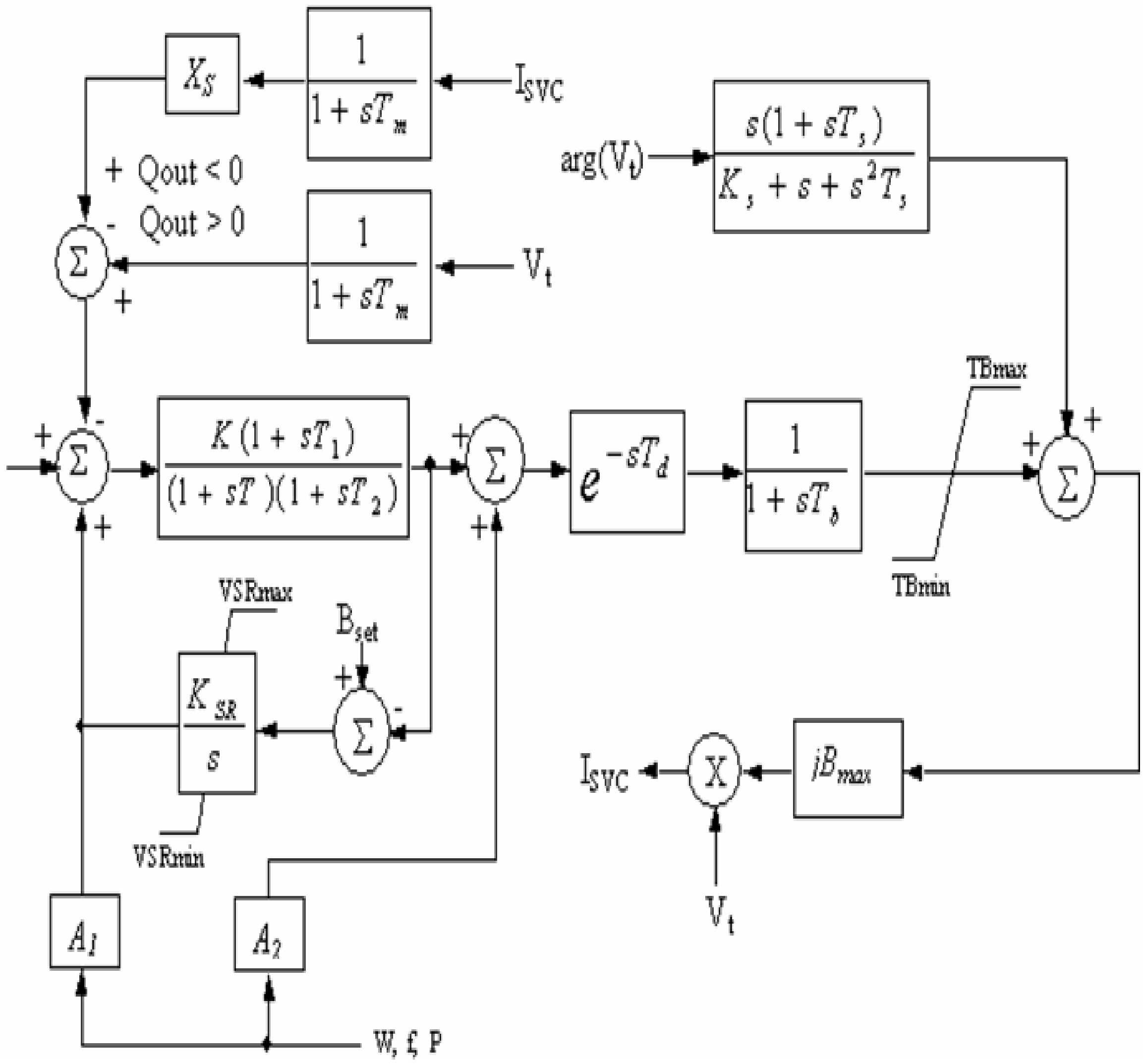

Figure (3.6) shows SVC control model type 3

3.4.2 Parameters and Sample Data

Parameters for this model and their sample data are shown in the following screen capture shown in figure (3.7)

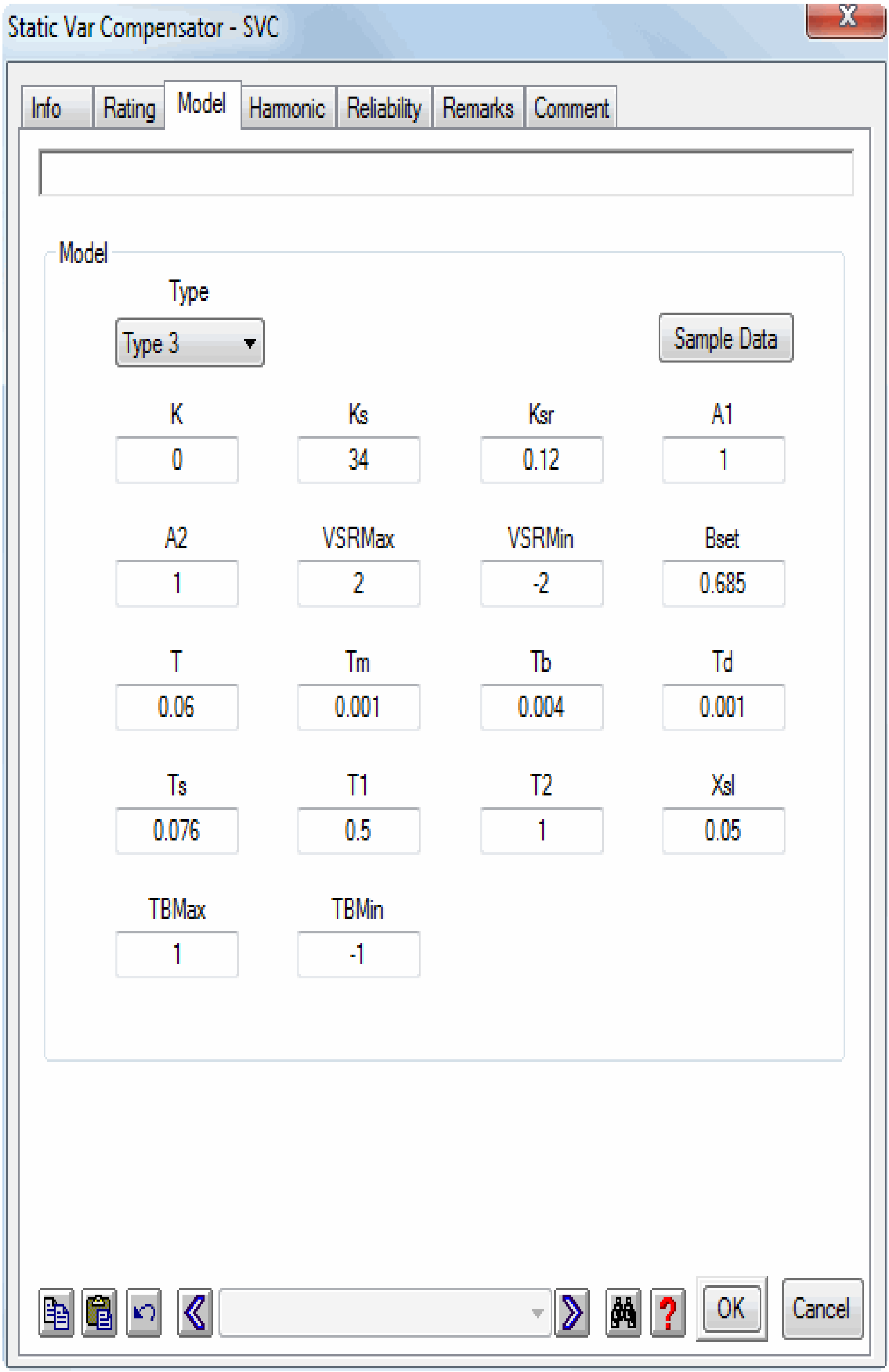

Figure (3.7) shows SVC parameters and sample data

3.4.3 Parameter Definitions and Units

Parameter definitions and their units are provided in the following table (3.2):

Parameter	Definition	Unit
K	Voltage regulator gain	p.u.
Ks	Synchronizing control gain	p.u.
Ksr	Susceptance regulator gain	p.u.
A1	Additional control signal gain	p.u.
A2	Additional control signal gain	p.u.
VSRmax	Maximum voltage limit	p.u.
VSRmin	Minimum voltage limit	p.u.
Bset	Susceptance set point	p.u.
T	Voltage regulator time constant	sec.
Tm	Measurement time constant	sec.
Tb	Thyristor phase control time constant	sec.
Td	Thyristor phase control delay	sec.
Ts	Synchronizing control time constant	sec.
T1	Voltage regulator time constant	sec.
T2	Voltage regulator time constant	sec.
Xsl	Slope	p.u.
TBmax	Maximum susceptance limit	p.u.
TBmin	Minimum susceptance limit	p.u.

Parameter	Model Type	Calculations
K	1	if Vini > Vref then K = 100 / SLL if Vini ≤ Vref then K = 100 / SLC
TBmax	All	TBmax = 1.0
TBmin	All	if (abs (Bc) < 0.00001) **TBmin** = -1.0 else **TBmin** = BL / Bc

CHAPTER FOUER

SIMULATION AND RESULTS ANYLISIS

4.1 Introduction:

The voltage profile of the entire system is presented from the load flow simulation as shown in Table (4.2) before installing SVC, it can be noticed that are seven buses are under voltage. The model analysis method has been successfully applied to the partial power system network shown in appendix(A), SVC stations have been installed at buses (ATP2, BAG1 and FAR1) a power flow program (ETAP) is develop to:

-Calculate the power flow solution before and after installing (SVC).

-Contingency analysis based on model analysis.

-Contingency Ranking and performance indices calculation.

4.2 Case study:

The network which has been studied is Sudanese electrical power system network. It contains of 82 bus bars, 7 synchronous generators, external grid, 15 2-winding transformers, 53 lump loads, 10 static loads,81transmission lines and 3 Static Var compensators.

Table 4.1: The statistics of the power system network components:

Number	Type	Number of units
1	External Grid	1
2	Synchronous Generator	7
3	2-Winding Transformer	15
4	Load	53
5	Shunt	10
6	Transmission line	81
7	Bus bar	82
8	Static Var Compensator	3

4.3 Power flow results:

Table 4.2 shows bus bars load flow results before installing SVC

Before installing SVC				
Bus number	Bus name	Voltage (kv)	Voltage (pu)	Angle (degree)
1	MWP500	500	100	0.0
2	ATB5	501.207	100.24	-3.7
3	MRK5	495.057	99.01	-7.5
4	KAB5	497.591	99.52	-8.2
5	WHL2	217.32	98.78	-8.9
6	WWA2	224.199	101.91	-8.2
7	DON2	224.488	102.04	-6.5
8	DBE2-DEB1	229.482	104.31	-5.3
9	DEB2-DEB2	225.354	102.43	-7.9
10	MWT2	226.71	103.05	-3.0
11	MWP2	228.25	103.75	-1.7
12	ATP2	204.044	92.75	-9.1
13	SHN2	213.564	97.07	-13.8
14	MRK2	219.803	99.91	-19.2
15	GAM2	216.633	98.47	-20.3
16	KAB2	217.989	99.09	-16.6
17	FRZ2	219.605	99.82	-16.3
18	GER2	220	100	-16.4
19	IBA2	219.107	99.59	-18.5
20	MHD2	218.739	99.43	-19.8
21	KLX2	218.662	99.39	-19.4
22	JAS2	216.357	98.34	-20.8
23	GAD2	216.821	98.55	-20.9
24	SOB2	218.26	99.21	-19.7
25	NHAS2	212.379	96.54	-23.6
26	MAR2	212.868	96.76	-24.2
27	MSH2	219.601	99.82	-20.6
28	RBK2	220	100	-20.5
29	SNJ2	216.894	98.59	-23.9
30	SNG2	220.215	100.1	-23.3

31	ROS2	220	100	-18.7
32	RNK2	221.743	100.79	-19.6
33	HWT2	222.164	100.98	-23.9
34	OBD2	219.753	99.89	-23.5
35	UMR2	221.215	100.55	-21.9
36	TND2	221.593	100.72	-21.4
37	DBT2	220.451	100.21	-24.2
38	ZBD2	220.172	100.08	-24.5
39	FUL2	220.578	100.26	-24.9
40	BBN2	221.008	100.46	-25.0
41	GDF2	222.1	100.95	-24.3
42	GRB2	221.561	100.71	-24.6
43	SHK2	222.108	100.96	-24.4
44	NHLF2	221.525	100.69	-24.7
45	ARO2	223.079	101.4	-24.9
46	KSL2	222.843	101.29	-24.9
47	HUD	219.055	99.57	-19.5
48	UTP2	222.204	101	-24.4
49	SHD2	220	100	-23.0
50	KHE1	108.179	98.34	-26.8
51	IZB1	106.438	96.76	-25.7
52	IBA1	107.226	97.48	-25.3
53	KHN1	110	100	-26.3
54	KUK1	108.472	98.61	-26.6
55	IZG1	107.955	98.14	-26.4
56	MHD1	107.232	97.48	-26.1
57	FAR1	102.906	93.55	-26.9
58	AFR1	103.735	94.3	-26.5
59	KLX1	104.558	95.05	-26.0
60	LOM1	104.525	95.02	-26.2
61	SHG1	105.233	95.67	-26.4
62	MUG	105.579	95.98	-26.6
63	BNT1	105.992	96.36	-26.5
64	OMD1	106.133	96.48	-26.5
65	GAM1	108.335	98.49	-25.5
66	JAS1	110.266	100.24	-24.7
67	BAG1	101.981	92.71	-24.0
68	SOB1-B1	103.382	94.21	-25.3

69	GAD1-B2	102.382	93.07	-23.7
70	NHAS1	114.092	103.72	-25.8
71	OHAS1	113.737	103.4	-25.9
72	GND1	113.373	103.07	-26.1
73	MAR1-B1	112.703	102.46	-26.8
74	MAN1	111.543	101.4	-27.7
75	ORBK1	111.36	101.24	-25.3
76	SNJ1	111.412	101.28	-25.2
77	HAG1	110.961	100.87	-26.5
78	SNP1	110	100	-25.2
79	MIN1	104.298	94.82	-26.2
80	FAO1	110.476	100.43	-27.3
81	GDF1	112.653	102.41	-25.9
82	GRB69	66	100	-25.3

From load flow results shown in tale (4.2), it can be noticed that there are seven buses are out of tolerance $\pm 10\%$ undervoltage condition and they are at (marginal state) which are highlighted by (violent) color and other buses are within limits.

Table (4.3) shows power flow results after installing SVC

After installing SVC				
Bus number	Bus name	Voltage (kv)	Voltage (pu)	Angle (degree)
1	MWP500	500	100	0.0
2	ATB5	508.975	101.79	-3.7
3	MRK5	496.176	99.24	-7.5
4	KAB5	498.75	99.75	-8.2
5	WHL2	217.32	98.78	-8.9
6	WWA2	224.199	101.91	-8.2
7	DON2	224.488	102.04	-6.5
8	DBE2-DEB1	229.482	104.31	-5.3
9	DEB2-DEB2	225.354	102.43	-7.9
10	MWT2	226.71	103.05	-3.0
11	MWP2	228.25	103.75	-1.7
12	ATP2	211.841	96.29	-9.1

13	SHN2	217.051	98.66	-13.8
14	MRK2	221.045	100.47	-19.2
15	GAM2	217.984	99.08	-20.3
16	KAB2	218.447	99.29	-16.6
17	FRZ2	219.775	99.9	-16.3
18	GER2	220	100	-16.4
19	IBA2	219.834	99.92	-18.5
20	MHD2	219.992	100	-19.8
21	KLX2	219.694	99.86	-19.4
22	JAS2	217.748	98.98	-20.8
23	GAD2	218.483	99.31	-20.9
24	SOB2	219.438	99.74	-19.7
25	NHAS2	214.153	97.34	-23.6
26	MAR2	214.277	97.4	-24.2
27	MSH2	219.601	99.82	-20.6
28	RBK2	220	100	-20.5
29	SNJ2	217.702	98.96	-23.9
30	SNG2	220.765	100.35	-23.3
31	ROS2	220	100	-18.7
32	RNK2	221.742	100.79	-19.6
33	HWT2	222.582	101.17	-23.9
34	OBD2	219.753	99.89	-23.5
35	UMR2	221.215	100.55	-21.9
36	TND2	221.593	100.72	-21.4
37	DBT2	220.451	100.21	-24.2
38	ZBD2	220.172	100.08	-24.5
39	FUL2	220.578	100.26	-24.9
40	BBN2	221.008	100.46	-25.0
41	GDF2	222.367	101.08	-24.3
42	GRB2	221.807	100.82	-24.6
43	SHK2	222.373	101.08	-24.4
44	NHLF2	221.772	100.81	-24.7
45	ARO2	223.329	101.51	-24.9
46	KSL2	223.092	101.41	-24.9
47	HUD	220.324	100.15	-19.5
48	UTP2	222.469	101.12	-24.4
49	SHD2	220	100	-23.0
50	KHE1	108.51	98.65	-26.8

51	IZB1	106.5	96.82	-25.7
52	IBA1	107.287	97.53	-25.3
53	KHN1	110	100	-26.3
54	KUK1	108.802	98.91	-26.6
55	IZG1	108.282	98.44	-26.4
56	MHD1	107.775	97.98	-26.1
57	FAR1	106.769	97.06	-26.9
58	AFR1	106.373	96.7	-26.5
59	KLX1	106.233	96.58	-26.0
60	LOM1	106.111	96.46	-26.2
61	SHG1	106.576	96.89	-26.4
62	MUG	106.625	96.93	-26.6
63	BNT1	106.934	97.21	-26.5
64	OMD1	106.922	97.2	-26.5
65	GAM1	109.234	99.3	-25.5
66	JAS1	111.407	101.28	-24.7
67	BAG1	106.992	97.27	-24.0
68	SOB1-B1	106.51	96.83	-25.3
69	GAD1-B2	106.97	97.25	-23.7
70	NHAS1	115.467	104.97	-25.8
71	OHAS1	115.156	104.69	-25.9
72	GND1	114.798	104.36	-26.1
73	MAR1-B1	113.483	103.17	-26.8
74	MAN1	112.335	102.12	-27.7
75	ORBK1	111.428	101.3	-25.3
76	SNJ1	111.479	101.34	-25.2
77	HAG1	111.458	101.33	-26.5
78	SNP1	110	100	-25.2
79	MIN1	104.298	94.82	-26.2
80	FAO1	111.089	100.99	-27.3
81	GDF1	112.857	102.6	-25.9
82	GRB69	66	100	-25.3

From load flow results shown in table 4.3 it can be noticed that after installing SVC there is only one bus out is of tolerance $\pm 10\%$ undervoltage condition and all other buses are within limits. SVC enhance bus voltage and which can be noticeable in figure 4.1 which describes the effect of SVC on the grid, the voltage difference in (pu) is shown in table 4.4.

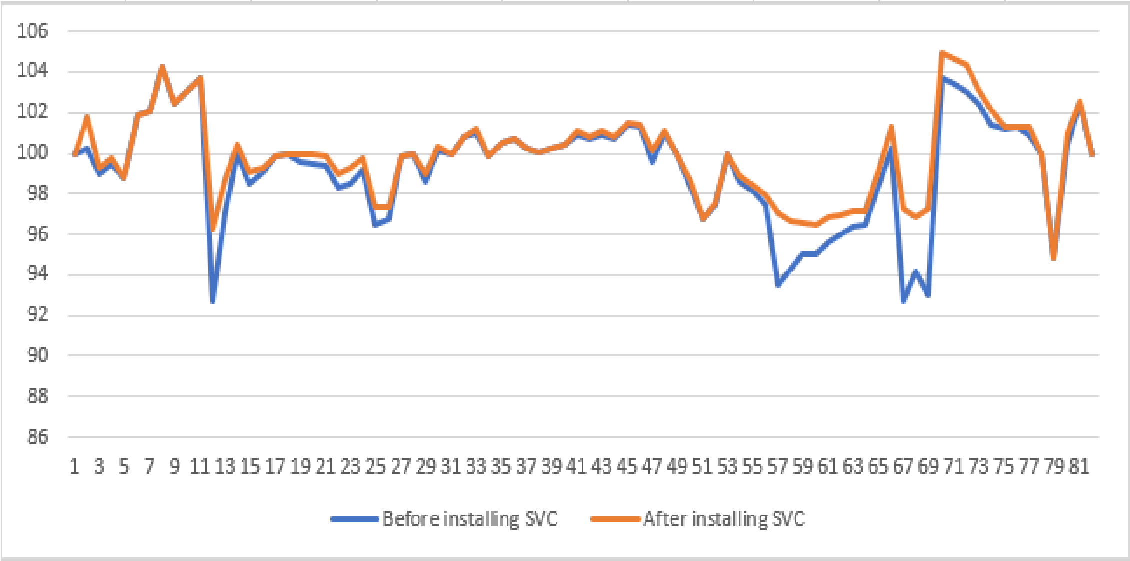

Figure 4.1 shows bus voltage results before and after installing SVC

Table 4.4 shows bus voltage difference (pu) before and after installing SVC

Bus number	Bus name	Voltage before installing SVC (pu)	Voltage Difference (pu)	Voltage after installing SVC (pu)
1	MWP500	100	0	100
2	ATB5	100.24	1.554	101.79
3	MRK5	99.01	0.224	99.24
4	KAB5	99.52	0.232	99.75
5	WHL2	98.78	0	98.78
6	WWA2	101.91	0	101.91
7	DON2	102.04	0	102.04
8	DBE2-DEB1	104.31	0	104.31
9	DEB2-DEB2	102.43	0	102.43
10	MWT2	103.05	0	103.05

11	MWP2	103.75	0	103.75
12	ATP2	92.75	3.544	96.29
13	SHN2	97.07	1.585	98.66
14	MRK2	99.91	0.564	100.47
15	GAM2	98.47	0.614	99.08
16	KAB2	99.09	0.209	99.29
17	FRZ2	99.82	0.078	99.9
18	GER2	100	0	100
19	IBA2	99.59	0.33	99.92
20	MHD2	99.43	0.569	100
21	KLX2	99.39	0.469	99.86
22	JAS2	98.34	0.632	98.98
23	GAD2	98.55	0.755	99.31
24	SOB2	99.21	0.535	99.74
25	NHAS2	96.54	0.806	97.34
26	MAR2	96.76	0.64	97.4
27	MSH2	99.82	0	99.82
28	RBK2	100	0	100
29	SNJ2	98.59	0.367	98.96
30	SNG2	100.1	0.25	100.35
31	ROS2	100	0	100
32	RNK2	100.79	0	100.79
33	HWT2	100.98	0.19	101.17
34	OBD2	99.89	0	99.89
35	UMR2	100.55	0	100.55
36	TND2	100.72	0	100.72
37	DBT2	100.21	0	100.21
38	ZBD2	100.08	0	100.08
39	FUL2	100.26	0	100.26

40	BBN2	100.46	0	100.46
41	GDF2	100.95	0.121	101.08
42	GRB2	100.71	0.112	100.82
43	SHK2	100.96	0.12	101.08
44	NHLF2	100.69	0.112	100.81
45	ARO2	101.4	0.113	101.51
46	KSL2	101.29	0.113	101.41
47	HUD	99.57	0.577	100.15
48	UTP2	101	0.12	101.12
49	SHD2	100	0	100
50	KHE1	98.34	0.301	98.65
51	IZB1	96.76	0.057	96.82
52	IBA1	97.48	0.056	97.53
53	KHN1	100	0	100
54	KUK1	98.61	0.3	98.91
55	IZG1	98.14	0.298	98.44
56	MHD1	97.48	0.494	97.98
57	FAR1	93.55	3.513	97.06
58	AFR1	94.3	2.398	96.7
59	KLX1	95.05	1.522	96.58
60	LOM1	95.02	1.441	96.46
61	SHG1	95.67	1.221	96.89
62	MUG	95.98	0.952	96.93
63	BNT1	96.36	0.856	97.21
64	OMD1	96.48	0.718	97.2
65	GAM1	98.49	0.817	99.3
66	JAS1	100.24	1.037	101.28
67	BAG1	92.71	4.556	97.27
68	SOB1-B1	94.21	2.615	96.83

69	GAD1-B2	93.07	4.171	97.25
70	NHAS1	103.72	1.25	104.97
71	OHAS1	103.4	1.29	104.69
72	GND1	103.07	1.295	104.36
73	MAR1-B1	102.46	0.71	103.17
74	MAN1	101.4	0.72	102.12
75	ORBK1	101.24	0.062	101.3
76	SNJ1	101.28	0.061	101.34
77	HAG1	100.87	0.451	101.33
78	SNP1	100	0	100
79	MIN1	94.82	0	94.82
80	FAO1	100.43	0.557	100.99
81	GDF1	102.41	0.186	102.6
82	GRB69	100	0	100

4.4 Contingency analysis results:

contingency analysis is studied for equipment outage (bus outage, generator outage, transformer outage and transmission line outage). For simplicity ten buses and ten transmission lines have been chosen which are the most sever. The outage effects on voltage profile taken before and after installing SVC and performance indexes have been calculated and ranked.

4.4.1 Bus outage results:

Ten buses have been chosen for outage, the effect on voltage profile of those buses outage before and after installing SVC is shown in table 4.5 and 4.6 respectively, performance indexes calculated and ranked according to (V/V_{SP}) descending ranking before and after installing SVC is shown in table 4.7 and 4.8 respectively.

Table 4.5 shows the effect of bus outage on voltage profile before installing SVC

N-1 Before installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Bus number	Bus name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	MWP500	No	0	0	0	0
3	MRK5	No	0	0	0	0
12	ATP2	Yes	1	0	0	0
53	KHN1	No	0	0	0	0
57	FAR1	Yes	1	0	0	0
58	AFR1	Yes	2	0	0	0
67	BAG1	Yes	1	0	0	0
68	SOB1-B1	Yes	1	0	0	0
69	GAD1-B2	Yes	1	0	0	0
79	MIN1	Yes	1	0	0	0

From table 4.5 it can be noticed that bus 1 outage can lead to blackout because it is the slack bus also buses 3 and 53 outage can lead to load flow results is not converge, all buses have at least one critical undervoltage condition which refer to the bus outage itself , voltage violation equals to bus voltage value in (pu), bus 58 has two critical undervoltage condition which its outage leads bus 57 to be out.

Table 4.6 shows the effect of bus outage on voltage profile after installing SVC

N-1 After installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Bus number	Bus name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	MWP500	No	0	0	0	0
3	MRK5	No	0	0	0	0
12	ATP2	Yes	1	0	0	0
53	KHN1	No	0	0	0	0
57	FAR1	Yes	1	0	0	0
58	AFR1	Yes	2	0	0	0
67	BAG1	Yes	1	0	0	0
68	SOB1-B1	Yes	1	0	0	0
69	GAD1-B2	Yes	1	0	0	0
79	MIN1	Yes	1	0	0	0

From table 4.6 it can be noticed that bus 1 outage can lead to blackout because it is the slack bus also buses 3 and 53 outage can lead to load flow results is not converge, all buses have at least one critical undervoltage condition which refer to the bus outage itself , voltage violation equals to bus voltage value in (pu), bus 58 has two critical undervoltage condition which its outage leads bus 57 to be out.

Performance indexes calculation:

Table 4.7 shows performance indexes for buses before installing SVC

N-1 Before installing SVC		Performance index Before installing SVC			
Bus number	Bus name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	MWP500	98.65944	1	1	0
53	KHN1	14.65961	10.51187	15.29676	19.74158
3	MRK5	2.572534	1857692	3.651374	3.861667

58	AFR1	2.152587	5.903805	0.038656	0.764751
79	MIN1	1.09637	0.080394	0.016585	0.825632
68	SOB1-B1	1.085105	0.024963	0.41377	0.795378
57	FAR1	1.067973	3.371307	0.028916	0.773023
69	GAD1-B2	1.061368	1.677012	0.090569	0.832695
12	ATP2	1.051808	0.268659	0.102882	0.842238
67	BAG1	1.048673	0.294113	0.044396	0.764448

Form table 4.7 it can be noticed that bus 1 has the greatest V/V_{SP} value and is the most sever bus because it is the slack bus and the ranking has been taken according to V/V_{SP} descending also the lowest V/V_{SP} value is bus 67 and it has the lowest effect.

Table 4.8 shows performance indexes for buses after installing SVC

N-1 After installing SVC		Performance index After installing SVC			
Bus number	Bus name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	MWP500	99.83643	1	1	0
53	KHN1	15.22548	1.502684	54.31559	22.78689
3	MRK	2.701768	1848113	11.44309	7.295102
58	AFR1	2.296483	0.138577	1.59973	1.084122
69	GAD-B2	1.170378	0.427068	3.769456	1.685238
68	SOB1-B1	1.164349	0.051285	3.308965	1.263833
67	BAG1	1.161122	0.067477	1.962	1.130723
57	FAR1	1.156684	0.074382	1.864611	1.130987
12	ATP2	1.1436	0.171253	4.880467	1.610309
79	MIN1	1.108798	0.06803	3.697988	1.587214

Form table 4.7 it can be noticed that bus 1 has the greatest V/V_{SP} value and is the most sever bus because it is the slack bus and the ranking has been taken according to V/V_{SP} descending also the lowest V/V_{SP} value is bus 79 and it has the lowest effect.

Comparison between results in table 4.7 and 4.8:

From table 4.7 and 4.8 it can be noticed that at the same cases bus 1 is the most severe then bus 3 and bus 53 because they have not converge results bus 67 is the lowest ranking value before SVC and bus 79 has the lowest ranking value after SVC, also the difference between ranking value is not too much this can be noticed from figure 4.2. this study can be more valuable in case of scheduled outage.

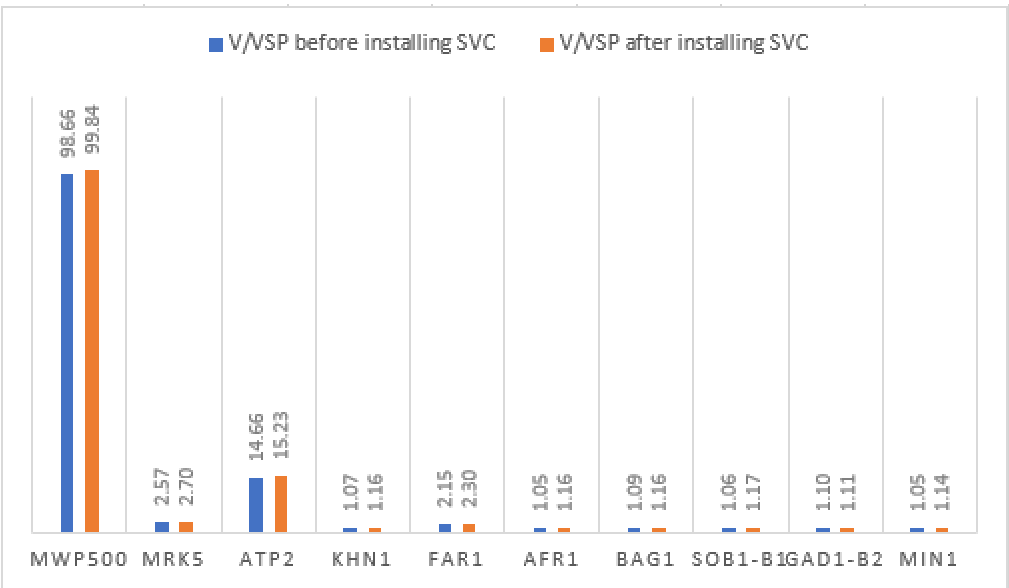

Figure 4.2 shows the value of V/V_{SP} before and after SVC

4.4.2 Generator outage:

the effect of generator outages on voltage profile and performance indexes calculation are shown in table 4.9, 4.10,4.11 and 4.12 before and after SVC respectively.

Table 4.9 shows the effect of generator outage on voltage profile before SVC

N-1 Before SVC			No.of undervoltage buses		No.of overvoltage buses	
Generator number	Generator name	Conv-rge	Critical	Marginal	Critical	Marginal
1	Gen 18	Yes	0	0	0	0
2	Gen 28	Yes	0	0	0	0
3	Gen 31	Yes	0	0	0	0
4	Gen 49	Yes	0	0	0	0
5	Gen 53	Yes	39	7	0	0
6	Gen 78	Yes	0	0	0	0
7	Gen 82	Yes	0	0	3	8

from table 4.9 it can be noticed that Gen 53 outage causes 39 buses to be critical under voltage condition and 7 buses on marginal undervoltage condition so it is most sever generator also Gen 82 outage cases 3 buses to be critical overvoltage condition and 8 buses to be marginal over voltage condition and the others outage does not affect voltage profile.

Table 4.10 shows the effect of generator outage on voltage profile after SVC

N-1 After SVC			No. of undervoltage buses		No. of overvoltage buses	
Generator number	Generator name	Conv-rge	Critical	Marginal	Critical	Marginal
1	Gen 18	Yes	0	0	0	0
2	Gen 28	Yes	0	0	0	0
3	Gen 31	Yes	0	0	0	0

4	Gen 49	Yes	0	0	0	0
5	Gen 53	Yes	9	13	0	0
6	Gen 78	Yes	0	0	0	0
7	Gen 82	Yes	0	0	6	5

From table 4.10 it can be noticed that Gen 53 outage causes 9 buses to be critical undervoltage condition and 13 buses on marginal undervoltage condition so it is most sever generator also Gen 82 outage cases 6 buses to be critical overvoltage condition and 5 buses to be marginal over voltage condition and the others outage does not affect voltage profile.

Comparison between results in table 4.9 and 4.10:

It can be obviously noticed that the outage of Gen 53 affected the voltage profile of the grid before and after SVC the number of buses affected to critical condition is 39 before SVC and 9 after SVC, hence it is less danger when using SVC, so the SVC had embedded the contingency outage in the grid and this can be shown in figure 4.4

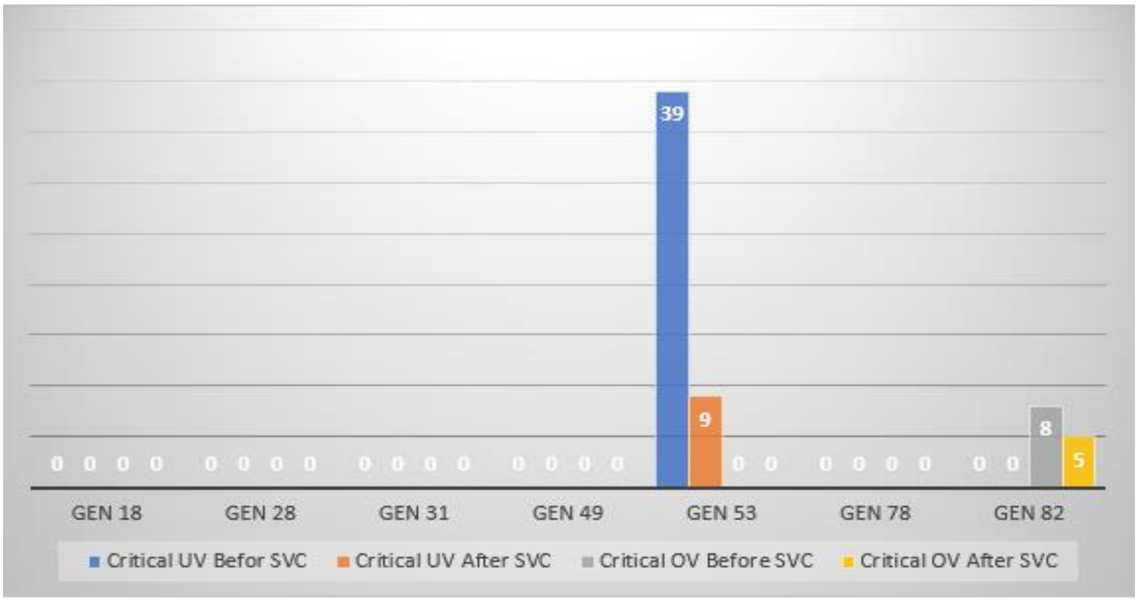

Figure 4.4 shows the effects of generator outage before and after SVC

Performance indexes calculation:

Table 4.11 shows the performance indexes before SVC

N-1 Before SVC		Performance index			
Generator number	Generator name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	Gen 53	2.941768	52.55804	6.609698	1.757384
2	Gen 82	0.167433	0.019771	1.00812	1.134075
3	Gen 18	0.014132	0.886733	0.205505	0.963409
4	Gen 28	0.008044	1.557588	0.126324	0.817863
5	Gen 78	0.005954	0.008363	0.034214	0.786199
6	Gen 49	0.00279	0.334861	0.051149	0.897957
7	Gen 31	0.001444	4.890996	0.158021	1.059433

From table 4.11 it can be noticed that Gen 53 has the greatest value of V/V_{SP} so it is the most sever and Gen 31 has the lowest V/V_{SP} effect on voltage profile.

Table 4.12 shows the performance indexes after SVC

N-1 After SVC		Performance index			
Generator number	Generator name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	Gen 53	0.295228	1.130353	39.46619	15.20285
2	Gen 82	0.179547	0.02011	1.570693	1.181648
3	Gen 18	0.013439	0.171247	1.423582	0.857688
4	Gen 28	0.008533	0.005922	0.122252	0.788579
5	Gen 78	0.003344	0.074657	0.118382	0.896603

6	Gen 49	0.003014	0.188815	0.466137	0.940066
7	Gen 31	0.001611	0.50694	0.529466	1.044336

From table 4.11 it can be noticed that Gen 53 has the greatest value of V/V_{SP} so it is the most sever and Gen 31 has the lowest V/V_{SP} effect on voltage profile.

4.4.3 Transformers outage:

The effect of transformer outages on voltage profile and performance indexes calculation are shown in table 4.13, 4.14,4.15 and 4.16 before and after SVC respectively.

Table 4.13 shows the effect of transformer outage on voltage profile before SVC

N-1 Before installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Transf. number	Transf. name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	T 01-11	Yes	7	0	0	0
2	T 02-12	Yes	0	0	0	0
3	T 03-14	Yes	0	1	0	0
4	T 04-16	Yes	0	0	0	0
5	T 15-65	Yes	0	0	0	0
6	T 21-59	Yes	0	0	0	0
7	T 22-66	Yes	0	1	0	0
8	T 23-69	Yes	0	0	0	0
9	T 25-70	Yes	3	0	0	0
10	T 26-73	Yes	2	2	0	0
11	T 29-76	Yes	0	0	0	0

12	T 41-81	Yes	2	0	0	0
13	T 42-82	Yes	1	0	3	8
14	T 52-19	Yes	0	0	0	0
15	T 56-20	Yes	0	0	0	0

From table 4.13 it can be noticed that T 01-11 outage causes 7 buses to be critical undervoltage condition and then transformer T 03-14 outage causes 1 bus to be marginal undervoltage condition also T 25-70 outage leads 3 buses to be critical undervoltage condition, T 26-73 outage causes 2 critical and 2 marginal undervoltage conditions, T 42-82 causes 1 critical undervoltage condition, 3 critical and 8 marginal overvoltage conditions.

Table 4.14 shows the effect of transformer outage on voltage profile after SVC

N-1 After installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Transf. number	Transf. name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	T 01-11	Yes	7	0	0	0
2	T 02-12	Yes	0	0	0	0
3	T 03-14	Yes	0	0	0	0
4	T 04-16	Yes	0	0	0	0
5	T 15-65	Yes	0	0	0	0
6	T 21-59	Yes	0	0	0	0
7	T 22-66	Yes	0	0	0	0
8	T 23-69	Yes	0	0	0	0
9	T 25-70	Yes	3	0	0	0
10	T 26-73	Yes	1	3	0	0
11	T 29-76	Yes	0	0	0	0
12	T 41-81	Yes	2	0	0	0

13	T 42-82	Yes	1	0	2	9
14	T 52-19	Yes	0	0	0	0
15	T 56-20	Yes	0	0	0	0

From table 4.14 it can be noticed that T 01-11 outage causes 7 buses to be critical undervoltage condition and then transformer T 03-14 outage causes no voltage profile effect also T 25-70 outage leads 3 buses to be critical undervoltage condition, T 26-73 outage causes 1 critical and 3 marginal undervoltage conditions, T 42-82 causes 1 critical undervoltage condition, 2 critical and 9 marginal overvoltage conditions.

Comparison between table 4.13 and 4.14:

From table 4.13 and table 4.14 it can be noticed that T 01-11 outage causes 7 buses to be critical undervoltage condition at the same cases before and after SVC also the number of critical cases is before SVC is more than after SVC.

Performance index calculation:

Table 4.15 shows the performance indexes calculation for transformers outage before SVC

N-1 before SVC		Performance index			
Transformer number	Transformer Name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	T 01-11	8.602272	0.082474	0.082474	0.453176
2	T 42-82	1.469191	0.086669	1.247239	0.445613
3	T 41-81	0.271316	0.649794	0.314571	0.463832
4	T 25-70	0.169238	1.020256	2.001295	0.461798
5	T 03-14	0.11753	4.994238	0.390611	1.166012
6	T 26-73	0.112694	1.166019	1.461346	0.460881
7	T 22-66	0.089034	46.42044	0.343091	0.451775

8	T 15-65	0.087915	388.4933	0.626043	0.466257
9	T 04-16	0.08165	2.129903	0.871659	0.432718
10	T 52-19	0.077941	296.0114	0.152938	0.424714
11	T 29-76	0.074841	0.480461	0.088265	0.454165
12	T 56-20	0.073816	686.5692	0.028122	0.491627
13	T 02-12	0.073734	0.823582	0.198008	0.481483
14	T 23-69	0.069431	0.38224	0.312716	0.45257
15	T 21-59	0.069315	77.68152	0.228581	0.429033

From table 4.15 it can be noticed that T 01-11 has the greatest V/V_{SP} value so it is the most sever and T 21-59 has the lowest V/V_{SP} value so it has the lowest effect on voltage profile.

Table 4.15 shows the performance indexes calculation for transformers outage after SVC

N-1 before SVC		Performance index			
Transformer number	Transformer Name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	T 01-11	8.940485	0.082474	0.082474	0.758286
2	T 42-82	1.380277	0.044722	1.901799	1.300038
3	T 41-81	0.201816	0.588148	0.331233	1.613541
4	T 25-70	0.103549	0.581162	6.271185	1.150414
5	T 26-73	0.057762	1.007387	2.316947	1.394323
6	T 03-14	0.015181	1.928833	1.367783	1.641239
7	T 22-66	0.00546	1.118695	4.262204	2.047737
8	T 15-65	0.004397	6.966852	13.92314	9.208984
9	T 04-16	0.003081	0.430882	6.061524	1.08886
10	T 02-12	0.002077	0.347211	1.104758	0.910405

11	T 29-76	0.001841	0.407405	0.204489	0.872002
12	T 52-19	0.001328	6.111347	2.987786	5.475775
13	T 23-69	0.000486	0.160891	1.838145	0.866559
14	T 21-59	0.000414	3.08639	2.386069	2.083212
15	T 56-20	8.25E-05	12.16782	0.794772	10.46958

From table 4.15 it can be noticed that T 01-11 has the greatest V/V_{SP} value so it is the most sever and T 56-20 has the lowest V/V_{SP} value so it has the lowest effect on voltage profile.

Comparison between table 4.15 and 4.16:

From table 4.15 and 4.16 it can be noticed that T 01-11 has the same ranking before and after SVC so it is the most sever both cases the lowest effect on voltage profile are T 21-59 and T56-20 before and after SVC respectively. this study can be more valuable in case of scheduled outage.

4.4.4 Transmission line outage:

The effect of transmission lines outages on voltage profile and performance indexes calculation are shown in table 4.17, 4.18,4.19 and 4.20 before and after SVC respectively.

Table 4.17 shows the effect of transmission lines outage on voltage profile before SVC

N-1 Before installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Line number	Line name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	L 01-03	No	0	0	0	0
2	L 06-09	Yes	2	0	0	0
3	L 08-09	Yes	4	0	0	0

4	L 10-11	No	0	0	0	0
5	L 28-36	Yes	7	0	0	0
6	L 34-35	Yes	5	0	0	0
7	L 34-37	Yes	4	0	0	0
8	L 35-36	Yes	6	0	0	0
9	L 37-38	Yes	3	0	0	0
10	L 38-39	Yes	2	0	0	0

From table 4.17 it can be noticed that L 01-03 and L 10-11 are the most sever because their outage causes load flow results to be not converge L 28-36 is the most sever because it causes 7 buses to be critical undervoltage condition and L 08-09 has 4 critical under voltage conditions.

Table 4.18 shows the effect of transmission lines outage on voltage profile after SVC

N-1 After installing SVC			No. of undervoltage buses		No. of overvoltage buses	
Line number	Line name	Converge (yes/no)	Critical	Marginal	Critical	Marginal
1	L 01-03	No	0	0	0	0
2	L 06-09	Yes	2	0	0	0
3	L 08-09	Yes	3	1	0	0
4	L 10-11	No	0	0	0	0
5	L 28-36	Yes	7	0	0	0
6	L 34-35	Yes	5	0	0	0
7	L 34-37	Yes	4	0	0	0
8	L 35-36	Yes	6	0	0	0
9	L 37-38	Yes	3	0	0	0
10	L 38-39	Yes	2	0	0	0

From table 4.17 it can be noticed that L 01-03 and L 10-11 are the most sever because their outage causes load flow results to be not converge L 28-36 is the most sever because it causes 7 buses to be critical undervoltage condition and L 08-09 has 3 critical under voltage conditions.

Performance index calculation:

Table 4.19 shows the performance indexes calculation for transmission lines outage before SVC

N-1 Before installing SVC		Performance index Before installing SVC			
Line number	Line name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	L 28-36	8.589636	0.538222	0.079082	0.813026
2	L 35-36	7.352404	0.516742	0.069469	0.813698
3	L 34-35	6.119379	0.44277	0.062063	0.811192
4	L 10-11	6.076374	27.26797	37.3316	4.641294
5	L 34-37	4.903142	0.143253	0.083659	0.796937
6	L 37-38	3.678107	0.083955	0.035905	0.792624
7	L 06-09	2.460236	0.022755	0.110359	0.806291
8	L 38-39	2.459764	0.05606	0.136106	0.825937
9	L 01-03	1.377789	1546169	3.399024	3.96884
10	L 08-09	0.108218	0.077743	0.800016	0.996749

From table 4.19 it can be noticed that L 28-36 has the greatest value of V/V_{SP} so it is the most sever on voltage profile and L 08-09 has the lowest value of V/V_{SP} so it has the lowest effect on voltage profile.

Table 4.19 shows the performance indexes calculation for transmission lines outage after SVC

N-1 After installing SVC		Performance index After installing SVC			
Line number	Line name	V/V_{SP}	ΔP	ΔQ	S/S_{SP}
1	L 28-36	8.589633	0.120042	0.110746	0.825477
2	L 35-36	7.352402	0.117404	0.099641	0.825862
3	L 34-35	6.119377	0.10688	0.087249	0.822337
4	L 10-11	6.078277	62.77034	37.87906	4.757994
5	L 34-37	4.903142	0.057792	0.089803	0.802527
6	L 37-38	3.678107	0.043562	0.03877	0.79646
7	L 06-09	2.460236	0.022755	0.110359	0.806291
8	L 38-39	2.459764	0.033452	0.137698	0.828804
9	L 01-03	1.34887	1484984	5.202187	6.979353
10	L 08-09	0.108261	0.077754	0.800336	0.996795

From table 4.19 it can be noticed that L 28-36 has the greatest value of V/V_{SP} so it is the most sever on voltage profile and L 08-09 has the lowest value of V/V_{SP} so it has the lowest effect on voltage profile.

Comparison between tables 4.17, 4.18 ,4.19 and 4.20:

From table 4,17 and 4.18 it can be noticed that the only difference is that L 08-09 has 4 critical under voltage conditions before SVC and 3 critical undervoltage conditions after SVC. From table 4.19 and 4.20 we notice that the lines have nearly the same V/V_{SP} values.

4.5 Overall discussion on results:

From power flow results before and after installing SVC it can be noticed that SVC enhance the buses voltage to be within limits, performance indexes have a different ranking before and after installing SVC. The most affected outages on voltage profile are bus (KHN1), bus (MRK5), generator (Gen 53), transformer (T 01-11), and transmission line (L 01-03) respectively.

CHAPTER FIVE

CONCLUSION AND RECOMENFATIONS

5.1 Conclusion:

Contingency analysis for single outage (N-1) has been performed for Sudanese National Grid (SNG). The outages study performed for 10 buses, 10 transmission lines which are the most sever, 7 synchronous generators and 15 transformers, performance indexes for contingency analysis have been calculated and ranked according to V/V_{SP} index which describes the change in voltage profile (voltage violation) before and after outage. The study performed in two cases before and after installing SVC.

The outages without using SVC affected Sudanese National Grid (SNG) and lead to a very dangerous critical voltage violation of bus bars.

SVC enhance Sudanese National Grid (SNG) against outage and decrease the voltage violation of bus bars so it has successfully embedded contingency outages.

The most affected outages on voltage profile are bus (KHN1), bus (MRK5), generator (Gen 53), transformer (T 01-11), and transmission line (L 01-03) respectively.

Recommendations:

1. Study the effect of double contingency outage (N-2).

2. The enhancement can be done using other FACTS devices such as (Thyristor -controlled series capacitors (TCSC), Unified power flow controlled (UBFC), etc.)

3. The study can be expanded to include more buses, more transmission lines or maybe includes the whole grid.

4. The effect of outages can perform to the effects on active power (MW), reactive power (MVAr) and losses.

5. contingency selection can be ranked using other performance indexes such as (active power ΔP , reactive power ΔQ , etc.)

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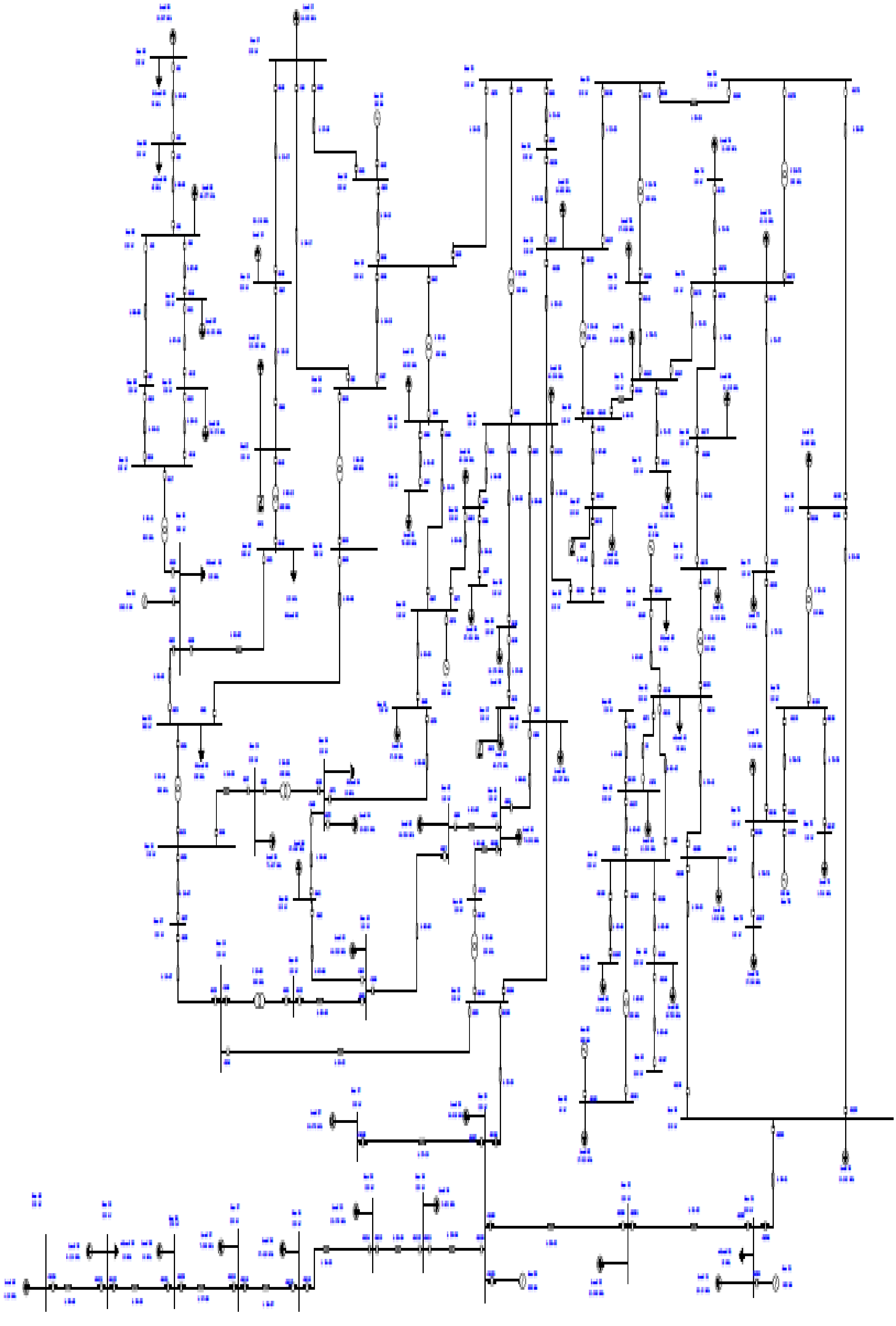
APPENDIX (A)



APPENDIX (B)

System Data:

B.1 Bus Data:

Bus No.	Bus Name	Bus Type	Voltage (KV)	Pg. (MW)	Qg. (MVAr)	Injected power MVAr
1	MWP500	Slack	500	0	0	-125
2	ATB5	Load	500	0	0	-125
3	MRK5	Load	500	0	0	-250
4	KAB5	Load	500	0	0	0
5	WHL2	Load	220	0	0	-30
6	WWA2	Load	220	0	0	-40
7	DEB2-B1	Load	220	0	0	0
8	DEB2-B2	Load	220	0	0	0
9	DON2	Load	220	0	0	0
10	MWT2	Load	220	0	0	0
11	MWP2	Load	220	0	0	0
12	ATB2	Load	220	0	0	0
13	SHN2	Load	220	0	0	0
14	MRK2	Load	220	0	0	0
15	GAM2	Load	220	0	0	0
16	KAB2	Load	220	0	0	0
17	FRZ2	Load	220	0	0	0
18	GER2	Regulated	220	186	0	0
19	IBA2	Load	220	0	0	0
20	MHD2	Load	220	0	0	0

21	KLX2	Load	220	0	0	0
22	JAS2	Load	220	0	0	0
23	GAD2	Load	220	0	0	0
24	SOB2	Load	220	0	0	0
25	NHAS2	Load	220	0	0	0
26	MAR2	Load	220	0	0	0
27	MSH2	Load	220	0	0	0
28	RBK2	Regulated	220	85	0	0
29	SNJ2	Load	220	0	0	0
30	SNG2	Load	220	0	0	0
31	ROS2	Regulated	220	148	0	-15
32	RNK2	Load	220	0	0	0
33	HWT2	Load	220	0	0	0
34	OBD2	Load	220	0	0	0
35	UMR2	Load	220	0	0	0
36	TND2	Load	220	0	0	0
37	DBT2	Load	220	0	0	0
38	ZBD2	Load	220	0	0	0
39	FUL2	Load	220	0	0	-15
40	BBN2	Load	220	0	0	0
41	GDF2	Load	220	0	0	-30
42	GRB2	Load	220	0	0	0
43	SHK2	Load	220	0	0	0
44	NHLF2	Load	220	0	0	0
45	ARO2	Load	220	0	0	0
46	KSL2	Load	220	0	0	0
47	HUD	Load	220	0	0	0
48	UTP2	Load	220	0	0	0
49	SHD2	Regulated	220	38	0	-30

50	KHE1	Load	110	0	0	0
51	IZB1	Load	110	0	0	0
52	IBA1	Load	110	0	0	0
53	KHN1	Regulated	110	76	0	0
54	KUK1	Load	110	0	0	0
55	IZG1	Load	110	0	0	0
56	MHD1	Load	110	0	0	15
57	FAR1	Load	110	0	0	0
58	AFR1	Load	110	0	0	0
59	KLX1	Load	110	0	0	0
60	LOM1	Load	110	0	0	0
61	SHG1	Load	110	0	0	0
62	MUG	Load	110	0	0	0
63	BNT1	Load	110	0	0	0
64	OMD1	Load	110	0	0	0
65	GAM1	Load	110	0	0	0
66	JAS1	Load	110	0	0	0
67	BAG1	Load	110	0	0	0
68	SOB1-B2	Load	110	0	0	0
69	GAD1-B2	Load	110	0	0	0
70	NHAS1	Load	110	0	0	0
71	OHAS1	Load	110	0	0	0
72	GND1	Load	110	0	0	0
73	MAR1-B1	Load	110	0	0	0
74	MAN1	Load	110	0	0	0
75	ORBK1	Load	110	0	0	0
76	SNJ1	Load	110	0	0	0
77	HAG1	Load	110	0	0	0
78	SNP1	Regulated	110	7	0	0

79	MIN1	Load	110	0	0	0
80	FAO1	Load	110	0	0	0
81	GDF1	Load	110	0	0	0
82	GRB66	Regulated	66	2	0	0

B.2 Transmission Lines Data:

From	To	voltage KV	R1 Ω/km	X1 Ω/km	B/2 μS/km
BAG1	GAD B2	110	1.044000	1.2630000	8.107400000
WHL2	WWA2	220	13.73500	61.910000	840.9090900
MWP2	MWT2	220	2.625700	13.923660	97.93388000
DON2	DEB2 B1	220	10.59287	56.170140	394.6281000
ATB 2	SHN2	220	4.690000	21.140000	1148.760331
MWT2	DEB2 B1	220	10.57158	56.057320	394.6281000
MWP2	DEB2 B2	220	13.21260	70.061570	491.7355400
DON2	WWA2	220	5.561010	22.327020	1361.570250
DON2	DEB2 B2	220	10.59287	56.170140	394.6281000
ATB5	MWB500	500	6.627500	65.329250	972.0000000
MWB500	MRK5	500	4.844000	47.748000	2844.000000
KAB5	MRK5	500	1.030500	10.156750	151.2000000
SHN2	FRZ2	220	3.852500	15.467480	944.2148800
GER2	FRZ2	220	0.167510	0.6725200	41.11570000
KAB2	IBA2	220	1.004980	4.5300000	245.8677700
IBA1	IZB1	110	0.368500	1.4795000	90.08264000
KUK1	KHE1	110	0.107210	0.4304000	26.28099000
KHN1	IBA1	110	0.402000	1.6140000	98.34711000
IZG1	MHD1	110	0.268000	1.0760000	65.61983500
KUK1	KHN1	110	0.086390	0.6795000	26.85850000
KHN1	IZG1	110	0.402000	1.6140000	98.34710000
MRK2	MHD2	220	0.703500	2.8245000	192.3014000
KLX1	AFR1	110	0.368500	1.4795000	90.08644000
AFR1	FAR1	110	0.469000	1.8830000	114.8760000
KLX1	KUK1	110	0.635100	2.7667000	86.77685000

KLX1	LOM1	110	0.100500	0.4035000	24.62800000
LOM1	SHG1	110	0.261300	1.8491000	63.96690000
SHG1	MUG	110	0.368510	1.4795000	90.08260000
MUG	BNT1	110	0.511104	0.5111040	31.15728000
OMD1	BNT1	110	0.197650	0.7935500	48.42970000
MHD1	OMD1	110	0.311550	1.2555000	76.28000000
GAM1	BNT1	110	0.552750	2.2192500	135.5370000
KLX2	SOB2	220	0.379900	2.0150000	56.61151000
SOB2	GAD2	220	1.254000	6.6494800	186.9834000
SOB1 B2	BAG1	110	6.264000	7.5844000	48.59500000
KLX1	SOB1 B2	110	3.480000	4.2100000	27.02400000
SHG1	JAS1	110	1.306500	5.2455000	319.8347000
GAD2	JAS2	220	1.205900	4.8419800	295.4545000
GAD2	NHAS2	220	3.268000	17.328990	487.6033000
GAD B2	OHAS1	110	26.79600	32.417000	208.2644000
OHAS1	NHAS1	110	0.167500	0.6725060	40.99173000
OHAS1	GND1	110	0.502500	2.0175060	123.1405000
OHAS1	MAR1 B1	110	19.14000	23.154990	148.7603000
JAS2	RBK2	220	4.94793	19.865600	1212.809000
MSH2	RBK2	220	3.59118	14.418408	808.1652000
NHAS2	MAR2	220	2.09000	11.082480	311.9834000
MAN1	MAR1 B1	110	6.85650	18.871705	198.3470000
MAR2	SNJ2	110	3.19198	16.926012	475.2066000
MAR1 B1	HAG1	110	12.1800	14.735000	94.21488000
HAG1	SNP1	110	20.8800	25.259990	161.9835000
ORBK1	SNJ1	110	33.4080	40.415990	259.5041300
SNP1	MIN1	110	24.0120	29.049000	186.7768600
MAR1 B1	FAO1	110	24.7080	29.891005	191.7355000
SNJ2	SNG2	220	1.90000	10.074990	283.0578000

SNG2	ROS2	220	6.76400	35.867013	1008.264400
ROS2	RNK2	220	4.69001	18.830020	1148.760331
SNG2	HWT2	220	3.01498	12.104900	737.6033000
ABK2	TND2	220	3.71852	14.929510	911.1570000
UMR2	OBD2	220	8.44198	33.893987	516.5289200
SNJ1	SNB1	110	3.47990	4.2100000	27.02420000
OBD2	DBT2	220	5.96298	23.941010	365.7020000
OBT2	ZBD2	220	4.42202	17.753990	270.6612000
ZBD2	FUL2	220	7.97298	32.010980	487.6033100
FUL2	BBN2	220	5.29302	21.250988	324.3802000
TND2	UMR2	220	2.62304	10.531356	642.5619000
RBK2	RNK2	220	5.460488	21.923500	1336.776800
HWT2	GDF2	220	3.350000	13.450000	820.2479400
GRB2	KSL2	220	3.182490	12.777500	778.9256000
GDF2	SHK2	220	0.276220	1.1089000	67.56100000
SHK2	GRB2	220	2.344980	9.4150100	574.3800000
GRB2	NHLF2	220	1.637130	6.5730100	400.8264500
KSL2	ARO2	220	1.465940	5.8857000	359.5041000
MRK2	HUD	220	0.301480	1.2104800	73.76733000
HUD	GAM2	220	0.937990	3.7660000	229.3388000
KAB2	FRZ2	220	1.273017	5.1109900	311.9835000
SHK2	UTP2	220	0.937990	3.7660000	229.3388400
GER2	IBA2	220	2.010000	8.0700200	491.7355000
IBA2	KLX2	220	0.468990	1.8830020	114.8760300
GDF2	SHD2	220	6.499000	26.093020	1592.975200
GDF1	FAO1	110	53.24400	60.740990	430.5785100
JAS2	GAM2	220	0.937990	4.2279800	229..3388000

B.3 Load Data:

Bus No.	Bus Name	P (MW)	Q (MVAr)
5	WHL2	14.360	11.483
7	DEB2-B1	33.456	23.961
9	DON2	50.320	46.148
10	MWT2	29.808	20.496
12	ATB2	101.338	70.734
13	SHN2	33.264	20.615
17	FRZ2	13.574	8.661
20	MHD2	60.883	37.732
23	GAD2	14.112	8.746
27	MSH2	6.989	25.534
28	RBK2	46.704	32.357
29	SNJ2	16.464	8.842
30	SNG2	12.029	5.585
31	ROS2	8.333	5.760
32	RNK2	0.403	22.385
33	HWT2	1.546	0.958
34	OBD2	19.757	31.778
35	UMR2	3.629	25.117
36	TND2	1.008	5.560
37	DBT2	6.250	3.939
38	ZBD2	3.360	23.764
39	FUL2	6.720	4.568
40	BBN2	3.360	2.503
43	SHK2	0.672	12.515
44	NHLF2	12.029	8.021
46	KSL2	16.666	10.678

50	KHE1	81.917	53.127
51	IZB1	68.006	39.992
52	IBA1	41.328	17.854
54	KUK1	44.621	20.718
55	IZG1	74.189	46.562
56	MHD1	12.634	8.128
57	FAR1	50.266	33.255
58	AFR1	17.203	8.477
59	KLX1	40.387	18.165
60	LOM1	85.344	58.018
61	SHG1	64.915	40.060
62	MUG	75.466	42.566
63	BNT1	59.069	30.588
64	OMD1	81.312	54.430
67	BAG1	36.490	24.236
70	NHAS1	24.730	12.738
71	OHAS1	11.088	5.864
72	GND1	27.821	14.253
73	MAR1-B1	56.717	26.986
74	MAN1	10.886	4.058
75	ORBK1	0.336	1.476
77	HAG1	7.594	4.037
78	SNP1	4.704	2.238
79	MIN1	14.381	9.552
80	FAO1	11.021	6.539
81	GDF1	18.614	12.315
82	GRB66	15.254	8.604

B.4 Transformer Data:

Name	KV Primary	KV Secondary	MVA	R (Ω)	X (Ω)	Freq. (HZ)	Tap ratio
TR NHAS	220	110	300	0	0.1534	50	0.905
TR KLX	110	220	300	0	0.1788	50	0.922
TR IBA	110	220	450	0	0.2895	50	0.905
TR ATB	220	500	600	0	0.2360	50	0.905
TR KAB	220	500	600	0	0.3360	50	0.915
TR MRK	500	220	900	0	0.5040	50	0.911
TR GDF	220	110	200	0	0.2400	50	0.975
TR GRB	220	66	200	0	0.2506	50	0.905
TR MAR	220	110	200	0	0.1409	50	0.918
TR GAD	110	220	150	0	0.2010	50	0.905
TR SNJ	220	110	110	0	0.1567	50	0.945
TR MHD	110	220	450	0	0.3801	50	0.975
TR GAM	220	110	300	0	0.2574	50	0.925
TR MWP	500	220	900	0	0.2194	50	0.967
TR JAS	220	110	150	0	0.1300	50	0.913

B.5 Static var compensator data:

SVC	SVC	Voltage rating	Inductive rating		Capacitive rating	
number	name	(kv)	Q_L (MVAr)	B_L (siemens)	Q_C (MVAr)	B_C (siemens)
1	ATP2	220	200	403.7	500	2249.4
2	BAG1	110	200	807.5	500	3749.0
3	FAR1	110	200	807.5	500	3749.0