بسم الله الرحمن الرحيم

Sudan University of Science and Technology

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Voltage Improvement ByUsing SVC

(Case Study: Sudan national grid)

تحسين الجهد بإستخدام معوض القدرة غير الفعالة الساكنه

(دراسة حالة: الشبكة القوميةالسودانية)

*A thesis submitted in partial fulfillment of the requirements for **M.Sc.** degree in power system engineering (Power)*

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قال – تعالى :-﴿وَمَا أُوتِيتُمْ مِنَ الْعِلْمِ إِلَّا قَلِيلًا﴾

[سورةالاسراء–الاية ٨٥]

صدق الله العظيم

Originality declaration

The author declares that the thesis submitted is research works and results obtained by the author under the guidance of his supervisor. As far as the author known, this thesis does not contain any research result published or written by other individual or group unless the content has been marked references. Any individual and group contributing to this thesis have been indicated in the thesis clearly. The author is fully aware of the legal consequences of this statement to me.

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Dedication

To whom she dressed me the life,Mother.

To whom always support me, My family.

The suns that burn to light for us,Teachers.

To whom I share with them the sorrow and sweet,Friends.

Acknowledgement

My thanks firstly go to the almighty God without whose help none of this could have been done.

And True thanks to Dr. Mohammed Osman Hassan *who gave me the golden opportunity to do this interesting project , I would like to thank him for his endless support.*

Also i would like to thanks to all teachers whom learn me in MSC for helping me in bringing this thesis to success.

I would also like to thank all of my friends who supported me while studying.

Abstract

Since the transmitted Load varies considerably from one hour to another, the reactive power balance in a Grid varies as well. A rapidly operating Static Var Compensator (SVC) can continuously provide the reactive power required under various system conditions.This thesis discussed the role of SVC in VAR compensation and their effect in improving voltage profile.In this project Sudan national grid under peak load was studied and amount of VAR compensation was found. Also a suitable location and sizes of SVCs were selected.

مستخلص البحث

بما أن القدرة المنقولة تتغير بصورة معتبرة من ساعة الى أخرى فإن إتزانالقدرة الغير فعاله يتغير ايضاً. بإمكان أجهزة (تعويض القدرة غير الفعالة الساكنة) توفيرالقدرة المطلوب بصورة مستمرة وتحت أوضاع مختلفة لمنظومة القدرة، هذه الإطروحة ناقشت دور هذه الأجهزة في تعويض القدرة وأثر ذلك في تحسين جهد الشبكة، و في هذا البحث تمت الدراسة على الشبكة السودانية القومية للكهرباء وقد تم تحديد أماكن ومقاسات مناسبة لأجهزة (تعويض القدرة غير الفعالة الساكنة) مما اسهم فى تحسين الجهد للشبكة القومية للكهرباء.

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List of Abbreviation

AFR	Afraa
ATB	Atbra
BAG	Bageer
BNT	Bant
DEB	Aldbaa
DG	Distributed Generators
DON	Dongla
FACT	Flexible AC Transmission Device
FAO	Alfaw
FAR	Alfaroog
FRZ	Free zone
GAD	Giad
GAM	Algmouea
GAR	Garee
GDF	Algdaref
GER	Algerba
HAG	Alhagabdala
HAS	Alhasahisa
HLF	Hlfaa
HWT	Alhawataa
IBA	Eidbabeker

IZB	Izba
IZG	Izergab
JAS	Jabelawlya
KAB	Alkabashe
KHN.	Khartom north
KLX	Kilooashraa
KSL	Kaslaa
KUK	Kokoo
LOM	Local market
MAR	Marengan
MHD	Almhadiyaa
MRK	Almrkyaat
MUG	Almogran
MWP	Marowee
OMD	Omdorman
POR	Portsudan
RBK	Rbak
RNK	Alrank
ROS	Alroseres
SVC	Static Var Compensator
SNJ	Sennar
TND	Tandalti

UMR	Um roaba
OBD	Alobeed

Chapter One

Introduction

1.1 Introduction

Power systems suffer greatly from voltage instabilityespecially due to excessive consumption or injection ofreactive power by the system elements and the consumers ‘loads.The voltage instability caused by the variation in thereactive power requirement of the system’s elements andthe consumers’ loads either result in excessive high or lowvoltage which may cause damage to the system and theconsumer’s load since the system elements and theconsumers’ loads are design to operate within a specificvoltage range.The system’s voltage goes high if there is excessiveinjection of reactive power by the system elements or theconsumers’ loads, but goes low if there is excessiveconsumption of reactive power by the system elements orthe consumers’ loads. As a result the system’s reactive power needs to becontinuously adjusted through effective reactive powercompensation if the variation in the system’s voltage mustbe kept within the allowable range. To achieve thisseveral methods have been used. The traditional methods used include reconfiguration of system structure, generator excitation regulation, synchronous generator,changing the voltage by transformer tap to adjust the powerflow in the grid, series compensation capacitor, switchingin/out the shunt reactor or shunt capacitor.With these methods the desired objectives were noteffectively achieved with wear and tear in the mechanicalcomponents and slow response being the major problems.However, extensive research works were carried outrecently leading to the discovery of FACTS devices whichhave been mainly used for solving various power systemsteady state control problems such as, voltage regulation,power flow control, and transfer capability enhancementwith near-instantaneous response These FACTSdevices include: Static VAR Compensator

(SVC),Thyristor- Controlled Series Capacitor (TCSC), Thyristor-Controlled Phase Shifter (TCPS), Static SynchronousCompensator (STATCOM), Static Synchronous SeriesCompensator (SSSC), Unified Power Flow Controller(UPFC), Interline Power Flow Controller (IPFC).

All the FACTS devices exhibit near instantaneousresponse to system changes and are made up of solid semiconductorcomponent thereby eliminating the problems ofmechanical wear and tear.

1.2 Static Var Compensator

Electrical loads both generate and absorb reactive power. Since the transmitted Load varies considerably from one hour to another, the reactive power balance in aGrid 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) or fixed capacitor (FC) and

Thyristor Switched or Controlled Reactors (TSR / TCR). The coordinated control of a combination of these branches varies the reactive power.

1.3 Modeling ofStatic VarCompensator:

Static VAR Compensator (SVC) is a shunt connectedFACTS controller whose main functionality is to regulate thevoltage at a given bus by controlling its equivalent reactance.Basically it consists of a fixed capacitor (FC) and a thyristorcontrolled reactor (TCR). Generally they are twoconfigurations of the SVC.

A) SVC total susceptance model. A changing susceptanceBsvc represents the fundamental frequency equivalentsusceptance of all shunt modules making up the SVC.

B) SVC firing angle model. The equivalent reactance XSVC, which is function of a changing firing angle α, is made up ofthe parallel combination of a thyristor controlled reactor(TCR) equivalent admittance and a fixed capacitive reactance. This model provides information onthe SVC firing angle required to achieve a given level ofcompensation [1].

1.4 Statement of Problem

Voltage improvement of sudan national grid by using Static Var Compensator (SVC).

1.5 Thesis Objectives

Objective of this thesis to find suitable location and size of SVCs devices that can minimizes the voltage deviation in Sudan national grid during peak load.

1.6 Thesis Methodology

The Sudan national grid under peak load was taken as case study, simulation was developed in load flow program by Neplan software which solves power flow equation using Newton-Raphson method.

The Methodology is Presented in Four Steps:

Step 1 in this step start load flow for Sudan national grid under peak load.

Step 2 in this step the voltage is measured and recorded for all buses.

Step3in this step the voltage is checked if all voltage within the limit stop otherwise go to step4

Step4 in this step the SVC devices is installed at most weak bus and then go to step1

1.7 Thesis Organization

This thesis is organized into five chapters these chapters can be summarized as follows: -

Chapter twoliterature review. **Chapter three**mathematical models of SVC.**Chapter four** presents the result and discussion of the simulation of National Grid of Sudan which is used as the case study in this thesis. **Chapter five** focuses on the general conclusions of the thesis and the possible solutions in order to improve the voltage profile of the Sudan National Grid and the recommendations for future work are represented.

Chapter Two

Literature Review

2.1 Introduction

Capacitors generate and reactors (inductors) absorb reactive power when connected to an ac power source. They have been used with mechanical switches for (coarsely) controlled var generation and absorption since the early days of ac power transmission. Continuously variable var generation or absorption for dynamic system compensation was originally provided by .over- or under-excited rotating synchronous machines and, later, by saturating reactors in conjunction with fixed capacitors. Since the early 1970 high power, line commutated thyristors in conjunction with capacitors and reactors have been employed in various circuit configurations to produce variable reactive output. These in effect provide a variable shunt impedance by synchronously switching shunt capacitors and/or reactors "in" and "out" of the network [2].

Using appropriate switch control, the var output can be controlled continuously from maximum capacitive to maximum inductive output at a given bus voltage. More recently gate turn-offthyristors and other power semiconductors with internal turnoff capability have been used in switching converter circuits to generate and absorb reactive power without the use of ac capacitors or reactors. These perform as ideal synchronous compensators (condensers), in which the magnitude of the internally generated ac voltage is varied to control the var output. All of the different semiconductor power circuits, with their internal control enabling them to produce var output proportional to an input reference, are collectively termed by the joint IEEE and CIGRE definition, static var generators (SVG). Thus, a static var compensator (SVC) is, by the IEEE CIGRE co-definition, a static var generator whose output is varied so as to maintain or control specific parameters (e.g., voltage, frequency) of the electric power system. It is important that the reader appreciate the difference between these two terms, static var generator and static var compensator, the static var generator is a self sufficiently functioning device that draws controllable reactive current from an alternating power source. The control input to the var generator can be an arbitrary (within the operating range) reactive current, impedance, or power reference signal that theSVG is to establish at its output. Thus, the static var generator can be viewed as a power amplifier that faithfully reproduces the reference signal at the desired power level. The functional use of the var generator is clearly defined by the reference signal provided. Consequently, according to the IEEE-CIGRE definition, a static var generator becomes a static var compensator when it is equipped with special external (or system) controls which derive the necessary reference for its input, from the operating requirements and prevailing variables of the power system, to execute the desired compensation of the transmission line. This means that different types of var generator can be operated with the same external control to provide substantially the same compensation functions. Evidently, the type and structure of the var generator will ultimately determine the basic operating characteristics (e.g., voltage vs. var output, response time, harmonic generation), whereas the external characteristics control the functional capabilities (e.g., voltage regulation, power factor control, power oscillation damping), of the static varcompensator.

2.2 Voltage Collapse Mitigation Techniques:

2.2.1 Power Capacitor:

Power Capacitor are used for improving power factor for a power system when the load is inductive, as stated before most of the loads are industrial loads and are inductive in nature; these results lowering of power factor in the nearby distribution zone. Some of the electrical authorities made compulsory to install power capacitor in the industrial loads.

2.2.2 Static VarCompensator:

Reactive power is latent soul of power system, balance of it is very important. Being a combination of capacitor and reactor SVC can inject or absorb reactive power dynamically. When a system is close to collapse, smaller increase in load will result in relatively large increase in reactive power absorption in the system. Now if that increased reactive power absorption is not supplied by the dynamic resources of reactive power of that region the system will surely go to voltage collapse. SVC in that response proved as very good reactive power source.

2.2.2.1 Static Var Compensator:

The electrical power system through the world is deregulating and DG is predicted to play an important role in the next coming years. DG technology includes Photovoltaic cell, wind turbine, fuel cells, micro-turbine etc. The advantages of DG in the field of voltage control, power quality improvement, Var control, stability are already accepted it also promotes renewable energy. DG can provide bulk-energy to sub-transmission or distribution network. DG is preferred to locate at the customer meter side. In the time of short-term or long-term stability fast reactive power support (recovery) is essential in this respect DG can play an important role in the system.

2.3 Basic Types of Facts Controllers

In general, FACTS Controllers can be divided into four categories

- Series Controllers
- Shunt Controllers
- Combined series-series Controllers
- Combined series-shunt Controllers

2.3.1 Series Controllers

The series Controller could be variable impedance, such as capacitor, reactor, etc., or a power electronics based variable source of main frequency, sub synchronous and harmonic frequencies (or a combination) to serve the desired need. In principle, all series Controllers inject voltage in series with the line. Even avariable impedance multiplied by the current flow through it, represents an injected series voltage in the line. As long as the voltage is in phase quadrature with the line current, the series Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well [2].

2.3.2 Shunt Controllers

As in the case of series Controllers, the shunt Controllers may be variable impedance, variable source, or a combination of these. In principle, all shunt Controllers inject current into the system at the point of connection. Even variable shunt impedance connected to the line voltage causes a variable current flow and hence represents injection of current into the line. As long as the injected current is in phase quadrature with the line voltage, the shunt Controller only supplies or consumes variable reactive power. Any other phase relationship will involve handling of real power as well [2].

2.3.3 Combined series-series Controllers

This could be a combination of separate series controllers, which are controlled in a coordinated manner, in a multiline transmission system. Or it could be a unified Controller, in which series Controllers provide independent series reactive compensation for each line but also transfer real power among the lines via the power link. The real power transfer capability of the unified series-series Controller, referred to as Interline Power Flow Controller, makes it possible to balance both the real and reactive power flow in the lines and thereby maximize the utilization of the transmission system. Note that the term "unified" here means that the de terminals of all Controller converters are all connected together for real power transfer.

2.3.4 Combined series-shunt Controllers

This could be a combination of separate shunt and series Controllers, which are controlled in a coordinated manner, or a Unified Power Flow Controllerwith series and shunt elements. In principle, combined shunt and series Controllers inject current into the system with the shunt part of the Controller and voltage in series in the line with the series part of the Controller. However, when the shunt and series Controllers are unified, there can be a real power exchange between the series and shunt Controllers via the power link.

2.4 Relative Importance of Different Types of Controllers

It is important to appreciate that the series-connected Controller impacts the driving voltage and hence the current and power flow directly. Therefore, if the purpose of the application is to control the current/power flow and damp oscillations, the series Controller for a given MVA size is several times more powerful than the shunt Controller.

As mentioned, the shunt Controller, on the other hand, is like a current source, which draws from or injects current into the line. The shunt Controller is therefore a good way to control voltage at and around the point of connection through injection of reactive current (leading or lagging), alone or a combination of active and reactive current for a more effective voltage control and damping of voltage oscillations.

This is not to say that the series Controller cannot be used to keep the line voltage within the specified range. After all, the voltage fluctuations are largely aconsequence of the voltage drop in series impedances of lines, transformers, and generators. Therefore, adding or subtracting the FACTS Controller voltage in series(main frequency, subsynchronous or harmonic voltage and combination thereof) can be the most cost-effective way of improving the voltage profile. Nevertheless, a shunt controller is much more effective in maintaining a required voltage profile at a substation bus. One important advantage of the shunt

Controlleris that it serves the bus node independently of the individual lines connected to the bus.

Series Controller solution may require, but not necessarily, a separate seriesController for several lines connected to the substation, particularly if the application calls for contingency outage of anyone line. However, this should not be a decisive reason for choosing a shunt-connected Controller, because the required MVA size of the series Controller is small compared to the shunt Controller, and, in any case, the shunt Controller does not provide control over the power flow in the lines.On the other hand, series-connected Controllers have to be designed to ride through contingency and dynamic overloads, and ride through or bypass short circuit currents. They can be protected by metal-oxide arresters or temporarily bypassed by solid-state devices when the fault current is too high, but they have to be rated to handle dynamic and contingency overload.

The above arguments suggest that a combination of the series and shunt Controllers can provide the best of both, i.e., an effective power/ current flow and line voltage control.For the combination of series and shunt Controllers, the shunt Controller can be a single unit serving in coordination with individual line Controllers .This arrangement can provide additional benefits (reactive power flow control) with unified Controllers.It is appropriate to state here that within the basic system security guidelines these Controllers enable the transmission owners to obtain, on a case-by-case basis, one or moreof the **following benefits:**

• Control of power flow as ordered. The use of control of the power flow may be to follow a contract, meet the utilities' own needs, ensure optimum power flow, ride through emergency conditions, or a combination thereof.

• Increase the loading capability of lines to their thermal capabilities, including short term and seasonal. This can be accomplished by overcoming other limitations, and sharing of power among lines according to their capability. It is also important to note that thermal capability of a line varies by a very large margin based on the environmental conditions and loading history.

• Increase the system security through raising the transient stability limit, limiting short-circuit currents and overloads, managing cascading blackouts and damping electromechanical oscillations of power systems and machines.

• Provide secure tie line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides.

• Provide greater flexibility in siting new generation.

• Upgrade of lines.

• Reduce reactive power flows, thus allowing the lines to carry more active power.

• Reduce loop flows.

• Increase utilization of lowest cost generation. One of the principal reasons for transmission interconnections is to utilize lowest cost generation. When this cannot be done, it follows that there is not enough cost-effective transmission capacity. Cost-effective enhancement of capacity will therefore allow increased use of lowest cost generation [2].

2.5 Steady State Power System Voltage Stability Analysis and Control with FACTS

Voltage stability analysis and control become increasingly important as the systems are being operated closer to their stability limits including voltage stability Limit. This is due to the fact that there is lack of network investments and there are large amounts of power transactions across regions for economical reasons in electricity market environments. It has been recognized that a number of the system blackouts including the recent blackouts that happened in North America and Europe are related to voltage instabilities of the systems.

For voltage stability analysis, a number of special techniques such as power flow based methods and dynamic simulations methods have been proposed and have been used in electric utilities. Power flow based methods, which are considered as steady state analysis methods, include the standard power flow methods, continuation power flow methods, optimization methods modal methods singular decomposition methods etc [3].

2.5.1 Voltage Collapse Definition and Causes

There are several definitions of voltage collapse in the literature, but all the definition considers different issues according to the author. According to definitions presented by IEEE voltage collapse is a process by which voltage instability leads to voltage drop in a significant part of the power system. Several reasons are there which leads to typical voltage instability in the power system, may be static or dynamic [3].

Chapter three

Mathematical Model

3.1 Introduction

An SVC (Static var compensators) is a shunt connected static generator and/ or absorber of reactive power in which the output is varied to maintain or control specific parameters of an electrical power system [4].

The general characteristics of SVCs are given in the list that follows:

1. The lowering of maintenance requirements from the absence of rotating parts
2. The very fast control-response time.
3. The feasibility of individual phase control.
4. The diminished losses.
5. The high reliability.
6. The lack of contribution to system short-circuit capacity.
7. The generation of harmonics by SVCs except thyristor-switched capacitors (TSCs).
8. The variation of SVC reactive-power generation as the square of terminal voltage when it is operating outside the linear controllable range, leading to a substantial reduction in reactive-power support at lower voltages.

Characteristics (1)–(5) of the foregoing list constitute the prominent advantages of SVCs, whereas characteristics (7) and (8) constitute disadvantages; however, characteristic (6) may be considered a merit or a demerit, depending on the application.

Those SVCs using higher-power–rated thyristors have been identified as key elements in flexible ac transmission systems (FACTSs), which are either controlled individually or coordinated with other dynamic devices in power systems, such as power-system stabilizers (PSS) and HVDC controllers. The ultimate control objectives may be to extend the power loading of existing transmission lines, as well as to regulate voltage and provide additional system damping. Although SVCs are used extensively at the present time for reactive-power compensation(See refs. [4]– [12]).

3.2 The Thyristor-Controlled Reactor (TCR)

ATCR is one of the most important building blocks of thyristor-based SVCs.Although it can be used alone, it is more often employed in conjunction with fixed or thyristor-switched capacitors to provide rapid, continuous control of reactive power over the entire selected lagging-to-leading range.

3.2.1 The Single-Phase TCR

A basic single-phase TCR comprises an anti-parallel–connected pair of thyristorvalves, $T1$ and $T2$, in series with a linear air-core reactor, as illustrated in Fig.3.1. The anti-parallel–connected thyristor pair acts like a bidirectional switch, with thyristor valve $T1$ conducting in positive half-cycles and thyristor valve $T2$ conducting in negative half-cycles of the supply voltage. The firing angle of the thyristors is measured from the zero crossing of the voltage appearing across its terminals.

The controllable range of the TCR firing angle, α, extends from 90 to 180.A firing angle of 90 results in full thyristor conduction with a continuous sinusoidal current flow in the TCR. As the firing angle is varied from 90 to close to 180, the current flows in the form of discontinuous pulses symmetrically located in the positive and negative half-cycles. Once the thyristor valves are fired, the cessation of current occurs at its natural zero crossing, a process known as the line commutation. The current reduces to zero for a firing angle of 180. Thyristor firing at angles below 90 introduces dc components in the current, disturbing the symmetrical operation of the two antiparallel valve branches. A characteristic of the line-commutation process with which the TCR operates is that once the valve conduction has commenced,any change in the firing angle can only be implemented in the next half-cycle,leading to the so-called thyristor deadtime.

Let the source voltage be expressed as

$$v_s(t) = V sin\ \omega t \qquad (3.1)$$

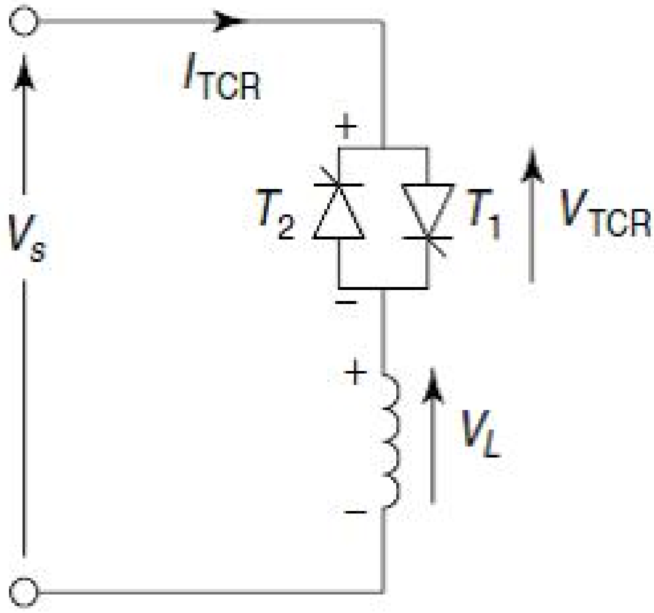

Figure 3.1 Single-Phase TCR

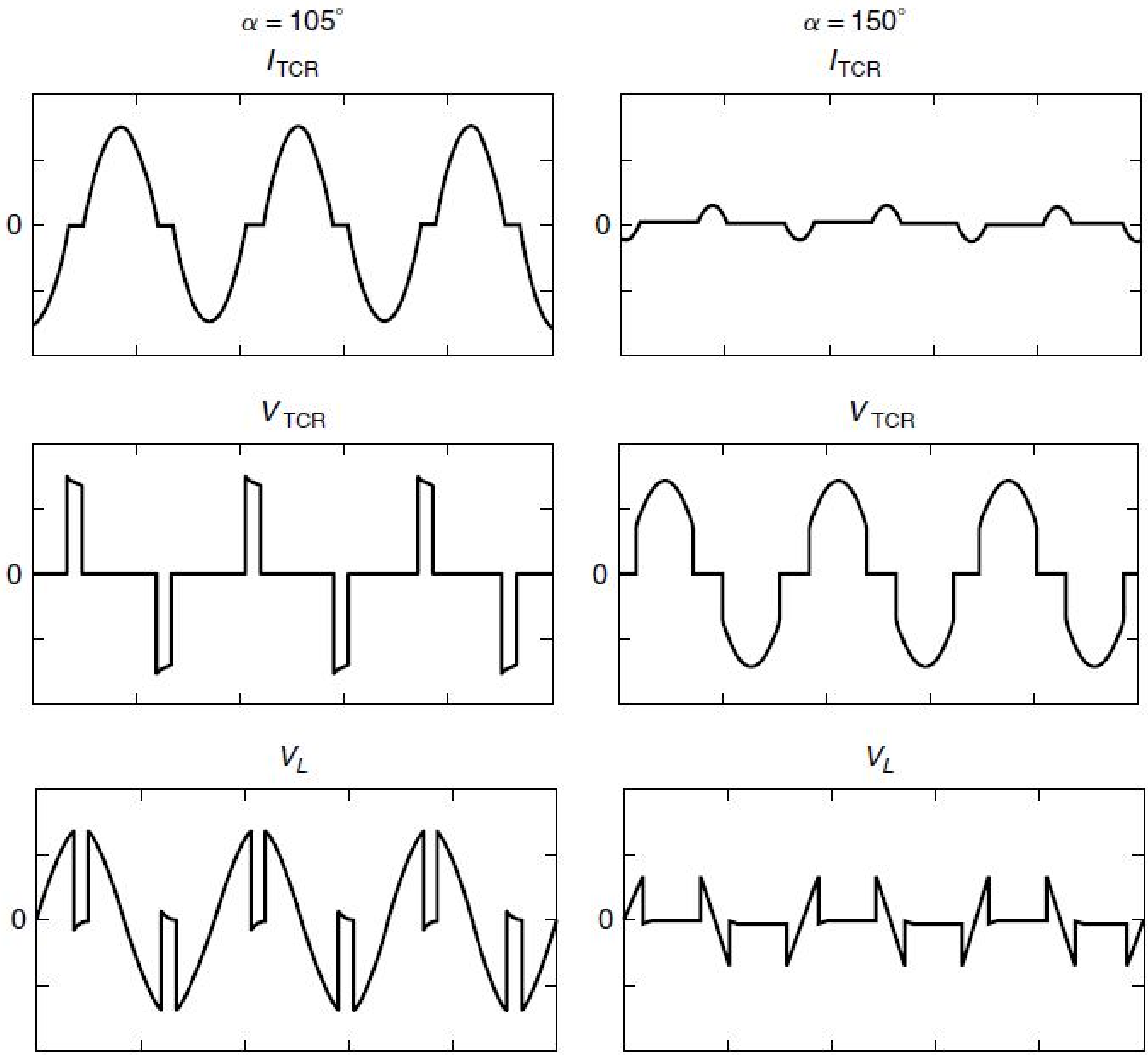

Figure 3.2 Represent the variation of firing angle

Where V=the peak value of the applied voltage and ωcthe angular frequency of supply voltage. The TCR current is then given by the following differential equation

$$L\frac{di}{dt} - v_s(t) = 0 \qquad (3.2)$$

Where L is the inductance of the TCR. Integrating Eq. (3.2), we get

$i(t) = \frac{1}{L}\int v_s(t)dt + C(3.3)$

Where C is the constant

Alternatively

$$i(t) = -\frac{V}{\omega L}cos\omega t + C \quad (3.4)$$

For the boundary condition, $i(\omega t=\alpha)=0$

$$i(t) = -\frac{V}{\omega L}(cos\alpha - cos\omega t) \quad (3.5)$$

Where α the firing angle measured from positive going zero crossing of theapplied voltage. Fourier analysis is used to derive the fundamental componentof the TCR current I_1 (α), which, in general, is given as

$$I_1(\alpha) = a_1 cos\omega t + b_1 sin\omega t \quad (3.6)$$

Where b_1 =0 because of the odd-wave symmetry, that is, $f(x) = f(-x)$. Also,no even harmonics are generated because of the half-wave symmetry, that is,

$f(x + T/2) = -f(x)$. The coefficient a_1 is given by

$$a_1 = \frac{4}{T}\int_0^{T/2} f(x)cos\frac{2\pi x}{T}dx \quad (3.7)$$

Solving,

$$I_1(\alpha) = \frac{V}{\omega L}(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi} sin2\alpha) \quad (3.8)$$

$$I_1(\alpha) = VB_{TCR}(\alpha) \quad (3.9)$$

Where

$$B_{TCR}(\alpha) = B_{max}\left(1 - \frac{2\alpha}{\pi} - \frac{1}{\pi} sin2\alpha\right) \quad (3.10)$$

$$B_{max} = \frac{1}{\omega L} \quad (3.11)$$

The variation of per-unit value of $\boldsymbol{B}_{\mathbf{TCR}}$ with firing angle α is depicted in Fig.3.3. The per-unit value of $\boldsymbol{B}_{\mathbf{TCR}}$ is obtained with respect to its maximum value*B*max as the base quantity.

The TCR thus acts like a variable susceptance. Variation of the firing anglechanges the susceptance and, consequently, the fundamental-current component,which leads to a variation of reactive power absorbed by the reactor because the applied ac voltage is constant. However, as the firing angle is increased beyond 90, the current becomes nonsinusoidal, and harmonics aregenerated. If the two thyristors are fired symmetrically in the positive and negativehalf-cycles, then only odd-order harmonics are produced. The harmonicscan be deduced through a Fourier analysis of higher-frequency components [4].

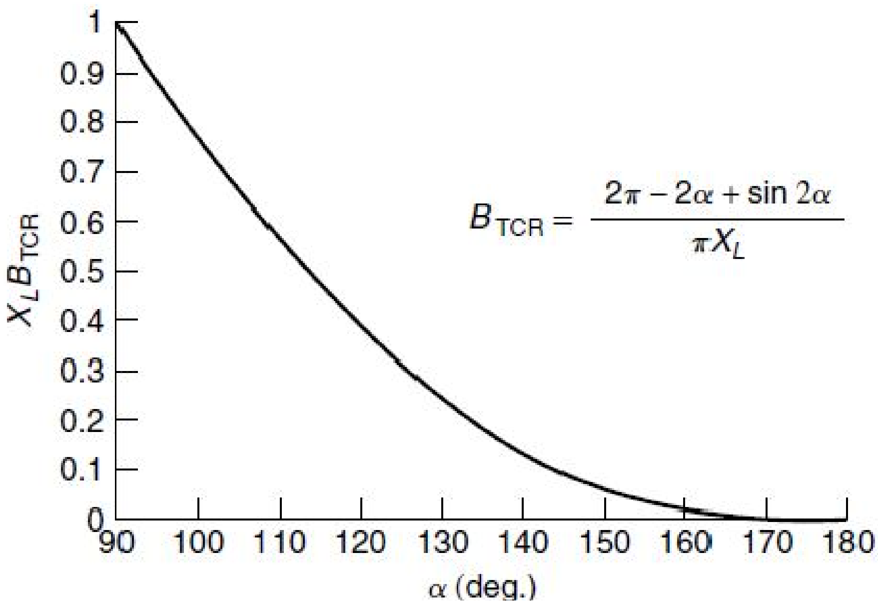

Figure 3.3 Control characteristics of the TCR susceptance,$\mathbf{B}_{\mathbf{TCR}}$

The rms value of the nth-order harmonic is expressed as a function of α in thefollowing equation:

$$I_n(\alpha) = \frac{V}{\omega L}\frac{2}{\pi}\left[-2\frac{cos\alpha}{n}\ sinn\alpha + \frac{\sin{(n-1)\alpha}}{n-1} + \frac{\sin{(n+1)\alpha}}{n+1}\right] \quad (3.12)$$

$$= \frac{V}{\omega L}\frac{4}{\pi}\left[\frac{sin\alpha\cos(n\alpha) - n\ cos\ \alpha\ \sin{(n\alpha)}}{n(n^2-1)}\right] (3.13)$$

Where

$n = 2k + 1$ and $k = 1, 2, 3, \ldots$

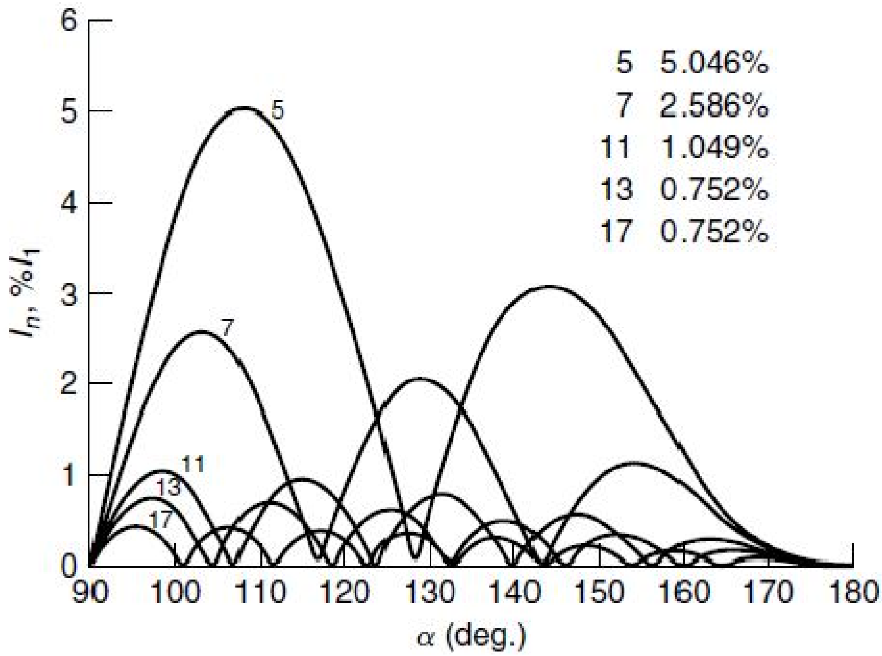

Fig.3.4 Harmonics in a TCR current

The variation of the amplitude of different harmonics is shown in Fig. 3.4,whereas the same for the total harmonic-current content is displayed in Fig.3.5. It is seen that all the harmonics do not peak at the same firing angle. Themaximum values of various harmonic currents, each expressed as a percentageof the fundamental component, are listed in Fig. 3.4.

It should be noted that a thryistor valve usually comprises many parallel-connectedstrings, each constituting many serially connected thyristors. The seriesconnection enhances the voltage-blocking capability of the valve to correspondto the secondary voltage of the coupling transformer. On the other hand, theparallel connection of strings extends the current capability of the valve. Theexact number of thyristors in series and parallel is determined from an optimizationprocess that depends on the rating of individual valves and the couplingtransformer.

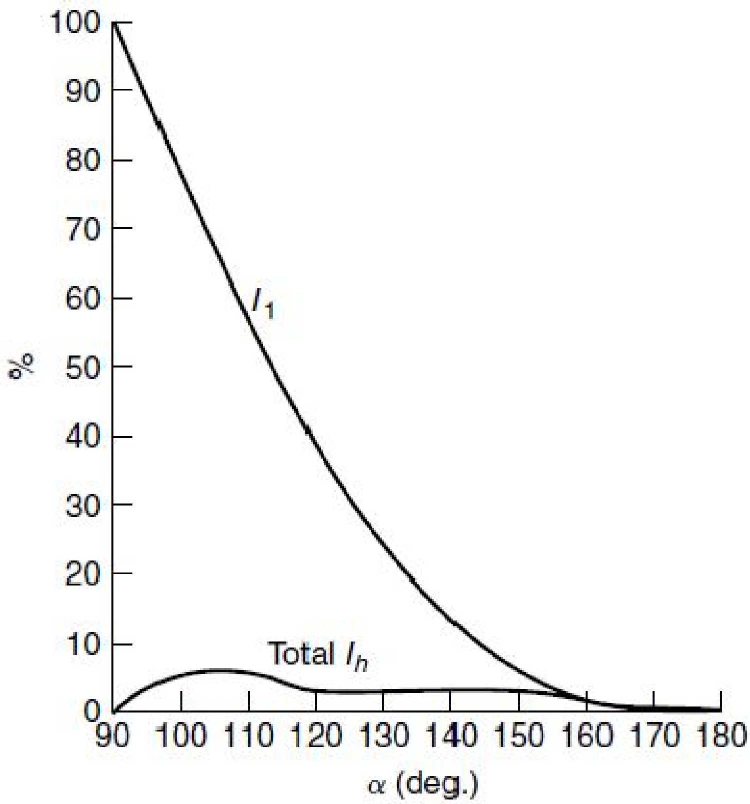

Fig.3.5 I_1& Total I_h

3.2.2 The 3-Phase TCR

A 3-phase, 6-pulse TCR comprises three single-phase TCRs connected in delta, as shown in Fig. 3.6. The phase- and line-current waveforms are also displayed in Fig. 3.7.

If the 3-phase supply voltages are balanced, if the three reactor units are identical,and also if all the thyristors are fired symmetrically with equal firing angles in each phase then the symmetric current pulses result in both positiveand negative half-cycles and the generating of only odd harmonics. The percentagevalues of harmonic currents with respect to fundamental both in the phases and in the lines are the same.

The delta connection of the three single-phase TCRs prevents the triplen (i.e.,multiples of third) harmonics from percolating into the transmission lines.

Thecancellation of its 3rd and multiple harmonics can be explained as follows: Let$\boldsymbol{i}_{\mathbf{ABn}}$, $\boldsymbol{i}_{\mathbf{BCn}}$, and $\boldsymbol{i}_{\mathbf{CAn}}$be the *n*th-order harmonic-phase currents in the respectivedelta branches, and let $\boldsymbol{i}_{\mathbf{An}}$, $\boldsymbol{i}_{\mathbf{Bn}}$, and $\boldsymbol{i}_{\mathbf{Cn}}$be the currents in the respective linesconnected to the delta-configured TCR. Then, the 3rd harmonic currents areexpressed as:

$$i_{AB\,3} = a_3 \cos(3\omega t + \phi_3) \quad (3.14)$$

$$i_{BC\,3} = a_3 \cos\left(3\omega t + \phi_3 - 3\frac{2\pi}{3}\right) \quad (3.15)$$

$$= a_3 \cos(3\omega t + \phi_3 - 2\pi) \quad (3.16)$$

$$i_{CA3} = a_3 \cos\left(3\omega t + \phi_3 - 3\frac{4\pi}{3}\right) \quad (3.17)$$

$$= a_3 \cos(3\omega t + \phi_3 - 4\pi) \quad (3.18)$$

Thus

$$i_{AB\,3} = i_{BC\,3} = i_{CA3}$$

All three currents are in phase and circulate in the thyristor delta, zero-sequence system. It follows that the 3rd harmonic line currents reduce to zero, as follows:

$i_{A\,3} = i_{AB\,3} - i_{C\,A3} = 0$ (3.19)

Like wise

$$i_{B\,3} = 0, i_{C\,3} = 0$$

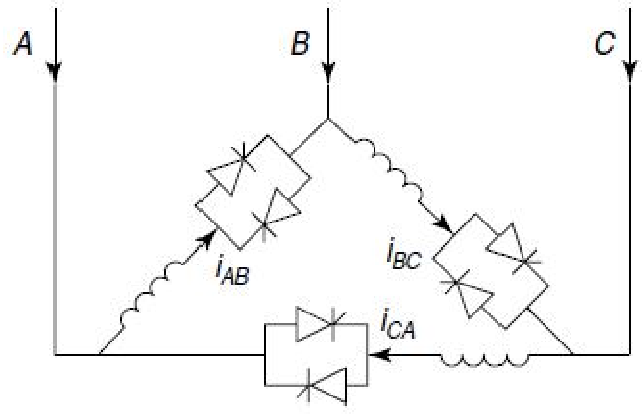

Fig. 3.6.Delta-connected TCR

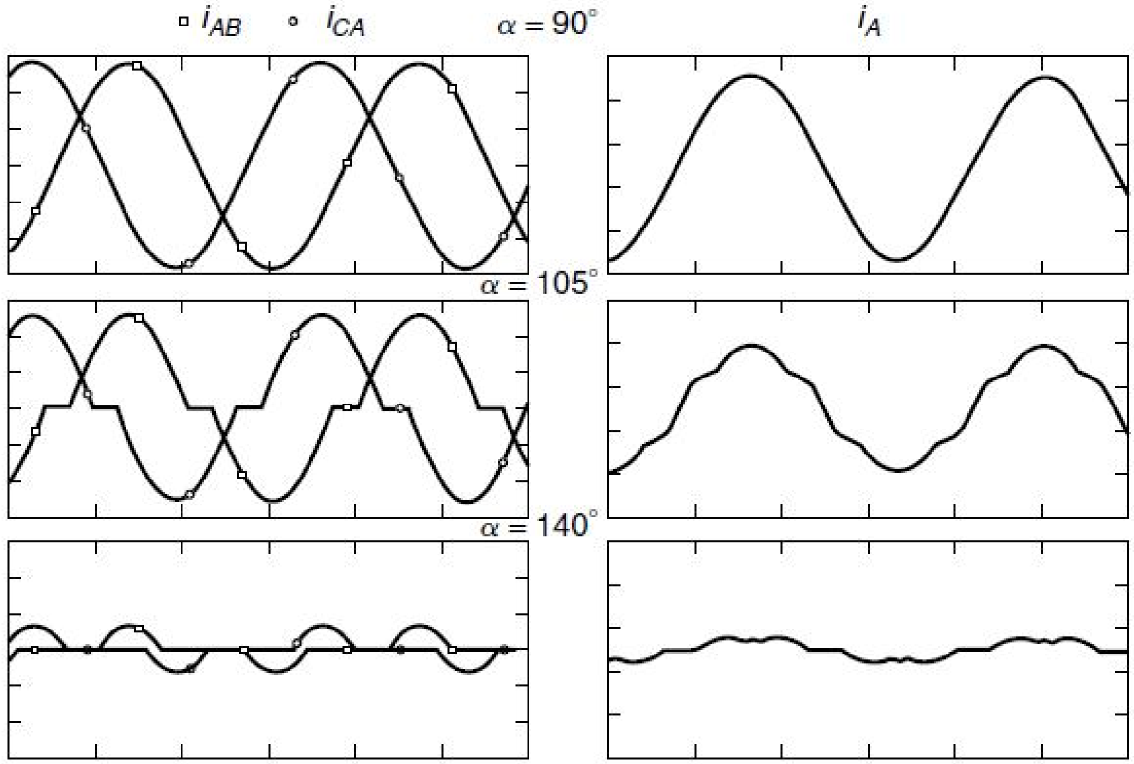

Fig.3.7 Delta-connected TCR and its phase and line currents for different α.

A closer analysis reveals that not only the 3rd harmonic but also all triplenharmonics get canceled out. Therefore, all harmonic components of the order$3p$ + 3, (3, 9, 15, 21, 27, etc.) cannot flow in the linesduring balanced operation.

A similar analysis can be done for the 5th and 7th harmonic current, asfollows:

For the 5th harmonic, let

$i_{AB\,5} = a_5 \cos(5\omega t + \phi_5)$(3.20)

$i_{BC\,5} = a_5 \cos\,(5\omega t + \phi_5 - 5\frac{2\pi}{3})$ (3.21)

$= a_5 \cos\,(5\omega t + \phi_5 - \frac{4\pi}{3})$ (3.22)

$i_{C\,A5} = a_5 \cos\left(5\omega t + \phi_5 - 5\frac{4\pi}{3}\right)$(3.23)

$= a_5 \cos\left(5\omega t + \phi_5 - \frac{2\pi}{3}\right)$(3.24)

Phase-shift angles for the three delta currents clearly indicate that the 5th harmonicrepresents a negative-sequence system of currents. The same applies forharmonics of the order 6*p* + 5, (5, 11, 17, etc.).

Furthermore, these harmonics do not cancel out in the line.

For the 7th harmonic,let

$i_{AB\,7} = a_7 \cos(7\omega t + \phi_7)$(3.25)

$i_{BC\,7} = a_7 \cos\left(7\omega t + \phi_7 - \frac{2\pi}{3}\right)$(3.26)

$i_{CA\,7} = a_7 \cos\left(7\omega t + \phi_7 - \frac{4\pi}{3}\right)$(3.27)

The phase-shift angles reveal that the 7th harmonic and all other harmonics ofthe order 6*p* + 1, (7, 13, 19, etc.), constitute a positivesequencesystem and moreover, that they *do* flow in the lines connecting to the6-pulse TCR.The stringent conditions mentioned previously for balanced operation maynot be fully satisfied in real life. For instance, the reactors may not be identicalin all three phases or the supply voltages may not be balanced. This imbalancein the emission of noncharacteristic harmonics, including triplen harmonics, into the line. The magnitude of these noncharacteristic harmonicsis insignificant under normal circumstances, but during severe disturbances,unequal firing of thyristors in positive and negative cycles may occur. This conditionresults in a dc component, which is sufficient to cause saturation of thecoupling transformer, creating increased harmonic emanation.

In addition to the harmonics, a small, in-phase component of current(0.5–2%) of fundamental frequency also flows in the TCR, which representsthe resistive losses in the TCR windings. Typical values of TCR quality factor(*QF*=w*L*/ *R*) accounting for these losses range from 40 to 100.

Filters are usually provided in shunt with the TCR, which are either of series.

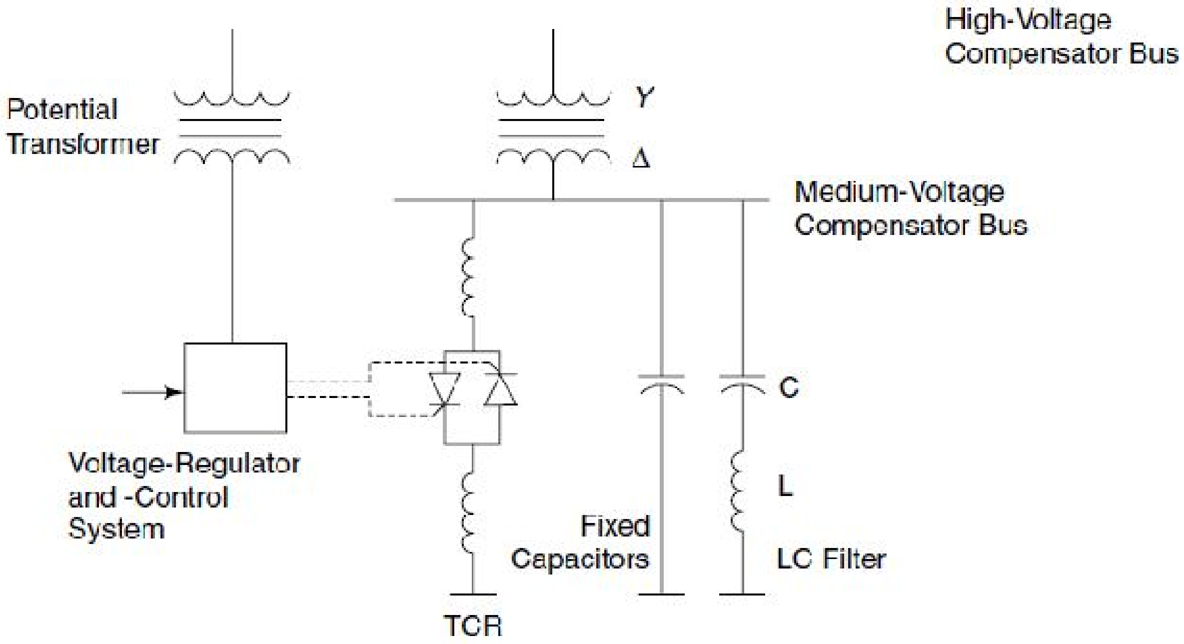

Fig.3.8.single line diagram of a TCR compensator with fixed-shunt capacitors LCor LCR configuration.

These filters are tuned to the dominant 5th and 7thharmonic frequencies. Sometimes, specific filters for 11th and 13th harmonicsa simple high-pass filter are also installed.

The schematic diagram of a 6-pulse TCR with filters is depicted in Fig. 3.8.As it is desirable in power-system applications to have controllable capacitivereactivepower, a capacitor is connected in shunt with the TCR. This capacitormay be fixed, or it may be switchable by means of mechanical or thyristorswitches. The main advantages of the TCR are flexibility of control and easein uprating.

Modular in nature, a TCR SVC can have itsrating extended by the addition of more TCR banks, as long as the couplingtransformerrating is not exceeded.

The TCRs do not possess high overload capability because the air-coredesign of their reactors. If the TCRs are expected to transiently withstandhigh overvoltages, a short-term overload capacity must be built into the TCRby design, or additional thyristor-switched overload reactors may need to beinstalled.

3.2.3 The Thyristor-Switched Reactor (TSR)

The TSR is a special case of a TCR in which the variable firing-angle controloption is not exercised. Instead, the device is operated in two states only: eitherfully on or fully off.If the thyristor valves are fired exactly at the voltage peaks correspondingto $\alpha = 90$ for the forward-thyristor valve $T1$ and $\alpha = 270$ (90 + 180) forthe reverse-thyristor valve $T2$, as depicted in Fig. 3.6, full conduction results.

The maximum inductive current flows in the TCR as if the thyristor switcheswere replaced by short circuits. However, if no firing pulses are issued to thethyristors, the TSR will remain in a blocked-off state, and no current can flow.

The TSR ensures a very rapid availability of rated inductive reactive power tothe system. When a large magnitude of controlled reactive power, Q, is required,a part of Q is usually assigned to a small TSR of rating, say, $Q/2$; the rest isrealized by means of a TCR also of a reduced rating $Q/2$. This arrangementresults in substantially decreased losses and harmonic content as compared toa single TCR of rating Q.

3.2.4 The Segmented TCR

One method of reducing harmonic generation is to segment the main TCR into$n$($n \geq 2$) parallel-connected TCRs, each having a reactive-power rating $1/n$ ofthe total TCR. Of these n TCRs, the firing angle of only one unit is controlled,whereas the others are either switched on or off to absorb the desired amountof reactive power. As the size of the controllable reactor is decreased with aconsequent increase in its inductance by a factor of n, the magnitude of each generated harmonic as given by Eq. (3.13) also attenuates by a factor of $n$compared to the rated fundamental component of the current. Correspondingly,the size and rating of required harmonic filters also attenuates.

The harmonic reduction achieved with this SVC configuration is accompaniedby increased costs because of the greater number of involved thyristors.Thus a segmented TCR with TSRs emerges as a more expensive option comparedto a nonsegmented TCR if the number of TCR segments is large.

3.3 Operating Characteristics of a TCR

3.3.1 Operating Characteristics Without Voltage Control

The simplestSVC configuration consists of a TCR connected to the power system as shown in Fig. 3.9. In the analysis of compensator performance, the fundamentalfrequency behavior is generally considered. In practice, harmonics arefiltered and reduced to very low values. The approach shown in Fig. 3.9 is veryconvenient for the performance analysis of the whole TCR branch is replaced byan equivalent continuously variable reactor. The sinusoidal current flowing inthis reactor is equal to the fundamental component of the nonsinusoidal current.

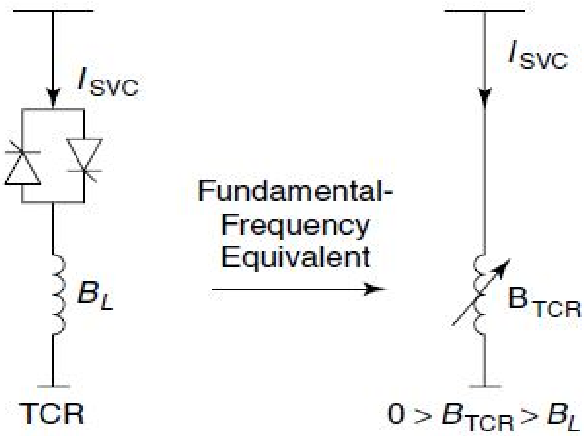

Fig.3.9. Simple SVC circuit using a TCR.

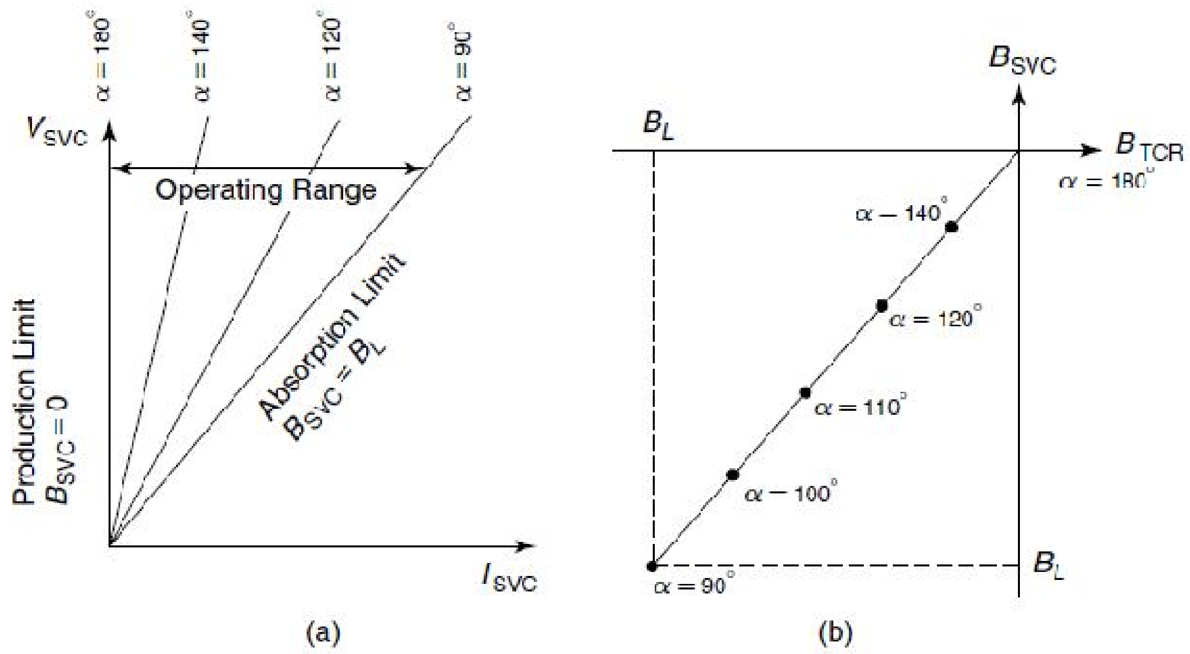

Figure 3.10 Different characteristics of an SVC: (a) the voltage–current characteristic and (b) the SVC TCR susceptance characteristic.

For a general SVC, which can be considered as a black box with an but purely reactive circuit inside, the overall compensator susceptance B_{SVC} can be defined with the following equation:

$\bar{I}_{SVC} = \bar{V} j B_{SVC}$ (3.28)

In the simple case of a TCR, the compensator susceptance is

$$B_{SVC} = B_{TCR}$$

Usually, three kinds of characteristics are of interest while analyzing an SVC, as described in the paragraphs that follow.

Voltage–Current Characteristic or Operating Characteristic This shows theSVC current as a function of the system voltage for different firing angles, as depicted in Fig. 3.10(a). This V-I characteristic is given in a very general sense. No control system is assumed to vary the firing angle, and any operating point within the two limits is possible depending on the system voltage and the setting of the firing angle (other currents and voltages may be shown, too). This characteristic clearly illustrates the limits of the operating range, and it may include the steady-state characteristics of the various possible controls. This characteristic is the usual way in which the system engineers prefer to look at the compensator, because the characteristic shows the steady-state performance of the SVC plant.

SVC TCR Susceptance Characteristics These illustrate the change of the total SVC susceptance when the TCR susceptance is varied, as shown in Fig. 3.10(b). The susceptance characteristic for this case is very simple becauseBSVC- BTCR. Note that the TCR susceptance is negative, indicating that the CR is an absorbing reactive component. These characteristics are of most interest to control-system analysis—the controls affect the TCR firing angle, whereas the total susceptance BSVC influences the power system.

Current Characteristics For more complex SVC arrangements, especially those including TSCs, it is not easy to see how the various branches contribute to the total SVC current. Therefore, these characteristics show the branch currents as a function of the total SVC current, and they are important for determining steady-state current ratings of the various components.

3.4 Operating Characteristic With Voltage Control

Characteristic of operating points if the effect of the voltage control is incorporated. Let us assume that the compensator is equipped with the voltage control shown in the system voltage is measured, and the feedback system varies $\mathbf{B_{TCR}}$ to maintain $\mathbf{V_{ref}}$ on the system. This characteristic shows the hard-voltage control of the compensator, which stabilizes the system voltage exactly to the set point $\mathbf{V_{ref}}$.

٣.٥The Fixed-Capacitor–Thyristor-Controlled Reactor

(FC–TCR)

3.٥.1 Configuration

The TCR provides continuously controllable reactive power only in the laggingpower-factor range. To extend the dynamic controllable range to the leadingpower-factor domain, a fixed-capacitor bank is connected in shunt with the TCR. The TCR MVA is rated larger than the fixed capacitor to compensate(cancel) the capacitive MVA and provide net inductive-reactive power shoulda lagging power-factor operation be desired. The fixed-capacitor banks, usuallyconnected in a star configuration, are split into more than one 3-phase group.Each capacitor contains a small tuning inductor that is connected in series andtunes the branch to act as a filter for a specific harmonic order. For instance, onecapacitor group is tuned to the 5th harmonic and another to the 7th, whereasyet another is designed to act as a high-pass filter. At fundamental frequency,the tuning reactors slightly reduce the net MVA rating of the fixed capacitors.

An FC–TCR compensator is shown in Fig. 3.11.

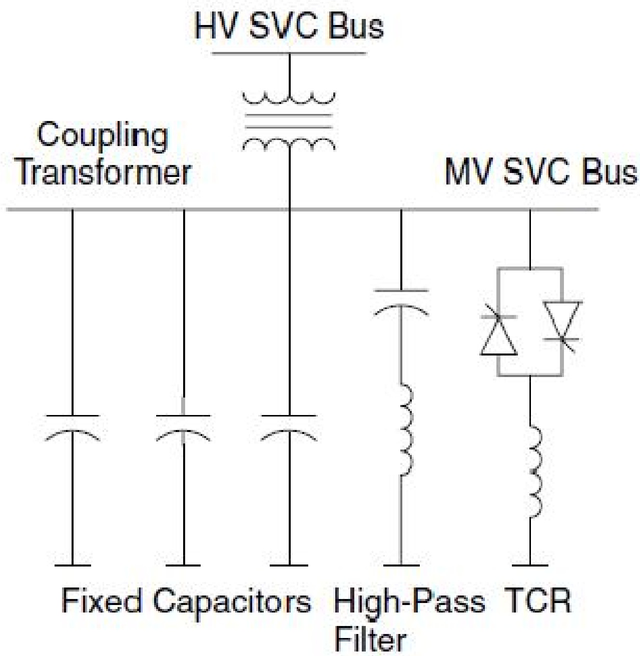

Fig.3.11. FC-TCR SVC

3.6 Operating Characteristic

3.6.1 Without the Step-Down Transformer

The operating *V-I* characteristicof an FC–TCR compensator is illustrated in Fig. 3.12. The fixed capacitorextends the operating-control range of the SVC to the leading side. The SVC current, *I*SVC, can be expressed as afunction of system voltage, *V*, and compensator susceptance, *B*SVC, as follows:

$$\bar{I}_{SVC} = \bar{V} j B_{SVC} \qquad (3.28)$$

$$B_{SVC}=B_C+B_{TCR} \text{ and } B_C=\omega C \qquad (3.29)$$

Figures 3.12(b) and (c) show the operating characteristic and the susceptance ofthis type of compensator, respectively, and both also show that var productionas well as var absorption is possible. By dimensioning the ratings of the TCRand the capacitor, respectively, the production and absorption ranges can beselected according to the system requirements.

3.6.2With the Step-Down Transformer

An FC–TCR SVC is usuallyconnected to the high-voltage power system by means of a step-down couplingtransformer, as shown in Fig. 3.22.The Compensator Susceptance The compensator susceptance, BSVC, isgiven by

$$B_{SVC}=\frac{B_\sigma(B_{C+}B_{TCR})}{B_\sigma+B_{C+}B_{TCR}} = \frac{1}{1+\frac{B_{C+}B_{TCR}}{B_\sigma}}(B_{C+}B_{TCR}) \quad (3.30)$$

WhereBσ is the susceptance of the transformer and $\mathbf{B_{TCR}}$ is variable from 0 toBL, according to the firing angles from 180 to 90.

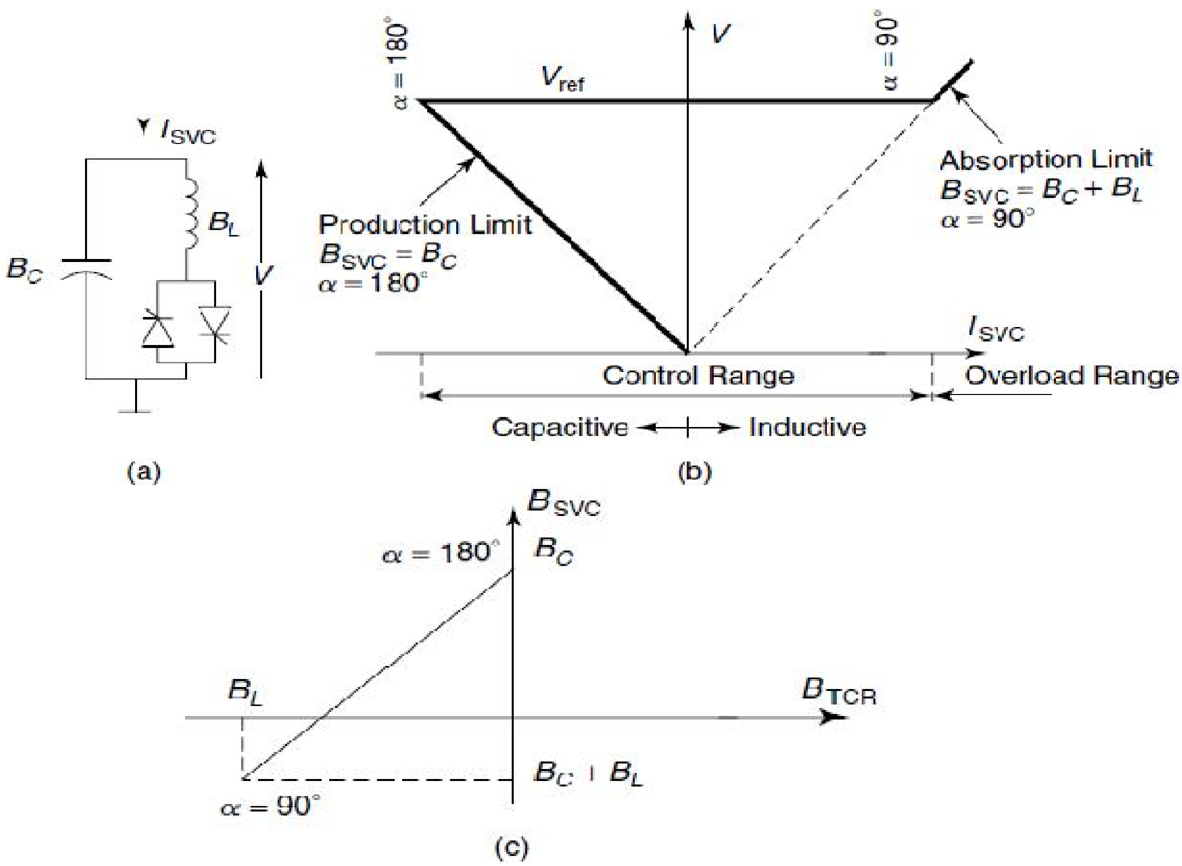

Figure 3.12 The operating characteristics of an FC–TCR without a coupling transformer.

From Eq. (3.27), the susceptance limits can be calculated. Susceptance at the production (capacitive) limit, that is, with $\boldsymbol{B_{TCR}}$ at α=180, is expressedAs

$$B_{SVC_{max}} = \frac{B_\sigma B_C}{B_\sigma + B_C} \qquad (3.31)$$

Susceptance at the absorption (inductive) limit, that is, with $B_{\mathbf{TCR}}=B_L$at α= 90 is given by

$$B_{SVC_{min}} = \frac{B_\sigma (B_C + B_L)}{B_\sigma + B_C + B_L} \qquad (3.32)$$

It must be noted that *BL* is a negative quantity. An analysis of Eq. (3.27)shows that the total susceptance*B*SVC of the static var compensator does notchange linearly with $B_{\mathbf{TCR}}$. However, if (B_C/ B_σ)<< 1 and (B_L/ B_σ) << 1, whichis usually the case, the nonlinearity is relatively small. This assumption impliesthat the reactance of the coupling transformer is greatly smaller than the reactance of either the fixed capacitor or TCR.

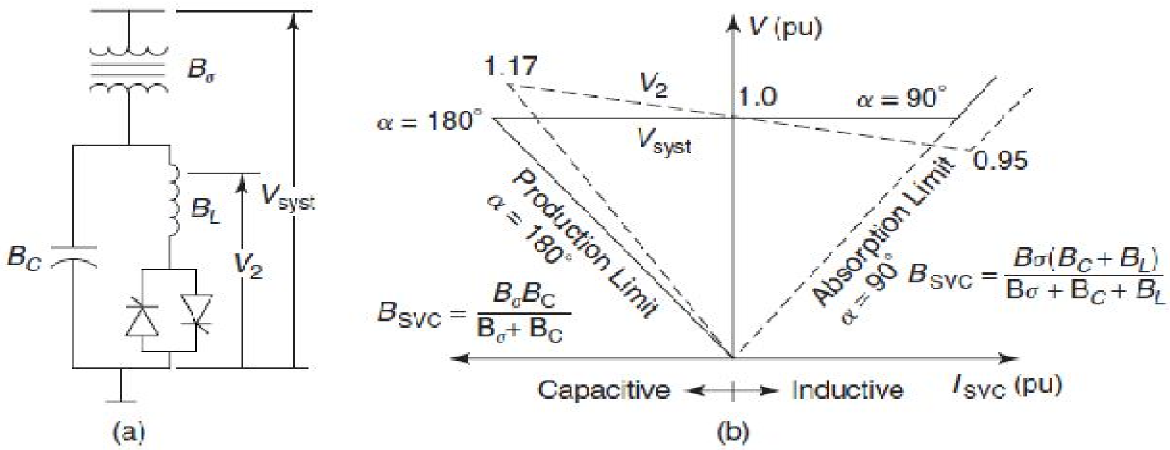

Figure 3.13 FC–TCR with a step-down transformer and its *V-I* characteristics

A drawback of the FC–TCR SVC is the circulation of large currents in the FC–TCR loop needed for cancellation of capacitive vars. This results in high steady-state losses, even when the SVC is not exchanging any reactive power with the power system, as shown in Fig. 3.14. Typical losses in an FC–TCR scheme vary from 0.5% to 0.7% of the MVA rating. However, these losses can be minimized by switching the fixed capacitors through mechanical breakers, ensuring that the capacitors are inserted in the compensator circuit only when leading vars are needed. Thus a smaller-size–interpolating TCR can be used, and consequently, the steady-state operating losses can be reduced.

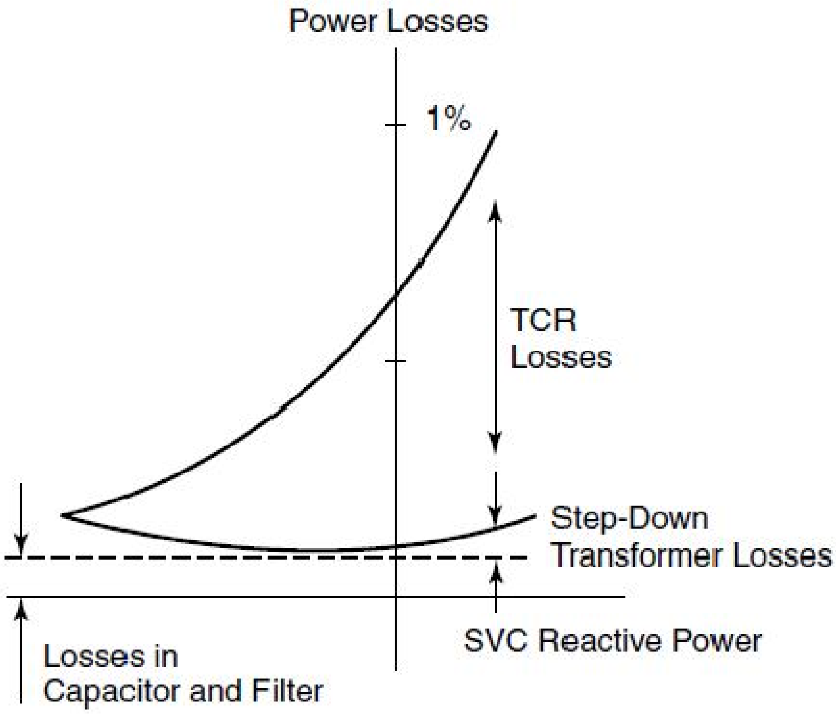

Fig.3.14 Losses in an FC–TCR.

3.7 The Mechanically Switched Capacitor ThyristorControlled Reactor (MSC-TCR)

In certain applications, especially those involving few capacitor switchings, an MSC–TCR has been shown to offer acceptable performance at much lower compensating system costs than a TSC–TCR.

The different MSC–TCR circuit configurations are shown in Fig. 3.15. The mechanically switched capacitor can be located at the high-voltage bus; however, in such a case, fixed-harmonic filters must be installed in shunt with the TCR on the transformer secondary to reduce the harmonic loading of the transformer.

One advantage of the MSC–TCR scheme lies in its lower capital cost from the elimination of the thyristor switches in the capacitor branches; another advantage, in the reduced operating costs in terms of losses. The disadvantage of the MSC–TCR is a slower speed of response. The mechanical switches can close in two cycles and open in about eight, compared to one-half to one cycle with thyristor switches. Some studies show that to compensate for the slower speed and to achieve a level of transient stability similar to a thyristorswitched capacitor–thyristor-controlled reactor (TSC–TCR), a 25% higher–rated MSC–TCR SVC may be needed.

Another problem with the MSC–TCR relates to the trapped charge that is invariably left on the capacitor following deenergization. The residual charge on the capacitors is usually dissipated in about five minutes through discharge resistors built into the capacitor units. If the capacitor is switched on within five minutes after deenergization, the trapped charge may lead to increased switching transients. The MSCs can be switched in only when the capacitors are discharged. One transformer, suchas a potential transformer, in parallel with each phase of the capacitor bank.Doing so aids in dissipating the trapped charge within 0.15 s.

The TCR in an MSC–TCR is designed to have a lower inductance as compared to a TCR in a TSC–TCR SVC of similar rating. This design is to permit the increase of its overload capacity to transiently balance the capacitive-reactive power output. A lower inductance TCR produces an increased level of harmonics and thus needs a more elaborate filtering than a TSC–TCR.

The mechanical switches also possess a finite life, typically 2000–5000 operations, compared to the infinite switching life of thyristors. The MSCs are usually switched two to four times a day; they are connected during heavy-load conditions and removed under light-load conditions. An MSC–TCR may not be very suitable for voltage-control applications in a system experiencing frequent disturbances; nevertheless, studies has shown that MSC–TCRs provide performance comparable to a TSC–TCR in damping-power swings between two areas and also in alleviating severe voltage depression from system faults, all at a much lower installed capital cost than an equivalent TSC–TCR. Losses with mechanically switched capacitors are fairly low; they lie in the range of 0.02–0.05%. Because capacitors are very sensitive to over voltages and over currents, appropriate protection strategies need to be employed.

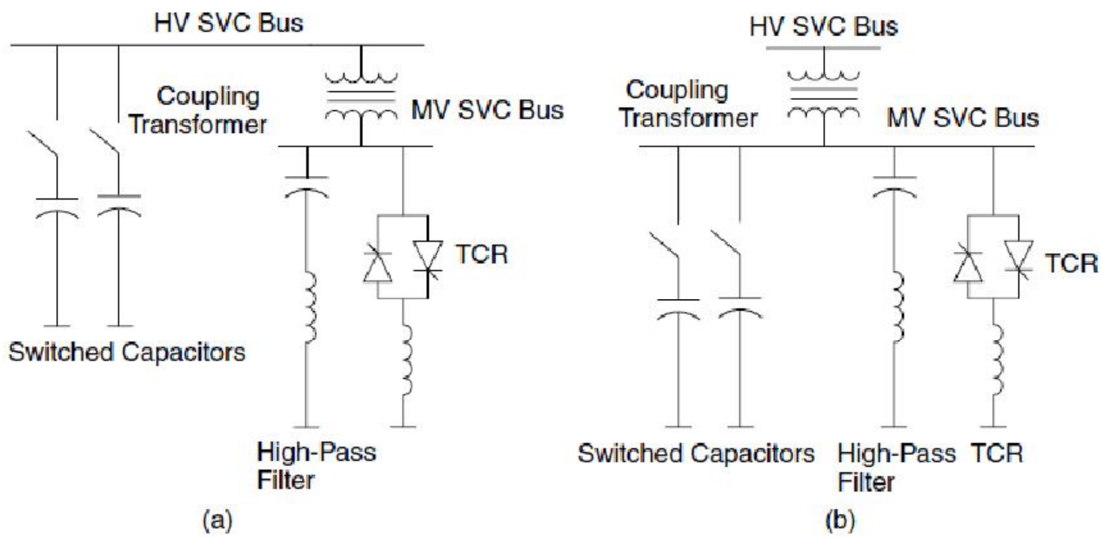

Fig.3.15 Different configurations of an MSC–TCR compensator.

3.8 The TSC Configuration

A basic single-phase TSC consists of an anti-parallel–connected thyristor-valvepair that acts as a bidirectional switch in series with a capacitor and a currentlimitingmall reactor. The thyristor switch allows the conduction for integral number of half-cycles. The capacitor is not phasecontrolled, as is a TCR, thethyristor valves are turnedon at an instant when minimum voltage is sensed across the valves to minimize these witching transients. Barring these initial transients, the TSC current is sinusoidaland free from harmonics, thus obviating the need for any filters. The small-series inductor is installed to limit current transients during overvoltageconditions and planned switching operations, as well as when switchingat incorrect instants or at the inappropriate voltage polarity. The inductor magnitudeis chosen to give a natural resonant frequency of four to five times the system nominal frequency, which ensures that the inductance neither creates aharmonic-resonant circuit with the network nor hampers the TSC control system.

Another function of this series inductor is to act in combination with thecapacitor as a filter for harmonics generated by the associated TCR. In somecases, discharge circuits are provided with the capacitors to rapidly dissipatethe remnant charge on the capacitor after a switch-off.

A practical TSC compensator involves *n* 3-phase TSC banks of equal ratingconnected in shunt. The overall TSC susceptance at any given instant is the sumof conducting TSC. In some cases, the ratings of different constituent TSC steps.

3.9 The Thyristor-Switched Capacitor Thyristorcontrolled Reactor (TSC–TCR)

3.9.1 Configuration

The TSC–TCR compensator shown usually comprises *n* TSC banksand a single TCR that are connected in parallel. The rating of the TCR is chosento be 1/ *n* of the total SVC rating. The capacitors can be switched in discretesteps, whereas continuous control within the reactive-power span of each stepis provided by the TCR. Thus the maximum inductive range of the SVC correspondsto the rating of the relatively small interpolating TCR.

As the size of TCR is small, the harmonic generation is also substantiallyreduced. The TSC branches are tuned with the series reactor to different dominantharmonic frequencies. To avoid a situation in which all TSCs and, consequently,the associated filters are switched off (with only the TCR in operation),an additional nonswitchable capacitive-filter branch is provided.

The main motivations in developing TSC–TCRs was for enhancing the operationalflexibility of the compensator during large disturbances and for reducingthe steady-state losses. A fixed capacitor–thyristor-controlled reactor (FC–TCR)behaves like a parallel LC circuit that tends to set up a resonance with the acsystem impedance during large disturbances. What particularly aggravates theproblem is when severe voltage swings are experienced and followed by loadrejection. In this event, a TSC–TCR can quickly operate to disconnect all thecapacitors from the compensator, precluding the resonant oscillations. This featureof disconnecting the capacitor in exigencies is not available with FC–TCRs.

3.10 Delays in the Firing System

1-Thyristor DeadtimeThe concept of thyristordeadtime in SVC controls can be explained on the basis of a single-phase,2-pulse TCR in which the firing angle can change from 90 to 180. In sucha TCR, the firing angle can only be varied once in each half-cycle; when theconduction starts in either half-cycle, any change in the firing angle of the samethyristor will not have any effect, impling that the desired firing-angle signal,aorder, may be sampled just twice in each cycle just before the positive- andnegative-voltage peaks. The sampling frequency thus needs to be no faster thantwice the fundamental frequency. If the aorder changes to a new value just beforethe positive-voltage peak, it can be implemented instantaneously with a zerodelay in the forward thyristor of the anti-parallel–connected pair. However, ifthe update in aorder occurs, in the worst casejust after the positive peak ofthe voltage across TCRthere will be a time delay of a half-cycle until thisupdate is picked up at the next sampling just before the negative-voltage peak.This delay, caused by the thyristors inability to respond to changes in aorderat any arbitrary time instant, is termed thyristordead time. For a 2-pulse TCR,the deadtime is a random quantity varying from 0 to $T/ 2$, where T is the timeperiod of the voltage wave. It is therefore assigned an average value of $T/ 4$.Extending the preceding argument to a 6-pulse TCR, it can be seen that thefrequency of sampling the signal aorder needs to be only six times the fundamentalfrequency. The sampling instants occur shortly before the six voltage peaks.

3.11 Protective Functions of SVC control

The SVC control also has functions to provide protection under faulted or overload conditions that may affect the equipment or system response. These are listed below:

1-Undervoltage Strategy

The SVC is ineffective under low voltage conditions due to faults in the system. However, the clearing of the fault can result in temporary overvoltagesdue to load rejection, particularly under weak system conditions. The response of the SVC required immediately after the fault clearing is oppositeof the normal voltage regulator function during a fault. To avoid delay inthe required response of the SVC, the normal voltage regulator action isdeactivated when voltage falls below a threshold (say 60% of the normalvoltage). TSC is blocked and Bref SVC is frozen at the previous value (priorto the voltage dip). The normal SVC regulator action is resumed after thevoltage climbs above a certain threshold (say 70%) and remains (above thethreshold) there for sometime (say 30 ms). The blocking of TSC also helpsin reducing the transient by preventing the capacitor discharge.

2-TCR Overcurrent Limiter

Under high voltage conditions, the SVC will be at its inductive limit and theTCR current may exceed its rated value. To protect the thyristor valves usedin TCR, it is necessary to limit the current through it by phase control. Toavoid interaction with voltage regulator function, a time delay is introduced(of the order of 100 ms). The overcurrent limiter takes into account theshort-term overload capability of the TCR.

3.12 Power Flow Study

In power engineering, the power flow study is an important tool involving numerical analysis applied to a power system. A power flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (voltages, voltage angles, real power and reactive power).

3.13 Power Flow Solution Methods:

There are four methods can be used to solve power flow equation. The methods are Newton-Raphson, Fast-Decoupled and Gauss-Seidel and DC power flow methods.

3.13.1 The Newton-Raphson Method:

For large power system, the Newton –Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration. Since in the power flow problem real power

3.14 Methodology:

Neplan program is widely used tool to perform load flow analysis in power system In this study, a model of the Sudan national grid was developed using Neplan .

The flow Chart for SVC size and location selection

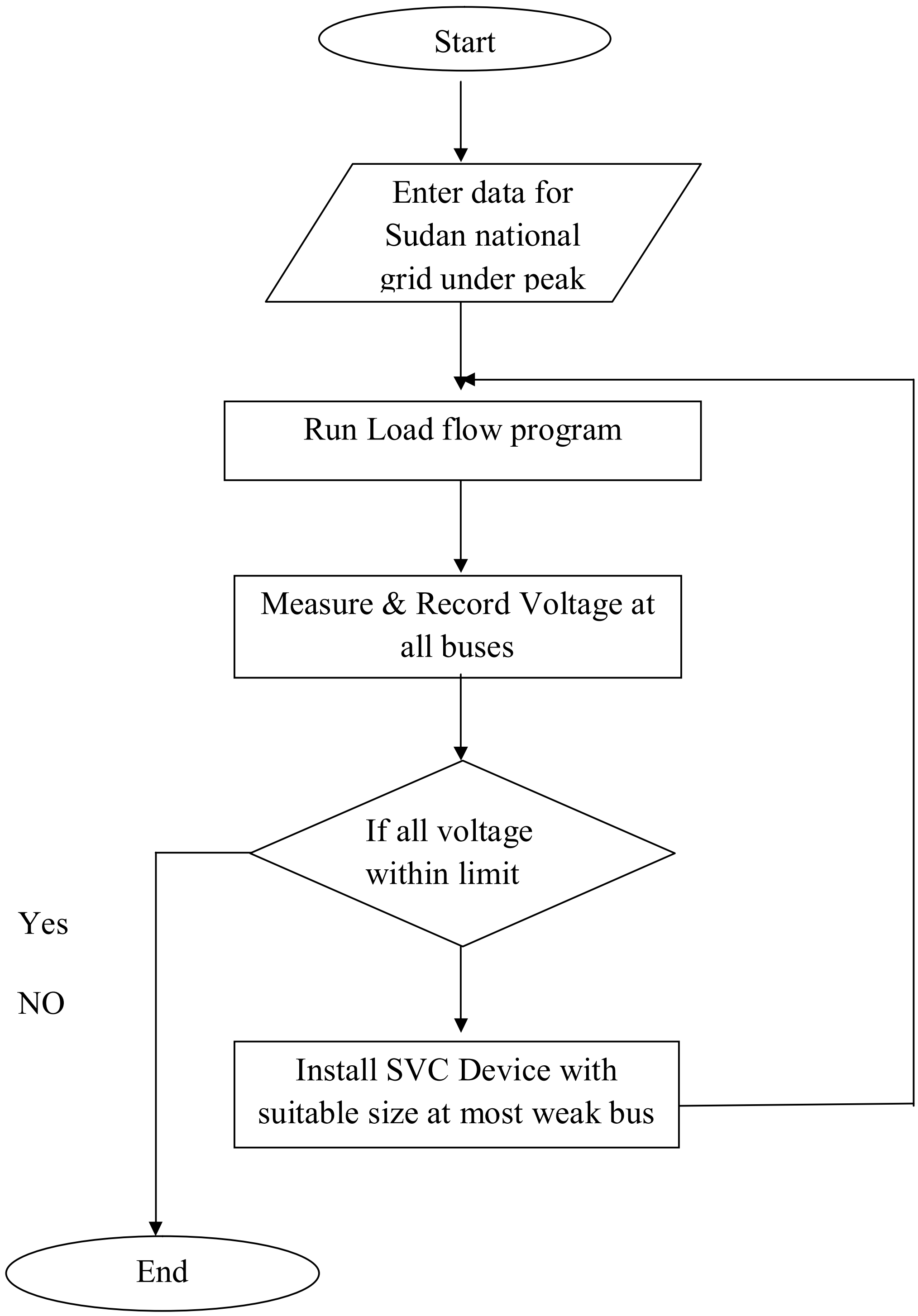

Fig .3.16 Flow chart A

Chapter four

Voltage Profile of National Grid (Case study)

4.1 National Grid Layout Description:

Electricity generation in Sudan was established in 1908, with installed capacity of 100 kW. Then the generation capacity was increased to 3,000 kW. In 1962, the first station was run hydro power plant to generate electricity Sennar reservoir with a capacity of 15 MW. Then added to the water stations discounted Girba station with a capacity of 17.8 MW and Rosaries plant design capacity of 280 MW. The Merowe Dam project is a multipurpose scheme for hydropower generation. With an installed capacity of 1250 MW.The Kosti station (steam generation)with an installed capacity of 500 MW.

4.2 Results and Discussions

4.2.1 Results

Table 4.1 shows the size and location of SVC. Table 4.2 and table 4.3 show the result from load flow of Sudan national grid for both cases with SVC and without SVC.

Table 4.1 SVC Size & location

S/N	Name	Rated KV	Mvar shared by SVC	QC Max	QL Max
1	FAO 1	110	-24	30	10
2	HAG1	110	-22.2	30	10
3	SOB1 B2	110	-39	50	15
4	LOM1	110	-208	215	30
5	OMD1	110	-219.8	220	40
6	BNT1	110	-147.3	160	40
7	MAN1	110	-44.3	60	12
8	FRZP2	220	85	20	85
9	DON2	220	42	10	60
10	UMR2	220	123	0	130

Table (4.1) shown the SVC devices which are selected for ten locations with specified sizes in national grid in order to improve voltage profile and Table(4.2 and 4.3) shown the voltage measurement from load flow for both case with and without installing SVC (Rows which highlighted with green color indicated to location of SVC device Installation).

Table 4.2 voltage values from load flow for 110 KV buses

		Without SVC			With SVC			
S/N	Node Bus	Voltage in KV	% V	Angle	Voltage in KV	% V	Angle	Location
1	AFR1	94.427	85.84	-18.4	108.264	98.42	-15	Khartoum
2	BAG1	96.022	87.29	-17.5	107.87	98.06	-14.2	Khartoum
3	BNT1	94.66	86.05	-18.9	110	100	-15.6	Omdurman
4	BSH1	87.924	79.93	-39.3	107.6	97.82	-31.7	East
5	FAO1	94.306	85.73	-13.6	110	100	-12.8	White Nile
6	GAD B2	97.147	88.32	-17.3	108.512	98.65	-14	Khartoum
7	GAD1 B1	97.149	88.32	-17.3	108.514	98.65	-14	Khartoum
8	GAM1	98.438	89.49	-17.7	111.233	101.12	-14.4	Omdurman
9	GDF 1	111.001	100.91	-4.8	114.143	103.77	-1.9	East
10	GND1	99.487	90.44	-16.8	107.778	97.98	-13.2	Gezera
11	HAG1	96.037	87.31	-16.2	110	100	-13.6	Gezera
12	HWT1	111.8	101.64	-4.5	114.687	104.26	-1.9	East
13	IZB1	99.787	90.72	-15.7	109.844	99.86	-12.6	Khar. North
14	IZG1	97.115	88.29	-17	108.739	98.85	-13.7	Khar. North
15	JAS1	97.513	88.65	-17.1	108.951	99.05	-13.8	Khartoum
16	KHE1	98.732	89.76	-16.2	109.441	99.49	-13.1	Khartoum
17	KHN1	100.105	91	-15.4	110.432	100.39	-12.3	Khar. North
18	KLX1	96.406	87.64	-17.4	109.679	99.71	-14.2	Khartoum
19	KUK1	99.215	90.2	-16	109.848	99.86	-12.8	Khar. North
20	LOM1	95.845	87.13	-18	110	100	-14.8	Khartoum
21	MAN1	85.927	78.12	-19.9	110	100	-17.5	Gezera
22	MAR1 B1	94.455	85.87	-16.9	108.534	98.67	-13.9	Gezera
23	MAR1 B2	94.455	85.87	-16.9	108.534	98.67	-13.9	Gezera
24	MHD1	96.231	87.48	-17.5	108.525	98.66	-14.2	Rever Nile
25	MIN1	89.26	81.15	-14.5	110	100	-14.6	White Nile
26	MSH1	110.116	100.11	-6.1	107.593	97.81	-3.1	White Nile
27	MUG`	94.173	85.61	-19.2	109.377	99.43	-15.8	Omdurman
28	NHAS1	100.399	91.27	-16.1	108.572	98.7	-12.7	Gezera
29	NRBK1	122.932	111.76	-4.6	114.522	104.11	-0.9	White Nile
30	OHAS1	100.26	91.15	-16.4	108.482	98.62	-12.9	Gezera
31	OMD1	94.684	86.08	-18.7	109.94	99.95	-15.4	Omdurman
32	ORBK1	98.611	89.65	-10.9	108.81	98.92	-8.1	White Nile
33	POR1	88.146	80.13	-38.9	107.645	97.86	-31.5	East
34	SHG1	94.78	86.16	-18.7	109.174	99.25	-15.3	Khartoum
35	SNG1	109.712	99.74	-6.9	113.471	103.16	-4.3	Blue Nile
36	SNJ 1	101.65	92.41	-12.1	111.433	101.3	-9	Blue Nile
37	SNP1	99.803	90.73	-12.7	111.277	101.16	-10.1	Blue Nile
38	SOB1 B1	96.279	87.53	-17.5	110	100	-14.6	Zone 1
39	SOB1 B2	96.279	87.53	-17.5	110	100	-14.6	Khartoum

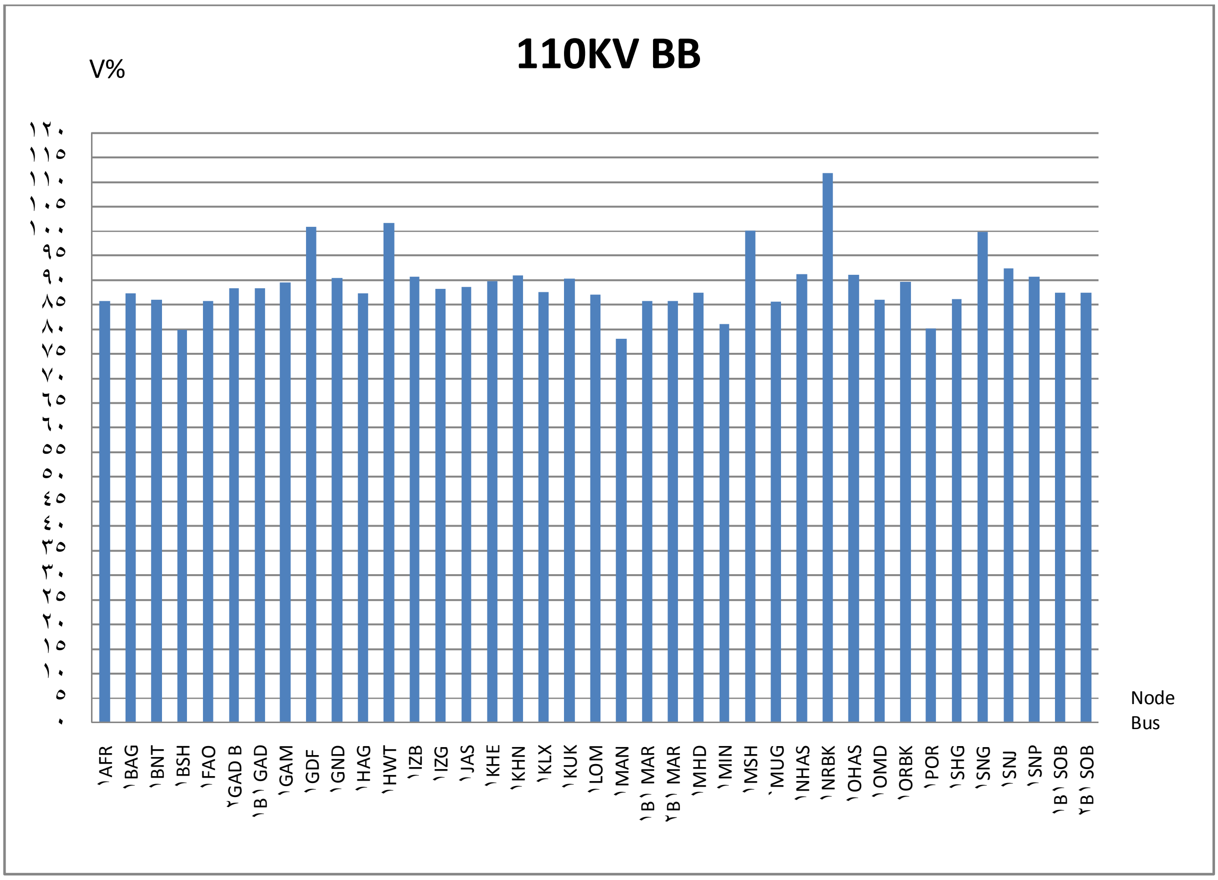

Fig.4.1 110KV BB voltage profile before installing SVC

From Fig.4.1The voltage profile for 110KV before installing SVC was varied from 78.12 % from rated at MAN1 to 111 % from rated at NRBK but generally the most node buses suffer from under voltages.

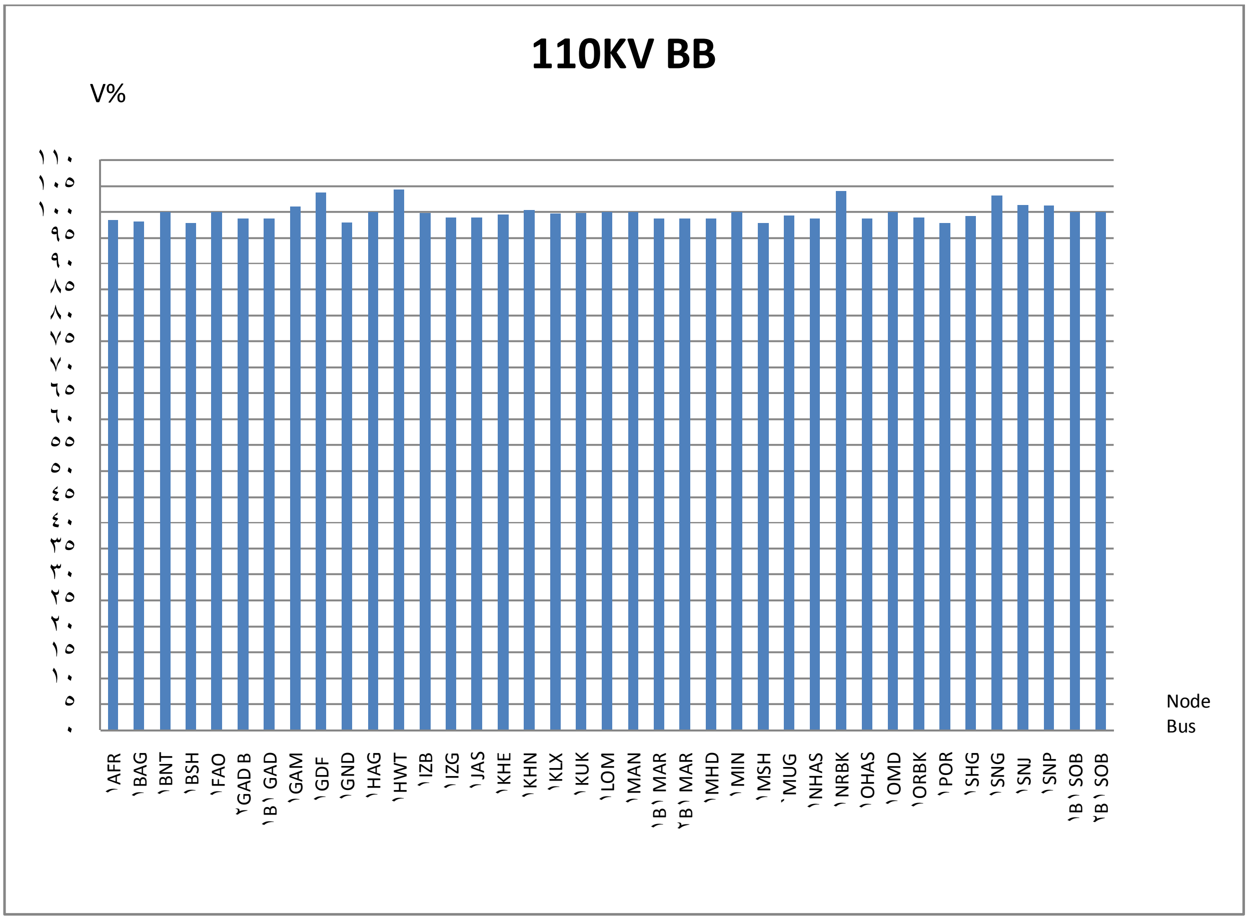

Fig.4.2 110KV BB voltage profile after installing SVC

From Fig.4.2 The voltage profile for 110KV after installing SVC it was observed that there are improvement in voltage profile for example the voltage at MAN 1 improved from 78 % from rated to 100% and voltage at NRBK improved from 111% from rated to 104 %, generally the voltage at all node bus within rated voltage.

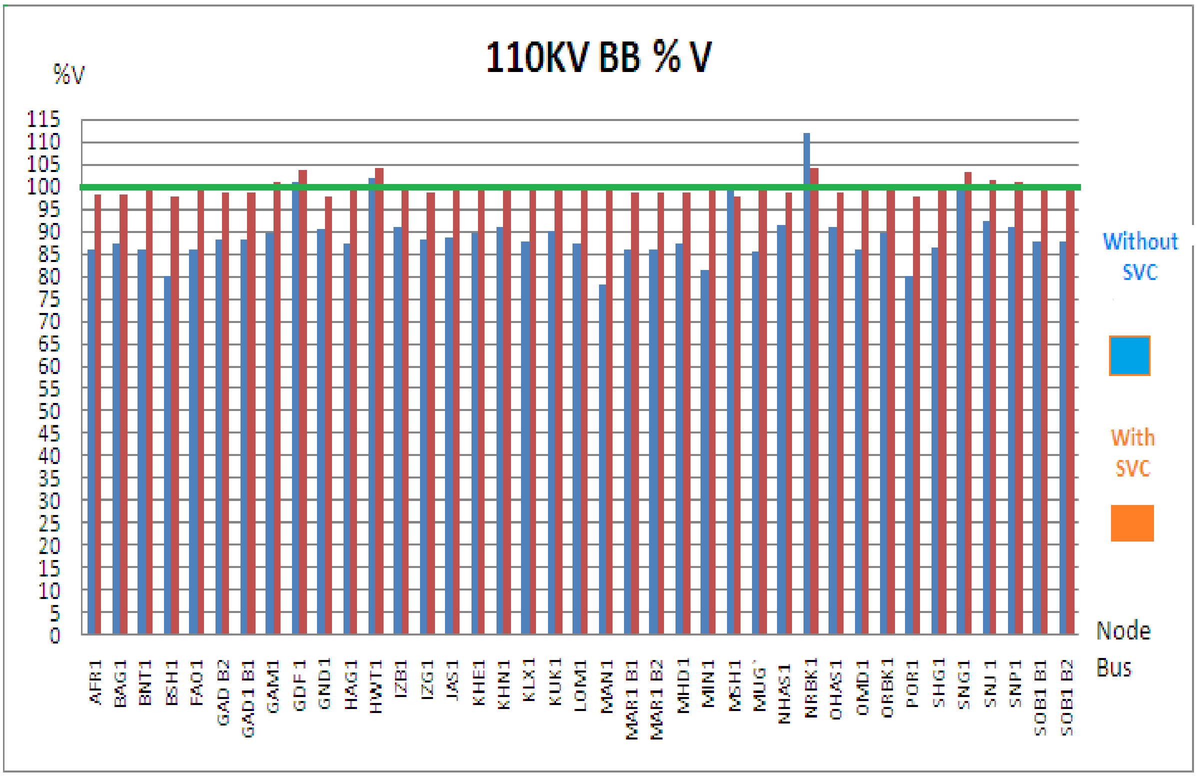

Fig.4.3 110KV BB voltage profile before & after installing SVC

The blue bars represent the percentage voltage before installing SVC while brown bars after installing SVC.

Table 4.3 voltage values from load flow for 220 KV+500KV buses

		Without SVC			With SVC			
S/N	Node Bus	Voltage in KV	% V	Angle	Voltage in KV	% V	Angle	Location
1	ATB2	214.044	97.29	-8.6	225.535	102.52	-6.5	North
2	ATB5	499.485	99.9	-3.7	520.36	104.07	-2.1	North
3	BBN2	237.481	107.95	-6.9	212.718	96.69	-3.7	Kord
4	DBT2	241.386	109.72	-6.2	213.731	97.15	-2.5	Kord
5	DEB2-B1	224.93	102.24	-5.4	219.663	99.85	-3.6	North
6	DEB2-B2	228.413	103.82	-4.5	223.21	101.46	-2.7	North
7	DON2	231.284	105.13	-6.4	220	100	-4.4	North
8	FRZ2	212.869	96.76	-9.8	225.168	102.35	-7.3	Khar. North
9	FRZP2	196.42	89.28	-33.1	220.213	100.1	-27.2	East
10	FUL2	237.059	107.75	-6.8	212.428	96.56	-3.6	Kord
11	GAD2	206.264	93.76	-12	220.199	100.09	-9.6	Khartoum
12	GAM2	210.73	95.79	-10.8	219.891	99.95	-8.6	Omdurman
13	GDF2	224.173	101.9	-2.9	228.047	103.66	-0.2	East
14	GER2	213.324	96.97	-9.7	225.166	102.35	-7.2	Khar. North
15	GRB2	225.966	102.71	-3.6	229.86	104.48	-0.9	East
16	GRO2	203.548	92.52	-33.5	228.205	103.73	-27.6	East
17	HUD	214.765	97.62	-10.1	220.596	100.27	-8	Omdurman
18	HWT2	223.802	101.73	-4.4	229.571	104.35	-1.8	East
19	HYA	204.31	92.87	-22.6	225.44	102.47	-18.7	Zone 1
20	IBA2	204.621	93.01	-12	221.608	100.73	-9.6	Khar. North
21	JAS2	210.578	95.72	-10.9	220.872	100.4	-8.7	Khartoum
22	KAB2	208.91	94.96	-10.2	224.664	102.12	-7.9	Khar. North
23	KAB5	473.433	94.69	-6.4	521.354	104.27	-4.4	Khar. North
24	KLX2	202.636	92.11	-12.8	220.832	100.38	-10.4	Khartoum
25	KSL2	226.888	103.13	-4.1	230.842	104.93	-1.3	East
26	LOM2	191.691	87.13	-18	220	100	-14.8	Khartoum
27	2-Mar	204.107	92.78	-11.5	220.255	100.12	-9.1	Zone 1
28	MHD2	213.64	97.11	-10.4	221.172	100.53	-8.4	Omdurman
29	MRK2	216.029	98.2	-9.9	220.789	100.36	-7.7	Omdurman
30	MRK5	475.923	95.18	-5.9	525.779	105.16	-4	Omdurman
31	MSH2	235.026	106.83	-5.8	229.684	104.4	-2.7	White Nile
32	MWP2	218.169	99.17	-1.6	220.613	100.28	-0.2	North

33	MWP500	519.018	103.8	0.4	534.356	106.87	1.7	North
34	MWT2	218.848	99.48	-2.7	219.78	99.9	-1.2	North
35	NHAS2	203.669	92.58	-12.8	219.384	99.72	-10.1	Gezera
36	NHLF2	225.845	102.66	-3.8	229.751	104.43	-1.1	East
37	OBD2	243.296	110.59	-5.5	214.501	97.5	-1.6	Kord
38	POR2	194.531	88.42	-32.9	219.847	99.93	-27.2	Zone 1
39	RBK2	252.7	114.86	-2.5	236.54	107.52	1.5	White Nile
40	RNK2	247.678	112.58	-1.4	238.074	108.22	2.2	Blue Nile
41	ROS2	240.158	109.16	-0.3	236.258	107.39	3	Blue Nile
42	SHG2	189.559	86.16	-18.7	218.349	99.25	-15.3	Khartoum
43	SHN2	213.594	97.09	-9.9	225.76	102.62	-7.5	North
44	SNG2	221.593	100.72	-5.7	229.03	104.1	-3.2	Blue Nile
45	SNJ2	213.623	97.1	-8.2	225.641	102.56	-5.8	Zone 1
46	SNK2	199.05	90.48	-28.4	222.882	101.31	-23.5	East
47	SOB2	203.514	92.51	-12.6	220.723	100.33	-10.2	Khartoum
48	SWK2	198.142	90.06	-33.2	222.144	100.97	-27.3	East
49	TND2	252.128	114.6	-3.4	227.759	103.53	0.9	White Nile
50	UMR2	249.953	113.62	-3.9	220	100	0.6	Kord
51	UTP2	224.473	102.03	-2.2	227.899	103.59	0.5	East
52	WHL2	229.109	104.14	-6.6	217.837	99.02	-4.6	North
53	WWA2	232.621	105.74	-6.6	221.246	100.57	-4.6	North
54	ZBD2	239.223	108.74	-6.4	212.661	96.66	-2.9	Kord

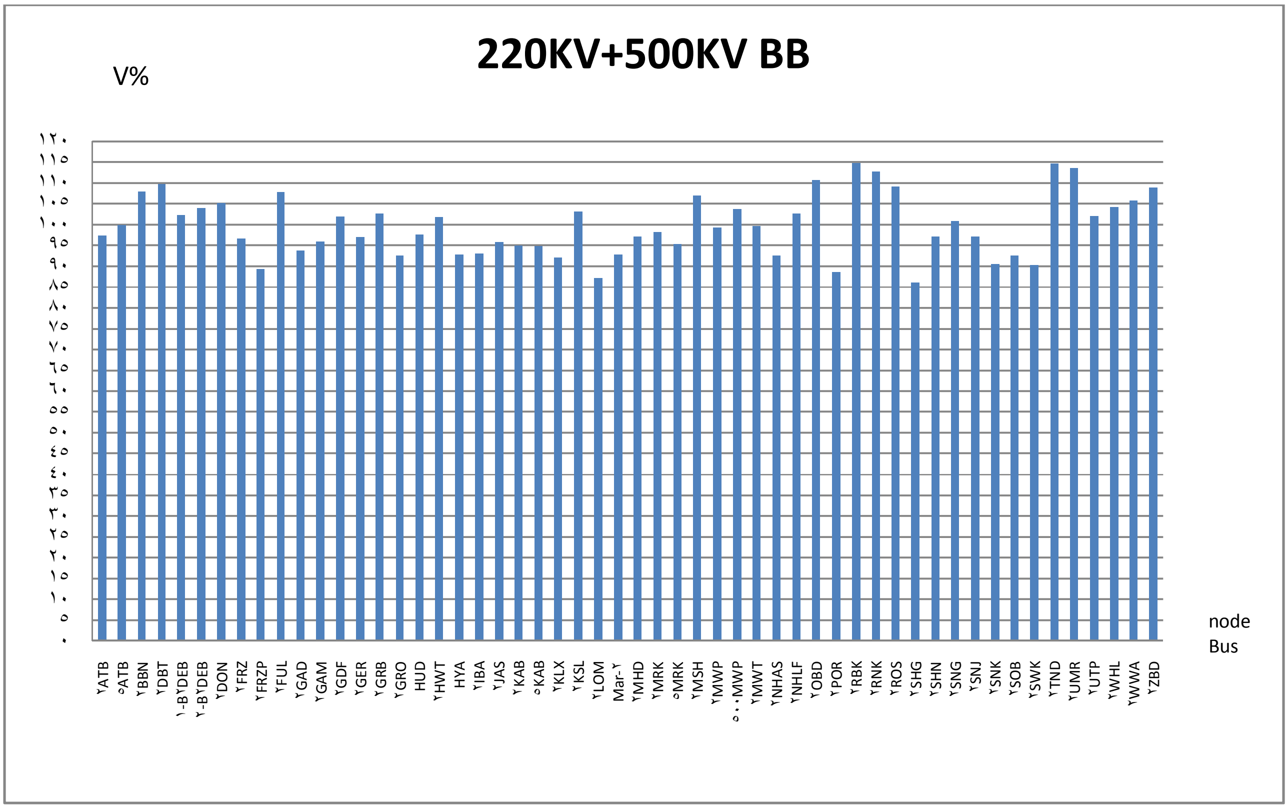

Fig.4.4 220KV+500KVBB voltage profile before installing SVC

From Fig.4.3The voltage profile for 220KV +500Kv before installing SVC was varied from 86 % from rated at SHG2 to 113 % from rated at UMR2.

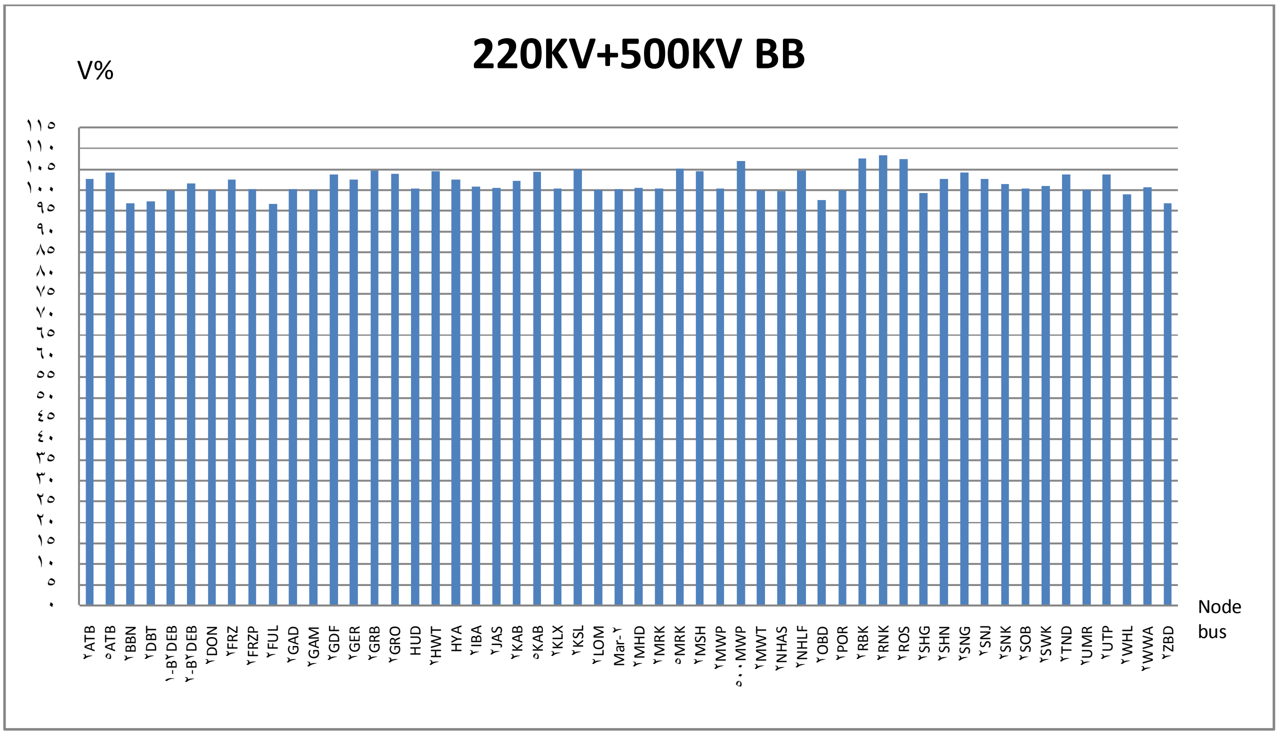

Fig.4.5 220KV+500KVBB voltage profile after installing SVC

From Fig.4.5The voltage profile for 220KV+500KV after installing SVC it was observed that there are improvement in voltage profile for example the voltage at SHG2 improved from 86 % from rated to 99% and voltage at UMR2 improved from 113% from rated to 100 %, generally the voltage at all node buses within rated voltage.

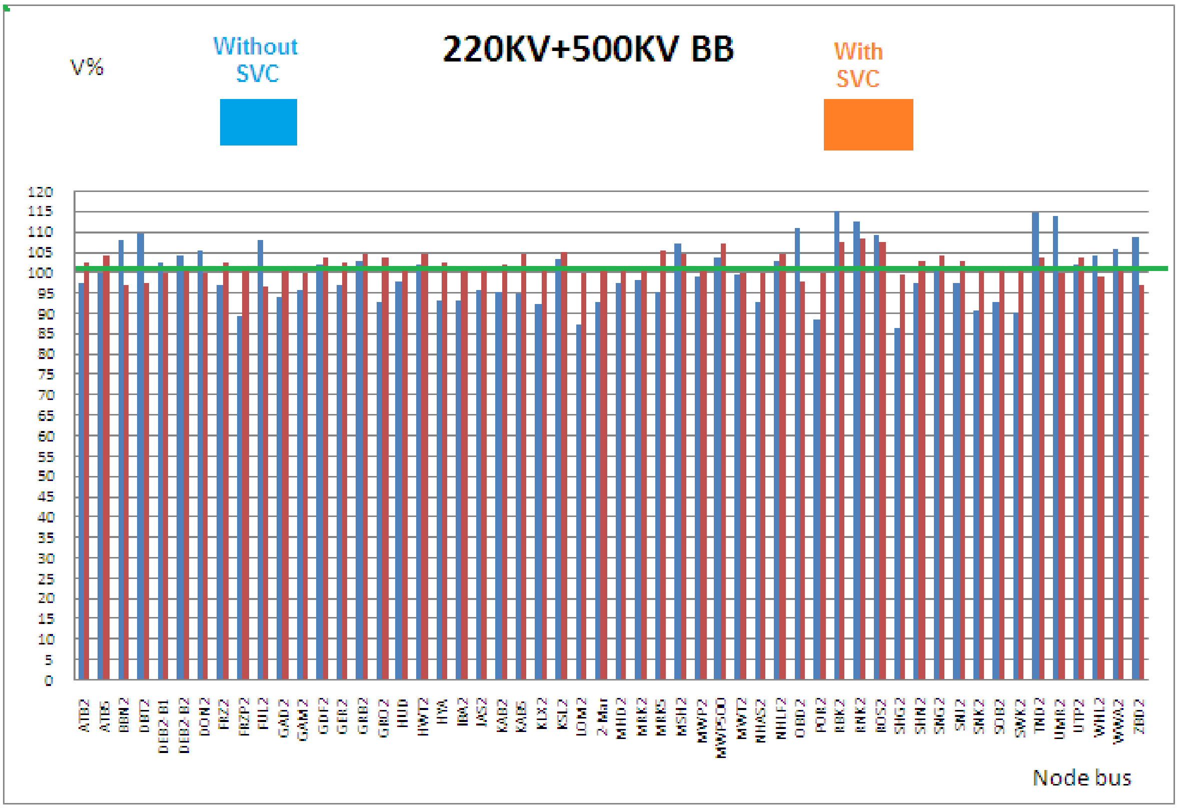

Fig.4.6 220KV+500KVBB voltage profile before and after installing SVC

The blue bars represent the percentage voltage before installing SVC while brown bars after installing SVC.

Table 4.4 voltage values from load flow for 110KV buses

S/N	Node Bus	Voltage Deviation before installing SVC	Voltage Deviation after installing SVC
1	AFR1	14.15727273	1.578181818
2	BAG1	12.70727273	1.936363636
3	BNT1	13.94545455	0
4	BSH1	20.06909091	2.181818182
5	FAO1	14.26727273	0
6	GAD B2	11.68454545	1.352727273
7	GAD1 B1	11.68272727	1.350909091
8	GAM1	10.51090909	-1.120909091
9	GDF 1	-0.91	-3.766363636
10	GND1	9.557272727	2.02
11	HAG1	12.69363636	0
12	HWT1	-1.636363636	-4.260909091
13	IZB1	9.284545455	0.141818182
14	IZG1	11.71363636	1.146363636
15	JAS1	11.35181818	0.953636364
16	KHE1	10.24363636	0.508181818
17	KHN1	8.995454545	-0.392727273
18	KLX1	12.35818182	0.291818182
19	KUK1	9.804545455	0.138181818
20	LOM1	12.86818182	0
21	MAN1	21.88454545	0
22	MAR1 B1	14.13181818	1.332727273
23	MAR1 B2	14.13181818	1.332727273
24	MHD1	12.51727273	1.340909091
25	MIN1	18.85454545	0
26	MSH1	-0.105454545	2.188181818
27	MUG`	14.38818182	0.566363636
28	NHAS1	8.728181818	1.298181818
29	NRBK1	-11.75636364	-4.110909091
30	OHAS1	8.854545455	1.38
31	OMD1	13.92363636	0.054545455
32	ORBK1	10.35363636	1.081818182
33	POR1	19.86727273	2.140909091
34	SHG1	13.83636364	0.750909091
35	SNG1	0.261818182	-3.155454545
36	SNJ 1	7.590909091	-1.302727273
37	SNP1	9.27	-1.160909091
38	SOB1 B1	12.47363636	0
39	SOB1 B2	12.47363636	0

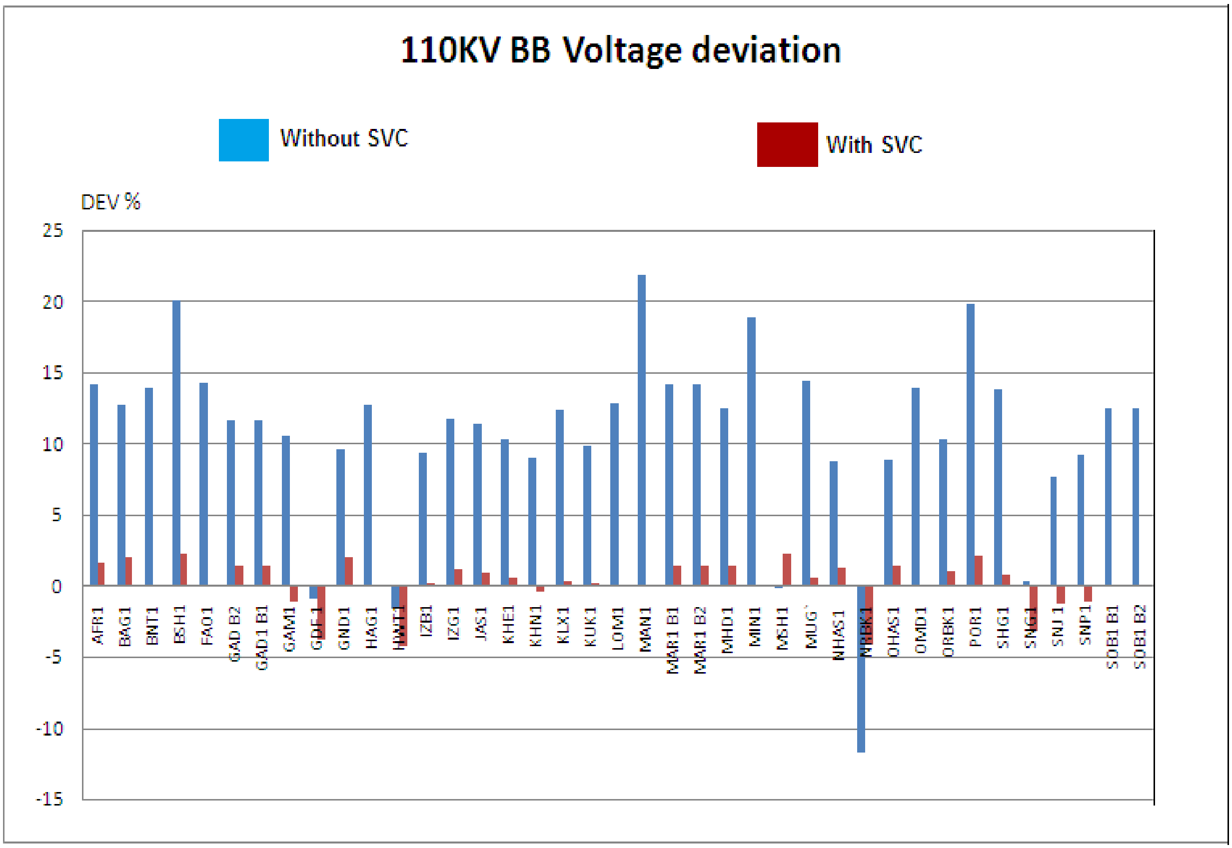

Fig.4.7 110KVBB voltage deviation before & after installing SVC

Figure 4.7 The voltage deviation from rated KV before and after installing SVC. The negative deviation indicated to over voltage & positive deviation to under voltage. This figure shown clearly the voltage deviation was decreased after installing SVC (the voltage deviation at location which SVC was installed decreased to zero at BNT,FAO,HAG,LOM,MAN,MINI& SOB B2) and 110 KV buses suffer from under voltage more than over voltage before installing SVC.

Table 4.5 voltage Deviation from load Rated for 220 KV+500KV buses

S/N	Node Bus	Voltage Deviation before installing SVC	Voltage Deviation after installing SVC
1	ATB2	2.707272727	-2.515909091
2	ATB5	0.103	-4.072
3	BBN2	-7.945909091	3.31
4	DBT2	-9.720909091	2.849545455
5	DEB2-B1	-2.240909091	0.153181818
6	DEB2-B2	-3.824090909	-1.459090909
7	DON2	-5.129090909	0
8	FRZ2	3.241363636	-2.349090909
9	FRZP2	10.71818182	-0.096818182
10	FUL2	-7.754090909	3.441818182
11	GAD2	6.243636364	-0.090454545
12	GAM2	4.213636364	0.049545455
13	GDF2	-1.896818182	-3.657727273
14	GER2	3.034545455	-2.348181818
15	GRB2	-2.711818182	-4.481818182
16	GRO2	7.478181818	-3.729545455
17	HUD	2.379545455	-0.270909091
18	HWT2	-1.728181818	-4.350454545
19	HYA	7.131818182	-2.472727273
20	IBA2	6.990454545	-0.730909091
21	JAS2	4.282727273	-0.396363636
22	KAB2	5.040909091	-2.12
23	KAB5	5.3134	-4.2708
24	KLX2	7.892727273	-0.378181818
25	KSL2	-3.130909091	-4.928181818
26	LOM2	12.86772727	0
27	2-Mar	7.224090909	-0.115909091
28	MHD2	2.890909091	-0.532727273
29	MRK2	1.805	-0.358636364
30	MRK5	4.8154	-5.1558
31	MSH2	-6.83	-4.401818182
32	MWP2	0.832272727	-0.278636364
33	MWP500	-3.8036	-6.8712
34	MWT2	0.523636364	0.1
35	NHAS2	7.423181818	0.28
36	NHLF2	-2.656818182	-4.432272727

37	OBD2	-10.58909091	2.499545455
38	POR2	11.57681818	0.069545455
39	RBK2	-14.86363636	-7.518181818
40	RNK2	-12.58090909	-8.215454545
41	ROS2	-9.162727273	-7.39
42	SHG2	13.83681818	0.750454545
43	SHN2	2.911818182	-2.618181818
44	SNG2	-0.724090909	-4.104545455
45	SNJ2	2.898636364	-2.564090909
46	SNK2	9.522727273	-1.31
47	SOB2	7.493636364	-0.328636364
48	SWK2	9.935454545	-0.974545455
49	TND2	-14.60363636	-3.526818182
50	UMR2	-13.615	0
51	UTP2	-2.033181818	-3.590454545
52	WHL2	-4.140454545	0.983181818
53	WWA2	-5.736818182	-0.566363636
54	ZBD2	-8.737727273	3.335909091

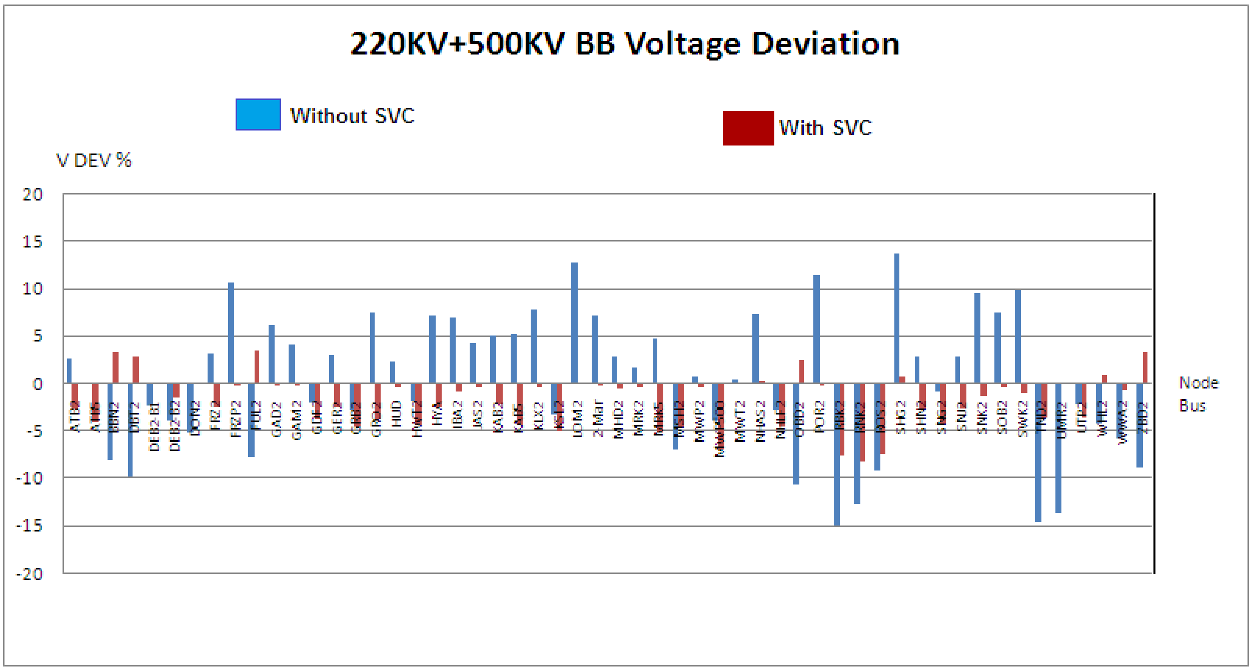

Fig.4.8 220KV+500KVBB voltage deviation before & after installing SVC

Figure 4.8 The voltage deviation from rated KV before and after installing SVC. The negative deviation indicated to over voltage and positive deviation to under voltage. This figure shown clearly the voltage deviation was decreased after installing SVC (the voltage deviation at location which SVC was installed decreased to zero at DON2 and UMR2).

4.3 Discussion

The total load for this case is 2515.06 MWs and the transmission losses are 98.34 MW (3.9%). For this case normal voltage control measures are undertaken; there are under voltage in some buses and over voltage in some buses as shown in tables above.

With the SVC the voltage is corrected to normal about 100% and the network losses are brought down slightly to 71.729 MW (2.9%).

Installing of SVC cause reduction in reactive power flows, thus allowing the lines to carry more active power and reduce the power loses and voltage drops in lines. Installing of any SVC at any node bus was not effected in that bus only but the improvement was extended to nearby buses which connected through lines although this decrease the cost bydecreasing thenumber of installing SVC but it also increase the loses through the lines when compared with installing SVC at any weak bus (VAR compensation for specified bus only).

Chapter five

Conclusion and Recommendations

5.1 Conclusion

Static Var Compensators (SVC) are easier to insert in the network since they are connected to the grid through a power transformer. SVCs are the key solution when the transmission system is pushed to its limits and needs a continuous voltage control with a short time response in a contingency situation. More over with the new SVC, based on voltage source converters, it is possible to support the system during faults and transient period or to improve power quality. It has found that by load flow using Neplan program when SVCs are installed in Sudan national grid during peak load, we have reduced branch losses and voltage profile was improved. Reduction of losses, increase of power transfer capability and voltage profile can also be optimized.

5.2 Recommendations

- Use multiple types of FACTs (the combination of the series and shunt can provide better solution than shunt combination only).
- The algorithm required some improvement to study the effect of SVC for both steady state and transient conditions.
- To study the effect of SVC in economic operation and transmission lines loss reduction.

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Appendix A

Three Winding Transformer Data:

	Name	Vector Group	Sr12	Sr23	Sr31	Ur1	Ur2	Ur3	ukr12(1)	ukr23(1)	ukr31(1)	uRr12(1)	uRr23(1)	uRr31(1)	ukr12(0)	ukr23(0)	ukr31(0)	uRr12(0)	uRr23(0)	uRr31(0)	I0	P Fe	Earthing primary	ZE1 activ	Earthing secondary
			MVA	MVA	MVA	kV	kV	kV	%	%	%	%	%	%	%	%	%	%	%	%	%	kW		%	
1	TR3-Atbara 1	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	direct
2	TR3-Atbara 2	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	direct
3	TR3-Eid Babiker TR1	YNy0d11	150	150	22.5	215	110	33	9.39	27.94	5.54	0.11	0.11	0.11	9.39	27.94	5.54	0.5	0.5	0.5	0	0	direct	100	Direct
4	TR3-Eid Babiker TR2	YNy0d11	150	150	22.5	215	110	33	9.65	26.81	5.62	0.11	0.11	0.11	9.65	26.81	5.62	0.5	0.5	0.5	0	0	direct	100	Direct
5	TR3-Eid Babiker TR3	YNy0d11	150	150	22.5	215	110	33	9.65	26.81	5.62	0.11	0.11	0.11	9.65	26.81	5.62	0.5	0.5	0.5	0	0	direct	100	Direct
6	TR3-El Kabashi 1	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	Direct
7	TR3-El Kabashi 2	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	Direct
8	TR3-Gamoeia 1	YNyn0d1	150	150	50	220	115	34.5	13	10	8.17	0.11	0.11	0.11	13	10	8.17	0.5	0.5	0.5	0	0	direct	100	Direct
9	TR3-Gamoeia 2	YNyn0d1	150	150	50	220	115	34.5	13	10	8.17	0.11	0.11	0.11	13	10	8.17	0.5	0.5	0.5	0	0	direct	100	Direct
10	TR3-GBA1	YNyn0d11	100	100	50	220	66	33	12.53	7.16	10.59	0.43	0.22	0.43	12.53	7.16	10.59	0.43	0.22	0.43	0	0	direct	100	Direct
11	TR3-GBA2	YNyn0d11	100	100	50	220	66	33	12.53	7.16	10.59	0.43	0.22	0.43	12.53	7.16	10.59	0.43	0.22	0.43	0	0	direct	100	Direct
12	TR3-Geradef TR1	YNyn0yn0	25	25	10	110	66	11	10	26.25	15	0.11	0.11	0.11	10	26.25	15	0.5	0.5	0.5	0	0	direct	100	Direct
13	TR3-Geradef TR2	YNyn0d11	100	100	50	220	110	33	12.63	9.36	11.38	0.11	0.11	0.11	12.63	9.36	11.38	0.5	0.5	0.5	0	0	direct	100	Direct
14	TR3-Geradef TR3	YNyn0yn0	25	25	10	110	66	11	10	26.25	15	0.11	0.11	0.11	10	26.25	15	0.5	0.5	0.5	0	0	direct	100	Direct
15	TR3-Geradef TR4	YNyn0d11	100	100	50	220	110	33	12.63	9.36	11.38	0.11	0.11	0.11	12.63	9.36	11.38	0.5	0.5	0.5	0	0	direct	100	Direct
16	TR3-Giad AT	YNy0d11	60	60	30	215	110	33	12.06	25.42	20.3	0.11	0.11	0.11	12.06	25.42	20.3	0.5	0.5	0.5	0	0	direct	100	Direct
17	TR3-HAS TR1	YNyn0d11	150	150	50	220	110	11	13.04	8.08	7.6	0.11	0.11	0.11	13.04	8.08	7.6	0.5	0.5	0.5	0	0	impedance	100	Impedance
18	TR3-Jebel Aulia 1	YNyn0d11	150	150	50	220	110	34.5	13	10	8.17	0.11	0.11	0.11	13	10	8.17	0.5	0.5	0.5	0	0	direct	100	Direct
19	TR3-Jebel Aulia 2	YNyn0d11	150	150	50	220	110	34.5	13	10	8.17	0.11	0.11	0.11	13	10	8.17	0.5	0.5	0.5	0	0	direct	100	Direct
20	TR3-KHN GT	YNd11d11	60	30	30	110	11	11	9.61	10	9.61	0.11	0.11	0.11	0	0	0	0	0	0	0	0	impedance	100	Impedance
21	TR3-Kilo X AT1	YNyn0d11	100	100	15	215	110	11	5.97	9.48	2.43	0.11	0.11	0.11	5.96	9.52	2.43	0.5	0.5	0.5	0	0	direct	100	Direct
22	TR3-Kilo X AT2	YNyn0d11	100	100	15	215	110	11	6.16	9.95	2.448	0.11	0.11	0.11	6.02	9.52	2.43	0.5	0.5	0.5	0	0	direct	100	Direct
23	TR3-Kilo X AT3	YNyn0d11	100	100	15	215	110	11	6.16	9.95	2.448	0.11	0.11	0.11	6.02	9.52	2.43	0.5	0.5	0.5	0	0	direct	100	Direct
24	TR3-Kuku 1	YNy0d11	30	30	7.5	110	33	11	12.26	7.69	5.45	0.11	0.11	0.11	12.26	7.69	5.45	0.5	0.5	0.5	0	0	direct	100	Direct
25	TR3-Kuku 2	YNy0d11	30	30	7.5	110	33	11	12.26	7.69	5.45	0.11	0.11	0.11	12.26	7.69	5.45	0.5	0.5	0.5	0	0	direct	100	Direct
26	TR3-Kuku 3	YNy0d11	30	30	7.5	110	33	11	12.26	7.69	5.45	0.11	0.11	0.11	12.26	7.69	5.45	0.5	0.5	0.5	0	0	direct	100	Direct
27	TR3-Mahadia 1	YNyn0d11	150	150	50	220	110	33	12.67	12.76	8.96	0.11	0.11	0.11	12.67	12.76	8.96	0.5	0.5	1.5	0	0	direct	100	Direct
28	TR3-Mahadia 2	YNyn0d11	150	150	50	220	110	33	12.67	12.76	8.96	0.11	0.11	0.11	12.67	12.76	8.96	0.5	0.5	1.5	0	0	direct	100	Direct
29	TR3-Mahadia 3	YNyn0d11	150	150	50	220	110	33	12.67	12.76	8.96	0.11	0.11	0.11	12.67	12.76	8.96	0.5	0.5	1.5	0	0	direct	100	Direct
30	TR3-Makhiyat 1	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	Direct
31	TR3-Makhiyat 2	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	Direct
32	TR3-Makhiyat 3	YNyn0d11	300	75	75	500	220	33	16.8	6.1	10.7	0.173	0.13	0.139	16.8	6.1	10.7	0.173	0.13	0.139	0.058	125.1	direct	100	Direct
33	TR3-Meringan TR1	YNyn0d11	80	80	30	215	110	11	14.09	7.93	8.86	0.11	0.11	0.11	14.09	7.93	8.86	0.5	0.5	0.5	0	0	direct	100	Direct
34	TR3-Meringan TR2	YNyn0d11	80	80	30	215	110	11	14.09	7.93	8.86	0.11	0.11	0.11	14.09	7.93	8.86	0.5	0.5	0.5	0	0	direct	100	Direct
35	TR3-Merowe Auto TR1	YNyn0d5	150	150	36	500	220	33	11	21	32	0.083	0.11	1.96	11	21	32	0.5	0.5	1.96	0	32	direct	100	Direct

36	**TR3-Merowe Auto TR2**	**YNyn0d5**	**150**	**150**	**36**	**500**	**220**	**33**	**11**	**21**	**32**	**0.11**	**0.11**	**1.96**	**11**	**21**	**32**	**0.5**	**0.5**	**1.96**	**0**	**0**	**direct**	**100**	**Direct**
37	**TR3-Merowe G1-2**	**YNd11d11**	**141**	**141**	**141**	**525**	**13.8**	**13.8**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**0.12**	**121.2**	**direct**	**100**	**Direct**
38	**TR3-Merowe G3-4**	**YNd11d11**	**141**	**141**	**141**	**525**	**13.8**	**13.8**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**0.12**	**121.2**	**direct**	**100**	**Direct**
39	**TR3-Merowe G5-6**	**YNd11d11**	**141**	**141**	**141**	**525**	**13.8**	**13.8**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**0.12**	**121.2**	**direct**	**100**	**Direct**
40	**TR3-Merowe G7-8**	**YNd11d11**	**141**	**141**	**141**	**525**	**13.8**	**13.8**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**0.12**	**121.2**	**direct**	**100**	**Direct**
41	**TR3-Merowe G9-10**	**YNd11d11**	**141**	**141**	**141**	**525**	**13.8**	**13.8**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**12.12**	**24.4**	**12.12**	**0.22**	**0.48**	**0.215**	**0.12**	**121.2**	**direct**	**100**	**Direct**
42	**TR3-POR1**	**YNyn0d11**	**100**	**100**	**30**	**220**	**110**	**33**	**16.2**	**6.32**	**11.7**	**0.11**	**0.11**	**0.11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**impedance**	**100**	**Impedance**
43	**TR3-POR2**	**YNyn0d11**	**100**	**100**	**30**	**220**	**110**	**33**	**16.2**	**6.32**	**11.7**	**0.11**	**0.11**	**0.11**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**impedance**	**100**	**Impedance**
44	**TR3-Rabak 1**	**YNyn0d11**	**100**	**100**	**30**	**220**	**110**	**11**	**14**	**12**	**8.364**	**0.11**	**0.11**	**0.25**	**14**	**12**	**8.364**	**0.5**	**0.5**	**0.25**	**0**	**0**	**direct**	**100**	**Direct**
45	**TR3-Rabak 2**	**YNyn0d11**	**100**	**100**	**30**	**220**	**110**	**11**	**14**	**12**	**8.364**	**0.11**	**0.11**	**0.25**	**14**	**12**	**8.364**	**0.5**	**0.5**	**0.25**	**0**	**0**	**direct**	**100**	**Direct**
46	**TR3-Roseires TR01 G1**	**YNd1d1**	**86**	**43**	**43**	**220**	**11**	**11**	**10.4**	**11.11**	**10.4**	**0.11**	**0.11**	**0.11**	**10.4**	**11.11**	**10.4**	**0.5**	**0.5**	**0.5**	**0**	**0**	**direct**	**100**	**Direct**
47	**TR3-Roseires TR02 G4**	**YNd1d1**	**89**	**44.5**	**44.5**	**220**	**11**	**11**	**10.4**	**11.11**	**10.4**	**0.11**	**0.11**	**0.11**	**10.4**	**11.11**	**10.4**	**0.5**	**0.5**	**0.5**	**0**	**0**	**direct**	**100**	**Direct**
48	**TR3-Roseires TR03 G5-6**	**YNd1d1**	**86**	**43**	**43**	**220**	**11**	**11**	**17.8**	**34.3**	**17.9**	**0.112**	**0.11**	**0.11**	**17.8**	**34.3**	**17.9**	**0.52**	**0.5**	**0.5**	**0**	**0**	**direct**	**100**	**Direct**
49	**TR3-Roseires TR04 G3-7**	**YNd1d1**	**86**	**43**	**43**	**220**	**11**	**11**	**17.8**	**34.3**	**17.9**	**0.111**	**0.111**	**0.111**	**17.8**	**34.3**	**17.9**	**0.51**	**0.51**	**0.51**	**0**	**0**	**direct**	**100**	**Direct**
50	**TR3-Sennar TR1**	**YNyn0d11**	**55**	**55**	**17.5**	**215**	**110**	**11**	**7.67**	**16.87**	**8.244**	**0.11**	**0.11**	**0.11**	**7.67**	**16.87**	**8.244**	**0.5**	**0.5**	**0.5**	**0**	**0**	**direct**	**100**	**Direct**
51	**TR3-Sennar TR2**	**YNyn0d11**	**55**	**55**	**30**	**220**	**110**	**33**	**8**	**16.7**	**11.89091**	**0.11**	**0.11**	**0.11**	**8**	**16.7**	**11.89091**	**0.5**	**0.5**	**0.5**	**0**	**0**	**direct**	**100**	**Direct**
52	**TR3-TR2**	**YNyn0d11**	**150**	**150**	**50**	**220**	**110**	**11**	**13.04**	**8.08**	**7.6**	**0.11**	**0.11**	**0.11**	**13.04**	**8.08**	**7.6**	**0.5**	**0.5**	**0.5**	**0**	**0**	**impedance**	**100**	**Impedance**

LINES DATA:

	Name	Type	Length	R(1)	X(1)	C(1)	B(1)	R(0)	X(0)	C(0)	B(0)	Units	Irmax (low)	Irmax (high)	Rated Temp	Temp. end of SC	Oper Temp	Max OperTemp	Q1(1)	Q2(1)	Q1(0)	Q2(0)	Shunt 1 active	Shunt 2 active	From	On	To	On	Zone
			km	Ohm/...	Ohm/...	uF/...	uS/...	Ohm/...	Ohm/...	uF/...	uS/...		A	A	°	°	°	°	Mvar	Mvar	Mvar	Mvar	%	%					
1	AFRAA-FAROUG 1	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	AFRAA	1	FAR1	1	KHARTOUM
2	AFRAA-FAROUG 2	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	AFRAA	1	FAR1	1	KHARTOUM
3	Atbara-Merowe Dam	ACSR 4 x 325 mm²	236.7	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	125	0	125	0	100	100	ATB5	1	MRW5_S1	1	NORTHERN
4	Atbara-Port Sudan	ACSR 1 x 480 mm²	448.92	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	30	0	30	100	100	POR2	1	ATB2	1	Red Sea
5	Atbara (NEC)-Shendi 1	ACSR 2 x 240 mm²	140	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	ATB2	1	SHN2	1	River Nile
6	Atbara (NEC)-Shendi 2	ACSR 2 x 240 mm²	140	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	ATB2	1	SHN2	1	River Nile
7	Bagair-Giad	ACSR 1 x 95 mm²	3	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	BAG1	1	GAD1	1	JAZEERA
8	BANAT-Mugran 1	ACSR 2 x 240 mm²	3.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	MUG1_1	1	BNT1	1	OMDURMAN
9	BANAT-Mugran 2	ACSR 2 x 240 mm²	3.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	MUG1_1	1	BNT1	1	OMDURMAN
10	BANAT-OMD 1	ACSR 2 x 240 mm²	5.9	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	BNT1	1	OMD1	1	OMDURMAN
11	BANAT-OMD 2	ACSR 2 x 240 mm²	5.9	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	BNT1	1	OMD1	1	OMDURMAN
12	Debba-Dongola 1	ACSR 1 x 480 mm²	139.38	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	DEB2S2	1	DON2S2	1	NORTHERN
13	Debba-Dongola 2	ACSR 1 x 480 mm²	139.38	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	DON2S1	0	DEB2S1	1	NORTHERN
14	DON-WWA-1	ACSR 2 x 240 mm² - 220 kV	166	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	DON2S2	1	WWA2	1	NORTHERN
15	DON-WWA-2	ACSR 2 x 240 mm²	166	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	DON2S1	0	WWA2	0	NORTHERN
16	EidBabiker-Garri 1	ACSR 2 x 240 mm² - 220 kV	60	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	IBA2	1	GAR2S1	1	KHARTOUM NORD
17	EidBabiker-Garri 2	ACSR 2 x 240 mm² - 220 kV	60	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	IBA2	1	GAR2S1	1	KHARTOUM NORD
18	EidBabiker-Izba 1	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	IZBA	1	KHARTOUM NORD
19	EidBabiker-Izba 2	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	IZBA	1	KHARTOUM NORD
20	El Fau-NGedaref	ACSR 1 x 95 mm²	153	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	FAO1	1	NGDF1	1	EASTERN
21	El Girba-Halfa1	ACSR 2 x 240 mm² - 220 kV	58	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GBA2	1	NHLF2	1	kassla
22	El Girba-Halfa2	ACSR 2 x 240 mm² - 220 kV	58	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GBA2	1	NHLF2	1	kassla
23	El Girba-Kassala	ACSR 1 x 120 mm²	85	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	460	460	20	80	40	80	0	0	0	0	100	100	GBA66	1	KSL66	1	kassla
24	El Girba-Kassala220_1	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	KSL2	1	GBA2	1	kassla

25	El Girba-Kassala220_2	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	KSL2	1	GBA2	1	kassla
26	El Girba-Kilo 3	ACSR 1 x 120 mm²	3	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	GBA66	1	KL366	1	kassla
27	El Girba-Showak	ACSR 1x 95 mm² - 66 kV	70	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	287	287	20	80	40	80	0	0	0	0	100	100	GBA66	1	SHK66	1	EASTERN
28	El Girba-Showak220_1	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	SHK2	1	GBA2	1	EASTERN
29	El Girba-Showak220_2	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	SHK2	1	GBA2	1	EASTERN
30	El Kabashi-EidBabiker 1	ACSR 2 x 240 mm²	30	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	IBA2	1	KHARTOUM NORD
31	El Kabashi-EidBabiker 2	ACSR 2 x 240 mm²	30	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	IBA2	1	KHARTOUM NORD
32	El Kabashi-Free Zone 1	ACSR 2 x 240 mm² - 220 kV	34	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	FRZ2	1	KHARTOUM NORD
33	El Kabashi-Free Zone 2	ACSR 2 x 240 mm² - 220 kV	34	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KAB2	1	FRZ2	1	KHARTOUM NORD
34	Gamoeia-Banat 1	ACSR 2 x 240 mm²	16.5	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM1	1	BNT1	1	OMDURMAN
35	Gamoeia-Banat 2	ACSR 2 x 240 mm²	16.5	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM1	1	BNT1	1	OMDURMAN
36	Gamoeia-Jebel Aulia 1	ACSR 2 x 240 mm² - 220 kV	37	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	JAS2	1	OMDURMAN
37	Gamoeia-Jebel Aulia 2	ACSR 2 x 240 mm² - 220 kV	37	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	JAS2	1	OMDURMAN
38	Garri-Free Zone 1	ACSR 2 x 240 mm² - 220 kV	5	0.067	0.302	0.01306	4.103	0.262	1.2	0.00574868	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAR2S 1	1	FRZ2	1	KHARTOUM NORD
39	Garri-Free Zone 2	ACSR 2 x 240 mm² - 220 kV	5	0.067	0.302	0.01306	4.103	0.262	1.2	0.00574868	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAR2S 1	1	FRZ2	1	KHARTOUM NORD
40	Gedarif-Raweshda	ACSR 1x 95 mm² - 66 kV	38	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	0	370	20	80	40	80	0	0	0	0	100	100	GDF66	1	RWS66	1	EASTERN
41	Gedarif-Shehedi 1	ACSR 2 x 240 mm² - 220 kV	192	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	15	0	100	100	GDF2	1	SHEH	1	EASTERN
42	Gedarif-Shehedi 2	ACSR 2 x 240 mm² - 220 kV	192	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	15	0	100	100	GDF2	1	SHEH	1	EASTERN
43	Gedarif-Showak220_1	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GDF2	1	SHK2	1	EASTERN
44	Gedarif-Showak220_2	ACSR 2 x 240 mm² - 220 kV	70	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	GDF2	1	SHK2	1	EASTERN
45	Giad-NHAS	ACSR 1 x 95 mm²	80.7	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	GAD1	1	NHAS-110	1	JAZEERA
46	HassaHeisa-Meringan	ACSR 1 x 95 mm²	55	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	HAS1	1	01-مارس	1	JAZEERA
47	Hawata-Gedarif 1	ACSR 2 x 240 mm² - 220 kV	100	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	HWT2	1	GDF2	1	EASTERN
48	Hawata-Gedarif 2	ACSR 2 x 240 mm² - 220 kV	100	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	HWT2	1	GDF2	1	EASTERN
49	Jebel Aulia-Giad 1	ACSR 2 x 240 mm² - 220 kV	36	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAD2	1	JAS2	1	KHARTOUM
50	Jebel Aulia-Giad 2	ACSR 2 x 240 mm² - 220 kV	36	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	GAD2	1	JAS2	1	KHARTOUM
51	JEBEL Aulia 33 SS-PS 2	ACSR 1 x 185 mm²	5	0.15	0.28	0.008913	2.8	0.45	0.9	0.003947	1.24	km	350	350	20	160	40	80	0	0	0	0	100	100	JAS33	1	JAP33	1	KHARTOUM
52	Kassala-Aroma1	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	ARO2	1	KSL2	1	kassla
53	Kassala-Aroma2	ACSR 2 x 240 mm² - 220 kV	95	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	ARO2	1	KSL2	1	kassla
54	Khartoum Nord-EidBabiker 1	ACSR 2 x 240 mm²	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IBA1	1	KHARTOUM NORD
55	Khartoum Nord-EidBabiker 2	ACSR 2 x 240 mm²	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IBA1	1	KHN1	1	KHARTOUM NORD
56	Khartoum Nord-Kuku 1	ACSR 2 x 350 mm²	4.5	0.0384	0.302	0.0095	2.985	0.3995	1.206	0.00653	2.051	km	1200	1200	20	80	40	80	0	0	0	0	100	100	KHN1	1	KUK1	1	KHARTOUM NORD
57	Khartoum Nord-Kuku 2	ACSR 2 x 350 mm²	4.5	0.0384	0.302	0.0095	2.985	0.3995	1.206	0.00653	2.051	km	1200	1200	20	80	40	80	0	0	0	0	100	100	KHN1	1	KUK1	1	KHARTOUM NORD
58	KHN-IZERGAB 1	ACSR 2 x 240 mm²	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IZG1-2	1	KHARTOUM NORD

59	KHN-IZERGAB 2	ACSR 2 x 240 mm²	12	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KHN1	1	IZG1-2	1	KHARTOUM NORD
60	Kilo X-AFRAA 1	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	AFRAA	1	KHARTOUM
61	Kilo X-AFRAA 2	ACSR 2 x 240 mm²	7	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	AFRAA	1	KHARTOUM
62	Kilo X-Bagair	ACSR 1 x 95 mm²	28	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	KLX1	1	BAG1	1	KHARTOUM
63	Kilo X-EidBabiker 1	ACSR 2 x 240 mm² - 220 kV	14	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KLX2	1	IBA2	1	KHARTOUM NORD
64	Kilo X-EidBabiker 2	ACSR 2 x 240 mm² - 220 kV	14	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	KLX2	1	IBA2	1	KHARTOUM NORD
65	Kilo X-Giad 1	ACSR 1 x 400 mm²	43	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	KLX2	0	GAD2	1	KHARTOUM
66	Kilo X-Giad 2	ACSR 1 x 400 mm²	43	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	KLX2	0	GAD2	1	KHARTOUM
67	Kilo X-Kuku 1	ACSR 1 x 350 mm²	14.6	0.087	0.379	0.0095	2.985	0.502	1.93	0.0043	1.351	km	780	780	20	80	40	80	0	0	0	0	100	100	KUK1	1	KLX1	1	KHARTOUM
68	Kilo X-Kuku 2	ACSR 1 x 350 mm²	14.6	0.087	0.379	0.0095	2.985	0.502	1.93	0.0043	1.351	km	780	780	20	80	40	80	0	0	0	0	100	100	KUK1	1	KLX1	1	KHARTOUM
69	Kilo X - Local Market 1	ACSR 2 x 240 mm²	3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	LOM1	1	KHARTOUM
70	Kilo X - Local Market 2	ACSR 2 x 240 mm²	3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KLX1	1	LOM1	1	KHARTOUM
71	Kuku-Karthum East 1	ACSR 2 x 240 mm²	3.2	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KUK1	1	KHE1	1	KHARTOUM NORD
72	Kuku-Karthum East 2	ACSR 2 x 240 mm²	3.2	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	KUK1	1	KHE1	1	KHARTOUM NORD
73	LOM SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	LOMSV C3	1	LOM SVC 33	1	Zone 1
74	Has SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	HAS-TCR 33	1	HAS SVC 33	1	Zone 1
75	KuKu SVC 33 kv Link		0.01	0.1	0.1	0	0	0	0	0	0	km	0	0	20	0	40	80	0	0	0	0	100	100	TCR KUK 33	1	KUK SVC 33	1	Zone 1
76	Magirus-Local Market 1	ACSR 2 x 240 mm²	7.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	LOM1	1	KHARTOUM
77	Magirus-Local Market 2	ACSR 2 x 240 mm²	7.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	LOM1	1	KHARTOUM
78	Mahadia-Izergab 1	ACSR 2 x 240 mm²	8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IZG1-1	1	MHD1-2	1	KHARTOUM NORD
79	Mahadia-Izergab 2	ACSR 2 x 240 mm²	8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	IZG1-1	1	MHD1-2	1	KHARTOUM NORD
80	Mahadia-Omdurman 1	ACSR 2 x 240 mm²	9.3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	OMD1	1	MHD1-1	1	OMDURMAN
81	Mahadia-Omdurman 2	ACSR 2 x 240 mm²	9.3	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	OMD1	1	MHD1-1	1	OMDURMAN
82	Makhiyat-El Kabashi	ACSR 4 x 325 mm²	36.8	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	0	0	0	100	100	KAB5	1	MRK5	1	NORTHERN
83	Makhiyat-Gamoeia 1	ACSR 2 x 240 mm²	37	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	MRK2	1	OMDURMAN
84	Makhiyat-Gamoeia 2	ACSR 2 x 240 mm²	37	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	GAM2	1	MRK2	1	OMDURMAN
85	Makhiyat-Mahadia 1	ACSR 2 x 240 mm² - 220 kV	21	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MRK2	1	MHD2	1	OMDURMAN
86	Makhiyat-Mahadia 2	ACSR 2 x 240 mm² - 220 kV	21	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MRK2	1	MHD2	1	OMDURMAN
87	Mashkur-Jebel Aulia 1	ACSR 2 x 240 mm² - 220 kV	147.7	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MSH2	1	JAS2	1	White Nile
88	Mashkur-Jebel Aulia 2	ACSR 2 x 240 mm² - 220 kV	147.7	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	MSH2	1	JAS2	1	White Nile
89	Meringan-Alfau	ACSR 1 x 95 mm²	71	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	01-مارس	0	FAO1	1	JAZEERA
90	Meringan-Hag Abdallah	ACSR 1 x 95 mm²	35	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	01-مارس	1	HAG1	1	JAZEERA
91	Meringan-Managil	ACSR 1 x 150 mm²	75.6	0.105	0.289	0.00965	3.032	0.315	0.867	0.0054	1.696	km	500	500	20	80	40	80	0	0	0	0	100	100	01-مارس	1	MAN1	1	JAZEERA
92	Meringan-Sennar 1	ACSR 1 x 400 mm²	84	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	SENJ2	1	JAZEERA
93	Meringan-Sennar 2	ACSR 1 x 400 mm²	84	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	SENJ2	1	JAZEERA

94	Merowe Dam-Makhiyat 1	ACSR 4 x 325 mm²	346	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	125	0	125	100	100	MRW5_S1	1	MRK5	1	NORTHERN
95	Merowe Dam-Makhiyat 2	ACSR 4 x 325 mm²	346	0.028	0.276	0.013083	4.11	0.3445	0.981	0.00999	3.138	km	2128	2890	20	80	40	80	0	125	0	125	100	100	MRW5_S1	1	MRK5	1	NORTHERN
96	Merowe Dam-Merowe Town 1	ACSR 1 x 480 mm²	34.55	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWAIS2	1	MWT2S2	1	NORTHERN
97	Merowe Dam-Merowe Town 2	ACSR 1 x 480 mm²	34.55	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWAIS2	0	MWT2S1	1	NORTHERN
98	Merowe Town-Debba 1	ACSR 1 x 480 mm²	139.3	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWT2S2	1	DEB2S2	1	NORTHERN
99	Merowe Town-Debba 2	ACSR 1 x 480 mm²	139.3	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	MWT2S1	1	DEB2S1	1	NORTHERN
100	Mugran-Magirus 1	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-1	1	MUG1	1	KHARTOUM
101	Mugran-Magirus 2	ACSR 2 x 240 mm²	11	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-1	1	MUG1	1	KHARTOUM
102	New Hasahesa-Giad 1	ACSR 1 x 400 mm²	87.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	GAD2	1	JAZEERA
103	New Hasahesa-Giad 2	ACSR 1 x 400 mm²	87.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	GAD2	1	JAZEERA
104	New Hasahesa-Meringan 1	ACSR 1 x 400 mm²	53.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	02-مارس	1	NHAS-220	1	JAZEERA
105	New Hasahesa-Meringan 2	ACSR 1 x 400 mm²	53.5	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	NHAS-220	1	02-مارس	1	JAZEERA
106	NGDF-GDF	ACSR 1 x 95 mm²	3	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	NGDF1	1	GDF1	1	EASTERN
107	NGER-Halfa	ACSR 1 x 120 mm²	52	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	NGBA66	1	NHLF66	1	kassla
108	NGER-KL3	ACSR 1 x 120 mm²	3	0.255	0.386	0.0097	3.047	0.44	1.45	0.0057	1.791	km	345	345	20	80	40	80	0	0	0	0	100	100	NGBA66	1	KL366	1	kassla
109	NHAS-Genaid 1	ACSR 2 x 240 mm²-110kv	15	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	GND1	1	JAZEERA
110	NHAS-Genaid 2	ACSR 2 x 240 mm²-110kv	15	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	GND1	1	JAZEERA
111	NHAS-HAS	ACSR 1 x 95 mm²	4.6	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	NHAS-110	1	HAS1	1	JAZEERA
112	POR-BSH 1	ACSR 2 x 240 mm²-110kv	20	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	POR1	1	BSH	1	Red Sea
113	POR-BSH 2	ACSR 2 x 240 mm²-110kv	20	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	POR1	1	BSH	1	Red Sea
114	Rabak-Mashkur 1	ACSR 2 x 240 mm² - 220 kV	107.2	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	MSH2	1	White Nile
115	Rabak-Mashkur 2	ACSR 2 x 240 mm² - 220 kV	107.2	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	MSH2	1	White Nile
116	Rabak-Tandalti 1	ACSR 2 x 240 mm² - 220 kV	111	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	TAN2	1	White Nile
117	Rabak-Tandalti 2	ACSR 2 x 240 mm² - 220 kV	111	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	TAN2	1	White Nile
118	Rank-Rabak 1	ACSR 2 x 240 mm² - 220 kV	163.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	RBK2	1	White Nile
119	Rank-Rabak 2	ACSR 2 x 240 mm² - 220 kV	163.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RBK2	1	RNK2	1	White Nile
120	Rawesda-Showak	ACSR 1x 95 mm² - 66 kV	32	0.348	0.397	0.00896	2.815	0.47	1.45	0.0057	1.791	km	287	287	20	80	40	80	0	0	0	0	100	100	SHK66	1	RWS66	1	EASTERN
121	Roseires-Rank 1	ACSR 2 x 240 mm² - 220 kV	172.8	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	ROS2	1	Blue nile
122	Roseires-Rank 2	ACSR 2 x 240 mm²	172.8	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	RNK2	1	ROS2	1	Blue nile
123	Sennar-Rabak	ACSR 1 x 95 mm²	96	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	324	324	20	80	40	80	0	0	0	0	100	100	RBK11	1	SENJ1	1	Sennar
124	Sennar-Sennar Hydro	ACSR 1 x 95 mm²	10	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENJ1	1	SENP1	1	Sennar
125	Sennar-Singa 1	ACSR 1 x 400 mm²	50	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SENJ2	1	SNG2	1	Sennar
126	Sennar-Singa 2	ACSR 1 x 400 mm²	50	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SENJ2	1	SNG2	1	Sennar

127	Sennar Hydro-Hag Abdallah	ACSR 1 x 95 mm²	60	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENP1	1	HAG1	1	Sennar
128	Sennar Hydro-Mina Sharif	ACSR 1 x 95 mm²	69	0.348	0.421	0.0086	2.702	0.546	1.38	0.0053	1.665	km	287	287	20	80	40	80	0	0	0	0	100	100	SENP1	1	MNA1	1	Sennar
129	Shagar-Jebel Aulia 1	ACSR 2 x 240 mm²	39	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	JAS1	1	KHARTOUM
130	Shagar-Jebel Aulia 2	ACSR 2 x 240 mm²	39	0.067	0.269	0.01306	4.103	0.262	1.044	0.00575	1.806	km	1250	1250	20	80	40	80	0	0	0	0	100	100	SHG1-2	1	JAS1	1	KHARTOUM
131	Shendi-Free Zone 1	ACSR 2 x 240 mm² - 220 kV	115	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SHN2	1	FRZ2	1	KHARTOUM NORD
132	Shendi-Free Zone 2	ACSR 2 x 240 mm² - 220 kV	115	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SHN2	1	FRZ2	1	KHARTOUM NORD
133	Singa-Hawata 1	ACSR 2 x 240 mm² - 220 kV	90	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SNG2	1	HWT2	1	Sennar
134	Singa-Hawata 2	ACSR 2 x 240 mm² - 220 kV	90	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	SNG2	1	HWT2	1	Sennar
135	Singa-Roseires 1	ACSR 1 x 400 mm²	178	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SNG2	1	ROS2	1	Blue nile
136	Singa-Roseires 2	ACSR 1 x 400 mm²	178	0.076	0.403	0.00902	2.834	0.551	2.159	0.0044	1.382	km	850	850	20	80	40	80	0	0	0	0	100	100	SNG2	1	ROS2	1	Blue nile
137	Tandalti-Umrawaba 1	ACSR 2 x 240 mm² - 220 kV	78.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	TAN2	1	UMR2	1	White Nile
138	Tandalti-Umrawaba 2	ACSR 2 x 240 mm² - 220 kV	78.3	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	TAN2	1	UMR2	1	White Nile
139	Umrawaba-Obeid 1	ACSR 2 x 240 mm² - 220 kV	126	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	UMR2	1	OBE2	1	North Kurdofan
140	Umrawaba-Obeid 2	ACSR 2 x 240 mm² - 220 kV	126	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	0	100	100	UMR2	1	OBE2	1	North Kurdofan
141	WWA-WLF 1	ACSR 2 x 240 mm² - 220 kV	204	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	WWA2	1	WLF	1	NORTHERN
142	WWA-WLF 2	ACSR 2 x 240 mm² - 220 kV	204	0.067	0.302	0.01306	4.103	0.262	1.2	0.00575	1.806	km	972	1250	20	80	40	80	0	0	0	15	100	100	WWA2	0	WLF	0	NORTHERN

GENERATORS

	Name	Type	Sr	Ur	cosphi	xd sat	xd' sat	xd" sat	x(2)	x(0)	Ufmax/ur	Earthing	ZE activ	Turbo	LF Type	P Gen	Q Gen	U reg	Q min	Q max	P min	P max	c0	c1	c2	Cos max	Model
Unit	-		MVA	kV	-	%	%	%	%	%	-		%	-	-	MW	Mvar	%	Mvar	Mvar	MW	MW	CU / (MW*MW)	CU / MW	CU		
1	El Girba Diesel GT1	Hydro	4.5	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	0	0	0	-1.363636364	1.363636364	0	3.6	0	0	1	0.8	Subtransient
2	El Girba Diesel GT2	Hydro	3.5	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	0	0	0	-1.060606061	1.060606061	0	2.8	0	0	1	0.8	Subtransient
3	El GirbaKap GT1	Hydro	6.6	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	1.7	-1	0	-2	2	0	5.28	0	0	1	0.8	Subtransient
4	El GirbaKap GT2	Hydro	6.6	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	3	-1	0	-2	2	0	5.28	0	0	1	0.8	Subtransient
5	El Girba pump 1	Hydro	2.6	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	1.6	-1	0	-0.787878788	0.787878788	0	2.08	0	0	1	0.8	Subtransient
6	El Girba pump 2	Hydro	2.6	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	1	-1	0	-0.787878788	0.787878788	0	2.08	0	0	1	0.8	Subtransient
7	El Girba pump 3	Hydro	2.6	6.6	0.8	114	31	20	20	5	1.3	isolated	100	1	PV	1.6	-1	0	-0.787878788	0.787878788	0	2.08	0	0	1	0.8	Subtransient
8	G-Shehedi	Etopia	200	220	0.85	160	28	31	31	20	1.3	isolated	100	1	PV	100	-50	103	-150	150	0	200	0.1	1	10	0.8	Classical
9	Garri GT1	Gas	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	31	0	101	-20	27	20	37.2	1	10	100	0.8	Subtransient
10	Garri GT2	Gas	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	18	3.2	101	-20	27	20	37.2	1	10	100	0.8	Subtransient
11	Garri GT3	Gas	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	31	2.2	101	-20	27	20	37.2	1	10	100	0.8	Subtransient
12	Garri GT4	Gas	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	31	2	101	-20	27	20	37.2	1	10	100	0.8	Subtransient
13	Garri GT5	Gas	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	0	0	101	-20	27	15	37.2	1	10	100	0.8	Subtransient
14	Garri GT6	Gas	41.3	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	0	0	101	-20	27	20	37.2	1	10	100	0.8	Subtransient
15	Garri GT7	Gas	41.3	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	26	7	100	-20	27	15	37.2	1	10	100	0.8	Subtransient

16	Garri GT8	Gas	41.3	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	31	8	100	-20	27	20	37.2	1	10	100	0.8	Subtransient
17	Garri ST1	Steam	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	24	1.8	101	-20	27	20	37.2	0.1	1	10	0.8	Subtransient
18	Garri ST2	Steam	41.3	11	0.9	160	24	16	16	8	1.3	isolated	100	1	PV	14	3.2	101	-20	27	15	37.2	0.1	1	10	0.8	Subtransient
19	Garri ST3	Steam	41.3	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	0	0	101	-20	27	15	37.2	0.1	1	10	0.8	Subtransient
20	Garri ST4	Steam	41.3	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	19	7	101	-20	27	20	37.2	0.1	1	10	0.8	Subtransient
21	Garri ST5	Steam	70	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	51	14	99	-15	27	30	60.001	0.1	1	10	0.8	Subtransient
22	Garri ST6	Steam	70	11	0.85	160	24	16	16	8	1.3	isolated	100	1	PV	51	11	99	-15	27	30	60	0.1	1	10	0.8	Subtransient
23	Kassala G1-4	Diesel	9.5	11	0.8	375	21.5	12	12	5	1.3	isolated	100	1	PV	5.8	5.7	100	-3	3.7	0	7.6	0.1	1	10	0.8	Subtransient
24	KN GT1	Gas	23.5	11	0.8	216	20	14.2	14.2	8	1.3	isolated	100	1	PV	0	0	100	-9	10.6	5	17	1	10	100	0.8	Subtransient
25	KN GT4	Gas	25	11	0.8	216	20	14.2	14.2	8	1.3	isolated	100	1	PV	0	0	104	-9	10.6	5	25	1	10	100	0.8	Subtransient
26	KN ST1	Steam	41.25	11	0.8	163	24	16.7	16.7	8	1.3	isolated	100	1	PV	0	0	105	-7	17	15	33	0.1	1	10	0.8	Subtransient
27	KN ST2	Steam	41.25	11	0.8	163	24	16.7	16.7	8	1.3	isolated	100	1	PV	0	0	104	-7	17	15	33	0.1	1	10	0.8	Subtransient
28	KN ST3	Steam	75	11	0.8	227	23	14.8	14.8	8.88	1.3	isolated	100	1	PV	50	18	100.7	-15	45	30	60	0.1	1	10	0.8	Subtransient
29	KN ST4	Steam	75	11	0.8	227	23	14.8	14.8	8.88	1.3	isolated	100	1	PV	50	6	99.6	-15	45	30	60	0.1	1	10	0.8	Subtransient
30	KN ST5	Steam	137.5	13.8	0.85	122	17.4	13.4	13.4	8	1.3	isolated	100	1	PV	80	31	102	-75	105	45	117	0.1	1	10	0.8	Subtransient
31	KN ST6	Steam	137.5	13.8	0.85	122	17.4	13.4	13.4	8	1.3	isolated	100	1	PV	92	31	102	-75	105	45	117	0.1	1	10	0.8	Subtransient
32	Merowe G1	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	34.864993	102	-109	67	80	125	0	0	1	0.8	Subtransient
33	Merowe G10	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	16	102	-109	67	80	125	0	0	1	0.8	Subtransient
34	Merowe G2	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	-0.996472	102	-109	67	80	125	0	0	1	0.8	Subtransient
35	Merowe G3	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	SL	95.7081755	29.2362611	102	-109	67	80	125	0	0	1	0.8	Subtransient
36	Merowe G4	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	0	102	-109	67	80	125	0	0	1	0.8	Subtransient
37	Merowe G5	Hydro	140	13.	0.9	88.	27.	18	19.	1	1.3	isolated	100	0	PV	110	19	102	-109	67	80	125	0	0	1	0.8	Subtransient

				8		3	5		6	5.2																	
38	Merowe G6	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	14	102	-109	67	80	125	0	0	1	0.8	Subtransient
39	Merowe G7	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	16	102	-109	67	80	125	0	0	1	0.8	Subtransient
40	Merowe G8	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	15	102	-109	67	80	125	0	0	1	0.8	Subtransient
41	Merowe G9	Hydro	140	13.8	0.9	88.3	27.5	18	19.6	15.2	1.3	isolated	100	0	PV	110	17	102	-109	67	80	125	0	0	1	0.8	Subtransient
42	RBKG1		140	11	0.9	0	0	0	0	0	1.3	isolated	100	1	PV	125	0	100	0	0	0	0	0	0	0	0.8	Classical
43	RBKG2		140	11	0.9	0	0	0	0	0	1.3	isolated	100	1	PV	125	0	100	0	0	0	0	0	0	0	0.8	Classical
44	RBKG3		140	11	0.9	0	0	0	0	0	1.3	isolated	100	1	PV	125	0	100	0	0	0	0	0	0	0	0.8	Classical
45	RBKG4		140	11	0.9	0	0	0	0	0	1.3	isolated	100	1	PV	125	0	100	0	0	0	0	0	0	0	0.8	Classical
46	Roseires G1	Hydro	44.5	11	0.9	123	44	30	30	24	1.3	isolated	100	0	PV	35	3	102	-16	16	22	40	0	0	1	0.8	Subtransient
47	Roseires G2	Hydro	44.5	11	0.9	123	44	30	30	24	1.3	isolated	100	0	PV	35	0	102	-16	16	22	40	0	0	1	0.8	Subtransient
48	Roseires G3	Hydro	44.5	11	0.9	123	44	30	30	24	1.3	isolated	100	0	PV	35	2	102	-16	16	22	40	0	0	1	0.8	Subtransient
49	Roseires G4	Hydro	43	11	0.9	87	27	23	23	24	1.3	isolated	100	0	PV	35	8	102	-16	16	22	40	0	0	1	0.8	Subtransient
50	Roseires G5	Hydro	43	11	0.9	87	27	23	23	24	1.3	isolated	100	0	PV	35	0	102	-16	16	22	40	0	0	1	0.8	Subtransient
51	Roseires G6	Hydro	43	11	0.9	87	27	23	23	24	1.3	isolated	100	0	PV	35	0	102	-16	16	22	40	0	0	1	0.8	Subtransient
52	Roseires G7	Hydro	43	11	0.9	87	27	23	23	24	1.3	isolated	100	0	PV	35	6	102	-16	16	22	40	0	0	1	0.8	Subtransient
53	Sennar G1	Hydro	9.4	11	0.8	102	30	20	20	16	1.3	isolated	100	0	PV	5	0.6	102	-5	5.6	0	7.5	0	0	1	0.8	Subtransient
54	Sennar G2	Hydro	9.4	11	0.8	102	30	20	20	16	1.3	isolated	100	0	PV	5	0.2	102	-5	5.6	0	7.5	0	0	1	0.8	Subtransient

	Name	Machine type	H	xd	xd'	xd"	xq	xq'	xq"	Td0'	Td0"	Tq0"	AVR ID	TUR ID	From	Area	Zone
Unit	-		s	%	%	%	%	%	%	s	s	s					
55	El Girba Diesel GT1	Round rotor	1	185	89	23.5	89	0	22	4.8	0.02	0.08	0	7460	GBA_6	Area 1	kassla
56	El Girba Diesel GT2	Round rotor	1.1	185	89	23.5	89	0	22	4.8	0.02	0.08	0	7471	GBA_6	Area 1	kassla
57	El GirbaKap GT1	Round rotor	3.5	113.8	30.6	20.5	68.3	0	20	6	0.05	0.1	0	7464	GBA_6	Area 1	kassla
58	El GirbaKap GT2	Round rotor	3.5	113.8	30.6	20.5	68.3	0	20	6	0.05	0.1	0	7480	GBA_6	Area 1	kassla
59	El Girba pump 1	Round rotor	4	128	32	25	92	0	31.5	5.2	0.05	0.06	0	7479	GBA_6	Area 1	kassla
60	El Girba pump 2	Round rotor	4	128	32	25	92	0	31.5	5.2	0.05	0.06	0	7472	GBA_6	Area 1	kassla
61	El Girba pump 3	Round rotor	4	128	32	25	92	0	31.5	5.2	0.05	0.06	0	7484	GBA_6	Area 1	kassla
62	G-Shehedi	Round rotor	50	0	28	0	0	0	0	0	0	0	0	0	SHEH	Area 1	Zone 1
63	Garri GT1	Round rotor	2.675	90	30.2	36.5	69	30	34.1	1.589	0.047	0.013	815427	815430	GAR_G1	Area 1	KHARTOUM NORD
64	Garri GT2	Round rotor	3.23	95.3	26	24	54	30	21	2.315	0.037	0.05	815470	815473	GAR_G2	Area 1	KHARTOUM NORD
65	Garri GT3	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	815513	815516	GAR_G4	Area 1	KHARTOUM NORD
66	Garri GT4	Round rotor	3.23	95.3	20	11	155.1	40	11	2.315	0.037	0.05	815556	815559	GAR_G5	Area 1	KHARTOUM NORD
67	Garri GT5	Round rotor	3.23	95.3	18	13.2	57.3	30	40.2	2.315	0.037	0.05	815599	815602	GAR_G7	Area 1	KHARTOUM NORD
68	Garri GT6	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	815642	815645	GAR_G8	Area 1	KHARTOUM NORD
69	Garri GT7	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	815685	815688	GAR_G10	Area 1	KHARTOUM NORD
70	Garri GT8	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	815728	815731	GAR_G11	Area 1	KHARTOUM NORD
71	Garri ST1	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	9454	9486	GAR_G3	Area 1	KHARTOUM NORD
72	Garri ST2	Round rotor	3.39	93	31.2	28.3	57.3	30	40.2	2.598	0.036	0.03	9526	9529	GAR_G6	Area 1	KHARTOUM NORD
73	Garri ST3	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	9569	9572	GAR_G9	Area 1	KHARTOUM NORD
74	Garri ST4	Round rotor	3.23	95.3	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	9612	9615	GAR_G12	Area 1	KHARTOUM NORD
75	Garri ST5	Round rotor	3.23	166	31.2	28.3	57.3	30	40.2	2.315	0.037	0.05	9655	9658	GAR_G13	Area 1	KHARTOUM NORD
76	Garri ST6	Round rotor	3.23	166	18	13.2	57.3	30	40.2	2.315	0.037	0.05	9698	9701	GAR_G14	Area 1	KHARTOUM NORD
77	Kassala G1-4	Round rotor	3	91	20	10	55	54.6	12	6	0.03	0.07	0	7517	KSL11	Area	kassla

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78	KN GT1	Round rotor	7.92	216	20	14.2	210	30	15	5.34	0.05	0.05	815343	815344	KHN11_GT1	Area 1	KHARTOUM NORD
79	KN GT4	Round rotor	7.92	216	20	14.2	210	30	15	5.34	0.05	0.05	815300	815301	KHN11_GT_4	Area 1	KHARTOUM NORD
80	KN ST1	Round rotor	3.155	163.4	23.2	17	160	48	16	7.2	0.05	0.048	7765	7501	KHN11_ST1	Area 1	KHARTOUM NORD
81	KN ST2	Round rotor	3.155	163.4	23.2	17	160	48	16	7.2	0.05	0.048	7778	7505	KHN11_ST2	Area 1	KHARTOUM NORD
82	KN ST3	Round rotor	3.976	230	23	14.8	210	55	16	7.69	0.04	0.048	7791	7512	KHN11_ST3	Area 1	KHARTOUM NORD
83	KN ST4	Round rotor	3.976	230	23	14.8	210	55	16	7.69	0.04	0.048	7804	7513	KHN11_ST4	Area 1	KHARTOUM NORD
84	KN ST5	Round rotor	6.14	197	27	24	190	48	20	8.2	0.035	0.035	9743	9744	KHN11_ST5	Area 1	KHARTOUM NORD
85	KN ST6	Round rotor	6.14	197	27	24	190	48	20	8.2	0.035	0.035	9786	9787	KHN11_ST6	Area 1	KHARTOUM NORD
86	Merowe G1	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6901	6945	MWP14_1	Area 1	NORTHERN
87	Merowe G10	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6888	6981	MWP14_10	Area 1	NORTHERN
88	Merowe G2	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6784	6949	MWP14_2	Area 1	NORTHERN
89	Merowe G3	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6797	6953	MWP14_3	Area 1	NORTHERN
90	Merowe G4	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6810	6957	MWP14_4	Area 1	NORTHERN
91	Merowe G5	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6823	6961	MWP14_5	Area 1	NORTHERN
92	Merowe G6	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6836	6965	MWP14_6	Area 1	NORTHERN
93	Merowe G7	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6849	6969	MWP14_7	Area 1	NORTHERN
94	Merowe G8	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6862	6973	MWP14_8	Area 1	NORTHERN
95	Merowe G9	Salient pole	3.35	88.3	27.5	18	60.1	0	21.3	8.843	0.089	0.219	6875	6977	MWP14_9	Area 1	NORTHERN
96	RBKG1	Round rotor	0	0	0	0	0	0	0	0	0	0	0	0	RBKG4	Area 1	White Nile
97	RBKG2	Round rotor	0	0	0	0	0	0	0	0	0	0	0	0	RBKG3	Area 1	White Nile
98	RBKG3	Round rotor	0	0	0	0	0	0	0	0	0	0	0	0	RBKG2	Area 1	White Nile
99	RBKG4	Round rotor	0	0	0	0	0	0	0	0	0	0	0	0	RBKG1	Area 1	White Nile
100	Roseires G1	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7661	7432	ROS11_1	Area 1	Blue nile
101	Roseires G2	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7687	7436	ROS11_2	Area	Blue nile

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102	Roseires G3	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7700	7440	ROS11_3	Area 1	Blue nile
103	Roseires G4	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7713	7450	ROS11_4	Area 1	Blue nile
104	Roseires G5	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7726	7451	ROS11_5	Area 1	Blue nile
105	Roseires G6	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7739	7452	ROS11_6	Area 1	Blue nile
106	Roseires G7	Salient pole	4.5	89	26	21	54	0	22	4.67	0.05	0.07	7752	7456	ROS11_7	Area 1	Blue nile
107	Sennar G1	Salient pole	2.22	102	30	20	65	30	25	5	0.041	0.074	7817	7488	SENP11_1	Area 1	Sennar
108	Sennar G2	Salient pole	2.22	102	30	20	65	30	25	5	0.041	0.074	7830	7492	SENP11_2	Area 1	Sennar

ASYNCH MACH Data:

	ID	Name	Pr	Sr	Ur	Ir	cosphi	eta	Ia/Ir	Number	Pole pairs	cosphi start	Ma/Mr	Mk/Mr	Rm	Rs/Rr	sr	LF type	P oper	Q oper
Unit	-		MW	MVA	kV	kA	-								Ohm	kgm2	%		MW	Mvar
1	7107	Jebel Aulia Hydro G1	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
2	7118	Jebel Aulia Hydro G2	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
3	7129	Jebel Aulia Hydro G3	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
4	7137	Jebel Aulia Hydro G4	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
5	7145	Jebel Aulia Hydro G5	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
6	7153	Jebel Aulia Hydro G6	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
7	7161	Jebel Aulia Hydro G7	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355
8	7169	Jebel Aulia Hydro G8	4.13	5.115	0.69	4.2795	0.85	0.95	6.5	1	1	0.3	1.7	2.2	0.004296	1	2.3	PQ oper	-3.8	2.355

Appendix - B