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REDUCING TRANSMISSION LOSSES BY USING STATIC VAR COMPENSATOR (SVC).

تقليل الفقد في خطوط النقل باستخدام معوض القدرة الرد فعلية الساكن

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of M.Sc. In Electrical Engineering (Power)

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الآيـة

قال تعالى:

{قَالُوا سُبْحَانَكَ لا عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيمُ الْحَكِيمُ}

صدق الله العظيم

سورة البقرة الاية (32)

DEDICATION

To

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

To

My Friends who have encouraged me to complete this work.

To anyone who have supported me with good ideas throughout the project

ACKNOWLEDGMENT

To the Almighty GOD "ALLAH" Who have granted me all these graces to fulfil this work and who blessed and supported me by His power in all my life. Without this guidance I would have never reached this position where I am writing this page. To Him I extend my heartfelt thanks.

I would like to show my greatest appreciation to my honourable supervisor ***Dr. Alfadil Zakariya***, Department of Electrical Engineering, He is not only a great Professor with deep vision but also most importantly a kind person. I sincerely thank for him exemplary guidance and encouragement. Without his encouragement and guidance, this project would not have materialized.

ABSTRACT

The fast growing of cities and population led the industrial section to grow as well, in addition to the domestic loads, this rapid increase in load demand forces power systems to operate under heavily stressed conditions, near critical limits due to economic and environmental constraints .

To avoid power systems collapse, improve the voltage stability, and reduce the transmission lines losses, the Flexible Alternative Current Transmission System (FACTS) it used. In this dissertation the Static Var Compensator (SVC) has been represented and discussed.

Sudanese national grid is undergoing changes as a result of constant power demand increase, thus stretching it beyond their voltage and thermal limit. This drastically affects the power quality delivered. Transmission systems should be flexible to respond to generation and load patterns, then incorporate this device in Sudanese grid to enhancement the performance. Simulations are carried out using (PSAT) package in (MATLAB) software.

The results obtained showed the effectiveness of SVC on voltage profile, power losses and power transfer through the line in the Sudanese national grid**.**

المستخلص

نسبة للنمو الهائل في حجم المدن مع ازدياد تعداد السكان ادى ذلك الى نمو القطاع الصناعي بشكل كبير بالاضافة الى الاحمال السكنية التي زادت مع ازدياد السكان واحتياجهم المتزايد للكهرباء كل هذه الاسباب اجبرت انظمة القدرة لأن تعمل تحت ظروف تشغيل باجهادت كبيرة ، وأن تعمل قرب الحدود الحرجة بسبب القيود الاقتصادية والبيئية.

لتجنب انهيار انظمة القدرة وتحسين استقرارية الجهد وتقليل الفقد في خطوط النقل يمكن استخدام النظم المرنة لنقل التيار المتردد (FACTS)في هذه الأطروحه تمت مناقشة وتمثيل معوض القدرة الرد فعلية الساكن(SVC).

هناك تغييرات مستمرة طرأت على الشبكة السودانية نتيجة للطلب المتزايد على القدرة وبالتالي امتدت لتتجاوز حدود الجهد واقصي قدرة منقولة وهذا يؤثر بشكل كبيرعلي جودة القدرة المنقولة حيث أنظمة نقل القدرة يجب ان تكون أكثر مرونة لمجابهة التغيرات في التوليد والحمل. تم ادراج هذه الأجهزة في الشبكة السودانية لتعزيز وتحسين الأداء. وتم تنفيذ المحاكاة بإستخدام PSAT Package من برنامج MATLAB.

اظهرت النتائج المتحصل عليها فعالية معوض القدرة الرد فعلية الساكن في تحسين قيم الجهد وتقليل الفقد في خطوط النقل وزيادة القدرة المنقولة خلال خطوط النقل في الشبكة القومية.

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CHAPTER ONE

INTRODUCTION

1.1 Background

Almost all bulk electric power is generated, transmitted and consumed in an alternating current (AC)network. Elements of AC systems produce and consume two kinds of power: real power (measured in watts) and reactive power (measured in volt-amperes reactive, or VAR). Real power accomplishes useful work (e.g. running motors and lighting lamps). Reactive power supports the voltages that must be controlled for system reliability [1].

It is expected that the secure, efficient and economical operation of power system will become more difficult because of more complex power flow in the future. As a result, the cost reduction and efficiency improvement are needed not only for the power plant operation but also for the power system operation.

Voltage profile is improved by controlling the production, absorption and flow of reactive power throughout the network. Reactive power flows are minimized so as to reduce system losses. [1]

Transmission losses can be calculated based on the natural properties of components in the power system: resistance, reactance, capacitance, voltage, current, and power, which are routinely calculated by utility companies as a way to specify what components will be added to the systems, in order to reduce losses and improve the voltage levels. The centralized voltage reactive control is one such control which can help not only to keep the system voltages within specified limits but also to preserve the reactive power balances for enhanced security and to decrease the transmission losses for the efficient system operation. [1]

Power flow solution is a solution of the network under steady state conditions subjected to certain constraints under which the system operates. The power flow solution gives the nodal voltages and phase angle given a set of power injections at all buses and specified voltages.

Voltage regulation is achieved by controlling the production, absorption and flow of reactive power throughout the network. Reactive power flows are minimized so as to reduce system losses. Sources and sinks of reactive power, such as shunt capacitors, shunt reactors, rotating synchronous condensers and SVC's are used for this purpose [1].

The SVC is a solid-state reactive power compensation device based on high power thyristor technology. An SVC can improve power system transmission and distribution performance in a number of ways. 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. The dynamic stability of the grid can also be improved, and active power oscillations mitigated.

1.2 Problem Statement

The increase in power demand has forced the power system to operate closer to its stability limits. Voltage instability and line overloading have become challenging problems. One of the major causes voltage instability is the reactive power unbalancing which occurs in stressed condition of power system [2]

Environmental constraints have negative effect on construction of new power plants and transmission lines. Great portion of the energy produced is consumed by big cities. Most of the time, it is impossible to build generation units near crowded cities which causes significant loss of energy due to long transmission lines [3].

As the transmission system's losses in Sudanese Grid electricity is needed to reduce; uses of FACTS controller become very important.

1.3 Objectives

- ❖ To reduce the losses in transmission line (500&220 KV) in Sudan national grid through SVC Technic by using (PSAT) program.
- ❖ Evaluate the performance of Sudan national grid.

1.4 Methodology

In order to achieve project's objectives, the following tasks were used:

Task1: Studying the database of Sudanese electricity Grid.

Task 2: Analyzing the total performance of the Grid in order to figure out the areas they have most transmission systems losses.

Task 3: Using Static Var Compensator to reduce the losses.

Task4: The simulation results should be obtained by using (PSAT) and compared the results.

1.5 Thesis Layout

This dissertation consists of five chapters. Chapter two discussed the Technical and Non-Technical losses and their resources Chapter Three gives brief description for various FACTS controllers, and then represents a full discussion on SVC, model, control capabilities and operating principles. In chapter four the approach developed is implemented on real case Sudanese national grid. conclusions and recommendation for future work are given in chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The main constituents of an ac power system are: generators, transmission (sub transmission), and distribution lines, and loads, with their related auxiliary support and protection equipment [4].

These lines carry large blocks of power which generally can be routed in any desired direction on the various links of the transmission system to achieve the desired economic and performance objectives [5].

Electricity losses occur at each stage of the power distribution process. beginning with the step-up transformers that connect power plants to the transmission system, and ending with the customer wiring beyond the retail meter.

2.2 Technical Losses

Technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation, sub transmission and distribution of power. Technical losses on distribution systems are primarily due to heat dissipation resulting from current passing through conductors and from magnetic losses in transformers. Losses are inherent to the distribution of electricity and cannot be eliminated. The major part of this loss is heat dissipation or (I^2R) loss in the distribution conductors. Since this loss depends upon the value of current, it is the maximum during peak load. Other causes of the technical loss are low power factor, phase imbalance, improper joints. This loss difference between in the transformer output and the sum of all invalid consumption Losses occur on sub transmission lines, distribution lines, station transformers, distribution transformers and secondary services to customers. Transformer losses include no-load losses that are independent of transformer loading and load losses that are dependent on the loading [6].

2.3 Main Reasons for Technical Losses

There are many reasons for Technical Losses such as

2.3.1 Lengthy distribution lines

One of the major reasons for loss is- Lengthy Distribution lines. It is good to take note here that the longer stretch of surface area through electricity transmission leads to more wear and tear and erosion and ultimately, loss of electricity in practically 11 KV and 415 volts lines, in rural areas are extended over long distances to feed loads scattered over large areas. Thus, the primary and secondary distributions lines in rural areas are largely radial laid usually extend over long distance, this results in high line resistance and therefore high I^2R losses in the line. This can be attributed to the fact that electricity generation canters and supply centres are not located within easy reach of each other. This leads to longer transmission lines and ultimately, larger losses in electricity through transmission [6].

2.3.2 Inadequate size of conductors of distribution lines

The size of the conductors should be selected on the basis of KVA/ KM capacity of standard conductor for a required voltage regulation, but rural loads are usually scattered and generally fed by radial feeders. The conductor size of these feeders should be adequate.

2.3.3 Installation of distribution transformers away from load canters

Distribution Transformers are not located at Load canter on the Secondary Distribution System. In most of case Distribution Transformers are not located centrally with respect to consumers. Consequently, the farthest consumers obtain an extremity low voltage even though a good voltage levels maintained at the transformers secondary. This again leads to higher line losses. (The reason for the line losses increasing as a result of decreased voltage at the consumers end therefore in order to reduce the voltage drop in the line to the farthest consumers, the distribution transformer should be located at the load centre to keep voltage drop within permissible limits).

In most LT distribution circuits, normally the Power Factor ranges from 0.65 to 0.75. A low Power Factor contributes towards high distribution losses. For a given load, if the Power Factor is low, the current drawn in highland the losses proportional to square of the current will be more. Thus, line losses owing to the poor PF can be reduced by improving the Power Factor. This can be done by application of shunt capacitors.

2.3.4 Low power factor of primary and secondary distribution system

Shunt capacitors can be connected either in secondary side (11 KV side) of the 33/11 KV power transformers or at various point of Distribution Line. The optimum rating of capacitor banks for a distribution system is 2/3 of the average KVAR requirement of that distribution system. The vantage point is at 2/3 of the length of the main distributor from the transformer. A more appropriate manner of improving this PF of the distribution system and thereby reduce the line losses is to connect capacitors across the terminals of the consumers having inductive loads. By connecting the capacitors across individual loads, the line loss is reduced from 4 to 9% depending upon the extent of PF improvement.

2.3.5 Load factor decreasing

Power consumption of customer varies throughout the day and over seasons. Residential customers generally draw their highest power demand in the evening hours. Same commercial customer load generally peak in the early afternoon. Because current level (hence, load) is the primary driver in distribution power losses, keeping power consumption more level throughout the day will lower peak power loss and overall energy losses. Lower power and energy losses are reduced by raising the load factor, which, evens out feeder demand variation throughout feeder. Companies use pricing power to influence consumers to shift electric-intensive activities during off-peak times such as, electric water and space heating, air conditioning, irrigating, and pool filter pumping [7].

2.3.6 Inadequate transformer size and selection

Distribution transformers use copper conductor windings to induce a magnetic field into a grain-oriented silicon steel core. Therefore, transformers have both load losses and no-load core losses. Transformer copper losses vary with load based on the resistive power loss equation (P loss $=I^2$R). For some utilities, economic transformer loading means loading distribution transformers to capacity-or slightly above capacity for a short time-in an effort to minimize capital costs and still maintain long transformer life. However, since peak generation is usually the most expensive, total cost of ownership (TCO) studies should take into account the cost of peak transformer losses. Increasing distribution transformer capacity during peak by one size will often resulting lower total peak power dissipation-more so if it is overloaded [7].

Transformer no-load excitation loss (iron loss) occurs from a changing magnetic field in the transformer core whenever it is energized. Core loss varies slightly with voltage but is essentially considered constant. Fixed iron loss depends on transformer core design and steel lamination molecular structure. Improved manufacturing of steel cores and in traducing amorphous metals (such as metallic glass) have reduced losses of cores.

2.3.7 Balancing three phase loads

Balancing 3-phase loads periodically throughout a network can reduce losses significantly. It can be done relatively easily on overhead networks and consequently offers considerable scope for cost effective loss reduction, given suitable incentives.

2.3.8 Switching off transformers

One method of reducing fixed losses is to switch off transformers in periods of low demand. If two transformers of a certain size are required at a substation during peak periods, only one might be required during times of low demand so that the other transformer might be switched off in order to reduce fixed losses. This will produce some offsetting increase in variable losses and might affect security and quality of supply as well as the operational condition of the transformer itself.

2.3.9 Harmonic

Harmonics are defined as sinusoidal voltage and current waveforms at integer multiples of the fundamental power frequency. Harmonics leads to the increase of power quality disturbances and losses in distribution systems. Because of the load characteristics, harmonics have an increasing effect on technical losses of the lines and transformers. [7]

2.4 Types of Technical Losses

There are two types of technical losses

2.4.1 Permanent (fixed) technical losses

Fixed losses do not vary according to current. These losses take the form of heat and noise and occur as long as a transformer is energized. Between 1/4 and 1/3 of technical losses on distribution networks are fixed losses. Fixed losses on a network can be influenced in the ways set out below.

2.4.1.1 Corona losses

Air is not a perfect insulator and even under normal condition, the air contains a number of free electrons and ions. Consider two large parallel conducting planes. When an electron gradient is set up between them, the electrons and ions acquire motion by this electric field and they maintain a very small current between the conducting planes. this current is negligible when the electric field intensity is less than 30KV/cm. But when the electric field intensity or potential gradient reaches the critical value of 30 KV/cm, the air in the immediate vicinity of conductors no more remains a dielectric and at this intensity the ions attain high velocity and on striking another neutral molecule dislodge one or more electron from the neutral molecule this produce a new electron and a positive ion which in turn are accelerated and collide with other air molecule to ionize them further.

Thus, the number of charge particles goes on increasing rabidly If a uniform field intensity is assumed between the electrodes such condition are produced everywhere in the gap, as a result of this, the saturation is reached. Therefore, the air becomes conducting, hence a complete electric break down occurs and arc is established between the two electrodes. When an alternating potential deference is applied across two conductors whose spacing large compassion with the diameter, then the surrounding the conductor is subjected to electro-static stresses. This stress or intensity is a maximum at the surface of the conductor and the decrease in inverse proportion to the distance from the center of the conductor. If this potential deference is gradually increased, a point will be reached when a faint luminous glow of violet colour will make its appearance, and at the same time a hissing noise will be heard. This phenomenon is called corona and is accompanied by the formation of ozone, as is indicated by the characteristics dour of this gas. This luminous glow is due to the fact that the atmospheric air around the conductor becomes conducting due to electrostatic stress. If the potential difference is raised still further, the glow and the noise will increase in intensity until eventually a spark over will take place. If the conductors are perfectly uniform and smooth, the glow will be uniform along their length, otherwise the rough points of the conductors will appear brighter with conductors only a short distance apart in comparison with their diameter the spark-over may take place before there is any luminous glow is observed [8].

Means of reducing Power Loss due to Corona are:

• The using of bundle conductors reduces corona loss.

• Spacing between conductors is selected so that corona is tolerable.

• Since the shape of conductors affect corona loss, cylindrical shape conductors have uniform field that reduces corona loss than any other shape.

• The voltage stress and electric field gradient should be minimized which can be accomplished by using good high voltage design practices. Using conductors with large radii reduce corona loss.

• Void free solid conductors and insulators should be used [9].

2.4.1.2 Leakage current losses

There are two types of leakage current ac leakage and dc leakage. Dc leakage current usually applies only to end-product equipment, not to power supplies. Ac leakage current is caused by a parallel combination of capacitance and dc resistance between a voltage source (ac line) and the grounded conductive parts of the equipment. The leakage caused by the dc resistance usually is insignificant compared to the ac impedance of various parallel capacitances. The capacitance may be intentional (such as in EMI filter capacitors) or unintentional. Some examples of unintentional capacitances are spacing on printed wiring boards, insulations between semiconductors and grounded heatsinks, and the primary-to-secondary capacitance of isolating transformers within the power supply.

2.4.1.3 Dielectric losses

Dielectric losses result from the heating effect on the dielectric material between the conductors. Power from the source is used in heating the dielectric. The heat produced is dissipated into the surrounding medium. When there is no potential difference between two conductors, the atoms in the dielectric material between them are normal and the orbits of the electrons are circular. When there is a potential difference between two conductors, the orbits of the electrons change. The excessive negative charge on one conductor repels electrons on the dielectric toward the positive conductor and thus distorts the orbits of the electrons. A change in the path of electrons requires more energy, introducing a power loss [10].

2.4.2 Variable technical losses

Variable losses vary with the amount of electricity distributed and are more precisely, proportional to the square of the current. Consequently, a 1% increase in current leads to an increase in losses of more than 1%. Between 2/3 and 3/4 of technical (or physical) losses on distribution networks are variable losses. By increasing the cross-sectional area of lines and cables for a given load, losses will fall. This leads to a direct trade-off between cost of losses and cost of capital expenditure. It has been suggested that optimal average utilization rate on a distribution network that considers the cost of losses in its design could be as low as 30 per cent [11].

There are several types of variables technical losses such as:

- Joule losses in lines in each voltage level
- Impedance losses
- Losses caused by contact resistance

2.5 Non-Technical (Commercial Losses)

Non-Technical losses are caused by actions external to the power system or are caused by loads and condition that the Technical losses computation failed to take into account. Non- Technical losses are more difficult to measure because these losses are often unaccounted for by the system operators and thus have no recorded information. On the other hand, it occurs as a result of theft, metering inaccuracies and unmetered energy. NTLs, by contrast, relate mainly to power theft in one form or another. Theft of power is energy delivered to customers that is not measured by the energy meter for the customer. This can happen as a result of meter tampering or by bypassing the meter. Losses due to metering inaccuracies are defined as the difference between the amount of energy actually delivered through the meters and the amount registered by the meters.

2.5.1 Main reasons for non-technical losses

There are many reasons of Non-Technical Losses:

- Tampering with meters to ensure the meter recorded a lower consumption reading.
- Errors in technical losses computation.
- Tapping (hooking) on LT lines.
- Arranging false readings by bribing meter readers.
- Stealing by bypassing the meter or otherwise making illegal connections.
- By just ignoring unpaid bills.
- Faulty energy meters or un-metered supply.
- Errors and delay in meter reading and billing.

- Non-payment by customers [12].

2.5.2 Commercial reasons for high distribution losses

These are related to theft of energy, meter reading, faulty meters and error in billing of customer and unmetered supply to customers. 99.95% of these losses occur on LT network. Theft of power has been done by connecting hooks of wires on L.T. distribution system. This power delivered to customers is not measured by energy meter. This direct and illegal hooking is possible only in L.T. distribution system. If we the L.T. system convert to H.T. system people cannot connect illegal hooks on HT lines. Theft of energy is also done by tempering of energy meters by various ways.

2.5.3 Loss reduction techniques

2.5.3.1Improving HT/LT ratio

Improving the HT/LT ratio by converting LT distribution network into HT distribution network. Converting LT lines to higher voltage consist high initial cost but after some specified time period this system is beneficial.

2.5.3.2Network reconfiguration

By using higher the cross-section area of the conductor, the losses will be lower. Reducing the length of LT lines or by relocation of transformer centres at load canters we can go for low distribution losses. Substitution of distribution transformers having higher fixed losses with those having lower no load losses such as amorphous core transformers of shunt capacitors for improvement of power factor [13].

2.5.3.3 By utilizing feeders as per capacity

The higher the load on power lines higher the losses. Distribution losses will increase if the load on distribution feeders crosses its limit.

2.5.3.4 Implementation of energy audit schemes

It should be mandatory for all utilities to carry out Energy Audits. Further time bound action for initiating studies for practical evaluation of the total losses into technical and non-technical losses has also to be drawn by the utilities to recognize high loss areas to initiate remedial measure to reduce the losses [13].

2.5.3.5 Public awareness

Utilities can aware public by campaigning regarding save of electrical energy. For this purpose, utility can employ energy conservation programmes.

2.6 Power System Analysis Toolbox (PSAT)

Is an open source power system analysis toolbox for MATLAB and GNU/Octave developed by Dr. Federico Milano. It can be used for power system analysis and control learning, education and research. The default power base is 100 MVA. This value can be changed in the main PSAT window. Buses define the voltage base in kV. Per unit values of each device are defined based on the power and voltage nominal rates of the device. Before running the power flow analysis the per unit value of each devices are converted to the system power base and to the voltage base of the bus at which the device is connected.

CHAPTER THREE

FLEXIBLE AC TRANSMISSION SYSTEM (FACTS)

3.1 Introduction

The FACTS controller is defined as ‘a power electronic based system and other static equipment that provide control of one or more AC transmission system parameter ‘[14].

There are two main objectives of FACTS controllers which are increasing the power transfer capability of transmission system and limit power flow over designated lines. In current power market, control of active and reactive power flow in a transmission line becomes a necessity aspect. Entry of more power generation companies has increased the need for enhanced secured operation of power systems, which are facing the threat of voltage instability leading to voltage collapse and also for minimization of active power loss leading to reduction in electricity cost. This achieved by load compensation which consists of improvement in power factor, balancing of real power drawn from the supply, better voltage regulation of large fluctuating loads, and also achieved by voltage support at a given terminal of the transmission line [15,16].

3.2 The FACTS controllers can be classified

1. Shunt connected controllers
2. Series connected controllers
3. Combined series-series controllers
4. Combined shunt-series controllers. [16]

3.2.1 Series compensator

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

between the injected voltage and the line current. The symbolic representation of series FACTS controller is shown in Figure 3.1 [17].

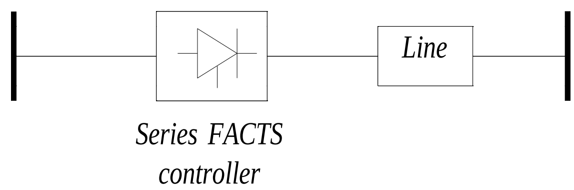


Figure 3.1: The symbolic of series compensation.

It controls the effective line parameters by connecting a variable reactance in series with the line. This increase the transmission line capability which in turn reduces transmission line net impedance. Example of Series compensator are Static Synchronous Series Compensator (SSSC) and Thyristor Control Series Compensator (TCSC) [17].

3.2.2 Shunt compensator

Similar to series controller, shunt Compensator have variable impedance or variable source or combination of both as shown in Figure 3.2. All shunt connected FACTS controllers inject current into the bus at the point of connection. The shunt impedance may be variable to vary the injected current. As long as this injected current is in phase quadrature with the line voltage, the shunt controller only supplies or absorbs variable reactive power. Any other phase relationship of the generated current with line voltage will involve real power flow [17].

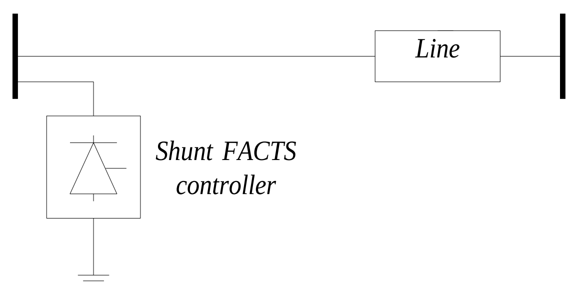


Figure 3.2: The symbolic of shunt compensation.

The operational pattern is same with an ideal synchronous machine that generates balanced three phase voltages with controllable amplitude and phase angle. The characteristics enables shunt compensators to be represented in positive sequence power flow studies with zero active power generation and reactive limits. Examples are Static Synchronous Compensator (STATCOM), Static Var Compensator (SVC). [18]

3.3.3 Series-Series compensator

It is the combination of two or more static synchronous compensators coupled through a common dc link to enhance bi-directional flow of real power between the ac terminals of SSSC and are controlled to provide independent reactance compensation for the adjustment of real power flow in each line and maintain the desired of reactive power flow among the power lines. Example of series – series compensator is Interline Power Flow Controller (IPFC). [19]

Figure 3.3 represent the symbolic of series- series compensation.

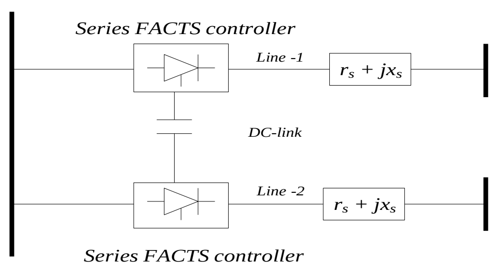


Figure 3.3: The symbolic of series- series compensation.

3.3.4 Series-Shunt compensator

It allows the simultaneous control of active power flow, reactive power flow and voltage magnitude at the series shunt compensator terminals. The active power control takes place between the series converter and the AC system, while the shunt converter generates or absorbs reactive power so as to provide voltage magnitude at the point of connection of the device and the AC system. Example of the series-shunt compensator is the unified power flow controller (UPFC) and thyristor controlled phase shifting Transformer (TCPST) [19].

Figure 3.4 represent the symbolic of series shunt compensation.

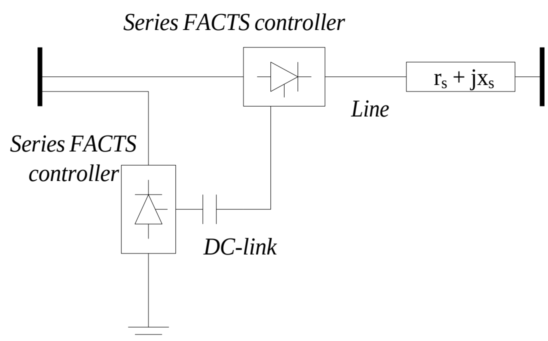


Figure 2.4: The symbolic of series- shunt compensation

3.4 Classification of FACTS Controllers Based on Power Electronic Devices

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

3.4.1 Variable impedance

3.4.1.1 Static VAR compensator (SVC)

The SVC consists of a TCR in parallel with a bank of capacitors. From an operational point of view, the SVC behaves like a shunt-connected variable reactance, which either generates or absorbs reactive power in order to regulate the voltage magnitude at the point of connection to the AC network. It is used extensively to provide fast reactive power and voltage regulation support. The firing angle control of the thyristor enables the SVC to have almost instantaneous speed of response. Generally, they are two configurations of the SVC. [19]

I. Shunt variable susceptance model

The SVC consists of a group of shunt-connected capacitors and reactors banks with fast control action by means of thyristor switching circuits. From the operational point of view, the SVC can be considered as a variable shunt reactance that adjusts automatically according to the system operative conditions. Depending on the nature of the equivalent SVC's reactance, i.e., capacitive or inductive, the SVC draws either capacitive or inductive current from the network. Suitable control of this equivalent reactance allows voltage magnitude regulation at the SVC point of connection. The most popular configuration for continuously controlled SVC is the combination of either fix capacitor and thyristor controlled reactor or thyristor switched capacitor and thyristor controlled reactor. For steady-state analysis, both configurations can be modeled along similar lines [20]. A changing susceptance Bsvc represents the fundamental frequency equivalent susceptance of all shunt modules making up the SVC as shown in Figure 3.5. is used to derive the SVC nonlinear power equations and the linearized equations required by Newton's method. With reference to Figure 3.5,

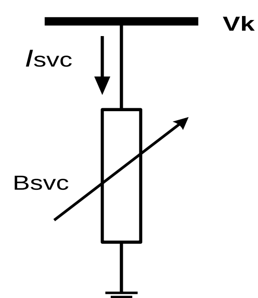


Figure 3.5: SVC susceptance model.

The current drawn by the SVC is

$$I_{SVC} = \mathrm{j}B_{SVC}V_k \quad (3.1)$$

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

$$Q_{SVC} = Q_k = -V_{2k}\, B_{SVC} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.2)$$

The linearized equation is given by equation (3.3), where the equivalent susceptance BSVC is taken to be the state variable:

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

At the end of iteration (i), the variable shunt susceptance BSVC is updated according to:

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

Where:

V_k= voltage at bus k.

B_{svc} = Susceptance.

Q_{SVC} = reactive power drawn by SVC.

I_{SVC} = the current drawn by the SVC.

Q_k = reactive power at bus k.

P_k = active power at bus k.

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

Once the level of compensation has been computed then the thyristor firing angle can be calculated. However, the additional calculation requires an iterative solution because the SVC susceptance and thyristor firing angle are nonlinearly related [21].

II. Firing angle model.

The equivalent reactance XSVC, which is function of a changing firing angle α, is made up of the parallel combination of a thyristor controlled reactor (TCR) equivalent admittance and a fixed capacitive reactance as shown in Figure 2.6. This model provides information on the SVC firing angle required to achieve a given level of compensation [21].

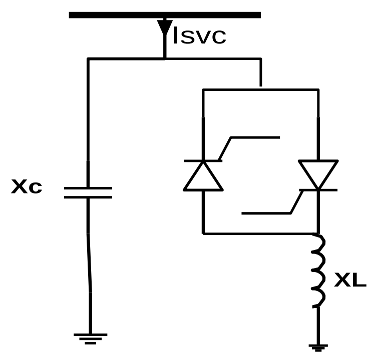


Figure 3.6: SVC firing angle model.

I_{SVC}= j B_{SVC} V_k............................... (3.7)

The fundamental frequency TCR equivalent reactance X_{TCR}

$X_{TCR}=\frac{\Pi X_L}{2(\Pi-\alpha)+\sin(2\alpha)}$........................... (3.8)

Where

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

And in terms of firing angle

$$X_L = \frac{\pi X_L}{2\pi - \alpha + \sin 2\alpha} \text{………………………..} \quad (3.9)$$

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

$$X_{SVC} = \frac{\pi x_C x_L}{X_C[X_c[2(\pi - \alpha) + \sin 2\alpha] - X_L]} \text{………………………..} \quad (3.10)$$

Where:

$X_C = {}^{1}/_{\omega C}$

$$Q_k = -v_k^2 \left\{ \frac{X_C X C^{2\pi - \alpha + \sin 2\alpha - \pi} X_L}{\pi X_C X_L} \right\} \text{…………………………..} \quad (3.11)$$

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

$$\begin{pmatrix} \Delta P_k \\ \Delta Q_k \end{pmatrix}^{(i)} = \begin{pmatrix} 0 & 0 \\ 0 & 2\frac{v_k^2}{\pi x_L}\{\cos 2\alpha - 1\} \end{pmatrix}^{(i)} \begin{pmatrix} \Delta \theta_k \\ \Delta \alpha \end{pmatrix}^{(i)} \text{……….……..} \quad (3.12)$$

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

$$\alpha^{(i)} = \alpha^{(i-1)} + \Delta\alpha^{(i)}) \text{……………………………………..} \quad (3.13)$$

$$V_k = V_{ref} + X_{SL} I_{SVC} \text{……………………………….…….} (3.14)$$

Where V_k and I_{SVC} stand for controlling bus voltage and SVC current [21].

III. SVC V-I characteristic

The typical steady-state control law of a SVC used here is depicted in Figure3.7, and may be represented by the following voltage-current characteristic:

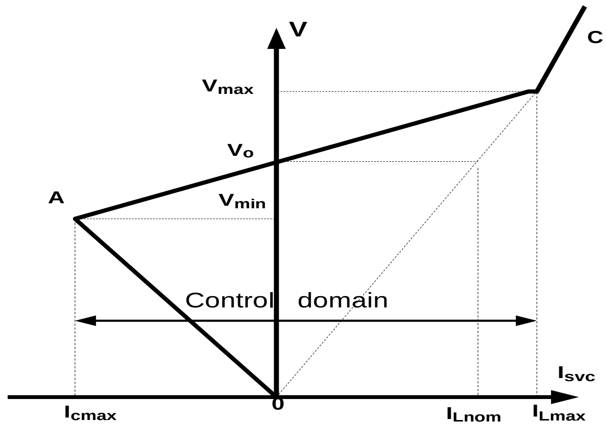


Figure 3.7: The V-I Characteristic Curve of SVC

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

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

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

The low voltages domain (OA), resulted from the limitation in the capacitive reactive power, i.e. Q < Q_{Cmax}. The SVC, in this case is out of the control area and it behaves like a fixed capacitive susceptance [22].

The reason for including the SVC voltage current slope in power flow studies is compelling. The slope can be represented by connecting the SVC models to an auxiliary bus coupled to the high voltage bus by an inductive reactance consisting of the transformer reactance and the SVC slope, in per unit (p.u) on the SVC base. A simpler representation assumes that the SVC slope, accounting for voltage regulation is zero. This assumption may be acceptable as long as the SVC is operating within the limits, but may lead to gross errors if the SVC is operating close to its reactive limits [21-22].

3.4.2 Variable source converter (VSC)

3.4.2.1 Static synchronous series compensator (SSSC)

Static Synchronous Series Compensator is based on solid-state voltage source converter designed to generate the desired voltage magnitude independent of line current. SSSC consists of a converter, DC bus (storage unit) and coupling transformer. The dc bus uses the inverter to synthesize an ac voltage waveform that is inserted in series with transmission line through the transformer with an appropriate phase angle and line current. If the injected voltage is in phase with the line current it exchanges a real power and if the injected voltage is in quadrature with line current it exchanges a reactive power. Therefore, it has the ability to exchange both the real and reactive power in a transmission line [23].

3.4.2.2 Static synchronous sompensator (STATCOM)

It is designed based on Voltage source converter (VSC) electronic device with Gate turn off thyristor and dc capacitor coupled with a step-down transformer tied to a transmission line. It converts the dc input voltage into ac output voltages to compensate the active and reactive power of the system. The STATCOM has better characteristics than SVC and it is used for voltage control and reactive power compensation. STATCOM placed on a transmission network improve the voltage stability of a power system by controlling the voltage in transmission and distribution systems, improves the damping power oscillation in transmission system, and provides the desired reactive power compensation of a power system [23].

3.4.2.3 Unified power flow controller (UPFC)

It is designed by combining the series compensator (SSSC) and shunt compensator (STATCOM) coupled with a common DC capacitor. It provides the ability to simultaneously control all the transmission parameters of power systems, i.e. voltage, impedance and phase angle. it consists of two converters – one connected in series with the transmission line through a series inserted transformer and the other one connected in shunt with the transmission line through a shunt transformer. The DC terminal of the two converters is connected together with a DC capacitor. The series converter control to inject voltage magnitude and phase angle in series with the line to control the active and reactive power flows on the transmission line. Hence the series converter will exchange active and reactive power with the line [23].

3.5 PSAT SVC Model

The two most popular configurations of this type of shunt controller are the fixed capacitor (FC) with a thyristor controlled reactor (TCR) and the thyristor switched capacitor (TSC) with TCR. Among these two setups, the second (TSC-TCR) minimizes stand-by losses;

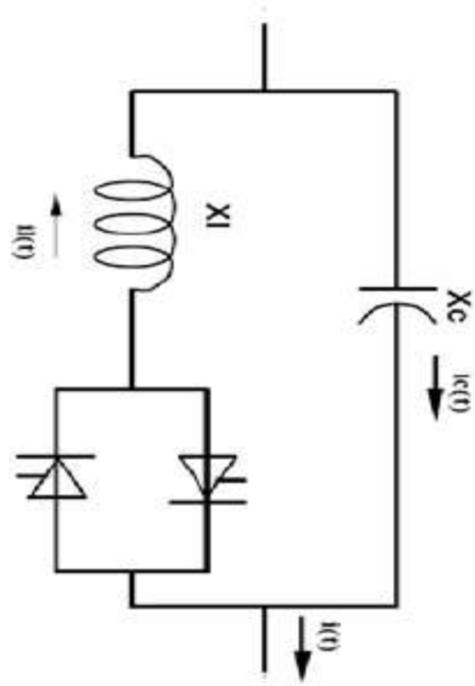


Figure 3.8 Equivalent FC-TCR circuit of SVC.

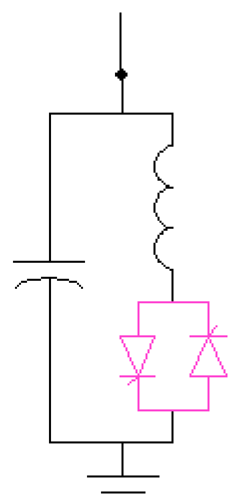


Figure 3.9 PSAT SVC Model

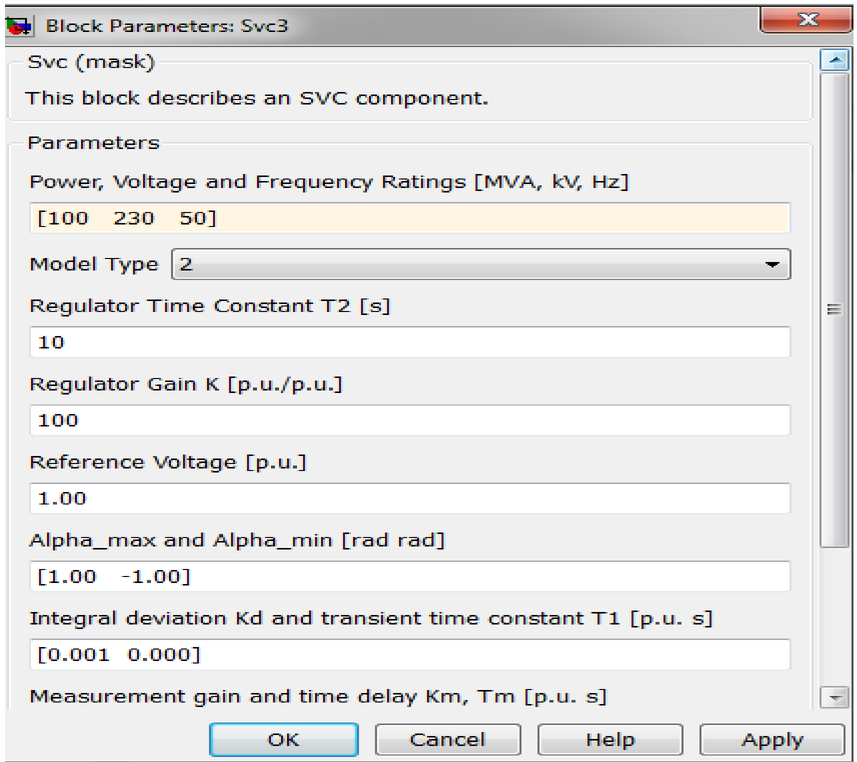


Figure 3.10 block parameter

CHAPTER FOUR

CASE STUDY

4.1 Introduction

In this dissertation, the case study is a part of National grid of Sudan. This network consists of 42 bus and tow voltage levels: 500, 220KV Data of the network of the national grid are obtained from the National grid control center at peak load condition.

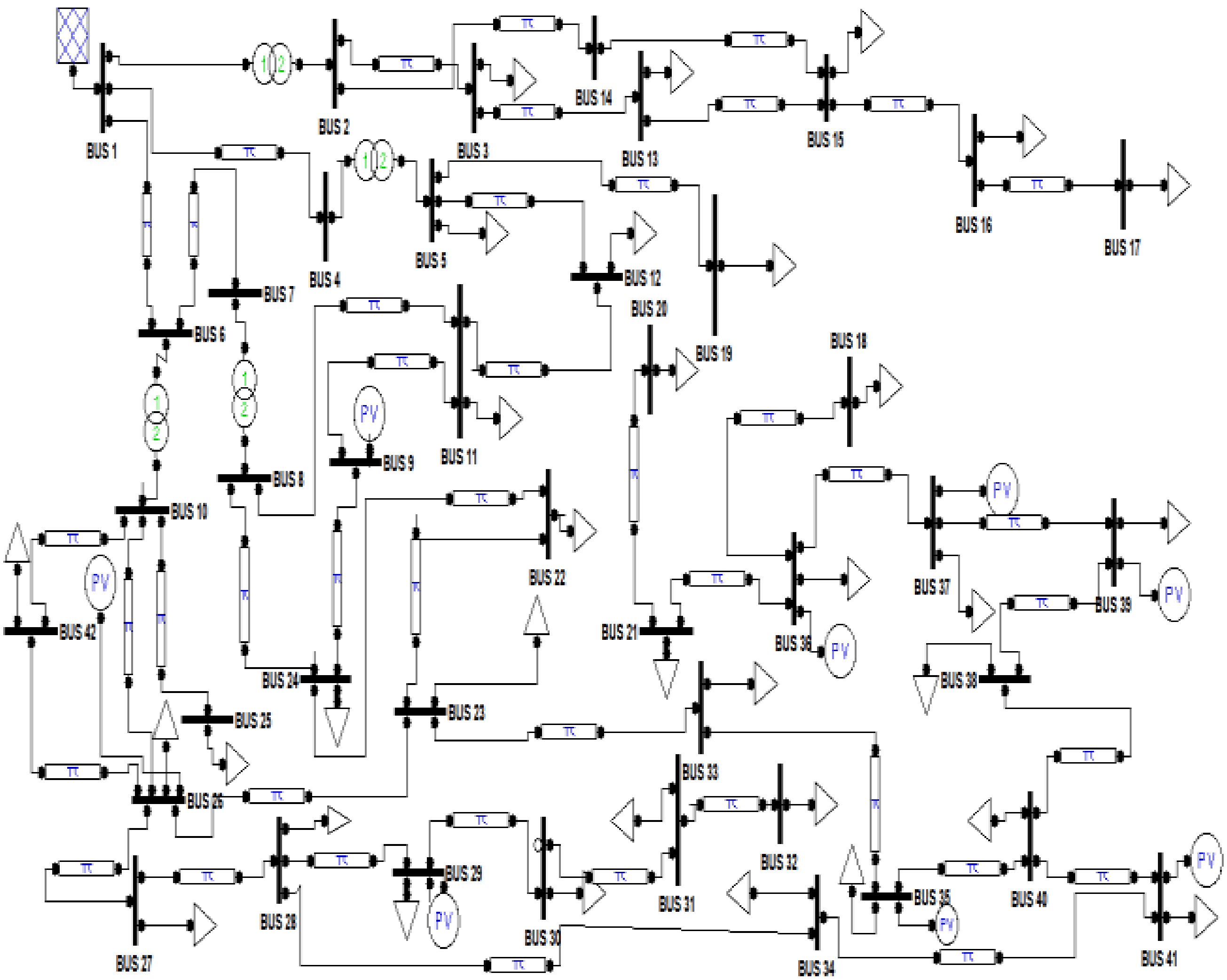


Figure 4.1 single line diagram of Sudanese electrical network.

4.2 System without FACTS controllers

The system is simulated in PSAT package in MATLAB software environment using the operational data given in appendix. In this study Newton-Raphson method was used to obtain the power-flow solution.

Table 4.1: Bus Voltage and angle at base case:

Bus Number	Bus Name	V	V	Phase
		Kv	[p.u.]	[rad]
1	MWP500	500.000	1.0000	0.0000
2	MWP	226.292	1.1695	-0.1725
3	MWT	225.335	1.1788	-0.1888
4	ATB500	512.031	1.0241	-0.0107
5	ATB220	217.717	0.9896	-0.0448
6	MRT1	517.757	1.0355	0.0430
7	KAB1	516.407	1.0328	0.0477
8	KAB	220.680	1.0031	0.0862
9	GAR	220.000	1.0000	0.0960
10	MRT	222.245	1.0102	0.0692
11	FRZ	220.098	1.0004	0.0916
12	SHN	219.361	0.9971	0.0201
13	**DEB**	**260.101**	**1.1823**	**-0.1922**
14	**DEB 2**	**262.740**	**1.1943**	**-0.1850**
15	**DON**	**264.717**	**1.2033**	**-0.2030**
16	WAWA	277.511	1.2614	-0.2179
17	OH	281.583	1.2799	-0.2247
18	NHAL	219.823	0.9992	0.4913
19	**POR**	**210.417**	**0.9564**	**-0.2482**
20	ARM	220.635	1.0029	0.4865
21	KSL	220.461	1.0021	0.4869
22	KX	219.442	0.9975	0.0992
23	GIAD	219.373	0.9972	0.1285
24	IBA	219.651	0.9984	0.0935
25	**MHD**	**203.588**	**0.9254**	**0.0634**
26	JAS	220.000	1.0000	0.1314
27	MSH	219.772	0.9990	0.2317
28	RBK	219.912	0.9996	0.3369
29	Kosti	220.000	1.0000	0.3659
30	TND	220.920	1.0042	0.3523
31	UMR	221.598	1.0073	0.3404
32	OBD	220.721	1.0033	0.3257

33	MAR	217.195	0.9873	0.2229
34	RNK	223.139	1.0143	0.3678
35	SNR	220.000	1.0000	0.3073
36	GRB	220.000	1.0000	0.4941
37	SHK	220.000	1.0000	0.5069
38	HWT	221.196	1.0054	0.4232
39	GDR	220.000	1.0000	0.5030
40	SNG	220.851	1.0039	0.3614
41	ROS	220.000	1.0000	0.4078
42	GAM	220.986	1.0045	0.0987

It can be observed from the results presented in Table 4.1 that all nodal voltages are within accepted voltage magnitude limits (i.e. 100 ±10% in the Sudan), but there are two buses in the network are near to the lower statutory limit and three buses out of limit.

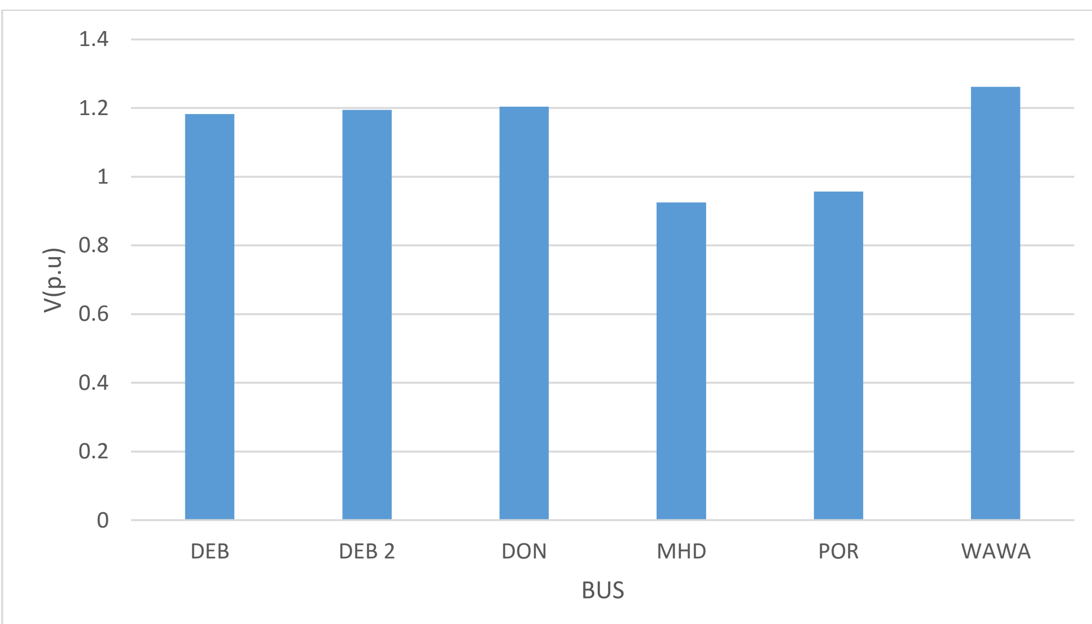
Table 4.2: Power flow results at base case:

From Bus	To Bus	Line	P Flow [MW]	Q Flow [MVar]	P Loss [MW]	Q Loss [MVar]
MWP500	MRT1	1	-124.453	-255.604	0.835	-360.147
MWT	DEB	2	46.939	-59.004	0.063	-1.577
KAB	FRZ	3	-21.778	14.003	0.036	-6.612
KAB	FRZ	4	-28.479	20.157	0.048	-4.967
GAR	FRZ	5	130.923	-43.515	0.131	-0.401
ATB220	SHN	6	-71.048	-3.945	1.017	-22.848
FRZ	SHN	7	96.422	-24.594	1.506	-15.991
GAR	FRZ	8	130.923	-43.515	0.131	-0.401
KAB	IBA	9	-32.349	29.369	0.086	-5.577
KAB	IBA	10	-32.349	29.369	0.086	-5.577
GAR	IBA	11	7.027	-3.277	0.005	-11.875
GAR	IBA	12	7.027	-3.277	0.005	-11.875
ATB220	POR	13	51.956	-25.940	1.956	-47.940
IBA	KX	14	-59.014	22.744	0.079	-2.412
IBA	KX	15	-59.014	22.744	0.079	-2.412
KX	GIAD	16	-78.093	13.856	0.433	-3.570
KX	GIAD	17	-78.093	13.856	0.433	-3.570
JAS	GIAD	18	14.572	5.447	0.015	-7.258
JAS	GIAD	19	14.572	5.447	0.015	-7.258
MRT	MHD	20	49.636	21.400	0.086	-3.850
MRT	MHD	21	49.636	21.400	0.086	-3.850
MRT	GAM	22	-117.875	49.348	0.839	-3.675

MRT	GAM	23	-117.875	49.348	0.839	-3.675
MWP500	MRT1	24	-124.453	-255.604	0.835	-360.147
JAS	MSH	25	-150.762	33.228	3.404	-4.493
JAS	MSH	26	-150.762	33.228	3.404	-4.493
MSH	RBK	27	-158.617	33.121	3.747	-2.941
MSH	RBK	28	-158.617	33.121	3.747	-2.941
kosti	TND	29	23.159	-21.276	0.082	-16.382
kosti	TND	30	23.159	-21.276	0.082	-16.382
TND	UMR	31	22.127	-18.944	0.066	-15.430
TND	UMR	32	22.127	-18.944	0.066	-15.430
UMR	OBD	33	18.511	-12.114	0.061	-25.814
UMR	OBD	34	18.511	-12.114	0.061	-25.814
MWP	MWT	35	68.652	-53.305	0.286	-5.014
RBK	RNK	36	-32.223	-22.967	0.245	-31.776
RBK	RNK	37	-32.223	-22.967	0.245	-31.776
GIAD	MAR	38	-74.720	16.782	1.388	-11.545
GIAD	MAR	39	-74.720	16.782	1.388	-11.545
GAM	JAS	40	-130.939	47.173	1.002	-2.865
SNG	ROS	41	-29.732	-3.345	0.267	-23.090
MAR	SNR	42	-117.257	3.527	1.872	-1.448
MAR	SNR	43	-117.257	3.527	1.872	-1.448
SNR	SNG	44	-126.879	14.729	1.290	-0.045
SNR	SNG	45	-126.879	14.729	1.290	-0.045
DEB	DON	46	24.689	-68.837	0.265	-8.354
SNG	ROS	47	-29.732	-3.345	0.267	-23.090
RNK	ROS	48	-32.843	3.809	0.358	-33.195
RNK	ROS	49	-32.843	3.809	0.358	-33.195
HWT	SNG	50	107.140	-26.560	1.453	-11.492
HWT	SNG	51	107.140	-26.560	1.453	-11.492
HWT	GDR	52	-108.540	25.660	1.977	-13.050
SHK	GDR	53	8.024	-9.222	0.007	-14.886
HWT	GDR	54	-108.540	25.660	1.977	-13.050
SHK	GDR	55	8.024	-9.222	0.007	-14.886
GRB	SHK	56	-31.137	0.907	0.088	-12.021
RBK	kosti	57	-163.591	33.729	1.051	-0.624
GRB	SHK	58	-31.137	0.907	0.088	-12.021
KSL	GRB	59	-13.831	0.212	0.026	-14.710
KSL	GRB	60	-13.831	0.212	0.026	-14.710
NHAL	GRB	61	-9.325	-5.400	0.006	-9.670
ARM	KSL	62	-1.070	-1.250	0.001	-8.752
NHAL	GRB	63	-9.325	-5.400	0.006	-9.670
KAB1	MRT1	64	114.594	-100.134	0.075	-39.698
MWP	MWT	65	68.652	-53.305	0.286	-5.014
ARM	KSL	66	-1.070	-1.250	0.001	-8.752
GAM	JAS	67	-130.939	47.173	1.002	-2.865
MWP500	ATB500	68	32.450	-216.754	0.268	-246.500

MWT	DEB	69	46.939	-59.004	0.063	-1.577
DEB	DON	70	24.689	-68.837	0.265	-8.354
RBK	kosti	71	-163.591	33.729	1.051	-0.624
MWP	DEB 2	72	14.008	-46.670	0.182	-18.194
MWP	DEB 2	73	14.008	-46.670	0.182	-18.194
DEB 2	DON	74	13.826	-28.476	0.060	-39.103
DEB 2	DON	75	13.826	-28.476	0.060	-39.103
DON	WAWA	76	6.673	-68.241	0.490	-31.995
DON	WAWA	77	6.673	-68.241	0.490	-31.995
WAWA	OH	78	3.730	-36.730	0.045	-45.162
ATB220	SHN	79	-71.048	-3.945	1.017	-22.848
WAWA	OH	80	3.730	-36.730	0.045	-45.162
FRZ	SHN	81	96.422	-24.594	1.506	-15.991
MWP500	MWP	82	168.601	-144.176	3.281	55.775
ATB500	ATB220	83	32.182	29.746	0.122	2.075
MRT1	MRT	84	-136.058	148.650	0.421	7.153
KAB1	KAB	85	-114.594	100.134	0.362	7.237
Total					**56.1956**	**-1955.9408**

Table 4.2 represent the power flow through the lines and it observed that all the lines did not reach their thermal limits.



Figures (4.2) shows the buses near to the lower limit and out of limit.

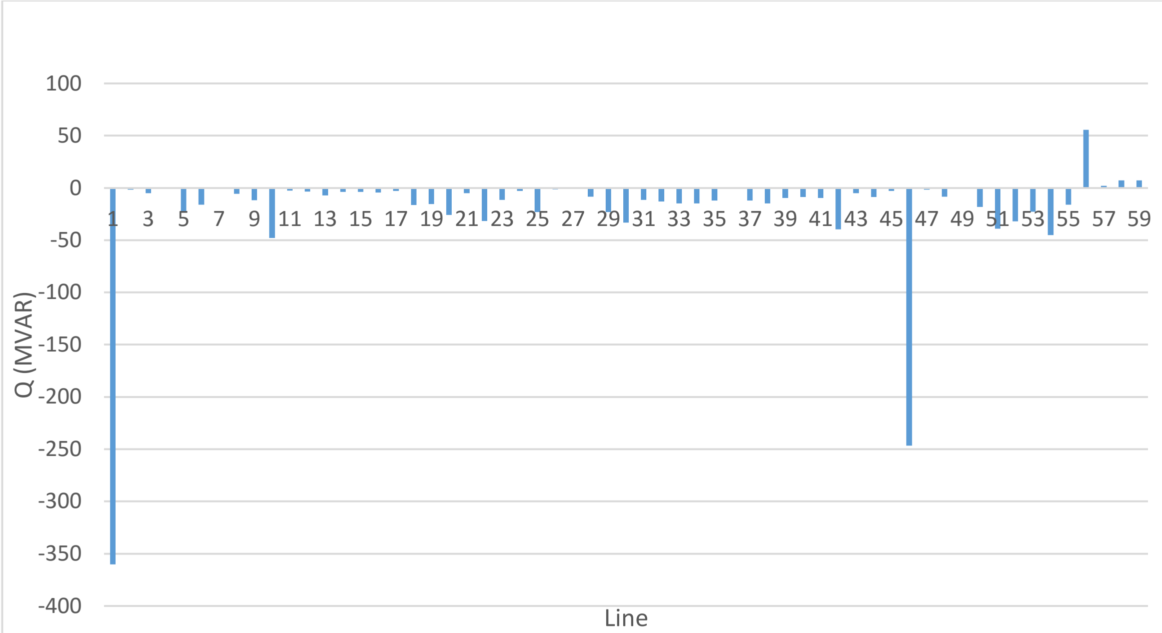


Figure 4.3: Reactive Power Losses at base case

The largest power flow takes place in the transmission line 11 (MWP500 – MRT1), Also the transmission line that incurs higher reactive power loss. The reactive power loss is-360.147 MVAr

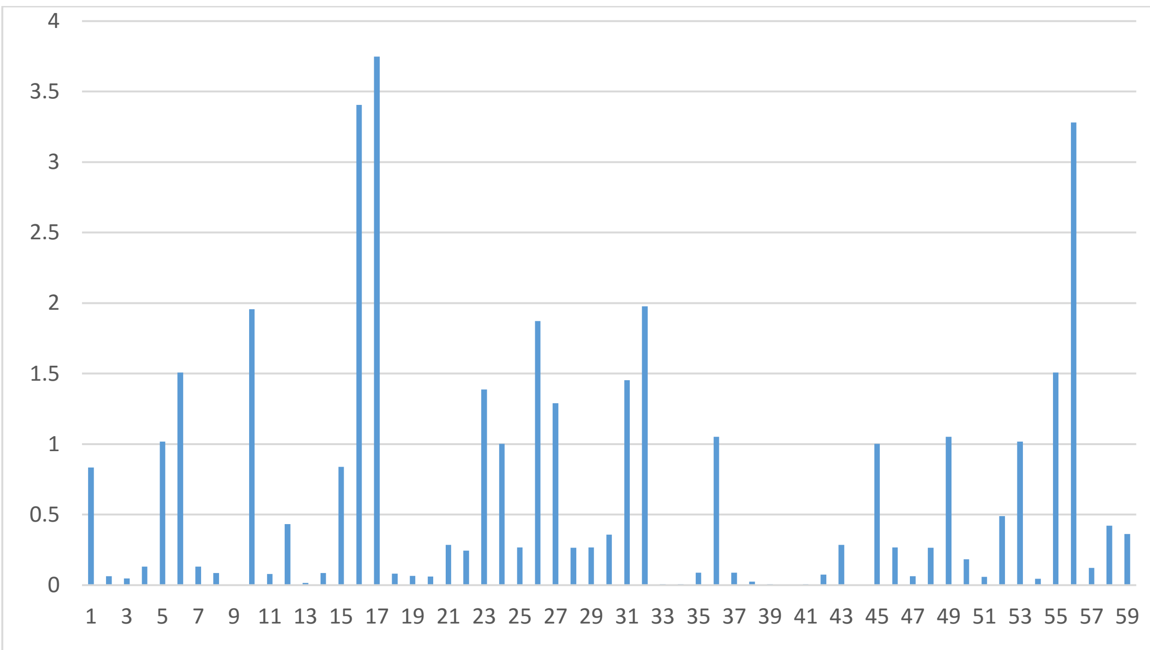


Figure 4.4: Active Power Losses at base case

The higher active power loss is 3.404 MW in line (JAS-MSH), and total active and reactive power loss is found to be 56.1956 MW and -1955.9408 MVAr respectively. The voltage profile enhancement and minimize active power losses by installing FACTS controllers static SVC.

4.3 System after incorporation SVC Controller

According to the obtaining results, SVC controllers are connected to buses (WAWA, POR MHD).

Table 4.3: Bus voltage and angle after installing SVC:

Bus Number	Bus Name	V	V	Phase
		Kv	[p.u.]	[rad]
1	MWP500	500.000	1.0000	0.0000
2	MWP	225.731	1.0260	-0.1424
3	MWT	224.852	1.0221	-0.1566
4	ATB500	218.945	0.9952	-0.0450
5	ATB220	512.566	1.0251	-0.0109
6	MRT1	516.933	1.0339	0.0433
7	KAB1	515.661	1.0313	0.0479
8	KAB	220.635	1.0029	0.0864
9	GAR	220.000	1.0000	0.0960
10	MRT	221.393	1.0063	0.0698
11	FRZ	220.112	1.0005	0.0917
12	SHN	219.927	0.9997	0.0199
13	**DEB**	224.757	1.0216	-0.1594
14	**DEB 2**	228.081	1.0367	-0.1528
15	**DON**	225.014	1.0228	-0.1671
16	**WAWA**	220.000	1.0000	-0.1688
17	OH	223.073	1.0140	-0.1757
18	NHAL	219.823	0.9992	0.4914
19	**POR**	220.000	1.0000	-0.2456
20	ARM	220.635	1.0029	0.4865
21	KSL	220.461	1.0021	0.4870
22	KX	219.421	0.9974	0.0993
23	GIAD	219.366	0.9971	0.1285
24	IBA	219.627	0.9983	0.0937

25	**MHD**	220.000	1.0000	0.0644
26	JAS	220.000	1.0000	0.1314
27	MSH	219.772	0.9990	0.2317
28	RBK	219.912	0.9996	0.3370
29	kosti	220.000	1.0000	0.3659
30	TND	220.920	1.0042	0.3524
31	UMR	221.598	1.0073	0.3405
32	OBD	220.721	1.0033	0.3258
33	MAR	217.193	0.9872	0.2230
34	RNK	223.139	1.0143	0.3679
35	SNR	220.000	1.0000	0.3073
36	GRB	220.000	1.0000	0.4941
37	SHK	220.000	1.0000	0.5070
38	HWT	221.196	1.0054	0.4232
39	GDR	220.000	1.0000	0.5030
40	SNG	220.851	1.0039	0.3615
41	ROS	220.000	1.0000	0.4078
42	GAM	220.561	1.0026	0.0990

It can be observe all of the six buses are return to their limits.

Table 4.4: Power flow results after installing SVC:

From Bus	To Bus	Line	P Flow [MW]	Q Flow [MVar]	P Loss [MW]	Q Loss [MVar]
MWP500	MRT1	1	-124.553	-251.251	0.810	-359.783
MWT	DEB	2	35.489	-2.095	0.019	-1.332
KAB	FRZ	3	-21.781	12.750	0.034	-6.620
KAB	FRZ	4	-28.482	18.517	0.045	-4.978
GAR	FRZ	5	130.883	-45.523	0.133	-0.396
ATB220	SHN	6	-70.989	-0.704	1.019	-23.064
FRZ	SHN	7	96.379	-28.044	1.521	-15.984
GAR	FRZ	8	130.883	-45.523	0.133	-0.396
KAB	IBA	9	-32.255	28.866	0.085	-5.582
KAB	IBA	10	-32.255	28.866	0.085	-5.582
GAR	IBA	11	7.067	-2.985	0.005	-11.873
GAR	IBA	12	7.067	-2.985	0.005	-11.873
ATB220	POR	13	51.944	-36.229	1.944	-50.969
IBA	KX	14	-58.878	22.536	0.079	-2.414
IBA	KX	15	-58.878	22.536	0.079	-2.414
KX	GIAD	16	-77.957	13.650	0.431	-3.579
KX	GIAD	17	-77.957	13.650	0.431	-3.579
JAS	GIAD	18	14.438	5.625	0.015	-7.258
JAS	GIAD	19	14.438	5.625	0.015	-7.258

MRT	MHD	20	49.662	35.593	0.112	-3.694
MRT	MHD	21	49.662	35.593	0.112	-3.694
MRT	GAM	22	-118.081	40.818	0.806	-3.782
MRT	GAM	23	-118.081	40.818	0.806	-3.782
MWP500	MRT1	24	-124.553	-251.251	0.810	-359.783
JAS	MSH	25	-150.767	33.231	3.404	-4.492
JAS	MSH	26	-150.767	33.231	3.404	-4.492
MSH	RBK	27	-158.622	33.123	3.747	-2.940
MSH	RBK	28	-158.622	33.123	3.747	-2.940
kosti	TND	29	23.159	-21.276	0.082	-16.382
kosti	TND	30	23.159	-21.276	0.082	-16.382
TND	UMR	31	22.127	-18.944	0.066	-15.430
TND	UMR	32	22.127	-18.944	0.066	-15.430
UMR	OBD	33	18.511	-12.114	0.061	-25.814
UMR	OBD	34	18.511	-12.114	0.061	-25.814
MWP	MWT	35	52.633	2.199	0.144	-4.206
RBK	RNK	36	-32.228	-22.965	0.245	-31.776
RBK	RNK	37	-32.228	-22.965	0.245	-31.776
GIAD	MAR	38	-74.715	16.762	1.387	-11.546
GIAD	MAR	39	-74.715	16.762	1.387	-11.546
GAM	JAS	40	-131.111	38.750	0.968	-3.004
SNG	ROS	41	-29.726	-3.346	0.267	-23.090
MAR	SNR	42	-117.252	3.508	1.872	-1.449
MAR	SNR	43	-117.252	3.508	1.872	-1.449
SNR	SNG	44	-126.874	14.727	1.290	-0.045
SNR	SNG	45	-126.874	14.727	1.290	-0.045
DEB	DON	46	17.970	-9.764	0.027	-7.021
SNG	ROS	47	-29.726	-3.346	0.267	-23.090
RNK	ROS	48	-32.848	3.810	0.358	-33.194
RNK	ROS	49	-32.848	3.810	0.358	-33.194
HWT	SNG	50	107.140	-26.560	1.453	-11.492
HWT	SNG	51	107.140	-26.560	1.453	-11.492
HWT	GDR	52	-108.540	25.660	1.977	-13.050
SHK	GDR	53	8.024	-9.222	0.007	-14.886
HWT	GDR	54	-108.540	25.660	1.977	-13.050
SHK	GDR	55	8.024	-9.222	0.007	-14.886
GRB	SHK	56	-31.137	0.907	0.088	-12.021
RBK	kosti	57	-163.591	33.727	1.051	-0.624
GRB	SHK	58	-31.137	0.907	0.088	-12.021
KSL	GRB	59	-13.831	0.212	0.026	-14.710
KSL	GRB	60	-13.831	0.212	0.026	-14.710
NHAL	GRB	61	-9.325	-5.400	0.006	-9.670
ARM	KSL	62	-1.070	-1.250	0.001	-8.752
NHAL	GRB	63	-9.325	-5.400	0.006	-9.670
KAB1	MRT1	64	114.424	-95.991	0.073	-39.599
MWP	MWT	65	52.633	2.199	0.144	-4.206

ARM	KSL	66	-1.070	-1.250	0.001	-8.752
GAM	JAS	67	-131.111	38.750	0.968	-3.004
MWP500	ATB500	68	32.564	-220.858	0.289	-246.556
MWT	DEB	69	35.489	-2.095	0.019	-1.332
DEB	DON	70	17.970	-9.764	0.027	-7.021
RBK	kosti	71	-163.591	33.727	1.051	-0.624
MWP	DEB 2	72	10.427	-22.281	0.050	-14.325
MWP	DEB 2	73	10.427	-22.281	0.050	-14.325
DEB 2	DON	74	10.376	-7.956	0.045	-28.851
DEB 2	DON	75	10.376	-7.956	0.045	-28.851
DON	WAWA	76	4.275	4.152	0.069	-22.927
DON	WAWA	77	4.275	4.152	0.069	-22.927
WAWA	OH	78	2.506	-22.698	0.026	-28.373
ATB220	SHN	79	-70.989	-0.704	1.019	-23.064
WAWA	OH	80	2.506	-22.698	0.026	-28.373
FRZ	SHN	81	96.379	-28.044	1.521	-15.984
MWP500	MWP	82	127.229	-21.304	1.109	18.860
ATB500	ATB220	83	32.274	25.698	0.108	1.836
MRT1	MRT	84	-136.377	160.671	0.462	7.849
KAB1	KAB	85	-114.424	95.991	0.350	6.991
Total					**51.918**	**-1910.808**

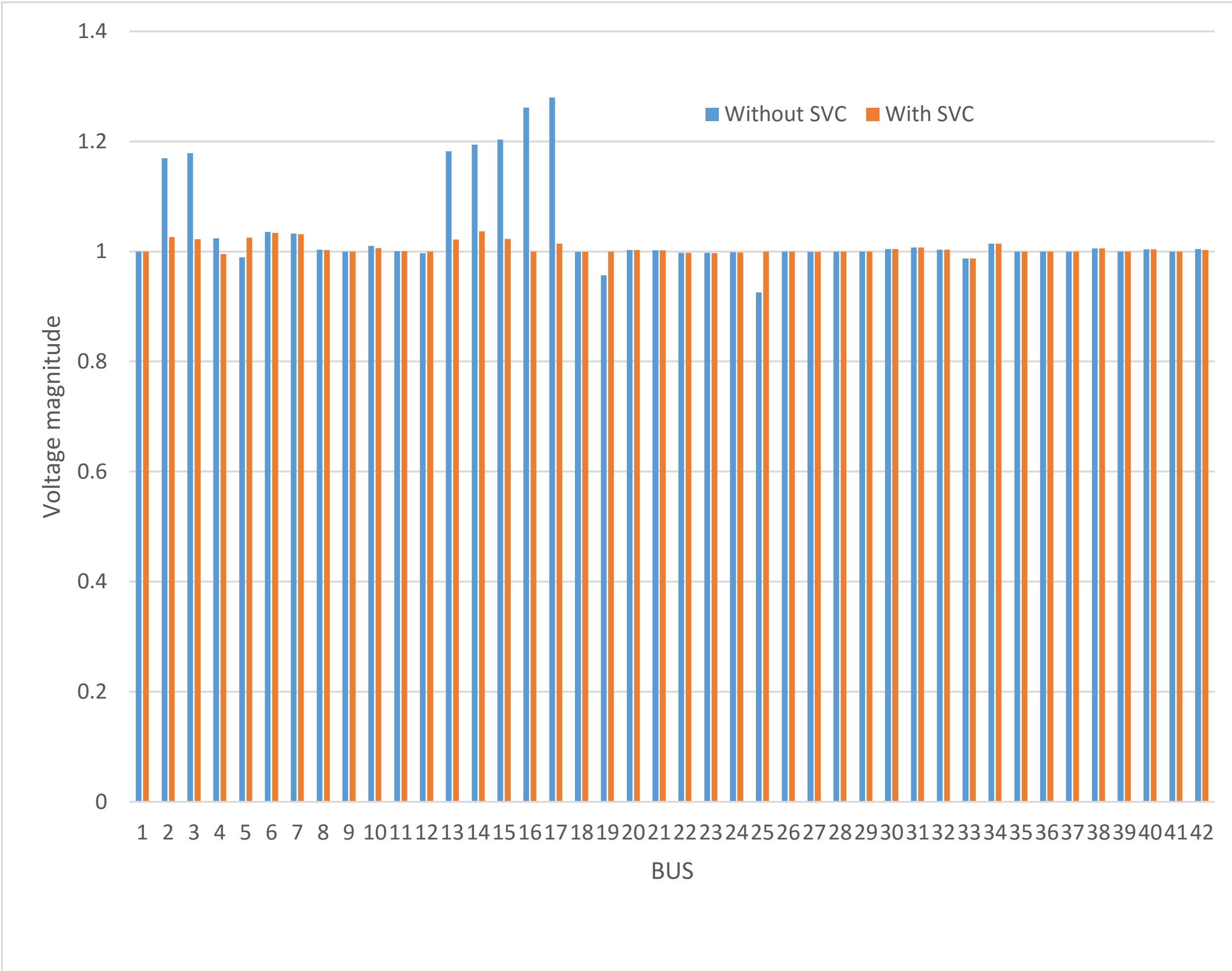


Figure 4.5: Voltage Magnitude with and without SVC.

The SVC injects or absorbs VAR into selected weakest bus and keeps the nodal voltage magnitude at 1 p.u. The action of the SVC results in an overall improved voltage profile the improvement is clearly appears in Figure 4.5.

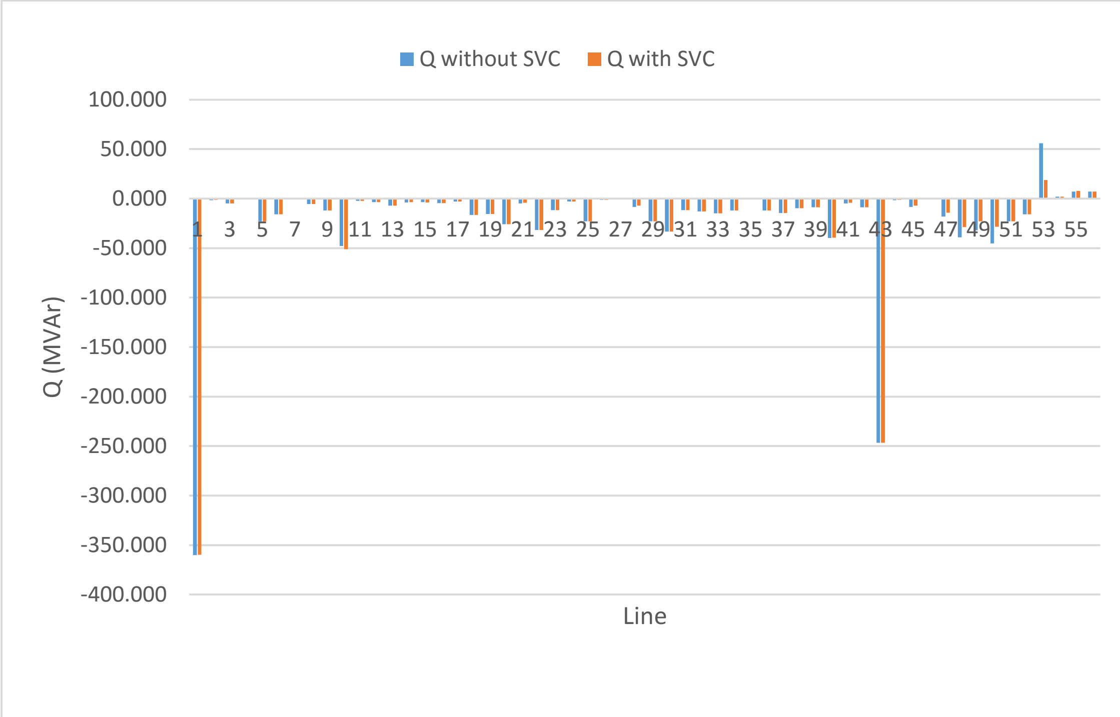


Figure 4.6: Reactive power losses without and with SVC

Figure 4.6 represent the reactive power losses in the line. The SVC generates reactive power in excess of the local demand compared with the base case, there is an increase of reactive power export to near bus this cause increased the power flow in the nearest lines from the location of SVC. It can be observed from the results presented in Figure 4.6 the reactive power losses increased in lines 10, 30 and 55 and decrease in the other lines. The total reactive power losses are decrease to -1910.808 MVAR compare with base case.

The total active power losses are decrease to 51.918 MW.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

One of the most important procedures in the electrical system is to control the level of voltages and make sure not to leave the limits allowed accordingly the control of the reactive power, and this is actually affecting the stability of the system.

It is necessary to make sure that the loss in transmission lines is minimal, the loss is reduced by using one of the methods either establish new lines and this is very expensive or install (FACTS) components, which is the cheapest and very effective way.

One of the most important elements is the SVC, which is connecting in parallel so it is very effective in voltages control.

In this study, PSAT was used to represent the network and the results were found to be appropriate. Also, SVC was introduced on the basis of the weakest BUS through the readings reached. This method proved effective compared to the optimal location method, which was discussed in previous studies on the same network.

5.2 Recommendations

- As for the length of the transmission line between Atbara and Port Sudan, it was proposed to establish a station between the two cities or to operate double circuit transmission line.
- Use the other FACTS controllers such as STATCOM, SSSC, UPFC and IPFC to improve performance and prevent sudden instability.
- Use some new optimization methods to select the optimal placement of FACTS controllers such as Genetics Algorithm GA, Particle Swarm Optimization PSO and other Artificial Intelligence.

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APPENDICES

Appendix A: Sudanese electrical network data.

□ Bus data:

Bus number	Type*	Pg MW	Qg MVAr	Pd MW	Qd MVAr	Bs MVAr	Base KV
1	3	0	0	0	0	-125	500
2	1	0	0	0	0	-125	500
3	1	0	0	0	0	-250	500
4	1	0	0	0	0	0	500
5	1	0	0	14.36	11.483	-30	220
6	1	0	0	0	0	-40	220
7	1	0	0	33.456	23.961	0	220
8	1	0	0	0	0	0	220
9	1	0	0	50.32	46.148	0	220
10	1	0	0	29.808	20.496	0	220
11	1	0	0	0	0	0	220
12	1	0	0	101.38	70.734	0	220
13	1	0	0	33.264	20.615	0	220
14	1	0	0	0	0	0	220
15	1	0	0	0	0	0	220
16	1	0	0	0	0	0	220
17	1	0	0	13.574	8.661	0	220
18	2	186	0	0	0	0	220
19	1	0	0	0	0	0	220
20	1	0	0	60.883	37.732	0	220
21	1	0	0	0	0	0	220
22	1	0	0	0	0	0	220
23	1	0	0	14.112	8.746	0	220
24	1	0	0	0	0	0	220
25	1	0	0	0	0	0	220
26	1	0	0	0	0	0	220
27	1	0	0	6.989	25.534	0	220
28	2	85	0	46.704	32.357	0	220
29	1	0	0	16.464	8.842	0	220
30	1	0	0	12.029	5.585	0	220
31	2	148	0	8.333	5.76	-15	220
32	1	0	0	0.403	22.385	0	220
33	1	0	0	1.546	0.958	0	220
34	1	0	0	19.757	31.778	0	220

35	1	0	0	3.629	25.117	0	220
36	1	0	0	1.008	5.56	0	220
37	1	0	0	6.25	3.939	0	220
38	1	0	0	3.36	23.764	0	220
39	1	0	0	6.72	4.568	-15	220
40	1	0	0	3.36	2.503	0	220
41	1	0	0	0	0	-30	220
42	1	0	0	0	0	0	220

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

Lines data:

from	to	R	X
kilox1	giad	0.076	0.403
kilox2	giad	0.076	0.403
meringan1	giad	0.076	0.403
meringan2	giad	0.076	0.403
meringan	sennar jun	0.076	0.403
sennar jun	singa	0.076	0.403
singa	roseires	0.076	0.403
garri	eid babiker	0.067	0.302
kilox	eid babiker	0.067	0.302
free zone	shendi	0.067	0.302
atbara	shendi	0.067	0.302
atbara	barber	0.067	0.302
barber	algobosh	0.067	0.302
barber	alsherek	0.067	0.302
alsherek	dagash	0.067	0.302
dagash	abuhamad	0.067	0.302
abuhamad	mugrat	0.067	0.302
jebel aulia	giad	0.067	0.302
jebel aulia	gamoeia	0.067	0.302
markhiat	mahdia	0.067	0.302
markhiat	gamoeia	0.067	0.302
garri	free zone	0.067	0.302
kabbashi	free zone	0.067	0.302
kabbashi	eid babiker	0.067	0.302
mushkur	jebel aulia	0.067	0.302
mushkur	rabak	0.067	0.302
rank	roseires	0.067	0.302
rabak	rank	0.067	0.302
rabak	kosti	0.067	0.302
kosti	tandalti	0.067	0.302
tandalti	umrawaba	0.067	0.302
rabak	umrawaba	0.067	0.302

umrawaba	elrahad	0.067	0.302
elrahad	obeid	0.067	0.302
obeid	aldebebat	0.067	0.302
aldebebat	abuzabad	0.067	0.302
abuzabad	alfula	0.067	0.302
alfula	babanosa	0.067	0.302
aldebebat	aldalang	0.067	0.302
umrawaba	abasia-tagali	0.067	0.302
abasia-tagali	rashad	0.067	0.302
rashad	abugibeha	0.067	0.302
abugibeha	kalogy	0.067	0.302
kalogy	talody	0.067	0.302
talody	kadogly	0.067	0.302
kadogly	lagawa	0.067	0.302
lagawa	alfula	0.067	0.302
singa	hawata	0.067	0.302
gedarif	gle alnahl	0.067	0.302
gle alnahl	hawata	0.067	0.302
hawata	eldender	0.067	0.302
eldender	senga	0.067	0.302
gedarif	showak	0.067	0.302
showak	girba	0.067	0.302
girba	kassala	0.067	0.302
girba	new halfa	0.067	0.302
kassala	aroma	0.067	0.302
merowe	merowe town	0.076	0.403
debba	merowe town	0.076	0.403
debba	dongola	0.076	0.403
dongola	wawa	0.067	0.302
wawa	old halfa	0.067	0.302
atbara	port sudan	0.076	0.403
port sudan	Arkiaey	0.067	0.302
port sudan	port sudan ring	0.067	0.302
merowe	markhiat	0.028	0.276