Addis Ababa University

Addis Ababa Institute of Technology

School of Electrical and Computer Engineering

Studies on Voltage Profile Improvement and Power Flow Control in Ethiopian Transmission Networks using FACTS devices

A thesis submitted to Addis Ababa Institute of Technology, School of Graduate Studies, Addis Ababa University in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical Power Engineering

By

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Declaration

I hereby declare that this MSc thesis entitled "**Studies on Voltage Profile Improvement and Power Flow Control in Ethiopian Transmission Networks using FACTS devices"** was prepared by me, with the guidance of my advisor. The work contained herein is my own except where explicitly stated otherwise in the text, and this work has not been submitted, in whole or part, for any other degree or professional qualification in this or any other university.

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TABLE OF CONTENTS

List of Figures

List of Tables

List of Abbreviations

AC	Alternating Current
DSR	Distributed Series Reactor
EEPNLDC	Ethiopian Electric Power National Load Dispatch Center
FACTS	Flexible AC Transmission System
FC-TCR	Fixed Capacitor Thyristor Controlled Reactor
GERD	Grand Ethiopian Renaissance Dam
HVDC	High Voltage DC transmission system
IPFC	Interline Power Flow Controller
MVA	Mega Volt Ampere
Mvar	Mega Volt Ampere Reactive
MW	Mega Watt
PI	Performance Index
PSAT	Power System Analysis Toolbox
Pu	Per Unit
SIA	Sensitivity Index Analysis
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Var compensator
TCSC	Thyristor Controlled Series Capacitor
TSSC	Thyristor Switched Series Capacitor
UPFC	Unified Power Flow Controller
VSC	Voltage Source Converter

Abstract

At present Ethiopian transmission network is operating at its full capacity due to increased demand resulting in unbalances in power flows and voltage profile violations. Control of power and voltage through appropriate allocation of active and reactive power suppliers increases system efficiency without the need to expand and build new power generation and transmission facilities. Flexible AC Transmission System (FACTS) controllers employ the latest technology in the design of power electronic switching devices for electric power transmission systems to control voltage and power flow and improve voltage regulation. This study investigated the control ability of employed Thyristor Controlled Series Capacitors (TCSCs) in the alleviation of line congestion, loss minimization, and Static Var compensators (SVCs) in enhancing system voltage profiles in Ethiopian high voltage transmission networks. Modeling and simulation of the transmission network with the incorporation of the FACTS devices have been performed using PSAT/MATLAB toolbox. The sensitivity analysis technique was performed on base case power flow results for optimal placement of the controllers. It is shown how the system behaves and performance is improved with comparative case studies without and with the devices. The final power flow solution result with four FACTS (two TCSC and two SVC) show the improvements and reduction of system maximum line loading, total real power loss, and voltage regulations from 91.16%, 4.46% (115.1 MW), and $\pm$15.6% base case to 81.47%, 3.68% (94 MW), and $\pm$7.3% respectively by the FACTS.

Keywords: TCSC; SVC; Optimal Placement; Sensitivity Analysis; Reactive Power Control.

Chapter One

Introduction

1.1. Background

The optimal performance of a power system requires flexibility in control of power flows in transmission networks and planned reactive support at system buses. This, in turn, enhances the system's reliability and efficiency. The country's demand for electricity is increasing to feed the technology-driven economy, while the proportionate expansion of power generation facilities and transmission lines to meet up such demand has been severely limited due to inadequate resources and environmental factors.

Less transmission capability means that more generation resources would be required regardless of whether the system is made up of large or small power plants. The EEP transmission network suffers both under and overvoltage problems besides limitations of power transfer capacity and the high transmission line losses leading the system to become less secure for riding through, large power flows with inadequate control, excessive reactive power in various parts of the system, large dynamic swings between different parts of the system and bottlenecks, and thus the full potential of transmission interconnections cannot be utilized. [1]

In large power system networks voltage and power flow control are both the challenge and the solution. It is, therefore, important that a balance of reactive power be obtained in the operation of electric power transmission systems because the control of voltage can be lost if this is not achieved. Adequate reactive power regulation of electric transmission networks can solve power quality problems by improving the power system voltage profile, transient stability improvement, increase of power transfer capacity, and minimization of transmission line loss.

In the transmission area, the application of a relatively new and well-established technology of power electronic-based FACTS controllers provides the principal role to enhance controllability and power transfer capability in AC systems. These devices are used to control the voltage and power flow in a transmission system to improve voltage regulation without the need to expand the power generation and transmission facilities. This study utilized Thyristor Controlled Series Capacitors (TCSCs) and Static Var compensators (SVCs) devices for the objectives of stabilizing transmission line power flow capacity, system loss reduction, and enhancing system voltage profiles through Sensitivity index analysis for transmission lines and Voltage performance index for buses to determine the optimal location of TCSCs and SVCs controllers respectively.

1.2. Statement of the problem

The energy demand of the country is increasing rapidly with increased industrialization and modernization of cities and towns. The transmission system plays a key role in delivering the energy generated to the demand centers, but the Ethiopian transmission system is a complex network involving different voltage levels and is also interconnected to neighboring countries for energy export this also adds another complexity to power flow control. Due to the increased demand, new transmission lines with higher voltage levels have been built over the lower voltage level ones in parallel or as a meshed system. As a result, if one of the lines becomes overloaded the operation of the whole system becomes jeopardized. This problem can be solved by building additional new transmission lines, but this research is aimed at utilizing and enhancing the performance of the existing transmission network using FACTS devices. Series FACTS provide power flow control in transmission networks by shifting power flow from overloaded lines to other lightly loaded lines. Furthermore, there is an impermissible voltage drop in the transmission network which in turn results in low voltage profiles at many buses of the system. Shunt FACTS are employed to overcome under/over voltage profile problems.

Additionally, although there are many types of research done using FACTS devices in our country, they are not done considering the whole system for optimal placement of the devices. Therefore, this needs further investigation and study, thus this thesis addresses the problems of voltage profile improvement and enhancement of power flows at 400kv, 230kV, and 132kV levels of the Ethiopian transmission network using FACTS devices.

1.3. Objective

The general objective of the thesis is to investigate the impacts of incorporating FACTS devices in EEP transmission networks of 400 kV, 230 kV, and 132kV and study the enhancement of voltage profile and power flow using FACTS devices.

The specific objectives include;

- To develop dynamic power system models for the FACTS devices and to develop the equations with and without FACTS.
- To develop a PSAT and MATLAB/SIMULINK model of the network.
- To perform simulation studies and identify the voltage profile and power flow problems in the transmission system.
- To determine the appropriate location of FACTS devices.
- To analyze, investigate and compare different mitigation techniques of voltage profile and power flow enhancement with different FACTS devices.
- To assess transmission line loss with and without the FACTS devices.
- To draw conclusions and recommend appropriate methods of voltage profile improvement and enhancement of power flows in the transmission system.

1.4. Significance of the Study

The result of the study will be useful for power system planners and decision-makers since it presents how system voltage profile, power transfer capacity, and transmission losses can be enhanced with FACTS without further expansion of new transmission lines, and it can be used as another means of replying to the growing power demand of the country. The ultimate achievements are to transfer energy over power lines with improved transfer capability, improved voltage regulation, maximum efficiency, and reliability, and deliver consumers at a nearly fixed voltage and frequency.

1.5. Scope of the study

Since the Ethiopian transmission system network is bulky, this study is limited only to voltage levels of 132kV, 230kV, and 400 kV.

- The transmission system model used in this study considered only the interconnected mesh system. Radial system line connections were treated as lumped loads at their respective starting bus.

1.6. Methodology

To study the usefulness of FACTS devices in voltage profile improvement and power flow control in 132kV, 230kV, and 400kV transmission systems of the Ethiopian national grid. The study follows the following procedures. First, the network model is built in PSAT/MATLAB Simulink environment. Then power flow analysis is performed on the base case loading of the system without FACTS. Parameters or state vectors of load flow solution such as voltage magnitude and phase angle profiles, real and reactive power flows, real and reactive power losses, and maximum loading capacity of each line are used for calculating sensitivity indexes of Power Flow Performance Indices (PI), reduction of power loss of a particular line sensitivity index (PLK) and Voltage performance index (PIV) of each bus. Based on the sensitivity indices lines and buses are ranked for optimal placement of FACTS devices. TCSC is used for power flow control and SVC for voltage profile improvement purposes.

Again, the network is built including one of the FACTS devices. The result of the power flow solution with FACTS is used for the analysis of system enhancement based on the required objective set. The processes are done repeatedly for multiple installations of FACTS. Results of load flow solutions without and with the control devices are compared to each other to show the effectiveness of the proposed method of system enhancement.

Thus, this study helps to understand which FACTS devices are the most efficient and can be used in the system for voltage profile improvement and power flow control ability of a power system. A summary of the whole procedure followed is shown in Figure 1.1.

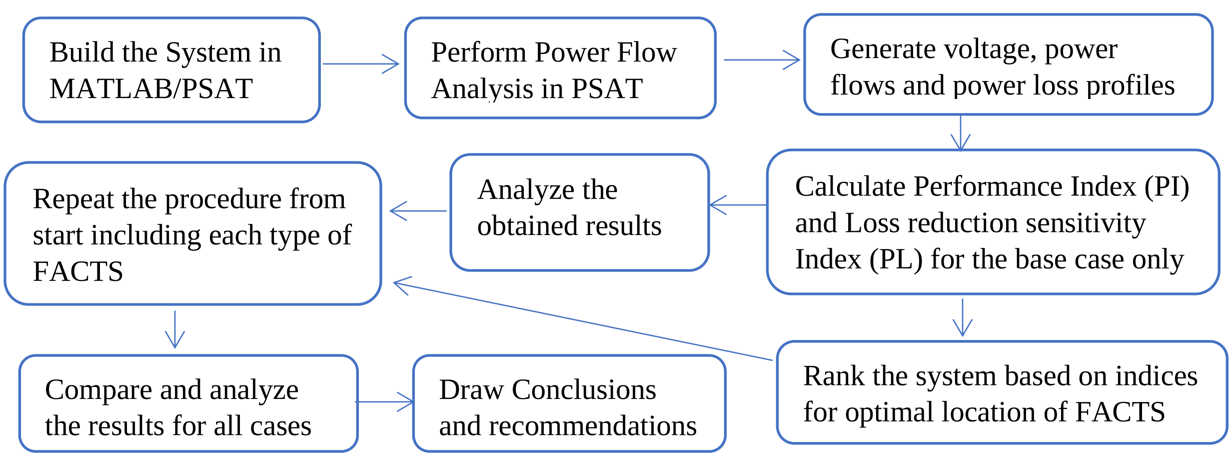

Figure 1. 1 Flow Chart of Conceptual Framework.

1.7. Thesis Layout

The layout of the whole thesis work is organized into five chapters. Chapter one is an introductory part giving the background of the study, the problem investigated, the objectives, and the significance and the methodology are stated clearly. Chapter two describes the theoretical background and literature review on techniques of performance evaluation of transmission networks, presents an overview of FACTS devices, performance enhancement using the optimal placement of FACTS, and lastly, presents literature reviews of previous works related to FACTS application on voltage profile enhancement and power flow control in transmission networks. Chapter three presents the modeling and the performance analysis of the Ethiopian transmission network using PSAT, data collection and analysis of the data in to the input format of the software, load flow analysis of the base case, sensitivity analysis, and identification of lines and buses. The fourth chapter presents case studies without and with optimal placement of FACTS, analysis of results, and discussion of performance enhancement from perspectives of power flow enhancement and voltage profile improvement through comparative analysis of the results under the base case and the specified case studies. The last chapter presents the conclusion, recommendation, and suggestions for future work.

Chapter Two

Performance Enhancement of Transmission Network Using Facts Devices and Literature Review

2.1. Introduction

Generally, load or power flow study is the first key solution for power system analysis that provides information (data) concerning the magnitudes and phase angles of load bus voltages, reactive powers at generator buses, real and reactive power flow on transmission lines. [2] The study is essential for performance evaluation and investigation of existing system equipment loadings, real and reactive power flows for all equipment interconnecting the buses, equipment losses, bus voltages magnitudes/angels, and reactive power requirements for a possible range of system operating conditions, to decide the best operation of the existing system and for planning future expansion needs to meet the increased load demand. [2]

In relation to load flow study the Newton Raphson method is the conventional mathematical formulation of the power flow analysis technique. In addition to this method, this chapter looks the technique of transmission system performance evaluation using load flow study, Flexible AC Transmission Systems (FACTS) devices main features, classification of FACTS. A brief description of the controllers and their relative application areas through sensitivity based optimal placement in transmission network and a review of related works of literature also discussed. Finally, literatures on the topic are reviewed.

2.2 Performance Evaluation of Transmission Network using Load Flow Studies

In comparation with other load flow methods, Newton Raphson method is a powerful method of solving non-linear algebraic equations; since it has fast convergence characteristics, fewer calculations, and advantages for large power system networks as computer storage requirements are less and increase almost linearly with the size of the problem. [3] The Newton Raphson method employs non linier equation in order to find voltage, current, active power, and reactive power at different buses. [4] The equation is provided as follows.

The current injected by the source into the I_i^{th} bus of a power system is

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2.1}$$

Where n is the number of buses in the system. Y_{ij} is the admittance between lines i and j. V_j is the voltage at bus j.

The above equation can be written in polar form as

$$I_i = \sum_{j=1}^{n} |Y_{ij}|\,|V_j| \angle(\theta_{ij} + \delta_j) \tag{2.2}$$

Where, θ_{ij} is the admittance angle between lines i and j. δ_j is the voltage angle of bus j.

We can write current in terms of active and reactive powers as

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.3}$$

Where P_i is the active power injected from bus i into the system, Q_i is the reactive power injected from bus i into the system. V_i is the voltage magnitude at bus i.

After substitution of I_i value in equation (2.3) we can get

$$P_i - jQ_i = (|V_i| \angle - \delta_i) \sum_{j=1}^{n} |Y_{ij}|\,|V_j| \angle(\theta_{ij} + \delta_j) \tag{2.4}$$

By separating real and imaginary terms, we get

$$P_i = \sum_{j=1}^{n} |Y_{ij}|\,|V_j||V_i| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.5}$$

$$Q_i = -\sum_{j=1}^{n} |Y_{ij}|\,|V_j||V_i| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.6}$$

Equations (2.5) and (2.6) constitute a set of nonlinear algebraic equations in terms of the independent variables, voltage magnitude in per unit, and phase angles in radians, we can easily observe that two equations for each load bus given by Eqn. (2.5) and (2.6) and one equation for each voltage-controlled bus, given by Eqn. (2.5). Expanding equations (2.5) and (2.6) by using Taylor's series and neglecting higher-order terms, we can find the relationship with the Jacobian matrix. [4]

$$\begin{bmatrix} \Delta P_1^K \\ \vdots \\ \Delta P_n^K \\ \hline \Delta Q_1^K \\ \vdots \\ \Delta Q_n^K \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_1^K}{\partial \delta_1^K} & \cdots & \frac{\partial P_1^K}{\partial \delta_n^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^K}{\partial \delta_1^K} & \cdots & \frac{\partial P_n^K}{\partial \delta_n^K} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_1^K}{\partial |V_1|^K} & \cdots & \frac{\partial P_1^K}{\partial |V_n|^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^K}{\partial |V_1|^K} & \cdots & \frac{\partial P_n^K}{\partial |V_n|^K} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_1^K}{\partial \delta_1^K} & \cdots & \frac{\partial Q_1^K}{\partial \delta_n^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^K}{\partial \delta_1^K} & \cdots & \frac{\partial Q_n^K}{\partial \delta_n^K} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_1^K}{\partial |V_1|^K} & \cdots & \frac{\partial Q_1^K}{\partial |V_n|^K} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^K}{\partial |V_1|^K} & \cdots & \frac{\partial Q_n^K}{\partial |V_n|^K} \end{pmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_1^K \\ \vdots \\ \Delta \delta_n^K \\ \hline \Delta |V_1|^K \\ \vdots \\ \Delta |V_n|^K \end{bmatrix} \tag{2.7}$$

Where, K is the current iteration number. i.e., K = 1, 2, 3, ……. n_{max} and n_{max} is the maximum iteration number.

The Jacobian matrix will give the linear relationship between small changes in the angle $\Delta\delta_i^K$ and changes in bus voltage ΔV_i^K with small variations in real power and reactive power ΔP_i^K and ΔQ_i^K. In the above equation, bus-1 is assumed to be the slack bus.

$$\begin{pmatrix}\Delta P \\ \Delta Q\end{pmatrix} = \begin{pmatrix}J_1 & J_2 \\ J_3 & J_4\end{pmatrix}\begin{pmatrix}\Delta\delta \\ \Delta|V|\end{pmatrix} \tag{2.8}$$

The diagonal elements are given as:

$$J_1(i,i) = \frac{\partial P_i}{\partial \delta_i} = |V_i| \sum_{\substack{j=1 \\ j\neq i}}^{n} |V_j||Y_{ij}| \, sin(\theta_{ij} - \delta_i + \delta_j)$$

$$J_2(i,i) = \frac{\partial P_i}{\partial V_i} = \sum_{\substack{j=1 \\ j\neq i}}^{n} |V_j| \, |Y_{ij}| \, cos(\theta_{ij} - \delta_i + \delta_j) + 2|V_i||Y_{ii}| \, cos(\theta_{ii})$$

$$J_3(i,i) = \frac{\partial Q_i}{\partial \delta_i} = |V_i| \sum_{\substack{j=1 \\ j\neq i}}^{n} |V_j| \, |Y_{ij}| \, cos(\theta_{ij} - \delta_i + \delta_j)$$

(2.9)

$$J_4(i,i) = \frac{\partial Q_i}{\partial V_i} = -\sum_{\substack{j=1 \\ j\neq i}}^{n} |V_j| \, |Y_{ij}| \, sin(\theta_{ij} - \delta_i + \delta_j) - 2|V_i||Y_{ii}| \, sin(\theta_{ii})$$

The off-diagonal elements ($j \neq i$) are:

$$J_1(i,j) = \frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \, sin(\theta_{ij} - \delta_i + \delta_j)$$

$$J_2(i,j) = \frac{\partial P_i}{\partial V_j} = |V_i||Y_{ij}| \, cos(\theta_{ij} - \delta_i + \delta_j)$$

$$J_3(i,j) = \frac{\partial Q_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \, cos(\theta_{ij} - \delta_i + \delta_j)$$

$$J_4(i,j) = \frac{\partial Q_i}{\partial V_j} = -|V_i||Y_{ij}| \, sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.10}$$

The power residuals ΔP_i^K and ΔQ_i^K can be written as

$$\Delta P_i^K = P_i^{sch} - P_i^K$$

$$\Delta Q_i^K = Q_i^{sch} - Q_i^K \tag{2.11}$$

Where, P_i^{sch} and Q_i^{sch} are the scheduled active and reactive power at bus i respectively.

From the power residuals and Jacobian matrix, we can get the voltage magnitude $|V_i|^K$ angle δ_i^K.

The new estimate values for bus voltages and angles are

$$\left|V_i^{(K+1)}\right| = \left|V_i^K\right| + \Delta\left|V_i^K\right| \tag{2.12}$$

$$\delta_i^{(K+1)} = \delta_i^K + \Delta\delta_i^K \tag{2.13}$$

Using new values of voltages and angles, the new values of real and reactive powers are calculated using equations (2.5) and (2.6), the new values of elements of the Jacobian matrix are calculated using equations (2.9) and (2.10), again the new values of voltages and angles are obtained and the processes are repeated until the power residuals ΔP_i^K and ΔQ_i^K are less than the desired accuracy. i.e., [2] [3] [5]

$$\left|P_i^K\right| \leq \varepsilon$$

$$\left|Q_i^K\right| \leq \varepsilon \quad (2.14)$$

For the static load flow equations solution to have practical significance, all the state and control variables must lie within specified practical limits. These limits, which are dictated by specifications of power system hardware and operating constraints, are described below: [3]

1) Voltage magnitude $|V_i|$ must satisfy the inequality

$$|V_i|_{min} \leq |V_i| \leq |V_i|_{max} \quad (2.15)$$

The power system equipment is designed to operate at fixed voltages with allowable variations of ±(5-10) % of the rated values. The magnitude of voltage for PV buses is maintained fixed.

2) Certain of the $\delta_i{}'s$ (state variables) must satisfy the inequality constraint.

$$\left|\delta_i - \delta_j\right| \leq \left|\delta_i - \delta_j\right|_{max} \quad (2.16)$$

This constraint limits the maximum permissible power angle of the transmission line connecting buses *i* and *j* are imposed by considerations of system stability.

3) Owing to physical limitations of P and/or Q generation sources, P_{Gi} and Q_{Gi} are constrained as follows:

$$P_{Gi,min} \leq P_{Gi} \leq P_{Gi,max}$$

$$Q_{Gi,min} \leq Q_{Gi} \leq Q_{Gi,max} \quad (2.17)$$

Also, for PQ buses reactive limits must be satisfied.

$$Q_{i,min} \leq Q_i \leq Q_{i,max} \quad (2.18)$$

Finally, the total generation of real and reactive power must be equal to the total load demand plus losses, i.e.

$$\sum_i P_{Gi} = \sum_i P_{Di} + P_L \quad (2.19)$$

$$\sum_i Q_{Gi} = \sum_i Q_{Di} + Q_L \quad (2.20)$$

Where, P_L and Q_L are real and reactive power losses respectively.

2.3. Flexible AC Transmission System (FACTS) Devices

The flexibility of electric power transmission is the ability to accommodate changes in the electric transmission system or operating conditions while maintaining sufficient steady-state and transient margins [1]. In this connection, FACTS can provide the possibilities of power flow control, which is defined as an alternating current transmission system incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability; according to IEEE PES. [1].

There are a number of benefits from a transmission network incorporating FACTS. Accordingly, FACTS can control of voltage and power flow as desired and in order to meet the utility's own needs, ensure optimum power flow, ride through emergency conditions, or a combination of these. [1] FACTS can also essential for voltage control; power quality improvement; power conditioning; flicker mitigation, and Interconnection of renewable and distributed generation and storage. [6] Besides, FACTS can increase the loading capability of lines to their thermal capabilities. This can be accomplished by overcoming other limitations and sharing power among lines according to their capability. Increase the system security by raising the transient stability limit, limiting short circuit currents and overloading, managing cascading blackouts, and damping electromechanical oscillations of power systems and machines. [1]

Further, FACTS provide secure tie line connections to neighboring utilities and regions thereby decreasing overall generation reserve requirements on both sides. Reduce reactive power flows, thus allowing the lines to carry more active power. Reduce loop-in flows. [6]

2.3.1 Types of FACTS Controllers and Their Relative Importance

FACTS Controllers are broadly classified into two types based on the basic element used for controlling switching purposes as: [6]

A. Thyristor based FACTS controllers and

Example: Static Var Compensator (SVC), Thyristor Controlled Series Capacitor (TCSC), Thyristor Switched Series Capacitor (TSSC) and Fixed Capacitor Thyristor Controlled Reactor (FC-TCR)

B. Voltage Source Converter based FACTS

Example: Static Synchronous Compensator (STATCOM) and Static Synchronous Series Compensator (SSSC)

While, the Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC) and

High Voltage DC transmission system (HVDC) controllers could be based on either.

According to their connection arrangement in a power system, FACTS Controllers can be classified into three categories: [1]

1. Series Controllers
2. Shunt Controllers
3. Combined Controllers

Series Controllers

The series Controller could be a variable impedance, such as a 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 variable 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 the handling of real power as well. Figure 2.1 (a) shows the series controller. Series Controller for a given MVA size is several times more powerful than the shunt Controller when the purpose of the application is to control the current, power flow, and damp oscillations. Some of the dominant examples of series controllers are: TCSC, SSSC, and TSSC.

Shunt Controllers

The shunt controllers inject either leading or lagging current into the system at the point of connection. When the injected current is in phase quadrature with the line voltage, the shunt controller supplies or consumes only variable reactive power. Similarly, any other phase relationships will alter both real and reactive power flows. Figure 2.1(b) shows the shunt controller. The shunt controller is used when the purpose of the application is to control voltage at and around the point of connection and damping of voltage oscillations. One important advantage of the shunt controller is that it serves the bus node independently of the individual lines connected to the bus. Some of the mainly used shunt controllers are SVC and STATCOM.

Combined Controllers

The combined controllers could be a configured as series-series or as series-shunt controllers and can be controlled in a coordinated or unified manner. They inject voltage through their series part and current into the line through their shunt part. They provide power flow control through their series part and independent voltage control through their shunt part. This adds flexibility in controllability and maximize the utilization of the existing transmission system. The main disadvantage of these controllers is the high cost due to the complexity in system setup. Figures 2.1(c) and 2.1(d) show configuration of combined series-series and series-shunt controllers respectively. Some examples of combined controllers are: Unified Power Flow Controller (UPFC), HVDC and Interline Power Flow Controller (IPFC).

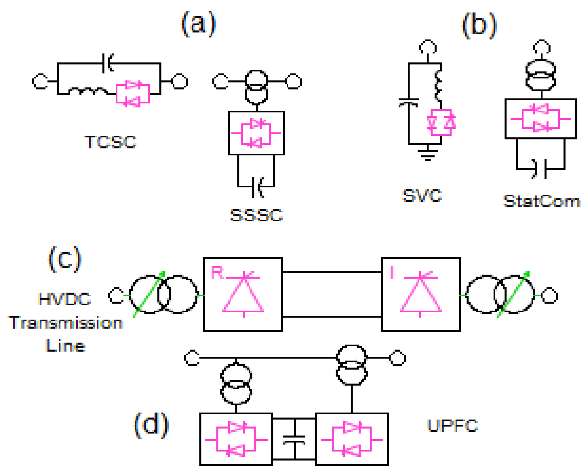

Figure 2. 1 Basic types of FACTS Controllers

(a) series controller (b) shunt controller (c) combined series-series controller (d) combined series-shunt controller

The relative importance of FACTS controllers: [6]

- The series Controller is used when the purpose of the application is to control the current, power flow, and damp oscillations, series Controller for a given MVA size is several times more powerful than the shunt Controller.
- The shunt Controller is used when the purpose of the application is to control voltage at and around the point of connection through injection of reactive current either leading or lagging, alone or a combination of active and reactive current for more effective voltage control and damping of voltage oscillations. One important advantage of the shunt Controller is that it serves the bus node independently of the individual lines connected to the bus. Also, the shunt Controller cannot provide control over the power flow in the lines.
- From the above arguments, it is advised that a combination of the series and shunt Controllers can provide the best of both, i.e., an effective current, power flow, and bus voltage control.

In this study FACTS controllers, TCSCs and SVCs are employed for power flow control in transmission lines and voltage profile enhancements in Ethiopian high voltage transmission networks. Before detailed mathematical models of the controllers, the Newton Raphson power flow solution technique is presented without FACTS devices and then models of TCSC and SVC are described with power flow equations incorporating the FACTS devices. Sensitivity index analysis is also presented for optimal allocation of the controllers.

2.3.2 Modeling of FACTS Devices

This portion is intended for developing load flow equations on the presence of FACTS devices on the network for various purposes of power system performance enhancement. In this thesis work TCSC is utilized for power flow control and reduction of real power loss of a particular line and SVC for voltage profile improvement purposes.

Mathematical Model of TCSC

The IEEE defined Thyristor Controlled Series Capacitor (TCSC): as a capacitive reactance compensator that consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance. [1] [7]

There are two alternative power flow models of TCSC in PSAT to assess the impact of TCSC controllers in transmission networks. The simpler TCSC model exploits the concept of a variable series reactance. The series reactance is adjusted automatically, within limits, to satisfy a specified amount of active power flows through it. The more advanced model used in this study uses directly the TCSC reactance firing angle characteristic, given in the form of a nonlinear relation. The TCSC firing angle is chosen to be the state variable in the Newton Raphson power flow solution. [7]

The power flow control model of a TCSC inserted in a transmission line between bus f and t is shown in Figure 2.2 below [7] [8].

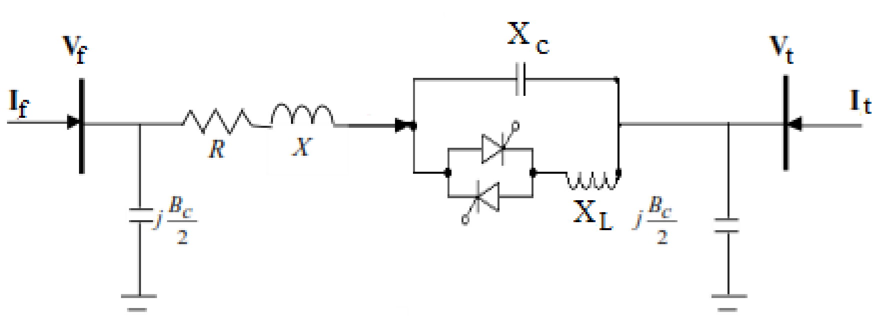

Figure 2. 2 The power flow control model of a TCSC inserted in a transmission line [8].

After the reactance value is determined using Newton's method then the associated firing angle

α_{TCSC} can be calculated. All the modules making up the TCSC have identical design characteristics and are made to operate at equal firing angles to avoid the additional iterative process required to find the firing angels since the TCSC reactance and firing angle are nonlinearly related. [7]

The real and reactive power flows in the line having TCSC are expressed as:

$$P_{ft} = G_{ff}V_f^2 + (G_{ft}\cos\delta_{ft} + B_{ft}\sin\delta_{ft})V_fV_t$$
$$Q_{ft} = -B_{ff}V_f^2 + (G_{ft}\sin\delta_{ft} - B_{ft}\cos\delta_{ft})V_fV_t \qquad (2.21)$$

Similarly,

$$P_{tf} = G_{tt}V_t^2 + (G_{tf}\cos\delta_{tf} + B_{tf}\sin\delta_{tf})V_fV_t$$
$$Q_{tf} = -B_{ff}V_t^2 + (G_{tf}\sin\delta_{tf} - B_{tf}\cos\delta_{tft})V_fV_t \qquad (2.22)$$

The new line parameters conductance and susceptance with TCSC are given as:

$$G_{ft} = -G_{ff} = \frac{R_{ft}}{R_{ft}^2+X_{eff}^2}, and\ B_{ft} = -B_{ff} = \frac{-X_{eff}}{R_{ft}^2+X_{eff}^2} \qquad (2.23)$$

Where, X_{eff} is the effective reactance of the line after series compensation.

$$X_{eff} = X_{line} - X_{TCSC} = X_{line}(1-K) \qquad (2.24)$$

Where K is the percentage of series compensation and is positive for capacitive and negative for inductive compensation given as:

$$K = \frac{X_{TCSC}}{X_{line}} \qquad (2.25)$$

The reactance X_{TCSC} of the TCSC module shown in Figure 2.2 at the fundamental frequency is calculated as:

$$X_{TCSC} = -X_C + C_1\{2(\pi-\alpha) + sin[\,2(\pi-\alpha)]\}$$
$$-C_2\cos^2(\pi-\alpha)\{\varpi\tan[\varpi(\pi-\alpha)] - \tan(\pi-\alpha)\} \qquad (2.26)$$

Where,

$$C_1 = \frac{X_C+X_{LC}}{\pi} \qquad (2.27)$$

$$C_2 = \frac{4X_{LC}^2}{\pi X_L} \qquad (2.28)$$

$$X_{LC} = \frac{X_CX_L}{X_C-X_L} \qquad (2.29)$$

$$\varpi = \sqrt{\frac{X_C}{X_L}} \qquad (2.30)$$

To obtain power flow solutions with TCSCs, the parameters such as capacitive reactance $X_C = 0.1\ p.u$ and a variable inductance $X_L = 0.2\ p.u$ are considered for all cases. TCSC has been used to control power flow in a line for different purposes like loss reduction, relief overloading, and redirecting power flow to other lines in the test system in this study.

Mathematical Model of SVC

The IEEE defined Static Var Compensator (SVC) as A shunt-connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current to maintain or control specific parameters of the electrical power system typically (bus voltage). [7]

The simple form SVC consists of a TCR in parallel with a fixed capacitor bank. 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 an almost instantaneous speed of response.

The SVC can be modeled as adjustable reactance with either firing angle limits or reactance limits. The firing angle and variable susceptance model equivalent circuits are shown, in Figure 2.3 and are used to derive the SVC equations required by Newton's method for power flow solutions in the presence of FACTS device SVC as: [1]

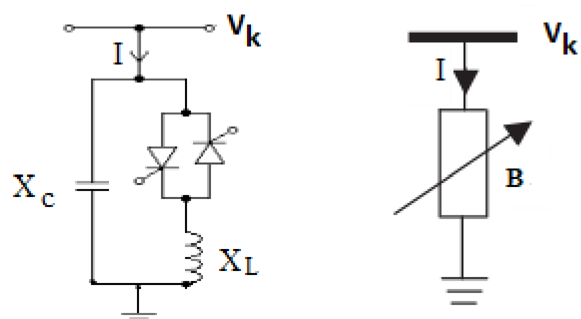

Figure 2. 3 SVC configurations in firing angle and variable susceptance models [7].

The current drawn by the SVC is

$$I_{SVC} = jB_{SVC}V_K \tag{2.31}$$

Where,

$$B_{SVC} = B_C - B_{TCR} = \frac{1}{X_C X_L}\left\{X_L - \frac{X_C}{\pi}[2(\pi - \alpha) + sin\,2\,\alpha]\right\}$$

$$X_L = \omega L$$

$$X_C = \frac{1}{\omega C} \tag{2.32}$$

Where α is the firing angle of the TCR and the reactive power delivered or drawn by the SVC, which is also the reactive power injected at bus *k*, is

$$Q_{SVC} = Q_K = -V_K^2 B_{SVC} \tag{2.33}$$

The 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 is calculated as.

$$Q_K = -\frac{V_K^2}{X_C X_L}\left\{X_L - \frac{X_C}{\pi}[2(\pi - \alpha_{SVC}) + sin(2\alpha_{SVC})]\right\} \tag{2.34}$$

To obtain power flow solutions with SVCs, the parameters such as capacitive reactance $X_C = 0.1\ p.u$ and a variable inductance $X_L = 0.2\ p.u$ are considered for all cases. Formulation of optimal location for placement of FACTS based on sensitivity analysis index is presented in the next section.

2.4 Performance Evaluation of Transmission Network using Optimal Placement of FACTS Devices

There have been several static and dynamic techniques proposed in many works of literature for the optimal placement of FACTS devices. The most commonly used techniques or algorithms are; Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Fuzzy Logic (FL), Artificial Neural Network (ANN), and Sensitivity Index Analysis (SIA). All of them are based on the objectives to be satisfied. A location that is the best for one objective may be less suitable for another objective. [9] The objectives of device placement from a power flow control point of view may be one of the following: [8]

- Reduction in the real power loss of a particular line *l* (P_{LK}). [8] [10] [11]
- Reduction in the total system real (P_{LT}) or reactive power loss (Q_{LT}). [8] [11] [12]
- Reduction in the real power flow performance index (*PI*). [5] [8] [10] [13]
- Power oscillation damping. [9]
- Minimization of the total generation cost. [8] [14]
- Minimization of the total system real power loss and total generation cost simultaneously. [8]

There are no FACTS controllers that can satisfy the control objective without affecting the rest of the system, but it is possible to minimize its influence. [9] This thesis uses a sensitivity analysis technique for optimal placement of FACTS based on objectives of reduction in the real power loss of a particular line and Reduction in the real power flow performance index (*PI*) and Voltage Performance Index of the buses (PI_V). These sensitivity indexes are calculated for each type of FACTS device from the base case power flow solution using the Newton Raphson method. In this thesis work, TCSC is utilized based on the above two objectives for power flow control and SVC for voltage profile improvement purposes at the same time.

2.4.1 Line Loss Sensitivity Index (a_K) of a particular line for TCSC

For TCSC reactance X_C placed between buses i and j in a line (*k*) having impedance ($Z = R + jX$). The sensitivity of a particular line (k) real power loss (P_{LK}) reduction of the line with respect to the control variable X_C of the TCSC is formulated as follows: [8] [11] [9]

$$a_K = \frac{\partial P_{LK}}{\partial X_c}\bigg|_{X_c=0} = \text{Line loss sensitivity for TCSC placed in line-}k\ (k = 1, \ldots n_l)$$

$$n_l \text{ is the number of branches} \quad (2.35)$$

Hence the real power loss (P_{LK}) in line-*l* connected between bus-*i* and bus-*j* is,

$$P_{LK} = G_{ii}(V_i^2 + V_j^2) + 2G_{ij}(V_i V_j \cos(\delta_{ij}))$$

$$= -G_{ij}(V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_{ij})) = -G_{ij}\left|V_i - V_j\right|^2 \quad (2.36)$$

Where,

$$G_{ii} = -G_{ij} = \frac{R}{R^2 + (X + X_c)^2} \quad (2.37)$$

From equations (2.35) – (2.37), a_K can be expressed as

$$a_K = \frac{\partial P_{LK}}{\partial X_c}\bigg|_{X_c=0} = -(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij})\frac{\partial G_{ij}}{\partial X_c} \quad (2.38)$$

Where,

$$\frac{\partial G_{ij}}{\partial X_c}\bigg|_{X_c=0} = \frac{2R(X + X_c)}{(R^2 + (X + X_c)^2)^2} = \frac{2RX}{Z^4} \quad (2.39)$$

The final equation is found by substituting equation (2.38) on equation (2.39).

$$a_K = \frac{\partial P_{LK}}{\partial X_c}\bigg|_{X_c=0} = -2(V_i^2 + V_j^2 - 2V_i V_j \cos\delta_{ij})\frac{RX}{Z^4} \quad (2.40)$$

2.4.2 Real Power Flow Sensitivity Index (b_K)

The severity of the system loading under normal and contingency cases can be described by a real power line flow performance index. The definition for the overload performance index (*PI*) is given below. [15] [8] [12]

$$PI = \sum_{l=1}^{n_l} w_i \left(\frac{P_{flowl}}{P_l^{max}}\right)^{2n} \tag{2.41}$$

Where,

P_{flowl} is the real power flow inline *l*

P_l^{max} is the rated capacity of line *l*

n is a positive number (n = 1, 2, 3…etc.). or the order of performance index to be calculated

n_l is the total number of lines in the network,

w_i is the real non-negative weighting coefficient which may be used to reflect the importance of lines.

PI will be small when all the lines are within their limits and will be a high value when there are one or more overloaded lines [3]. Thus, it provides a good measure of the severity of the line overloads for a given state of the power system. First-order performance indices are straightforward and give accurate results but they suffer masking effects. When n = 1, lines that are loaded almost below maximum limits contribute to the PI almost equal to lines loaded almost above maximum limits. The resulting PI will be large when many lines are loaded almost below their limit. Thus, the PI's ability to differentiate bad cases is limited, and is known as the *masking effect* [15] [8]. By most of the operational standards, the system with one huge violation is much more severe than that with many small violations. The masking effect can be avoided by using higher-order performance indices, which is $n > 1$. However, PI is defined as the sum of the squares of the real power flow deviations around the average. The values, $n = 2$ and $w_i = 1$ are taken and equation (2.41) is rewritten as [8] [15].

$$PI = \sum_{l=1}^{n_l} \left(\frac{P_{flowl}}{P_l^{max}}\right)^{4} \tag{2.42}$$

The sensitivity of *PI* concerning X_C which is here our control parameter of TCSC connected in series with a line between bus-*i* and bus-*j* is formulated as:

$$\frac{\partial PI}{\partial X_c} = 4 \sum_{l=1}^{n_l} \frac{{P_l}^3}{({P_l}^{max})^4} \frac{\partial P_l}{\partial X_c} \tag{2.43}$$

The real power flow in a line-*l* between buses *i* and *j* is;

$$P_{ij} = -G_{ij}V_i^2 + (G_{ij}\cos\delta_{ij} + B_{ij}\sin\delta_{ij})V_iV_j \tag{2.44}$$

$$G_{ij} = -\frac{R}{R^2+(X+X_c)^2} \;\; and \;\; B_{ij} = \frac{(X+X_c)}{R^2+(X+X_c)^2} \tag{2.45}$$

$$and, \;\; \frac{\partial P_{ij}}{\partial X_c} = -\frac{\partial G_{ij}}{\partial X_c}V_i^2 + \left(\frac{\partial G_{ij}}{\partial X_c}\cos\delta_{ij} + \frac{\partial B_{ij}}{\partial X_c}\sin\delta_{ij}\right)V_iV_j \tag{2.46}$$

Where,

$$\left.\frac{\partial G_{ij}}{\partial X_c}\right|_{X_c=0} = \frac{2R(X+X_c)}{(R^2+(X+X_c)^2)^2} = \frac{2RX}{Z^4} \tag{2.47}$$

And,

$$\left.\frac{\partial B_{ij}}{\partial X_c}\right|_{X_c=0} = \frac{R^2-(X+X_c)^2}{(R^2+(X+X_c)^2)^2} = \frac{(R^2-X^2)}{Z^4} \tag{2.48}$$

The real power flow PI sensitivity index concerning the control parameter of TCSC X_c can be represented as;

$$b_K = \left.\frac{\partial PI}{\partial X_c}\right|_{X_c=0} \tag{2.49}$$

The final equation after substituting is rewritten as:

$$b_K = \left.\frac{\partial PI}{\partial X_c}\right|_{X_c=0} = 4\sum_{l=1}^{n_l}\frac{{P_l}^3}{({P_l}^{max})^4}\left(-2\frac{RX}{Z^4}V_i^2 + \left(2\frac{RX}{Z^4}\cos\delta_{ij} + \frac{(R^2-X^2)}{Z^4}\sin\delta_{ij}\right)V_iV_j\right) \tag{2.50}$$

Using equations (2.40) and (2.50) the optimal placement of series FACTS devices such as TCSCs in a particular line can be selected based on the sensitivity indices which have absolute large values is the best location for placement for the two objectives. These indices give the lines overloading limits violations which can be solved by either reducing the line flows in overloaded lines by introducing additional line reactance or increasing the line loadability limit with series FACTS by altering the natural impedance of the line for lightly loaded lines.

2.4.3 Voltage Performance Index (PI_V)

The power system deficiency due to violation of bus voltages is described by the voltage performance index [16].

$$PI_V = \sum_{l=1}^{n_l} w_i\left(\frac{|V_i| - |V_i^{spc}|}{|V_i^{lim}|}\right)^{2n} \tag{2.51}$$

Where $|V_i|$ is the voltage magnitude at bus *i*, $\left|V_i^{spc}\right|$ is the specified voltage magnitude at bus *i*, $\left|V_i^{lim}\right|$ is the voltage deviation limit of the bus which is found by taking the average value of the minimum and the maximum allowable voltages 0.95 p.u. and 1.05 p.u. respectively at bus *i*.

weighting factor, w_i, and exponent n is taken 1. This voltage performance index will give information about the voltage level deviation of each bus and it can be used to choose the buses of power system which require reactive power compensation. Therefore, this index is used for optimal placement of SVC at the network.

2.5. Literature Review

There have been different researches done using FACTS devices on transmission networks across the world for purposes of power system performance enhancement and power flow control objectives. The various researches that are done in our country and other countries in the area are summarized below.

Study and Analysis of Thyristor Controlled Series Capacitor (TCSC) for Improving of Transmission System Capacity, G/Michael Gebrie [17]. The thesis investigates the benefits of implementing TCSC on transmission lines that stretched from GERD-Dedessa-Holleta for improvement of transmission line capacity using DigSILENT software. The results of the study after the use of TCSC at Dedessa showed; that the power transfer capacity was increased from 5759 MW to 5916.35 MW, voltage regulation was decreased from 3.95% to 3.02%, Steady and dynamic stabilities, voltage and current of the system were improved. Also, a comparison of cost-benefit analysis was done with the building of a new transmission line and concluded the cost of TCSC is 10% of the building of new transmission line which is a cost-effective method.

Study on Power Transfer Capability and Voltage Stability Improvement using SVC, Abebaw Yalew [18]. Presented research findings from a simulation study on three 500 kV transmission lines from Renaissance dam to Dedessa then to Holleta substation at different loading conditions using MATLAB. The study evaluated the possible installation of SVCs at the three substations and observed the effect on the voltage stability and transferred power. It was possible to observe that the best location of the SVC was Holeta substation as the power transferred and voltage stability were better than if it was at Dedesa or GERD. The study has also compared the installation of series capacitive compensator with SVCs. The author recommended series capacitive compensator to be installed in the network for better voltage stability and power transfer improvement than SVCs.

Studies on Applications of FACTS Devices to Improve Overloading and Unbalanced Power System Operating Conditions on Ethiopian Grid, Abiy Atakure [19]. The paper investigates the application of Distributed Series Reactors (DSRs) on 400kV, 230kV, and 132 kV National Transmission lines using simulation studies on Power System Simulation for Engineers (PSS/E) environment to control power flow, to improve the overloaded capacity of lines, and also investigated the possibility of shifting power to other parallel branches which are not loaded. The study showed the percent of power flow utilization for different level DSRs having different reactance values of the line for different voltage levels. It has shown for 132kV overloaded lines the placement of DSRs having 20%, 30% and 50% of reactance value of the overloaded line can increase the power transfer capacity utilization of the transmission system by 84.8%, 82.42%, and 79% respectively. The study also has presented the cost-benefit analysis of DSRs for improving an overloaded transmission line with the construction of a new line for the same amount of power transfer capacity enhancement purposes. The study didn't combine optimal allocation problem with the power flow control problem hence the solution probably may not be the overall optimal solution.

Optimal Placement of Thyristor Controlled Series Compensator (TCSC) on Nigerian 330kV Transmission Grid to Minimize Real Power Losses, M. N. Nwohu**,** [20]. The paper explores the use of FACTS devices to improve the power system security and availability through an optimal location and parameter settings of FACTS devices. The Nigerian 330kV transmission grid was modeled and simulated in a PSAT environment as a 35-bus system. The methodology was based on power flow analysis on the existing network using the Newton Raphson method to find buses outside normal voltage limits and lines which violated their thermal limits. Genetic Algorithm (GA) optimization technique is used for optimal location placement of TCSC on the grid, to control power flow and improve bus voltages. The study has shown TCSC is among the FACTS devices that are capable of reducing transmission line losses and increasing the voltage profile of the buses. The study has shown the reduction of overall active power losses from the initial 60.34MW (2.1%) without application of TCSC to 45.35MW (1.5%) with the application of TCSC.

Performance Analysis of Static VAR Compensators (SVC), On Congestion Management and Voltage Profile in Power Systems with PSAT Toolbox, Houari Boudjella [21]. The study used SVC is to control the power flow and maintain voltage in a standard IEEE-9 bus test system of 230kV using PSAT Simulink environment. The authors have shown successful results such as power flow control was achieved, line congestion was minimized, transient stability was improved, faster steady state was achieved, and improved voltage profile was gained through the application of SVC.

The interest of FACTS to improve voltage and losses reduction in the western Algerian network, Guentri Hocine [22]. The authors investigated transmission system having 102 buses with three different voltage levels of 400kV, 220kV, and 60kV western Algerian transmission network consisting of 138 transmission lines, 7 generation stations, 92 loads, and 3 compensation nodes through the application of TCSC the test result showed:

The control device TCSC has played a very important part in the compensation field and it was possible to reduce losses in the transmission lines and also possible to improve voltage quality in several busses. They had implemented four TCSCs at best suspicious buses of the network which had low voltage profiles, the authors have compared the loss and voltage improvement in the system without and with TCSC thereby simultaneously system performance was improved.

Performance Analysis and Comparison of Various FACTS Devices in Power System, Mukesh Kumar and Nitin Saxena [23]. The paper investigates the enhancement in voltage stability margin as well as the improvement in power transfer capability of transmission line in a power system with the incorporation of STATCOM, FC-TCR, and SSSC. A simple transmission line system is modeled in MATLAB/SIMULINK environment. The load flow results are first obtained for an uncompensated system, and the voltage and real and reactive power were studied. The results so obtained are compared with the results obtained after compensating the system using STATCOM, FC-TCR, and SSSC to show the voltage stability margin enhancement. The results so obtained after simulation demonstrate the performance of the system for each of the FACTS devices in improving the power profile and thereby voltage stability of the same.

Improving the voltage stability of Electrical power systems using shunt FACTS devices, Ahmed Mostafa Mohammed [24]. The paper investigates a 20-bus 400kV transmission network of India at different penetration levels of Induction motors leading to voltage stability problem of voltage collapse. A simulation study was done using PSAT simulation environment shower for different induction motor penetration levels, of the total load, and different fault locations and system contingencies, a FACTS device, SVC, was then optimally allocated and sized to prevent the voltage collapse from happening. The allocation and sizing were done by using a buildup search program based on the heuristic optimization technique.

Power System Contingency Analysis by using Voltage and Active Power Performance Index, Ummidi Sirisha [16]. The paper used the Newton Raphson method for load flow solutions on 5-Bus, 6-Bus, IEEE-14 Bus, and IEEE-30 Bus test systems in MATLAB environment. The authors investigated contingency for each line outage, load flow analysis was done on each system, and the active power and voltage performance indices were calculated. The summation of the two indices gives the performance index value through which ranking of severity was given to each line. Based on this ranking (the sensitivity of each line) they recommended the optimal placement of FACTS devices to control the power flow and to maintain a good voltage profile at every bus.

Most of the above studies focus on the application benefits of FACTS devices for power system performance enhancement and techniques of optimal allocation of the devices. Therefore, an important lesson is drawn from the above research works to employ the benefits of FACTS devices on the Ethiopian transmission networks for power flow control and voltage profile improvement objectives.

Chapter Three

Modeling and Performance Analysis of Ethiopian Transmission Network Using PSAT

3.1 Introduction

In this chapter, the Ethiopian high voltage grid data collected of generators, transmission lines, transformers, loads, fixed capacitors, and inductors are presented in section 3.2 with explanations of the associated input data formats of the PSAT software; thereafter a brief introduction of the tool used for modeling and simulation, PSAT/MATLAB toolbox and the single line diagram of the EEP's high voltage transmission network model developed are subsequently presented in sections 3.3 and 3.4. Load flow analysis performed on the network to investigate the performance of the existing system is discussed in section 3.5. Finally, sensitivity analysis and identification of weak lines and buses are discussed in detail. These data have been collected from EEP National Load Dispatch Center (EEPNLDC).

3.2 Network Input Data

This section describes the input data format of the grid or the bus components, which are used for defining the network topology, as well as the basic components for power flow analysis. They are transmission line, transformer, slack bus, constant power and constant voltage generator (PV), constant power load (PQ), and constant admittance (fixed shunt reactors and capacitors). The input files prepared according to input formats to PSAT are given after the description of each component. [25]

Bus Data

Every power system network topology is defined by "bus" components, bus data format is shown in Figure 3.1. Bus numbers can be in any order, and voltage ratings V_b are mandatory. Voltage magnitudes V_0 and phase angle θ_0 can be optionally set if the power flow solution is known or if a custom initial guess is needed. If voltages are not specified, a flat start is used (V = 1 at all buses except for the PV and slack generator buses, and θ = 0). As there is no restriction in defining file format and to trace easily the network buses are named according to their voltage level and their names. (For example, 400GILGEL-GIBE-3). Buses are defined in the structure Bus. con. [25]

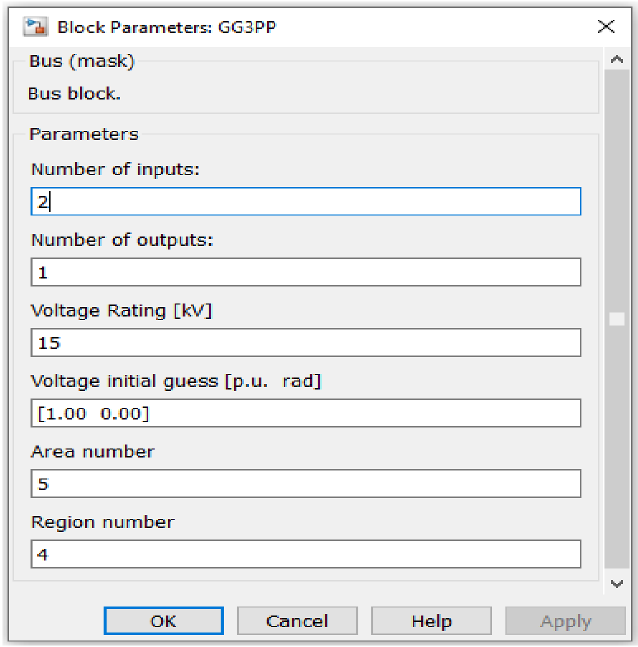

Figure 3. 1 Bus Data Format.

Generators Data

In the PSAT environment, there are two types of input data in generation modeling, i.e., synchronous machine model input and its mask (SW for slack generator and PV for other generators). Figure 3.2 shows the input data formats for both generator types.

Generators are modeled as voltage-controlled sources that control the voltage magnitude and active power injection into the bus. In a network, at least one of the generators must be configured as a reference or slack generator (SW) it controls the voltage magnitude and angle. The others are called PV generators. The description and input data format for the types is given below. The generators data used in this study is also presented after the description of types of generators.

Slack Generator

Slack generator is modeled as fixed voltage magnitude and phase angle as:

$$V = V_0 \ \ and \ \ \theta = \theta_0 \qquad (3.1)$$

The phase θ_0 is assumed to be the reference angle of the system. Figure 3.2 depicts the slack generator data, which contains operational limit data of maximum and minimum reactive power limit and voltage limits which are also used in optimal power flow and continuation power flow analysis. In this study, Gilgel-Gibe-3 is used as a slack generator because it is the generator for which the absolute value of the specified generation is maximum. [26] Slack generators are defined in the structure SW.con.

PV Generator

PV generators fix the voltage magnitude and the real power injected at the buses where they are connected unless their reactive power limits are violated, as follows:

$$P = -P_g \;\; and \;\; V = V_0 \tag{3.2}$$

Figure 3.2 depicts PV generator data, which includes reactive power and voltage limits needed for power flow analysis. The PV connected to the reference bus is set as slack. For other PVs, if the check of PV reactive limits is enforced and when a limit is violated, the PV generator is switched to a PQ bus, as follows:

$$P = -P_g \;\; and \;\; Q = -Q_{max,min} \tag{3.3}$$

After solving the power flow, the PQ buses are switched back to PV buses, assuming V = V_0 at the bus where the PV generators are connected. PV generators are defined in the structure PV.con.

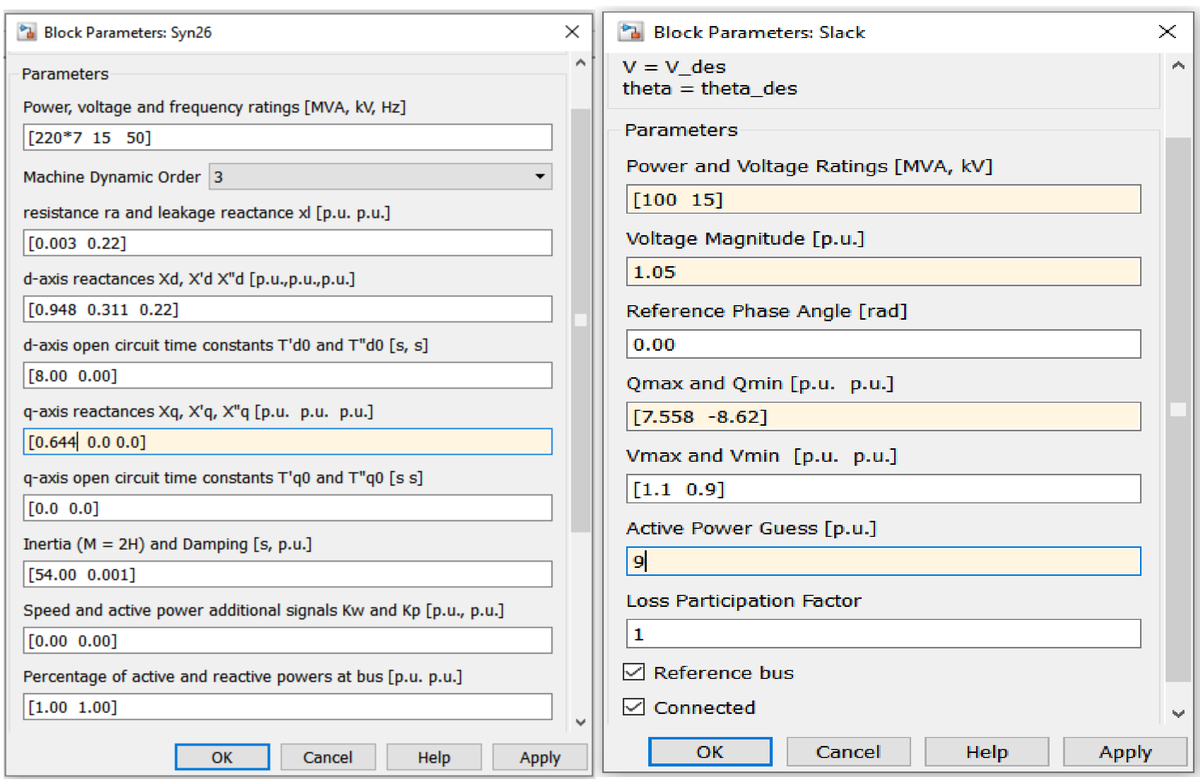

Figure 3. 2 Slack or PV and Synchronous Generator Data Formats.

Generation data collected for this study are prepared in the following final form shown in Table 3.1 for simulation purposes.

Table 3. 1 Ethiopian existing generator units' data except diesel generators.

Generator	V_{rate} (kV)	No Unit	S_n MVA	P_G (MW)	Q_{max} Mvar	Q_{min} Mvar	R_l (pu)	X_l (pu)	X_d (pu)	X'_d (pu)	X''_d (pu)	X_q (pu)
Aba Samuel	6.3	2	5.38	3.37	0.35	-0.17	0	0.25	1	0.3	0.25	0.4
Awash2	10.5	2	40	13	25.8	-32	0	0.16	1.04	0.349	0.16	0.4
Awash3	10.5	2	40	13	25.8	-32	0	0.16	1.04	0.349	0.16	0.4
Beless	15	4	532	461.2	77.2	-133.2	0	0.25	1.03	0.31	0.25	0.824
Fincha2	13.8	4	160	101.2	87.8	-98.8	0	0.2	0.96	0.3	0.2	0.768
Genale-III	13.8	3	375	150.2	197.4	-117	0.0044	0.22	0.22	0.22	0.22	0.22
G-Gibe2	15	4	500	278.4	246.8	-311.4	0	0.22	1.11	0.26	0.22	0.8325
G-Gibe3	15	7	1540	955.9	755.8	-862	0.003	0.22	0.95	0.31	0.22	0.855
G-Gibe1	13.8	3	219	129.2	97.4	-117.5	0	0.16	0.94	0.21	0.16	0.752
Koka	10.5	2	36	12.4	26.2	-24	0	0.24	0.7	0.339	0.24	0.4
M-Wakena	13.8	3	135	29.8	89.2	-107.1	0	0.17	1	0.29	0.17	0.8
Neshe	13.8	2	106	89.8	33.8	-17.2	0	0.212	0.99	0.271	0.212	0.792
Tekeze	13.8	3	260.1	176.1	298.2	-174	0	0.173	1	0.229	0.173	0.8
Tis-Aba2	10.5	1	40	14.9	22.2	-30.5	0	0.25	1	0.3	0.25	0.4
Adama WF-I	33	1	53.72	26.9	17	-17	0	1	1	1	1	1
AdamaWF-II	33	1	161.16	88	49.67	0	0.009	0.8	0.8	0.8	0.8	0.8
AshegodaWF	33	1	188.53	8.3	58.4	0	0	0.8	0.8	0.8	0..8	0.8
Reppie WE	10.5	2	62.5	25.2	16	-16	0	0.25	1	0.3	0.25	1

Transmission lines Data

Transmission lines are modeled as lumped $\boldsymbol{\pi}$ circuits. The input data format of transmission lines is given in Figure 3.3. The user can define data in absolute values or in p.u. In the latter case, the length *l*` of the line has to be `*l* = 0. If *l* # 0, it is assumed that parameters are expressed in unit per km [25]. The collected line parameters were given in p.u. on a common base. When more than one transmission lines exist between the same buses, then they can be represented as a single equivalent line, or individual line data can be entered between the same buses repeatedly. For the equivalent circuit, the impedance value per line is divided by their number, the susceptance value per line is multiplied by their number, and then converted to a common base [26]. In this study, 14 lines are double circuits and are modeled as the equivalent circuit considering n = 2. [27]

In the input data format of transmission lines. I_{max}, P_{max} and S_{max} define the limits for currents, active power flows and apparent power flows ($S = \sqrt{P^2 + Q^2}$). These limits are optional in power flow computations, but can be used to check the limits violations. The equations used to find the line flow limits are formulated as: [2]
The maximum current limit in p.u. can be calculated from the given MVA limit of the line. First, divide the MVA limit by the base MVA which is 100 MVA. Using the approximation that p.u. voltage magnitudes are 1.0 p.u. at all buses, the p.u. current limits are then equal to the p.u. apparent power flow limits.

The maximum real power limit in (MW) or the Surge Impedance Loading (SIL) of the line can be calculated from the p.u. data are given as: here also the p.u. the voltage at all busses is assumed to be 1 p.u.

$$P_{max} = SIL = \frac{S_{base}}{\sqrt{\frac{R_{pu}+jX_{pu}}{jB_{pu}}}} \quad (3.4)$$

The maximum apparent power flow limit can now be calculated using the values for SIL and length. To account for short lines (less than 50 miles or 80 kilometers), enforce a maximum apparent power flow limit of 3.0 × SIL. For longer lines, we use the line loadability characteristic giving the relationships between S^{max}, SIL, and line length (l in miles) as [2].

$$S^{Max} = \text{Line loadability in multiples of SIL}$$

$$S^{Max} = 42.4(l)^{-0.6595} \quad (3.5)$$

The transmission lines used in the study are given in Table 3.2.

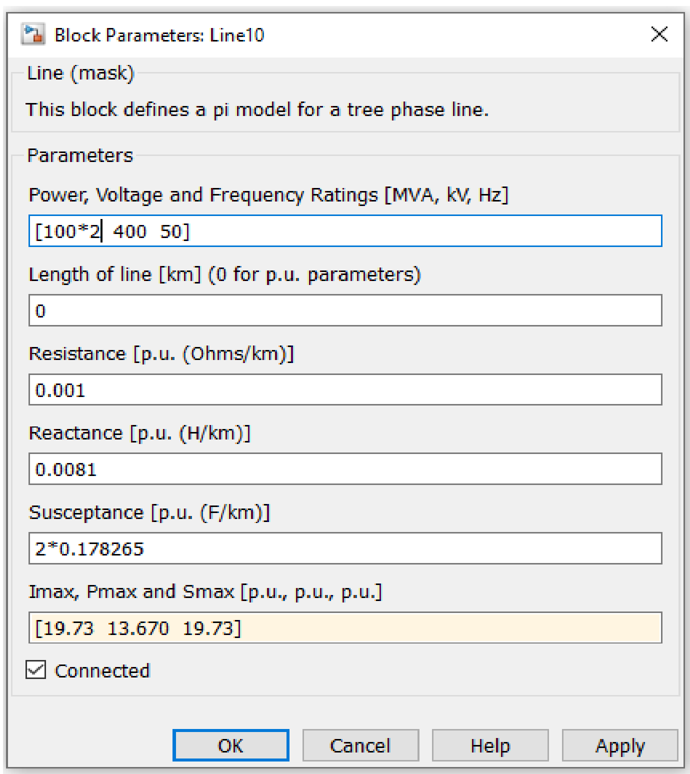

Figure 3. 3 Line Data Format.

Table 3. 2 Transmission Lines Data used.

Line	From Bus	To Bus	V (kV)	*R (p.u)*	*X (p.u)*	*B/2 (p.u)*	MVA	Length (Km)	№
1	230AXUM	230TEKEZE	230	0.020153	0.059806	0.096038	318	114.49	**1**
2	400SULULTA	400HOLETA	400	0.0006	0.005	0.110525	1973	31	**1**
3	400WSODO	400GGG3	400	0.0005	0.00405	0.35653	1973	50	**2**
4	230KOKA	230GELAN	230	0.011017	0.044456	0.042032	331	57	**1**

5	230KOKA	230EIZONE	230	0.007731	0.031197	0.029496	331	40	**1**
6	230LEGETFO	230BOLEARBSA	230	0.000751	0.0021	0.003372	402	3.5	**1**
7	230WOLDIYA	230COMOLCHA	230	0.021496	0.063793	0.102441	318	106.32	**1**
8	230KALITI1	230BOLERABSA	230	0.007598	0.021239	0.034106	402	35.4	**1**
9	230COTEBE1	230LEGETAFO	230	0.00085	0.0024	0.01542	402	8	**2**
10	230SULULTA	230LEGETAFO	230	0.00225	0.0063	0.04046	402	21	**2**
11	400BDAR	400DMARKOS	400	0.002997	0.03986	0.551195	1341	193.73	**1**
12	400DMAROS	400SULULTA	400	0.003335	0.04436	0.61342	1341	215.6	**1**
13	230MOTA	230BDAR2	230	0.012781	0.066429	0.06003	280	81.13	**1**
14	400HOLETA	400SEBETA2	400	0.000141	0.001691	0.103773	1205	17.36	**2**
15	400GELAN	400SEBETA2	400	0.0007	0.0057	0.11039	1973	33	**1**
16	230MEHONI	230MEKELE	230	0.020982	0.060405	0.091305	402	98	**1**
17	400GELAN	400WSODO	400	0.0055	0.0432	0.951945	1973	267	**1**
18	400SEBETA2	400GGIBE2	400	0.002839	0.037756	0.522095	1341	183.5	**1**
19	400WSODO	400GGIBE2	400	0.0025	0.0207	0.397965	1973	119	**1**
20	400YIRGLEM	400WSODO	400	0.0012	0.00985	0.7558	1973	113	**2**
21	400GGNEW	400GGIBE2	400	0.000431	0.005737	0.07934	1341	27.89	**1**
22	400YIRGLEM	400Gendawa	400	0.00285	0.0222	1.9538	1973	274	**2**
23	230ALAMTA	230ASHEGDWF	230	0.0265	0.0762	0.11524	402	140.7	**1**
24	400GRANDR	400BELES	400	0.00445	0.046028	0.726475	543	241	**1**
25	132BDAR2	132TABAY2	132	0.035482	0.070505	0.006905	91	28.96	**1**
26	132KOKA	132DZEYIT	132	0.057652	0.093882	0.009	82	38.55	**1**
27	230BDAR2	230NIFASMW	230	0.027501	0.084074	0.12708	318	136.4	**1**
28	132AWASSA	132ALABA	132	0.103158	0.194158	0.018808	82	80	**1**
29	132WSODO	132ALABA	132	0.079702	0.150011	0.01453	89	61.81	**1**
30	132YIGALM	132AWASSA	132	0.052477	0.085456	0.008195	82	35.09	**1**
31	230GASHENA	230NIFASMW	230	0.020626	0.063056	0.09531	318	102.3	**1**
32	132YIGALM	132YIGALEM2	132	0.048939	0.097917	0.009415	91	6	**1**
33	132AWASH	132KOKA	132	0.037911	0.061736	0.00592	82	25.35	**1**
34	230DBRHAN	230COMBLCHA	230	0.025733	0.072	0.115614	318	120	**1**
35	132SHSMNE	132ATULU	132	0.114899	0.187107	0.01794	82	76.83	**1**
36	132ASSELA	132ATULU	132	0.076217	0.124114	0.0119	82	50.96	**1**
37	132WERGNU	132COTEBE	132	0.003664	0.005967	0.00057	82	2.45	**1**
38	230TEKEZE	230MEKELE	230	0.021228	0.062997	0.10116	318	105	**1**
39	132BLEMIMB	132COTEBE	132	0.010466	0.017046	0.001633	82	6.999	**1**
40	400BDAR	400BELES	400	0.000958	0.012159	0.188565	1341	62.84	**1**
41	132GELAN	132DZEIT	132	0.0351	0.0661	0.006355	82	27	**1**
42	132KNORIT	132GELAN	132	0.028671	0.054074	0.0052	115	22	**1**
43	132EGEDA	132GELAN	132	0.0572	0.1078	0.01034	115	44	**1**
44	132SEBETA1	132BLION	132	0.016816	0.033646	0.003237	91	13.75	**1**
45	132GELAN	132KALITI1	132	0.013	0.024	0.00235	115	9.94	**1**
46	132GELAN	132YESU	132	0.0104	0.0196	0.001885	115	8	**1**
47	132KALITI1	132YESU	132	0.011925	0.02249	0.002163	115	9.15	**1**
48	230DBRHAN	230SINOSTILL	230	0.036152	0.110521	0.167056	318	117.89	**1**
49	132MEKNISA	132KALITI1	132	0.024167	0.039355	0.003775	82	16.16	**1**
50	132KALITI1	132WEREGENU	132	0.026919	0.043839	0.004188	82	18	**1**
51	132KALITI2	132KALITI1	132	0.010439	0.016999	0.00163	82	6.98	**1**
52	132KALITI1	132KALITINEW	132	0.002243	0.003653	0.00035	82	1.5	**1**
53	132KALITiNW	132BLEMIMB	132	0.017422	0.028373	0.002719	82	11.651	**1**
54	230LEGETFO	230SINOSTILL	230	0.010311	0.030601	0.049138	318	51	**1**
55	132WENJI	132KOKA	132	0.011007	0.017924	0.00172	82	7.36	**1**
56	132MOJO	132KNORIT	132	0.019545	0.036863	0.003545	115	15.057	**1**
57	132NAZRET2	132ADAMAWF1	132	0.007182	0.011695	0.001121	82	4.8	**1**
58	132EGEDA	132KOKA	132	0.035578	0.057937	0.005555	82	23.79	**1**
59	132KOKA	132NAZRET2	132	0.017176	0.02797	0.00268	82	11.48	**1**
60	132MOJO	132KOKA	132	0.026068	0.049165	0.004728	115	20.082	**1**
61	132WENJI	132AWASH	132	0.022435	0.036534	0.003503	82	15.002	**1**
62	132ASSELA	132WENJI	132	0.054135	0.088155	0.008452	82	36.198	**1**
63	230METEMA	230GONDER2	230	0.012589	0.036786	0.229251	360	120.97	**2**
64	230SUDB	230METEMA	230	0.003831	0.010722	0.068865	402	36.5	**2**
65	230MLKWYG	230MWAKNA	230	0.000906	0.0039	0.003687	257	5	**1**
66	230GONDER2	230BDAR2	230	0.014663	0.042213	0.255224	402	136.97	**2**
67	230DMRKOS	230MOTA	230	0.017209	0.089447	0.08083	280	111.76	**1**
68	230GASHENA	230ALAMATA	230	0.020626	0.063056	0.09531	318	102.3	**1**
69	230DMRKOS	230FINCHA	230	0.014652	0.076154	0.068815	280	95.15	**1**
70	230FINCA2	230FINCHA	230	0.001673	0.005116	0.007735	318	8.3	**1**
71	230GHEDO	230FINCHA	230	0.010041	0.053852	0.04852	284	67.19	**1**
72	132GEFERSA	132SEBETA1	132	0.016122	0.026253	0.002515	82	10.78	**1**
73	132GEFERSA	132KALITI1	132	0.037014	0.060275	0.00578	82	24.75	**1**
74	132MLKWYG	132SHSMNE	132	0.153691	0.28927	0.02802	89	119.19	**1**

75	230NESHI	230FINCA2	230	0.005897	0.018027	0.02725	318	29.25	**1**
76	230FINCA2	230GHEDO	230	0.014058	0.042977	0.06496	318	69.72	**1**
77	230GHEDO	230GEFERSA	230	0.012259	0.046569	0.256275	341	133.02	**2**
78	132KALITI2	132KALITIGS	132	0.005982	0.009742	0.000934	91	4	**1**
79	230WOLKITE	230SEBETA1	230	0.030445	0.087649	0.132485	402	136	**1**
80	230GEFERSA	230TORHAYL	230	0.002361	0.0066	0.010598	402	11	**1**
81	132KALITI1	132KALITIGS	132	0.004487	0.007306	0.000701	82	3	**1**
82	230ENDSLSE	230AXUM	230	0.012825	0.038059	0.061115	318	51	**1**
83	230GEFERSA	230SULULTA	230	0.001691	0.005019	0.03224	318	16.73	**2**
84	132REPPIWE	132MEKANISA	132	0.0091	0.0171	0.001645	115	7	**1**
85	230AGARO	230GIMA NEW	230	0.008307	0.023219	0.037285	402	38.7	**1**
86	230AGARO	230BEDELE	230	0.017494	0.048897	0.078521	402	81.5	**1**
87	230GGIBE1	230GGNEW	230	0.000407	0.001934	0.00744	274	5	**2**
88	230GGNEW	230WOLKITE	230	0.010779	0.056025	0.050625	280	70	**1**
89	230ALAMTA	230MEHONI	230	0.008876	0.025592	0.038664	318	41.5	**1**
90	132BLION	132REPPIWE	132	0.008973	0.014612	0.001402	82	6	**1**
91	230GIMA NW	230GGNEW	230	0.014081	0.039358	0.063202	402	65.6	**1**
92	230HOSSANA	230WOLKITE	230	0.019119	0.055043	0.083199	402	89.3	**1**
93	230SEBETA2	230SEBETA1	230	0.001161	0.005888	0.02228	280	15.02	**2**
94	230SEBETA1	230KALITI1	230	0.002314	0.011264	0.010345	274	14.26	**1**
95	230SEBETA1	230TORHAYL	230	0.001564	0.00438	0.007033	402	7.3	**1**
96	230GELAN	230KALITI1	230	0.00081	0.003844	0.01479	257	9.94	**2**
97	230EIZONE	230GELAN	230	0.003866	0.015599	0.014748	331	20	**1**
98	230MELK W	230KOKA	230	0.029689	0.127801	0.12083	257	163.86	**1**
99	230KOKA	230ADAMAWF2	230	0.0022	0.0065	0.009785	402	10.5	**1**
100	230ALAMTA	230WOLDIYA	230	0.01263	0.037482	0.06019	318	62.473	**1**
101	230KOKA	230AWASH7K	230	0.022453	0.100028	0.096199	353	129.32	**1**
102	230DDAWA-3	230AWASH7K	230	0.035593	0.158565	0.152496	353	205	**1**
103	230DDAWA-3	230HURSO	230	0.003791	0.010689	0.016835	255	17.66	**1**
104	230MEKELE	230ASHEGDWF	230	0.0041	0.0117	0.0177	402	19	**1**
105	230KOKA	230HURSO	230	0.075556	0.211189	0.339131	402	352	**1**
106	230HURSO	230ADIGALA	230	0.028047	0.080746	0.12205	402	134	**1**
107	230ADIGALA	230DJBTBR	230	0.015626	0.044988	0.068001	402	80	**1**

Transformer Data

Two-winding transformers are modeled as series reactance neglecting iron losses. Figure 3.4 depicts the transformer data format which is also included in the structure Line.con. The voltage ratio k_t is zero for transmission lines and it is different from zero for transformers [25]. Although there are three-winding transformers in the network, only two winding transformers are required for this study. Transformer data collected were given on p.u. on their own base MVA, therefore the data should be converted to p.u. on system base considering MVA $_{base} = 100$ MVA.

Since transformers are modeled similarly as transmission lines, if 'n' number of transformers exists between the same buses, then a transformer can be represented as a single equivalent transformer, or individual transformer data can be inputted between the same buses n times [26]. For the equivalent circuit i.e., the impedance value per transformer on its rating is divided by n and then converted to a common base. [27] The conversion of given p.u. resistance and reactance are formulated as follows: All transformers used are shown below in Table 3.3.

$$R_{new}(pu) = R_{given}(pu)\left(\frac{MVA_{new}}{MVA_{given}}\right)\left(\frac{V_{B,given}^2}{V_{B,new}^2}\right)$$

$$X_{new}(pu) = X_{given}(pu)\left(\frac{MVA_{new}}{MVA_{given}}\right)\left(\frac{V_{B,given}^2}{V_{B,new}^2}\right) \tag{3.5}$$

Where,

$R_{given}(pu)$ and $X_{given}(pu)$ are the old (p.u) resistance and reactance respectively.

$R_{new}(pu)$ and $X_{new}(pu)$ are the new (p.u) resistance and reactance respectively.

$V_{B,given}$ and $V_{B,new}$ are the old and new base voltages respectively.

MVA_{given} and MVA_{new} are the old and the new Apparent power bases respectively

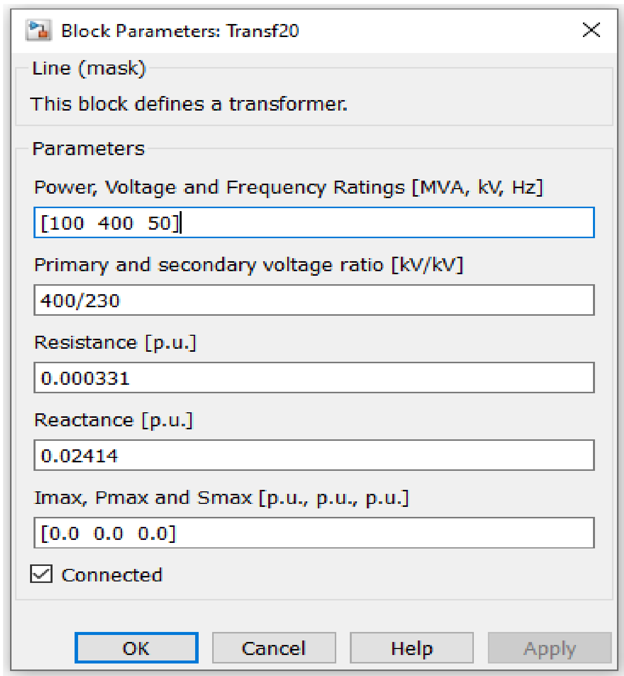

Figure 3. 4 Transformer Data Format.

Table 3. 3 Transformers Data used.

No	From Bus Name	To Bus Name	S_n (MVA)	№	*R (p.u)*	*X (p.u)*
1	FINCHA 230	FINCHA2 13.8	40.25	4	0.002578	0.043106
2	ABA SAMUEL 45	ABA SAMUEL 6.3	6.6	1	0.026212	0.931394
3	ADAMA II WF 230	ADAMA WF-II 33	90	2	0.001815	0.077222
4	ADAM-I WIND 132	ADAMA WF-I 33	55	1	0.006804	0.189091
5	ASHEGDA WF 230	ASHEGDA-WF 33	63	2	0.003056	0.099206
6	BELES 400	BELES 15	133	4	0.000377	0.025282
7	GENDAWAIII 400	GENALE-III 13.8	110	3	0	0.042424
8	GI GIBE-1 230	G-GIBE1 13.8	73	3	0.001371	0.058123
9	GI GIBE-2 400	G-GIBE2 15	125	4	0.000529	0.02872
10	MELKA-WAKA 230	M-WAKENA 13.8	45	3	0.00275	0.078741
11	NESHE 230	NESHE-1 13.8	53	2	0.003538	0.113491
12	T-ABAY2 132	TIS-ABAy2 10.5	40	1	0.010771	0.32625
13	TEKEZE 230	TEKEZE 13.8	90	3	0.00121	0.049815
14	KOKA 132	KOKA 10.5	18	2	0.015278	0.109444
15	AWASH 132	AWASH 10.5	20	4	0.00625	0.130375
16	REPPIE WE 132	REPPIE WE 10.5	63	1	0.003041	0.346825
17	G-GIB3 15	G-GIBE3 400	220.5	7	0.000482	0.015261
18	WOLAYTA 400	W SODO-II 132	250	1	0.0002	0.049805
19	YIRGALEMII 400	YIRGALEM-II 230	250	2	0.000337	0.02552
20	G. GIBE NEW 400	G. GIBE NEW 230	400	1	0.000259	0.01885

21	GELAN 400	GELAN 230	500	2	0	0.01217
22	YIRGALEM-II 230	YIRGALEM II 132	125	2	0.000964	0.04956
23	GELAN 230	GELAN 132	125	3	0.000581	0.031627
24	BAHIRDAR-II 400	BAHIR DAR-2 230	250	2	0.000354	0.023727
25	DEBRE MARKS 400	DEBR-MARKS 230	250	2	0.000413	0.0234
26	SEBETA-2 400	SEBETA-2 230	250	2	0.000331	0.02414
27	SULULTA 400	SULULTA 230	250	3	0.000226	0.016333
28	BAHIR DAR2 230	B.DAR-2 132	63	2	0.002236	0.094444
29	GEFERSA 230	GEFERSA 132	125	4	0.000483	0.02456
30	SEBATA-1 230	SEBATA -I 132	125	2	0.000699	0.03208
31	COTOBEI-I 230	COTEBEI-I 132	125	2	0.000568	0.056
32	KALITI1 230	KALITI1 132	125	3	0.000644	0.03296
33	M WAK-YUGO 230	M WAK-YGO 132	63	2	0.003806	0.099524

Load Data

Loads are modeled as constant active and reactive power consumers and the input data required for load flow solution is as shown below in Figure 3.5. The whole used load data is populated in Table 3.4. PQ loads are defined in the structure PQ.con.

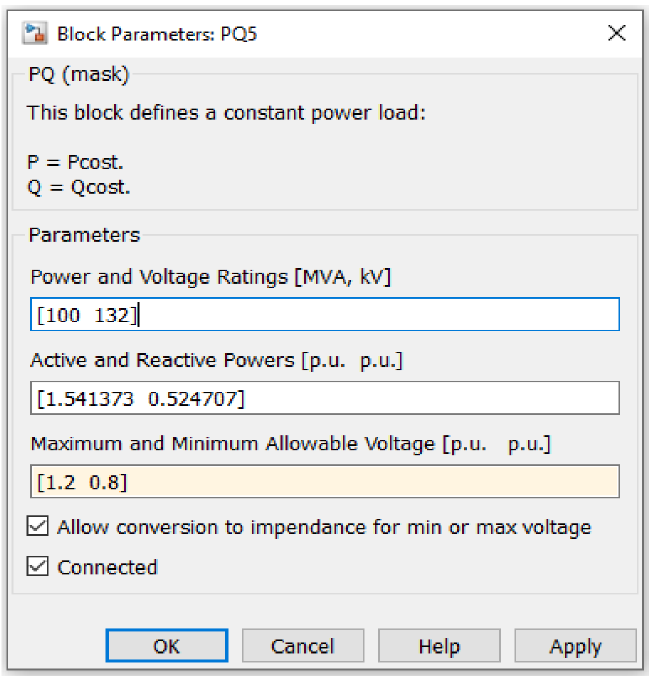

Figure 3. 5 PQ Load Data Format.

Table 3. 4 Load Data used.

NO	BUS	P [MW]	Q[Mvar]	NO	BUS	P [MW]	Q[Mvar]
1	400GRANDR	15.9788	1.07268	36	230AXUM	3.7716	1.7915
2	230WOLKITE	20.3304	9.8399	37	230AWASH7K	20.3043	8.5068
3	230WOLDIYA	9.2397	4.472	38	230ALAMATA	24.3136	11.7866
4	230TORHAYL	5.4262	0.123	39	230AGARO	2.525	1.2557
5	230TEKEZE	2.3287	1.1752	40	230ADIGALA	0.4341	-0.8888
6	230SULULTA	49.6272	18.9605	41	132YIGALM	17.3795	6.1326
7	230SUDB	185	0	42	132YIGALEM2	28.571	13.6344
8	230SINOSTILL	20.855	9.931	43	132YESU	32.3276	15.64
9	230SEBETA2	49.5489	24.2583	44	132WSODO	29.3161	15.9089
10	230NIFASMW	4.6258	0.5002	45	132WEREGENU	54.5209	26.4
11	230MOTA	2.4989	1.2096	46	132WENJI	5.9769	2.8927

12	230METEMA	1.9673	0.9522	47	132SHSMNE	20.8476	8.752
13	230MEKELE	175.2094	82.9428	48	132SEBETA1	154.1373	52.4707
14	230MEHONI	4.124	1.6228	49	132NAZRET2	56.9646	27.5495
15	230LEGETAFO	46.6735	22.6296	50	132MOJO	28.4855	13.7902
16	230KOKA	53.4845	25.8636	51	132MELKYGO	20.8601	8.3308
17	230HURSO	0.4341	0.2102	52	132MEKANISA	54.7824	19.8009
18	230HOSSANA	20.4661	10.8591	53	132KOKA	8.8	4.2
19	230GONDER2	23.6902	10.8937	54	132KNORIT	8.2686	4.0019
20	230GIMMA NEW	31.596	14.8437	55	132KALITINEW	36.3959	17.9151
21	230GHEDO	54.5361	17.01702	56	132KALITIGS	4.1342	2.0011
22	230GGNEW	6.876	2.4148	57	132KALITI2	73.5335	27.8761
23	230GASHENA	4.238	0.2231	58	132KALITI1	89.9306	40.4531
24	230FINCHA	7.4884	3.6245	59	132GELAN	28.3229	13.7167
25	230FINCA2	4.7956	2.3198	60	132GEFERSA	212.4279	99.5179
26	230ENDASILASE	21.8903	10.7759	61	132EGEDA	7.8543	3.8049
27	230EIZONE	23.2974	1.12758	62	132DZEIT	55.7315	26.9793
28	230DM	35.5616	15.4456	63	132COTEBE	84.6765	39.1733
29	230DJBTBR	30	14.5	64	132BLION	24.5418	18.6894
30	230DDAWA-3	83.7624	35.6101	65	132BLEMIMB	3.5141	0.5271
31	230DBRHAN	35.5233	15.5403	66	132AWASSA	40.1403	17.9625
32	230COMBOLCHA	63.0643	24.3886	67	132AWASH	24	11.6
33	230BOLEARABSA	3.08	1.5	68	132ATULU	4.9731	2.4078
34	230BEDELE	21.2194	11.48	69	132ASSELA	29.2299	12.2577
35	230BDAR2	44.5907	21.4963	70	132ALABA	6.6148	3.2016

Shunt Data

Shunt reactors and capacitors are modeled as voltage dependent loads in the network. Shunt capacitors supply reactive power at the point of connection, whereas shunt reactors consume reactive power. They are included in the network admittance matrix. For shunt inductive reactor, susceptance is negative and for shunt capacitor, susceptance value is positive. The data format for simulation input is shown in Figure 3.6 below.

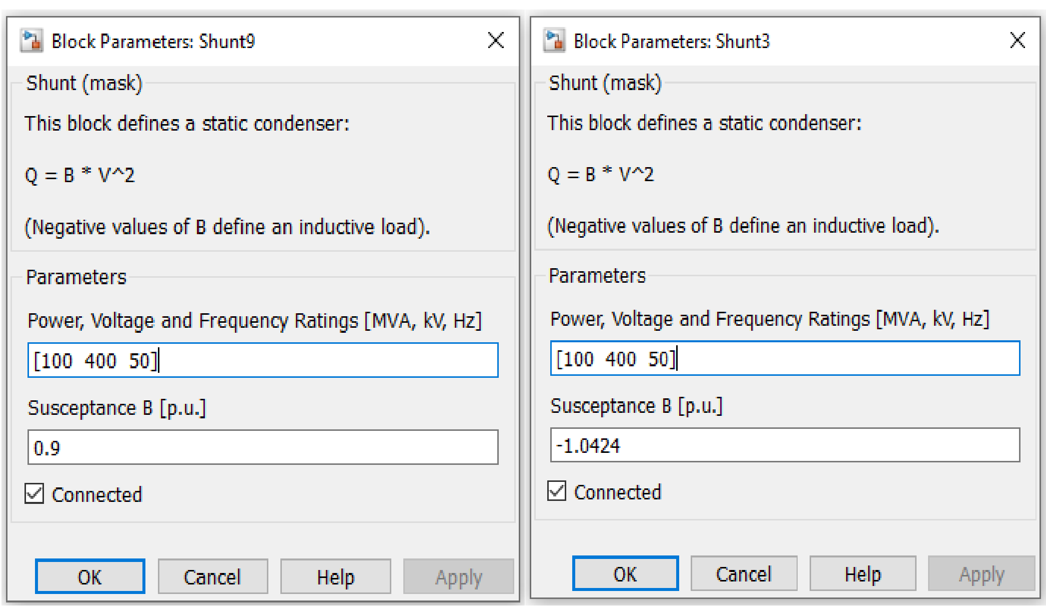

Figure 3. 6 Shunt Admittance Data Format.

Table 3. 5 Shunt Admittance Data used.

No	Bus	Bus [kV]	B-Shunt [Mvar]	B-Shunt [p.u]
1	230BEDELE	230	-17.37	-0.1737
2	230ENDASILASE	230	-34.74	-0.3474
3	230KOKA	230	-17.37	-0.1737
4	230MELK W	230	-17.37	-0.1737
5	230MELKYGO	230	-69.48	-0.6948
6	400BELES	400	-52.12	-0.5212
7	400GELAN	400	-104.24	-1.0424
8	400GELAN	400	90	0.9
9	400G.GNEW	400	-17.37	-0.1737
10	400GRANDR	400	-52.12	-0.5212
11	400SEBETA2	400	90	0.9
12	400WSODO	400	-104.24	-1.0424

3.3 Power System Analysis Toolbox (PSAT)

Power System Analysis Toolbox (PSAT) is an open-source MATLAB toolbox for static and dynamic analysis and control of small to large size electric power systems. PSAT is a very flexible and modular tool for power flow (PF), Continuation Power Flow (CPF), Optimal Power Flow (OPF), Small Signal Stability Analysis (SSSA), Time Domain Simulation (TDS), and Phasor measurement unit (PMU) placement routines [28]. The software provides several static and dynamic models of power system components. Calculations and simulations can be executed using both graphic user interface (GUI) and command line. A Simulink library provides a user-friendly tool for network design. The greatest advantage of PSAT is that being free and open-source, allowing the users to develop their models. [25] To perform power system analysis, PSAT is equipped with a variety of component models of: [25]

- *Power Flow Data*: Bus bars, transmission lines and transformers, slack buses, PV generators, constant power loads, and shunt admittances.
- *CPF and OPF Data*: Power supply bids and limits, generator power reserves, generator ramping data, and power demand bids and limits.
- *Switching Operations*: Transmission line faults and transmission line breakers.
- *Measurements*: Bus frequency and phasor measurement units (PMU).
- *Loads*: Voltage-dependent loads, frequency-dependent loads, ZIP (impedance, constant current, and constant power) loads, exponential recovery loads, thermostatically controlled loads, Jimma's loads, and mixed loads.
- *Machines*: Synchronous machines and induction motors of different dynamic orders.
- *Controls*: Turbine Governors, Automatic Voltage Regulators, Power System Stabilizer, Over-excitation limiters, and Secondary Voltage Regulation (Central Area Controllers and Cluster

Controllers).

- *Regulating Transformers*: Load tap changer with voltage or reactive power regulators and phase-shifting transformers.
- *FACTS:* SVCs, TCSCs, SSSCs, UPFCs, and HVDC transmission systems.
- *Wind Turbines and Wind models*: Constant and variable speed wind turbines of squirrel cage induction motor, doubly fed induction generator, and direct drive synchronous generator.
- *Other Models*: Synchronous machine dynamic shaft, dynamic phasor RLC series circuit, sub-synchronous resonance model, Solid Oxide Fuel Cell, and sub-transmission area equivalents.

Besides analysis routines and models, PSAT includes a variety of visualization and additional features of PSAT such as: [25].

- Single line diagram editor (Simulink library);
- GUIs for settings system and routine parameters;
- User-defined model construction and installation;
- Plotting and outputting results with formats of (Latex, Excel, ASCII, and HTML);
- Data conversion to and from other formats;
- Command line usage.

In the following subsections, a brief description of the main PSAT features is presented.

Overview of PSAT Graphical User Interfaces (GUIs)

All procedures implemented in PSAT can be launched from this window through menus, buttons, and shortcuts. The main settings, such as the system base or the maximum number of iterations, selection of power flow solver algorithm methods, are shown in the main window. Other system parameters and specific settings have dedicated GUIs. PSAT does not rely on GUIs and makes use of global variables to store both setting parameters and data in formats of mdl and slx. This approach allows using PSAT from the command line as needed in many applications. Figure 3.7 below shows the main graphical user interface (GUI) of PSAT. [29]

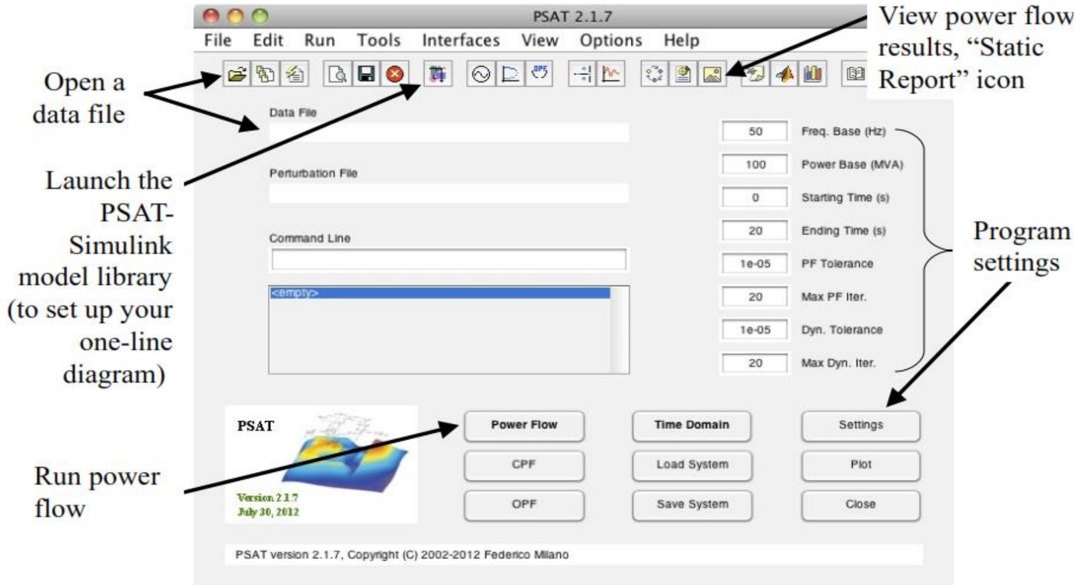

Figure 3. 7 The main Graphical User Interface (GUI) [30].

Simulink Library

PSAT allows drawing electrical schemes utilizing pictorial blocks. Figure 3.8 depicts the complete PSAT Simulink library. The PSAT computational engine is purely MATLAB based and the Simulink environment is used only as a graphical tool. Simulink models are read by PSAT to exploit network topology and extract component data. [29]

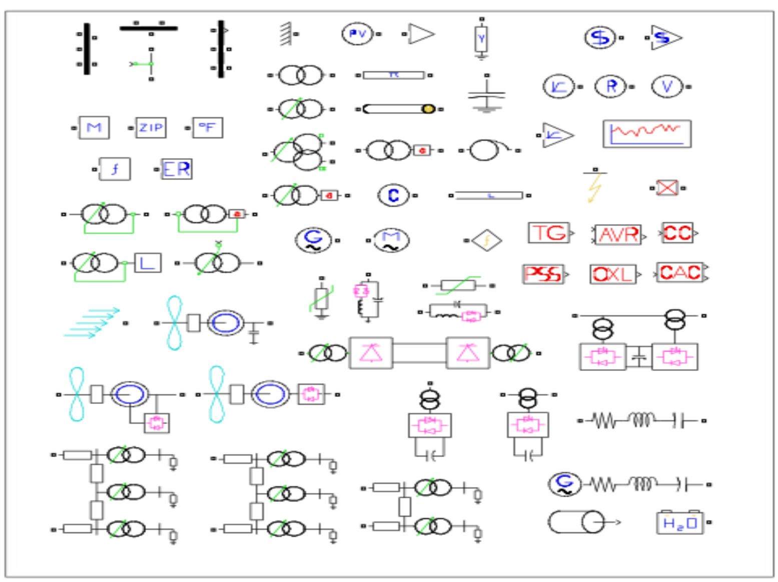

Figure 3. 8 Simulink library [25].

Data Conversion and User Defined Models

To ensure portability and promote contributions, PSAT is provided with a variety of tools, such as a set of data format conversion functions and the capability of defining user-defined models. The data format conversion functions allow converting data files to and from formats commonly in use in power system analysis. The user-defined model tools allow extending the capabilities of PSAT and help end-users to quickly set up their models. Figure 3.9 shows the GUIs for data format conversion and user defined models. [29]

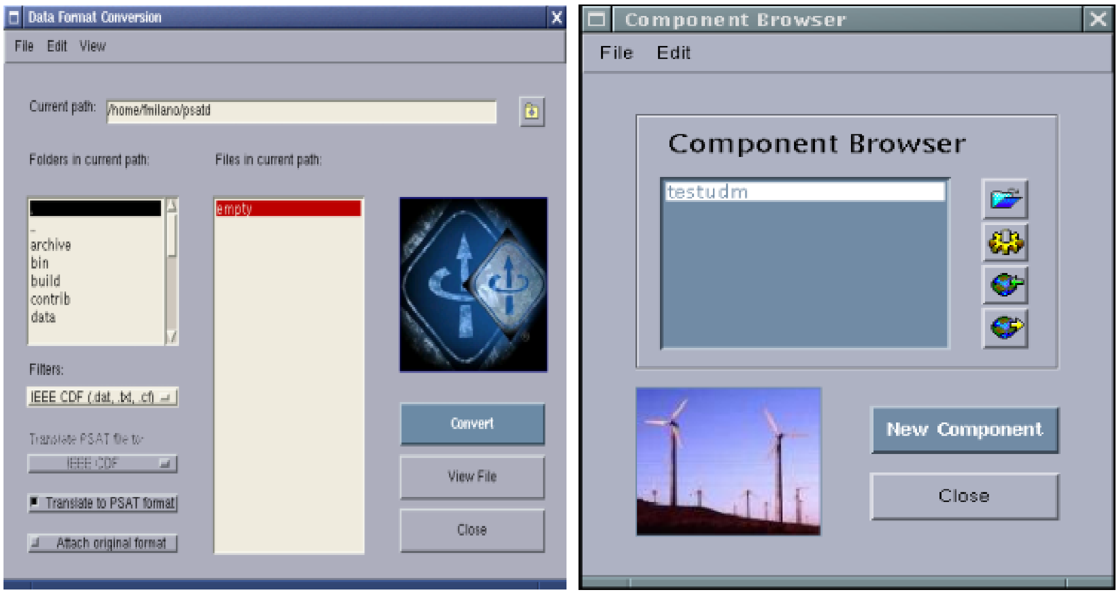

Figure 3. 9 GUIs for data format conversion and user defined models [29].

3.4 Base Case Network model

Ethiopian high voltage transmission network model developed in PSAT is shown in Figure 3.10. As the Ethiopian high voltage network is a bulk transmission system, the existing transmission network diagram as of June 2020 is shown in Appendix A. [31] The base case is redrawn and modeled excluding distribution systems, and loads are represented at substation levels. The model is used for power flow control and voltage enhancement purposes from the base case power flow analysis to enhance both objectives. Summary of the main components of the power system are given in Table 3.6. The model is as of May 22, 2019 peak load demand recorded by EEPNLDC.

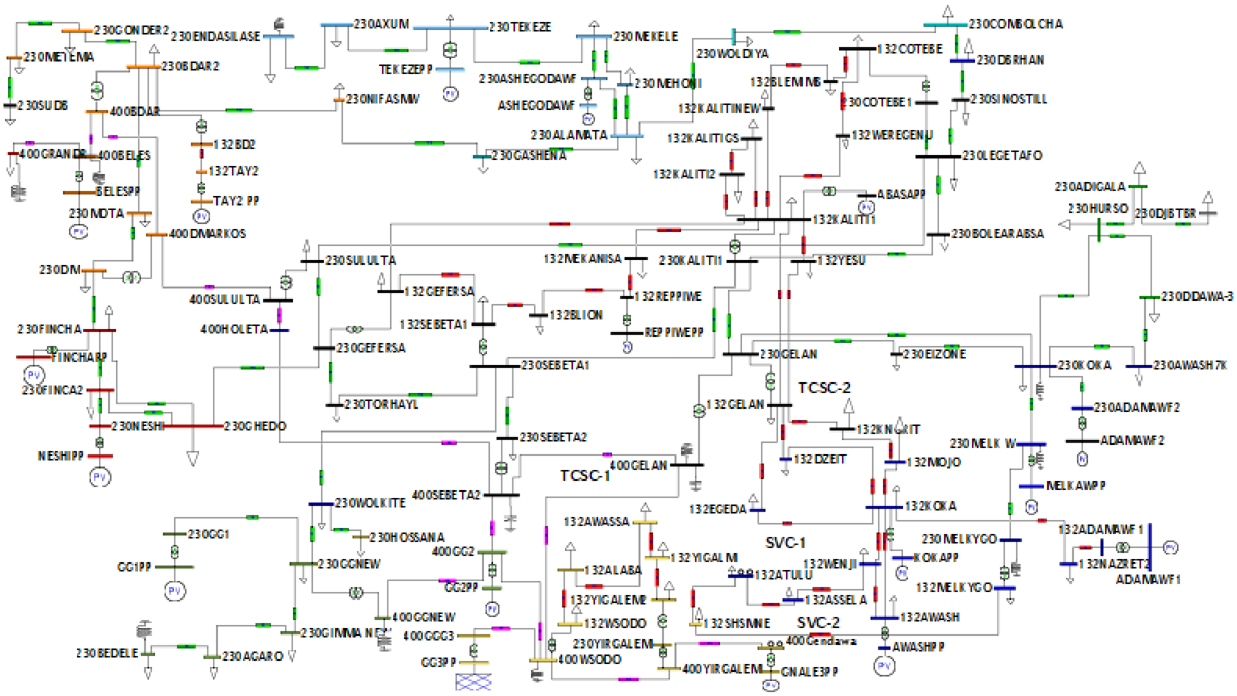

Figure 3. 10 Base case model of EEP high voltage network in PSAT.

Table 3. 6 Summary of network data statistics.

№	Name of component	Number
1	Total Buses	116
2	Lines	107
3	Transformers	33
4	Generators	17
5	Load buses	70
6	Fixed Shunt Inductors and Capacitors	10 and 2

3.5 Load Flow Analysis on Ethiopian Network

The base case is a system operating under normal or steady-state conditions. Power flow programs are used to study power systems under both normal operating conditions and disturbance conditions. The essential requirements for successful power system operation under normal conditions require the following: [26]

- System frequency and loads remain constant.
- Generators supply the load plus losses.
- Bus voltage magnitudes remain close to rated values.
- Generators operate within specified real and reactive power limits.
- Transmission lines and transformers are not overloaded.

The purpose of base case simulation is to investigate equipment loadings, power losses, bus voltages and phase angles, and reactive power requirements for a possible range of system operating conditions.

Power flow solution was performed on the base case system and the algorithm converges after 11 iterations. Results of bus data and branch or line flow records are given in Table 3.7 and Table 3.8 respectively. The bus result show: 17 generators supply 2576.76 MW active power and 31.043 Mvar reactive power to total loads of 2461.63 MW and 1315.8 Mvar including shunts. The total real and reactive power losses are 115.12 MW and -1284.8 Mvar respectively. The network visualization of the base case is represented in Figure 3.11 shows the voltage distribution of different areas in the system. It shows the power flow solution record of bus voltages, areas with dark blue color are having low voltage levels from the lower limit 0.9 p.u. and areas with dark red are having voltage level more than 1.1 p.u.

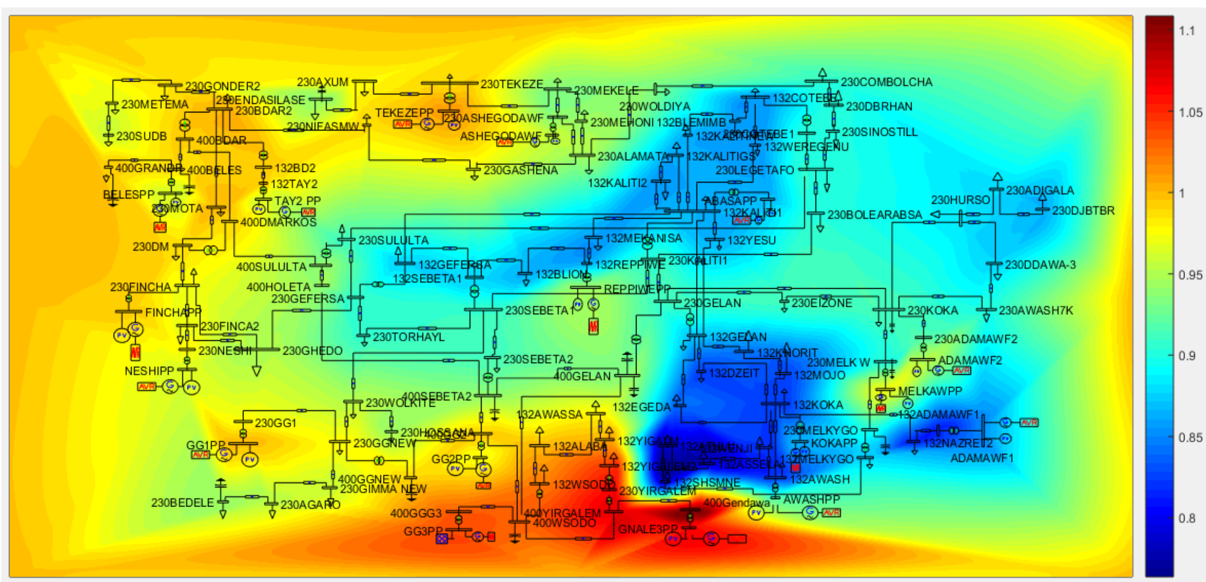

Figure 3. 11 Base case bus voltage network visualization.

Considering voltage violations outside the range 0.9 p.u. to 1.1 p.u. which is the provided emergency voltage in the Ethiopian Electric Power system. [32] The bus records show low voltages at the following buses; 132Adamitulu-(0.8464), 132Assela-(0.8472), 132Shsmne-(0.8525), 132Nazret2-(0.873), 132Adamawf-1-(0.8772), 132Wenji-(0.878), 132Koka-(0.883), 132Awash-(0.8831), 132Dzeit-(0.8855), 132Mojo-(0.8868), 132Geda-(0.8968). High voltages at 400Yirgalem-(1.1004) and 400Gendawa– (1.1271) buses all in p.u.

Table 3. 7 Base case power flow bus data records.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.9241	-0.7428	3.37	0.35	0	0
ADAMAWF1	0.9127	-0.7540	26.9	17	0	0
ADAMAWF2	1	-0.6204	88	35.2296	0	0
ASHEGODAWF	1	-0.8181	8.3	16.0205	0	0
AWASHPP	0.9539	-0.7399	26	25.8	0	0
BELESPP	1	-0.3830	461.2	-106.3655	0	0
FINCHAPP	1.03	-0.5420	101.2	23.8498	0	0
GG1PP	1.02	-0.4345	129.2	18.6115	0	0
GG2PP	1	-0.3072	278.4	-86.0136	0	0
GG3PP	1.05	0	955.789	90.1331	0	0
GNALE3PP	1.0796	-0.2474	150.2	-117	0	0
KOKAPP	0.9163	-0.7988	12.4	26.2	0	0
MELKAWPP	1	-0.6904	29.8	72.0696	0	0
NESHIPP	1	-0.4654	89.8	-14.1660	0	0
REPPIWEPP	0.9734	-0.6475	25.2	16	0	0
TAY2 PP	1	-0.5476	14.9	-11.8499	0	0
TEKEZEPP	1.03	-0.6552	1.761	0.251745	0	0
132ADAMAWF1	**0.8772**	-0.8161	0	0	0	0
132ALABA	1.0343	-0.3807	0	0	6.6148	3.2016
132ASSELA	**0.8472**	-0.8465	0	0	29.2299	12.2577
132ATULU	**0.8464**	-0.8502	0	0	4.9731	2.4078
132AWASH	**0.8831**	-0.8162	0	0	24	11.6
132AWASSA	1.0142	-0.4095	0	0	40.1403	17.9625
132BD2	1.0416	-0.6094	0	0	0	0
132BLEMIMB	0.9180	-0.7511	0	0	3.5141	0.5271
132BLION	0.9208	-0.7421	0	0	24.5418	18.694
132COTEBE	0.9168	-0.7523	0	0	84.6765	39.1733
132DZEIT	**0.8855**	-0.7907	0	0	55.7315	26.9793
132EGEDA	**0.8968**	-0.7897	0	0	7.8543	3.8049
132GEFERSA	0.9323	-0.7308	0	0	212.4279	99.5179
132GELAN	0.9288	-0.7439	0	0	28.3229	13.7167
132KALITI1	0.9228	-0.7464	0	0	89.9306	40.4531
132KALITI2	0.9158	-0.7522	0	0	73.5335	27.8761
132KALITIGS	0.9196	-0.7490	0	0	4.1342	2.0011
132KALITINEW	0.9208	-0.7479	0	0	36.3959	17.9151
132KNORIT	0.9017	-0.7764	0	0	8.2686	4.0019
132KOKA	**0.8830**	-0.8107	0	0	8.8	4.2
132MEKANISA	0.9143	-0.7514	0	0	54.7824	19.8009
132MELKYGO	0.9199	-0.7671	0	0	20.8601	8.3308
132MOJO	**0.8868**	-0.7967	0	0	28.4855	13.7902
132NAZRET2	**0.8730**	-0.8188	0	0	56.9646	27.5495
132REPPIWE	0.9199	-0.7447	0	0	0	0
132SEBETA1	0.9334	-0.7304	0	0	154.1373	52.4707
132SHSMNE	**0.8525**	-0.8434	0	0	20.8476	8.752
132TAY2	1.0383	-0.5957	0	0	0	0
132WENJI	**0.8780**	-0.8171	0	0	5.9769	2.8927
132WEREGENU	0.9141	-0.7540	0	0	54.5209	26.4
132WSODO	1.0552	-0.3499	0	0	29.3161	15.9089
132YESU	0.9223	-0.7480	0	0	32.3276	15.64
132YIGALEM2	1.0755	-0.3687	0	0	28.571	13.6344
132YIGALM	1.0380	-0.3970	0	0	17.3795	6.1326
230ADAMAWF2	0.9735	-0.6896	0	0	0	0
230ADIGALA	0.9594	-0.8924	0	0	0.4341	-0.8888
230AGARO	0.9907	-0.5339	0	0	2.525	1.2557
230ALAMATA	0.9942	-0.8190	0	0	24.3136	11.7866
230ASHEGODAWF	0.9839	-0.8260	0	0	0	0
230AWASH7K	0.9675	-0.7759	0	0	20.3043	8.5068
230AXUM	1.0100	-0.7525	0	0	3.7716	1.7915
230BDAR2	1.0521	-0.6224	0	0	44.5907	21.4963

230BEDELE	0.9766	-0.5409	0	0	21.2194	28.0457
230BOLEARABSA	0.9572	-0.6769	0	0	3.08	1.5
230COMBOLCHA	0.9623	-0.8444	0	0	63.0643	24.3886
230COTEBE1	0.9543	-0.6802	0	0	0	0
230DBRHAN	0.9577	-0.8111	0	0	35.5233	15.5403
230DDAWA-3	0.9564	-0.8654	0	0	83.7624	35.6101
230DJBTBR	0.9504	-0.9057	0	0	30	14.5
230DM	1.0374	-0.5941	0	0	35.5616	15.4456
230EIZONE	0.9659	-0.6739	0	0	23.2974	1.12758
230ENDASILASE	0.9735	-0.7637	0	0	21.8903	43.7019
230FINCA2	1.0167	-0.5830	0	0	4.7956	2.3198
230FINCHA	1.0183	-0.5830	0	0	7.4884	3.6245
230GASHENA	1.0207	-0.7650	0	0	4.238	0.2231
230GEFERSA	0.9612	-0.6675	0	0	0	0
230GELAN	0.9646	-0.6593	0	0	0	0
230GG1	1.0103	-0.5073	0	0	0	0
230GGNEW	1.0096	-0.5097	0	0	6.876	2.4148
230GHEDO	0.9979	-0.6201	0	0	54.5361	17.0170
230GIMMA NEW	0.9953	-0.5292	0	0	31.596	14.8437
230GONDER2	1.0429	-0.7142	0	0	23.6902	10.8937
230HOSSANA	0.9892	-0.5936	0	0	20.4661	10.8591
230HURSO	0.9607	-0.8627	0	0	0.4341	0.2102
230KALITI1	0.9592	-0.6671	0	0	0	0
230KOKA	0.9696	-0.6950	0	0	53.4845	42.1938
230LEGETAFO	0.9570	-0.6778	0	0	46.6735	22.6296
230MEHONI	0.9913	-0.8228	0	0	4.124	1.6228
230MEKELE	0.9786	-0.8269	0	0	175.2094	82.9428
230MELK W	0.9427	-0.7132	0	0	0	15.4357
230MELKYGO	0.9390	-0.7145	0	0	0	61.2585
230METEMA	1.0297	-0.7827	0	0	1.9673	0.9522
230MOTA	1.0508	-0.6123	0	0	2.4989	1.2096
230NESHI	1.0181	-0.5662	0	0	0	0
230NIFASMW	1.0392	-0.7070	0	0	4.6258	0.5002
230SEBETA1	0.9613	-0.6613	0	0	0	0
230SEBETA2	0.9675	-0.6490	0	0	49.5489	24.2583
230SINOSTILL	0.9562	-0.7131	0	0	20.855	9.931
230SUDB	1.0234	-0.8018	0	0	185	0
230SULULTA	0.9658	-0.6643	0	0	49.6272	18.9605
230TEKEZE	1.0193	-0.7386	0	0	2.3287	1.1752
230TORHAYL	0.9612	-0.6639	0	0	5.4262	0.123
230WOLDIYA	0.9843	-0.8314	0	0	9.2397	4.472
230WOLKITE	0.9947	-0.5827	0	0	20.3304	9.8399
230YIRGALEM	1.0918	-0.3389	0	0	0	0
400BDAR	1.0409	-0.5479	0	0	0	0
400BELES	1.0318	-0.4967	0	0	0	55.4884
400DMARKOS	1.0396	-0.5846	0	0	0	0
400GELAN	0.9863	-0.5828	0	0	0	13.8523
400GG2	1.0264	-0.3857	0	0	0	0
400GGG3	1.0616	-0.2916	0	0	0	0
400GGNEW	1.0249	-0.3892	0	0	0	18.2445
400GRANDR	1.0404	-0.5044	0	0	15.9788	57.4944
400GENDAWA	**1.1271**	-0.2998	0	0	0	0
400HOLETA	0.9916	-0.5897	0	0	0	0
400SEBETA2	0.9914	-0.5846	0	0	0	-88.4566
400SULULTA	0.9907	-0.6049	0	0	0	0
400WSODO	1.0635	-0.3264	0	0	0	117.8997
400YIRGALEM	**1.1004**	-0.3240	0	0	0	0
Total Generation and Load			**2576.76**	**31.0435**	**2461.636**	**1315.834**

From branch power flow records shown in Table 3.8 Transmission lines and transformers account for 104.97 MW (91.18%) and 10.153 MW (8.82%) respectively of the total real power loss of

115.123 MW (4.67%). The highest real losses occur along line 17 (Wolytasodo-Gelan), line 18 (GGibe2-Sebeta2), and line 66 (BahirDar2-Gondor2) with 21.61, 8.189, and 6.847 all in MW respectively. These three lines account for 31.83% of the total loss. Therefore, transmission lines losses need to be reduced besides power flow control and voltage profile improvement, for this reason, power loss reduction sensitivity index analysis for a particular line is also done in this study from a power flow control perspective for loss reduction.

Table 3. 8 Branch power flow records of the base case.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	18.612	-128.975	-9.092	0.225	9.519
109	FINCHAPP	230FINCHA	101.2	23.850	-100.937	-19.457	0.263	4.393
110	TAY2 PP	132TAY2	14.9	-11.850	-14.861	13.032	0.039	1.182
111	KOKAPP	132KOKA	12.4	26.2	-12.247	-25.105	0.153	1.095
112	MELKAWPP	230MELK W	29.8	72.070	-29.633	-67.281	0.167	4.789
113	400BDAR	230BDAR2	342.902	-41.491	-342.513	67.619	0.390	26.128
114	400DMARKOS	230DM	44.000	8.970	-43.992	-8.533	0.008	0.437
115	132BD2	230BDAR2	14.739	-11.782	-14.731	12.092	0.007	0.310
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.817	-14.701	0.083	2.299
117	400YIRGALEM	230YIRGALEM	71.093	36.879	-71.075	-35.528	0.018	1.351
118	GG2PP	400GG2	278.4	-86.014	-277.951	110.398	0.449	24.385
119	400GGNEW	230GGNEW	65.989	12.177	-65.978	-4.096	0.011	8.081
120	400SEBETA2	230SEBETA2	257.015	102.905	-256.757	-84.080	0.258	18.825
121	400SULULTA	230SULULTA	349.758	156.270	-349.420	-131.836	0.338	24.434
122	ADAMAWF2	230ADAMAWF2	88	35.230	-87.837	-28.291	0.163	6.939
123	REPPIWEPP	132REPPIWE	25.2	16	-25.171	-12.739	0.029	3.261
124	GNALE3PP	400GENDAWA	150.2	-117	-150.200	130.192	0.000	13.192
125	GG3PP	400GGG3	955.789	90.133	-951.757	190.537	4.033	280.670
126	400GELAN	230GELAN	597.735	198.397	-597.735	-148.774	0.000	49.623
127	230GEFERSA	132GEFERSA	233.112	115.558	-232.758	-97.561	0.354	17.996
128	400WSODO	132WSODO	53.002	18.146	-52.996	-16.764	0.006	1.382
129	230GELAN	132GELAN	241.534	114.945	-241.087	-90.627	0.447	24.319
130	TEKEZEPP	230TEKEZE	176.1	25.174	-175.739	-10.315	0.361	14.859
131	230COTEBE1	132COTEBE	113.196	66.900	-113.087	-56.269	0.108	10.631
132	230KALITI1	132KALITI1	214.800	110.163	-214.392	-89.287	0.408	20.877
133	230MELKYGO	132MELKYGO	46.287	17.465	-46.181	-14.702	0.106	2.763
134	230YIRGALEM	132YIGALEM2	71.075	35.528	-71.023	-32.903	0.052	2.625
135	ASHEGODAWF	230ASHEGODWF	8.3	16.020	-8.290	-15.698	0.010	0.323
136	ABASAPP	132KALITI1	3.37	0.35	-3.366	-0.337	0.004	0.013
137	BELESPP	400BELES	461.2	-106.366	-460.355	163.002	0.845	56.636
138	NESHIPP	230NESHI	89.8	-14.166	-89.507	23.546	0.293	9.380
139	230SEBETA1	132SEBETA1	194.995	86.068	-194.651	-70.296	0.344	15.771
140	AWASHPP	132AWASH	26	25.8	-25.816	-21.982	0.184	3.818
1	230AXUM	230TEKEZE	-26.142	-16.500	26.286	-2.847	0.144	-19.348
2	400SULULTA	400HOLETA	-294.929	8.573	295.463	-25.836	0.534	-17.263
3	400WSODO	400GGG3	-947.638	143.396	951.757	-190.537	4.119	-47.142
4	230KOKA	230GELAN	-67.842	25.040	68.480	-30.329	0.638	-5.289
5	230KOKA	230EIZONE	-56.676	23.601	56.998	-27.829	0.321	-4.228
6	230LEGETAFO	230BOLEARABSA	-37.480	3.466	37.492	-4.052	0.012	-0.585
7	230WOLDIYA	230COMBOLCHA	27.693	14.791	-27.388	-33.293	0.306	-18.502
8	230KALITI1	230BOLEARABSA	40.711	-8.425	-40.572	2.552	0.139	-5.874
9	230COTEBE1	230LEGETAFO	-113.196	-66.900	113.355	64.534	0.160	-2.366
10	230SULULTA	230LEGETAFO	219.785	54.122	-218.539	-58.112	1.246	-3.990
11	400BDAR	400DMARKOS	99.578	-62.000	-99.304	-53.633	0.274	-115.63
12	400DMARKOS	400SULULTA	55.304	44.663	-54.830	-164.843	0.474	-120.18
13	230MOTA	230BDAR2	15.854	-11.676	-15.822	-1.429	0.032	-13.106
14	400HOLETA	400SEBETA2	-295.463	25.836	295.590	-44.715	0.127	-18.879

15	400GELAN	400SEBETA2	20.228	-101.385	-20.166	80.302	0.062	-21.083
16	230MEHONI	230MEKELE	12.353	7.647	-12.261	-25.098	0.092	-17.452
17	400GELAN	400WSODO	-617.963	-110.865	639.573	80.330	**21.610**	-30.535
18	400SEBETA2	400GG2	-532.439	-50.035	540.628	52.623	**8.189**	2.588
19	400WSODO	400GG2	331.682	114.894	-328.685	-177.016	2.997	-62.122
20	400YIRGALEM	400WSODO	78.288	311.361	-76.619	-474.665	1.669	-163.304
21	400GGNEW	400GG2	-65.989	-30.421	66.009	13.994	0.020	-16.427
22	400YIRGALEM	400GENDAWA	-149.381	-348.240	150.200	-130.192	0.819	-478.432
23	230ALAMATA	230ASHEGODWF	12.200	-2.159	-12.137	-20.207	0.063	-22.365
24	400GRANDR	400BELES	-15.979	-57.494	16.008	-98.193	0.029	-155.687
25	132BD2	132TAY2	-14.739	11.782	14.861	-13.032	0.122	-1.250
26	132KOKA	132DZEIT	-13.016	5.182	13.167	-6.344	0.151	-1.162
27	230BDAR2	230NIFASMW	105.371	-27.778	-102.565	8.565	2.805	-19.213
28	132AWASSA	132ALABA	-16.388	-3.497	16.660	0.062	0.272	-3.435
29	132WSODO	132ALABA	23.680	0.855	-23.274	-3.263	0.406	-2.408
30	132YIGALM	132AWASSA	24.135	13.363	-23.752	-14.466	0.383	-1.103
31	230GASHENA	230NIFASMW	-96.107	-5.557	97.939	-9.065	1.832	-14.621
32	132YIGALM	132YIGALEM2	-41.514	-19.495	42.452	19.268	0.938	-0.227
33	132AWASH	132KOKA	-5.017	2.668	5.034	-3.563	0.017	-0.896
34	230DBRHAN	230COMBOLCHA	36.137	-28.924	-35.677	8.904	0.461	-20.020
35	132SHSMNE	132ATULU	3.170	-0.426	-3.153	-2.135	0.017	-2.561
36	132ASSELA	132ATULU	1.824	-1.427	-1.820	-0.273	0.004	-1.700
37	132WEREGNU	132COTEBE	-35.774	-19.416	35.846	19.439	0.073	0.023
38	230TEKEZE	230MEKELE	147.124	11.988	-142.598	-18.753	**4.526**	-6.765
39	132BLEMIMB	132COTEBE	7.443	2.080	-7.435	-2.343	0.007	-0.263
40	400BDAR	400BELES	-442.481	103.491	444.348	-120.298	1.867	-16.807
41	132GELAN	132DZEIT	71.205	23.932	-68.898	-20.635	2.307	3.297
42	132KNORIT	132GELAN	-57.705	-14.250	58.946	15.720	1.242	1.470
43	132EGEDA	132GELAN	-38.299	-6.311	39.364	6.593	1.065	0.283
44	132SEBETA1	132BLION	38.020	15.871	-37.691	-15.768	0.329	0.103
45	132GELAN	132KALITI1	16.505	14.197	-16.433	-14.466	0.072	-0.269
46	132GELAN	132YESU	26.744	16.468	-26.625	-16.565	0.120	-0.098
47	132KALITI1	132YESU	5.708	-1.284	-5.703	0.925	0.005	-0.359
48	230DBRHAN	230SINOSTILL	-71.661	13.384	74.010	-36.798	2.349	-23.414
49	132MEKANISA	132KALITI1	-16.650	-9.822	16.756	9.358	0.106	-0.464
50	132KALITI1	132WEREGENU	18.875	6.485	-18.747	-6.984	0.127	-0.499
51	132KALITI2	132KALITI1	-37.703	-14.383	37.906	14.436	0.202	0.054
52	132KALITI1	132KALITINEW	47.449	20.159	-47.379	-20.105	0.070	0.055
53	132KALITINEW	132BLEMIMB	10.983	2.190	-10.957	-2.607	0.026	-0.417
54	230LEGETAFO	230SINOSTILL	95.990	-32.518	-94.865	26.867	1.126	-5.651
55	132WENJI	132KOKA	-31.036	-5.573	31.178	5.537	0.142	-0.036
56	132MOJO	132KNORIT	-48.822	-9.656	49.436	10.248	0.614	0.591
57	132NAZRET2	132ADAMAWF1	-26.730	-14.730	26.817	14.701	0.088	-0.029
58	132EGEDA	132KOKA	30.445	2.506	-30.031	-2.712	0.414	-0.206
59	132KOKA	132NAZRET2	30.477	12.800	-30.235	-12.819	0.242	-0.019
60	132MOJO	132KOKA	20.337	-4.134	-20.195	3.661	0.142	-0.473
61	132WENJI	132AWASH	-6.801	-8.205	6.833	7.714	0.032	-0.491
62	132ASSELA	132WENJI	-31.054	-10.831	31.860	10.885	0.806	0.055
63	230METEMA	230GONDER2	-188.221	10.053	192.567	-46.597	4.346	-36.544
64	230SUDB	230METEMA	-185.000	0.000	186.254	-11.005	1.254	-11.005
65	230MELKYGO	230MELK W	-46.287	-78.723	46.372	78.437	0.085	-0.286
66	230GONDER2	230BDAR2	-216.258	35.704	223.105	-72.000	**6.847**	-36.296
67	230DM	230MOTA	18.464	-27.513	-18.353	10.467	0.111	-17.046
68	230GASHENA	230ALAMATA	91.869	5.333	-90.152	-19.435	1.717	-14.102
69	230DM	230FINCHA	-10.034	20.600	10.155	-34.517	0.120	-13.916
70	230FINCA2	230FINCHA	-8.528	-30.829	8.544	29.275	0.016	-1.553
71	230GHEDO	230FINCHA	-74.143	-27.681	74.750	21.074	0.607	-6.607
72	132GEFERSA	132SEBETA1	-2.492	-2.389	2.494	1.955	0.002	-0.434
73	132GEFERSA	132KALITI1	22.821	0.433	-22.599	-1.065	0.222	-0.633
74	132MELKYGO	132SHSMNE	25.321	6.371	-24.018	-8.326	1.303	-1.954
75	230NESHI	230FINCA2	89.507	-23.546	-89.027	19.373	0.480	-4.173
76	230FINCA2	230GHEDO	92.760	9.136	-91.555	-18.637	1.204	-9.501
77	230GHEDO	230GEFERSA	111.163	29.301	-109.313	-65.341	1.850	-36.040

78	132KALITI2	132KALITIGS	-35.830	-13.494	35.934	13.506	0.104	0.013
79	230WOLKITE	230SEBETA1	89.251	-2.851	-86.767	-15.350	2.484	-18.201
80	230GEFERSA	230TORHAYL	-43.977	13.973	44.032	-15.777	0.055	-1.804
81	132KALITI1	132KALITIGS	40.167	15.548	-40.069	-15.507	0.098	0.040
82	230ENDASLASE	230AXUM	-21.890	-43.702	22.371	14.709	0.480	-28.993
83	230GEFERSA	230SULULTA	-79.822	-64.190	80.008	58.754	0.185	-5.436
84	132REPPIWE	132MEKANISA	38.301	10.019	-38.133	-9.979	0.169	0.041
85	230AGARO	230GIMMA NEW	-23.905	-14.554	23.963	7.365	0.058	-7.189
86	230AGARO	230BEDELE	21.380	13.298	-21.219	-28.046	0.160	-14.747
87	230GG1	230GGNEW	128.975	9.092	-128.909	-10.293	0.067	-1.201
88	230GGNEW	230WOLKITE	131.977	1.141	-130.131	-1.715	1.846	-0.574
89	230ALAMATA	230MEHONI	16.504	1.727	-16.477	-9.270	0.027	-7.542
90	132BLION	132REPPIWE	13.149	-2.926	-13.130	2.719	0.019	-0.206
91	230GIMA NEW	230GGNEW	-55.559	-22.208	56.034	10.833	0.475	-11.375
92	230HOSSANA	230WOLKITE	-20.466	-10.859	20.549	-5.273	0.083	-16.132
93	230SEBETA2	230SEBETA1	207.208	59.821	-206.628	-61.024	0.580	-1.203
94	230SEBETA1	230KALITI1	48.896	7.132	-48.835	-8.740	0.062	-1.608
95	230SEBETA1	230TORHAYL	49.504	-16.826	-49.458	15.654	0.046	-1.171
96	230GELAN	230KALITI1	207.126	92.397	-206.676	-92.998	0.450	-0.601
97	230EIZONE	230GELAN	-80.295	26.701	80.595	-28.240	0.300	-1.538
98	230MELK W	230KOKA	-16.739	-26.593	16.917	5.260	0.178	-21.333
99	230KOKA	230ADAMAWF2	-87.638	-29.551	87.837	28.291	0.199	-1.260
100	230ALAMATA	230WOLDIYA	37.134	8.080	-36.933	-19.263	0.201	-11.183
101	230KOKA	230AWASH7K	73.239	-20.413	-71.927	8.208	1.312	-12.205
102	230DDAWA-3	230AWASH7K	-50.607	-6.985	51.622	-16.715	1.015	-23.700
103	230DDAWA-3	230HURSO	-33.156	-28.625	33.232	25.746	0.076	-2.879
104	230MEKELE	230ASHEGODWF	-20.350	-39.091	20.427	35.904	0.078	-3.187
105	230KOKA	230HURSO	68.517	-46.131	-64.581	-6.052	3.936	-52.182
106	230HURSO	230ADIGALA	30.915	-19.904	-30.602	-1.693	0.313	-21.597
107	230ADIGALA	230DJBTBR	30.168	2.582	-30.000	-14.500	0.168	-11.918
Total Real and Reactive Losses in (MW and Mvar)							**115.123**	**-1284.8**

3.6 Sensitivity Analysis and Weak Lines and Buses Identification

First, the sensitivity indexes analysis of each line and voltage performance indexes of each bus of the system should be calculated using the power flow results of the base case and line parameters. Then, weak lines and buses should be identified and described for optimal placement of TCSC and SVC on the network. These two points are presented in the following sub-topics one by one.

3.6.1 Sensitivity Analysis

The results of the sensitivity indices analysis for reduction of power loss of a particular line (a_k) and for reduction of power flow performance (b_k) with respect to a TCSC controller reactance X_C inserted in the line are given in Table 3.9. The Voltage performance index (PI_V) values computed for buses of the system are given in Table 3.10. Lines and buses are ranked based on the sensitivity indices from the most severe to the least severe for implementation of the FACTS devices TCSC and SVC respectively.

Table 3. 9 Sensitivity indices for reductions of power flow performance and power loss in a line.

Line	From Bus	To Bus	Line rating (MVA)	Line Loss (MW)	Line flow (MVA)	Percent of line Loading	P flow performance index	P flow sensitivity index b_k	P Loss sensitivity index a_k
41	**132GELAN**	**132DZEIT**	**82**	**2.307**	**75.119**	**91.61**	**0.7043**	**-1.5988**	0.0402
93	230SEBETA2	230SEBETA1	280	0.580	215.67	77.03	**0.3521**	**-0.29028**	0.0118
52	132KALITI1	132KALITINEW	82	0.070	51.554	62.87	0.1562	**-0.34211**	0.0012
44	132SEBETA1	132BLION	91	0.329	41.200	45.27	0.0420	-0.2544	0.0095
81	132KALITI1	132KALITIGS	82	0.098	43.071	52.53	0.0761	-0.17191	0.0016
42	**132KNORIT**	**132GELAN**	**115**	**1.242**	**59.438**	**51.69**	**0.0714**	**0.158592**	0.0216
32	132YIGALM	132YIGALEM2	91	0.938	45.864	50.40	0.0645	**0.14606**	0.017
37	132WERGENU	132COTEBE	82	0.073	40.703	49.64	0.0607	**0.144825**	0.0012
51	132KALITI2	132KALITI1	82	0.202	40.354	49.21	0.0586	**0.132077**	0.0034
96	230GELAN	230KALITI1	514	0.450	226.8	44.16	0.0380	0.128487	0.0093
56	132MOJO	132KNORIT	115	0.614	49.768	43.28	0.0351	0.077109	0.0107
78	132KALITI2	132KALITIGS	91	0.104	38.287	42.07	0.0313	0.070555	0.0018
62	132ASSELA	132WENJI	82	0.806	32.888	40.11	0.0259	0.058945	0.0137
17	**400GELAN**	**400WSODO**	**1973**	**21.61**	**627.829**	**31.82**	**0.0103**	**0.008355**	**0.4337**
18	400SEBETA2	400GG2	1341	**8.189**	**534.785**	**39.88**	**0.0253**	**0.006541**	**0.166**
66	230GONDER2	230BDAR2	402	**6.847**	**219.185**	**54.52**	**0.0884**	**0.055906**	**0.1289**
8	230KALITI1	230BOLEARBS	402	0.139	41.573	10.34	0.0001	-5.3E-05	**0.1221**
38	230TEKEZE	230MEKELE	318	4.526	147.612	46.42	0.0464	-0.03474	**0.0855**
63	230METEMA	230GONDER2	360	4.346	188.489	52.36	0.0752	0.050311	**0.0819**
3	400WSODO	400GGG3	1973	4.119	958.425	48.58	0.0557	0.013215	**0.0819**
105	230KOKA	230HURSO	402	3.936	82.599	20.55	0.0018	-0.00099	**0.0736**
55	132WENJI	132KOKA	82	0.142	31.532	38.45	0.0219	0.047412	0.0024
57	132NAZRET2	132ADMAWF1	82	0.088	30.520	37.22	0.0192	0.044055	0.0015
64	230SUDB	230METEMA	402	1.254	185.000	46.02	0.0449	0.03149	0.0235
43	132EGEDA	132GELAN	115	1.065	38.815	33.75	0.0130	0.028006	0.0186
49	132MEKANISA	132KALITI1	82	0.106	19.331	23.57	0.0031	0.021998	0.0032
83	230GEFERSA	230SULULTA	318	0.185	102.43	32.21	0.0108	0.009105	0.0038
65	230MELKYGO	230MELK W	257	0.085	91.323	35.53	0.0159	0.008189	0.0016
31	230GASHENA	230NIFASMW	318	1.832	96.268	30.27	0.0084	0.00588	0.0345
71	230GHEDO	230FINCHA	284	0.607	79.142	27.87	0.0060	0.004352	0.0117
28	132AWASSA	132ALABA	82	0.272	16.757	20.44	0.0017	0.003682	0.0049
40	400BDAR	400BELES	1341	1.867	454.422	33.89	0.0132	0.003151	0.0373
97	230EIZONE	230GELAN	331	0.300	84.618	25.56	0.0043	0.002652	0.0056
99	230KOKA	230ADAMWF2	402	0.199	92.486	23.01	0.0028	0.001968	0.0036
25	132BD2	132TAY2	91	0.122	18.869	20.74	0.0019	0.001722	0.0022
48	230DBRHAN	230SINOSTILL	318	2.349	72.900	22.92	0.0028	0.001711	0.0441
4	230KOKA	230GELAN	331	0.638	72.316	21.85	0.0023	0.001356	0.0119
26	132KOKA	132DZEIT	82	0.151	14.010	17.08	0.0009	0.001126	0.0025
14	400HOLETA	400SEBETA2	1205	0.127	296.59	24.61	0.0037	0.000959	0.0026
1	230AXUM	230TEKEZE	318	0.144	30.914	9.72	0.0001	0.000932	0.0432
5	230KOKA	230EIZONE	331	0.321	61.394	18.55	0.0012	0.00068	0.0059
82	230ENDASLSE	230AXUM	318	0.480	48.878	15.37	0.0006	0.000651	0.0219
61	132WENJI	132AWASH	82	0.032	10.657	13.00	0.0003	0.000628	0.0005
103	230DDAWA-3	230HURSO	255	0.076	43.803	17.18	0.0009	0.000613	0.0014
91	230GIMMANW	230GGNEW	402	0.475	59.833	14.88	0.0005	0.000358	0.0089
102	230DDAWA-3	230AWASH7K	353	1.015	51.087	14.47	0.0004	0.00031	0.0196
22	400YIRGALEM	400GENDAWA	1973	0.819	378.927	19.21	0.0014	0.000139	0.0161
2	400SULULTA	400HOLETA	1973	0.534	295.053	14.95	0.0005	0.000131	0.0108
98	230MELK W	230KOKA	257	0.178	31.422	12.23	0.0002	0.000128	0.0039
80	230GEFERSA	230TORHAYL	402	0.055	46.143	11.48	0.0002	0.000102	0.001
104	230MEKELE	230ASHEGDWF	402	0.078	44.071	10.96	0.0001	7.81E-05	0.0015
6	230LEGETAFO	230BOLEARBSA	402	0.012	37.640	9.36	0.0001	5.59E-05	0.0002
70	230FINCA2	230FINCHA	318	0.016	31.987	10.06	0.0001	3.76E-05	0.0003
33	132AWASH	132KOKA	82	0.017	5.683	6.93	0.0000	2.47E-05	0.0003
85	230AGARO	230GIMA NEW	402	0.058	27.986	6.96	0.0000	1.66E-05	0.0011
24	400GRANDR	400BELES	543	0.029	59.674	10.99	0.0001	8.53E-06	0.0006
92	230HOSSANA	230WOLKITE	402	0.083	23.169	5.76	0.0000	7.28E-06	0.0016
69	230DM	230FINCHA	280	0.120	22.914	8.18	0.0000	7.03E-06	0.0026

21	400GGNEW	400GG2	1341	0.020	72.663	5.42	0.0000	2.03E-06	0.0004
15	400GELAN	400SEBETA2	1973	0.062	103.383	5.24	0.0000	-1.2E-07	0.0007
23	230ALAMATA	230ASHEGDWF	402	0.063	12.390	3.08	0.0000	-7.9E-07	0.0013
36	132ASSELA	132ATULU	82	0.004	2.316	2.82	0.0000	-8.1E-07	0.0001
72	132GEFERSA	132SEBETA1	82	0.002	3.452	4.21	0.0000	-1E-06	0.00001
12	400DMARKOS	400SULULTA	1341	0.474	71.087	5.30	0.0000	-1.5E-06	0.0088
16	230MEHONI	230MEKELE	402	0.092	14.528	3.61	0.0000	-1.7E-06	0.0019
35	132SHSMNE	132ATULU	82	0.017	3.199	3.90	0.0000	-4.8E-06	0.0003
47	132KALITI1	132YESU	115	0.005	5.850	5.09	0.0000	-5.2E-06	0.0001
89	230ALAMATA	230MEHONI	318	0.027	16.594	5.22	0.0000	-6.1E-06	0.0005
11	400BDAR	400DMARKOS	1341	0.274	117.302	8.75	0.0001	-1.3E-05	0.0055
13	230MOTA	230BDAR2	280	0.032	19.690	7.03	0.0000	-1.3E-05	0.0006
86	230AGARO	230BEDELE	402	0.160	25.178	6.26	0.0000	-1.3E-05	0.003
107	230ADIGALA	230DJBTBR	402	0.168	30.278	7.53	0.0000	-2.5E-05	0.0031
106	230HURSO	230ADIGALA	402	0.313	36.768	9.15	0.0001	-3.9E-05	0.0059
90	132BLION	132REPPIWE	82	0.019	13.471	16.43	0.0007	-4.7E-05	0.0001
67	230DM	230MOTA	280	0.111	33.134	11.83	0.0002	-6.3E-05	0.0021
20	400YIRGALEM	400WSODO	1973	1.669	321.053	16.27	0.0007	-6.5E-05	0.0324
7	230WOLDIYA	230COMBLCHA	318	0.306	31.396	9.87	0.0001	-7.1E-05	0.0054
39	132BLEMIMB	132COTEBE	82	0.007	7.728	9.42	0.0001	-0.00014	0.0001
100	230ALAMATA	230WOLDIYA	318	0.201	38.003	11.95	0.0002	-0.00015	0.0037
95	230SEBETA1	230TORHAYL	402	0.046	52.285	13.01	0.0003	-0.00017	0.0008
34	230DBRHAN	230COMBLCHA	318	0.461	46.287	14.56	0.0004	-0.0002	0.0085
19	400WSODO	400GG2	1973	2.997	351.018	17.79	0.0010	-0.00025	0.0592
53	132KALITINW	132BLEMIMB	82	0.026	11.199	13.66	0.0003	-0.00063	0.0004
94	230SEBETA1	230KALITI1	274	0.062	49.413	18.03	0.0011	-0.00065	0.0011
101	230KOKA	230AWASH7K	353	1.312	76.030	21.54	0.0022	-0.00149	0.0254
79	230WOLKITE	230SEBETA1	402	2.484	89.296	22.21	0.0024	-0.00185	0.0471
60	132MOJO	132KOKA	115	0.142	20.752	18.05	0.0011	-0.00191	0.0025
45	132GELAN	132KALITI1	115	0.072	21.770	18.93	0.0013	-0.00387	0.0014
75	230NESHI	230FINCA2	318	0.480	92.553	29.10	0.0072	-0.00464	0.0092
68	230GASHENA	230ALAMATA	318	1.717	92.024	28.94	0.0070	-0.00525	0.0324
76	230FINCA2	230GHEDO	318	1.204	93.209	29.31	0.0074	-0.00548	0.0226
54	230LEGETAFO	230SINOSTILL	318	1.126	101.349	31.87	0.0103	-0.00634	0.0211
50	132KALITI1	132WEREGENU	82	0.127	19.958	24.34	0.0035	-0.0072	0.002
27	230BDAR2	230NIFASMW	318	2.805	108.971	34.27	0.0138	-0.00907	0.0528
77	230GHEDO	230GEFERSA	341	1.850	114.960	33.71	0.0129	-0.00994	0.0346
29	132WSODO	132ALABA	89	0.406	23.696	26.62	0.0050	-0.01088	0.0073
73	132GEFERSA	132KALITI1	82	0.222	22.826	27.84	0.0060	-0.01133	0.0036
46	132GELAN	132YESU	115	0.120	31.408	27.31	0.0056	-0.01447	0.0022
84	132REPPIWE	132MEKANISA	115	0.169	39.590	34.43	0.0141	-0.01459	0.002
74	132MELKYGO	132SHSMNE	89	1.303	26.110	29.34	0.0074	-0.01656	0.0224
9	230COTEBE1	230LEGETAFO	402	0.160	131.487	32.71	0.0114	-0.0244	0.0276
30	132YIGALM	132AWASSA	82	0.383	27.587	33.64	0.0128	-0.02966	0.0066
87	230GG1	230GGNEW	274	0.067	129.296	47.19	0.0496	-0.03698	0.0013
88	230GGNEW	230WOLKITE	280	1.846	131.982	47.14	0.0494	-0.03765	0.0365
58	132EGEDA	132KOKA	82	0.414	30.548	37.25	0.0193	-0.03991	0.007
59	132KOKA	132NAZRET2	82	0.242	33.055	40.31	0.0264	-0.05993	0.0041
10	230SULULTA	230LEGETAFO	402	1.246	226.351	56.31	0.1005	-0.07663	0.0233
Total system Lines Power flow performance index (PI)							**2.5845**		

The sensitivity indices show relationship between line power flow performance and line loss reduction factors with respect to the inserted TCSC controller in the lines. As expected, the lines power flow performance sensitivity index calculated using sensitivity analysis essentially agrees with the power flow performance index of the lines evaluated from results of load flow study as shown in Table 3.9. Similarly, the real power loss reduction sensitivity index agrees with the real power loss associated with the lines as shown in Table 3.9. The total system lines power flow performance index is 2.5845, but the most heavily loaded line in the system is line 41 having 0.7043 power flow performance index and is loaded 91.61%. The loading level of this line has to be decreased if the performance of the whole system is desired to be reduced.

Figure 3.12 shows transmission lines analysis result with regards to line capacity enhancement with TCSCs. It can be seen from figure 3.12 that there is un utilized capacity in the 400 kV and 230 kV lines and many 132 kV lines are operating near to their maximum capacity. The 400 kV and 230 kV lines have an average 79.8% and 76.9% unused capacities respectively, while the 132 kV lines have an average of 47.7% unused capacity. From table 3.9 and Figure 3.12 it can be seen that the power flow 75.12 MVA in line 41 between 132Gelan and 132Debrezeyit is very close to its maximum capacity 82 MVA.

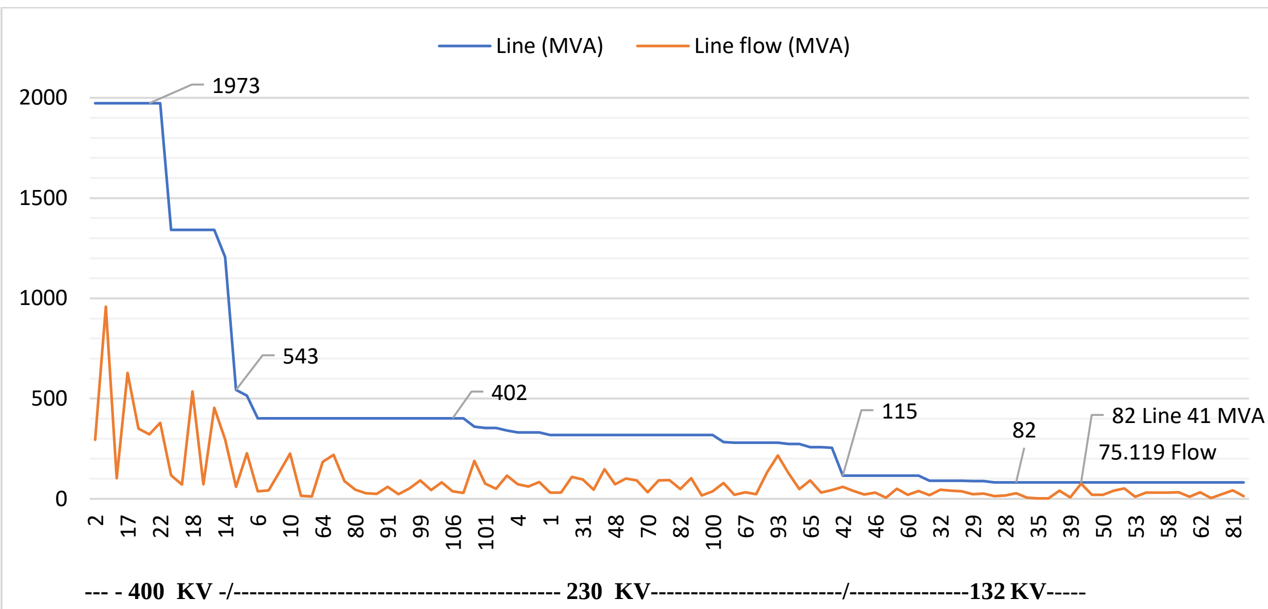

Figure 3. 12 Line power flow and line rating in MVA.

The branches loading in percentage of their MVA rating together with lines voltage group is shown in Figure 3.13. The maximum loading records at various voltage levels of the network is as follows: line 41 (91.61%), line 93 (77.03%) and line 3 (48.58%) from 132 kV, 230 kV and 400 kV voltage levels respectively.

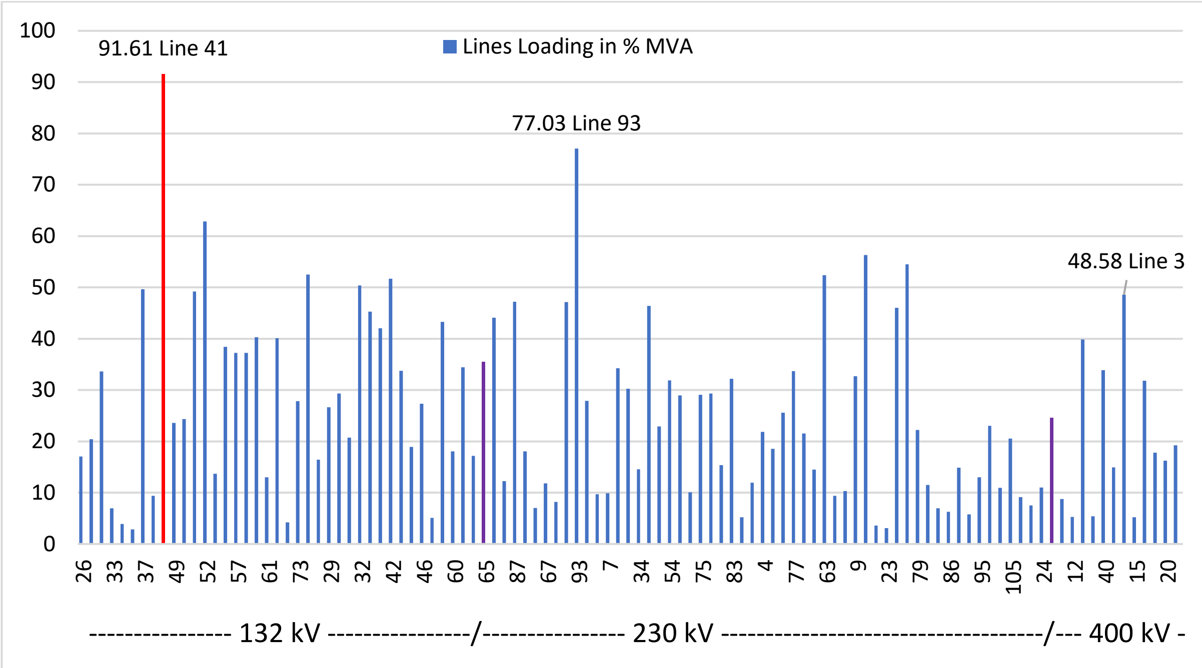

Figure 3. 13 Line loadings in percent of MVA rating.

The calculated results of Voltage performance indices of the buses of the system are given in Table 3.10. The indices show the deviation of bus voltages from the nominal 1 p.u value. Buses 132Atulu, 132Assela, 132Shsmne and 400Gendawa have the largest absolute maximum voltage performance indexes.

Table 3. 10 Voltage Performance Index (**PI$_V$**) values for buses of the system.

Bus Name	V (p.u)	PI$_V$	Bus Name	V (p.u)	PI$_V$	Bus Name	V (p.u)	PI$_V$
132ATULU	**0.846**	**0.0236**	132WSODO	1.055	0.0030	400GG2	1.026	0.0007
132ASSELA	**0.847**	**0.0234**	230BDAR2	1.052	0.0027	400GGNEW	1.025	0.0006
132SHSMNE	**0.853**	**0.0217**	230MOTA	1.051	0.0026	230BEDELE	0.977	0.0005
400GENDAWA	**1.127**	**0.0162**	230DJBTBR	0.950	0.0025	230SUDB	1.023	0.0005
132NAZRET2	0.873	0.0161	AWASHPP	0.954	0.0021	230MEKELE	0.979	0.0005
132ADAMAWF1	0.877	0.0151	230COTEBE1	0.954	0.0021	230GASHENA	1.021	0.0004
132WENJI	0.878	0.0149	230SINOSTILL	0.956	0.0019	230TEKEZE	1.019	0.0004
132KOKA	0.883	0.0137	230DDAWA-3	0.956	0.0019	230FINCHA	1.018	0.0003
132AWASH	0.883	0.0137	230LEGETAFO	0.957	0.0019	230NESHI	1.018	0.0003
132DZEIT	0.885	0.0131	230GONDER2	1.043	0.0018	230FINCA2	1.017	0.0003
132MOJO	0.887	0.0128	230BOLEARABSA	0.957	0.0018	230ASHEGODAWF	0.984	0.0003
132EGEDA	0.897	0.0106	230DBRHAN	0.958	0.0018	230WOLDIYA	0.984	0.0002
400YIRGALEM	**1.100**	**0.0101**	132BD2	1.042	0.0017	132AWASSA	1.014	0.0002
132KNORIT	0.902	0.0097	400BDAR	1.041	0.0017	400GELAN	0.986	0.0002
230YIRGALEM	1.092	0.0084	230KALITI1	0.959	0.0017	230HOSSANA	0.989	0.0001
ADAMAWF1	0.913	0.0076	230ADIGALA	0.959	0.0016	230GG1	1.010	0.0001
132WEREGENU	0.914	0.0074	400GRANDR	1.040	0.0016	230AXUM	1.010	0.0001
132MEKANISA	0.914	0.0073	400DMARKOS	1.040	0.0016	230GGNEW	1.010	0.0001
132KALITI2	0.916	0.0071	230HURSO	0.961	0.0015	400SULULTA	0.991	0.0001
KOKAPP	0.916	0.0070	230NIFASMW	1.039	0.0015	230AGARO	0.991	0.0001
132COTEBE	0.917	0.0069	230GEFERSA	0.961	0.0015	230MEHONI	0.991	0.0001
132BLEMIMB	0.918	0.0067	230TORHAYL	0.961	0.0015	400SEBETA2	0.991	0.0001
132KALITIGS	0.920	0.0065	230SEBETA1	0.961	0.0015	400HOLETA	0.992	0.0001

132MELKYGO	0.920	0.0064	132TAY2	1.038	0.0015	230ALAMATA	0.994	0.0000
132REPPIWE	0.920	0.0064	132YIGALM	1.038	0.0014	230WOLKITE	0.995	0.0000
GNALE3PP	1.080	0.0063	230COMBOLCHA	0.962	0.0014	230GIMMA NEW	0.995	0.0000
132BLION	0.921	0.0063	230DM	1.037	0.0014	230GHEDO	0.998	0.0000
132KALITINEW	0.921	0.0063	230GELAN	0.965	0.0013	ADAMAWF2	1	0
132YESU	0.922	0.0060	132ALABA	1.034	0.0012	ASHEGODAWF	1	0
132KALITI1	0.923	0.0060	230SULULTA	0.966	0.0012	BELESPP	1	0
ABASAPP	0.924	0.0058	230EIZONE	0.966	0.0012	FINCHAPP	1.03	0
132YIGALEM2	1.075	0.0057	230SEBETA2	0.967	0.0011	GG1PP	1.02	0
132GELAN	0.929	0.0051	230AWASH7K	0.968	0.0011	GG2PP	1	0
132GEFERSA	0.932	0.0046	400BELES	1.032	0.0010	GG3PP	1.05	0
132SEBETA1	0.933	0.0044	230KOKA	0.970	0.0009	MELKAWPP	1	0
400WSODO	1.064	0.0040	230METEMA	1.030	0.0009	NESHIPP	1	0
400GGG3	1.062	0.0038	REPPIWEPP	0.973	0.0007	TAY2 PP	1	0
230MELKYGO	0.939	0.0037	230ADAMAWF2	0.974	0.0007	TEKEZEPP	1.030	0
230MELK W	0.943	0.0033	230ENDASILASE	0.974	0.0007			
Total System Voltage Performance Index					**0.436**			

3.6.2 The Weak Lines and Buses

Lines with absolute maximum sensitivity index are candidates for installation of TCSCs and buses with maximum voltage performance index are candidates for SVCs installations.

For reduction of power flow performance index there are two groups of lines with positive and negative indices. Line 42 is best suited because its sensitivity index is the most positive from others followed by line 32. Line 41 is best suited as its sensitivity index is the most negative from others followed by line 93. This indicates placement of TCSC in lines 42 and 41 will reduce the power flow performance index of the system.

For line loss reduction line 17 is best suited as its sensitivity is more positive than others followed by line 18.

For voltage profile improvement purposes bus 132 kV Adamitulu has the most positive voltage performance index from others followed by bus 132 kV Assela. Similarly, bus 400 kV Gendawa has the most positive voltage performance index (absolute voltage deviation greater than the upper limit of 1.1 p. u) from others followed by bus 400 kV Yirgalem. By analyzing the voltage profiles of the base case power flow result, it is clear that buses 132 kV Adamitulu and 400 kV Gendawa are the weakest and the stiffest buses in the system respectively. Therefore, installation of SVC at Adamitulu and at Gendawa will reduce the voltage performance index of the system.

After identification of the possible locations of the FACTS, optimal placement criteria and requirements are presented at in chapter four together with modes of the FACTS required to meet the objectives.

Chapter Four

Performance Enhancement of Ethiopian Transmission Network Using Optimal Placement of FACTS Devices

4.1. Introduction

In general, FACTS devices should be placed on the most sensitive lines and buses based on the sensitivity indices. The indices computed for the type of FACTS device should be placed in the lines from the base-case load flow solution. For the objectives of reductions of power flow performance index and power loss on individual lines, capacitive mode TCSC should be placed in a line (*l*) having the most positive sensitivity indices and inductive mode TCSC in the lines having the most negative sensitivity indices. There are various ways of determining the placement of the devices.

Hence, it is essential to analyze and discuss the optimal places of FACTS devices on the basis of power system accounting the FACTS models in the Newton Raphson power flow by placing single and multiple TCSC and SVC devices. This chapter is devoted on description of the criteria for optimal placement of FACTS devices. Also, the chapter looks on simulation studies with and without single and multiple FACTS are presented in detail. Finally, analysis on voltage regulation, reduction of real power loss, reduction of transmission line loading level and summary of the approach followed are presented.

4.2 Requirements for Optimal Placement of FACTS Devices

The FACTS devices should be placed on the most sensitive lines and buses based on the sensitivity indices. With the sensitivity indices computed for the type of FACTS device to be placed in the lines from the base-case load flow solution. For the objectives of reductions of power flow performance index and power loss on individual lines, capacitive mode TCSC should be placed in a line (*l*) having the most positive sensitivity indices and inductive mode TCSC in the lines having the most negative sensitivity indices.

There are various ways of determining the placement of the devices, but the strategy that has been implemented is to analyze the power flow in various branches before and after the placement of these devices [8]. SVCs are placed in buses that have higher voltage performance indices. For the placement of TCSCs devices, the main requirements or criteria include:

1. The sending end bus must be either a load bus or a generator bus with no regulating

generation.

2. The device should not be placed in the line containing generation buses, even if the sensitivity is the highest. (Compensation will chance the reactive power balance between the sources. i.e., one of them will act as a source and the other as a sink).
3. For power flow performance reduction of the system, capacitive TCSCs should be placed on lines with most positive and inductive TCSCs on lines with most negative power flow sensitivity indexes.
4. For loss reduction of the system loss, capacitive TCSCs should be placed on lines having the most positive loss reduction sensitivity indexes.

The above selection criteria suggest lines with maximum and minimum values should be selected from the identified lines in section 3.6.2.

Capacitive TCSC should be used in lines 17, 18 and 66 for objective of reducing real power loss. For reduction of power flow performance index of the whole system, Capacitive TCSC should be used in lines 42, 32 and 37 and Inductive mode TCSC should be used in the lines 41, 93 and 52 to decrease the power flows since these lines are the most loaded from others.

Capacitive SVC should be used at 132Atulu and Inductive mode at 400Gendawa for maintaining under/over voltage problems to the allowed emergency minimum 0.9 p.u. and maximum 1.1 p.u. range.

Lines 17 and 42 together with buses 132Atulu and 400Gendawa are selected for placement and are shown in Figure 4.1. Although, inductive TCSC compensation is not the main theme of this study an attempt has been made to show the possibility of line overloading relief with a case study in line 41.

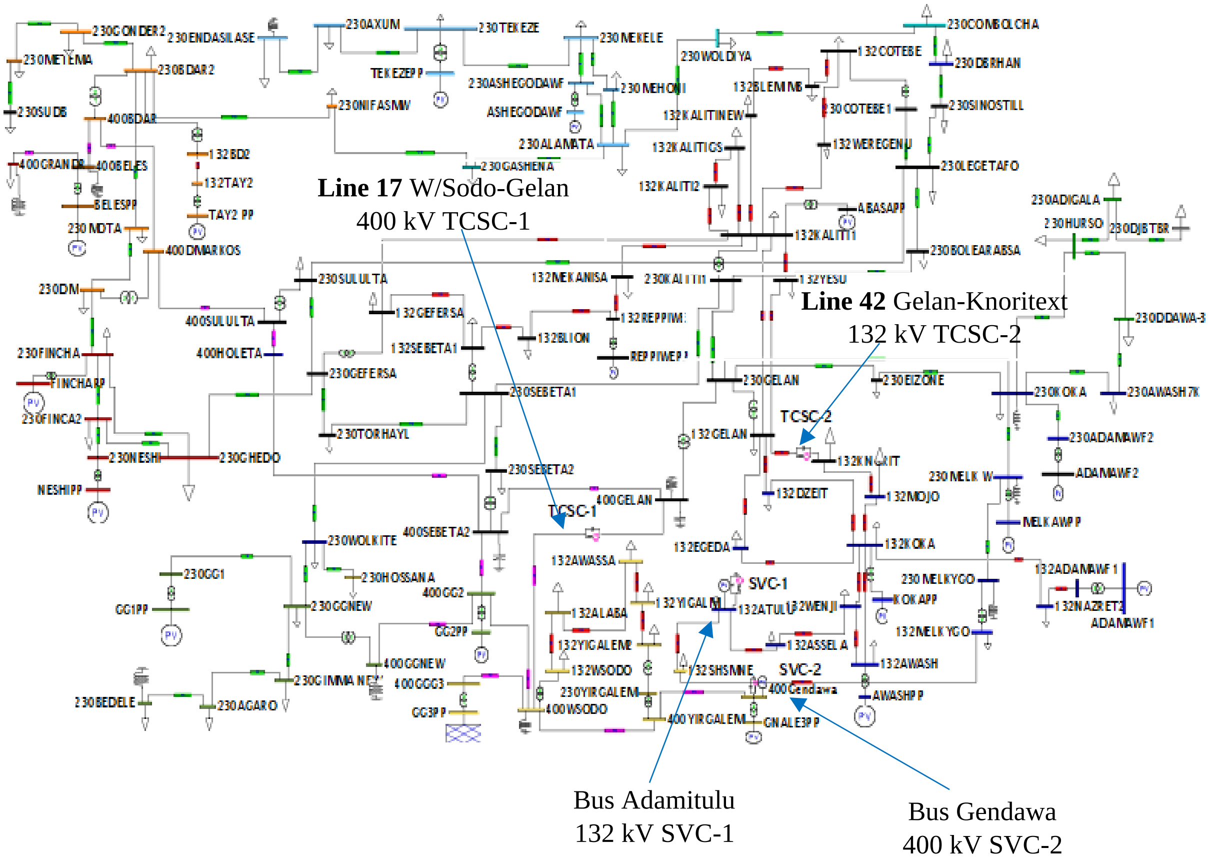

Figure 4. 1 The selected lines and buses for FACTS placement.

4.3. Simulation Studies of the Network with and without FACTS

The subsequent sections analyze and discuss the presence of FACTS devices in the base case power system accounting the FACTS models in the Newton Raphson power flow by placing single and multiple TCSC and SVC devices. Figure 4.1 shows the situation of this places on the network. TCSCs are placed on the lines selected based on sensitivity indices determined using sensitivity analysis technique. SVCs are placed on buses that have higher voltage performance or sensitivity indices.

4.3.1 With TCSCs

Here, a TCSC is inserted in the lines selected one at a time and a load flow solution is conducted to analyze the improvement of the system with the TCSC device. The range of the reactance of the installed TCSCs is appropriately chosen between -70% and +20% of existing line reactance [-0.7*X* to 0.2*X*]. Where *X* is the reactance of the corresponding transmission line in which installation of TCSC is desired. (i.e., the maximum capacitive compensation is 70% and the maximum inductive compensation is 20% of the line inductance). Different compensation degrees of (K) are used for all cases on desired changes of line flow and reactance of the line to control power flows.

When an inductive TCSC is connected in series with line 41 between 132Gelan and 132Debrezeyit with $X_{TCSC} = -0.01322\ p.u$ for K = -20% to decrease the power flow of the line as this line is heavily loaded and has the most negative value of power flow performance sensitivity index. The load flow solution results show insignificant reduction of bus voltages. Power flow in the line was able to be reduced to 67.623 MW from 71.2 MW, the loss of the line was reduced to 2.127 MW from 2.307 MW but the total system loss was increased to 115.24 MW from 115.123 MW due to increased reactive power line flows in the system. The report of bus and line flows are shown in Appendix B.1 and B.2.

Similarly, when a capacitive TCSC is connected in series with line 42 between 132Gelan and 132K-Texit with $X_{TCSC} = 0.0054074\ p.u$ at K = 10% to increase the power flow or transfer capacity of the line as this line has the most positive sensitivity index of power flow performance. The load flow solution results show marginal improvement of bus voltages and reduction of the total loss of the system from the base case. Power flow in the line was able to be increased to 60.407MW from 57.705 MW, the loss of the line was reduced to 1.17 MW from 1.242 MW and the total system loss was reduced to 114.92 MW from 115.123 MW. The report of bus and line flows are shown in Appendix B.3 and B.4.

From the above two case studies, only one line with series TCSC can be used to control the real power flows in both lines because these lines run in parallel, either increasing the series inductive compensation percentage of line 41 or increasing the series capacitive compensation percentage of line 42 will increase the power flow in line 42 and will decrease the power flow in line 41. But the TCSC in line 41was maintained at its maximum inductive series compensation of 20% and the TCSC in line 42 is at its low percentage of series capacitive compensation of 10%, so the capacitive TCSC at line 42 is selected for further analysis for the purpose of power flow control in the two lines since it is possible to increase its compensation level and regulate power flows in both lines.

Similarly, when a capacitive TCSC is connected in series with line 17 between 400Wolaytasodo and 400Gelan with $X_{TCSC} = 0.01728\ p.u$ at K = 40% to decrease the power loss of the system since this line has the most positive power loss reduction sensitivity index it is best suited for capacitive TCSC. The load flow solution results show the real power loss of line reduced to 17.82 MW from 21.61 MW. the total system loss was reduced to 102.23 MW from 115.123 MW. Also, the line flow is increased to 743.15 from 617.69 MW. The bus voltage records of the system are improved much from the base case due to the increased power flow and reduction of loss in the line. Power flow result of bus voltage records with and without one TCSC in the lines is shown in Figure 4.2. The report of bus and line flows are shown in Appendix B.5 and B.6.

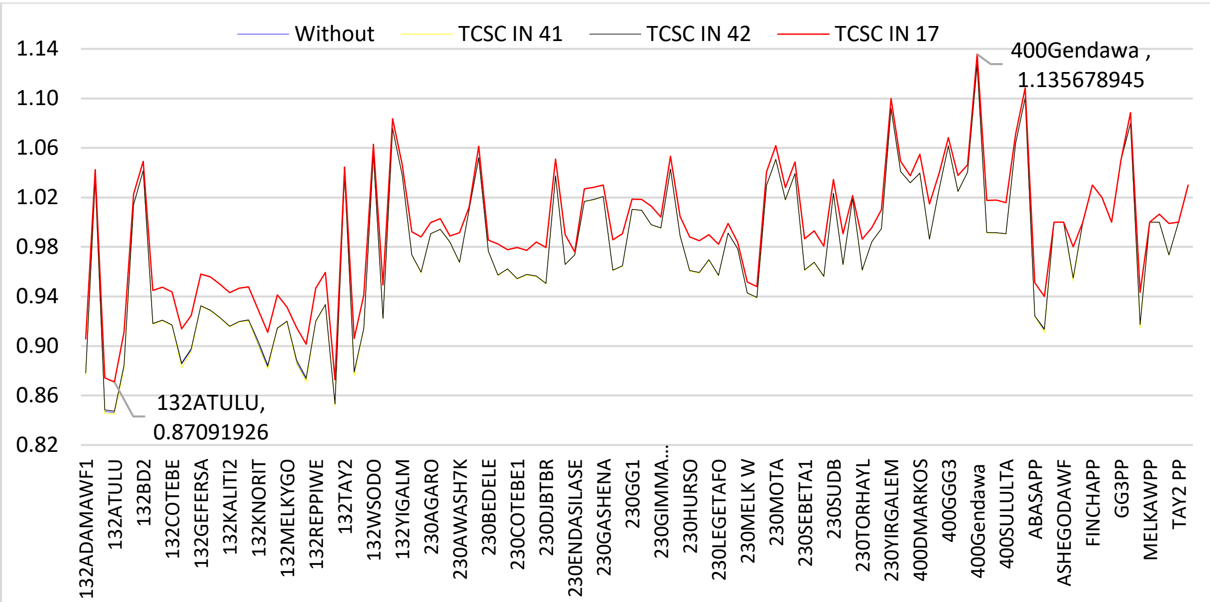

Figure 4. 2 Voltage profiles in p.u. without and with one TCSC.

Here the two capacitive TCSC devices are installed simultaneously in lines 42 and 17 (TCSC1 and TCSC2) respectively. With $X_{TCSC-1} = 0.03623\ p.u$ at K = 67% here the attempt is to control the real power flow in the lines 41 and 42 to 65 and 70 MW respectively, so that the two lines share the total power flows in the lines in the proportion of their apparent power or MVA. The TCSC-2 $X_{TCSC-2} = 0.02592\ p.u$ at K = 60% is desired for power flow increment to 825 MW and power loss reduction of the whole system at the same time.

The load flow solution results show, real power losses are reduced by 0.713, 7.561 and 22.553 in MW in the lines 42, 17 and of the total system respectively. Bus voltage records of the base case minimum 0.846 is enhanced to 0.896 and the maximum 1.1271 further increases to 1.144 all in p.u this comparison is shown in Figure 4.3. Many lines were relieved from base case loading level, the maximum 91.16% before in line 41 is reduced to 84.45%, due to system loss reduction and reduced reactive power flows in lines by the TCSCs as shown in Figure 4.4. The report of bus and line flows are shown in Appendix B.7 and B.8.

Summary of the controllers' parameters of the FACTS for both variable susceptance and firing angle models and the controlled state variables with one and with two TCSCs is given in

Table4.1. Line power flow results with and without the installed TCSCs in the lines are shown in Table 4.2.

Table 4. 1 Summary of controlled state variables and controllers' parameters with TCSCs.

Number of TCSCs	One			Two	
With TCSC in line No	41	42	17	42	17
$X_{TCSC}(pu)$	-0.01322	0.0054074	0.01728	0.03623	0.02592
$\alpha_{TCSC}(rad)$	-1.5574	0.92015	0.92015	0.92015	0.92015
Compensation %	-20	10	40	67	60
Power flow without (MW)	71.2	57.705	617.96	57.705	617.96
Specified Power flow with (MW)	67.623	60.407	743.15	70	825
Line loss reduction in %	7.76	5.64	17.52	34.98	57.4
Total real power loss with (MW)	115.24	114.93	102.23	92.57	
Min/Max Voltage without (p.u)	0.8462…………1.127				
Minimum Voltage with (p.u)	0.845	0.847	0.87	0.896	
Maximum Voltage with (p.u)	1.127	1.1272	1.137	1.1448	

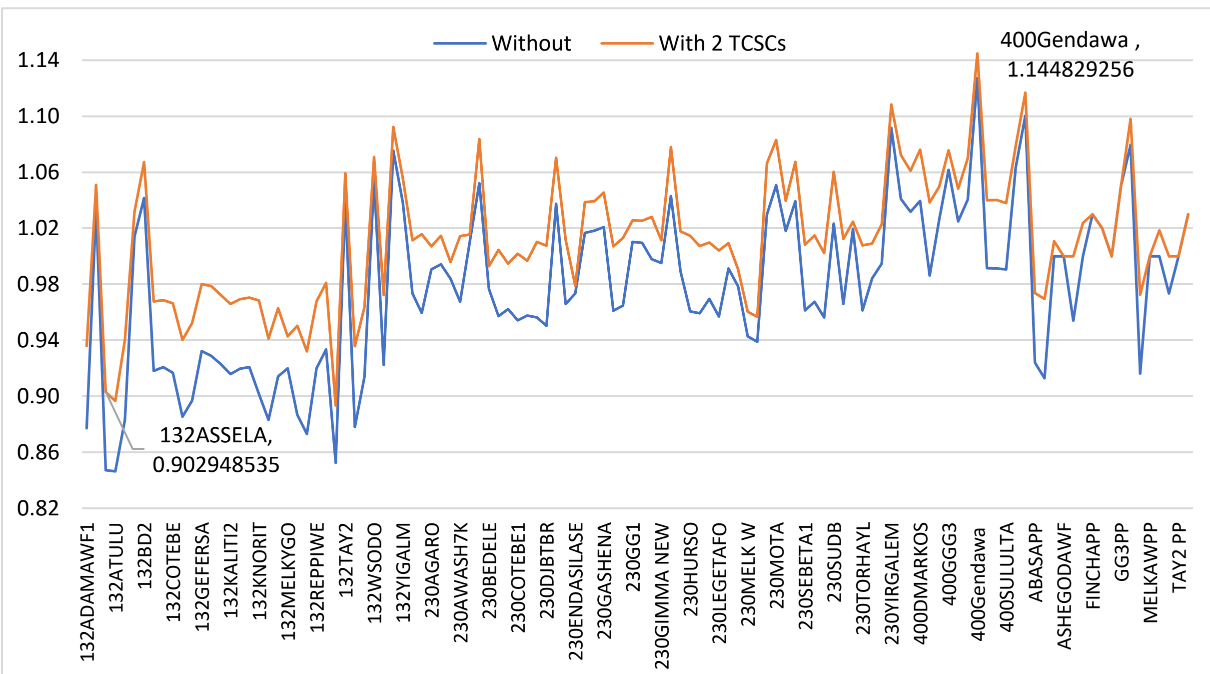

Figure 4. 3 Voltage profiles in p.u. without and with two TCSCs.

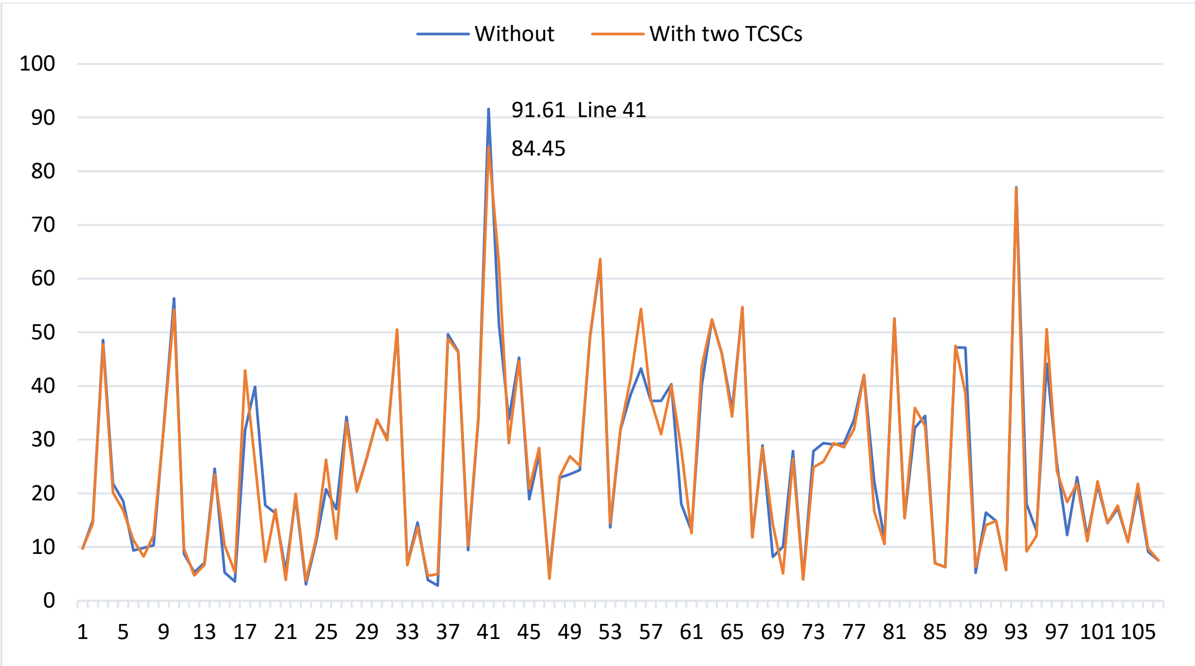

Figure 4. 4 Branches loading in the percentage of their MVA without and with two TCSCs.

Table 4. 2 Lines real power flows and losses without and with one and two TCSCs.

Line	From bus	To bus	Line Flow [MW]				Line Loss [MW]			
			Without	TCSC in Line 42	TCSC in Line 17	Both TCSCs	Without	TCSC in 42	TCSC in 17	Two TCSCs
108	GG1PP	230GG1	129.2	129.2	129.2	129.2	0.225	0.224	0.220	0.221
109	FINCHAPP	230FINCHA	101.2	101.2	101.2	101.2	0.263	0.263	0.249	0.266
110	TAY2 PP	132TAY2	14.9	14.9	14.9	14.9	0.039	0.039	0.044	0.060
111	KOKAPP	132KOKA	12.4	12.4	12.4	12.4	0.153	0.152	0.144	0.136
112	MELKAWPP	230MELK W	29.8	29.8	29.8	29.8	0.167	0.167	0.126	0.092
113	400BDAR	230BDAR2	342.902	342.892	340.796	340.333	0.390	0.390	0.380	0.362
114	400DMARKOS	230DM	44.0	43.990	42.424	41.206	0.008	0.008	0.008	0.009
115	132BD2	230BDAR2	14.739	14.738	14.717	14.653	0.007	0.007	0.008	0.011
116	ADAMAWF1	132ADAMAWF1	26.9	26.900	26.9	26.9	0.083	0.082	0.078	0.073
117	400YIRGALEM	230YIRGALEM	71.093	71.094	71.114	71.137	0.018	0.018	0.018	0.017
118	GG2PP	400GG2	278.4	278.4	278.4	278.4	0.449	0.449	0.501	0.559
119	400GGNEW	230GGNEW	65.989	65.969	50.854	40.685	0.011	0.011	0.007	0.004
120	400SEBETA2	230SEBETA2	257.015	256.992	254.513	252.461	0.258	0.258	0.245	0.234
121	400SULULTA	230SULULTA	349.758	349.733	346.055	343.249	0.338	0.338	0.319	0.306
122	ADAMAWF2	230ADAMAWF2	88	88	88	88	0.163	0.163	0.143	0.138
123	REPPIWEPP	132REPPIWE	25.2	25.2	25.2	25.2	0.029	0.029	0.027	0.022
124	GNALE3PP	400GENDAWA	150.2	150.2	150.2	150.2	0	0	0	0
125	GG3PP	400GGG3	955.789	955.599	942.901	933.237	4.033	4.031	3.908	3.817
126	400GELAN	230GELAN	597.735	597.653	619.003	632.314	0	0	0	0
127	230GEFERSA	132GEFERSA	233.112	233.097	231.892	231.244	0.354	0.354	0.331	0.315
128	400WSODO	132WSODO	53.002	53.001	52.948	52.891	0.006	0.006	0.005	0.005
129	230GELAN	132GELAN	241.534	241.557	243.937	245.607	0.447	0.447	0.430	0.417
130	TEKEZEPP	230TEKEZE	176.100	176.100	176.1	176.1	0.361	0.361	0.358	0.356
131	230COTEBE1	132COTEBE	113.196	113.186	112.236	111.735	0.108	0.108	0.100	0.095
132	230KALITI1	132KALITI1	214.800	214.798	215.788	216.441	0.408	0.408	0.389	0.375
133	230MELKYGO	132MELKYGO	46.287	46.148	45.507	43.912	0.106	0.105	0.097	0.087
134	230YIRGALEM	132YIGALEM2	71.075	71.075	71.096	71.120	0.052	0.052	0.051	0.050
135	ASHEGODWF	230ASHEGOWF	8.3	8.3	8.3	8.3	0.010	0.010	0.006	0.003
136	ABASAPP	132KALITI1	3.37	3.37	3.37	3.37	0.004	0.004	0.003	0.003
137	BELESPP	400BELES	461.2	461.200	461.2	461.2	0.845	0.845	0.865	0.829
138	NESHIPP	230NESHI	89.8	89.8	89.8	89.8	0.293	0.293	0.292	0.285
139	230SEBETA1	132SEBETA1	194.995	194.985	193.823	192.742	0.344	0.344	0.323	0.308
140	AWASHPP	132AWASH	26	26	26	26	0.184	0.184	0.175	0.149
1	230AXUM	230TEKEZE	-26.142	-26.142	-26.142	-26.141	0.144	0.144	0.143	0.142
2	400SULULTA	400HOLETA	-294.929	-294.883	-287.474	-282.843	0.534	0.534	0.481	0.446

3	400WSODO	400GGG3	-947.638	-947.451	-935.009	-925.537	4.119	4.117	3.984	**3.883**
4	230KOKA	230GELAN	-67.842	-67.769	-67.333	-66.479	0.638	0.636	0.540	0.489
5	230KOKA	230EIZONE	-56.676	-56.607	-56.222	-55.422	0.321	0.320	0.266	0.239
6	230LEGETAFO	230BOLEARABSA	-37.480	-37.494	-42.288	-45.375	0.012	0.012	0.014	0.015
7	230WOLDIYA	230COMBOLCHA	27.693	27.685	26.075	25.786	0.306	0.305	0.225	0.185
8	230KALITI1	230BOLEARABSA	40.711	40.725	45.546	48.649	0.139	0.139	0.164	0.178
9	230COTEBE1	230LEGETAFO	-113.196	-113.186	-112.236	-111.735	0.160	0.160	0.148	0.140
10	230SULULTA	230LEGETAFO	219.785	219.768	215.274	211.646	1.246	1.246	1.136	1.053
11	400BDAR	400DMARKOS	99.578	99.589	101.639	102.223	0.274	0.274	0.292	0.279
12	400DMARKOS	400SULULTA	55.304	55.324	58.922	60.738	0.474	0.474	0.341	0.332
13	230MOTA	230BDAR2	15.854	15.854	15.772	15.341	0.032	0.032	0.029	0.027
14	400HOLETA	400SEBETA2	-295.463	-295.416	-287.954	-283.289	0.127	0.127	0.113	0.105
15	400GELAN	400SEBETA2	20.228	20.226	124.152	192.954	0.062	0.062	0.137	0.261
16	230MEHONI	230MEKELE	12.353	12.353	12.354	12.375	0.092	0.092	0.124	0.180
17	**400GELAN**	**400WSODO**	**-617.963**	**-617.879**	**-743.156**	**-825.268**	**21.610**	**21.599**	**17.817**	**14.049**
18	400SEBETA2	400GG2	-532.439	-532.372	-418.566	-343.162	8.189	8.185	4.802	**3.100**
19	400WSODO	400GG2	331.682	331.590	197.632	109.791	2.997	2.996	1.297	0.676
20	400YIRGALEM	400WSODO	78.288	78.288	78.258	78.225	1.669	1.670	1.715	1.764
21	400GGNEW	400GG2	-65.989	-65.969	-50.854	-40.685	0.020	0.020	0.012	0.009
22	400YIRGALEM	400GENDAWA	-149.381	-149.381	-149.372	-149.362	0.819	0.819	0.828	0.838
23	230ALAMATA	230ASHEGODWF	12.200	12.200	12.195	12.215	0.063	0.063	0.091	0.149
24	400GRANDR	400BELES	-15.979	-15.979	-15.979	-15.979	0.029	0.029	0.029	0.029
25	132BD2	132TAY2	-14.739	-14.738	-14.717	-14.653	0.122	0.122	0.139	0.187
26	132KOKA	132DZEIT	-13.016	-12.326	-13.207	-7.933	0.151	0.139	0.144	0.064
27	230BDAR2	230NIFASMW	105.371	105.360	103.385	102.918	2.805	2.805	2.654	2.499
28	132AWASSA	132ALABA	-16.388	-16.387	-16.348	-16.306	0.272	0.272	0.266	0.259
29	132WSODO	132ALABA	23.680	23.680	23.626	23.569	0.406	0.406	0.397	0.389
30	132YIGALM	132AWASSA	24.135	24.135	24.170	24.208	0.383	0.382	0.378	0.374
31	230GASHENA	230NIFASMW	-96.107	-96.098	-94.373	-94.119	1.832	1.832	1.733	1.674
32	132YIGALM	132YIGALEM2	-41.514	-41.515	-41.549	-41.587	0.938	0.938	0.925	0.911
33	132AWASH	132KOKA	-5.017	-5.037	-5.106	-5.310	0.017	0.017	0.016	0.013
34	230DBRHAN	230COMBLCHA	36.137	36.145	37.645	37.861	0.461	0.460	0.431	0.398
35	132SHSMNE	132ATULU	3.170	3.048	2.556	1.168	0.017	0.016	0.011	0.009
36	132ASSELA	132ATULU	1.824	1.945	2.435	3.833	0.004	0.004	0.007	0.019
37	132WREGNU	132COTEBE	-35.774	-35.769	-35.304	-35.059	0.073	0.073	0.067	0.063
38	230TEKEZE	230MEKELE	147.124	147.124	147.128	147.132	4.526	4.526	4.470	4.407
39	132BLEMIMB	132COTEBE	7.443	7.447	7.919	8.167	0.007	0.008	0.008	0.008
40	400BDAR	400BELES	-442.481	-442.481	-442.434	-442.555	1.867	1.867	1.893	1.808
41	**132GELAN**	**132DZEIT**	**71.205**	**70.454**	**71.261**	**65.496**	**2.307**	**2.257**	**2.178**	**1.768**
42	**132KNORIT**	**132GELAN**	**-57.705**	**-59.236**	**-57.868**	**-70.051**	**1.242**	**1.172**	**1.176**	**0.529**
43	132EGEDA	132GELAN	-38.299	-37.618	-38.447	-33.197	1.065	1.024	1.010	0.712
44	132SEBETA1	132BLION	38.020	38.011	37.107	36.378	0.329	0.329	0.297	0.290
45	132GELAN	132KALITI1	16.505	16.527	17.890	18.821	0.072	0.073	0.076	0.079
46	132GELAN	132YESU	26.744	26.757	27.533	28.061	0.120	0.120	0.118	0.117
47	132KALITI1	132YESU	5.708	5.695	4.917	4.387	0.005	0.005	0.003	0.003
48	230DBRHAN	230SINOSTILL	-71.661	-71.668	-73.168	-73.384	2.349	2.349	2.262	2.146
49	132MEKANSA	132KALITI1	-16.650	-16.659	-17.509	-18.208	0.106	0.106	0.108	0.125
50	132KALITI1	132WEREGENU	18.875	18.879	19.344	19.584	0.127	0.127	0.126	0.123
51	132KALITI2	132KALITI1	-37.703	-37.703	-37.704	-37.704	0.202	0.202	0.191	0.182
52	132KALITI1	132KALITINEW	47.449	47.453	47.924	48.168	0.070	0.070	0.067	0.065
53	132KALITINW	132BLEMIMB	10.983	10.987	11.460	11.707	0.026	0.026	0.027	0.026
54	230LEGETAFO	230SINOSTILL	95.990	95.997	97.369	97.418	1.126	1.126	1.084	1.033
55	132WENJI	132KOKA	-31.036	-31.142	-31.547	-32.740	0.142	0.142	0.139	0.144
56	132MOJO	132KNORIT	-48.822	-50.317	-49.018	-60.939	0.614	0.650	0.582	0.844
57	132NAZRET2	132ADAMAWF1	-26.730	-26.730	-26.740	-26.749	0.088	0.087	0.083	0.078
58	132EGEDA	132KOKA	30.445	29.764	30.593	25.343	0.414	0.395	0.394	0.255
59	132KOKA	132NAZRET2	30.477	30.475	30.451	30.426	0.242	0.241	0.226	0.210
60	132MOJO	132KOKA	20.337	21.832	20.532	32.453	0.142	0.161	0.135	0.304
61	132WENJI	132AWASH	-6.801	-6.821	-6.900	-7.135	0.032	0.032	0.032	0.026
62	132ASSELA	132WENJI	-31.054	-31.175	-31.665	-33.063	0.806	0.810	0.806	0.836
63	230METEMA	230GONDER2	-188.221	-188.221	-188.195	-188.136	4.346	4.346	4.262	**4.074**
64	230SUDB	230METEMA	-185.000	-185.000	-185	-185.000	1.254	1.254	1.228	1.168
65	230MELKYGO	230MELK W	-46.287	-46.148	-45.507	-43.912	0.085	0.085	0.081	0.076
66	230GONDER2	230BDAR2	-216.258	-216.257	-216.147	-215.900	6.847	6.847	6.745	**6.517**
67	230DM	230MOTA	18.464	18.464	18.365	17.939	0.111	0.111	0.094	0.100
68	230GASHENA	230ALAMATA	91.869	91.860	90.135	89.881	1.717	1.717	1.636	1.632
69	230DM	230FINCHA	-10.034	-10.043	-11.510	-12.304	0.120	0.121	0.168	0.290
70	230FINCA2	230FINCHA	-8.528	-8.520	-7.102	-6.154	0.016	0.016	0.009	0.004
71	230GHEDO	230FINCHA	-74.143	-74.143	-74.119	-74.167	0.607	0.607	0.555	0.527
72	132GEFERSA	132SEBETA1	-2.492	-2.490	-2.253	-1.918	0.002	0.002	0.002	0.002

73	132GEFERSA	132KALITI1	22.821	22.806	21.386	20.418	0.222	0.222	0.184	0.161
74	132MELKYGO	132SHSMNE	25.321	25.183	24.550	22.964	1.303	1.287	1.146	0.949
75	230NESHI	230FINCA2	89.507	89.507	89.508	89.515	0.480	0.480	0.479	0.467
76	230FINCA2	230GHEDO	92.760	92.752	91.336	90.406	1.204	1.204	1.115	1.066
77	230GHEDO	230GEFERSA	111.163	111.155	109.804	108.971	1.850	1.848	1.569	1.423
78	132KALITI2	132KALITIGS	-35.830	-35.830	-35.830	-35.830	0.104	0.104	0.098	0.094
79	230WOLKITE	230SEBETA1	89.251	89.231	74.566	64.648	2.484	2.482	1.663	1.219
80	230GEFERSA	230TORHAYL	-43.977	-43.977	-43.018	-42.235	0.055	0.055	0.047	0.042
81	132KALITI1	132KALITIGS	40.167	40.166	40.155	40.146	0.098	0.098	0.092	0.088
82	230ENDASLSE	230AXUM	-21.890	-21.890	-21.890	-21.890	0.480	0.480	0.480	0.479
83	230GEFERSA	230SULULTA	-79.822	-79.814	-80.639	-81.460	0.185	0.185	0.195	0.209
84	132REPPIWE	132MEKANISA	38.301	38.292	37.425	36.711	0.169	0.169	0.153	0.136
85	230AGARO	230GIMMA NEW	-23.905	-23.905	-23.903	-23.902	0.058	0.058	0.057	0.056
86	230AGARO	230BEDELE	21.380	21.380	21.378	21.377	0.160	0.160	0.158	0.157
87	230GG1	230GGNEW	128.975	128.976	128.980	128.979	0.067	0.067	0.065	0.065
88	230GGNEW	230WOLKITE	131.977	131.957	116.865	106.706	1.846	1.845	1.421	1.184
89	230ALAMATA	230MEHONI	16.504	16.504	16.510	16.543	0.027	0.027	0.032	0.044
90	132BLION	132REPPIWE	13.149	13.140	12.268	11.546	0.019	0.019	0.016	0.013
91	230GIMA NW	230GGNEW	-55.559	-55.559	-55.556	-55.554	0.475	0.475	0.466	0.458
92	230HOSSANA	230WOLKITE	-20.466	-20.466	-20.466	-20.466	0.083	0.083	0.080	0.078
93	230SEBETA2	230SEBETA1	207.208	207.185	204.720	202.678	0.580	0.580	0.549	0.525
94	230SEBETA1	230KALITI1	48.896	48.867	34.720	25.099	0.062	0.061	0.030	0.015
95	230SEBETA1	230TORHAYL	49.504	49.504	48.530	47.739	0.046	0.046	0.039	0.036
96	230GELAN	230KALITI1	207.126	207.167	227.145	240.541	0.450	0.450	0.502	0.535
97	230EIZONE	230GELAN	-80.295	-80.225	-79.785	-78.958	0.300	0.299	0.262	0.240
98	230MELK W	230KOKA	-16.739	-16.599	-15.914	-14.280	0.178	0.176	0.286	0.435
99	230KOKA	230ADAMAWF2	-87.638	-87.638	-87.684	-87.696	0.199	0.199	0.173	0.167
100	230ALAMATA	230WOLDIYA	37.134	37.126	35.480	35.179	0.201	0.201	0.166	0.153
101	230KOKA	230AWASH7K	73.239	73.239	73.315	73.407	1.312	1.312	1.282	1.259
102	230DDAWA-3	230AWASH7K	-50.607	-50.608	-50.752	-50.898	1.015	1.015	0.977	0.945
103	230DDAWA-3	230HURSO	-33.156	-33.155	-33.010	-32.864	0.076	0.076	0.074	0.072
104	230MEKELE	230ASHEGODWF	-20.350	-20.350	-20.321	-20.289	0.078	0.078	0.076	0.075
105	230KOKA	230HURSO	68.517	68.515	68.239	67.990	3.936	3.935	3.826	3.742
106	230HURSO	230ADIGALA	30.915	30.915	30.895	30.878	0.313	0.313	0.304	0.297
107	230ADIGALA	230DJBTBR	30.168	30.168	30.157	30.147	0.168	0.168	0.157	0.147
Total real power generation (MW)							**2576.76**	**2576.57**	**2563.87**	**2554.2**
Total reactive power generation (Mvar)							**31.043**	**29.867**	**-151.06**	**-305.4**
Total real power loss (MW)							**115.123**	**114.93**	**102.23**	**92.57**
Total reactive power loss (Mvar)							**-1284.8**	**-1286**	**-1468.9**	**-1629.8**

4.3.2 With SVCs

SVC is here needed from the above analysis, it was possible to control power flows in the lines by changing the reactance of the line, and lines were relieved from overloading by decreasing the loadability of the lines, simultaneously the losses of the lines and total system were also reduced using TCSCs but the improvement of voltage for some buses is out of the permissible ranges and also there is an impermissible voltage drop and high voltage at some buses in the system. Therefore, SVC is implemented according to the voltage performance indices of the buses for optimal placement of SVC in the system. For the SVCs the reactive power required at the bus to improve the base case bus voltage to the desired voltage with SVC is the change of voltage (ΔV), which is given as input to the controller, then the required reactive power (Q_{SVC}) is calculated first and then the firing angle will be calculated from the load flow solution with additional one extra iteration.

For improvement of system voltages, bus 132Adamitulu has the most negative deviation value of voltage less than the minimum emergency state of system operation condition 0.9 p.u. and bus 400Gendawa has the most positive deviation value greater than 1.1 p.u. these two buses are selected for SVC placement for voltage profile improvement of the whole system. Here an attempt has been made to find the reactive power requirement of the compensator for the desired voltage at the bus. Also, an attempt has been made to control the bus voltages of 132Adamitulu to 0.95 p.u. and 400Gendawa to 1.07 p.u. from the base case p.u voltages of 0.846 and 1.127 respectively by installing a single SVC one at a time.

When a capacitive SVC is installed in shunt at bus 132Adamitulu whose base case p.u voltage was 0.846 the desired voltage at the bus is 0.95 p.u. i.e., $\Delta V = 0.1036$ p.u. with this ΔV as input controller to the SVC determines the required Q_{SVC}, B_{SVC}, and firing angle of the SVC (α_{SVC}). The voltage of the bus is kept at 0.95 p.u. with 41.974 Mvar as desired and on many buses, voltages were also improved as shown in (Figure 4.5) giving comparative bus voltage records without and with the SVC at the bus. The reference voltage of SVC connected to the bus is maintained fixed by a PV generator programmed at 0.95 p.u. the total loss of the system is reduced to 113.78 MW from 115.123 MW. Maximum and minimum p.u. voltage records with the SVC are at bus 400Gendawa 1.1335 and 132Nazret-II 0.9073. The report of bus and line flows are shown in Appendix B.9 and B.10.

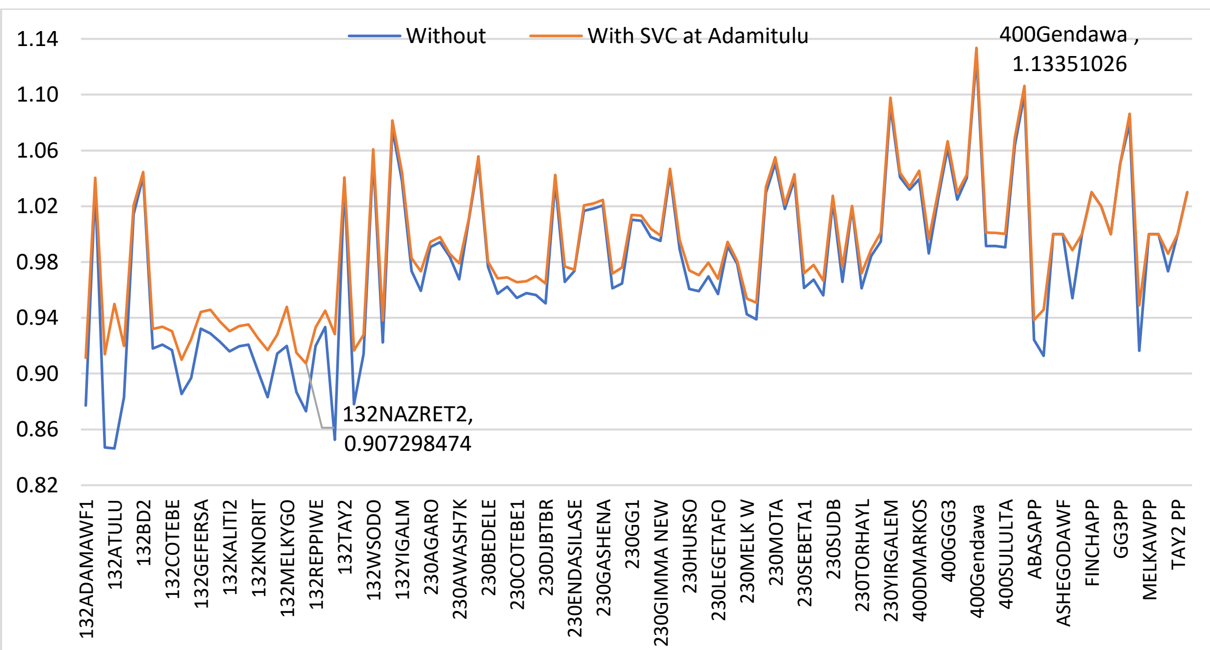

Figure 4. 5 Voltage profiles in p.u. without and with SVC at 132Adamitulu.

When an inductive SVC is connected in shunt at bus 400Gendawa whose base case p.u voltage was 1.127 the desired voltage at the bus is 1.07 p.u. i.e., ΔV = -0.05714 p.u. with this ΔV as input controller to the SVC to determine the required B_{SVC}, firing angle of the SVC (α_{SVC}), and Q_{SVC}. The voltage of the bus is kept at 1.07 p.u. with -85.36 Mvar as desired and many of the systems, bus voltages were decreased from the base case as shown in (Figure 4.6) giving comparative bus voltage records without and with the SVC at the bus. The reference voltage of SVC connected to the bus is maintained fixed by a PV generator programmed at 1.07 p.u. The total system loss is increased to 117.56 MW from 115.123 MW since the SVC consumes reactive power it results in increased reactive power generation which in turn results in overall system voltage reduction and increased total real power loss of the system. The minimum bus voltage record is 0.83 p.u. at 132Assela. The summary and values of parameters of the SVCs controllers used in single cases are given together with two SVCs in Table 4.3. The report of bus and line flows are shown in Appendix B.11 and B.12.

When the two SVCs in single cases are used together to control their respective buses for the same desired voltage. The reactive power support and expend at 132Addamitulu and 400Gendawa is 48.83 and -97.244 Mvar respectively, which are greater than independently controlling the buses. Minimum voltage is 0.8935 p.u. at 132Nazret-2 bus. The overall system voltage is improved from the base case and it was also possible to enhance voltage levels between the limits using only two SVCs as shown in Figure 4.7. The total real power loss is increased to 116.39 MW from 115.123 MWs. The report of bus and line flows are shown in Appendix B.13 and B.14.

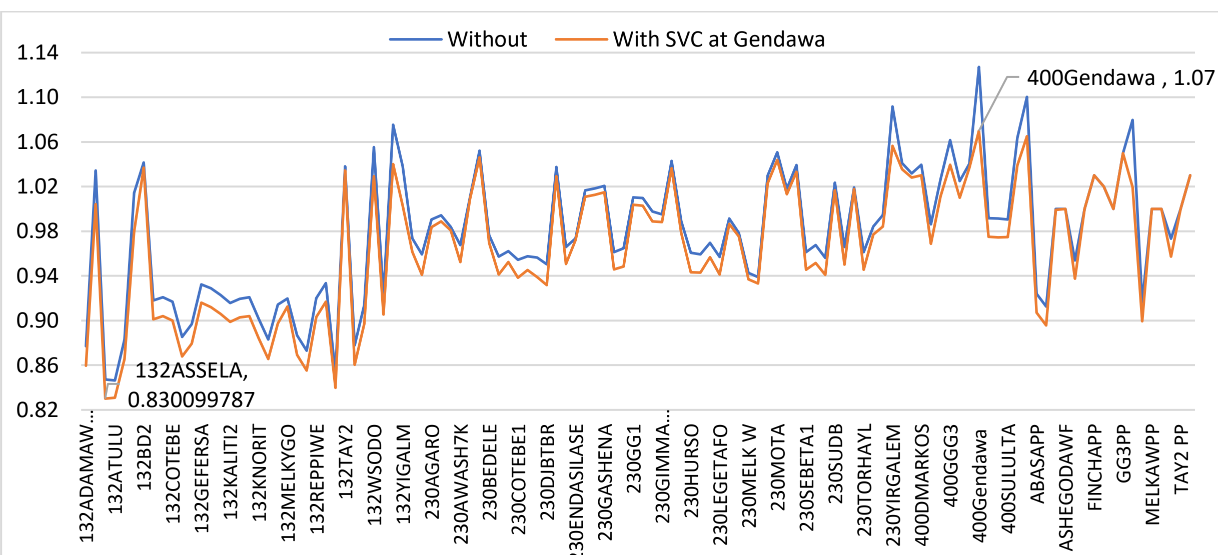

Figure 4. 6 Voltage profiles in p.u. without and with SVC at 400Gendawa.

The parameters of the SVCs controllers used in one and two at a time are given in Table 4.3 for both variable susceptance model and firing angle model to meet the desired voltages at the buses.

Table 4. 3 Parameter values of the SVCs controllers with one and with two SVCs.

No of SVC	One		Two (Both)	
Name of SVC	SVC-1	SVC-2	SVC-1	SVC-2
Bus Name	132Adamtulu	400Gendawa	132Adamtulu	400Gendawa
b_Svc (p.u)	0.46508	-0.7456	0.54105	-0.84837
q _Svc (p.u)	0.41974	-0.8536	0.4883	-0.97244
alpha_Svc (rad)	0.6185	-0.7313	0.6524	-0.76648
Vbus_Svc (p.u)	0.95	1.07	0.95	1.07
Vmin (p.u)	0.9073	0.830	0.8935	
Vmax (p.u)	1.1335	1.07	1.07	
Total loss without (MW).	115.123			
Total loss with (MW)	113.78	117.56	116.39	

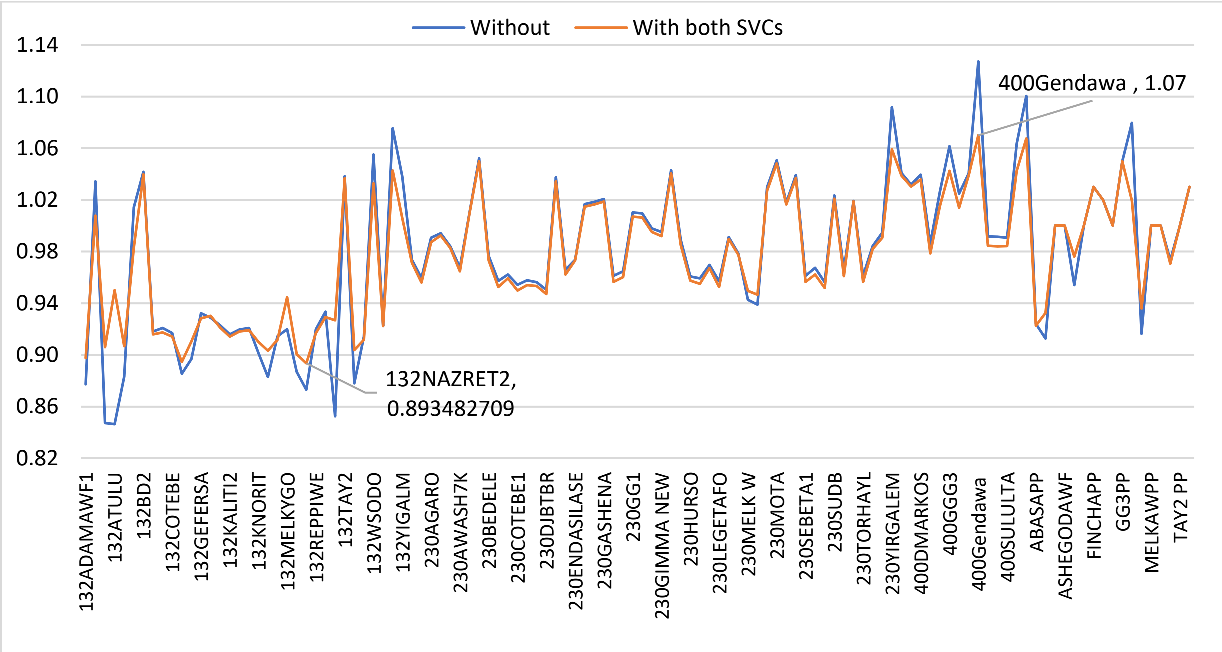

Figure 4. 7 Voltage profiles in p.u. without and with two SVCs.

4.3.3 With TCSCs and SVCs

Now both the two TCSCs and the two SVCs in the previous case studies are considered as final study in the presence of different type FACTS to assess the performance enhancement of the system when the controllers are used together.

TCSCs devices have been installed in line 42 (TCSC-1) and line 17 (TCSC-2) and SVCs in buses 132Adamitulu (SVC-1) and 400Gendawa (SVC-2) simultaneously. The line flows in lines 42 and 17 are desired to 70 and 825 from 57.72 and 617.96 all in MW respectively. The two SVCs are required to maintain their respective bus voltages at 0.95 and 1.07 p.u. With TCSC-1 controlling lines 42 and 41, real power flow in line 42 is increased by 20.9%, and that of 41 decreased by 9.2%. With TCSC-2 in line 17 real power flow increases by 33.4%. The total system real power loss decreased to 94.056 from 115.123 in MW. It can be seen from Figure 4.8 that voltage profiles were improved and maintained with in maximum and minimum ranges of 0.9242 p.u. and 1.0722 p.u. Many lines were relived from congestion and the maximum line loading 91.61% is decreased to 81.47%. The report of bus and line flows are shown in Appendix B.15 and B.16.

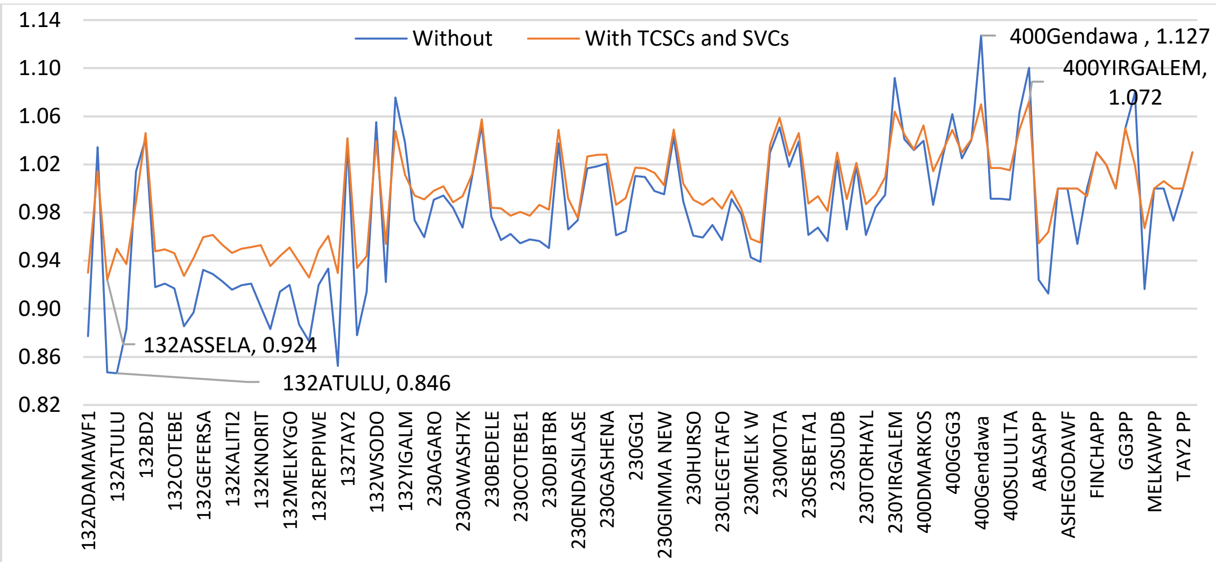

Figure 4. 8 Voltage profiles in p.u. without and with TCSCs and SVCs.

The summary of power flow results and parameters of the controllers are given for both variable susceptance and firing angle models to meet the desired line flows and voltages at the buses are given in Table 4.4.

Table 4. 4 Summary of the FACTS controller's parameter and controlled state variables with TCSCs and SVCs.

FACT	**Parameter**	**TCSC-1**	**TCSC-2**
		Line 42	Line 17
TCSC	$X_{TCSC}(p.u)$	0.03623	0.02592
	$\alpha_{TCSC}(p.u)$	0.92015	0.92015
	Power flow without (MW)	57.71	617.96
	Specified Power flow with (MW)	69.774	825.52
	Compensation %	67	60
SVC	Bus	**SVC-1**	**SVC-2**
		Adamitulu	Gendawa
	b_Svc (p.u)	0.3671	-1.0458
	q _Svc (p.u)	0.3313	-1.1974
	alpha_Svc (rad)	0.5694	-0.8268
Min/Max voltage without FACTS (p.u)		0.846------1.127	
Min/Max voltage with FACTS (p.u)		0.9242------1.0722	
Total real power generation without (MW)		2576.76	
Total real power generation with (MW)		2555.69	
Real power loss saved (MW)		21.067 (18.3%)	
Total reactive power generation without (Mvar)		31.043	

Total reactive power generation with (Mvar)	-159.2
Reactive power change due to FACTS (Mvar)	190.24
Total power flow performance without	2.5845
Total power flow performance with FACTS	2.3637

4.4. Analysis of results

In order to assess the impacts of the TCSCs and the SVCs on system performance improvement, it is necessary to show comparative result analysis of the simulation studies without and with TCSCs, with SVCs, with both TCSCs and SVCs and with each other. The performance of the uncompensated transmission network is enhanced with two TCSCs and two SVCs through sensitivity based optimal placement of the devices. The enhancement is evaluated concerning voltage regulation, reduction of real power loss, reduction of transmission line loading level, with the FACTS setting required in order to attain the desired new performance level.

4.4.1 Analysis of power flow bus results

Power flow bus data records: voltage profiles and power record details of the base case and with FACTS devices are summarized in Table 4.5. Voltage profiles of the uncompensated transmission network maximum and minimum records 1.127 and 0.846 are improved to 1.145 and 0.897, 1.072 and 0.894 and 1.07 and 0.924 all in p.u. with two TCSCs, with two SVCs and with combined TCSCs and SVCs respectively. The voltage magnitude profiles are graphically represented in Figure 4.9 voltage records shown by back color were better enhanced and maintained within voltage regulation ranges of maximum (+7.2%) and minimum (-7.5%) with the combined TCSCs and SVCs.

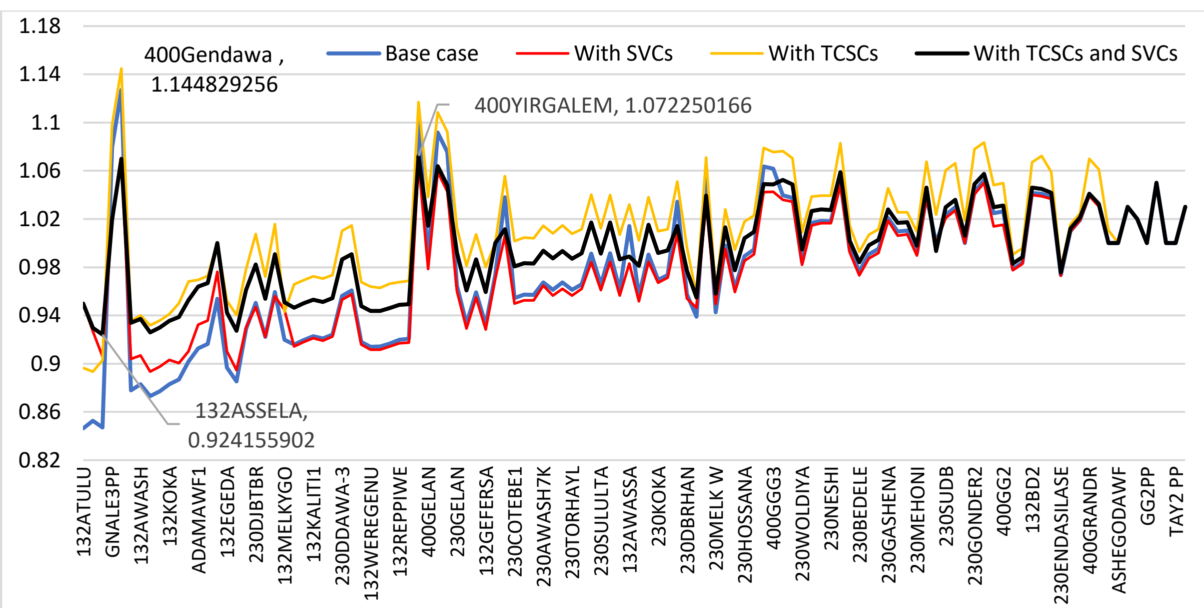

Figure 4. 9 Bus voltage records of the system in different scenarios.

Table 4. 5 Voltage profiles in p.u. and power details without and with FACTS devices.

Bus Name	Voltage profile in different scenarios in p.u.				P load	Q load
	Base case	With TCSCs	With SVCs	With TCSCs and SVCs	[MW]	[Mvar]
132ADAMAWF1	0.877	0.936	0.898	0.930	0.000	0.000
132ALABA	1.034	1.051	1.008	1.014	6.615	3.202
132ASSELA	0.847	0.903	0.906	**0.924**	**29.230**	**12.258**
132ATULU	**0.846**	**0.897**	**0.95**	**0.950**	**4.973**	**2.408**
132AWASH	0.883	0.940	0.907	0.937	24.000	11.600
132AWASSA	1.014	1.032	0.983	0.989	40.140	17.963
132BD2	1.042	1.067	1.040	1.046	0.000	0.000
132BLEMIMB	0.918	0.968	0.916	0.948	3.514	0.527
132BLION	0.921	0.969	0.917	0.949	24.542	18.694
132COTEBE	0.917	0.966	0.914	0.946	84.677	39.173
132DZEIT	0.885	0.940	0.895	0.927	55.732	26.979
132EGEDA	0.897	0.952	0.910	0.942	7.854	3.805
132GEFERSA	0.932	0.980	0.928	0.959	212.428	99.518
132GELAN	**0.929**	**0.979**	**0.930**	**0.961**	**28.323**	**13.717**
132KALITI1	0.923	0.972	0.921	0.953	89.931	40.453
132KALITI2	0.916	0.966	0.914	0.946	73.534	27.876
132KALITIGS	0.920	0.969	0.918	0.950	4.134	2.001
132KALITINEW	0.921	0.971	0.919	0.951	36.396	17.915
132KNORIT	**0.902**	**0.968**	**0.910**	**0.953**	**8.269**	**4.002**
132KOKA	0.883	0.941	0.903	0.935	8.800	4.200
132MEKANISA	0.914	0.963	0.912	0.944	54.782	19.801
132MELKYGO	0.920	0.943	0.945	0.951	20.860	8.331
132MOJO	0.887	0.950	0.900	0.939	28.486	13.790
132NAZRET2	0.873	0.932	**0.893**	0.926	56.965	27.550
132REPPIWE	0.920	0.968	0.917	0.949	0.000	0.000
132SEBETA1	0.933	0.981	0.929	0.961	154.137	52.471
132SHSMNE	0.853	**0.893**	0.927	0.930	20.848	8.752
132TAY2	1.038	1.059	1.037	1.042	0.000	0.000
132WENJI	0.878	0.936	0.904	0.934	5.977	2.893
132WEREGENU	0.914	0.964	0.912	0.944	54.521	26.400
132WSODO	1.055	1.071	1.033	1.039	29.316	15.909
132YESU	0.922	0.972	0.922	0.954	32.328	15.640
132YIGALEM2	1.075	1.092	1.043	1.048	28.571	13.634
132YIGALM	1.038	1.055	1.006	1.011	17.380	6.133
230ADAMAWF2	0.974	1.011	0.971	0.994	0.000	0.000
230ADIGALA	0.959	1.016	0.956	0.991	0.434	-0.889
230AGARO	0.991	1.007	0.987	0.998	2.525	1.256
230ALAMATA	0.994	1.015	0.992	1.002	24.314	11.787
230ASHEGODAWF	0.984	0.996	0.983	0.988	0.000	0.000
230AWASH7K	0.968	1.014	0.965	0.994	20.304	8.507
230AXUM	1.010	1.015	1.010	1.012	3.772	1.792
230BDAR2	1.052	1.084	1.050	1.057	44.591	21.496
230BEDELE	0.977	0.993	0.973	0.984	21.219	28.046
230BOLEARABSA	0.957	1.004	0.953	0.983	3.080	1.500
230COMBOLCHA	0.962	0.995	0.959	0.977	63.064	24.389
230COTEBE1	0.954	1.002	0.950	0.981	0.000	0.000
230DBRHAN	0.958	0.997	0.954	0.977	35.523	15.540
230DDAWA-3	0.956	1.010	0.953	0.986	83.762	35.610
230DJBTBR	0.950	1.008	0.947	0.982	30.000	14.500
230DM	1.037	1.070	1.034	1.049	35.562	15.446
230EIZONE	0.966	1.012	0.962	0.992	23.297	1.128
230ENDASILASE	0.974	0.979	0.973	0.976	21.890	43.702
230FINCA2	1.017	1.039	1.015	1.027	4.796	2.320
230FINCHA	1.018	1.039	1.017	1.028	7.488	3.625
230GASHENA	1.021	1.045	1.019	1.028	4.238	0.223
230GEFERSA	0.961	1.007	0.957	0.986	0.000	0.000
230GELAN	0.965	1.013	0.960	0.992	0.000	0.000
230GG1	1.010	1.026	1.007	1.017	0.000	0.000

230GGNEW	1.010	1.025	1.006	1.017	6.876	2.415
230GHEDO	0.998	1.028	0.995	1.013	54.536	17.017
230GIMMA NEW	0.995	1.011	0.992	1.003	31.596	14.844
230GONDER2	1.043	1.078	1.041	1.049	23.690	10.894
230HOSSANA	0.989	1.018	0.985	1.004	20.466	10.859
230HURSO	0.961	1.015	0.958	0.991	0.434	0.210
230KALITI1	0.959	1.007	0.955	0.986	0.000	0.000
230KOKA	0.970	1.010	0.967	0.992	53.485	42.194
230LEGETAFO	0.957	1.004	0.952	0.983	46.674	22.630
230MEHONI	0.991	1.009	0.990	0.998	4.124	1.623
230MEKELE	0.979	0.991	0.978	0.983	175.209	82.943
230MELK W	0.943	0.960	0.950	0.958	0.000	15.436
230MELKYGO	0.939	0.957	0.947	0.955	0.000	61.259
230METEMA	1.030	1.066	1.027	1.036	1.967	0.952
230MOTA	1.051	1.083	1.048	1.059	2.499	1.210
230NESHI	1.018	1.039	1.016	1.028	0.000	0.000
230NIFASMW	1.039	1.067	1.037	1.046	4.626	0.500
230SEBETA1	0.961	1.008	0.957	0.987	0.000	0.000
230SEBETA2	0.967	1.015	0.962	0.993	49.549	24.258
230SINOSTILL	0.956	1.002	0.952	0.981	20.855	9.931
230SUDB	1.023	1.060	1.021	1.030	185.000	0.000
230SULULTA	0.966	1.012	0.961	0.991	49.627	18.961
230TEKEZE	1.019	1.025	1.019	1.021	2.329	1.175
230TORHAYL	0.961	1.008	0.957	0.987	5.426	0.123
230WOLDIYA	0.984	1.009	0.982	0.995	9.240	4.472
230WOLKITE	0.995	1.023	0.991	1.009	20.330	9.840
230YIRGALEM	1.092	**1.108**	1.059	1.064	0.000	0.000
400BDAR	1.041	1.072	1.039	1.045	0.000	0.000
400BELES	1.032	1.061	1.030	1.032	0.000	55.488
400DMARKOS	1.040	1.076	1.036	1.052	0.000	0.000
400GELAN	**0.986**	**1.038**	**0.979**	**1.014**	**0.000**	**13.852**
400GG2	1.026	1.050	1.015	1.031	0.000	0.000
400GGG3	1.062	1.076	1.043	1.049	0.000	0.000
400GGNEW	1.025	1.048	1.014	1.030	0.000	18.245
400GRANDR	1.040	1.070	1.039	1.041	15.979	57.494
400GENDAWA	**1.127**	**1.145**	**1.070**	**1.070**	**0.000**	**0.000**
400HOLETA	0.992	1.040	0.985	1.017	0.000	0.000
400SEBETA2	0.991	1.040	0.984	1.017	0.000	-88.457
400SULULTA	0.991	1.038	0.984	1.015	0.000	0.000
400WSODO	**1.064**	**1.079**	**1.042**	**1.049**	**0.000**	**117.900**
400YIRGALEM	**1.100**	**1.117**	**1.068**	**1.072**	**0**	**0**
ABASAPP	0.924	0.974	0.922	0.954	0	0
ADAMAWF1	0.913	0.970	0.932	0.964	0	0
ADAMAWF2	1	1.011	1	1	0	0
ASHEGODAWF	1	1	1	1	0	0
AWASHPP	0.954	1	0.976	1	0	0
BELESPP	1	1.024	1	0.994	0	0
FINCHAPP	1.03	1.03	1.03	1.03	0	0
GG1PP	1.02	1.02	1.02	1.02	0	0
GG2PP	1	1	1	1	0	0
GG3PP	1.05	1.05	1.05	1.05	0	0
GNALE3PP	1.080	1.098	1.019	1.019	0	0
KOKAPP	0.916	0.973	0.936	0.967	0	0
MELKAWPP	1	1	1	1	0	0
NESHIPP	1	1.019	1	1.006	0	0
REPPIWEPP	0.973	1	0.971	1	0	0
TAY2 PP	1	1	1	1	0	0
TEKEZEPP	1.03	1.03	1.03	1.03	0	0
P gen [MW]	2576.759	2554.207	2578.022	2555.693	The loads shown above are for base case only, fixed passive shunts	
Q gen [Mvar]	31.043	-305.408	96.954	-159.197		
P load [MW]	2461.636	2461.636	2461.636	2461.636		
Q load [Mvar]	1315.834	1324.394	1312.585	1312.886		

P loss [MW]	115.123	92.571	116.386	94.056	change depending on system voltage.
Q loss [Mvar]	-1284.79	-1629.802	-1215.631	-1472.082	
Change P gen [MW]	-	-22.552	1.263	-21.067	
Change Q gen [Mvar]	-	-336.451	65.911	-190.240	
% Reduction in P loss	-	19.59	-1.1	18.30	

Total Real Power Generation and Loss

The total real power generation in MW for the system with TCSCs, with SVCs and with combined TCSCs and SVCs are 2554.2, 2578.02 and 2555.69 respectively, while the real power losses are reduced by 22.55 (19.59%), increased by 1.263 (1.1%) and reduced by 21.067 (18.3%) all in MWs and in percentages respectively. Total loss of the system with combined FACTS (TCSCs and SVCs) is increased from with only TCSCs for the reason that inductive SVC (reactive power sink) is used in the process for restoring the furtherly increasing maximum voltage profile due to reduction of system reactance by the capacitive TCSCs employed as a result reactive power flows and loss of the system are increased. Figure 4.10 shows the summary of power flow results of total real power generation and loss records with the FACTS.

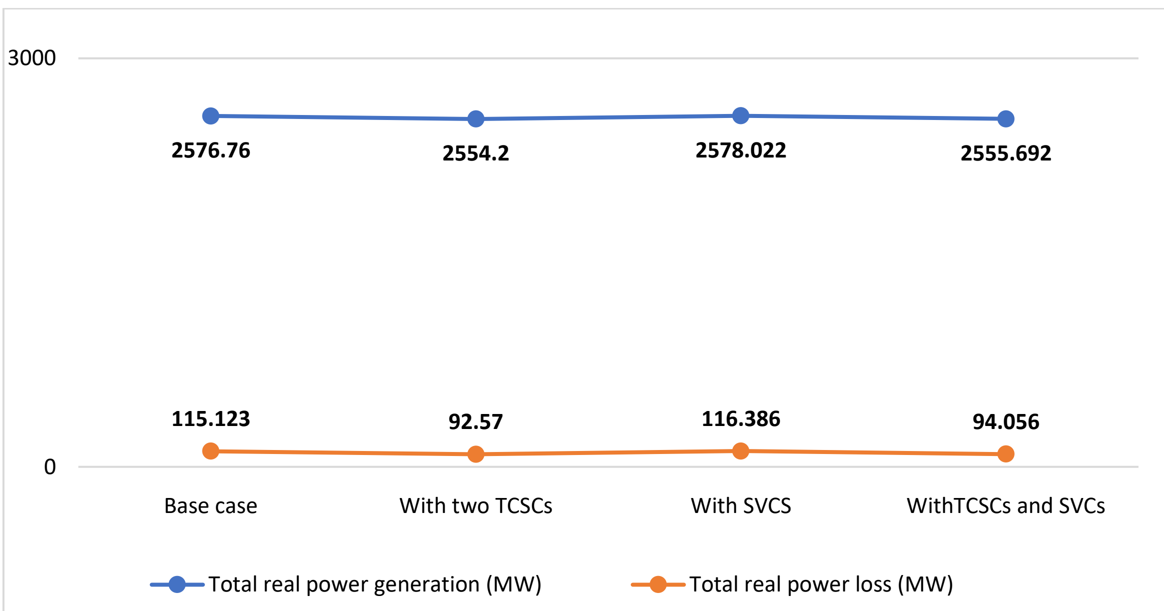

Figure 4. 10 Total real power generation and total real power loss with the FACTS.

Total Reactive Power Generation and Loss

The total reactive power generation in Mvar for the system with TCSCs, with SVCs, and with combined TCSCs and SVCs decreased by 336.44, increased by 65.91, and decreased by 190.24 respectively from the base case reactive power generation which stood at 31.043 Mvar. Similarly, the reactive power losses are decreased by 26.85%, increased by 5.38%, and decreased by 14.58% with the FACTS respectively. Reactive generation and losses are a little bit more for the system with combined FACTS than with TCSCs due to increased reactive power requirement by the inductive SVC at 400Gendawa bus to overcome the over-voltage problem. These comparisons are shown blow in Figure 4.11.

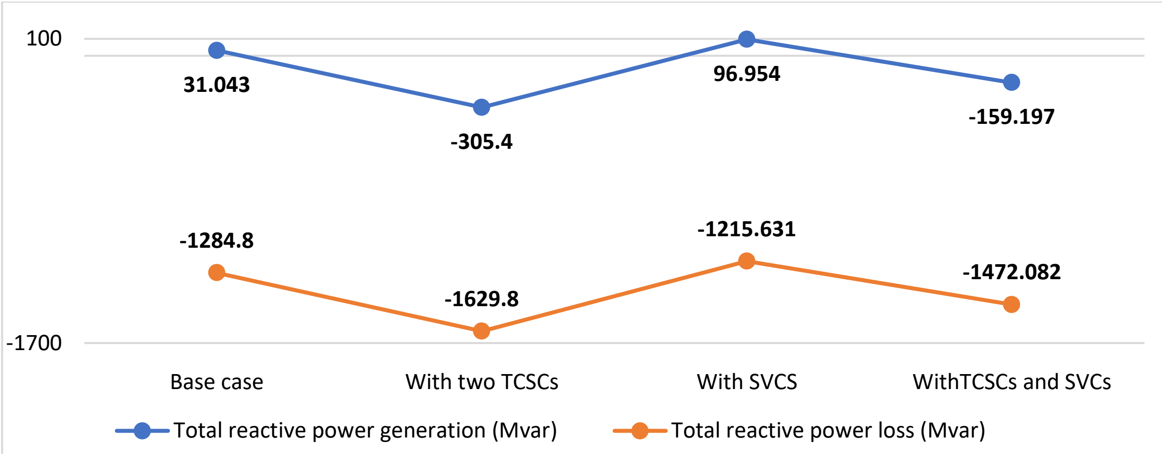

Figure 4. 11 Total reactive power generation and loss.

4.4.2 Analysis of branch power flow results

Summary of branch power flow records: MVA power flow, loading percentage, real power loss and lines power flow performance indices of the base case and with the FACTS devices are given in Table 4.6. Based on the single line model of the transmission network, the effects of the FACTS are seen on the nearby lines that are directly connected to the affected lines. From the table the first 21 lines shown in bold text are selected to show performance enhancement of the system with the FACTS.

Power Flow (S_{ft}) and changes of each line

Figure 4.12 Shows the comparison of MVA power flows and percentage changes without and with FACTS over the 400, 230 and 132 kV transmission lines affected (17, 42, 35, 36, 20 and 22) and directly connected to the affected lines.

The power flows of lines 17 and 42 are increased by 32.31% (208.523 MVA) and 18.18% (10.81MVA) by the series capacitive TCSCs having rated values of 60% and 67% of the lines inductances respectively. Similarly, the flows of lines 35 and 36 are increased by 322% (10.31 MVA) and 849% (19.67 MVA) respectively due to capacitive SVC injection of 33.13 Mvar at 132 kV Adamitulu bus. While, flows of lines 20 and 22 are reduced by 45.2% (145.1 MVA) and 35.7% (135.3 MVA) respectively due to removal of 119.74 Mvar reactive power from 400 kV Gendawa bus by inductive SVC. As a result, power flows are redirected from lower capacity lines 18 and 41 to higher capacity lines 17 and 42 respectively.

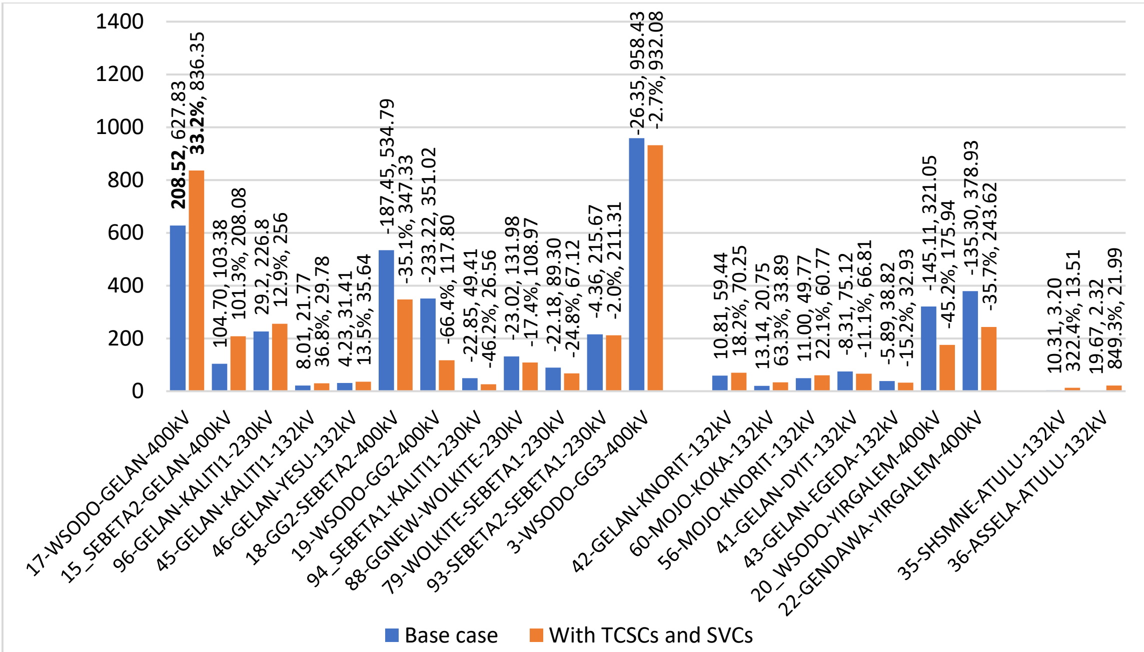

Figure 4. 12 Power flow changes of the affected and directly connected lines.

Figure 4.13 shows the power flow changes in MVA of other lines that are indirectly affected by the changes in the affected line power flows. Power flows in most of the system lines is decreased but there is negligible increase in some lines from the base case as shown in figure 4.13.

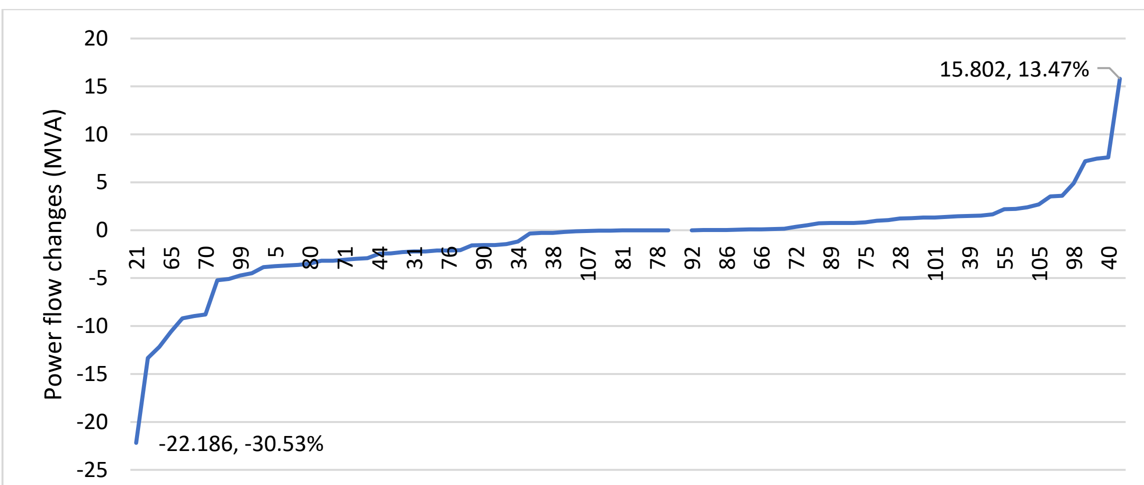

Figure 4. 13 Power flow changes of other lines.

Real Power Loss and changes of each line

The real power loss of affected lines 17 and 42 decreased by 32.6% (7.041 MW) and 58.7% (0.7029 MW) from the base case 21.61 MW and 1.242 MW respectively. While losses are increased by 0.174 and 0.398 MWs at lines 35 and 36 respectively due to increased reactive power flows by the capacitive TCSC. Losses in many lines are reduced, due to the reduction of line 17 loss as this line is the principal path of power delivery from the major power sources to the biggest demand center of Addis Ababa. Total transmission lines losses are reduced by 17.9% (20.61 MW), transformer losses are reduced by 0.395% (0.455MW), and the total real power losses are reduced by 18.3% (21.067MW) from 115.123 MW. Figures 4.14 and 4.15 show the improvement of line losses with the FACTS. The overall system real power losses account 4.47% and 3.68% of the EEP's total generation capacity 2576.8 MW at the base case and with the FACTS respectively. Hence the overall EEP transmission system efficiency is enhanced to 96.32% from 95.53%.

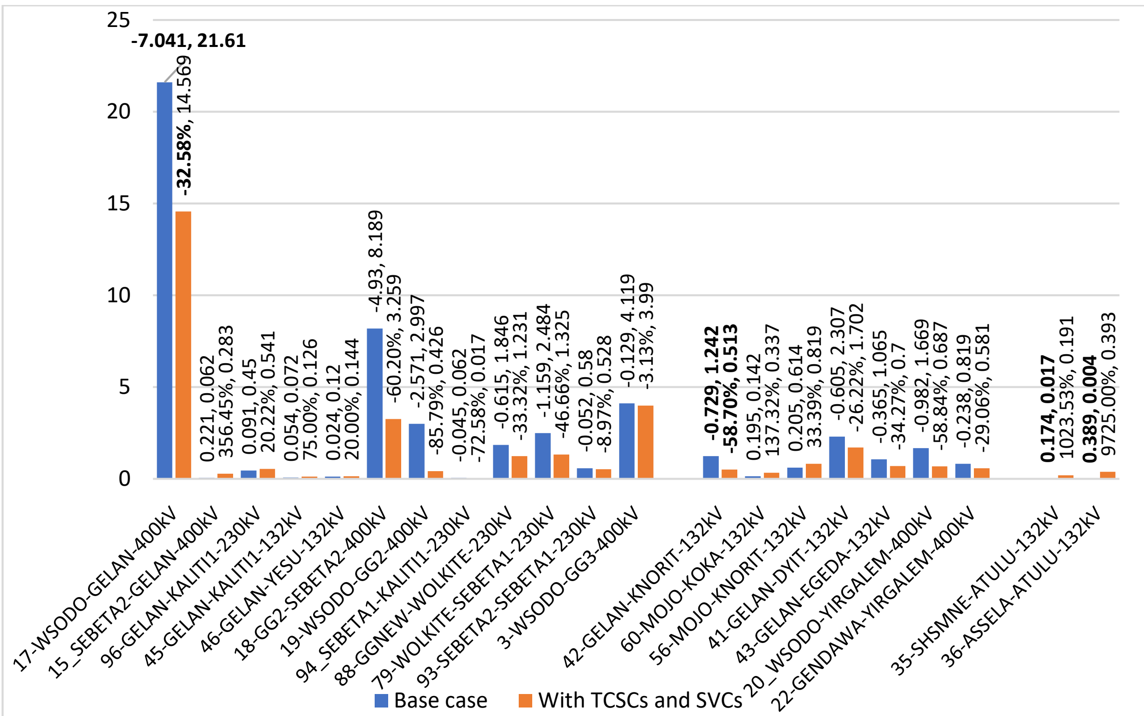

Figure 4. 14 Real power loss changes of the affected and directly connected lines.

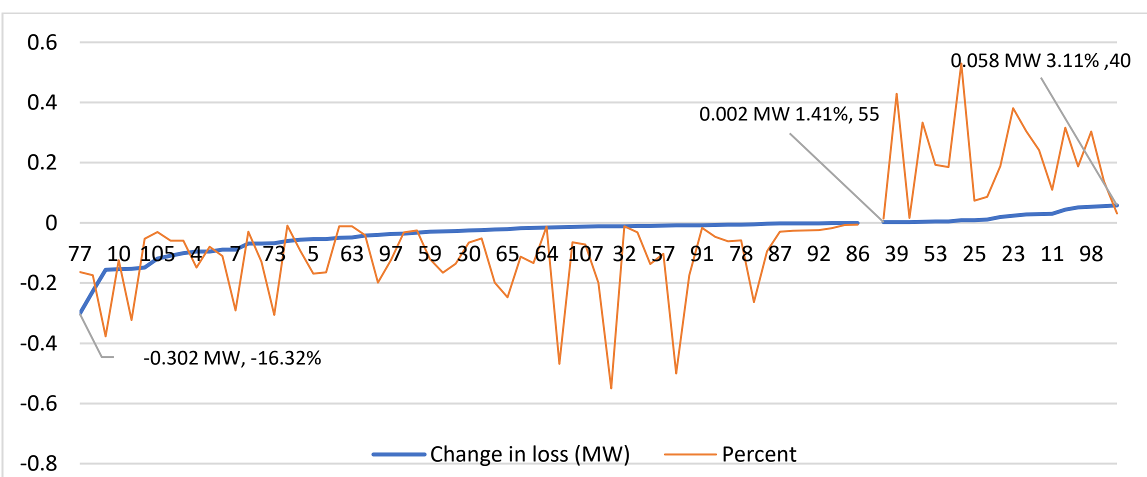

Figure 4. 15 Real power loss changes of other lines.

Loading and Performance changes of each line

Figure 4.16 shows percentage loadings and power flow performance changes of the affected and directly connected lines from the base by the FACTS. The most loaded line 41 has a 91.61% loading (0.7043 performance index) in the base state which, decreases to 81.47% loading (0.4405) in exchange for increments of lines 17 to 10.57% loading (0.0323) and 42 to 9.39% loading (0.1392), the loading changes of many lines of the system are reduced from the base case shown in Table 4.6.

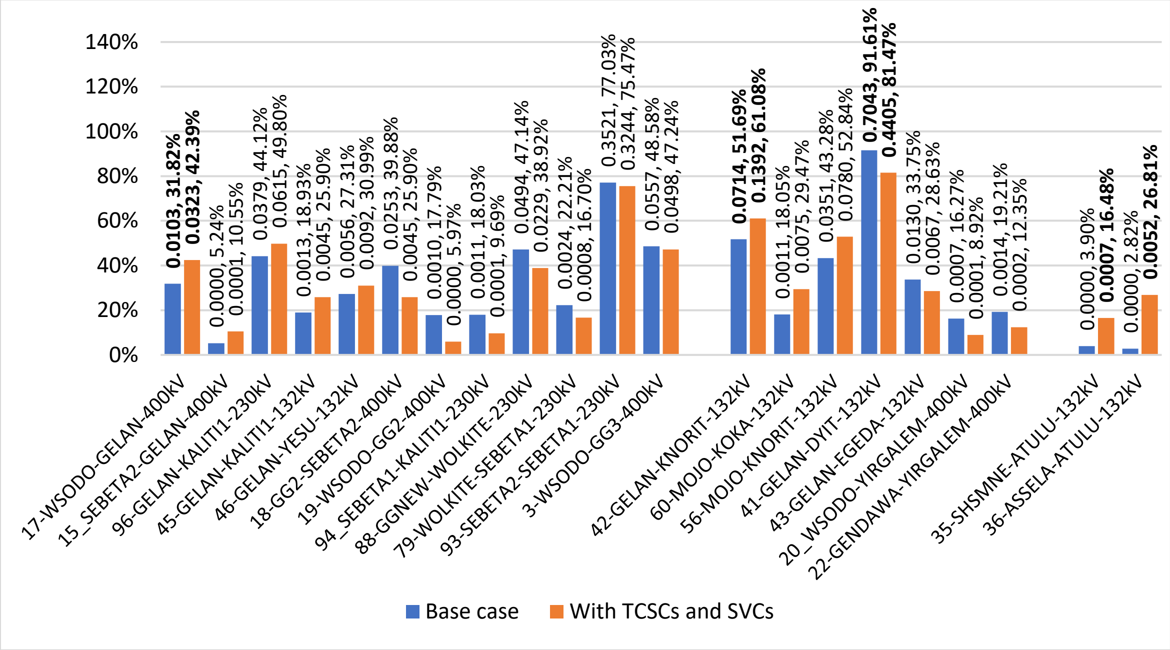

Figure 4. 16 The loading and performance changes of the affected and directly connected lines.

The power flow performance index values of lines at the base case and after placing TCSCs in lines 17 and 42 and SVCs at the two buses Gendawa and Adamitulu is shown in Figure 4.17. The most congested line 41 having a 0.7043 performance index in the base state, decreased by 0.2638 (51.87%) in exchange to increment of lines 17 by 0.02204 (64.9%) and 42 by 0.0678 (42.8%) with the FACTS. As result, the total system power flow performance index is reduced by 0.221 (8.8%) from base case 2.584 to 2.367.

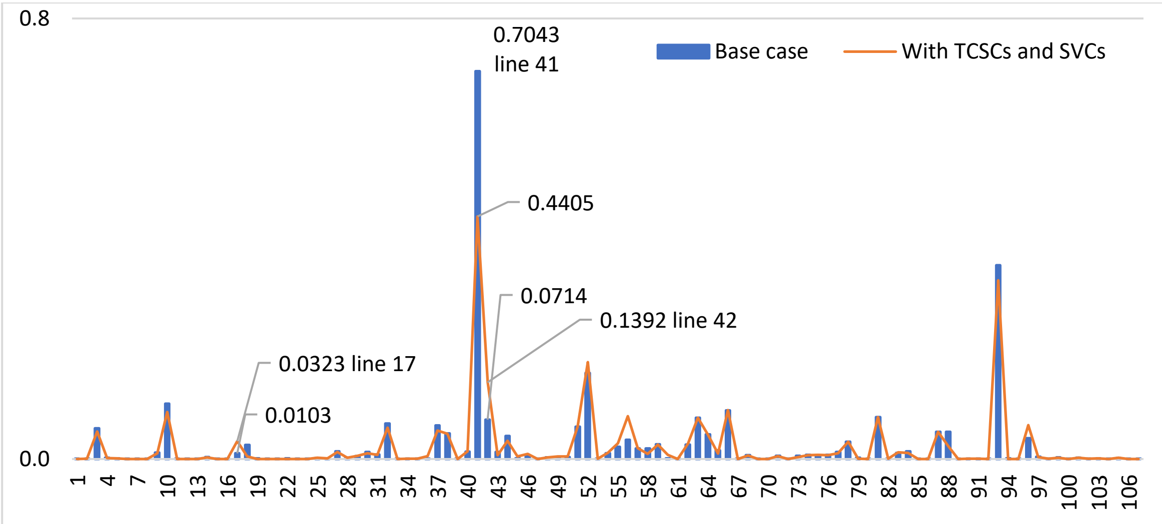

Figure 4. 17 Lines power flow performance index at the base case and with FACTS.

Table 4. 6 Branch records of power flow, real power loss, percentage of loading, and power flow Performance index with FACTS.

Line	From	To	Line MVA	Line Flow (MVA)		Loading in % MVA		Line power flow Performance index		Line loss (MW)	
				Base case	With FACTS	Base case	With FACTS	Base case	With FACTS	Base case	With FACTS
3	**400WSODO**	**400GGG3**	**1973**	**958.425**	**932.075**	**48.58**	**47.24**	**0.0557**	**0.0498**	**4.119**	**3.99**
15	**400GELAN**	**400SEBETA2**	**1973**	**103.383**	**208.081**	**5.24**	**10.55**	**0**	**0.0001**	**0.062**	**0.283**
17	**400GELAN**	**400WSODO**	**1973**	**627.829**	**836.352**	**31.82**	**42.39**	**0.0103**	**0.0323**	**21.61**	**14.569**
18	**400SEBETA2**	**400GG2**	**1341**	**534.785**	**347.333**	**39.88**	**25.9**	**0.0253**	**0.0045**	**8.189**	**3.259**
19	**400WSODO**	**400GG2**	**1973**	**351.018**	**117.797**	**17.79**	**5.97**	**0.001**	**0**	**2.997**	**0.426**
20	**400YIRGALEM**	**400WSODO**	**1973**	**321.053**	**175.942**	**16.27**	**8.92**	**0.0007**	**0.0001**	**1.669**	**0.687**
22	**400YIRGALEM**	**400GENDAWA**	**1973**	**378.927**	**243.624**	**19.21**	**12.35**	**0.0014**	**0.0002**	**0.819**	**0.581**
35	**132SHSMNE**	**132ATULU**	**82**	**3.199**	**13.511**	**3.9**	**16.48**	**0**	**0.0007**	**0.017**	**0.191**
36	**132ASSELA**	**132ATULU**	**82**	**2.316**	**21.985**	**2.82**	**26.81**	**0**	**0.0052**	**0.004**	**0.393**
41	**132GELAN**	**132DZEIT**	**82**	**75.119**	**66.806**	**91.61**	**81.47**	**0.7043**	**0.4405**	**2.307**	**1.702**
42	**132KNORIT**	**132GELAN**	**115**	**59.438**	**70.246**	**51.69**	**61.08**	**0.0714**	**0.1392**	**1.242**	**0.513**
43	**132EGEDA**	**132GELAN**	**115**	**38.815**	**32.93**	**33.75**	**28.63**	**0.013**	**0.0067**	**1.065**	**0.7**
45	**132GELAN**	**132KALITI1**	**115**	**21.77**	**29.784**	**18.93**	**25.9**	**0.0013**	**0.0045**	**0.072**	**0.126**
46	**132GELAN**	**132YESU**	**115**	**31.408**	**35.642**	**27.31**	**30.99**	**0.0056**	**0.0092**	**0.12**	**0.144**
56	**132MOJO**	**132KNORIT**	**115**	**49.768**	**60.771**	**43.28**	**52.84**	**0.0351**	**0.078**	**0.614**	**0.819**
60	**132MOJO**	**132KOKA**	**115**	**20.752**	**33.89**	**18.05**	**29.47**	**0.0011**	**0.0075**	**0.142**	**0.337**
79	**230WOLKITE**	**230SEBETA1**	**402**	**89.296**	**67.118**	**22.21**	**16.7**	**0.0024**	**0.0008**	**2.484**	**1.325**
88	**230GGNEW**	**230WOLKITE**	**280**	**131.982**	**108.965**	**47.14**	**38.92**	**0.0494**	**0.0229**	**1.846**	**1.231**
93	**230SEBETA2**	**230SEBETA1**	**280**	**215.67**	**211.309**	**77.03**	**75.47**	**0.3521**	**0.3244**	**0.58**	**0.528**
94	**230SEBETA1**	**230KALITI1**	**274**	**49.413**	**26.562**	**18.03**	**9.69**	**0.0011**	**0.0001**	**0.062**	**0.017**
96	**230GELAN**	**230KALITI1**	**514**	**226.8**	**256**	**44.12**	**49.8**	**0.0379**	**0.0615**	**0.45**	**0.541**
1	230AXUM	230TEKEZE	318	30.914	30.92	9.72	9.72	0.0001	0.0001	0.144	0.143
2	400SULULTA	400HOLETA	1973	295.053	282.878	14.95	14.34	0.0005	0.0004	0.534	0.465
4	230KOKA	230GELAN	331	72.316	68.687	21.85	20.75	0.0023	0.0019	0.638	0.543
5	230KOKA	230EIZONE	331	61.394	57.634	18.55	17.41	0.0012	0.0009	0.321	0.267
6	230LEGETAFO	230BOLEARBSA	402	37.64	45.094	9.36	11.22	0.0001	0.0002	0.012	0.016
7	230WOLDIYA	230COMBLCHA	318	31.396	26.922	9.87	8.47	0.0001	0.0001	0.306	0.217
8	230KALITI1	230BOLEARBS	402	41.573	48.764	10.34	12.13	0.0001	0.0002	0.139	0.183
9	230COTEBE1	230LEGETAFO	402	131.487	127.626	32.71	31.75	0.0114	0.0102	0.16	0.142
10	230SULULTA	230LEGETAFO	402	226.351	217.406	56.31	54.08	0.1005	0.0855	1.246	1.092
11	400BDAR	400DMARKOS	1341	117.302	133.104	8.75	9.93	0.0001	0.0001	0.274	0.304
12	400DMARKOS	400SULULTA	1341	71.087	61.893	5.3	4.62	0	0	0.474	0.321
13	230MOTA	230BDAR2	280	19.69	17.617	7.03	6.29	0	0	0.032	0.029
14	400HOLETA	400SEBETA2	1205	296.59	283.251	24.61	23.51	0.0037	0.0031	0.127	0.11
16	230MEHONI	230MEKELE	402	14.528	16.748	3.61	4.17	0	0	0.092	0.12

21	400GGNEW	400GG2	1341	72.663	50.477	5.42	3.76	0	0	0.02	0.009
23	230ALAMATA	230ASHEGDWF	402	12.39	12.342	3.08	3.07	0	0	0.063	0.087
24	400GRANDR	400BELES	543	59.674	59.74	10.99	11	0.0001	0.0001	0.029	0.029
25	132BD2	132TAY2	91	18.869	19.625	20.74	21.57	0.0019	0.0022	0.122	0.131
26	132KOKA	132DZEIT	82	14.01	14.085	17.08	17.18	0.0009	0.0009	0.151	0.144
27	230BDAR2	230NIFASMW	318	108.971	106.861	34.27	33.6	0.0138	0.0127	2.805	2.656
28	132AWASSA	132ALABA	82	16.757	17.969	20.44	21.91	0.0017	0.0023	0.272	0.323
29	132WSODO	132ALABA	89	23.696	24.762	26.62	27.82	0.005	0.006	0.406	0.462
30	132YIGALM	132AWASSA	82	27.587	26.05	33.64	31.77	0.0128	0.0102	0.383	0.358
31	230GASHENA	230NIFASMW	318	96.268	94.046	30.27	29.57	0.0084	0.0076	1.832	1.723
32	132YIGALM	132YIGALEM2	91	45.864	44.401	50.4	48.79	0.0645	0.0567	0.938	0.927
33	132AWASH	132KOKA	82	5.683	7.339	6.93	8.95	0	0.0001	0.017	0.026
34	230DBRHAN	230COMBLCHA	318	46.287	45.101	14.56	14.18	0.0004	0.0004	0.461	0.437
37	132WERGENU	132COTEBE	82	40.703	39.115	49.64	47.7	0.0607	0.0518	0.073	0.063
38	230TEKEZE	230MEKELE	318	147.612	147.346	46.42	46.34	0.0464	0.0461	4.526	4.476
39	132BLEMIMB	132COTEBE	82	7.728	9.203	9.42	11.22	0.0001	0.0002	0.007	0.01
40	400BDAR	400BELES	1341	454.422	462.006	33.89	34.45	0.0132	0.0141	1.867	1.925
44	132SEBETA1	132BLION	91	41.2	38.736	45.27	42.57	0.042	0.0328	0.329	0.275
47	132KALITI1	132YESU	115	5.85	6.559	5.09	5.7	0	0	0.005	0.005
48	230DBRHAN	230SINOSTILL	318	72.9	74.141	22.92	23.31	0.0028	0.003	2.349	2.28
49	132MEKANISA	132KALITI1	82	19.331	21.714	23.57	26.48	0.0031	0.0049	0.106	0.126
50	132KALITI1	132WEREGENU	82	19.958	21.428	24.34	26.13	0.0035	0.0047	0.127	0.138
51	132KALITI2	132KALITI1	82	40.354	40.354	49.21	49.21	0.0586	0.0586	0.202	0.189
52	132KALITI1	132KALITINEW	82	51.554	53.093	62.87	64.75	0.1562	0.1758	0.07	0.07
53	132KALITINW	132BLEMIMB	82	11.199	12.577	13.66	15.34	0.0003	0.0006	0.026	0.031
54	230LEGETAFO	230SINOSTILL	318	101.349	102.349	31.87	32.19	0.0103	0.0107	1.126	1.09
55	132WENJI	132KOKA	82	31.532	33.725	38.45	41.13	0.0219	0.0286	0.142	0.144
57	132NAZRET2	132ADMAWF1	82	30.52	30.668	37.22	37.4	0.0192	0.0196	0.088	0.079
58	132EGEDA	132KOKA	82	30.548	25.455	37.25	31.04	0.0193	0.0093	0.414	0.258
59	132KOKA	132NAZRET2	82	33.055	32.871	40.31	40.09	0.0264	0.0258	0.242	0.213
61	132WENJI	132AWASH	82	10.657	8.23	13	10.04	0.0003	0.0001	0.032	0.017
62	132ASSELA	132WENJI	82	32.888	33.419	40.11	40.76	0.0259	0.0276	0.806	0.717
63	230METEMA	230GONDER2	360	188.489	188.486	52.36	52.36	0.0752	0.0752	4.346	4.297
64	230SUDB	230METEMA	402	185	185	46.02	46.02	0.0449	0.0449	1.254	1.238
65	230MELKYGO	230MELK W	257	91.323	80.718	35.53	31.41	0.0159	0.0097	0.085	0.064
66	230GONDER2	230BDAR2	402	219.185	219.279	54.52	54.55	0.0884	0.0885	6.847	6.787
67	230DM	230MOTA	280	33.134	30.232	11.83	10.8	0.0002	0.0001	0.111	0.089
68	230GASHENA	230ALAMATA	318	92.024	89.803	28.94	28.24	0.007	0.0064	1.717	1.616
69	230DM	230FINCHA	280	22.914	26.498	8.18	9.46	0	0.0001	0.12	0.149
70	230FINCA2	230FINCHA	318	31.987	23.21	10.06	7.3	0.0001	0	0.016	0.008
71	230GHEDO	230FINCHA	284	79.142	76.063	27.87	26.78	0.006	0.0051	0.607	0.551
72	132GEFERSA	132SEBETA1	82	3.452	3.817	4.21	4.66	0	0	0.002	0.002
73	132GEFERSA	132KALITI1	82	22.826	19.637	27.84	23.95	0.006	0.0033	0.222	0.154
74	132MELKYGO	132SHSMNE	89	26.11	25.771	29.34	28.96	0.0074	0.007	1.303	1.076
75	230NESHI	230FINCA2	318	92.553	93.368	29.1	29.36	0.0072	0.0074	0.48	0.479
76	230FINCA2	230GHEDO	318	93.209	91.11	29.31	28.65	0.0074	0.0067	1.204	1.109
77	230GHEDO	230GEFERSA	341	114.96	109.727	33.71	32.18	0.0129	0.0107	1.85	1.548
78	132KALITI2	132KALITIGS	91	38.287	38.286	42.07	42.07	0.0313	0.0313	0.104	0.098
80	230GEFERSA	230TORHAYL	402	46.143	42.661	11.48	10.61	0.0002	0.0001	0.055	0.044
81	132KALITI1	132KALITIGS	82	43.071	43.044	52.53	52.49	0.0761	0.0759	0.098	0.092
82	230ENDASLSE	230AXUM	318	48.878	49	15.37	15.41	0.0006	0.0006	0.48	0.48
83	230GEFERSA	230SULULTA	318	102.43	105.952	32.21	33.32	0.0108	0.0123	0.185	0.188
84	132REPPIWE	132MEKANISA	115	39.59	37.306	34.43	32.44	0.0141	0.0111	0.169	0.141
85	230AGARO	230GIMA NEW	402	27.986	27.995	6.96	6.96	0	0	0.058	0.057
86	230AGARO	230BEDELE	402	25.178	25.187	6.26	6.27	0	0	0.16	0.159
87	230GG1	230GGNEW	274	129.296	129.014	47.19	47.09	0.0496	0.0492	0.067	0.065
89	230ALAMATA	230MEHONI	318	16.594	17.336	5.22	5.45	0	0	0.027	0.032
90	132BLION	132REPPIWE	82	13.471	11.922	16.43	14.54	0.0007	0.0004	0.019	0.014

91	230GIMMANW	230GGNEW	402	59.833	59.796	14.88	14.87	0.0005	0.0005	0.475	0.467
92	230HOSSANA	230WOLKITE	402	23.169	23.169	5.76	5.76	0	0	0.083	0.081
95	230SEBETA1	230TORHAYL	402	52.285	48.606	13.01	12.09	0.0003	0.0002	0.046	0.038
97	230EIZONE	230GELAN	331	84.618	81.43	25.56	24.6	0.0043	0.0037	0.3	0.263
98	230MELK W	230KOKA	257	31.422	36.319	12.23	14.13	0.0002	0.0004	0.178	0.232
99	230KOKA	230ADAMWF2	402	92.486	87.775	23.01	21.83	0.0028	0.0023	0.199	0.172
100	230ALAMATA	230WOLDIYA	318	38.003	35.021	11.95	11.01	0.0002	0.0001	0.201	0.161
101	230KOKA	230AWASH7K	353	76.03	77.351	21.54	21.91	0.0022	0.0023	1.312	1.279
102	230DDAWA-3	230AWASH7K	353	51.087	51.083	14.47	14.47	0.0004	0.0004	1.015	0.973
103	230DDAWA-3	230HURSO	255	43.803	44.547	17.18	17.47	0.0009	0.0009	0.076	0.074
104	230MEKELE	230ASHEGDWF	402	44.071	43.97	10.96	10.94	0.0001	0.0001	0.078	0.076
105	230KOKA	230HURSO	402	82.599	85.292	20.55	21.22	0.0018	0.002	3.936	3.817
106	230HURSO	230ADIGALA	402	36.768	38.081	9.15	9.47	0.0001	0.0001	0.313	0.303
107	230ADIGALA	230DJBTBR	402	30.278	30.204	7.53	7.51	0	0	0.168	0.156
Total system power flow Performance Index (PI)								**2.5845**	**2.3637**		
Total real power loss of Transmission lines (MW)										**104.97**	**84.359**
Total real power loss of Transformers (MW)										**10.153**	**9.698**
Total real power loss (MW)										**115.123**	**94.057**

4.5. Summary

It can be summarized that sensitivity analysis based optimal placement of TCSCs on the most sensitive lines is implemented for objectives of power flow performance reduction and total system real power loss reduction. Criteria for a given branch flow is defined and are then used for selection and ranking for possible placement of the TCSCs. The voltage performance index for selection of weak buses for SVCs placement is applied for enhancement of voltage profiles of the system at the same time. After incorporating FACTS models in the conventional Newton Raphson power flow simulation study with TCSCs is performed at first for purposes of reduction of system real power loss, for balancing power flows and for restoring nodal voltage magnitude at the point of compensation. Then SVCs are installed together with the TCSCs for restoring voltage profiles of system between the allowed maximum and minimum normal operating limits. Finally, the optimal settings for parameters of FACTS devices are determined for the desired line power flows, loss reduction, and the desired voltage objectives of the system under investigation The validity of the proposed methodology is demonstrated through enhancement of the system by the FACTS devices.

Chapter Five
Conclusion, Recommendation, and Future Work

5.1. Conclusion

This study presents and explains the control of the real power flows in a transmission line by TCSC and the enhancement of voltage profiles by SVCs on Ethiopian transmission networks using the merits of the newly emerging FACTS devices or controllers. TCSCs installed are capable of controlling the reactance of the lines thereby redirecting power flows in transmission systems either by increasing the power flow of lightly loaded lines or decreasing the power flow in heavily loaded lines depending on the series compensation type. The SVCs control the voltage at the point of installation by injecting or absorbing the reactive power requirement of the system.

The study discussed the operation of the TCSCs and SVCs with both firing angle mode and variable susceptance mode control strategies to acquire desired controlled variables and it is concluded that the proposed strategy gives the same results. Sensitivity index analysis was employed to determine the optimal locations of the controllers on the network and its effectiveness was observed through simulation studies.

Two capacitive TCSCs were installed on the network and from the results, it was possible to control line flows based on objectives of reduction of line overloading, loss reduction of the particular lines, and at the same time enhancement of voltage profiles were possible. With two SVCs further enhancement of the system, voltage profiles have been presented on the most sensitive buses.

Power flow solution results of multi-type installations show the reduction of system maximum line loading, total real power loss, and voltage regulation ranges from 91.16%, 4.46% (115.1 MW), and (-15.6% to +12.7%) base case to 81.47%, 3.68% (94 MW), and (-7.5% to +7.73%) respectively by the FACTS. Simultaneously most of the system lines were relieved from loading level as a result of reactive power support at the spot and reduction of transmission system reactance. Consecutively the performance of the whole system was able to be reduced to 2.36 from 2.58.

5.2. Recommendation

Based on the thesis work and problems investigated during the system modelling stage, it is recommended that the following points are to be considered.

- EEP should consider the economic and operational benefits that may be gained through incorporating FACTS in the network instead of plans of expansion and new line buildings.
- In this study dynamic, SVC was used to control the overvoltage problem, it recommended installing fixed shunt inductor from consideration of economic and additional control requirement perspectives.
- It has been found in the study both capacitive and inductive fixed shunt devices were operating at the same time at bus this shows ineffective system operation, so it is recommended to operate only one at a time in switched mode depending on the system reactive power requirement.
- In the system, some transmission lines run in parallel having different line parameters and ratings, this condition leads to overloading of the lower impedance line thereby limiting the loading of both lines even though the higher impedance line is not fully loaded. EEP should consider the merits of FACTS to control line flows as desired to alleviate the problems foreseen.

5.3. Suggestions for Future works

- The FACTS utilized are considered on their control ability of line flow control and voltage profile enhancements, for implementation their impact on system oscillation damping, short circuit capacity enhancement, and sub synchronous resonance may be studied.
- Additional SVCs and TCSCs having the next absolute higher sensitivity indices can be installed on the network for further enhancements of voltage profiles, and power flow control for loss reduction and reduction of the system power flow performance index.
- Other types of FACTS can be used both in transmission and distribution systems and be compared to check the effectiveness of the proposed method.
- Other researchers can extend further studies on the system taking into cost considerations of the FACTS devices for the reduction of the number of needed devices during optimal placement objective function formulation.

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List of Appendices

Appendix A. The existing transmission network

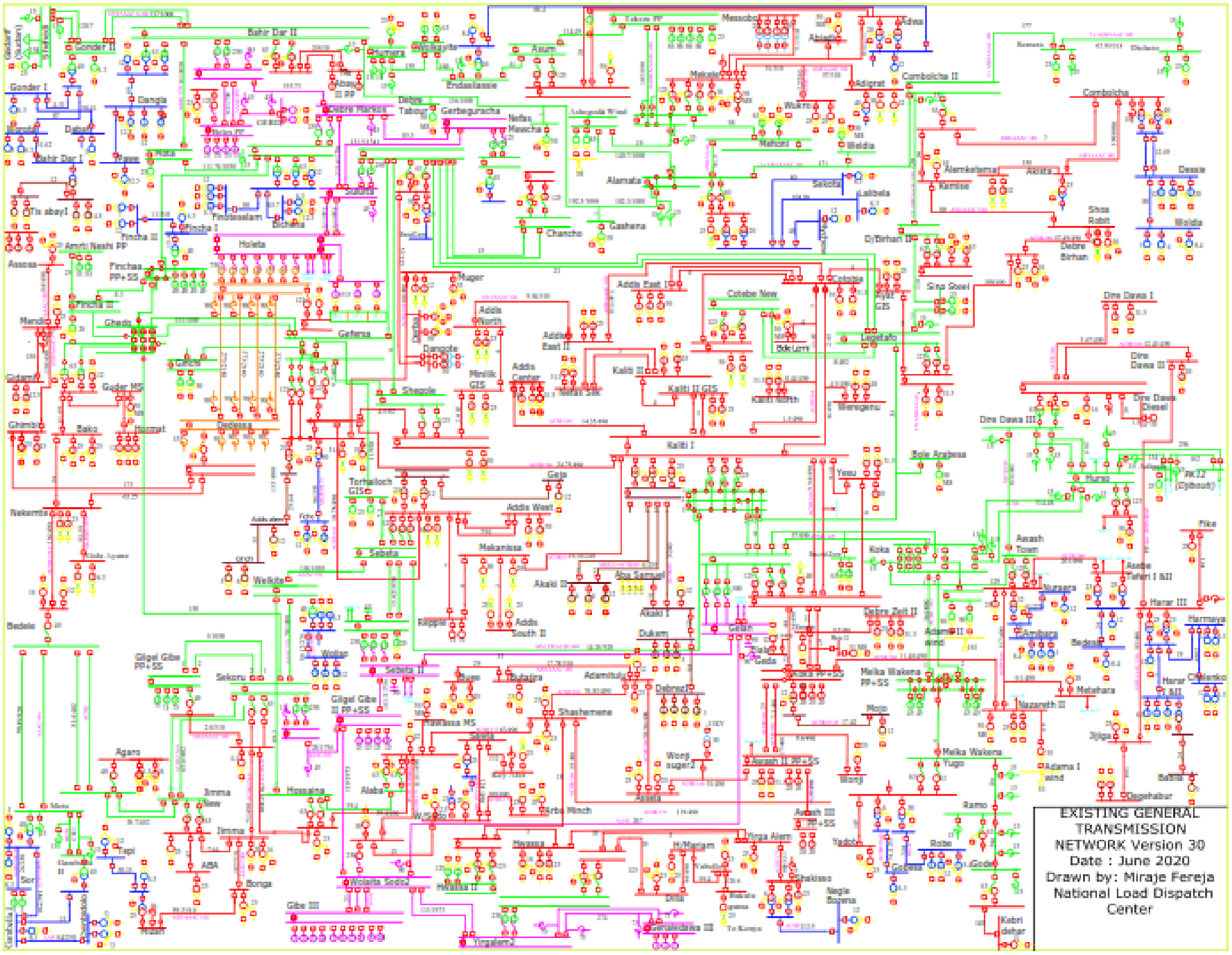

Figure **A 1.** The existing general transmission network diagram [31].

Appendix B. Power Flow Reports of the Case Studies

Power flow report with TCSC in line 41.

The resulting bus and line flow reports are given in Table **B.1** and **B.2**.

Table **B. 1** Power flow bus report with 20% Inductive TCSC in line 41.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
SABASAPP	0.9237	-0.7431	3.37	0.35	0	0
ADAMAWF1	0.9111	-0.7574	26.9	17	0	0
ADAMAWF2	1	-0.6208	88	35.54957	0	0
ASHEGODAWF	1	-0.8185	8.3	16.08193	0	0
AWASHPP	0.9524	-0.7433	26	25.8	0	0
BELESPP	1	-0.3833	461.2	-106.115	0	0
FINCHAPP	1.03	-0.5423	101.2	24.10358	0	0
GG1PP	1.02	-0.4348	129.2	18.78834	0	0
GG2PP	1	-0.3074	278.4	-85.5142	0	0
GG3PP	1.05	0	955.9036	90.65003	0	0
GNALE3PP	1.0794	-0.2475	150.2	-117	0	0
KOKAPP	0.9147	-0.8024	12.4	26.2	0	0
MELKAWPP	1	-0.6913	29.8	72.3104	0	0
NESHIPP	1	-0.4657	89.8	-14.0826	0	0
REPPIWEPP	0.973	-0.6477	25.2	16	0	0
TAY2 PP	1	-0.5479	14.9	-11.829	0	0
TEKEZE PP	1.03	-0.6556	176.1	25.23037	0	0
132ADAMAWF1	0.8755	-0.8198	0	0	0	0
132ALABA	1.0341	-0.3808	0	0	6.6148	3.2016
132ASSELA	0.8456	-0.8498	0	0	29.2299	12.2577
132ATULU	0.8451	-0.8532	0	0	4.9731	2.4078
132AWASH	0.8814	-0.8198	0	0	24	11.6
132AWASSA	1.014	-0.4096	0	0	40.1403	17.9625
132BD2	1.0415	-0.6097	0	0	0	0
132BLEMIMB	0.9176	-0.7514	0	0	3.5141	0.5271
132BLION	0.9204	-0.7425	0	0	24.5418	18.694
132COTEBE	0.9164	-0.7526	0	0	84.6765	39.1733
132DZEIT	0.8823	-0.7987	0	0	55.7315	26.9793
132EGEDA	0.8956	-0.7921	0	0	7.8543	3.8049
132GEFERSA	0.932	-0.7311	0	0	212.4279	99.5179
132GELAN	0.9283	-0.7442	0	0	28.3229	13.7167
132KALITI1	0.9224	-0.7467	0	0	89.9306	40.4531
132KALITI2	0.9154	-0.7525	0	0	73.5335	27.8761
132KALITIGS	0.9192	-0.7493	0	0	4.1342	2.0011
132KALITINEW	0.9204	-0.7482	0	0	36.3959	17.9151
132KNORIT	0.9007	-0.7779	0	0	8.2686	4.0019
132KOKA	0.8814	-0.8143	0	0	8.8	4.2
132MEKANISA	0.9139	-0.7517	0	0	54.7824	19.8009
132MELKYGO	0.9196	-0.7683	0	0	20.8601	8.3308
132MOJO	0.8855	-0.7991	0	0	28.4855	13.7902
132NAZRET2	0.8713	-0.8225	0	0	56.9646	27.5495
132REPPIWE	0.9196	-0.745	0	0	0	0
132SEBETA1	0.933	-0.7307	0	0	154.1373	52.4707
132SHSMNE	0.8516	-0.8456	0	0	20.8476	8.752
132TAY2	1.0382	-0.596	0	0	0	0
132WENJI	0.8764	-0.8207	0	0	5.9769	2.8927
132WEREGENU	0.9137	-0.7543	0	0	54.5209	26.4
132WSODO	1.055	-0.35	0	0	29.3161	15.9089
132YESU	0.9219	-0.7483	0	0	32.3276	15.64
132YIGALEM2	1.0753	-0.3688	0	0	28.571	13.6344
132YIGALM	1.0379	-0.3971	0	0	17.3795	6.1326
230ADAMAWF2	0.9733	-0.69	0	0	0	0
230ADIGALA	0.959	-0.8928	0	0	0.4341	-0.8888
230AGARO	0.9906	-0.5341	0	0	2.525	1.2557
230ALAMATA	0.9941	-0.8193	0	0	24.3136	11.7866
230ASHEGODAWF	0.9838	-0.8264	0	0	0	0
230AWASH7K	0.9672	-0.7763	0	0	20.3043	8.5068
230AXUM	1.01	-0.7529	0	0	3.7716	1.7915
230BDAR2	1.052	-0.6226	0	0	44.5907	21.4963

230BEDELE	0.9765	-0.5411	0	0	21.2194	28.04204
230BOLEARABSA	0.9569	-0.6772	0	0	3.08	1.5
230COMBOLCHA	0.9621	-0.8448	0	0	63.0643	24.3886
230COTEBE1	0.954	-0.6805	0	0	0	0
230DBRHAN	0.9574	-0.8114	0	0	35.5233	15.5403
230DDAWA-3	0.956	-0.8658	0	0	83.7624	35.6101
230DJBTBR	0.95	-0.9062	0	0	30	14.5
230DM	1.0373	-0.5944	0	0	35.5616	15.4456
230EIZONE	0.9655	-0.6742	0	0	23.2974	1.12758
230ENDASILASE	0.9735	-0.7641	0	0	21.8903	43.69997
230FINCA2	1.0166	-0.5832	0	0	4.7956	2.3198
230FINCHA	1.0182	-0.5833	0	0	7.4884	3.6245
230GASHENA	1.0206	-0.7653	0	0	4.238	0.2231
230GEFERSA	0.9609	-0.6677	0	0	0	0
230GELAN	0.9643	-0.6596	0	0	0	0
230GG1	1.0102	-0.5075	0	0	0	0
230GGNEW	1.0095	-0.5099	0	0	6.876	2.4148
230GHEDO	0.9977	-0.6203	0	0	54.5361	17.01702
230GIMMA NEW	0.9952	-0.5294	0	0	31.596	14.8437
230GONDER2	1.0428	-0.7145	0	0	23.6902	10.8937
230HOSSANA	0.989	-0.5938	0	0	20.4661	10.8591
230HURSO	0.9604	-0.8631	0	0	0.4341	0.2102
230KALITI1	0.9589	-0.6673	0	0	0	0
230KOKA	0.9693	-0.6953	0	0	53.4845	42.18473
230LEGETAFO	0.9567	-0.6781	0	0	46.6735	22.6296
230MEHONI	0.9912	-0.8231	0	0	4.124	1.6228
230MEKELE	0.9785	-0.8272	0	0	175.2094	82.9428
230MELK W	0.9425	-0.7141	0	0	0	15.42947
230MELKYGO	0.9388	-0.7153	0	0	0	61.23289
230METEMA	1.0296	-0.783	0	0	1.9673	0.9522
230MOTA	1.0506	-0.6125	0	0	2.4989	1.2096
230NESHI	1.018	-0.5665	0	0	0	0
230NIFASMW	1.0391	-0.7073	0	0	4.6258	0.5002
230SEBETA1	0.961	-0.6616	0	0	0	0
230SEBETA2	0.9672	-0.6492	0	0	49.5489	24.2583
230SINOSTILL	0.9559	-0.7134	0	0	20.855	9.931
230SUDB	1.0233	-0.8021	0	0	185	0
230SULULTA	0.9655	-0.6645	0	0	49.6272	18.9605
230TEKEZE	1.0193	-0.739	0	0	2.3287	1.1752
230TORHAYL	0.9609	-0.6642	0	0	5.4262	0.123
230WOLDIYA	0.9841	-0.8318	0	0	9.2397	4.472
230WOLKITE	0.9945	-0.5829	0	0	20.3304	9.8399
230YIRGALEM	1.0916	-0.339	0	0	0	0
400BDAR	1.0408	-0.5481	0	0	0	0
400BELES	1.0317	-0.4969	0	0	0	55.48158
400DMARKOS	1.0394	-0.5849	0	0	0	0
400GELAN	0.986	-0.583	0	0	0	13.84428
400GG2	1.0262	-0.3858	0	0	0	0
400GGG3	1.0615	-0.2917	0	0	0	0
400GGNEW	1.0247	-0.3893	0	0	0	18.23949
400GRANDR	1.0404	-0.5046	0	0	15.9788	57.4875
400GENDAWA	1.127	-0.2999	0	0	0	0
400HOLETA	0.9913	-0.5899	0	0	0	0
400SEBETA2	0.9911	-0.5848	0	0	0	-88.4076
400SULULTA	0.9904	-0.6051	0	0	0	0
400WSODO	1.0633	-0.3265	0	0	0	117.8632
400YIRGALEM	1.1002	-0.324	0	0	0	0
Total			2576.874	33.52335	2461.636	1315.774

Table **B. 2** Power flow Branch report with 20% Inductive TCSC in line 41.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	18.788	-128.98	-9.2656	0.22462	9.52277
109	FINCHAPP	230FINCHA	101.2	24.104	-100.94	-19.706	0.26295	4.39772
110	TAY2 PP	132TAY2	14.9	-11.829	-14.861	13.0099	0.03899	1.18082
111	KOKAPP	132KOKA	12.4	26.2	-12.247	-25.101	0.15341	1.09891
112	MELKAWPP	230MELK W	29.8	72.31	-29.632	-67.494	0.16821	4.81644
113	400BDAR	230BDAR2	342.927	-41.437	-342.54	67.5724	0.38984	26.1354
114	400DMARKOS	230DM	44.0181	8.886	-44.01	-8.4492	0.00771	0.43678

115	132BD2	230BDAR2	14.7388	-11.759	-14.731	12.0688	0.00733	0.30937
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.817	-14.693	0.08295	2.30672
117	400YIRGALEM	230YIRGALEM	71.0928	36.88	-71.075	-35.529	0.01802	1.35119
118	GG2PP	400GG2	278.4	-85.514	-277.95	109.874	0.44852	24.3601
119	400GGNEW	230GGNEW	66.0181	12.159	-66.007	-4.0697	0.01116	8.08931
120	400SEBETA2	230SEBETA2	257.02	102.99	-256.76	-84.149	0.25834	18.8406
121	400SULULTA	230SULULTA	349.763	156.4	-349.42	-131.95	0.33866	24.4549
122	ADAMAWF2	230ADAMAWF2	88	35.55	-87.837	-28.594	0.16347	6.95601
123	REPPIWEPP	132REPPIWE	25.2	16	-25.171	-12.736	0.02861	3.26382
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	130.197	0	13.1972
125	GG3PP	400GGG3	955.904	90.65	-951.87	190.115	4.03408	280.765
126	400GELAN	230GELAN	597.742	198.67	-597.74	-149	0	49.6664
127	230GEFERSA	132GEFERSA	233.132	115.68	-232.78	-97.664	0.3546	18.0175
128	400WSODO	132WSODO	53.003	18.151	-52.997	-16.769	0.00555	1.38244
129	230GELAN	132GELAN	241.313	115.41	-240.87	-91.072	0.44714	24.3349
130	TEKEZEPP	230TEKEZE	176.1	25.23	-175.74	-10.37	0.36096	14.8603
131	230COTEBE1	132COTEBE	113.195	67.013	-113.09	-56.366	0.10837	10.6473
132	230KALITI1	132KALITI1	214.744	110.4	-214.33	-89.497	0.40869	20.9006
133	230MELKYGO	132MELKYGO	46.5765	17.568	-46.469	-14.77	0.10713	2.79838
134	230YIRGALEM	132YIGALEM2	71.0748	35.529	-71.023	-32.903	0.05193	2.62607
135	ASHEGODAWF	230ASHEGODWF	8.3	16.082	-8.29	-15.757	0.01001	0.32493
136	ABASAPP	132KALITI1	3.37	0.35	-3.3665	-0.3375	0.00353	0.01253
137	BELESPP	400BELES	461.2	-106.12	-460.36	162.738	0.84435	56.6229
138	NESHIPP	230NESHI	89.8	-14.083	-89.508	23.4596	0.29249	9.37703
139	230SEBETA1	132SEBETA1	195.013	86.144	-194.67	-70.355	0.34451	15.7884
140	AWASHPP	132AWASH	26	25.8	-25.815	-21.969	0.18488	3.83071
1	230AXUM	230TEKEZE	-26.142	-16.5	26.2861	-2.8465	0.1439	-19.347
2	400SULULTA	400HOLETA	-294.98	8.62	295.512	-25.867	0.53458	-17.247
3	400WSODO	400GGG3	-947.75	143.01	951.869	-190.12	4.12064	-47.105
4	230KOKA	230GELAN	-67.994	25.203	68.6362	-30.472	0.64172	-5.2684
5	230KOKA	230EIZONE	-56.821	23.756	57.1444	-27.972	0.32354	-4.2157
6	230LEGETAFO	230BOLEARABSA	-37.467	3.5163	37.4784	-4.1011	0.01164	-0.5848
7	230WOLDIYA	230COMBOLCHA	27.7125	14.866	-27.406	-33.359	0.30683	-18.493
8	230KALITI1	230BOLEARABSA	40.6976	-8.4703	-40.558	2.60109	0.13923	-5.8692
9	230COTEBE1	230LEGETAFO	-113.2	-67.013	113.355	64.65	0.15987	-2.3632
10	230SULULTA	230LEGETAFO	219.784	54.27	-218.54	-58.252	1.24729	-3.9819
11	400BDAR	400DMARKOS	99.5541	-61.798	-99.28	-53.807	0.27434	-115.6
12	400DMARKOS	400SULULTA	55.2617	44.921	-54.786	-165.02	0.47591	-120.1
13	230MOTA	230BDAR2	15.8561	-11.706	-15.824	-1.3968	0.0321	-13.103
14	400HOLETA	400SEBETA2	-295.51	25.867	295.639	-44.733	0.12717	-18.866
15	400GELAN	400SEBETA2	20.2493	-101.52	-20.187	80.4514	0.0623	-21.069
16	230MEHONI	230MEKELE	12.3529	7.5974	-12.262	-25.047	0.09121	-17.45
17	400GELAN	400WSODO	-617.99	-110.99	639.616	80.6615	21.6249	-30.331
18	400SEBETA2	400GG2	-532.47	-50.3	540.666	53.0055	8.19432	2.70534
19	400WSODO	400GG2	331.75	114.77	-328.75	-176.86	2.9978	-62.088
20	400YIRGALEM	400WSODO	78.2888	311.2	-76.621	-474.45	1.66824	-163.26
21	400GGNEW	400GG2	-66.018	-30.398	66.038	13.9762	0.01989	-16.422
22	400YIRGALEM	400GENDAWA	-149.38	-348.08	150.2	-130.2	0.8184	-478.27
23	230ALAMATA	230ASHEGODWF	12.2004	-2.2132	-12.138	-20.149	0.06249	-22.362
24	400GRANDR	400BELES	-15.979	-57.488	16.0077	-98.181	0.02888	-155.67
25	132BD2	132TAY2	-14.739	11.759	14.861	-13.01	0.12223	-1.2504
26	132KOKA	132DZEIT	-9.6744	4.5168	9.76407	-5.7706	0.08965	-1.2537
27	230BDAR2	230NIFASMW	105.395	-27.774	-102.59	8.57191	2.80718	-19.202
28	132AWASSA	132ALABA	-16.389	-3.4986	16.6606	0.06527	0.27192	-3.4334
29	132WSODO	132ALABA	23.6814	0.8598	-23.275	-3.2669	0.40596	-2.4071
30	132YIGALM	132AWASSA	24.1342	13.362	-23.752	-14.464	0.38261	-1.1023
31	230GASHENA	230NIFASMW	-96.128	-5.5414	97.9615	-9.0721	1.83353	-14.613
32	132YIGALM	132YIGALEM2	-41.514	-19.494	42.4519	19.2685	0.93816	-0.2257
33	132AWASH	132KOKA	-4.9765	2.6625	4.99333	-3.5549	0.01684	-0.8924
34	230DBRHAN	230COMBOLCHA	36.1198	-28.979	-35.659	8.97042	0.46109	-20.009
35	132SHSMNE	132ATULU	3.42861	-0.4205	-3.4088	-2.1292	0.01985	-2.5498
36	132ASSELA	132ATULU	1.56731	-1.4174	-1.5643	-0.2786	0.00296	-1.6959
37	132WEREGNU	132COTEBE	-35.773	-19.464	35.846	19.4866	0.07272	0.02298
38	230TEKEZE	230MEKELE	147.124	12.041	-142.6	-18.803	4.52674	-6.7615
39	132BLEMIMB	132COTEBE	7.443	2.0315	-7.4355	-2.294	0.00747	-0.2625
40	400BDAR	400BELES	-442.48	103.24	444.348	-120.04	1.86685	-16.804
41	132GELAN	132DZEIT	67.6234	24.975	-65.496	-21.209	2.12781	3.76615
42	132KNORIT	132GELAN	-59.452	-14.066	60.7668	15.6759	1.31498	1.61019
43	132EGEDA	132GELAN	-39.737	-6.0614	40.8826	6.49998	1.14561	0.4386
44	132SEBETA1	132BLION	38.034	15.932	-37.704	-15.827	0.3302	0.10474
45	132GELAN	132KALITI1	16.5175	13.904	-16.446	-14.175	0.07117	-0.2711

46	132GELAN	132YESU	26.7522	16.301	-26.633	-16.399	0.11907	-0.0982
47	132KALITI1	132YESU	5.6992	-1.1178	-5.6945	0.75886	0.00467	-0.3589
48	230DBRHAN	230SINOSTILL	-71.643	13.439	73.9934	-36.831	2.35031	-23.392
49	132MEKANISA	132KALITI1	-16.637	-9.7666	16.7433	9.3027	0.10594	-0.4639
50	132KALITI1	132WEREGENU	18.8749	6.4379	-18.748	-6.9364	0.12733	-0.4985
51	132KALITI2	132KALITI1	-37.703	-14.383	37.9058	14.4369	0.20237	0.05429
52	132KALITI1	132KALITINEW	47.449	20.111	-47.379	-20.057	0.07005	0.05466
53	132KALITINEW	132BLEMIMB	10.9831	2.1417	-10.957	-2.5586	0.02596	-0.4169
54	230LEGETAFO	230SINOSTILL	95.9748	-32.544	-94.848	26.9004	1.1264	-5.6438
55	132WENJI	132KOKA	-30.812	-5.5815	30.9519	5.54429	0.14031	-0.0372
56	132MOJO	132KNORIT	-50.526	-9.3902	51.1832	10.0639	0.65699	0.67362
57	132NAZRET2	132ADAMAWF1	-26.729	-14.721	26.8171	14.6933	0.08785	-0.0279
58	132EGEDA	132KOKA	31.8827	2.2565	-31.429	-2.394	0.45414	-0.1375
59	132KOKA	132NAZRET2	30.4783	12.812	-30.235	-12.828	0.24287	-0.0162
60	132MOJO	132KOKA	22.0407	-4.4	-21.874	3.97675	0.16689	-0.4232
61	132WENJI	132AWASH	-6.7599	-8.1964	6.79161	7.7068	0.0317	-0.4896
62	132ASSELA	132WENJI	-30.797	-10.84	31.5946	10.8852	0.79735	0.04488
63	230METEMA	230GONDER2	-188.22	10.049	192.569	-46.579	4.3472	-36.53
64	230SUDB	230METEMA	-185	-3E-13	186.254	-11.001	1.25414	-11.001
65	230MELKYGO	230MELK W	-46.577	-78.801	46.6621	78.5173	0.08561	-0.2839
66	230GONDER2	230BDAR2	-216.26	35.685	223.107	-71.967	6.84857	-36.281
67	230DM	230MOTA	18.4663	-27.537	-18.355	10.4961	0.11131	-17.04
68	230GASHENA	230ALAMATA	91.89	5.3183	-90.172	-19.413	1.71797	-14.095
69	230DM	230FINCHA	-10.018	20.54	10.1375	-34.455	0.12	-13.915
70	230FINCA2	230FINCHA	-8.5452	-30.889	8.56105	29.3359	0.01584	-1.5529
71	230GHEDO	230FINCHA	-74.142	-27.801	74.7501	21.2007	0.60777	-6.6004
72	132GEFERSA	132SEBETA1	-2.4951	-2.3865	2.49714	1.9524	0.00203	-0.4341
73	132GEFERSA	132KALITI1	22.8447	0.5323	-22.622	-1.1632	0.22284	-0.6309
74	132MELKYGO	132SHSMNE	25.6093	6.4392	-24.276	-8.3315	1.33307	-1.8923
75	230NESHI	230FINCA2	89.5075	-23.46	-89.027	19.2875	0.48015	-4.1721
76	230FINCA2	230GHEDO	92.777	9.2815	-91.571	-18.775	1.2057	-9.4931
77	230GHEDO	230GEFERSA	111.177	29.559	-109.32	-65.562	1.85388	-36.003
78	132KALITI2	132KALITIGS	-35.83	-13.494	35.9346	13.5065	0.10449	0.01299
79	230WOLKITE	230SEBETA1	89.2783	-2.7254	-86.792	-15.454	2.48673	-18.179
80	230GEFERSA	230TORHAYL	-43.981	14.032	44.0363	-15.835	0.05523	-1.8027
81	132KALITI1	132KALITIGS	40.1667	15.548	-40.069	-15.508	0.09794	0.04069
82	230ENDASLASE	230AXUM	-21.89	-43.7	22.3706	14.7088	0.48031	-28.991
83	230GEFERSA	230SULULTA	-79.827	-64.151	80.0127	58.7194	0.18525	-5.432
84	132REPPIWE	132MEKANISA	38.3143	10.076	-38.145	-10.034	0.16921	0.04147
85	230AGARO	230GIMMA NEW	-23.905	-14.554	23.963	7.36585	0.05842	-7.1878
86	230AGARO	230BEDELE	21.3795	13.298	-21.219	-28.042	0.16013	-14.744
87	230GG1	230GGNEW	128.975	9.2656	-128.91	-10.466	0.06674	-1.2005
88	230GGNEW	230WOLKITE	132.006	1.2835	-130.16	-1.8476	1.84744	-0.564
89	230ALAMATA	230MEHONI	16.504	1.6792	-16.477	-9.2202	0.02718	-7.5411
90	132BLION	132REPPIWE	13.162	-2.8666	-13.143	2.66044	0.01915	-0.2061
91	230GIMA NEW	230GGNEW	-55.559	-22.21	56.034	10.8374	0.47507	-11.372
92	230HOSSANA	230WOLKITE	-20.466	-10.859	20.5494	-5.2669	0.08333	-16.126
93	230SEBETA2	230SEBETA1	207.213	59.891	-206.63	-61.088	0.58033	-1.1975
94	230SEBETA1	230KALITI1	48.9026	7.2803	-48.841	-8.8869	0.06162	-1.6065
95	230SEBETA1	230TORHAYL	49.5085	-16.882	-49.463	15.7119	0.04597	-1.1702
96	230GELAN	230KALITI1	207.05	92.441	-206.6	-93.04	0.44981	-0.5992
97	230EIZONE	230GELAN	-80.442	26.844	80.7431	-28.375	0.30136	-1.5304
98	230MELK W	230KOKA	-17.03	-26.453	17.2099	5.13916	0.17953	-21.314
99	230KOKA	230ADAMAWF2	-87.637	-29.851	87.8365	28.5936	0.19942	-1.2571
100	230ALAMATA	230WOLDIYA	37.154	8.1604	-36.952	-19.338	0.20187	-11.178
101	230KOKA	230AWASH7K	73.2376	-20.363	-71.925	8.17051	1.31236	-12.192
102	230DDAWA-3	230AWASH7K	-50.605	-7.0002	51.621	-16.677	1.01603	-23.678
103	230DDAWA-3	230HURSO	-33.157	-28.61	33.2335	25.7328	0.076	-2.877
104	230MEKELE	230ASHEGODWF	-20.35	-39.093	20.4279	35.9063	0.07762	-3.1864
105	230KOKA	230HURSO	68.5204	-46.07	-64.583	-6.0669	3.93761	-52.137
106	230HURSO	230ADIGALA	30.9153	-19.876	-30.602	-1.7034	0.31324	-21.579
107	230ADIGALA	230DJBTBR	30.1679	2.5922	-30	-14.5	0.16793	-11.908
Total							115.237	-1282.3

Power flow report with TCSC in line 42.

The resulting bus and line flow reports are given in Table **B**.**3** and **B**.**4**.

Table **B. 3** Power flow bus report with 10% Capacitive TCSC in line 42

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.9243	-0.743	3.37	0.35	0	0
ADAMAWF1	0.914	-0.753	26.9	17	0	0
ADAMAWF2	1	-0.62	88	35.09377	0	0
ASHEGODAWF	1	-0.818	8.3	15.99551	0	0
AWASHPP	0.9551	-0.739	26	25.8	0	0
BELESPP	1	-0.383	461.2	-106.469	0	0
FINCHAPP	1.03	-0.542	101.2	23.74657	0	0
GG1PP	1.02	-0.434	129.2	18.53713	0	0
GG2PP	1	-0.307	278.4	-86.2456	0	0
GG3PP	1.05	0	955.599	89.84156	0	0
GNALE3PP	1.0797	-0.247	150.2	-117	0	0
KOKAPP	0.9176	-0.797	12.4	26.2	0	0
MELKAWPP	1	-0.69	29.8	71.92424	0	0
NESHIPP	1	-0.465	89.8	-14.2	0	0
REPPIWEPP	0.9735	-0.647	25.2	16	0	0
TAY2 PP	1	-0.547	14.9	-11.8586	0	0
TEKEZE PP	1.03	-0.655	176.1	25.15176	0	0
132ADAMAWF1	0.8785	-0.815	0	0	0	0
132ALABA	1.0344	-0.381	0	0	6.6148	3.2016
132ASSELA	0.8483	-0.845	0	0	29.2299	12.2577
132ATULU	0.8474	-0.849	0	0	4.9731	2.4078
132AWASH	0.8843	-0.815	0	0	24	11.6
132AWASSA	1.0143	-0.409	0	0	40.1403	17.9625
132BD2	1.0417	-0.609	0	0	0	0
132BLEMIMB	0.9182	-0.751	0	0	3.5141	0.5271
132BLION	0.9209	-0.742	0	0	24.5418	18.694
132COTEBE	0.9169	-0.752	0	0	84.6765	39.1733
132DZEIT	0.8861	-0.79	0	0	55.7315	26.9793
132EGEDA	0.8977	-0.789	0	0	7.8543	3.8049
132GEFERSA	0.9325	-0.731	0	0	212.4279	99.5179
132GELAN	0.929	-0.744	0	0	28.3229	13.7167
132KALITI1	0.9229	-0.746	0	0	89.9306	40.4531
132KALITI2	0.916	-0.752	0	0	73.5335	27.8761
132KALITIGS	0.9198	-0.749	0	0	4.1342	2.0011
132KALITINEW	0.921	-0.748	0	0	36.3959	17.9151
132KNORIT	0.904	-0.774	0	0	8.2686	4.0019
132KOKA	0.8843	-0.809	0	0	8.8	4.2
132MEKANISA	0.9144	-0.751	0	0	54.7824	19.8009
132MELKYGO	0.9201	-0.766	0	0	20.8601	8.3308
132MOJO	0.8887	-0.794	0	0	28.4855	13.7902
132NAZRET2	0.8743	-0.817	0	0	56.9646	27.5495
132REPPIWE	0.9201	-0.744	0	0	0	0
132SEBETA1	0.9335	-0.73	0	0	154.1373	52.4707
132SHSMNE	0.8533	-0.842	0	0	20.8476	8.752
132TAY2	1.0383	-0.596	0	0	0	0
132WENJI	0.8793	-0.816	0	0	5.9769	2.8927
132WEREGENU	0.9142	-0.754	0	0	54.5209	26.4
132WSODO	1.0553	-0.35	0	0	29.3161	15.9089
132YESU	0.9225	-0.748	0	0	32.3276	15.64
132YIGALEM2	1.0756	-0.369	0	0	28.571	13.6344
132YIGALM	1.0381	-0.397	0	0	17.3795	6.1326
230ADAMAWF2	0.9736	-0.689	0	0	0	0
230ADIGALA	0.9595	-0.892	0	0	0.4341	-0.8888
230AGARO	0.9907	-0.534	0	0	2.525	1.2557
230ALAMATA	0.9942	-0.819	0	0	24.3136	11.7866
230ASHEGODAWF	0.9839	-0.826	0	0	0	0
230AWASH7K	0.9677	-0.776	0	0	20.3043	8.5068
230AXUM	1.01	-0.752	0	0	3.7716	1.7915
230BDAR2	1.0521	-0.622	0	0	44.5907	21.4963
230BEDELE	0.9766	-0.541	0	0	21.2194	28.04724
230BOLEARABSA	0.9573	-0.677	0	0	3.08	1.5
230COMBOLCHA	0.9623	-0.844	0	0	63.0643	24.3886

230COTEBE1	0.9544	-0.68	0	0	0	0
230DBRHAN	0.9578	-0.811	0	0	35.5233	15.5403
230DDAWA-3	0.9565	-0.865	0	0	83.7624	35.6101
230DJBTBR	0.9506	-0.905	0	0	30	14.5
230DM	1.0375	-0.594	0	0	35.5616	15.4456
230EIZONE	0.966	-0.674	0	0	23.2974	1.12758
230ENDASILASE	0.9736	-0.763	0	0	21.8903	43.70259
230FINCA2	1.0167	-0.583	0	0	4.7956	2.3198
230FINCHA	1.0184	-0.583	0	0	7.4884	3.6245
230GASHENA	1.0208	-0.765	0	0	4.238	0.2231
230GEFERSA	0.9613	-0.667	0	0	0	0
230GELAN	0.9648	-0.659	0	0	0	0
230GG1	1.0104	-0.507	0	0	0	0
230GGNEW	1.0097	-0.51	0	0	6.876	2.4148
230GHEDO	0.9979	-0.62	0	0	54.5361	17.01702
230GIMMA NEW	0.9953	-0.529	0	0	31.596	14.8437
230GONDER2	1.043	-0.714	0	0	23.6902	10.8937
230HOSSANA	0.9892	-0.593	0	0	20.4661	10.8591
230HURSO	0.9609	-0.862	0	0	0.4341	0.2102
230KALITI1	0.9593	-0.667	0	0	0	0
230KOKA	0.9697	-0.695	0	0	53.4845	42.19759
230LEGETAFO	0.9571	-0.678	0	0	46.6735	22.6296
230MEHONI	0.9913	-0.823	0	0	4.124	1.6228
230MEKELE	0.9786	-0.827	0	0	175.2094	82.9428
230MELK W	0.9428	-0.713	0	0	0	15.43943
230MELKYGO	0.9391	-0.714	0	0	0	61.27421
230METEMA	1.0298	-0.783	0	0	1.9673	0.9522
230MOTA	1.0508	-0.612	0	0	2.4989	1.2096
230NESHI	1.0181	-0.566	0	0	0	0
230NIFASMW	1.0392	-0.707	0	0	4.6258	0.5002
230SEBETA1	0.9614	-0.661	0	0	0	0
230SEBETA2	0.9676	-0.649	0	0	49.5489	24.2583
230SINOSTILL	0.9563	-0.713	0	0	20.855	9.931
230SUDB	1.0234	-0.802	0	0	185	0
230SULULTA	0.9659	-0.664	0	0	49.6272	18.9605
230TEKEZE	1.0193	-0.738	0	0	2.3287	1.1752
230TORHAYL	0.9614	-0.664	0	0	5.4262	0.123
230WOLDIYA	0.9843	-0.831	0	0	9.2397	4.472
230WOLKITE	0.9948	-0.583	0	0	20.3304	9.8399
230YIRGALEM	1.0919	-0.339	0	0	0	0
400BDAR	1.0409	-0.548	0	0	0	0
400BELES	1.0318	-0.496	0	0	0	55.49118
400DMARKOS	1.0396	-0.584	0	0	0	0
400GELAN	0.9864	-0.583	0	0	0	13.85566
400GG2	1.0265	-0.386	0	0	0	0
400GGG3	1.0617	-0.292	0	0	0	0
400GGNEW	1.0249	-0.389	0	0	0	18.24692
400GRANDR	1.0405	-0.504	0	0	15.9788	57.49728
400GENDAWA	1.1272	-0.3	0	0	0	0
400HOLETA	0.9917	-0.59	0	0	0	0
400SEBETA2	0.9915	-0.584	0	0	0	-88.4774
400SULULTA	0.9908	-0.605	0	0	0	0
400WSODO	1.0636	-0.326	0	0	0	117.9173
400YIRGALEM	1.1005	-0.324	0	0	0	0
Total			2576.569	29.86695	2461.636	1315.868

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Table **B. 4** Power flow branch report with 10% Capacitive TCSC in line 42.

			Line Flow From		Line Flow To		Line losses	
Line	From Bus	To Bus	[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	18.53713	-128.976	-9.0196	0.2245	9.51753
109	FINCHAPP	230FINCHA	101.2	23.74657	-100.937	-19.3558	0.26253	4.39078
110	TAY2 PP	132TAY2	14.9	-11.8586	-14.8609	13.0417	0.03906	1.1831
111	KOKAPP	132KOKA	12.4	26.2	-12.2475	-25.1078	0.15247	1.09217
112	MELKAWPP	230MELK W	29.8	71.92424	-29.6333	-67.1517	0.16668	4.77258
113	400BDAR	230BDAR2	342.8918	-41.5129	-342.502	67.63779	0.38969	26.1249
114	400DMARKOS	230DM	43.9904	9.006039	-43.9827	-8.56952	0.00771	0.43652
115	132BD2	230BDAR2	14.73848	-11.7914	-14.7311	12.10139	0.00734	0.30995
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.8176	-14.7076	0.08243	2.29237
117	400YIRGALEM	230YIRGALEM	71.0935	36.87802	-71.0755	-35.5275	0.01801	1.35053

118	GG2PP	400GG2	278.4	-86.2456	-277.951	110.6417	0.44919	24.3962
119	400GGNEW	230GGNEW	65.96869	12.18634	-65.9576	-4.11082	0.01114	8.07551
120	400SEBETA2	230SEBETA2	256.9924	102.8864	-256.734	-84.0694	0.25801	18.817
121	400SULULTA	230SULULTA	349.7327	156.2371	-349.394	-131.814	0.33823	24.4236
122	ADAMAWF2	230ADAMAWF2	88	35.09377	-87.8371	-28.1626	0.16289	6.93114
123	REPPIWEPP	132REPPIWE	25.2	16	-25.1714	-12.7396	0.02858	3.26045
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	130.19	0	13.19
125	GG3PP	400GGG3	955.599	89.84156	-951.568	190.702	4.0309	280.544
126	400GELAN	230GELAN	597.6531	198.3256	-597.653	-148.73	0	49.5953
127	230GEFERSA	132GEFERSA	233.0973	115.5203	-232.743	-97.5328	0.35401	17.9875
128	400WSODO	132WSODO	53.00124	18.1428	-52.9957	-16.7612	0.00555	1.38159
129	230GELAN	132GELAN	241.5572	114.8081	-241.111	-90.5028	0.4466	24.3054
130	TEKEZEPP	230TEKEZE	176.1	25.15176	-175.739	-10.2933	0.36091	14.8585
131	230COTEBE1	132COTEBE	113.1864	66.86718	-113.078	-56.243	0.10814	10.6242
132	230KALITI1	132KALITI1	214.7982	110.0964	-214.39	-89.231	0.408	20.8654
133	230MELKYGO	132MELKYGO	46.1478	17.35787	-46.0428	-14.6145	0.10502	2.74334
134	230YIRGALEM	132YIGALEM2	71.0755	35.52749	-71.0236	-32.9027	0.0519	2.6248
135	ASHEGODAWF	230ASHEGODWF	8.3	15.99551	-8.29008	-15.6733	0.00992	0.32218
136	ABASAPP	132KALITI1	3.37	0.35	-3.36648	-0.33748	0.00352	0.01252
137	BELESPP	400BELES	461.2	-106.469	-460.355	163.1114	0.84464	56.642
138	NESHIPP	230NESHI	89.8	-14.2	-89.5074	23.58076	0.29261	9.3808
139	230SEBETA1	132SEBETA1	194.9846	86.04692	-194.641	-70.2824	0.34399	15.7646
140	AWASHPP	132AWASH	26	25.8	-25.8162	-21.991	0.18383	3.80899
1	230AXUM	230TEKEZE	-26.1422	-16.5006	26.28609	-2.84783	0.14389	-19.348
2	400SULULTA	400HOLETA	-294.883	8.529212	295.4163	-25.7996	0.5338	-17.27
3	400WSODO	400GGG3	-947.451	143.533	951.5681	-190.702	4.11714	-47.169
4	230KOKA	230GELAN	-67.7689	24.98175	68.40505	-30.2794	0.63614	-5.2977
5	230KOKA	230EIZONE	-56.6068	23.54606	56.92722	-27.7792	0.32039	-4.2331
6	230LEGETAFO	230BOLEARABSA	-37.4941	3.448666	37.50576	-4.03402	0.01164	-0.5854
7	230WOLDIYA	230COMBOLCHA	27.68501	14.76043	-27.3798	-33.2668	0.30525	-18.506
8	230KALITI1	230BOLEARABSA	40.72498	-8.40913	-40.5858	2.534024	0.13922	-5.8751
9	230COTEBE1	230LEGETAFO	-113.186	-66.8672	113.3459	64.50039	0.15953	-2.3668
10	230SULULTA	230LEGETAFO	219.7682	54.07725	-218.523	-58.0709	1.2455	-3.9936
11	400BDAR	400DMARKOS	99.5887	-62.0838	-99.3142	-53.5609	0.2745	-115.64
12	400DMARKOS	400SULULTA	55.32381	44.55491	-54.8502	-164.766	0.47361	-120.21
13	230MOTA	230BDAR2	15.85385	-11.6642	-15.8218	-1.44273	0.03203	-13.107
14	400HOLETA	400SEBETA2	-295.416	25.79962	295.5433	-44.6844	0.12698	-18.885
15	400GELAN	400SEBETA2	20.22575	-101.319	-20.1638	80.22985	0.06197	-21.089
16	230MEHONI	230MEKELE	12.35278	7.666775	-12.2611	-25.1191	0.09169	-17.452
17	400GELAN	400WSODO	-617.879	-110.863	639.4777	80.20151	21.5988	-30.661
18	400SEBETA2	400GG2	-532.372	-49.9545	540.5567	52.47044	8.18481	2.5159
19	400WSODO	400GG2	331.5901	114.972	-328.594	-177.116	2.99566	-62.144
20	400YIRGALEM	400WSODO	78.28781	311.4402	-76.6181	-474.767	1.66973	-163.33
21	400GGNEW	400GG2	-65.9687	-30.4333	65.98855	14.00375	0.01986	-16.43
22	400YIRGALEM	400GENDAWA	-149.381	-348.318	150.2	-130.19	0.81869	-478.51
23	230ALAMATA	230ASHEGODWF	12.20012	-2.13631	-12.1373	-20.2304	0.06287	-22.367
24	400GRANDR	400BELES	-15.9788	-57.4973	16.00768	-98.1978	0.02888	-155.7
25	132BD2	132TAY2	-14.7385	11.79143	14.86094	-13.0417	0.12246	-1.2503
26	132KOKA	132DZEIT	-12.3261	5.333332	12.46494	-6.51763	0.13888	-1.1843
27	230BDAR2	230NIFASMW	105.3604	-27.7791	-102.556	8.561269	2.80462	-19.218
28	132AWASSA	132ALABA	-16.3874	-3.49569	16.65912	0.059846	0.27172	-3.4358
29	132WSODO	132ALABA	23.6796	0.852308	-23.2739	-3.26145	0.40568	-2.4091
30	132YIGALM	132AWASSA	24.13537	13.36335	-23.7529	-14.4668	0.38247	-1.1035
31	230GASHENA	230NIFASMW	-96.0981	-5.56329	97.92993	-9.06147	1.83181	-14.625
32	132YIGALM	132YIGALEM2	-41.5149	-19.496	42.45259	19.26829	0.93772	-0.2277
33	132AWASH	132KOKA	-5.03657	2.665247	5.05361	-3.5634	0.01704	-0.8981
34	230DBRHAN	230COMBOLCHA	36.14495	-28.9027	-35.6845	8.878237	0.46041	-20.024
35	132SHSMNE	132ATULU	3.047753	-0.4791	-3.03201	-2.08958	0.01574	-2.5687
36	132ASSELA	132ATULU	1.94539	-1.38564	-1.94109	-0.31822	0.0043	-1.7039
37	132WEREGNU	132COTEBE	-35.7691	-19.403	35.84156	19.42549	0.07251	0.02253
38	230TEKEZE	230MEKELE	147.1243	11.9659	-142.599	-18.7329	4.52572	-6.767
39	132BLEMIMB	132COTEBE	7.447307	2.093031	-7.4398	-2.35577	0.0075	-0.2627
40	400BDAR	400BELES	-442.481	103.5967	444.3477	-120.405	1.86718	-16.808
41	132GELAN	132DZEIT	70.45365	23.66499	-68.1964	-20.4617	2.25721	3.20332
42	132KNORIT	132GELAN	-59.2355	-14.6541	60.40734	15.99049	1.17183	1.33643
43	132EGEDA	132GELAN	-37.6178	-6.14066	38.64223	6.345582	1.02439	0.20492
44	132SEBETA1	132BLION	38.01097	15.85469	-37.6819	-15.7529	0.32905	0.10183
45	132GELAN	132KALITI1	16.52748	14.27331	-16.4548	-14.5421	0.07271	-0.2688
46	132GELAN	132YESU	26.75696	16.51168	-26.6372	-16.609	0.11978	-0.0974
47	132KALITI1	132YESU	5.695138	-1.32837	-5.69041	0.969041	0.00472	-0.3593
48	230DBRHAN	230SINOSTILL	-71.6683	13.36235	74.01682	-36.7845	2.34857	-23.422

49	132MEKANISA	132KALITI1	-16.6587	-9.83618	16.76506	9.372222	0.1064	-0.464
50	132KALITI1	132WEREGENU	18.87933	6.49788	-18.7518	-6.99704	0.12748	-0.4992
51	132KALITI2	132KALITI1	-37.7034	-14.3826	37.90554	14.43611	0.20211	0.05353
52	132KALITI1	132KALITINEW	47.45336	20.17239	-47.3833	-20.1178	0.07004	0.05457
53	132KALITINEW	132BLEMIMB	10.98742	2.20272	-10.9614	-2.62013	0.02601	-0.4174
54	230LEGETAFO	230SINOSTILL	95.99742	-32.5078	-94.8718	26.85346	1.1256	-5.6543
55	132WENJI	132KOKA	-31.1416	-5.60389	31.28393	5.568186	0.14233	-0.0357
56	132MOJO	132KNORIT	-50.317	-9.99608	50.96691	10.65216	0.64988	0.65608
57	132NAZRET2	132ADAMAWF1	-26.7303	-14.7376	26.81757	14.70763	0.0873	-0.03
58	132EGEDA	132KOKA	29.76354	2.335764	-29.369	-2.5754	0.39451	-0.2396
59	132KOKA	132NAZRET2	30.47545	12.7901	-30.2343	-12.8119	0.24111	-0.0218
60	132MOJO	132KOKA	21.83153	-3.79412	-21.6704	3.355008	0.16117	-0.4391
61	132WENJI	132AWASH	-6.82091	-8.2187	6.852738	7.725766	0.03183	-0.4929
62	132ASSELA	132WENJI	-31.1753	-10.8721	31.98561	10.92989	0.81032	0.05783
63	230METEMA	230GONDER2	-188.221	10.05491	192.5669	-46.6048	4.34586	-36.55
64	230SUDB	230METEMA	-185	-4.6E-13	186.2537	-11.0071	1.25372	-11.007
65	230MELKYGO	230MELK W	-46.1478	-78.6321	46.23268	78.34455	0.08487	-0.2875
66	230GONDER2	230BDAR2	-216.257	35.71105	223.104	-72.0137	6.84693	-36.303
67	230DM	230MOTA	18.46378	-27.5029	-18.3527	10.45457	0.11103	-17.048
68	230GASHENA	230ALAMATA	91.86012	5.340188	-90.1436	-19.445	1.71652	-14.105
69	230DM	230FINCHA	-10.0427	20.6268	10.1634	-34.5433	0.12071	-13.916
70	230FINCA2	230FINCHA	-8.52033	-30.8054	8.536073	29.25175	0.01575	-1.5537
71	230GHEDO	230FINCHA	-74.1429	-27.6329	74.7496	21.02284	0.60669	-6.6101
72	132GEFERSA	132SEBETA1	-2.49029	-2.39152	2.492313	1.956969	0.00203	-0.4346
73	132GEFERSA	132KALITI1	22.80573	0.40645	-22.584	-1.04028	0.22175	-0.6338
74	132MELKYGO	132SHSMNE	25.18268	6.283729	-23.8954	-8.2729	1.28733	-1.9892
75	230NESHI	230FINCA2	89.50739	-23.5808	-89.0271	19.40752	0.4803	-4.1732
76	230FINCA2	230GHEDO	92.75182	9.078088	-91.548	-18.5821	1.20383	-9.504
77	230GHEDO	230GEFERSA	111.1548	29.19801	-109.307	-65.2533	1.8479	-36.055
78	132KALITI2	132KALITIGS	-35.8301	-13.4935	35.93443	13.50609	0.10436	0.01258
79	230WOLKITE	230SEBETA1	89.2315	-2.89915	-86.7497	-15.312	2.48179	-18.211
80	230GEFERSA	230TORHAYL	-43.9766	13.94624	44.03168	-15.751	0.0551	-1.8048
81	132KALITI1	132KALITIGS	40.16644	15.54753	-40.0686	-15.5072	0.09781	0.04033
82	230ENDASLASE	230AXUM	-21.8903	-43.7026	22.3706	14.70907	0.4803	-28.994
83	230GEFERSA	230SULULTA	-79.8139	-64.2133	79.99905	58.77581	0.18518	-5.4375
84	132REPPIWE	132MEKANISA	38.29243	10.00488	-38.1237	-9.96472	0.16868	0.04016
85	230AGARO	230GIMMA NEW	-23.9045	-14.554	23.96291	7.363939	0.0584	-7.1901
86	230AGARO	230BEDELE	21.3795	13.29832	-21.2194	-28.0472	0.1601	-14.749
87	230GG1	230GGNEW	128.9755	9.019598	-128.909	-10.2207	0.0667	-1.2011
88	230GGNEW	230WOLKITE	131.9565	1.085495	-130.111	-1.66495	1.84526	-0.5795
89	230ALAMATA	230MEHONI	16.50402	1.746585	-16.4768	-9.28957	0.02724	-7.543
90	132BLION	132REPPIWE	13.14012	-2.94115	-13.121	2.734679	0.01911	-0.2065
91	230GIMA NEW	230GGNEW	-55.5589	-22.2076	56.03382	10.83121	0.47491	-11.376
92	230HOSSANA	230WOLKITE	-20.4661	-10.8591	20.54938	-5.2758	0.08328	-16.135
93	230SEBETA2	230SEBETA1	207.1855	59.81114	-206.606	-61.0163	0.57956	-1.2051
94	230SEBETA1	230KALITI1	48.86731	7.080973	-48.8059	-8.69037	0.0614	-1.6094
95	230SEBETA1	230TORHAYL	49.50376	-16.7996	-49.4579	15.62803	0.04588	-1.1716
96	230GELAN	230KALITI1	207.1671	92.3948	-206.717	-92.9969	0.44974	-0.6021
97	230EIZONE	230GELAN	-80.2246	26.65159	80.52382	-28.1932	0.2992	-1.5416
98	230MELK W	230KOKA	-16.5994	-26.6323	16.77575	5.289265	0.17639	-21.343
99	230KOKA	230ADAMAWF2	-87.6384	-29.4233	87.83711	28.16263	0.1987	-1.2607
100	230ALAMATA	230WOLDIYA	37.12585	8.048129	-36.9247	-19.2324	0.20115	-11.184
101	230KOKA	230AWASH7K	73.23888	-20.4349	-71.9272	8.224488	1.31172	-12.21
102	230DDAWA-3	230AWASH7K	-50.6076	-6.9781	51.62285	-16.7313	1.01524	-23.709
103	230DDAWA-3	230HURSO	-33.1548	-28.632	33.23075	25.7515	0.07596	-2.8805
104	230MEKELE	230ASHEGODWF	-20.3497	-39.0907	20.42734	35.9037	0.0776	-3.187
105	230KOKA	230HURSO	68.51502	-46.1565	-64.5797	-6.04545	3.93532	-52.202
106	230HURSO	230ADIGALA	30.91486	-19.9162	-30.6018	-1.68859	0.31304	-21.605
107	230ADIGALA	230DJBTBR	30.16771	2.577388	-30	-14.5	0.16771	-11.923
Total							114.9328	-1286

Power flow report with TCSC in line 17.

The resulting bus and line flow reports given in Table **B.5** and **B.6**.

Table **B. 5** Power flow bus report with 40% Capacitive TCSC in line 17

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.951	-0.6512	3.37	0.35	0	0
ADAMAWF1	0.9401	-0.6617	26.9	17	0	0
ADAMAWF2	1	-0.5295	88	10.84237	0	0
ASHEGODAWF	1	-0.7225	8.3	10.90095	0	0
AWASHPP	0.9802	-0.6483	26	25.8	0	0
BELESPP	1	-0.2994	461.2	-129.16	0	0
FINCHAPP	1.03	-0.4554	101.2	0.29319	0	0
GG1PP	1.02	-0.372	129.2	3.875128	0	0
GG2PP	1	-0.2756	278.4	-130.959	0	0
GG3PP	1.05	0	942.9015	64.45057	0	0
GNALE3PP	1.0886	-0.2421	150.2	-117	0	0
KOKAPP	0.9434	-0.7038	12.4	26.2	0	0
MELKAWPP	1	-0.5943	29.8	60.76656	0	0
NESHIPP	1.0065	-0.3807	89.8	-17.2	0	0
REPPIWEPP	0.999	-0.5616	25.2	16	0	0
TAY2 PP	1	-0.4611	14.9	-13.7387	0	0
TEKEZE PP	1.03	-0.5596	176.1	20.51809	0	0
132ADAMAWF1	0.9055	-0.7201	0	0	0	0
132ALABA	1.0424	-0.3733	0	0	6.6148	3.2016
132ASSELA	0.8743	-0.7483	0	0	29.2299	12.2577
132ATULU	0.8709	-0.7513	0	0	4.9731	2.4078
132AWASH	0.911	-0.7202	0	0	24	11.6
132AWASSA	1.0227	-0.4017	0	0	40.1403	17.9625
132BD2	1.0491	-0.5233	0	0	0	0
132BLEMIMB	0.9449	-0.6592	0	0	3.5141	0.5271
132BLION	0.9474	-0.6513	0	0	24.5418	18.694
132COTEBE	0.9436	-0.6604	0	0	84.6765	39.1733
132DZEIT	0.9138	-0.6961	0	0	55.7315	26.9793
132EGEDA	0.9247	-0.6953	0	0	7.8543	3.8049
132GEFERSA	0.9582	-0.6406	0	0	212.4279	99.5179
132GELAN	0.9559	-0.652	0	0	28.3229	13.7167
132KALITI1	0.9497	-0.6546	0	0	89.9306	40.4531
132KALITI2	0.943	-0.6601	0	0	73.5335	27.8761
132KALITIGS	0.9467	-0.6571	0	0	4.1342	2.0011
132KALITINEW	0.9478	-0.656	0	0	36.3959	17.9151
132KNORIT	0.9295	-0.6827	0	0	8.2686	4.0019
132KOKA	0.9111	-0.715	0	0	8.8	4.2
132MEKANISA	0.9413	-0.6597	0	0	54.7824	19.8009
132MELKYGO	0.9315	-0.6691	0	0	20.8601	8.3308
132MOJO	0.915	-0.7018	0	0	28.4855	13.7902
132NAZRET2	0.9015	-0.7227	0	0	56.9646	27.5495
132REPPIWE	0.9467	-0.6536	0	0	0	0
132SEBETA1	0.9594	-0.6405	0	0	154.1373	52.4707
132SHSMNE	0.8727	-0.7439	0	0	20.8476	8.752
132TAY2	1.0444	-0.5091	0	0	0	0
132WENJI	0.906	-0.721	0	0	5.9769	2.8927
132WEREGENU	0.941	-0.662	0	0	54.5209	26.4
132WSODO	1.0628	-0.3429	0	0	29.3161	15.9089
132YESU	0.9494	-0.656	0	0	32.3276	15.64
132YIGALEM2	1.0836	-0.3615	0	0	28.571	13.6344
132YIGALM	1.0465	-0.3894	0	0	17.3795	6.1326
230ADAMAWF2	0.9923	-0.5978	0	0	0	0
230ADIGALA	0.9881	-0.7935	0	0	0.4341	-0.8888
230AGARO	0.9996	-0.4706	0	0	2.525	1.2557
230ALAMATA	1.0028	-0.7249	0	0	24.3136	11.7866
230ASHEGODAWF	0.989	-0.7305	0	0	0	0
230AWASH7K	0.9914	-0.6817	0	0	20.3043	8.5068
230AXUM	1.0123	-0.6567	0	0	3.7716	1.7915
230BDAR2	1.0614	-0.5361	0	0	44.5907	21.4963
230BEDELE	0.9856	-0.4774	0	0	21.2194	28.35199
230BOLEARABSA	0.9825	-0.5896	0	0	3.08	1.5
230COMBOLCHA	0.9779	-0.7501	0	0	63.0643	24.3886

230COTEBE1	0.9797	-0.5928	0	0	0	0
230DBRHAN	0.9774	-0.7181	0	0	35.5233	15.5403
230DDAWA-3	0.9839	-0.7676	0	0	83.7624	35.6101
230DJBTBR	0.9796	-0.8062	0	0	30	14.5
230DM	1.0509	-0.5093	0	0	35.5616	15.4456
230EIZONE	0.99	-0.5845	0	0	23.2974	1.12758
230ENDASILASE	0.9758	-0.6678	0	0	21.8903	43.85689
230FINCA2	1.027	-0.4966	0	0	4.7956	2.3198
230FINCHA	1.0282	-0.4966	0	0	7.4884	3.6245
230GASHENA	1.03	-0.6732	0	0	4.238	0.2231
230GEFERSA	0.9858	-0.5808	0	0	0	0
230GELAN	0.9906	-0.5711	0	0	0	0
230GG1	1.0187	-0.4443	0	0	0	0
230GGNEW	1.0183	-0.4467	0	0	6.876	2.4148
230GHEDO	1.013	-0.5337	0	0	54.5361	17.01702
230GIMMA NEW	1.0042	-0.466	0	0	31.596	14.8437
230GONDER2	1.0533	-0.6264	0	0	23.6902	10.8937
230HOSSANA	1.0047	-0.5215	0	0	20.4661	10.8591
230HURSO	0.9882	-0.765	0	0	0.4341	0.2102
230KALITI1	0.9851	-0.5793	0	0	0	0
230KOKA	0.99	-0.6035	0	0	53.4845	42.88926
230LEGETAFO	0.9822	-0.5905	0	0	46.6735	22.6296
230MEHONI	0.9989	-0.7282	0	0	4.124	1.6228
230MEKELE	0.9837	-0.7314	0	0	175.2094	82.9428
230MELK W	0.9516	-0.6172	0	0	0	15.72868
230MELKYGO	0.948	-0.6184	0	0	0	62.43792
230METEMA	1.0406	-0.6937	0	0	1.9673	0.9522
230MOTA	1.0619	-0.5265	0	0	2.4989	1.2096
230NESHI	1.0278	-0.48	0	0	0	0
230NIFASMW	1.0487	-0.6176	0	0	4.6258	0.5002
230SEBETA1	0.9865	-0.5754	0	0	0	0
230SEBETA2	0.993	-0.5639	0	0	49.5489	24.2583
230SINOSTILL	0.9806	-0.6242	0	0	20.855	9.931
230SUDB	1.0343	-0.7124	0	0	185	0
230SULULTA	0.9906	-0.5779	0	0	49.6272	18.9605
230TEKEZE	1.0215	-0.6428	0	0	2.3287	1.1752
230TORHAYL	0.9862	-0.5777	0	0	5.4262	0.123
230WOLDIYA	0.9955	-0.7372	0	0	9.2397	4.472
230WOLKITE	1.01	-0.5108	0	0	20.3304	9.8399
230YIRGALEM	1.0998	-0.3322	0	0	0	0
400BDAR	1.0493	-0.4632	0	0	0	0
400BELES	1.0375	-0.4125	0	0	0	56.10699
400DMARKOS	1.0547	-0.5004	0	0	0	0
400GELAN	1.0147	-0.4961	0	0	0	14.66284
400GG2	1.0393	-0.3533	0	0	0	0
400GGG3	1.0684	-0.2858	0	0	0	0
400GGNEW	1.0378	-0.3559	0	0	0	18.70726
400GRANDR	1.0462	-0.4202	0	0	15.9788	58.12492
400GENDAWA	1.1357	-0.2937	0	0	0	0
400HOLETA	1.0177	-0.5081	0	0	0	0
400SEBETA2	1.0178	-0.5034	0	0	0	-93.2325
400SULULTA	1.0158	-0.522	0	0	0	0
400WSODO	1.0709	-0.3198	0	0	0	119.5552
400YIRGALEM	1.1084	-0.3174	0	0	0	0
Total			2563.871	-151.061	2461.636	1317.866

Table **B. 6** Power flow branch report with 40% Capacitive TCSC in line 17.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	3.87513	-128.98	5.45882	0.22017	9.33395
109	FINCHAPP	230FINCHA	101.2	0.29319	-100.951	3.868486	0.24884	4.16168
110	TAY2 PP	132TAY2	14.9	-13.739	-14.8558	15.07884	0.04424	1.34011
111	KOKAPP	132KOKA	12.4	26.2	-12.2558	-25.1669	0.14422	1.03306
112	MELKAWPP	230MELK W	29.8	60.7666	-29.674	-57.1597	0.12597	3.60681
113	400BDAR	230BDAR2	340.796	-46.124	-340.416	71.61075	0.38017	25.4872
114	400DMARKOS	230DM	42.4242	16.7282	-42.4165	-16.2908	0.00772	0.43743
115	132BD2	230BDAR2	14.7172	-13.841	-14.7089	14.19094	0.00829	0.35005
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.8221	-14.8334	0.07791	2.16663
117	400YIRGALEM	230YIRGALEM	71.1141	36.8154	-71.0963	-35.4843	0.01775	1.33108

118	GG2PP	400GG2	278.4	-130.96	-277.899	158.1442	0.50054	27.1854
119	400GGNEW	230GGNEW	50.8544	12.9686	-50.8477	-8.14777	0.00665	4.82081
120	400SEBETA2	230SEBETA2	254.513	108.873	-254.269	-91.0157	0.24485	17.8572
121	400SULULTA	230SULULTA	346.055	160.981	-345.736	-137.912	0.31947	23.0692
122	ADAMAWF2	230ADAMAWF2	88	10.8424	-87.8573	-4.7715	0.14267	6.07087
123	REPPIWEPP	132REPPIWE	25.2	16	-25.1729	-12.9036	0.02714	3.0964
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	129.9762	-2E-14	12.9762
125	GG3PP	400GGG3	942.901	64.4506	-938.993	207.5589	3.90828	272.01
126	400GELAN	230GELAN	619.003	224.405	-619.003	-173.167	-3E-13	51.2382
127	230GEFERSA	132GEFERSA	231.892	112.993	-231.561	-96.175	0.331	16.8182
128	400WSODO	132WSODO	52.948	17.891	-52.9425	-16.5347	0.00545	1.35627
129	230GELAN	132GELAN	243.937	114.134	-243.508	-90.7576	0.42953	23.3764
130	TEKEZEPP	230TEKEZE	176.1	20.5181	-175.742	-5.75897	0.3585	14.7591
131	230COTEBE1	132COTEBE	112.236	65.6761	-112.135	-55.8093	0.10043	9.86684
132	230KALITI1	132KALITI1	215.788	109.367	-215.399	-89.4873	0.38873	19.8796
133	230MELKYGO	132MELKYGO	45.5074	15.1182	-45.4099	-12.5715	0.09749	2.54665
134	230YIRGALEM	132YIGALEM2	71.0963	35.4843	-71.0452	-32.8974	0.05116	2.58699
135	ASHEGODAWF	230ASHEGODWF	8.3	10.901	-8.29427	-10.7147	0.00573	0.18624
136	ABASAPP	132KALITI1	3.37	0.35	-3.36667	-0.33818	0.00333	0.01182
137	BELESPP	400BELES	461.2	-129.16	-460.335	187.1541	0.86479	57.9937
138	NESHIPP	230NESHI	89.8	-17.2	-89.5079	26.56471	0.2921	9.36471
139	230SEBETA1	132SEBETA1	193.823	85.5798	-193.5	-70.7833	0.32287	14.7965
140	AWASHPP	132AWASH	26	25.8	-25.8254	-22.1831	0.17456	3.61691
1	230AXUM	230TEKEZE	-26.1418	-16.514	26.2849	-2.92446	0.14315	-19.439
2	400SULULTA	400HOLETA	-287.474	-13.393	287.954	-5.45236	0.4806	-18.845
3	400WSODO	400GGG3	-935.009	158.242	938.993	-207.559	3.98412	-49.317
4	230KOKA	230GELAN	-67.3329	12.4493	67.8733	-18.5129	0.54044	-6.0636
5	230KOKA	230EIZONE	-56.2216	11.6323	56.4875	-16.3414	0.26595	-4.709
6	230LEGETAFO	230BOLEARABSA	-42.2884	2.1803	42.3024	-2.79205	0.01397	-0.6117
7	230WOLDIYA	230COMBOLCHA	26.0749	8.73765	-25.85	-28.0194	0.22486	-19.282
8	230KALITI1	230BOLEARABSA	45.5462	-7.4358	-45.3824	1.292046	0.16377	-6.1438
9	230COTEBE1	230LEGETAFO	-112.236	-65.676	112.384	63.12661	0.14806	-2.5495
10	230SULULTA	230LEGETAFO	215.274	52.8353	-214.138	-57.5271	1.13649	-4.6919
11	400BDAR	400DMARKOS	101.639	-80.802	-101.346	-37.3179	0.29222	-118.12
12	400DMARKOS	400SULULTA	58.9221	20.5897	-58.5814	-147.589	0.34062	-127
13	230MOTA	230BDAR2	15.7718	-8.8595	-15.7431	-4.52332	0.02869	-13.383
14	400HOLETA	400SEBETA2	-287.954	5.45236	288.067	-25.5916	0.11325	-20.139
15	400GELAN	400SEBETA2	124.152	-80.631	-124.015	58.94745	0.1374	-21.683
16	230MEHONI	230MEKELE	12.3537	11.7882	-12.2298	-29.3769	0.12393	-17.589
17	400GELAN	400WSODO	-743.156	-158.44	760.972	91.17658	17.8167	-67.26
18	400SEBETA2	400GG2	-418.566	-48.996	423.368	2.384209	4.80211	-46.612
19	400WSODO	400GG2	197.632	97.3699	-196.335	-175.256	1.2972	-77.886
20	400YIRGALEM	400WSODO	78.2584	318.778	-76.5435	-484.235	1.71491	-165.46
21	400GGNEW	400GG2	-50.8544	-31.676	50.8669	14.72787	0.01249	-16.948
22	400YIRGALEM	400GENDAWA	-149.372	-355.59	150.2	-129.976	0.8275	-485.57
23	230ALAMATA	230ASHEGODWF	12.1946	2.43786	-12.1036	-25.0364	0.09103	-22.599
24	400GRANDR	400BELES	-15.9788	-58.125	16.0078	-99.3022	0.02899	-157.43
25	132BD2	132TAY2	-14.7172	13.8409	14.8558	-15.0788	0.13854	-1.238
26	132KOKA	132DZEIT	-13.2074	4.94543	13.3511	-6.21005	0.14365	-1.2646
27	230BDAR2	230NIFASMW	103.385	-27.782	-100.732	7.601537	2.65358	-20.18
28	132AWASSA	132ALABA	-16.3485	-3.407	16.6141	-0.10392	0.26564	-3.5109
29	132WSODO	132ALABA	23.6264	0.62582	-23.2289	-3.09768	0.3975	-2.4719
30	132YIGALM	132AWASSA	24.1699	13.4167	-23.7918	-14.5555	0.37813	-1.1388
31	230GASHENA	230NIFASMW	-94.3726	-7.1937	96.1058	-8.10174	1.7332	-15.295
32	132YIGALM	132YIGALEM2	-41.5494	-19.549	42.4742	19.26295	0.92476	-0.2864
33	132AWASH	132KOKA	-5.10647	2.55108	5.12261	-3.50756	0.01614	-0.9565
34	230DBRHAN	230COMBOLCHA	37.645	-24.525	-37.2143	3.630788	0.43072	-20.895
35	132SHSMNE	132ATULU	2.55576	-2.1041	-2.54508	-0.60552	0.01068	-2.7096
36	132ASSELA	132ATULU	2.43475	0.00094	-2.42802	-1.80228	0.00674	-1.8013
37	132WEREGNU	132COTEBE	-35.3036	-19.197	35.3703	19.20465	0.06674	0.00745
38	230TEKEZE	230MEKELE	147.128	7.50823	-142.658	-14.5888	4.46975	-7.0806
39	132BLEMIMB	132COTEBE	7.9194	2.29053	-7.91135	-2.56865	0.00805	-0.2781
40	400BDAR	400BELES	-442.434	126.926	444.327	-143.959	1.89303	-17.033
41	132GELAN	132DZEIT	71.261	23.7604	-69.0826	-20.7693	2.17844	2.99116
42	132KNORIT	132GELAN	-57.8685	-14.361	59.0441	15.6542	1.1756	1.29294
43	132EGEDA	132GELAN	-38.4472	-6.4756	39.457	6.549896	1.00982	0.0743
44	132SEBETA1	132BLION	37.1074	15.5437	-36.81	-15.537	0.29742	0.0067
45	132GELAN	132KALITI1	17.8905	14.4652	-17.8143	-14.7512	0.0762	-0.286
46	132GELAN	132YESU	27.5326	16.6112	-27.4142	-16.7303	0.11835	-0.1191
47	132KALITI1	132YESU	4.9168	-1.4738	-4.91339	1.090268	0.00341	-0.3836
48	230DBRHAN	230SINOSTILL	-73.1683	8.98515	75.4299	-34.0915	2.26156	-25.106

49	132MEKANISA	132KALITI1	-17.51	-9.8225	17.6182	9.323653	0.10818	-0.4988
50	132KALITI1	132WEREGENU	19.3438	6.66009	-19.2173	-7.2028	0.12645	-0.5427
51	132KALITI2	132KALITI1	-37.7036	-14.383	37.8942	14.40136	0.19068	0.01855
52	132KALITI1	132KALITINEW	47.9236	20.3362	-47.8562	-20.2894	0.06743	0.0468
53	132KALITINEW	132BLEMIMB	11.4603	2.3743	-11.4335	-2.81763	0.0268	-0.4433
54	230LEGETAFO	230SINOSTILL	97.3686	-30.409	-96.2849	24.16048	1.08368	-6.2489
55	132WENJI	132KOKA	-31.5469	-6.5646	31.6859	6.506965	0.13899	-0.0576
56	132MOJO	132KNORIT	-49.0175	-9.864	49.5999	10.35935	0.58231	0.49533
57	132NAZRET2	132ADAMAWF1	-26.7396	-14.882	26.8221	14.83337	0.08253	-0.0485
58	132EGEDA	132KOKA	30.5929	2.67069	-30.1993	-2.96587	0.39357	-0.2952
59	132KOKA	132NAZRET2	30.4509	12.5951	-30.225	-12.6676	0.22586	-0.0725
60	132MOJO	132KOKA	20.532	-3.9262	-20.3969	3.392857	0.13515	-0.5333
61	132WENJI	132AWASH	-6.90019	-8.5586	6.93191	8.032011	0.03171	-0.5266
62	132ASSELA	132WENJI	-31.6647	-12.259	32.4702	12.23052	0.80552	-0.0281
63	230METEMA	230GONDER2	-188.195	10.4364	192.457	-48.2385	4.26221	-37.802
64	230SUDB	230METEMA	-185	5.3E-13	186.228	-11.3886	1.22755	-11.389
65	230MELKYGO	230MELK W	-45.5074	-77.556	45.5884	77.23959	0.081	-0.3165
66	230GONDER2	230BDAR2	-216.147	37.3448	222.892	-74.9928	6.74465	-37.648
67	230DM	230MOTA	18.3646	-25.204	-18.2707	7.649864	0.09383	-17.554
68	230GASHENA	230ALAMATA	90.1346	6.97064	-88.4983	-21.6649	1.63625	-14.694
69	230DM	230FINCHA	-11.5097	26.0493	11.6775	-40.0526	0.16779	-14.003
70	230FINCA2	230FINCHA	-7.10247	-22.904	7.11101	21.2963	0.00854	-1.6075
71	230GHEDO	230FINCHA	-74.1192	-18.395	74.6743	11.26334	0.55512	-7.1317
72	132GEFERSA	132SEBETA1	-2.25313	-3.2273	2.2556	2.768914	0.00247	-0.4584
73	132GEFERSA	132KALITI1	21.3864	-0.1156	-21.2019	-0.63607	0.18446	-0.7516
74	132MELKYGO	132SHSMNE	24.5498	4.24072	-23.4034	-6.6479	1.14646	-2.4072
75	230NESHI	230FINCA2	89.5079	-26.565	-89.0294	22.27453	0.47852	-4.2902
76	230FINCA2	230GHEDO	91.3362	-1.6905	-90.2208	-8.41735	1.11546	-10.108
77	230GHEDO	230GEFERSA	109.804	9.7954	-108.235	-48.661	1.56887	-38.866
78	132KALITI2	132KALITIGS	-35.8299	-13.493	35.9284	13.48687	0.09846	-0.0064
79	230WOLKITE	230SEBETA1	74.5664	-9.98	-72.9034	-11.6425	1.66304	-21.623
80	230GEFERSA	230TORHAYL	-43.0181	7.50117	43.0649	-9.43116	0.04673	-1.93
81	132KALITI1	132KALITIGS	40.1549	15.5123	-40.0626	-15.488	0.09228	0.02429
82	230ENDASLASE	230AXUM	-21.8903	-43.857	22.3702	14.72269	0.47986	-29.134
83	230GEFERSA	230SULULTA	-80.639	-71.833	80.8343	66.11631	0.19529	-5.7171
84	132REPPIWE	132MEKANISA	37.425	9.97206	-37.2724	-9.97844	0.15262	-0.0064
85	230AGARO	230GIMMA NEW	-23.9029	-14.577	23.9601	7.252212	0.05729	-7.3252
86	230AGARO	230BEDELE	21.3779	13.3217	-21.2194	-28.352	0.15845	-15.03
87	230GG1	230GGNEW	128.98	-5.4588	-128.915	4.225596	0.06533	-1.2332
88	230GGNEW	230WOLKITE	116.865	-8.9636	-115.443	5.93608	1.42114	-3.0275
89	230ALAMATA	230MEHONI	16.51	5.75773	-16.4777	-13.411	0.03227	-7.6532
90	132BLION	132REPPIWE	12.2682	-3.157	-12.2522	2.931542	0.01597	-0.2255
91	230GIMA NEW	230GGNEW	-55.5561	-22.096	56.0217	10.47096	0.46555	-11.625
92	230HOSSANA	230WOLKITE	-20.4661	-10.859	20.5466	-5.79594	0.08047	-16.655
93	230SEBETA2	230SEBETA1	204.72	66.7574	-204.17	-68.3362	0.54925	-1.5788
94	230SEBETA1	230KALITI1	34.7201	4.9652	-34.6906	-6.83224	0.02951	-1.867
95	230SEBETA1	230TORHAYL	48.5305	-10.566	-48.4911	9.30816	0.03942	-1.2582
96	230GELAN	230KALITI1	227.145	94.5948	-226.644	-95.0989	0.50171	-0.5041
97	230EIZONE	230GELAN	-79.7849	15.2138	80.047	-17.0493	0.26202	-1.8355
98	230MELK W	230KOKA	-15.9144	-35.809	16.2002	14.25402	0.28579	-21.555
99	230KOKA	230ADAMAWF2	-87.6841	-6.1825	87.8573	4.771497	0.17318	-1.411
100	230ALAMATA	230WOLDIYA	35.4802	1.68266	-35.3146	-13.2097	0.16561	-11.527
101	230KOKA	230AWASH7K	73.315	-24.274	-72.0333	11.09936	1.28176	-13.175
102	230DDAWA-3	230AWASH7K	-50.7523	-5.7943	51.729	-19.6062	0.97666	-25.4
103	230DDAWA-3	230HURSO	-33.0101	-29.816	33.0839	26.75013	0.07379	-3.0657
104	230MEKELE	230ASHEGODWF	-20.3215	-38.977	20.3978	35.75111	0.07634	-3.226
105	230KOKA	230HURSO	68.2389	-50.768	-64.4127	-4.89611	3.82627	-55.664
106	230HURSO	230ADIGALA	30.8947	-22.064	-30.591	-0.89761	0.30369	-22.962
107	230ADIGALA	230DJBTBR	30.1569	1.78641	-30	-14.5	0.1569	-12.714
Total							102.235	-1468.9

Power flow report with two TCSC

The resulting bus and line flow reports are given in Table **B**.**7** and **B**.**8**.

Table **B. 7** Power flow bus report with two Capacitive TCSCs 67% in line 42 and 60% in 17.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.974	-0.591	3.37	0.35	0	0
ADAMAWF1	0.97	-0.592	26.9	17	0	0
ADAMAWF2	1.011	-0.471	88	0	0	0
ASHEGODAWF	1	-0.655	8.3	3.94144	0	0
AWASHPP	1	-0.577	26	22.7035	0	0
BELESPP	1.024	-0.254	461.2	-133.2	0	0
FINCHAPP	1.03	-0.399	101.2	-26.38	0	0
GG1PP	1.02	-0.33	129.2	-8.2997	0	0
GG2PP	1	-0.254	278.4	-167.66	0	0
GG3PP	1.05	0	933.237	38.2833	0	0
GNALE3PP	1.098	-0.238	150.2	-117	0	0
KOKAPP	0.973	-0.631	12.4	26.2	0	0
MELKAWPP	1	-0.529	29.8	49.6569	0	0
NESHIPP	1.019	-0.327	89.8	-17.2	0	0
REPPIWEPP	1	-0.502	25.2	10.2496	0	0
TAY2 PP	1	-0.405	14.9	-18.242	0	0
TEKEZE PP	1.03	-0.492	176.1	14.1891	0	0
132ADAMAWF1	0.936	-0.647	0	0	0	0
132ALABA	1.051	-0.367	0	0	6.6148	3.2016
132ASSELA	0.903	-0.673	0	0	29.2299	12.2577
132ATULU	0.897	-0.677	0	0	4.9731	2.4078
132AWASH	0.94	-0.646	0	0	24	11.6
132AWASSA	1.032	-0.395	0	0	40.1403	17.9625
132BD2	1.067	-0.468	0	0	0	0
132BLEMIMB	0.968	-0.598	0	0	3.5141	0.5271
132BLION	0.969	-0.59	0	0	24.5418	18.694
132COTEBE	0.966	-0.599	0	0	84.6765	39.1733
132DZEIT	0.94	-0.629	0	0	55.7315	26.9793
132EGEDA	0.952	-0.626	0	0	7.8543	3.8049
132GEFERSA	0.98	-0.581	0	0	212.428	99.5179
132GELAN	0.979	-0.591	0	0	28.3229	13.7167
132KALITI1	0.972	-0.594	0	0	89.9306	40.4531
132KALITI2	0.966	-0.599	0	0	73.5335	27.8761
132KALITIGS	0.969	-0.596	0	0	4.1342	2.0011
132KALITINEW	0.971	-0.595	0	0	36.3959	17.9151
132KNORIT	0.968	-0.602	0	0	8.2686	4.0019
132KOKA	0.941	-0.642	0	0	8.8	4.2
132MEKANISA	0.963	-0.598	0	0	54.7824	19.8009
132MELKYGO	0.943	-0.601	0	0	20.8601	8.3308
132MOJO	0.95	-0.624	0	0	28.4855	13.7902
132NAZRET2	0.932	-0.649	0	0	56.9646	27.5495
132REPPIWE	0.968	-0.592	0	0	0	0
132SEBETA1	0.981	-0.581	0	0	154.137	52.4707
132SHSMNE	0.893	-0.671	0	0	20.8476	8.752
132TAY2	1.059	-0.453	0	0	0	0
132WENJI	0.936	-0.647	0	0	5.9769	2.8927
132WEREGENU	0.964	-0.601	0	0	54.5209	26.4
132WSODO	1.071	-0.337	0	0	29.3161	15.9089
132YESU	0.972	-0.595	0	0	32.3276	15.64
132YIGALEM2	1.092	-0.355	0	0	28.571	13.6344
132YIGALM	1.055	-0.383	0	0	17.3795	6.1326
230ADAMAWF2	1.011	-0.538	0	0	0	0
230ADIGALA	1.016	-0.727	0	0	0.4341	-0.8888
230AGARO	1.007	-0.428	0	0	2.525	1.2557
230ALAMATA	1.015	-0.659	0	0	24.3136	11.7866
230ASHEGODAWF	0.996	-0.663	0	0	0	0
230AWASH7K	1.014	-0.619	0	0	20.3043	8.5068
230AXUM	1.015	-0.588	0	0	3.7716	1.7915
230BDAR2	1.084	-0.481	0	0	44.5907	21.4963
230BEDELE	0.993	-0.435	0	0	21.2194	28.607
230BOLEARABSA	1.004	-0.532	0	0	3.08	1.5
230COMBOLCHA	0.995	-0.685	0	0	63.0643	24.3886

230COTEBE1	1.002	-0.535	0	0	0	0
230DBRHAN	0.997	-0.655	0	0	35.5233	15.5403
230DDAWA-3	1.01	-0.702	0	0	83.7624	35.6101
230DJBTBR	1.008	-0.739	0	0	30	14.5
230DM	1.07	-0.455	0	0	35.5616	15.4456
230EIZONE	1.012	-0.526	0	0	23.2974	1.12758
230ENDASILASE	0.979	-0.6	0	0	21.8903	44.0682
230FINCA2	1.039	-0.441	0	0	4.7956	2.3198
230FINCHA	1.039	-0.44	0	0	7.4884	3.6245
230GASHENA	1.045	-0.61	0	0	4.238	0.2231
230GEFERSA	1.007	-0.524	0	0	0	0
230GELAN	1.013	-0.513	0	0	0	0
230GG1	1.026	-0.402	0	0	0	0
230GGNEW	1.025	-0.405	0	0	6.876	2.4148
230GHEDO	1.028	-0.477	0	0	54.5361	17.017
230GIMMA NEW	1.011	-0.424	0	0	31.596	14.8437
230GONDER2	1.078	-0.568	0	0	23.6902	10.8937
230HOSSANA	1.018	-0.473	0	0	20.4661	10.8591
230HURSO	1.015	-0.699	0	0	0.4341	0.2102
230KALITI1	1.007	-0.522	0	0	0	0
230KOKA	1.01	-0.543	0	0	53.4845	43.5782
230LEGETAFO	1.004	-0.533	0	0	46.6735	22.6296
230MEHONI	1.009	-0.662	0	0	4.124	1.6228
230MEKELE	0.991	-0.664	0	0	175.209	82.9428
230MELK W	0.96	-0.552	0	0	0	16.0194
230MELKYGO	0.957	-0.553	0	0	0	63.6092
230METEMA	1.066	-0.632	0	0	1.9673	0.9522
230MOTA	1.083	-0.472	0	0	2.4989	1.2096
230NESHI	1.039	-0.424	0	0	0	0
230NIFASMW	1.067	-0.558	0	0	4.6258	0.5002
230SEBETA1	1.008	-0.519	0	0	0	0
230SEBETA2	1.015	-0.508	0	0	49.5489	24.2583
230SINOSTILL	1.002	-0.565	0	0	20.855	9.931
230SUDB	1.06	-0.65	0	0	185	0
230SULULTA	1.012	-0.521	0	0	49.6272	18.9605
230TEKEZE	1.025	-0.575	0	0	2.3287	1.1752
230TORHAYL	1.008	-0.521	0	0	5.4262	0.123
230WOLDIYA	1.009	-0.672	0	0	9.2397	4.472
230WOLKITE	1.023	-0.463	0	0	20.3304	9.8399
230YIRGALEM	1.108	-0.327	0	0	0	0
400BDAR	1.072	-0.411	0	0	0	0
400BELES	1.061	-0.362	0	0	0	58.6791
400DMARKOS	1.076	-0.447	0	0	0	0
400GELAN	1.038	-0.44	0	0	0	15.3556
400GG2	1.05	-0.331	0	0	0	0
400GGG3	1.076	-0.281	0	0	0	0
400GGNEW	1.048	-0.333	0	0	0	19.0881
400GRANDR	1.07	-0.37	0	0	15.9788	60.7465
400GENDAWA	1.145	-0.289	0	0	0	0
400HOLETA	1.04	-0.455	0	0	0	0
400SEBETA2	1.04	-0.451	0	0	0	-97.377
400SULULTA	1.038	-0.468	0	0	0	0
400WSODO	1.079	-0.314	0	0	0	121.344
400YIRGALEM	1.117	-0.312	0	0	0	0
Total			2554.21	-305.41	2461.64	1324.39

Table **B. 8** Power flow branch report with two Capacitive TCSCs 67% in line 42 and 60% in 17

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	-8.2997	-128.98	17.6638	0.22088	9.36404
109	FINCHAPP	230FINCHA	101.2	-26.38	-100.93	30.8247	0.26574	4.44443
110	TAY2 PP	132TAY2	14.9	-18.242	-14.84	20.0515	0.05976	1.80992
111	KOKAPP	132KOKA	12.4	26.2	-12.264	-25.228	0.1357	0.97207
112	MELKAWPP	230MELK W	29.8	49.6569	-29.708	-47.016	0.09223	2.64084
113	400BDAR	230BDAR2	340.333	-43.97	-339.97	68.2685	0.36244	24.2983
114	400DMARKOS	230DM	41.2055	26.3204	-41.197	-25.837	0.00853	0.483
115	132BD2	230BDAR2	14.653	-18.863	-14.642	19.3356	0.0112	0.47296
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.827	-14.963	0.07326	2.03717
117	400YIRGALEM	230YIRGALEM	71.137	36.7502	-71.12	-35.44	0.01747	1.31052

118	GG2PP	400GG2	278.4	-167.66	-277.84	197.993	0.5585	30.3331
119	400GGNEW	230GGNEW	40.685	14.0936	-40.681	-10.914	0.00439	3.18005
120	400SEBETA2	230SEBETA2	252.461	113.396	-252.23	-96.307	0.23432	17.0893
121	400SULULTA	230SULULTA	343.249	167.576	-342.94	-145.45	0.3064	22.1255
122	ADAMAWF2	230ADAMAWF2	88	3.4E-13	-87.862	5.85303	0.13755	5.85303
123	REPPIWEPP	132REPPIWE	25.2	10.2496	-25.178	-7.683	0.0225	2.56665
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	129.751	0	12.7507
125	GG3PP	400GGG3	933.237	38.2833	-929.42	227.386	3.81718	265.669
126	400GELAN	230GELAN	632.314	240.584	-632.31	-188.93	-2E-13	51.6555
127	230GEFERSA	132GEFERSA	231.244	112.59	-230.93	-96.572	0.31524	16.0175
128	400WSODO	132WSODO	52.8907	17.6183	-52.885	-16.289	0.00534	1.32955
129	230GELAN	132GELAN	245.607	115.002	-245.19	-92.332	0.41654	22.6698
130	TEKEZEPP	230TEKEZE	176.1	14.1891	-175.74	0.46688	0.35599	14.656
131	230COTEBE1	132COTEBE	111.735	65.5161	-111.64	-56.153	0.09531	9.36337
132	230KALITI1	132KALITI1	216.441	110.121	-216.07	-90.963	0.37462	19.1581
133	230MELKYGO	132MELKYGO	43.9116	12.7581	-43.825	-10.485	0.08702	2.27311
134	230YIRGALEM	132YIGALEM2	71.1196	35.4397	-71.069	-32.893	0.05037	2.54703
135	ASHEGODAWF	230ASHEGODWF	8.3	3.94144	-8.2974	-3.8577	0.00258	0.08376
136	ABASAPP	132KALITI1	3.37	0.35	-3.3668	-0.3387	0.00317	0.01128
137	BELESPP	400BELES	461.2	-133.2	-460.37	188.798	0.82906	55.5978
138	NESHIPP	230NESHI	89.8	-17.2	-89.515	26.3451	0.28525	9.14511
139	230SEBETA1	132SEBETA1	192.742	86.7467	-192.43	-72.646	0.30768	14.1007
140	AWASHPP	132AWASH	26	22.7035	-25.851	-19.618	0.14893	3.08586
1	230AXUM	230TEKEZE	-26.1412	-16.533	26.2833	-3.0293	0.14216	-19.562
2	400SULULTA	400HOLETA	-282.843	-17.293	283.289	-2.8573	0.44564	-20.15
3	400WSODO	400GGG3	-925.537	176.083	929.42	-227.39	3.88273	-51.303
4	230KOKA	230GELAN	-66.4785	6.22671	66.9679	-12.851	0.48935	-6.6246
5	230KOKA	230EIZONE	-55.4225	5.71211	55.6611	-10.776	0.23861	-5.0635
6	230LEGETAFO	230BOLEARABSA	-45.3748	1.81653	45.3902	-2.4538	0.01537	-0.6373
7	230WOLDIYA	230COMBOLCHA	25.786	4.10582	-25.601	-24.125	0.18495	-20.019
8	230KALITI1	230BOLEARABSA	48.6486	-7.3567	-48.47	0.95381	0.17837	-6.4028
9	230COTEBE1	230LEGETAFO	-111.735	-65.516	111.876	62.8104	0.14043	-2.7057
10	230SULULTA	230LEGETAFO	211.646	52.2654	-210.59	-57.542	1.05334	-5.2769
11	400BDAR	400DMARKOS	102.223	-79.621	-101.94	-43.886	0.27922	-123.51
12	400DMARKOS	400SULULTA	60.7378	17.5656	-60.406	-150.28	0.33231	-132.72
13	230MOTA	230BDAR2	15.3408	-10.734	-15.314	-3.2151	0.02713	-13.949
14	400HOLETA	400SEBETA2	-283.289	2.85734	283.394	-24.052	0.10488	-21.195
15	400GELAN	400SEBETA2	192.954	-66.337	-192.69	44.6136	0.26092	-21.723
16	230MEHONI	230MEKELE	12.3749	17.5218	-12.195	-35.265	0.17973	-17.744
17	400GELAN	400WSODO	-825.268	-189.6	839.317	86.4867	14.0492	-103.12
18	400SEBETA2	400GG2	-343.162	-36.58	346.262	-36.216	3.10034	-72.796
19	400WSODO	400GG2	109.791	93.0258	-109.11	-177.61	0.67592	-84.588
20	400YIRGALEM	400WSODO	78.2254	326.775	-76.461	-494.56	1.76431	-167.78
21	400GGNEW	400GG2	-40.685	-33.182	40.6938	15.8367	0.00884	-17.345
22	400YIRGALEM	400GENDAWA	-149.362	-363.53	150.2	-129.75	0.83756	-493.28
23	230ALAMATA	230ASHEGODWF	12.2146	8.81791	-12.066	-31.682	0.14851	-22.865
24	400GRANDR	400BELES	-15.9788	-60.746	16.0083	-103.91	0.02948	-164.66
25	132BD2	132TAY2	-14.653	18.8626	14.8402	-20.051	0.18721	-1.1888
26	132KOKA	132DZEIT	-7.9327	5.16996	7.99682	-6.6584	0.06413	-1.4884
27	230BDAR2	230NIFASMW	102.918	-23.778	-100.42	2.01687	2.49934	-21.761
28	132AWASSA	132ALABA	-16.3062	-3.3102	16.5655	-0.2821	0.25927	-3.5923
29	132WSODO	132ALABA	23.5692	0.37983	-23.18	-2.9195	0.38892	-2.5397
30	132YIGALM	132AWASSA	24.2076	13.4752	-23.834	-14.652	0.37356	-1.1772
31	230GASHENA	230NIFASMW	-94.1192	-13.645	95.7927	-2.5171	1.67357	-16.162
32	132YIGALM	132YIGALEM2	-41.5871	-19.608	42.4982	19.2583	0.91107	-0.3495
33	132AWASH	132KOKA	-5.31038	1.148	5.32367	-2.1741	0.01329	-1.0261
34	230DBRHAN	230COMBOLCHA	37.8608	-21.545	-37.463	-0.2639	0.39756	-21.809
35	132SHSMNE	132ATULU	1.16789	-3.6564	-1.1588	0.79712	0.00909	-2.8593
36	132ASSELA	132ATULU	3.83288	1.30835	-3.8143	-3.2049	0.01859	-1.8966
37	132WEREGNU	132COTEBE	-35.0589	-19.374	35.1221	19.3708	0.06319	-0.0033
38	230TEKEZE	230MEKELE	147.132	1.38725	-142.73	-8.8578	4.40653	-7.4706
39	132BLEMIMB	132COTEBE	8.16662	2.09898	-8.1586	-2.3914	0.00802	-0.2924
40	400BDAR	400BELES	-442.555	123.591	444.363	-143.56	1.80754	-19.971
41	132GELAN	132DZEIT	65.496	22.4794	-63.728	-20.321	1.76766	2.15851
42	132KNORIT	132GELAN	-70.0513	-18.866	70.5806	18.8789	0.52927	0.01279
43	132EGEDA	132GELAN	-33.1974	-6.0551	33.9091	5.46859	0.71171	-0.5865
44	132SEBETA1	132BLION	36.3781	18.0464	-36.088	-18.081	0.29007	-0.0348
45	132GELAN	132KALITI1	18.821	14.9246	-18.742	-15.226	0.07924	-0.301
46	132GELAN	132YESU	28.0607	16.8636	-27.944	-17.002	0.11706	-0.1381
47	132KALITI1	132YESU	4.38667	-1.7654	-4.3839	1.36166	0.00273	-0.4037
48	230DBRHAN	230SINOSTILL	-73.3841	6.0052	75.5299	-32.821	2.14577	-26.815

49	132MEKANISA	132KALITI1	-18.2079	-12.438	18.3324	11.9343	0.12451	-0.5042
50	132KALITI1	132WEREGENU	19.5845	6.44032	-19.462	-7.0259	0.1225	-0.5856
51	132KALITI2	132KALITI1	-37.7037	-14.383	37.8854	14.3728	0.18176	-0.0102
52	132KALITI1	132KALITINEW	48.1677	20.1128	-48.103	-20.074	0.06467	0.03926
53	132KALITINEW	132BLEMIMB	11.7072	2.15849	-11.681	-2.6261	0.02643	-0.4676
54	230LEGETAFO	230SINOSTILL	97.418	-29.714	-96.385	22.8895	1.03309	-6.8247
55	132WENJI	132KOKA	-32.7403	-8.9474	32.8848	8.8798	0.1445	-0.0676
56	132MOJO	132KNORIT	-60.9389	-13.925	61.7827	14.8642	0.84384	0.93914
57	132NAZRET2	132ADAMAWF1	-26.7491	-15.032	26.8267	14.9628	0.07761	-0.0691
58	132EGEDA	132KOKA	25.3431	2.25021	-25.088	-2.8308	0.25497	-0.5806
59	132KOKA	132NAZRET2	30.4259	12.39	-30.215	-12.518	0.2104	-0.1276
60	132MOJO	132KOKA	32.4534	0.13488	-32.149	-0.407	0.30414	-0.2721
61	132WENJI	132AWASH	-7.13535	-7.4435	7.16145	6.86968	0.0261	-0.5738
62	132ASSELA	132WENJI	-33.0628	-13.566	33.8987	13.4982	0.83592	-0.0678
63	230METEMA	230GONDER2	-188.136	11.3496	192.21	-52.147	4.07381	-40.797
64	230SUDB	230METEMA	-185	-1E-11	186.168	-12.302	1.16841	-12.302
65	230MELKYGO	230MELK W	-43.9116	-76.367	43.9879	76.018	0.07629	-0.3492
66	230GONDER2	230BDAR2	-215.9	41.2531	222.417	-82.108	6.51733	-40.855
67	230DM	230MOTA	17.9394	-27.748	-17.84	9.52418	0.09968	-18.224
68	230GASHENA	230ALAMATA	89.8812	13.422	-88.249	-28.662	1.63171	-15.241
69	230DM	230FINCHA	-12.304	38.1397	12.5943	-51.949	0.29026	-13.81
70	230FINCA2	230FINCHA	-6.15371	-14.96	6.15739	13.3015	0.00368	-1.6588
71	230GHEDO	230FINCHA	-74.1674	-11.742	74.6942	4.19863	0.52683	-7.5438
72	132GEFERSA	132SEBETA1	-1.9179	-2.6101	1.91946	2.12889	0.00156	-0.4812
73	132GEFERSA	132KALITI1	20.4184	-0.3356	-20.258	-0.5046	0.16065	-0.8402
74	132MELKYGO	132SHSMNE	22.9645	2.15414	-22.015	-5.0956	0.94899	-2.9414
75	230NESHI	230FINCA2	89.5147	-26.345	-89.048	21.8894	0.46719	-4.4557
76	230FINCA2	230GHEDO	90.4057	-9.2489	-89.34	-1.3647	1.06581	-10.614
77	230GHEDO	230GEFERSA	108.971	-3.9099	-107.55	-37.15	1.42295	-41.06
78	132KALITI2	132KALITIGS	-35.8298	-13.493	35.9237	13.4711	0.09386	-0.022
79	230WOLKITE	230SEBETA1	64.6478	-17.212	-63.429	-6.607	1.21921	-23.819
80	230GEFERSA	230TORHAYL	-42.2351	4.73757	42.2774	-6.7705	0.04231	-2.0329
81	132KALITI1	132KALITIGS	40.1459	15.4833	-40.058	-15.472	0.08796	0.01116
82	230ENDASLASE	230AXUM	-21.8903	-44.068	22.3696	14.7414	0.47928	-29.327
83	230GEFERSA	230SULULTA	-81.4604	-80.177	81.6697	74.2244	0.20924	-5.953
84	132REPPIWE	132MEKANISA	36.7109	7.31221	-36.575	-7.3624	0.1364	-0.0502
85	230AGARO	230GIMMA NEW	-23.9015	-14.597	23.9579	7.15895	0.05638	-7.4381
86	230AGARO	230BEDELE	21.3765	13.3414	-21.219	-28.607	0.15713	-15.266
87	230GG1	230GGNEW	128.979	-17.664	-128.91	16.4098	0.06547	-1.254
88	230GGNEW	230WOLKITE	106.706	-18.081	-105.52	13.6135	1.18383	-4.468
89	230ALAMATA	230MEHONI	16.5427	11.3526	-16.499	-19.145	0.04387	-7.792
90	132BLION	132REPPIWE	11.5462	-0.6128	-11.533	0.37076	0.01277	-0.242
91	230GIMA NEW	230GGNEW	-55.5539	-22.003	56.0119	10.1705	0.45797	-11.832
92	230HOSSANA	230WOLKITE	-20.4661	-10.859	20.5443	-6.2412	0.07823	-17.1
93	230SEBETA2	230SEBETA1	202.678	72.0484	-202.15	-73.942	0.52527	-1.8938
94	230SEBETA1	230KALITI1	25.0993	1.77857	-25.085	-3.8089	0.01453	-2.0303
95	230SEBETA1	230TORHAYL	47.7395	-7.9761	-47.704	6.6475	0.03588	-1.3286
96	230GELAN	230KALITI1	240.541	98.4792	-240.01	-98.955	0.53536	-0.4759
97	230EIZONE	230GELAN	-78.9585	9.64804	79.1987	-11.701	0.24024	-2.053
98	230MELK W	230KOKA	-14.2801	-45.021	14.7152	23.4283	0.43512	-21.593
99	230KOKA	230ADAMAWF2	-87.6959	4.34606	87.8624	-5.853	0.16652	-1.507
100	230ALAMATA	230WOLDIYA	35.1786	-3.2947	-35.026	-8.5778	0.15287	-11.872
101	230KOKA	230AWASH7K	73.4073	-28.016	-72.148	13.9147	1.25934	-14.101
102	230DDAWA-3	230AWASH7K	-50.8984	-4.6267	51.8436	-22.421	0.94517	-27.048
103	230DDAWA-3	230HURSO	-32.864	-30.983	32.9359	27.735	0.07193	-3.2484
104	230MEKELE	230ASHEGODWF	-20.2888	-38.82	20.3635	35.5401	0.07465	-3.2794
105	230KOKA	230HURSO	67.9899	-55.276	-64.248	-3.7613	3.74188	-59.037
106	230HURSO	230ADIGALA	30.8781	-24.184	-30.582	-0.1171	0.29657	-24.301
107	230ADIGALA	230DJBTBR	30.1474	1.00588	-30	-14.5	0.14741	-13.494
Total							92.5711	-1629.8

Power flow report with SVC at 132Atulu.

The resulting bus and line flow reports are given in Table **B**.**9** and **B**.**10**

Table **B. 9** Power flow bus report with Capacitive SVC-1.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.9385	-0.73357	3.37	0.35	0	0
ADAMAWF1	0.94574	-0.75532	26.9	17	0	0
ADAMAWF2	1	-0.61293	88	23.3715	0	0
ASHEGODAWF	1	-0.80675	8.3	13.874	0	0
AWASHPP	0.98843	-0.74434	26	25.8	0	0
BELESPP	1	-0.37649	461.2	-115.107	0	0
FINCHAPP	1.03	-0.53432	101.2	14.9763	0	0
GG1PP	1.02	-0.42903	129.2	12.4626	0	0
GG2PP	1	-0.30455	278.4	-103.029	0	0
GG3PP	1.05	0	954.463	73.4982	0	0
GNALE3PP	1.0863	-0.24638	150.2	-117	0	0
KOKAPP	0.94903	-0.79694	12.4	26.2	0	0
MELKAWPP	1	-0.68409	29.8	57.8413	0	0
NESHIPP	1	-0.45798	89.8	-17.0842	0	0
REPPIWEPP	0.98598	-0.64068	25.2	16	0	0
TAY2 PP	1	-0.53998	14.9	-12.5792	0	0
TEKEZE PP	1.03	-0.64387	176.1	23.2221	0	0
132ADAMAWF1	0.91133	-0.81304	0	0	0	0
132ALABA	1.04032	-0.37804	0	0	6.6148	3.2016
132ASSELA	0.91376	-0.85996	0	0	29.2299	12.2577
132ATULU	0.95	-0.88607	0	41.9741	4.9731	2.4078
132AWASH	0.91983	-0.81492	0	0	24	11.6
132AWASSA	1.02056	-0.40653	0	0	40.1403	17.9625
132BD2	1.04453	-0.60192	0	0	0	0
132BLEMIMB	0.93193	-0.74136	0	0	3.5141	0.5271
132BLION	0.93356	-0.73273	0	0	24.5418	18.694
132COTEBE	0.93037	-0.74243	0	0	84.6765	39.1733
132DZEIT	0.90995	-0.78355	0	0	55.7315	26.9793
132EGEDA	0.92474	-0.78477	0	0	7.8543	3.8049
132GEFERSA	0.94415	-0.72151	0	0	212.4279	99.5179
132GELAN	0.94575	-0.73548	0	0	28.3229	13.7167
132KALITI1	0.93722	-0.73704	0	0	89.9306	40.4531
132KALITI2	0.93037	-0.74268	0	0	73.5335	27.8761
132KALITIGS	0.93409	-0.73959	0	0	4.1342	2.0011
132KALITINEW	0.93523	-0.73847	0	0	36.3959	17.9151
132KNORIT	0.92532	-0.77007	0	0	8.2686	4.0019
132KOKA	0.91687	-0.80793	0	0	8.8	4.2
132MEKANISA	0.92792	-0.74181	0	0	54.7824	19.8009
132MELKYGO	0.94796	-0.76084	0	0	20.8601	8.3308
132MOJO	0.91503	-0.79159	0	0	28.4855	13.7902
132NAZRET2	0.9073	-0.81553	0	0	56.9646	27.5495
132REPPIWE	0.9331	-0.73528	0	0	0	0
132SEBETA1	0.94518	-0.72125	0	0	154.1373	52.4707
132SHSMNE	0.92822	-0.85918	0	0	20.8476	8.752
132TAY2	1.04064	-0.58802	0	0	0	0
132WENJI	0.91661	-0.8168	0	0	5.9769	2.8927
132WEREGENU	0.92782	-0.74412	0	0	54.5209	26.4
132WSODO	1.06088	-0.34757	0	0	29.3161	15.9089
132YESU	0.93815	-0.73907	0	0	32.3276	15.64
132YIGALEM2	1.08157	-0.3662	0	0	28.571	13.6344
132YIGALM	1.04433	-0.39419	0	0	17.3795	6.1326
230ADAMAWF2	0.98268	-0.68171	0	0	0	0
230ADIGALA	0.97341	-0.88095	0	0	0.4341	-0.8888
230AGARO	0.99442	-0.52803	0	0	2.525	1.2557
230ALAMATA	0.99781	-0.80825	0	0	24.3136	11.7866
230ASHEGODAWF	0.98601	-0.81467	0	0	0	0
230AWASH7K	0.97918	-0.76679	0	0	20.3043	8.5068
230AXUM	1.01097	-0.74103	0	0	3.7716	1.7915
230BDAR2	1.05566	-0.61479	0	0	44.5907	21.4963
230BEDELE	0.98032	-0.53497	0	0	21.2194	28.1732
230BOLEARABSA	0.96821	-0.66942	0	0	3.08	1.5
230COMBOLCHA	0.96898	-0.83368	0	0	63.0643	24.3886

230COTEBE1	0.96543	-0.6726	0	0	0	0
230DBRHAN	0.96619	-0.80095	0	0	35.5233	15.5403
230DDAWA-3	0.96979	-0.85449	0	0	83.7624	35.6101
230DJBTBR	0.96466	-0.89397	0	0	30	14.5
230DM	1.04255	-0.58715	0	0	35.5616	15.4456
230EIZONE	0.9768	-0.66669	0	0	23.2974	1.12758
230ENDASILASE	0.9745	-0.75221	0	0	21.8903	43.7668
230FINCA2	1.02053	-0.57534	0	0	4.7956	2.3198
230FINCHA	1.02206	-0.5754	0	0	7.4884	3.6245
230GASHENA	1.02452	-0.75521	0	0	4.238	0.2231
230GEFERSA	0.9717	-0.65997	0	0	0	0
230GELAN	0.97607	-0.65245	0	0	0	0
230GG1	1.01383	-0.50154	0	0	0	0
230GGNEW	1.01324	-0.50396	0	0	6.876	2.4148
230GHEDO	1.00399	-0.61252	0	0	54.5361	17.017
230GIMMA NEW	0.99897	-0.52335	0	0	31.596	14.8437
230GONDER2	1.04692	-0.70603	0	0	23.6902	10.8937
230HOSSANA	0.99576	-0.58708	0	0	20.4661	10.8591
230HURSO	0.97413	-0.85186	0	0	0.4341	0.2102
230KALITI1	0.97067	-0.66	0	0	0	0
230KOKA	0.97954	-0.68723	0	0	53.4845	42.5301
230LEGETAFO	0.96795	-0.67027	0	0	46.6735	22.6296
230MEHONI	0.99449	-0.81186	0	0	4.124	1.6228
230MEKELE	0.98071	-0.81555	0	0	175.2094	82.9428
230MELK W	0.95389	-0.70702	0	0	0	15.805
230MELKYGO	0.95078	-0.70842	0	0	0	62.8091
230METEMA	1.03393	-0.77408	0	0	1.9673	0.9522
230MOTA	1.05503	-0.60491	0	0	2.4989	1.2096
230NESHI	1.02137	-0.55852	0	0	0	0
230NIFASMW	1.043	-0.69814	0	0	4.6258	0.5002
230SEBETA1	0.97207	-0.65412	0	0	0	0
230SEBETA2	0.97802	-0.64201	0	0	49.5489	24.2583
230SINOSTILL	0.96677	-0.70482	0	0	20.855	9.931
230SUDB	1.02761	-0.79301	0	0	185	0
230SULULTA	0.97632	-0.65687	0	0	49.6272	18.9605
230TEKEZE	1.02024	-0.72718	0	0	2.3287	1.1752
230TORHAYL	0.97191	-0.65662	0	0	5.4262	0.123
230WOLDIYA	0.98905	-0.82066	0	0	9.2397	4.472
230WOLKITE	1.00119	-0.57628	0	0	20.3304	9.8399
230YIRGALEM	1.09776	-0.33681	0	0	0	0
400BDAR	1.04409	-0.54095	0	0	0	0
400BELES	1.03401	-0.48992	0	0	0	55.7252
400DMARKOS	1.04534	-0.57788	0	0	0	0
400GELAN	0.99622	-0.5773	0	0	0	14.1325
400GG2	1.03126	-0.38269	0	0	0	0
400GGG3	1.06661	-0.28986	0	0	0	0
400GGNEW	1.02972	-0.38612	0	0	0	18.4178
400GRANDR	1.04267	-0.49762	0	0	15.9788	57.7358
400GENDAWA	1.13351	-0.29814	0	0	0	0
400HOLETA	1.00115	-0.58396	0	0	0	0
400SEBETA2	1.00098	-0.57896	0	0	0	-90.176
400SULULTA	1.00019	-0.59871	0	0	0	0
400WSODO	1.06905	-0.32435	0	0	0	119.133
400YIRGALEM	1.10635	-0.32198	0	0	0	0
Total			2575.43	-18.2293	2461.636	1318.73

Table **B. 10** Power flow branch report with Capacitive SVC-1.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	12.4626	-128.978	-3.0503	0.222	9.41233
109	FINCHAPP	230FINCHA	101.2	14.9763	-100.946	-10.723	0.2543	4.25278
110	TAY2 PP	132TAY2	14.9	-12.5792	-14.859	13.8198	0.041	1.24055
111	KOKAPP	132KOKA	12.4	26.2	-12.2575	-25.179	0.1425	1.02094
112	MELKAWPP	230MELK W	29.8	57.8413	-29.6836	-54.508	0.1164	3.33361
113	400BDAR	230BDAR2	342.043	-43.3726	-341.657	69.2458	0.3859	25.8732
114	400DMARKOS	230DM	43.3498	11.9135	-43.3421	-11.481	0.0076	0.4328
115	132BD2	230BDAR2	14.7307	-12.5737	-14.723	12.8982	0.0077	0.32454
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.823	-14.859	0.077	2.14088
117	400YIRGALEM	230YIRGALEM	71.1088	36.8313	-71.0909	-35.495	0.0178	1.33603

118	GG2PP	400GG2	278.4	-103.029	-277.934	128.338	0.466	25.3085
119	400GGNEW	230GGNEW	65.0894	12.751	-65.0786	-4.9302	0.0108	7.82077
120	400SEBETA2	230SEBETA2	256.916	99.7183	-256.665	-81.42	0.2509	18.2985
121	400SULULTA	230SULULTA	349.492	151.345	-349.164	-127.65	0.3281	23.6924
122	ADAMAWF2	230ADAMAWF2	88	23.3715	-87.8495	-16.97	0.1505	6.4019
123	REPPIWEPP	132REPPIWE	25.2	16	-25.1721	-12.821	0.0279	3.17863
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	130.031	0	13.0306
125	GG3PP	400GGG3	954.463	73.4982	-950.453	205.571	4.0097	279.07
126	400GELAN	230GELAN	599.853	187.505	-599.853	-139.07	0	48.435
127	230GEFERSA	132GEFERSA	231.944	111.524	-231.604	-94.296	0.3391	17.2288
128	400WSODO	132WSODO	52.9616	17.9556	-52.9562	-16.593	0.0055	1.36271
129	230GELAN	132GELAN	243.894	99.1442	-243.471	-76.134	0.4228	23.0098
130	TEKEZEPP	230TEKEZE	176.1	23.2221	-175.74	-8.4075	0.3598	14.8147
131	230COTEBE1	132COTEBE	112.559	63.199	-112.457	-53.187	0.1019	10.012
132	230KALITI1	132KALITI1	214.441	102.515	-214.055	-82.752	0.3864	19.7626
133	230MELKYGO	132MELKYGO	47.5348	2.12224	-47.4393	0.37035	0.0954	2.4926
134	230YIRGALEM	132YIGALEM2	71.0909	35.4952	-71.0396	-32.899	0.0513	2.59661
135	ASHEGODAWF	230ASHEGODWF	8.3	13.874	-8.29201	-13.615	0.008	0.25931
136	ABASAPP	132KALITI1	3.37	0.35	-3.36658	-0.3379	0.0034	0.01214
137	BELESPP	400BELES	461.2	-115.107	-460.348	172.233	0.8519	57.1258
138	NESHIPP	230NESHI	89.8	-17.0842	-89.5042	26.5674	0.2958	9.48321
139	230SEBETA1	132SEBETA1	193.967	83.6759	-193.636	-68.526	0.3306	15.1502
140	AWASHPP	132AWASH	26	25.8	-25.8283	-22.243	0.1717	3.55664
1	230AXUM	230TEKEZE	-26.142	-16.5062	26.2856	-2.8797	0.1436	-19.386
2	400SULULTA	400HOLETA	-293.12	7.08704	293.6377	-24.911	0.5173	-17.824
3	400WSODO	400GGG3	-946.36	157.392	950.4528	-205.57	4.09	-48.179
4	230KOKA	230GELAN	-68.373	21.8681	68.98692	-27.429	0.6138	-5.5605
5	230KOKA	230EIZONE	-57.189	20.582	57.49688	-24.985	0.3077	-4.4029
6	230LEGETAFO	230BOLEARABSA	-37.377	1.1537	37.38797	-1.7544	0.0112	-0.6007
7	230WOLDIYA	230COMBOLCHA	27.0194	12.1186	-26.7513	-30.962	0.2681	-18.843
8	230KALITI1	230BOLEARABSA	40.6017	-6.29127	-40.468	0.25438	0.1337	-6.0369
9	230COTEBE1	230LEGETAFO	-112.56	-63.199	112.7093	60.7415	0.1503	-2.4575
10	230SULULTA	230LEGETAFO	219.759	48.6731	-218.554	-52.946	1.2051	-4.2732
11	400BDAR	400DMARKOS	100.421	-69.0604	-100.142	-47.541	0.2795	-116.6
12	400DMARKOS	400SULULTA	56.792	35.6278	-56.372	-158.43	0.4201	-122.8
13	230MOTA	230BDAR2	15.7997	-10.6448	-15.7693	-2.5686	0.0305	-13.213
14	400HOLETA	400SEBETA2	-293.64	24.9107	293.7607	-44.234	0.1231	-19.323
15	400GELAN	400SEBETA2	18.4945	-96.372	-18.4406	74.7945	0.0539	-21.578
16	230MEHONI	230MEKELE	12.3517	9.37522	-12.2474	-26.887	0.1042	-17.511
17	400GELAN	400WSODO	-618.35	-105.265	639.5433	68.4781	21.196	-36.787
18	400SEBETA2	400GG2	-532.24	-40.1029	540.2671	39.0674	8.0307	-1.0355
19	400WSODO	400GG2	330.421	118.839	-327.442	-181.98	2.9789	-63.141
20	400YIRGALEM	400WSODO	78.2661	316.89	-76.5628	-481.8	1.7033	-164.91
21	400GGNEW	400GG2	-65.089	-31.1687	65.10872	14.5755	0.0193	-16.593
22	400YIRGALEM	400GENDAWA	-149.37	-353.722	150.2	-130.03	0.8252	-483.75
23	230ALAMATA	230ASHEGODWF	12.1958	-0.24142	-12.1226	-22.226	0.0732	-22.467
24	400GRANDR	400BELES	-15.979	-57.7358	16.00772	-98.617	0.0289	-156.35
25	132BD2	132TAY2	-14.731	12.5737	14.85904	-13.82	0.1283	-1.2461
26	132KOKA	132DZEIT	-12.6	14.0118	12.85809	-15.093	0.2584	-1.0809
27	230BDAR2	230NIFASMW	104.537	-27.9155	-101.794	8.31599	2.7434	-19.6
28	132AWASSA	132ALABA	-16.358	-3.42979	16.62568	-0.0618	0.2672	-3.4916
29	132WSODO	132ALABA	23.6401	0.68402	-23.2405	-3.1398	0.3996	-2.4558
30	132YIGALM	132AWASSA	24.161	13.403	-23.7818	-14.533	0.3792	-1.1298
31	230GASHENA	230NIFASMW	-95.377	-6.08215	97.168	-8.8162	1.7906	-14.898
32	132YIGALM	132YIGALEM2	-41.541	-19.5356	42.46859	19.2642	0.9281	-0.2713
33	132AWASH	132KOKA	-4.9467	6.97822	4.982749	-7.9181	0.036	-0.9399
34	230DBRHAN	230COMBOLCHA	36.7576	-26.9771	-36.313	6.5734	0.4447	-20.404
35	132SHSMNE	132ATULU	4.458	-14.9182	-4.19302	12.1849	0.265	-2.7333
36	132ASSELA	132ATULU	1.46439	-28.3346	-0.78008	27.3814	0.6843	-0.9532
37	132WEREGNU	132COTEBE	-35.463	-17.8951	35.53008	17.9059	0.0671	0.01084
38	230TEKEZE	230MEKELE	147.126	10.112	-142.624	-17.012	4.5014	-6.9005
39	132BLEMIMB	132COTEBE	7.75852	3.62363	-7.74955	-3.8922	0.009	-0.2686
40	400BDAR	400BELES	-442.46	112.433	444.3404	-129.34	1.8759	-16.908
41	132GELAN	132DZEIT	70.6386	14.6506	-68.5896	-11.887	2.049	2.76408
42	132KNORIT	132GELAN	-57.755	-3.81218	58.87591	5.01571	1.1208	1.20353
43	132EGEDA	132GELAN	-38.243	2.37659	39.22882	-2.3286	0.9854	0.04802
44	132SEBETA1	132BLION	37.2031	13.9529	-36.9044	-13.926	0.2987	0.02643
45	132GELAN	132KALITI1	18.5261	23.3606	-18.3954	-23.536	0.1306	-0.1754
46	132GELAN	132YESU	27.8785	21.7193	-27.7325	-21.779	0.1461	-0.0592
47	132KALITI1	132YESU	4.60343	-6.50316	-4.59514	6.13851	0.0083	-0.3646
48	230DBRHAN	230SINOSTILL	-72.281	11.4368	74.58722	-35.595	2.3063	-24.158

49	132MEKANISA	132KALITI1	-17.42	-11.5375	17.54058	11.0771	0.1205	-0.4605
50	132KALITI1	132WEREGENU	19.1922	7.99526	-19.0579	-8.5049	0.1343	-0.5096
51	132KALITI2	132KALITI1	-37.704	-14.3827	37.8994	14.4175	0.1959	0.03475
52	132KALITI1	132KALITINEW	47.7674	21.6916	-47.6971	-21.638	0.0703	0.05316
53	132KALITINEW	132BLEMIMB	11.3012	3.72337	-11.2726	-4.1507	0.0286	-0.4274
54	230LEGETAFO	230SINOSTILL	96.5481	-31.5785	-95.4422	25.6641	1.1059	-5.9144
55	132WENJI	132KOKA	-30.706	17.5372	30.87039	-17.558	0.1645	-0.0213
56	132MOJO	132KNORIT	-48.928	0.64381	49.48654	-0.1897	0.559	0.45409
57	132NAZRET2	132ADAMAWF1	-26.741	-14.9116	26.82301	14.8591	0.0816	-0.0525
58	132EGEDA	132KOKA	30.3891	-6.18149	-29.9914	5.8872	0.3978	-0.2943
59	132KOKA	132NAZRET2	30.4459	12.5547	-30.2231	-12.638	0.2228	-0.0832
60	132MOJO	132KOKA	20.442	-14.434	-20.2506	14.0019	0.1915	-0.4322
61	132WENJI	132AWASH	-6.7587	-4.22925	6.775068	3.66515	0.0163	-0.5641
62	132ASSELA	132WENJI	-30.694	16.0769	31.48775	-16.201	0.7935	-0.1237
63	230METEMA	230GONDER2	-188.21	10.2012	192.5243	-47.231	4.3134	-37.03
64	230SUDB	230METEMA	-185	1.1E-12	186.2436	-11.153	1.2436	-11.153
65	230MELKYGO	230MELK W	-47.535	-64.9314	47.59922	64.5401	0.0645	-0.3913
66	230GONDER2	230BDAR2	-216.21	36.3374	223.0217	-73.156	6.8072	-36.819
67	230DM	230MOTA	18.4029	-26.6757	-18.2986	9.43523	0.1043	-17.24
68	230GASHENA	230ALAMATA	91.1394	5.85905	-89.4577	-20.211	1.6817	-14.352
69	230DM	230FINCHA	-10.622	22.7108	10.76049	-36.661	0.1381	-13.95
70	230FINCA2	230FINCHA	-7.9254	-28.7201	7.938919	27.1479	0.0135	-1.5722
71	230GHEDO	230FINCHA	-74.176	-23.4481	74.75791	16.6123	0.5824	-6.8358
72	132GEFERSA	132SEBETA1	-2.2938	-2.5478	2.295774	2.10207	0.0019	-0.4457
73	132GEFERSA	132KALITI1	21.4704	-2.67446	-21.2771	1.96637	0.1933	-0.7081
74	132MELKYGO	132SHSMNE	26.5792	-8.70115	-25.3056	6.16619	1.2736	-2.535
75	230NESHI	230FINCA2	89.5042	-26.5674	-89.0195	22.3683	0.4847	-4.1991
76	230FINCA2	230GHEDO	92.1493	4.03203	-90.9874	-13.793	1.1619	-9.7612
77	230GHEDO	230GEFERSA	110.627	20.2243	-108.915	-57.521	1.7115	-37.297
78	132KALITI2	132KALITIGS	-35.83	-13.4934	35.93115	13.4958	0.1012	0.00239
79	230WOLKITE	230SEBETA1	88.403	-7.35313	-86.0187	-11.581	2.3843	-18.935
80	230GEFERSA	230TORHAYL	-43.434	11.5886	43.48509	-13.447	0.0511	-1.8588
81	132KALITI1	132KALITIGS	40.1602	15.5286	-40.0654	-15.497	0.0948	0.03171
82	230ENDASLASE	230AXUM	-21.89	-43.7668	22.37042	14.7147	0.4801	-29.052
83	230GEFERSA	230SULULTA	-79.594	-65.5918	79.77781	60.0193	0.1835	-5.5725
84	132REPPIWE	132MEKANISA	37.5168	8.26885	-37.3623	-8.2634	0.1545	0.00547
85	230AGARO	230GIMMA NEW	-23.904	-14.5636	23.96175	7.31773	0.0579	-7.2459
86	230AGARO	230BEDELE	21.3788	13.3079	-21.2194	-28.173	0.1594	-14.865
87	230GG1	230GGNEW	128.978	3.05029	-128.912	-4.2656	0.0659	-1.2153
88	230GGNEW	230WOLKITE	131.086	-3.90113	-129.282	3.00716	1.8043	-0.894
89	230ALAMATA	230MEHONI	16.5046	3.40822	-16.4757	-10.998	0.029	-7.5898
90	132BLION	132REPPIWE	12.3626	-4.76754	-12.3446	4.55252	0.018	-0.215
91	230GIMA NEW	230GGNEW	-55.558	-22.1614	56.02875	10.6822	0.471	-11.479
92	230HOSSANA	230WOLKITE	-20.466	-10.8591	20.54818	-5.4939	0.0821	-16.353
93	230SEBETA2	230SEBETA1	207.116	57.1615	-206.553	-58.541	0.5631	-1.3797
94	230SEBETA1	230KALITI1	49.6511	0.98006	-49.5907	-2.638	0.0605	-1.6579
95	230SEBETA1	230TORHAYL	48.9541	-14.5333	-48.9113	13.3244	0.0429	-1.2089
96	230GELAN	230KALITI1	205.888	92.8521	-205.452	-93.586	0.4357	-0.7337
97	230EIZONE	230GELAN	-80.794	23.8573	81.08463	-25.498	0.2904	-1.6407
98	230MELK W	230KOKA	-17.916	-25.8373	18.09226	4.00963	0.1766	-21.828
99	230KOKA	230ADAMAWF2	-87.666	-18.3123	87.84955	16.9696	0.1831	-1.3427
100	230ALAMATA	230WOLDIYA	36.4437	5.25786	-36.2591	-16.591	0.1845	-11.333
101	230KOKA	230AWASH7K	73.2732	-22.2921	-71.9769	9.61326	1.2963	-12.679
102	230DDAWA-3	230AWASH7K	-50.677	-6.40739	51.67264	-18.12	0.9957	-24.527
103	230DDAWA-3	230HURSO	-33.085	-29.2027	33.16037	26.233	0.0749	-2.9697
104	230MEKELE	230ASHEGODWF	-20.338	-39.0436	20.4146	35.8403	0.0771	-3.2033
105	230KOKA	230HURSO	68.3787	-48.3854	-64.4992	-5.4915	3.8796	-53.877
106	230HURSO	230ADIGALA	30.9047	-20.9517	-30.5964	-1.3073	0.3082	-22.259
107	230ADIGALA	230DJBTBR	30.1623	2.19611	-30	-14.5	0.1623	-12.304
Total							113.8	-1337

Power flow report with SVC at 400.Gendawa

The resulting bus and line flow reports are given in Table **B**.**11** and **B**.**12**

Table **B. 11** Power flow bus report with Inductive SVC-2.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.9073	-0.7682	3.37	0.35	0	0
ADAMAWF1	0.8956	-0.77963	26.9	17	0	0
ADAMAWF2	0.9992	-0.64458	88	49.7	0	0
ASHEGODAWF	1	-0.84696	8.3	19.24424	0	0
AWASHPP	0.9376	-0.76521	26	25.8	0	0
BELESPP	1	-0.40432	461.2	-92.1468	0	0
FINCHAPP	1.03	-0.56518	101.2	37.27565	0	0
GG1PP	1.02	-0.45307	129.2	30.19932	0	0
GG2PP	1	-0.31896	278.4	-33.3754	0	0
GG3PP	1.05	0	958.231	162.9437	0	0
GNALE3PP	1.0195	-0.24303	150.2	-117	0	0
KOKAPP	0.8994	-0.82632	12.4	26.2	0	0
MELKAWPP	1	-0.71815	29.8	79.21011	0	0
NESHIPP	1	-0.48822	89.8	-9.76535	0	0
REPPIWEPP	0.9573	-0.66951	25.2	16	0	0
TAY2 PP	1	-0.57081	14.9	-10.6718	0	0
TEKEZE PP	1.03	-0.68413	176.1	28.10689	0	0
132ADAMAWF1	0.8595	-0.84425	0	0	0	0
132ALABA	1.0044	-0.3916	0	0	6.6148	3.2016
132ASSELA	0.8301	-0.87598	0	0	29.2299	12.2577
132ATULU	0.8309	-0.88013	0	0	4.9731	2.4078
132AWASH	0.8656	-0.8443	0	0	24	11.6
132AWASSA	0.9798	-0.42184	0	0	40.1403	17.9625
132BD2	1.0369	-0.63235	0	0	0	0
132BLEMIMB	0.9011	-0.7768	0	0	3.5141	0.5271
132BLION	0.9041	-0.76754	0	0	24.5418	18.694
132COTEBE	0.8999	-0.7781	0	0	84.6765	39.1733
132DZEIT	0.8678	-0.8179	0	0	55.7315	26.9793
132EGEDA	0.8794	-0.81684	0	0	7.8543	3.8049
132GEFERSA	0.9161	-0.75586	0	0	212.4279	99.5179
132GELAN	0.912	-0.76935	0	0	28.3229	13.7167
132KALITI1	0.906	-0.77191	0	0	89.9306	40.4531
132KALITI2	0.8989	-0.77795	0	0	73.5335	27.8761
132KALITIGS	0.9027	-0.77464	0	0	4.1342	2.0011
132KALITINEW	0.904	-0.77348	0	0	36.3959	17.9151
132KNORIT	0.8843	-0.80307	0	0	8.2686	4.0019
132KOKA	0.8655	-0.83861	0	0	8.8	4.2
132MEKANISA	0.8974	-0.77713	0	0	54.7824	19.8009
132MELKYGO	0.9125	-0.79602	0	0	20.8601	8.3308
132MOJO	0.8693	-0.82406	0	0	28.4855	13.7902
132NAZRET2	0.8552	-0.84709	0	0	56.9646	27.5495
132REPPIWE	0.9032	-0.77019	0	0	0	0
132SEBETA1	0.917	-0.7554	0	0	154.1373	52.4707
132SHSMNE	0.8399	-0.87356	0	0	20.8476	8.752
132TAY2	1.0344	-0.61893	0	0	0	0
132WENJI	0.8605	-0.84528	0	0	5.9769	2.8927
132WEREGENU	0.8971	-0.77986	0	0	54.5209	26.4
132WSODO	1.0294	-0.35964	0	0	29.3161	15.9089
132YESU	0.9054	-0.77362	0	0	32.3276	15.64
132YIGALEM2	1.0401	-0.37792	0	0	28.571	13.6344
132YIGALM	1.0029	-0.40824	0	0	17.3795	6.1326
230ADAMAWF2	0.9616	-0.71442	0	0	0	0
230ADIGALA	0.941	-0.92201	0	0	0.4341	-0.8888
230AGARO	0.9837	-0.55303	0	0	2.525	1.2557
230ALAMATA	0.9887	-0.84687	0	0	24.3136	11.7866
230ASHEGODAWF	0.9807	-0.85475	0	0	0	0
230AWASH7K	0.9524	-0.80232	0	0	20.3043	8.5068
230AXUM	1.0086	-0.78148	0	0	3.7716	1.7915
230BDAR2	1.0463	-0.6454	0	0	44.5907	21.4963
230BEDELE	0.9695	-0.56016	0	0	21.2194	27.80668
230BOLEARABSA	0.9413	-0.70002	0	0	3.08	1.5
230COMBOLCHA	0.9524	-0.87237	0	0	63.0643	24.3886

230COTEBE1	0.9384	-0.70339	0	0	0	0
230DBRHAN	0.9453	-0.83806	0	0	35.5233	15.5403
230DDAWA-3	0.9388	-0.89432	0	0	83.7624	35.6101
230DJBTBR	0.9317	-0.93587	0	0	30	14.5
230DM	1.0291	-0.61624	0	0	35.5616	15.4456
230EIZONE	0.9508	-0.69724	0	0	23.2974	1.12758
230ENDASILASE	0.9721	-0.79274	0	0	21.8903	43.60435
230FINCA2	1.0109	-0.60603	0	0	4.7956	2.3198
230FINCHA	1.0127	-0.6061	0	0	7.4884	3.6245
230GASHENA	1.0149	-0.79138	0	0	4.238	0.2231
230GEFERSA	0.9458	-0.69035	0	0	0	0
230GELAN	0.9485	-0.6818	0	0	0	0
230GG1	1.0037	-0.52608	0	0	0	0
230GGNEW	1.0028	-0.52847	0	0	6.876	2.4148
230GHEDO	0.9888	-0.64304	0	0	54.5361	17.01702
230GIMMA NEW	0.9883	-0.54825	0	0	31.596	14.8437
230GONDER2	1.0365	-0.73814	0	0	23.6902	10.8937
230HOSSANA	0.9785	-0.61422	0	0	20.4661	10.8591
230HURSO	0.9432	-0.89144	0	0	0.4341	0.2102
230KALITI1	0.9431	-0.68983	0	0	0	0
230KOKA	0.9567	-0.71961	0	0	53.4845	41.76204
230LEGETAFO	0.9411	-0.70095	0	0	46.6735	22.6296
230MEHONI	0.9865	-0.85092	0	0	4.124	1.6228
230MEKELE	0.9753	-0.85564	0	0	175.2094	82.9428
230MELK W	0.9371	-0.74087	0	0	0	15.252
230MELKYGO	0.9333	-0.74214	0	0	0	60.51929
230METEMA	1.023	-0.80752	0	0	1.9673	0.9522
230MOTA	1.0438	-0.63493	0	0	2.4989	1.2096
230NESHI	1.0131	-0.58934	0	0	0	0
230NIFASMW	1.0332	-0.7319	0	0	4.6258	0.5002
230SEBETA1	0.9455	-0.68383	0	0	0	0
230SEBETA2	0.9515	-0.67103	0	0	49.5489	24.2583
230SINOSTILL	0.9409	-0.73729	0	0	20.855	9.931
230SUDB	1.0165	-0.82686	0	0	185	0
230SULULTA	0.9502	-0.68696	0	0	49.6272	18.9605
230TEKEZE	1.0179	-0.76757	0	0	2.3287	1.1752
230TORHAYL	0.9456	-0.6866	0	0	5.4262	0.123
230WOLDIYA	0.9771	-0.8593	0	0	9.2397	4.472
230WOLKITE	0.9842	-0.6031	0	0	20.3304	9.8399
230YIRGALEM	1.0564	-0.34644	0	0	0	0
400BDAR	1.0356	-0.56984	0	0	0	0
400BELES	1.0282	-0.51831	0	0	0	55.10424
400DMARKOS	1.0301	-0.60635	0	0	0	0
400GELAN	0.9687	-0.60263	0	0	0	13.36331
400GG2	1.0113	-0.39828	0	0	0	0
400GGG3	1.0394	-0.29846	0	0	0	0
400GGNEW	1.01	-0.40202	0	0	0	17.71888
400GRANDR	1.0368	-0.52608	0	0	15.9788	57.1029
400GENDAWA	1.07	-0.30147	0	-85.3624	0	0
400HOLETA	0.975	-0.60991	0	0	0	0
400SEBETA2	0.9746	-0.60455	0	0	0	-85.4916
400SULULTA	0.9748	-0.62571	0	0	0	0
400WSODO	1.0389	-0.33465	0	0	0	112.5077
400YIRGALEM	1.0651	-0.33057	0	0	0	0
Total			2579.2	143.7082	2461.636	1309.926

Table **B. 12** Power flow branch report with Inductive SVC-2.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	30.1993	-1.2897	-0.2036	0.232	9.83506
109	FINCHAPP	230FINCHA	101.2	37.2757	-1.0092	-0.3255	0.2826	4.72626
110	TAY2 PP	132TAY2	14.9	-10.672	-0.1486	0.11768	0.0362	1.09587
111	KOKAPP	132KOKA	12.4	26.2	-0.1224	-0.2506	0.1587	1.13671
112	MELKAWPP	230MELK W	29.8	79.2101	-0.296	-0.7357	0.197	5.63963
113	400BDAR	230BDAR2	344.161	-38.63	-3.4376	0.65164	0.3958	26.5343
114	400DMARKOS	230DM	44.8538	3.77169	-0.4485	-0.0332	0.0079	0.4468
115	132BD2	230BDAR2	14.7502	-10.512	-0.1474	0.108	0.0068	0.28804
116	ADAMAWF1	132ADAMAWF1	26.9	17	-0.2681	-0.1461	0.0858	2.38731
117	400YIRGALEM	230YIRGALEM	70.4863	35.8436	-0.7047	-0.3444	0.0187	1.40559

118	GG2PP	400GG2	278.4	-33.375	-2.7798	0.55955	0.4157	22.5798
119	400GGNEW	230GGNEW	67.7764	8.04996	-0.6776	0.00558	0.0119	8.60826
120	400SEBETA2	230SEBETA2	256.551	98.5051	-2.5629	-0.7931	0.2632	19.1923
121	400SULULTA	230SULULTA	349.092	152.743	-3.4875	-1.2778	0.3458	24.9679
122	ADAMAWF2	230ADAMAWF2	88	49.7	-0.8781	-0.418	0.1856	7.89941
123	REPPIWEPP	132REPPIWE	25.2	16	-0.2517	-0.1263	0.0296	3.37161
124	GNALE3PP	400GENDAWA	150.2	-117	-1.502	1.31795	-2E-14	14.7945
125	GG3PP	400GGG3	958.231	162.944	-9.541	1.24761	4.1338	287.705
126	400GELAN	230GELAN	597.127	184.717	-5.9713	-1.3405	2E-13	50.6651
127	230GEFERSA	132GEFERSA	233.256	117.282	-2.3289	-0.9857	0.3683	18.7157
128	400WSODO	132WSODO	53.7299	20.3726	-0.5372	-0.1885	0.0061	1.52353
129	230GELAN	132GELAN	241.264	115.537	-2.408	-0.9038	0.4622	25.1557
130	TEKEZEPP	230TEKEZE	176.1	28.1069	-1.7574	-0.1317	0.3627	14.9324
131	230COTEBE1	132COTEBE	113.243	67.622	-1.1313	-0.5656	0.1126	11.0627
132	230KALITI1	132KALITI1	214.694	110.732	-2.1427	-0.8911	0.4229	21.626
133	230MELKYGO	132MELKYGO	46.8071	18.9088	-0.467	-0.16	0.1115	2.91185
134	230YIRGALEM	132YIGALEM2	70.4675	34.438	-0.7041	-0.3171	0.054	2.7318
135	ASHEGODAWF	230ASHEGODWF	8.3	19.2442	-0.0829	-0.1881	0.0134	0.43576
136	ABASAPP	132KALITI1	3.37	0.35	-0.0337	-0.0034	0.0037	0.01299
137	BELESPP	400BELES	461.2	-92.147	-4.6037	1.4807	0.8339	55.9228
138	NESHIPP	230NESHI	89.8	-9.7653	-0.8951	0.19026	0.2888	9.26019
139	230SEBETA1	132SEBETA1	195.166	86.5348	-1.9481	-0.7018	0.3569	16.3561
140	AWASHPP	132AWASH	26	25.8	-0.2581	-0.2185	0.1908	3.95287
1	230AXUM	230TEKEZE	-26.142	-16.492	0.26287	-0.028	0.1444	-19.291
2	400SULULTA	400HOLETA	-296.46	22.7036	2.97017	-0.3903	0.5619	-16.327
3	400WSODO	400GGG3	-949.85	82.1594	9.54097	-1.2476	4.247	-42.602
4	230KOKA	230GELAN	-68.217	32.1833	0.68933	-0.3692	0.7164	-4.7376
5	230KOKA	230EIZONE	-57.014	30.3914	0.57381	-0.3428	0.3671	-3.8848
6	230LEGETAFO	230BOLEARABSA	-37.077	4.75862	0.37089	-0.0532	0.0119	-0.5643
7	230WOLDIYA	230COMBOLCHA	28.6273	18.5605	-0.2826	-0.3655	0.3653	-17.99
8	230KALITI1	230BOLEARABSA	40.311	-9.4802	-0.4017	0.03823	0.1424	-5.6573
9	230COTEBE1	230LEGETAFO	-113.24	-67.622	1.13409	0.65367	0.1662	-2.2546
10	230SULULTA	230LEGETAFO	219.538	55.392	-2.1825	-0.5902	1.2881	-3.6299
11	400BDAR	400DMARKOS	98.3421	-50.435	-0.9807	-0.6355	0.2724	-113.98
12	400DMARKOS	400SULULTA	53.2159	59.7734	-0.5264	-1.7545	0.579	-115.67
13	230MOTA	230BDAR2	15.9181	-13.33	-0.1588	0.00401	0.0351	-12.929
14	400HOLETA	400SEBETA2	-297.02	39.0309	2.97151	-0.5714	0.1344	-18.112
15	400GELAN	400SEBETA2	19.19	-113.01	-0.1911	0.92826	0.0813	-20.183
16	230MEHONI	230MEKELE	12.3586	5.07204	-0.1228	-0.2243	0.0749	-17.355
17	400GELAN	400WSODO	-616.32	-85.071	6.38581	0.6786	22.263	-17.211
18	400SEBETA2	400GG2	-534.59	-48.696	5.43135	0.593	8.5415	10.604
19	400WSODO	400GG2	335.832	65.318	-3.3295	-1.2509	2.8839	-59.775
20	400YIRGALEM	400WSODO	79.1511	187.952	-0.7829	-3.4822	0.8586	-160.27
21	400GGNEW	400GG2	-67.776	-25.769	0.67797	0.09837	0.0207	-15.932
22	400YIRGALEM	400GENDAWA	-149.64	-223.8	1.502	-2.1716	0.5626	-440.95
23	230ALAMATA	230ASHEGODWF	12.2125	-5.0108	-0.1216	-0.1719	0.051	-22.202
24	400GRANDR	400BELES	-15.979	-57.103	0.16008	-0.975	0.0288	-154.61
25	132BD2	132TAY2	-14.75	10.5122	0.14864	-0.1177	0.1136	-1.2555
26	132KOKA	132DZEIT	-12.895	5.30063	0.1305	-0.064	0.1554	-1.0987
27	230BDAR2	230NIFASMW	106.558	-27.731	-1.0366	0.09122	2.9006	-18.61
28	132AWASSA	132ALABA	-17.008	-4.97	0.1733	0.01872	0.3216	-3.0978
29	132WSODO	132ALABA	24.4077	2.94018	-0.2394	-0.0507	0.4632	-2.1336
30	132YIGALM	132AWASSA	23.5062	11.9904	-0.2313	-0.1299	0.3739	-1.0021
31	230GASHENA	230NIFASMW	-97.137	-4.5775	0.99032	-0.0962	1.8949	-14.199
32	132YIGALM	132YIGALEM2	-40.886	-18.123	0.41843	0.18072	0.9568	-0.0511
33	132AWASH	132KOKA	-4.9606	2.72517	0.04978	-0.0358	0.0175	-0.8584
34	230DBRHAN	230COMBOLCHA	35.2915	-31.611	-0.348	0.12161	0.4891	-19.449
35	132SHSMNE	132ATULU	3.57146	0.55789	-0.0355	-0.0302	0.0262	-2.4614
36	132ASSELA	132ATULU	1.43235	-2.2457	-0.0143	0.00611	0.0045	-1.6342
37	132WEREGNU	132COTEBE	-35.794	-19.555	0.3587	0.19586	0.0757	0.03117
38	230TEKEZE	230MEKELE	147.122	14.7983	-1.4256	-0.2135	4.5657	-6.5547
39	132BLEMIMB	132COTEBE	7.4237	1.94764	-0.0742	-0.022	0.0077	-0.2524
40	400BDAR	400BELES	-442.5	89.0643	4.44358	-1.0567	1.8558	-16.606
41	132GELAN	132DZEIT	71.1752	24.0802	-0.6878	-0.2058	2.3935	3.50027
42	132KNORIT	132GELAN	-57.602	-14.216	0.58888	0.15803	1.2863	1.58688
43	132EGEDA	132GELAN	-38.206	-6.237	0.39307	0.06653	1.1014	0.41602
44	132SEBETA1	132BLION	38.1356	16.1946	-0.3779	-0.1604	0.345	0.15366
45	132GELAN	132KALITI1	16.4128	13.8478	-0.1634	-0.141	0.0729	-0.2537
46	132GELAN	132YESU	26.6955	16.2804	-0.2657	-0.1636	0.1229	-0.0797
47	132KALITI1	132YESU	5.75994	-1.0656	-0.0576	0.0072	0.0049	-0.3455
48	230DBRHAN	230SINOSTILL	-70.815	16.0705	0.73232	-0.3839	2.4177	-22.324

49	132MEKANISA	132KALITI1	-16.56	-9.6938	0.16668	0.09257	0.1088	-0.4367
50	132KALITI1	132WEREGENU	18.8584	6.37851	-0.1873	-0.0685	0.1315	-0.4667
51	132KALITI2	132KALITI1	-37.703	-14.382	0.37913	0.14459	0.2099	0.07636
52	132KALITI1	132KALITINEW	47.433	20.0513	-0.4736	-0.1999	0.0725	0.06076
53	132KALITINEW	132BLEMIMB	10.9646	2.07541	-0.1094	-0.0247	0.0268	-0.3993
54	230LEGETAFO	230SINOSTILL	95.244	-33.734	-0.9409	0.28464	1.1565	-5.27
55	132WENJI	132KOKA	-30.71	-5.0211	0.30853	0.04999	0.1437	-0.0221
56	132MOJO	132KNORIT	-48.697	-9.5606	0.49333	0.10215	0.6357	0.65401
57	132NAZRET2	132ADAMAWF1	-26.723	-14.629	0.26814	0.14613	0.0909	-0.0167
58	132EGEDA	132KOKA	30.3515	2.43208	-0.2992	-0.0258	0.4275	-0.1495
59	132KOKA	132NAZRET2	30.4941	12.935	-0.3024	-0.1292	0.2528	0.01489
60	132MOJO	132KOKA	20.2118	-4.2296	-0.2007	0.03794	0.1461	-0.4358
61	132WENJI	132AWASH	-6.738	-7.9919	0.0677	0.07522	0.0319	-0.4699
62	132ASSELA	132WENJI	-30.662	-10.012	0.31471	0.1012	0.8085	0.1083
63	230METEMA	230GONDER2	-188.24	9.81391	1.92638	-0.4557	4.4003	-35.759
64	230SUDB	230METEMA	-185	9.3E-13	1.86271	-0.1077	1.2707	-10.766
65	230MELKYGO	230MELK W	-46.807	-79.428	0.46895	0.79161	0.0879	-0.2666
66	230GONDER2	230BDAR2	-216.33	34.6788	2.23242	-0.7013	6.9139	-35.451
67	230DM	230MOTA	18.5398	-28.85	-0.1842	0.12121	0.1227	-16.73
68	230GASHENA	230ALAMATA	92.8989	4.35436	-0.9113	-0.1808	1.7684	-13.729
69	230DM	230FINCHA	-9.2555	16.7296	0.09347	-0.306	0.0917	-13.869
70	230FINCA2	230FINCHA	-9.3538	-33.634	0.09373	0.32109	0.0191	-1.5254
71	230GHEDO	230FINCHA	-74.06	-33.653	0.74709	0.27415	0.6492	-6.238
72	132GEFERSA	132SEBETA1	-2.5348	-1.933	0.02537	0.01513	0.0018	-0.4196
73	132GEFERSA	132KALITI1	22.9949	0.98164	-0.2276	-0.0156	0.2342	-0.5781
74	132MELKYGO	132SHSMNE	25.8355	7.66616	-0.2442	-0.0931	1.4165	-1.6437
75	230NESHI	230FINCA2	89.5112	-19.026	-0.8904	0.14898	0.4755	-4.1279
76	230FINCA2	230GHEDO	93.5939	16.4168	-0.9232	-0.255	1.2782	-9.0816
77	230GHEDO	230GEFERSA	111.839	42.1343	-1.0976	-0.7622	2.0831	-34.089
78	132KALITI2	132KALITIGS	-35.83	-13.494	0.35939	0.13519	0.1084	0.02493
79	230WOLKITE	230SEBETA1	90.9278	2.4653	-0.8826	-0.1945	2.6724	-16.982
80	230GEFERSA	230TORHAYL	-44.097	17.6302	0.44157	-0.1936	0.0604	-1.7266
81	132KALITI1	132KALITIGS	40.1743	15.5705	-0.4007	-0.1552	0.1016	0.05084
82	230ENDASLASE	230AXUM	-21.89	-43.604	0.22371	0.147	0.4806	-28.904
83	230GEFERSA	230SULULTA	-79.403	-58.689	0.79582	0.53423	0.1781	-5.266
84	132REPPIWE	132MEKANISA	38.3992	10.1718	-0.3822	-0.1011	0.1763	0.06473
85	230AGARO	230GIMMA NEW	-23.906	-14.536	0.23965	0.07452	0.0593	-7.0834
86	230AGARO	230BEDELE	21.3809	13.28	-0.2122	-0.2781	0.1615	-14.527
87	230GG1	230GGNEW	128.968	20.3643	-1.289	-0.2153	0.069	-1.17
88	230GGNEW	230WOLKITE	133.744	7.44465	-1.3181	-0.0739	1.9342	0.05873
89	230ALAMATA	230MEHONI	16.5082	-0.774	-0.1648	-0.0669	0.0256	-7.4688
90	132BLION	132REPPIWE	13.2487	-2.653	-0.1323	0.02457	0.02	-0.1964
91	230GIMA NEW	230GGNEW	-55.561	-22.296	0.56044	0.11116	0.4825	-11.18
92	230HOSSANA	230WOLKITE	-20.466	-10.859	0.20551	-0.0492	0.0853	-15.778
93	230SEBETA2	230SEBETA1	206.739	55.0545	-2.0615	-0.5607	0.5897	-1.0172
94	230SEBETA1	230KALITI1	49.605	9.33594	-0.4954	-0.1086	0.0664	-1.5215
95	230SEBETA1	230TORHAYL	49.6331	-20.352	-0.4958	0.19234	0.0499	-1.1178
96	230GELAN	230KALITI1	205.923	89.9155	-2.0547	-0.9039	0.4565	-0.4784
97	230EIZONE	230GELAN	-80.679	33.1486	0.81008	-0.3448	0.3292	-1.3315
98	230MELK W	230KOKA	-17.292	-20.843	0.17428	-0.0024	0.1365	-21.081
99	230KOKA	230ADAMAWF2	-87.587	-42.931	0.87814	0.41801	0.2269	-1.1301
100	230ALAMATA	230WOLDIYA	38.0962	12.0815	-0.3787	-0.2303	0.2292	-10.951
101	230KOKA	230AWASH7K	73.2008	-17.967	-0.7187	0.06385	1.3351	-11.582
102	230DDAWA-3	230AWASH7K	-50.518	-7.7305	0.51561	-0.1489	1.0438	-22.622
103	230DDAWA-3	230HURSO	-33.245	-27.88	0.33322	0.25117	0.0775	-2.7629
104	230MEKELE	230ASHEGODWF	-20.37	-39.162	0.20448	0.36	0.0784	-3.1622
105	230KOKA	230HURSO	68.7046	-43.2	-0.6469	-0.0678	4.0187	-49.976
106	230HURSO	230ADIGALA	30.9297	-18.552	-0.3061	-0.0219	0.3203	-20.743
107	230ADIGALA	230DJBTBR	30.1753	3.0799	-0.3	-0.145	0.1753	-11.42
Total							117.56	-1166.2

Power flow report with two SVCs at 132Atulu and 400Gendawa.

The resulting bus and line flow reports are given in Table **B**.**13** and **B**.**14**

Table **B. 13** Power flow bus report with two SVCs.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.9225	-0.76	3.37	0.35	0	0
ADAMAWF1	0.9324	-0.784	26.9	17	0	0
ADAMAWF2	1	-0.638	88	38.045	0	0
ASHEGODAWF	1	-0.836	8.3	17.038	0	0
AWASHPP	0.9761	-0.773	26	25.8	0	0
BELESPP	1	-0.399	461.2	-100.96	0	0
FINCHAPP	1.03	-0.558	101.2	28.232	0	0
GG1PP	1.02	-0.449	129.2	24.227	0	0
GG2PP	1	-0.317	278.4	-47.151	0	0
GG3PP	1.05	0	957.0522	152.37	0	0
GNALE3PP	1.0195	-0.241	150.2	-117	0	0
KOKAPP	0.9358	-0.827	12.4	26.2	0	0
MELKAWPP	1	-0.714	29.8	63.261	0	0
NESHIPP	1	-0.482	89.8	-12.741	0	0
REPPIWEPP	0.9705	-0.664	25.2	16	0	0
TAY2 PP	1	-0.564	14.9	-11.409	0	0
TEKEZE PP	1.03	-0.674	176.1	26.1	0	0
132ADAMAWF1	0.8976	-0.843	0	0	0	0
132ALABA	1.0078	-0.39	0	0	6.6148	3.2016
132ASSELA	0.906	-0.895	0	0	29.2299	12.2577
132ATULU	0.95	-0.925	0	48.83	4.9731	2.4078
132AWASH	0.9067	-0.846	0	0	24	11.6
132AWASSA	0.983	-0.42	0	0	40.1403	17.9625
132BD2	1.0399	-0.626	0	0	0	0
132BLEMIMB	0.9158	-0.768	0	0	3.5141	0.5271
132BLION	0.9174	-0.759	0	0	24.5418	18.694
132COTEBE	0.9142	-0.769	0	0	84.6765	39.1733
132DZEIT	0.8947	-0.812	0	0	55.7315	26.9793
132EGEDA	0.9103	-0.814	0	0	7.8543	3.8049
132GEFERSA	0.9283	-0.747	0	0	212.4279	99.5179
132GELAN	0.9301	-0.762	0	0	28.3229	13.7167
132KALITI1	0.9212	-0.763	0	0	89.9306	40.4531
132KALITI2	0.9142	-0.769	0	0	73.5335	27.8761
132KALITIGS	0.918	-0.766	0	0	4.1342	2.0011
132KALITINEW	0.9192	-0.765	0	0	36.3959	17.9151
132KNORIT	0.9103	-0.798	0	0	8.2686	4.0019
132KOKA	0.9032	-0.838	0	0	8.8	4.2
132MEKANISA	0.9117	-0.768	0	0	54.7824	19.8009
132MELKYGO	0.9446	-0.792	0	0	20.8601	8.3308
132MOJO	0.9004	-0.821	0	0	28.4855	13.7902
132NAZRET2	0.8935	-0.846	0	0	56.9646	27.5495
132REPPIWE	0.9169	-0.762	0	0	0	0
132SEBETA1	0.9292	-0.747	0	0	154.1373	52.4707
132SHSMNE	0.9267	-0.895	0	0	20.8476	8.752
132TAY2	1.0368	-0.612	0	0	0	0
132WENJI	0.9038	-0.848	0	0	5.9769	2.8927
132WEREGENU	0.9116	-0.771	0	0	54.5209	26.4
132WSODO	1.0328	-0.358	0	0	29.3161	15.9089
132YESU	0.9223	-0.766	0	0	32.3276	15.64
132YIGALEM2	1.0428	-0.376	0	0	28.571	13.6344
132YIGALM	1.0059	-0.406	0	0	17.3795	6.1326
230ADAMAWF2	0.9714	-0.708	0	0	0	0
230ADIGALA	0.956	-0.911	0	0	0.4341	-0.8888
230AGARO	0.9873	-0.548	0	0	2.525	1.2557
230ALAMATA	0.9925	-0.837	0	0	24.3136	11.7866
230ASHEGODAWF	0.9829	-0.844	0	0	0	0
230AWASH7K	0.9648	-0.794	0	0	20.3043	8.5068
230AXUM	1.0096	-0.771	0	0	3.7716	1.7915
230BDAR2	1.0499	-0.639	0	0	44.5907	21.4963
230BEDELE	0.9731	-0.555	0	0	21.2194	27.92967
230BOLEARABSA	0.9527	-0.694	0	0	3.08	1.5
230COMBOLCHA	0.9593	-0.862	0	0	63.0643	24.3886

230COTEBE1	0.9498	-0.697	0	0	0	0
230DBRHAN	0.954	-0.829	0	0	35.5233	15.5403
230DDAWA-3	0.9532	-0.884	0	0	83.7624	35.6101
230DJBTBR	0.947	-0.925	0	0	30	14.5
230DM	1.0343	-0.61	0	0	35.5616	15.4456
230EIZONE	0.9621	-0.691	0	0	23.2974	1.12758
230ENDASILASE	0.9731	-0.782	0	0	21.8903	43.67106
230FINCA2	1.0148	-0.599	0	0	4.7956	2.3198
230FINCHA	1.0165	-0.599	0	0	7.4884	3.6245
230GASHENA	1.0188	-0.783	0	0	4.238	0.2231
230GEFERSA	0.9566	-0.684	0	0	0	0
230GELAN	0.9603	-0.676	0	0	0	0
230GG1	1.0071	-0.521	0	0	0	0
230GGNEW	1.0063	-0.524	0	0	6.876	2.4148
230GHEDO	0.995	-0.636	0	0	54.5361	17.01702
230GIMMA NEW	0.9919	-0.543	0	0	31.596	14.8437
230GONDER2	1.0405	-0.731	0	0	23.6902	10.8937
230HOSSANA	0.9851	-0.609	0	0	20.4661	10.8591
230HURSO	0.9575	-0.881	0	0	0.4341	0.2102
230KALITI1	0.9549	-0.684	0	0	0	0
230KOKA	0.9672	-0.713	0	0	53.4845	42.11439
230LEGETAFO	0.9524	-0.694	0	0	46.6735	22.6296
230MEHONI	0.9898	-0.841	0	0	4.124	1.6228
230MEKELE	0.9775	-0.845	0	0	175.2094	82.9428
230MELK W	0.9496	-0.736	0	0	0	15.66379
230MELKYGO	0.9465	-0.738	0	0	0	62.25073
230METEMA	1.0272	-0.8	0	0	1.9673	0.9522
230MOTA	1.0481	-0.629	0	0	2.4989	1.2096
230NESHI	1.0164	-0.583	0	0	0	0
230NIFASMW	1.0371	-0.724	0	0	4.6258	0.5002
230SEBETA1	0.9565	-0.678	0	0	0	0
230SEBETA2	0.9622	-0.665	0	0	49.5489	24.2583
230SINOSTILL	0.9518	-0.73	0	0	20.855	9.931
230SUDB	1.0208	-0.819	0	0	185	0
230SULULTA	0.9609	-0.681	0	0	49.6272	18.9605
230TEKEZE	1.0188	-0.757	0	0	2.3287	1.1752
230TORHAYL	0.9565	-0.68	0	0	5.4262	0.123
230WOLDIYA	0.9821	-0.849	0	0	9.2397	4.472
230WOLKITE	0.9907	-0.598	0	0	20.3304	9.8399
230YIRGALEM	1.059	-0.345	0	0	0	0
400BDAR	1.0389	-0.564	0	0	0	0
400BELES	1.0304	-0.513	0	0	0	55.34206
400DMARKOS	1.0359	-0.601	0	0	0	0
400GELAN	0.9785	-0.598	0	0	0	13.63451
400GG2	1.0152	-0.396	0	0	0	0
400GGG3	1.0426	-0.297	0	0	0	0
400GGNEW	1.0139	-0.4	0	0	0	17.85768
400GRANDR	1.0391	-0.52	0	0	15.9788	57.3453
400GENDAWA	1.07	-0.3	0	-97.244	0	0
400HOLETA	0.9845	-0.605	0	0	0	0
400SEBETA2	0.9841	-0.6	0	0	0	-87.1623
400SULULTA	0.9843	-0.621	0	0	0	0
400WSODO	1.0424	-0.333	0	0	0	113.2623
400YIRGALEM	1.0676	-0.329	0	0	0	0
Total			2578.022	96.954	2461.636	1312.585

Table **B. 14** Power flow branch report with two SVCs.

			Line Flow From		Line Flow To		Line losses	
Line	From Bus	To Bus	[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	24.227	-128.972	-14.573	0.2277	9.6535
109	FINCHAPP	230FINCHA	101.2	28.232	-100.932	-23.747	0.2682	4.4855
110	TAY2 PP	132TAY2	14.9	-11.409	-14.8621	12.5578	0.0379	1.149
111	KOKAPP	132KOKA	12.4	26.2	-12.2534	-25.15	0.1466	1.0499
112	MELKAWPP	230MELK W	29.8	63.261	-29.6655	-59.41	0.1345	3.8504
113	400BDAR	230BDAR2	343.262	-40.561	-342.87	66.8271	0.3918	26.266
114	400DMARKOS	230DM	44.1686	6.6096	-44.1609	-6.1747	0.0077	0.4349
115	132BD2	230BDAR2	14.7431	-11.305	-14.7359	11.6067	0.0071	0.3013
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.8208	-14.798	0.0792	2.2025
117	400YIRGALEM	230YIRGALEM	70.4186	35.63	-70.4	-34.237	0.0186	1.3935

118	GG2PP	400GG2	278.4	-47.151	-277.978	70.0491	0.4216	22.898
119	400GGNEW	230GGNEW	66.9094	8.1589	-66.8979	0.17153	0.0115	8.3305
120	400SEBETA2	230SEBETA2	256.415	94.125	-256.16	-75.529	0.255	18.597
121	400SULULTA	230SULULTA	348.747	146.44	-348.413	-122.31	0.3341	24.128
122	ADAMAWF2	230ADAMAWF2	88	38.045	-87.8332	-30.947	0.1668	7.0978
123	REPPIWEPP	132REPPIWE	25.2	16	-25.1712	-12.719	0.0288	3.2808
124	GNALE3PP	400GENDAWA	150.2	-117	-150.2	131.795	0	14.795
125	GG3PP	400GGG3	957.052	152.37	-952.943	133.629	4.1093	286
126	400GELAN	230GELAN	599.689	169.92	-599.689	-120.54	-4E-13	49.38
127	230GEFERSA	132GEFERSA	231.944	112.77	-231.593	-94.912	0.3514	17.853
128	400WSODO	132WSODO	53.7811	20.449	-53.775	-18.932	0.0061	1.5173
129	230GELAN	132GELAN	244.094	97.46	-243.658	-73.767	0.4353	23.693
130	TEKEZEPP	230TEKEZE	176.1	26.1	-175.739	-11.218	0.3615	14.881
131	230COTEBE1	132COTEBE	112.54	63.407	-112.435	-53.05	0.1054	10.357
132	230KALITI1	132KALITI1	214.334	101.96	-213.936	-81.602	0.3982	20.363
133	230MELKYGO	132MELKYGO	48.4048	1.3136	-48.3051	1.29105	0.0997	2.6046
134	230YIRGALEM	132YIGALEM2	70.4	34.237	-70.3465	-31.528	0.0536	2.7084
135	ASHEGODAWF	230ASHEGODWF	8.3	17.038	-8.28903	-16.681	0.011	0.3563
136	ABASAPP	132KALITI1	3.37	0.35	-3.36646	-0.3374	0.0035	0.0126
137	BELESPP	400BELES	461.2	-100.96	-460.36	157.309	0.8403	56.353
138	NESHIPP	230NESHI	89.8	-12.741	-89.5088	22.0773	0.2912	9.3362
139	230SEBETA1	132SEBETA1	194.012	83.773	-193.67	-68.114	0.3417	15.659
140	AWASHPP	132AWASH	26	25.8	-25.824	-22.153	0.176	3.6469
1	230AXUM	230TEKEZE	-26.1423	-16.498	26.28633	-2.8322	0.144	-19.33
2	400SULULTA	400HOLETA	-294.478	22.902	295.0221	-39.79	0.544	-16.888
3	400WSODO	400GGG3	-948.724	90.306	952.9429	-133.63	4.2185	-43.323
4	230KOKA	230GELAN	-68.9045	29.737	69.59712	-34.75	0.6926	-5.0135
5	230KOKA	230EIZONE	-57.6754	28.061	58.02875	-32.125	0.3534	-4.0641
6	230LEGETAFO	230BOLEARABSA	-36.8967	2.2106	36.90798	-2.7908	0.0113	-0.5802
7	230WOLDIYA	230COMBOLCHA	27.9301	15.847	-27.6087	-34.201	0.3214	-18.354
8	230KALITI1	230BOLEARABSA	40.1235	-7.1174	-39.988	1.29084	0.1355	-5.8265
9	230COTEBE1	230LEGETAFO	-112.54	-63.407	112.6958	61.0565	0.1556	-2.3507
10	230SULULTA	230LEGETAFO	219.521	49.14	-218.279	-53.068	1.2423	-3.9277
11	400BDAR	400DMARKOS	99.228	-57.424	-98.9544	-57.573	0.2735	-115
12	400DMARKOS	400SULULTA	54.7858	50.963	-54.2687	-169.34	0.5172	-118.38
13	230MOTA	230BDAR2	15.8522	-12.313	-15.8192	-0.7269	0.033	-13.04
14	400HOLETA	400SEBETA2	-295.022	39.79	295.1523	-58.338	0.1302	-18.547
15	400GELAN	400SEBETA2	16.9727	-108.76	-16.9001	88.0924	0.0726	-20.669
16	230MEHONI	230MEKELE	12.3541	6.8317	-12.2681	-24.254	0.086	-17.422
17	400GELAN	400WSODO	-616.662	-74.789	638.521	51.902	21.859	-22.887
18	400SEBETA2	400GG2	-534.668	-36.718	543.0534	43.8627	8.3857	7.1449
19	400WSODO	400GG2	334.844	63.117	-332.004	-123.86	2.84	-60.745
20	400YIRGALEM	400WSODO	79.2191	177.32	-78.4222	-339.04	0.7969	-161.72
21	400GGNEW	400GG2	-66.9094	-26.017	66.92946	9.94978	0.0201	-16.067
22	400YIRGALEM	400GENDAWA	-149.638	-212.95	150.2	-229.04	0.5623	-441.99
23	230ALAMATA	230ASHEGODWF	12.2034	-3.0619	-12.1448	-19.254	0.0586	-22.315
24	400GRANDR	400BELES	-15.9788	-57.345	16.00766	-97.93	0.0289	-155.28
25	132BD2	132TAY2	-14.7431	11.305	14.86207	-12.558	0.119	-1.2525
26	132KOKA	132DZEIT	-12.4718	15.456	12.76701	-16.43	0.2952	-0.974
27	230BDAR2	230NIFASMW	105.678	-27.903	-102.844	8.89228	2.8345	-19.011
28	132AWASSA	132ALABA	-17.0593	-5.0975	17.38147	1.97621	0.3222	-3.1212
29	132WSODO	132ALABA	24.4589	3.0227	-23.9963	-5.1778	0.4626	-2.1551
30	132YIGALM	132AWASSA	23.4495	11.844	-23.081	-12.865	0.3685	-1.021
31	230GASHENA	230NIFASMW	-96.368	-5.0956	98.21806	-9.3925	1.8501	-14.488
32	132YIGALM	132YIGALEM2	-40.829	-17.977	41.77547	17.8939	0.9465	-0.0828
33	132AWASH	132KOKA	-4.90635	7.6893	4.948278	-8.5907	0.0419	-0.9014
34	230DBRHAN	230COMBOLCHA	35.9241	-29.665	-35.4556	9.81273	0.4685	-19.852
35	132SHSMNE	132ATULU	5.21262	-16.074	-4.89366	13.4337	0.319	-2.6403
36	132ASSELA	132ATULU	1.05927	-33.443	-0.07944	32.9881	0.9798	-0.4551
37	132WEREGNU	132COTEBE	-35.4515	-17.823	35.5209	17.8413	0.0693	0.0179
38	230TEKEZE	230MEKELE	147.124	12.875	-142.585	-19.575	4.5382	-6.7
39	132BLEMIMB	132COTEBE	7.77195	3.7061	-7.76257	-3.9642	0.0094	-0.2581
40	400BDAR	400BELES	-442.49	97.985	444.352	-114.72	1.8623	-16.736
41	132GELAN	132DZEIT	70.6002	13.449	-68.4985	-10.549	2.1017	2.8995
42	132KNORIT	132GELAN	-57.7452	-2.2473	58.90019	3.54498	1.155	1.2977
43	132EGEDA	132GELAN	-38.2126	3.7405	39.23505	-3.5649	1.0225	0.1756
44	132SEBETA1	132BLION	37.2178	14.011	-36.9083	-13.943	0.3095	0.0674
45	132GELAN	132KALITI1	18.6492	24.333	-18.5065	-24.472	0.1427	-0.1392
46	132GELAN	132YESU	27.9508	22.289	-27.7963	-22.322	0.1545	-0.0322
47	132KALITI1	132YESU	4.5408	-7.0312	-4.53131	6.68165	0.0095	-0.3496
48	230DBRHAN	230SINOSTILL	-71.4474	14.125	73.81663	-37.219	2.3693	-23.095

49	132MEKANISA	132KALITI1	-17.4231	-11.652	17.54873	11.2225	0.1256	-0.4295
50	132KALITI1	132WEREGENU	19.2091	8.1008	-19.0694	-8.5766	0.1397	-0.4758
51	132KALITI2	132KALITI1	-37.7034	-14.383	37.90632	14.4384	0.2029	0.0559
52	132KALITI1	132KALITINEW	47.7847	21.799	-47.7117	-21.739	0.0729	0.0595
53	132KALITINEW	132BLEMIMB	11.3158	3.824	-11.286	-4.2332	0.0298	-0.4091
54	230LEGETAFO	230SINOSTILL	95.8065	-32.829	-94.6716	27.2885	1.1348	-5.5405
55	132WENJI	132KOKA	-30.4716	21.591	30.66036	-21.564	0.1888	0.0266
56	132MOJO	132KNORIT	-48.8986	2.2636	49.47659	-1.7546	0.578	0.509
57	132NAZRET2	132ADAMAWF1	-26.7369	-14.841	26.8208	14.7975	0.0839	-0.0431
58	132EGEDA	132KOKA	30.3583	-7.5454	-29.941	7.31137	0.4172	-0.2341
59	132KOKA	132NAZRET2	30.4579	12.651	-30.2277	-12.709	0.2302	-0.0578
60	132MOJO	132KOKA	20.4131	-16.054	-20.2002	15.6864	0.2129	-0.3674
61	132WENJI	132AWASH	-6.71527	-3.4134	6.730345	2.86382	0.0151	-0.5496
62	132ASSELA	132WENJI	-30.2892	21.186	31.20998	-21.07	0.9208	0.1153
63	230METEMA	230GONDER2	-188.227	9.9636	192.5938	-46.214	4.3663	-36.25
64	230SUDB	230METEMA	-185	-7E-13	186.2601	-10.916	1.2601	-10.916
65	230MELKYGO	230MELK W	-48.4048	-63.564	48.46898	63.1775	0.0641	-0.3868
66	230GONDER2	230BDAR2	-216.284	35.32	223.156	-71.3	6.8721	-35.98
67	230DM	230MOTA	18.4665	-28.031	-18.3511	11.1038	0.1153	-16.927
68	230GASHENA	230ALAMATA	92.13	4.8725	-90.3999	-18.864	1.7301	-13.992
69	230DM	230FINCHA	-9.86716	18.76	9.973954	-32.677	0.1068	-13.917
70	230FINCA2	230FINCHA	-8.73766	-31.468	8.754184	29.9225	0.0165	-1.5453
71	230GHEDO	230FINCHA	-74.0972	-29.38	74.71526	22.877	0.6181	-6.5026
72	132GEFERSA	132SEBETA1	-2.31358	-2.0636	2.315218	1.63238	0.0016	-0.4312
73	132GEFERSA	132KALITI1	21.4782	-2.542	-21.2783	1.87894	0.1999	-0.663
74	132MELKYGO	132SHSMNE	27.445	-9.6218	-26.0602	7.32199	1.3848	-2.2999
75	230NESHI	230FINCA2	89.5088	-22.077	-89.0303	17.9182	0.4785	-4.1591
76	230FINCA2	230GHEDO	92.9724	11.23	-91.7486	-20.61	1.2238	-9.3803
77	230GHEDO	230GEFERSA	111.31	32.973	-109.399	-68.455	1.9111	-35.482
78	132KALITI2	132KALITIGS	-35.8301	-13.494	35.93484	13.5074	0.1048	0.0138
79	230WOLKITE	230SEBETA1	90.1219	-2.2018	-87.5664	-15.566	2.5555	-17.768
80	230GEFERSA	230TORHAYL	-43.4563	15.307	43.51183	-17.091	0.0556	-1.784
81	132KALITI1	132KALITIGS	40.1672	15.55	-40.069	-15.508	0.0982	0.0414
82	230ENDASLASE	230AXUM	-21.8903	-43.671	22.37069	14.7063	0.4804	-28.965
83	230GEFERSA	230SULULTA	-79.089	-59.617	79.26396	54.2097	0.1749	-5.4078
84	132REPPIWE	132MEKANISA	37.5192	8.1742	-37.3593	-8.1489	0.1598	0.0253
85	230AGARO	230GIMMA NEW	-23.9052	-14.545	23.96401	7.40712	0.0588	-7.1379
86	230AGARO	230BEDELE	21.3802	13.289	-21.2194	-27.93	0.1608	-14.64
87	230GG1	230GGNEW	128.972	14.573	-128.905	-15.76	0.0677	-1.1865
88	230GGNEW	230WOLKITE	132.888	2.2029	-131.002	-2.499	1.8854	-0.2961
89	230ALAMATA	230MEHONI	16.5047	0.9349	-16.4781	-8.4545	0.0266	-7.5195
90	132BLION	132REPPIWE	12.3665	-4.7505	-12.3479	4.54494	0.0186	-0.2056
91	230GIMA NEW	230GGNEW	-55.56	-22.251	56.03862	10.9705	0.4786	-11.28
92	230HOSSANA	230WOLKITE	-20.4661	-10.859	20.55015	-5.1391	0.084	-15.998
93	230SEBETA2	230SEBETA1	206.612	51.27	-206.041	-52.476	0.5707	-1.2056
94	230SEBETA1	230KALITI1	50.6109	2.3944	-50.5459	-3.9675	0.0651	-1.5731
95	230SEBETA1	230TORHAYL	48.9843	-18.125	-48.938	16.9679	0.0462	-1.1574
96	230GELAN	230KALITI1	204.352	90.258	-203.912	-90.88	0.4403	-0.6217
97	230EIZONE	230GELAN	-81.3262	30.997	81.6461	-32.432	0.3199	-1.4343
98	230MELK W	230KOKA	-18.8035	-19.431	18.94384	-2.1654	0.1404	-21.596
99	230KOKA	230ADAMAWF2	-87.6296	-32.185	87.83319	30.9473	0.2036	-1.2373
100	230ALAMATA	230WOLDIYA	37.3783	9.2043	-37.1698	-20.319	0.2085	-11.115
101	230KOKA	230AWASH7K	73.231	-19.967	-71.9151	7.87499	1.3159	-12.092
102	230DDAWA-3	230AWASH7K	-50.5904	-7.1214	51.61078	-16.382	1.0204	-23.503
103	230DDAWA-3	230HURSO	-33.172	-28.489	33.24828	25.6306	0.0762	-2.8581
104	230MEKELE	230ASHEGODWF	-20.356	-39.114	20.43383	35.9347	0.0779	-3.1791
105	230KOKA	230HURSO	68.5502	-45.595	-64.5999	-6.1845	3.9503	-51.78
106	230HURSO	230ADIGALA	30.9176	-19.656	-30.6032	-1.7843	0.3143	-21.441
107	230ADIGALA	230DJBTBR	30.1691	2.6731	-30	-14.5	0.1691	-11.827
Total							116.39	-1215.6

Power Flow Report with TCSCs and SVCs (Final case Study)

The resulting bus and line flow reports are given in Table **B.15** and **B.16**

P S A T 2.1.10

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File: C:\Users\user\Desktop\psat2\FINAL_CASE_.mdl
Date: 28-Feb-2022 16:50:30

NETWORK STATISTICS

Buses:	116
Lines:	107
Transformers:	33
Generators:	17
Loads:	70
FACTS	4

SOLUTION STATISTICS

Number of Iterations:	9
Maximum P mismatch [p.u.]	5.3E-12
Maximum Q mismatch [p.u.]	9.1E-12
Power rate [MVA]	100

STATE VARIABLES

alpha_Svc_1	-0.82684
vm_Svc_1	1.07
alpha_Svc_2	0.569391
vm_Svc_2	0.95
x1_Tcsc_1	0.920151
x1_Tcsc_2	0.920151

OTHER ALGEBRAIC VARIABLES

vref_Svc_1	1.069992
q_Svc_1	-1.19736
vref_Svc_2	0.950006
q_Svc_2	0.331311
x0_Tcsc_1	0.920151
pref_Tcsc_1	-0.69773
x0_Tcsc_2	0.920151
pref_Tcsc_2	-8.24245

GLOBAL SUMMARY REPORT

TOTAL GENERATION	
REAL POWER [p.u.]	25.55693
REACTIVE POWER [p.u.]	-1.591966
TOTAL LOAD	
REAL POWER [p.u.]	24.61636
REACTIVE POWER [p.u.]	13.12886
TOTAL LOSSES	
REAL POWER [p.u.]	0.940565
REACTIVE POWER [p.u.]	-14.72082

Table **B. 15** Power flow bus report with combined TCSCs and SVCs.

Bus Name	V [p.u.]	Phase [rad]	P gen [MW]	Q gen [Mvar]	P load [MW]	Q load [Mvar]
ABASAPP	0.95436	-0.614	3.37	0.35	0	0
ADAMAWF1	0.96383	-0.622	26.9	17	0	0
ADAMAWF2	1	-0.492	88	8.568052	0	0
ASHEGODAWF	1	-0.687	8.3	11.48906	0	0
AWASHPP	1	-0.61	26	23.88177	0	0
BELESPP	0.99354	-0.26	461.2	-133.2	0	0
FINCHAPP	1.03	-0.419	101.2	1.190213	0	0
GG1PP	1.02	-0.347	129.2	6.374084	0	0
GG2PP	1	-0.265	278.4	-102.562	0	0
GG3PP	1.05	0	934.7227	126.1451	0	0
GNALE3PP	1.01949	-0.231	150.2	-117	0	0
KOKAPP	0.96696	-0.662	12.4	26.2	0	0
MELKAWPP	1	-0.557	29.8	52.38438	0	0
NESHIPP	1.0062	-0.344	89.8	-17.2	0	0
REPPIWEPP	1	-0.524	25.2	15.67936	0	0
TAY2 PP	1	-0.424	14.9	-12.9452	0	0
TEKEZE PP	1.03	-0.524	176.1	21.05296	0	0
132ADAMAWF1	0.93001	-0.678	0	0	0	0
132ALABA	1.01421	-0.379	0	0	6.6148	3.2016
132ASSELA	0.92416	-0.72	0	0	29.2299	12.2577
132ATULU	0.95	-0.742	0	33.13108	4.9731	2.4078
132AWASH	0.93711	-0.679	0	0	24	11.6
132AWASSA	0.98899	-0.409	0	0	40.1403	17.9625
132BD2	1.04599	-0.486	0	0	0	0
132BLEMIMB	0.94778	-0.621	0	0	3.5141	0.5271
132BLION	0.94926	-0.614	0	0	24.5418	18.694
132COTEBE	0.94618	-0.623	0	0	84.6765	39.1733
132DZEIT	0.92722	-0.656	0	0	55.7315	26.9793
132EGEDA	0.94231	-0.655	0	0	7.8543	3.8049
132GEFERSA	0.95949	-0.603	0	0	212.4279	99.5179
132GELAN	0.96132	-0.615	0	0	28.3229	13.7167
132KALITI1	0.9531	-0.617	0	0	89.9306	40.4531
132KALITI2	0.94637	-0.622	0	0	73.5335	27.8761
132KALITIGS	0.95002	-0.619	0	0	4.1342	2.0011
132KALITINEW	0.95113	-0.618	0	0	36.3959	17.9151
132KNORIT	0.95288	-0.627	0	0	8.2686	4.0019
132KOKA	0.9354	-0.673	0	0	8.8	4.2
132MEKANISA	0.94381	-0.622	0	0	54.7824	19.8009
132MELKYGO	0.95107	-0.632	0	0	20.8601	8.3308
132MOJO	0.93882	-0.652	0	0	28.4855	13.7902
132NAZRET2	0.92605	-0.68	0	0	56.9646	27.5495
132REPPIWE	0.94885	-0.616	0	0	0	0
132SEBETA1	0.96066	-0.603	0	0	154.1373	52.4707
132SHSMNE	0.9297	-0.721	0	0	20.8476	8.752
132TAY2	1.04183	-0.472	0	0	0	0
132WENJI	0.93384	-0.681	0	0	5.9769	2.8927
132WEREGENU	0.9437	-0.624	0	0	54.5209	26.4
132WSODO	1.0394	-0.348	0	0	29.3161	15.9089
132YESU	0.95393	-0.618	0	0	32.3276	15.64
132YIGALEM2	1.04786	-0.365	0	0	28.571	13.6344
132YIGALM	1.01149	-0.395	0	0	17.3795	6.1326
230ADAMAWF2	0.9941	-0.56	0	0	0	0
230ADIGALA	0.9908	-0.755	0	0	0.4341	-0.8888
230AGARO	0.99812	-0.446	0	0	2.525	1.2557
230ALAMATA	1.00184	-0.689	0	0	24.3136	11.7866
230ASHEGODAWF	0.98838	-0.695	0	0	0	0
230AWASH7K	0.99366	-0.644	0	0	20.3043	8.5068
230AXUM	1.01204	-0.621	0	0	3.7716	1.7915
230BDAR2	1.05747	-0.499	0	0	44.5907	21.4963
230BEDELE	0.98404	-0.453	0	0	21.2194	28.29987
230BOLEARABSA	0.98341	-0.553	0	0	3.08	1.5
230COMBOLCHA	0.97745	-0.714	0	0	63.0643	24.3886
230COTEBE1	0.98062	-0.556	0	0	0	0
230DBRHAN	0.97736	-0.682	0	0	35.5233	15.5403
230DDAWA-3	0.98643	-0.729	0	0	83.7624	35.6101
230DJBTBR	0.98231	-0.768	0	0	30	14.5
230DM	1.04876	-0.473	0	0	35.5616	15.4456

230EIZONE	0.99161	-0.547	0	0	23.2974	1.12758
230ENDASILASE	0.97557	-0.632	0	0	21.8903	43.83906
230FINCA2	1.02667	-0.46	0	0	4.7956	2.3198
230FINCHA	1.02784	-0.46	0	0	7.4884	3.6245
230GASHENA	1.02808	-0.637	0	0	4.238	0.2231
230GEFERSA	0.98646	-0.544	0	0	0	0
230GELAN	0.99202	-0.533	0	0	0	0
230GG1	1.01729	-0.419	0	0	0	0
230GGNEW	1.01682	-0.422	0	0	6.876	2.4148
230GHEDO	1.01304	-0.497	0	0	54.5361	17.01702
230GIMMA NEW	1.00264	-0.441	0	0	31.596	14.8437
230GONDER2	1.04893	-0.59	0	0	23.6902	10.8937
230HOSSANA	1.00406	-0.492	0	0	20.4661	10.8591
230HURSO	0.99076	-0.727	0	0	0.4341	0.2102
230KALITI1	0.98644	-0.542	0	0	0	0
230KOKA	0.99194	-0.566	0	0	53.4845	42.95487
230LEGETAFO	0.98309	-0.554	0	0	46.6735	22.6296
230MEHONI	0.99804	-0.692	0	0	4.124	1.6228
230MEKELE	0.98309	-0.696	0	0	175.2094	82.9428
230MELK W	0.95819	-0.58	0	0	0	15.94774
230MELKYGO	0.95505	-0.582	0	0	0	63.37373
230METEMA	1.03603	-0.658	0	0	1.9673	0.9522
230MOTA	1.05874	-0.49	0	0	2.4989	1.2096
230NESHI	1.0275	-0.443	0	0	0	0
230NIFASMW	1.04592	-0.581	0	0	4.6258	0.5002
230SEBETA1	0.98737	-0.539	0	0	0	0
230SEBETA2	0.99347	-0.527	0	0	49.5489	24.2583
230SINOSTILL	0.98123	-0.587	0	0	20.855	9.931
230SUDB	1.02972	-0.677	0	0	185	0
230SULULTA	0.9912	-0.541	0	0	49.6272	18.9605
230TEKEZE	1.02129	-0.607	0	0	2.3287	1.1752
230TORHAYL	0.987	-0.541	0	0	5.4262	0.123
230WOLDIYA	0.99475	-0.701	0	0	9.2397	4.472
230WOLKITE	1.00937	-0.482	0	0	20.3304	9.8399
230YIRGALEM	1.06378	-0.334	0	0	0	0
400BDAR	1.04492	-0.426	0	0	0	0
400BELES	1.03244	-0.375	0	0	0	55.55596
400DMARKOS	1.05235	-0.464	0	0	0	0
400GELAN	1.0143	-0.457	0	0	0	14.65021
400GG2	1.03113	-0.343	0	0	0	0
400GGG3	1.04869	-0.288	0	0	0	0
400GGNEW	1.02991	-0.345	0	0	0	18.42449
400GRANDR	1.04108	-0.383	0	0	15.9788	57.5633
400GENDAWA	1.07	-0.289	0	-119.736	0	0
400HOLETA	1.01697	-0.472	0	0	0	0
400SEBETA2	1.01706	-0.468	0	0	0	-93.0975
400SULULTA	1.01523	-0.486	0	0	0	0
400WSODO	1.04896	-0.323	0	0	0	114.6978
400YIRGALEM	1.07225	-0.319	0	0	0	0
Total			2555.693	-159.197	2461.636	1312.886

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Table **B. 16** Power flow branch report combined TCSCs and SVCs.

Line	From Bus	To Bus	Line Flow From		Line Flow To		Line losses	
			[MW]	[Mvar]	[MW]	[Mvar]	[MW]	[Mvar]
108	GG1PP	230GG1	129.2	6.374	-128.979	2.974	0.221	9.348
109	FINCHAPP	230FINCHA	101.2	1.190	-100.951	2.972	0.249	4.162
110	TAY2 PP	132TAY2	14.9	-12.945	-14.858	14.216	0.042	1.271
111	KOKAPP	132KOKA	12.4	26.2	-12.263	-25.217	0.137	0.983
112	MELKAWPP	230MELK W	29.8	52.384	-29.700	-49.524	0.100	2.860
113	400BDAR	230BDAR2	340.277	-47.822	-339.894	73.480	0.383	25.658
114	400DMARKOS	230DM	42.079	15.576	-42.072	-15.150	0.008	0.425
115	132BD2	230BDAR2	14.727	-12.972	-14.719	13.305	0.008	0.332
116	ADAMAWF1	132ADAMAWF1	26.9	17	-26.826	-14.939	0.074	2.061
117	400YIRGALEM	230YIRGALEM	70.290	35.226	-70.272	-33.855	0.018	1.371
118	GG2PP	400GG2	278.4	-102.562	-277.935	127.843	0.465	25.281
119	400GGNEW	230GGNEW	42.555	8.722	-42.551	-5.369	0.005	3.353
120	400SEBETA2	230SEBETA2	251.827	103.448	-251.590	-86.151	0.237	17.297
121	400SULULTA	230SULULTA	342.077	153.966	-341.768	-131.657	0.309	22.309
122	ADAMAWF2	230ADAMAWF2	88	8.568	-87.858	-2.531	0.142	6.037

123	REPPIWEPP	132REPPIWE	25.2	15.679	-25.173	-12.624	0.027	3.055
124	GNALE3PP	400GENDAWA	150.2	-117	-150.200	131.795	0.000	14.795
125	GG3PP	400GGG3	934.723	126.145	-930.830	144.769	3.893	270.914
126	400GELAN	230GELAN	633.365	209.980	-633.365	-157.311	0.000	52.669
127	230GEFERSA	132GEFERSA	230.269	110.529	-229.945	-94.063	0.324	16.466
128	400WSODO	132WSODO	53.879	20.596	-53.873	-19.090	0.006	1.506
129	230GELAN	132GELAN	247.039	101.735	-246.618	-78.796	0.421	22.939
130	TEKEZEPP	230TEKEZE	176.1	21.053	-175.741	-6.283	0.359	14.770
131	230COTEBE1	132COTEBE	111.072	62.861	-110.976	-53.375	0.097	9.486
132	230KALITI1	132KALITI1	215.976	103.591	-215.596	-84.156	0.380	19.435
133	230MELKYGO	132MELKYGO	45.631	3.208	-45.544	-0.925	0.087	2.283
134	230YIRGALEM	132YIGALEM2	70.272	33.855	-70.219	-31.190	0.053	2.665
135	ASHEGODAWF	230ASHEGODWF	8.3	11.489	-8.294	-11.290	0.006	0.199
136	ABASAPP	132KALITI1	3.37	0.35	-3.367	-0.338	0.003	0.012
137	BELESPP	400BELES	461.2	-133.2	-460.320	192.222	0.880	59.022
138	NESHIPP	230NESHI	89.8	-17.2	-89.508	26.571	0.292	9.371
139	230SEBETA1	132SEBETA1	192.409	84.186	-192.092	-69.672	0.317	14.514
140	AWASHPP	132AWASH	26	23.882	-25.844	-20.654	0.156	3.228
1	230AXUM	230TEKEZE	-26.142	-16.513	26.285	-2.916	0.143	-19.428
2	400SULULTA	400HOLETA	-282.670	-10.849	283.135	-8.097	0.465	-18.946
3	400WSODO	400GGG3	-926.840	98.648	930.830	-144.769	3.990	-46.121
4	230KOKA	230GELAN	-67.339	13.540	67.882	-19.623	0.543	-6.082
5	230KOKA	230EIZONE	-56.225	12.668	56.492	-17.391	0.267	-4.723
6	230LEGETAFO	230BOLEARABSA	-45.082	1.047	45.098	-1.655	0.016	-0.608
7	230WOLDIYA	230COMBOLCHA	25.597	8.343	-25.380	-27.624	0.217	-19.282
8	230KALITI1	230BOLEARABSA	48.361	-6.260	-48.178	0.155	0.183	-6.105
9	230COTEBE1	230LEGETAFO	-111.072	-62.861	111.214	60.290	0.142	-2.571
10	230SULULTA	230LEGETAFO	211.767	49.191	-210.676	-54.019	1.092	-4.829
11	400BDAR	400DMARKOS	102.111	-85.381	-101.807	-31.805	0.304	-117.186
12	400DMARKOS	400SULULTA	59.728	16.229	-59.407	-143.117	0.321	-126.888
13	230MOTA	230BDAR2	15.859	-7.672	-15.830	-5.620	0.029	-13.292
14	400HOLETA	400SEBETA2	-283.135	8.097	283.245	-28.248	0.110	-20.151
15	400GELAN	400SEBETA2	190.880	-82.839	-190.598	62.365	0.283	-20.474
16	230MEHONI	230MEKELE	12.353	11.309	-12.233	-28.883	0.120	-17.574
17	400GELAN	400WSODO	-824.245	-141.792	838.814	53.543	14.569	-88.249
18	400SEBETA2	400GG2	-344.474	-44.467	347.734	-21.705	3.259	-66.172
19	400WSODO	400GG2	112.790	33.979	-112.363	-116.550	0.426	-82.571
20	400YIRGALEM	400WSODO	79.329	157.043	-78.642	-321.464	0.687	-164.421
21	400GGNEW	400GG2	-42.555	-27.147	42.564	10.412	0.009	-16.734
22	400YIRGALEM	400GENDAWA	-149.619	-192.268	150.200	-251.530	0.581	-443.798
23	230ALAMATA	230ASHEGODWF	12.194	1.906	-12.107	-24.479	0.087	-22.573
24	400GRANDR	400BELES	-15.979	-57.563	16.008	-98.314	0.029	-155.877
25	132BD2	132TAY2	-14.727	12.972	14.858	-14.216	0.131	-1.244
26	132KOKA	132DZEIT	-7.355	12.012	7.499	-13.339	0.144	-1.327
27	230BDAR2	230NIFASMW	102.872	-28.925	-100.216	8.932	2.656	-19.993
28	132AWASSA	132ALABA	-17.157	-5.341	17.480	2.176	0.323	-3.166
29	132WSODO	132ALABA	24.557	3.182	-24.095	-5.377	0.462	-2.196
30	132YIGALM	132AWASSA	23.342	11.565	-22.983	-12.621	0.358	-1.056
31	230GASHENA	230NIFASMW	-93.867	-5.801	95.590	-9.432	1.723	-15.233
32	132YIGALM	132YIGALEM2	-40.721	-17.698	41.648	17.555	0.927	-0.142
33	132AWASH	132KOKA	-5.132	5.246	5.157	-6.242	0.026	-0.996
34	230DBRHAN	230COMBOLCHA	38.122	-24.101	-37.684	3.236	0.437	-20.866
35	132SHSMNE	132ATULU	2.761	-13.226	-2.569	10.368	0.191	-2.858
36	132ASSELA	132ATULU	2.796	-21.806	-2.404	20.355	0.393	-1.451
37	132WEREGNU	132COTEBE	-34.730	-17.995	34.793	17.996	0.063	0.001
38	230TEKEZE	230MEKELE	147.127	8.024	-142.652	-15.069	4.476	-7.046
39	132BLEMIMB	132COTEBE	8.504	3.517	-8.494	-3.794	0.010	-0.277
40	400BDAR	400BELES	-442.388	133.203	444.312	-149.464	1.925	-16.260
41	132GELAN	132DZEIT	64.932	15.712	-63.230	-13.640	1.702	2.072
42	132KNORIT	132GELAN	-69.773	-8.135	70.286	8.151	0.513	0.016
43	132EGEDA	132GELAN	-32.924	0.607	33.624	-1.161	0.700	-0.555
44	132SEBETA1	132BLION	35.957	14.407	-35.682	-14.447	0.275	-0.040
45	132GELAN	132KALITI1	20.463	21.641	-20.337	-21.839	0.126	-0.198
46	132GELAN	132YESU	28.989	20.737	-28.845	-20.812	0.144	-0.075
47	132KALITI1	132YESU	3.488	-5.555	-3.483	5.172	0.005	-0.383
48	230DBRHAN	230SINOSTILL	-73.645	8.561	75.925	-33.632	2.280	-25.071
49	132MEKANISA	132KALITI1	-18.624	-11.164	18.750	10.690	0.126	-0.474
50	132KALITI1	132WEREGENU	19.929	7.876	-19.791	-8.405	0.138	-0.529
51	132KALITI2	132KALITI1	-37.704	-14.383	37.893	14.397	0.189	0.014
52	132KALITI1	132KALITINEW	48.515	21.569	-48.445	-21.519	0.070	0.050
53	132KALITINEW	132BLEMIMB	12.049	3.604	-12.018	-4.044	0.031	-0.440

54	230LEGETAFO	230SINOSTILL	97.870	-29.948	-96.780	23.701	1.090	-6.246
55	132WENJI	132KOKA	-31.761	11.340	31.905	-11.406	0.144	-0.066
56	132MOJO	132KNORIT	-60.686	-3.224	61.504	4.133	0.819	0.910
57	132NAZRET2	132ADAMAWF1	-26.747	-15.004	26.826	14.939	0.079	-0.065
58	132EGEDA	132KOKA	25.070	-4.412	-24.812	3.852	0.258	-0.559
59	132KOKA	132NAZRET2	30.431	12.429	-30.217	-12.546	0.213	-0.117
60	132MOJO	132KOKA	32.200	-10.567	-31.863	10.372	0.337	-0.194
61	132WENJI	132AWASH	-6.959	-4.394	6.976	3.808	0.017	-0.586
62	132ASSELA	132WENJI	-32.026	9.548	32.743	-9.840	0.717	-0.291
63	230METEMA	230GONDER2	-188.206	10.275	192.503	-47.549	4.297	-37.274
64	230SUDB	230METEMA	-185.000	0.000	186.238	-11.228	1.238	-11.228
65	230MELKYGO	230MELK W	-45.631	-66.581	45.696	66.183	0.064	-0.398
66	230GONDER2	230BDAR2	-216.193	36.655	222.980	-73.736	6.787	-37.081
67	230DM	230MOTA	18.447	-23.952	-18.358	6.462	0.089	-17.490
68	230GASHENA	230ALAMATA	89.629	5.578	-88.014	-20.279	1.616	-14.701
69	230DM	230FINCHA	-11.937	23.657	12.085	-37.722	0.149	-14.065
70	230FINCA2	230FINCHA	-6.845	-22.177	6.853	20.569	0.008	-1.608
71	230GHEDO	230FINCHA	-73.973	-17.705	74.525	10.556	0.551	-7.149
72	132GEFERSA	132SEBETA1	-1.995	-3.254	1.998	2.794	0.002	-0.460
73	132GEFERSA	132KALITI1	19.513	-2.201	-19.359	1.395	0.154	-0.806
74	132MELKYGO	132SHSMNE	24.684	-7.406	-23.608	4.474	1.076	-2.932
75	230NESHI	230FINCA2	89.508	-26.571	-89.029	22.286	0.479	-4.285
76	230FINCA2	230GHEDO	91.078	-2.428	-89.969	-7.695	1.109	-10.123
77	230GHEDO	230GEFERSA	109.406	8.383	-107.859	-47.361	1.548	-38.978
78	132KALITI2	132KALITIGS	-35.830	-13.493	35.928	13.485	0.098	-0.009
79	230WOLKITE	230SEBETA1	66.457	-9.395	-65.133	-13.205	1.325	-22.600
80	230GEFERSA	230TORHAYL	-42.225	6.085	42.269	-8.025	0.044	-1.939
81	132KALITI1	132KALITIGS	40.153	15.508	-40.062	-15.486	0.092	0.022
82	230ENDASLASE	230AXUM	-21.890	-43.839	22.370	14.721	0.480	-29.118
83	230GEFERSA	230SULULTA	-80.186	-69.253	80.374	63.506	0.188	-5.748
84	132REPPIWE	132MEKANISA	36.299	8.607	-36.158	-8.637	0.141	-0.030
85	230AGARO	230GIMMA NEW	-23.903	-14.573	23.961	7.271	0.057	-7.302
86	230AGARO	230BEDELE	21.378	13.318	-21.219	-28.300	0.159	-14.982
87	230GG1	230GGNEW	128.979	-2.974	-128.914	1.746	0.065	-1.228
88	230GGNEW	230WOLKITE	108.565	-9.325	-107.334	5.328	1.231	-3.996
89	230ALAMATA	230MEHONI	16.509	5.291	-16.477	-12.932	0.032	-7.641
90	132BLION	132REPPIWE	11.140	-4.247	-11.126	4.017	0.014	-0.230
91	230GIMA NEW	230GGNEW	-55.557	-22.115	56.024	10.532	0.467	-11.583
92	230HOSSANA	230WOLKITE	-20.466	-10.859	20.547	-5.773	0.081	-16.632
93	230SEBETA2	230SEBETA1	202.041	61.893	-201.513	-63.584	0.528	-1.691
94	230SEBETA1	230KALITI1	26.503	1.770	-26.486	-3.703	0.017	-1.933
95	230SEBETA1	230TORHAYL	47.733	-9.167	-47.696	7.902	0.038	-1.265
96	230GELAN	230KALITI1	238.391	93.304	-237.850	-93.629	0.541	-0.324
97	230EIZONE	230GELAN	-79.790	16.263	80.052	-18.105	0.263	-1.842
98	230MELK W	230KOKA	-15.996	-32.607	16.228	10.624	0.232	-21.982
99	230KOKA	230ADAMAWF2	-87.686	-3.953	87.858	2.531	0.172	-1.421
100	230ALAMATA	230WOLDIYA	34.997	1.295	-34.836	-12.815	0.161	-11.520
101	230KOKA	230AWASH7K	73.323	-24.634	-72.044	11.369	1.279	-13.264
102	230DDAWA-3	230AWASH7K	-50.766	-5.683	51.740	-19.876	0.973	-25.559
103	230DDAWA-3	230HURSO	-32.996	-29.927	33.070	26.844	0.074	-3.083
104	230MEKELE	230ASHEGODWF	-20.325	-38.990	20.401	35.769	0.076	-3.222
105	230KOKA	230HURSO	68.214	-51.201	-64.397	-4.788	3.817	-55.988
106	230HURSO	230ADIGALA	30.893	-22.267	-30.590	-0.823	0.303	-23.090
107	230ADIGALA	230DJBTBR	30.156	1.712	-30.000	-14.500	0.156	-12.788
Total							94.056	-1472.082