ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

School of Electrical and Computer Engineering

ACTIVE POWER FLOW CONTROL IN ETHIOPIAN HIGH VOLTAGE TRANSMISSION NETWORKS USING PHASE SHIFTING TRANSFORMER TO ENHANCE UTILIZATION OF TRANSMISSION LINES

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Power Engineering Stream

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A thesis submitted to Addis Ababa Institute of Technology, School of Graduate Studies, and Addis Ababa University

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MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

(ELECTRICAL POWER ENGINEERING)

By

Yemane Esayas

Advisor: Dr.- Ing. Fekadu Shewarega

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Declaration

I, the undersigned, declare that this MSc thesis work is my original work, has not been presented for fulfillment of a degree in this or any other universities, and all sources of materials used for the thesis work have been duly acknowledged.

Name: Yemane Esayas

Signature: ____________________

Place: Addis Ababa Institute of Technology, Addis Ababa University,

Addis Ababa

Date of Submission: June, 2018

This thesis has been submitted for examination with my approval as a university advisor.

Dr.- Ing. Fekadu Shewarega ____________________

Advisor's Name Signature

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Abstract

The electricity supply industry of Ethiopia is undergoing a major transformation that requires a redefined approach to increase the utilization of existing transmission line assets. Overloading of transmission lines in a power system sometimes result stability issues, which may lead to unwanted tripping or failure of equipments. The cause could be uneven loading of interconnectors or parallel transmission lines in meshed networks due to different impedances caused by the tower geometry, conductor sizing, number of sub-conductors and line length. Under these conditions, to ensure economical and reliable operation of the grid, active power flow through the lines should be controlled within their capability limits.

In view of above, the power flow needs to be controlled in order to enhance utilization of high voltage transmission lines and secure the power system. Thus Control of power in AC network requires special technology to be implemented on case to case basis. Operating efficiency of electric transmission system can be improved by using appropriate Flexible Alternating Current Transmission System (FACTS) devices. Phase shifting transformer is one of the FACTS families, which can be used for power control in ac network.

This thesis presents a study on active power flow control within Ethiopian network for optimum utilization of transmission lines using phase shifting transformer (PST). The study is performed first by reviewing literatures on the use of phase shifting transformers how to redirect active power flow in transmission networks throughout the world. To demonstrate the active power flow control in the network, a 400/400 kV phase shifting transformer having a size of 685 MVA with a phase shifting angle range of -20^0 to$+20^0$ and the high voltage transmission networks was modeled using PSSE software(Power System Simulation for Engineers) for the peak load of 2040 MW in the year 2017. From the power flow studies/solution, various overloaded and under loaded transmission lines are identified. By varying the phase angle of the phase shifting transformer, several simulations are conducted to investigate the impact of PST on the active power flow distribution.

In this study, it has been demonstrated that the active power flow patterns which originally flow via the low impedance and lower voltage system is fully controlled and restructured using phase shifting transformer. By varying the phase shifting transformer angle, the active power flow in the transmission lines can be redirected towards the alternate high voltage path. As the Phase shifting transformer angle increased from -20° to +20°, the loading of Wolayta - Gibe II and Sebeta II-Gibe II 400kV transmission lines vary from 4% to 35% and 11% to 42% respectively. Similarly, Gelan - Wolayta400kV transmission line load increases from 15% to 43% as the Phase shifting transformer angle decreases from +20° to -20°

Conventional ways of solving the network bottlenecks based on reinforcement and building new transmission lines cannot be taken as sufficient and fast due to the problems of acquiring new corridors and environmental limitations. Installation of Phase Shifting Transformer in the transmission network is a better solution for controlling the active power flow and effective utilization of existing high voltage transmission network assets.

Key words: PSSE, phase shifting transformer (PST), power flow control, FACTS devices, phase shifting angle

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List of Acronyms

AC	Alternating Current
CEE	Central and Eastern Europe
CSC	Convertible Static Compensator
DC	Direct Current
EEP	Ethiopian Electric Power
EHV	Extra high Voltage
FACTS	Flexible Alternating Current Transmission System
GERD	Grand Ethiopian Renaissance Dam
HV	High Voltage
HVDC	High Voltage Direct Current Transmission
IEEE	Institute of Electrical and Electronics Engineers
IPFC	Interline Power Flow Controller
Km	Kilo-Meters
kV	Kilo Volt
MVA	Mega Volt Ampere
MW	Mega Watt
OLTC	On-Load Tap Changer
pu	Per Unit
PST	Phase Shifting Transformer
PSS/E	Power System Simulator for Engineering
SCC	Short Circuit Capacity
SCR	Short Circuit Ratio
SVC	Static Var Compensator
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
TCSC	Thyristor Controlled Series Compensator
TSOs	Transmission System Operators
UPFC	Unified Power Flow Controller
VSC	Voltage Source Converter

List of Symbols and Variables

I	Current
S	Apparent/complex power
P	Active power
Vi	Voltage at the i^{th} bus (sending end of the line)
Vj	Voltage at the j^{th} bus (receiving end of the line)
Z	Impedance of the Transmission Line
X_L	The transmission line reactance
R	The transmission line resistance
B	The transmission line susceptance
X_{PST}	The phase shifting transformer reactance
δ_i	Phase angle at the i^{th} bus (sending end of the line)
δ_j	Phase angle at the j^{th} bus (receiving end of the line)
ΔV	Deviation/Change in Quadrature voltage
V_{S1}	Source terminal voltage of phase shifting transformer
V_{L1}	Load terminal voltage of phase shifting transformer
Zeq	Equivalent Impedances of bus
α -	Phase angle between Source and Load the terminal voltages of the Phase shifting Transformer
α_{max}	Maximum phase shifting angle
α_{min}	Minimum phase shifting angle
σ	The phase shift angle by the phase shifting transformer
S_{PST}	Apparent/complex power rating of phase shifting transformer
P_G	Active Power Generation
P_D	Active Power Demand

Chapter 1

Introduction

1.1 Background

In recent years, Ethiopian grid system has undergone/progressed towards rapid development and expansion processes. Many big hydro power plants and very long EHV transmission lines has been added to the grid to serve the fast growing economy of the country, also in the near future many more power plants are expected to be connected with the power grid.

The Ethiopian National Grid is 100% powered by renewable energy resources mainly coming from hydro and wind power plants with a total installed capacity of 4,094.2MW as of Feb. 2016. Installed Capacity of Hydro power plants is 2657MW, Wind power plant 328MW and others. In addition, GERD hydro power project having a capacity of 6000MW is also expected to be connected stage by stage. In the year 2020 the total installed capacity of the Ethiopian National Grid will be more than 10,000MW [1].

According to the company's current standard practices the high voltage transmission system is currently based on four (04) different voltage levels (i.e. 500, 400, 230 & 132kV) ,the sub transmission system is based on two voltage levels (i.e. 66 & 45kV) and the distribution system is based on two voltage levels (i.e. 33 & 15kV).

The total length of transmission & sub-transmission system is around 19,323 km as detailed below.

Voltage Levels	500kV	400kV	230kV	132kV	66kV	45kV
Transmission Line Length(km)	2476.04	2352.52	7189.93	5106.64	1953.51	244.32
Total length(km)	19,323					

There could be uneven loading of parallel transmission lines due to different impedances caused by the tower geometry, conductor sizing, number of sub-conductors and line length. The distribution of the power flow between two parallel lines is dictated by their impedances.

The line with the smaller impedance carries more power and vice versa. In most situations, one of the two lines will be operating well below its nominal rating because it's lower impedance.

In view of above, the power flows need to be controlled in order to achieve the optimum utilization of transmission lines capacity by implementing a phase shifting transformer in ac transmission networks to mitigate unbalanced sharing of power among circuits.

If any component gets congested its effect is felt by the system and the network is overburdened and is stressed to its limits. Different methods can be used for the relief purpose. The removal of the overloaded transmission line from the system might solve the problem but still there is a possibility of magnifying the stress on other transmission line and power system components. Therefore a Specially designed power system devices can control the flow of active and/or reactive power in power systems.

Usually transformers are used to transport electric power between different voltage levels of the electric grid. Transformers may also be used to phase angle control between the primary (source) and the secondary (load) side. Such special transformers are termed phase shifting transformers (phase angle regulating transformers) or simply phase-shifters. These transformers create a phase shift between the primary side voltage and the secondary side voltage. The purpose of this phase shift is usually to control the power flow over ac transmission lines. Both the magnitude and the direction of the power flow can be controlled by varying the phase shift angle.

Traditionally, the Phase Shifting Transformer (PST) was considered as the only device able to control both magnitude and direction of the active and reactive power flow. Though, today other devices are available, yet the traditional PST is still the most widely used technology.

1.2 Statement of the Problem

Currently, the generation of electric power is expanding at a rapid rate to meet the increasing demand. However, due to uneven loading of interconnectors in meshed networks, the actual power transferred through the transmission lines is lower than its carrying capacities which results in an overall congested transmission system. Moreover, due to different impedances of parallel transmission lines caused by the tower geometry, conductor size, number of sub-conductors and length of lines, one of the two lines operate under overloaded condition.

This thesis addresses the above noted issues in Ethiopian high voltage transmission networks and investigates solution by using phase shifting transformers (PSTs) to control the active power flow through high voltage transmission lines.

1.3 Objectives

General Objective

The general objective of this thesis is to investigate the appropriate locations and rating of phase shifting transformers (PSTs) and to implement it in Ethiopian transmission networks to control the active power flow through high voltage transmission lines

Specific objectives

The specific objectives of the study are as follows:

- To study the basic operation of Phase Shifting Transformer
- To identify the overloaded and under loaded existing HV transmission lines of Ethiopian transmission networks
- To determine appropriate ratings and location of PSTs in the HV transmission networks
- To integrate PST in the network and carry out load flow analysis
- To control the active power flow across the high voltage transmission lines
- To enhance utilization of existing high voltage transmission lines
- To relieve overloaded transmission lines
- To draw conclusions and make recommendations based on the findings of this research work

1.4 Methodology

For this thesis the methodology starts from the problem identification, literature review, data collection and network modeling using PPS/E software. The following steps have been followed for conducting the proposed studies:

- ✓ Collecting of the high voltage transmission line data, and peak loads of 2017peak load from Load Dispatch Center and power system planning (Appendix 4 :and Appendix 5 :)
- ✓ Modeling the transmission network using PSSE software
- ✓ Run the power flow without PST and identify the overloaded and under loaded high voltage transmission lines
- ✓ Identifying the point at which PST would be introduced in order to Control the active power flow within the network
- ✓ Finally, to run the load flow with PST at different phase shifting angle and control the active power flow through the lines to achieve a maximum utilization without over loading.

1.5 Outline of the Thesis

The present chapter includes the introductory material, problem statement, and objectives and the proposed research methodology. Chapter 2 presents literature review on applications of phase shifting transformers to control power flow in high voltage transmission networks. The power flow control using FACTS devices is presented in Chapter 3. Applications of phase shifting transformers to control the power flows in a transmission lines regardless of the impedance of the network is also discussed in this chapter. Chapter 4 includes modeling of phase shifting transformers, simulation studies and analysis of results. Conclusions, recommendations and suggestions for future work are presented in Chapter 5. Finally, the thesis ends with the list of references and appendices.

Chapter 2

Literatures Review on Application of Phase Shifting Transformers

2.1 Introduction

It is a generally recognized fact that one of the most problems encountered in the real power system operation within utility and different utilities connections is that, instability due to transmission lines overloading and regulating the power flow in a flexible means of operation. Such problems would become more complex as the number of systems increase.

In view of above, the power flows need to be controlled in order to achieve the optimum utilization of transmission lines capacity and secure the power system. A Phase shifting transformers have been used throughout the world to solve some of these problems. In this chapter some of the existing literatures on the use of phase shifting transformer throughout the world is reviewed and presented.

2.2 Applications of Phase Shift Transformers

The use of phase shifting transformers to control power flow was recognized early in the electrical power system development and early studies of its application were published in the 1930s [2]. Here, W.J Lyman, express that one of the most difficulties encountered during operation of interconnected system was securing accurate and flexible means of controlling the power flow across the tie line. And this problem became complicated as the number of interconnected system increased resulting improper load division across inter-Companies power exchange agreements, tie line capacity and the power system components of the utilities.

The author discusses that, in small systems, power flow control was easily achieved by power system development coordination like adjustment of governor speed, selecting parallel circuits or compensation. If the power system element on the tie line enters the problem, it results in conditions that cannot be controlled by the adjustment of the governor. For this reason, the experimental and analytical methods of the power flow control have been conducted by altering the transmission voltage phase angle and the required power control across the closed rings and parallel paths were achieved. The actual tests was performed and analyzed on a 250 mi high voltage transmission ring interconnected system involving five difference power companies (i.e. the systems of the West Penn Power Company, Ohio Power Company, Ohio Public Service, Pennsylvania and Ohio Power and Light Company, and the Duquesne Light Company).

The overall results strongly supported that the phase angle regulation can achieve the required power flow control in a system that have ring or parallel power flows.

2.3 Application of Phase Shifting Transformers in Cross Border Power Flow Control

R. KORAB and R. OWCZAREK[3] have discussed how the unscheduled power flows due to cross-border energy trading within the CEE (Central and eastern Europe) region and an even increasing of renewable energy resources in Germany can block a significant part of the transmission capacities on the interconnectors region particularly to the tie-lines of the Polish and Czech power systems. By that time Re-dispatching (i.e. increasing generation in one location balanced by decreasing generation in another location) the power station was the remedial action of the system operators.

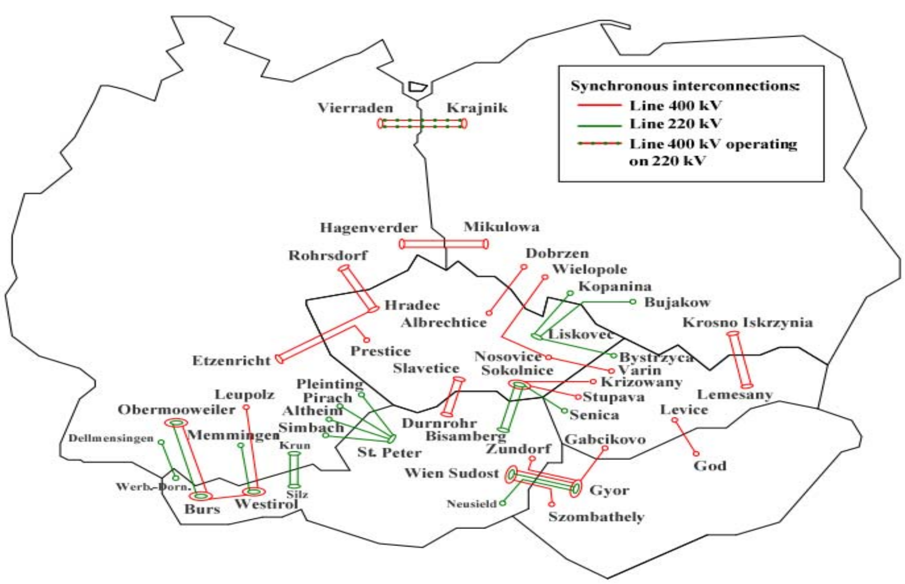


Figure 2. 1 Main tie-lines in the CEE region

The paper presented a study on the possibilities for cross-border active power flow control using PSTs installed in the tie-lines on Polish–German and Czech–German interfaces to insure the safe operation of the required power flows from the German to the Polish system to be maintained at a level below 1300 MW in summer and 1600 MW in winter.

Considering the summer and winter peak load demands, the studies have been performed using PLANS distribution software and the power flow calculation was analyzed.

The result of the analysis shows that the installation of PSTs in each circuit of Poland-Germany interconnection (i.e.Mikulowa-Hagenverder and Krajni-Vierraden lines) can reduce the flow of unscheduled power between the countries power system. Verboomen et. el. [4] have presented principles of altering the electrical angle of the desired voltage within certain limits using phase shifting transformers. As a case study the author model five interconnectors to Netherlands powers system from its neighboring countries which are Belgium and Germany. The result showed that due to an overloading of the southern interconnectors compared to the northern interconnectors, installation of the phase shifting transformers on the Netherlands-Germany interconnection increase the import from the northern part of the country and also distributing the loading of the interconnectors more equally

In reference [5], the authors discussed the problems encountered by power system operators in line near to full load contributes more losses to system. However, using power flow controlling devices, power can be shifted from congested lines to lines with more free capacity, lowering total system losses. Simulations were performed on the IEEE New England 39- bus system to evaluate the use of the phase shifting transformers and High Voltage Direct Current Transmission [HVDC] systems to reduce the power system losses, in comparison with other power flow control devices. MATPOWER software has been used to calculate the load flow and compare the overall system losses.

The authors showed that power flow controlling devices including the phase shifting transformers can reduce the power system losses. However, in meshed power systems, the deployment of power flow control devices must be well coordinated. Otherwise, if one Transmission System Operator were to operate a phase shifting transformer located in his local control area without looking or coordinating with his neighboring control area, the latter phase shifting transformer operated may counteract the actions of the previous one.

Paola Bresesti [6] have shown that the fast growth of electricity trading increases the Cross Border Exchanges among national systems which results uncontrolled parallel power flows and overloading of some transmission facilities. These flows affect the system security of the countries which are not directly involved in the transaction and incurred additional costs for power transits on Transmission system operators (TSOs).The thesis mainly focused on parallel flow phenomenon of the Italian East-Border Interconnection.

To mention a few, the authors have discussed how Phase shifting transformers maintain a secure, efficient and economical operation of the interconnections, and also how to control the flow of active and/or reactive power in interconnected power systems to minimize parallel flow, line overloads and parallel-line load sharing.

Finally, these authors have pointed out that the PSTs give a remarkable solution to control a power flow, relive considerable overload and improving the operation security of the Italian East border interconnection.

2.4 Phase Shifting Transformers During Peak Power Demand

To meet the accelerated growth of Indian power sector optimal use of existing transmission lines is preferred rather than constructing of new transmission lines. Publications [7] discussed applications of the phase shifting transformer in Indian grid either in overloaded or under-loaded transmission lines.PST is proposed in under-loaded line for sharing load from over loaded lines. Similarly, PST is introduced in overloaded lines to limit power flow within its capability.

For demonstrating how to maximize the utilization of the existing transmission lines by controlling the power flow using Phase Shifting Transformer, Maharashtra zone and Utter Pradesh zone of an Indian grid were considered and modeled using PSS/E software [8].The power flow solution showed that loads are situated far from power generation and with the planning new generation, existing transmission lines get overloaded especially the lines with lower impedance. The authors have demonstrated that by introducing and regulating the Phase Shifting Transformer either in lightly loaded or overloaded lines, we can control the active power distribution over the transmission lines and optimize loading conditions.

2.5 Conclusions

In most of the application reviewed above, because of the deregulation of the electricity industry[5], the phase shifting transformers are used to control power flow across the transmission lines in order to relief overloading within the particular utility and also to control unscheduled power flow across the tie-lines.

From the reviewed literatures the main benefits of the phase shifting transformers are to redirect the power flow to other lines that are carrying little load ,to control unscheduled power flow through tie-lines ,to control the parallel power flows in inter-country transmission systems, and to reduce system losses.

Utilization of phase shifting transformer also proved to be more beneficial than building new transmission lines. This is advantageous because of building of new lines require high investment and the problem of getting the right-way.

Still now no work has been done on the use of phase shifting transformers for Ethiopian grid. Therefore my thesis attempt to study on the implementation of phase shifting transformer to control the active power flows within Ethiopia grid

Chapter 3

Power flow Control in Transmission Lines Using Phase Shifting Transformers

3.1 Introduction

Power flow control becomes a key focus area due to the power flow congestion in the transmission grid which encountered more often than before. In this chapter, we discuss power flow through a transmission line as well as power flow control using FACTS devices and Phase Shifting Transformers (PSTs). Different types of phase shifting transformers and their possible configurations are described in detail.

3.2 Power flow through a transmission line

Power flow in a transmission line is governed by the sending and receiving-end bus voltages, the angle difference between buses and the impedance of the line, as illustrated in Figure 3. 1 below [2, 3]

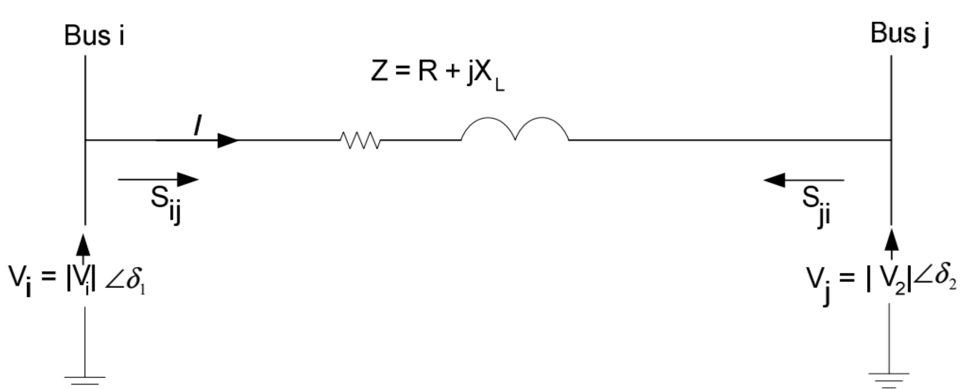


Figure 3. 1 Power trough a transmission line

$$P = \frac{|V_i||V_j|\sin(\delta_1 - \delta_2)}{Z} \quad (3.\ 1)$$

Where

P = Active power transmitted through a transmission line

V_i = Voltage at the sending end of the line

V_j = Voltage at the receiving end of the line

Z = Impedance of the transmission line

$\delta_1 - \delta_2$ = Phase angle difference between sending-end and receiving-end voltages

3.3 Controlled parameters

As shown in equation (3.1), the active power through a transmission line is a function of four variables: line reactance, phase angle and bus voltages. Any of these parameters can be altered to indirectly change the line power flow, provided a meshed grid is considered [9].

Conventional means to control these parameters are addition of series impedances (inductances or capacitors) and the use of phase shifting transformers (PSTs). Modern developments in power electronics add new functionalities to these devices and lead to categorized them under the term flexible AC transmission systems (FACTS) as a whole family of controllers [10].

The possibilities of controlling the parameters are discussed hereafter.

Line reactance control

The active line power is inversely proportional to the line reactance. It is impossible to directly control the reactance, but it can be compensated by a series capacitor. Fixed series capacitors are sometimes used for permanent compensation.

Voltages control

The bus voltage magnitude cannot deviate much from 1 p.u. Therefore, this quantity is not considered for power flow control.

Phase angle control

Phase angle control can be attained in a relatively easy way by injecting a quadrature voltage. This is established in a Phase Shifting Transformer (PST) by injecting a part of the voltage between two phases in the third phase using a tap variable transformer [11].

This kind of power flow control gives rise to nonlinearities, because of the sine function of power equation.

There are also devices that are based on power electronics, such as the unified power flow controller (UPFC), which have capabilities that reach much further than power flow control alone.

3.4 Power Flow Controller Technologies

The fast changing of electrical energy demand becomes a challenge for the system operators. The power flow over a transmission system can be limited by Thermal limits, Voltage limits, Stability limits, Loop flows etc.

Technically, limitations on power transfer can always be removed by adding new transmission and/or generation capacity. Finding suitable right-of-ways to construct a new transmission lines, and gaining the necessary investment capital is more time-consuming than ever. Due to this situation, looking for ways to utilize the existing transmission lines more efficiently require a special attention.

Today the developments of Flexible AC Transmission Systems (FACTS), based on high power electronics, are designed to remove such limitations and offer a powerful new means of controlling capability of the power flow in the grid in order to meet the fast-changing energy market challenges. Various basic applications of FACTS-devices are reviewed.

Static Var Compensator (SVC)

A shunt- connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current in order to maintain or control specific parameters of the electrical power system (typically bus voltage).

The term, “SVC” has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability. It includes separate equipment for leading and lagging vars.

The thyristor– switched reactor for absorbing reactive power and thyristor – switched capacitor for supplying the reactive power are the most applicable[9],[10]

Thyristor Controlled Series Compensator (TCSC)

It is designed based on the thyristor based FACTS technology that has the ability to control the line impedance with a thyristor-controlled capacitor placed in series with the transmission line. It is used to increase the transmission line capability by installing a series capacitor that reduces the net series impedance thus allowing additional power to be transferred. TCSC device consists of three main components: Capacitor bank, bypass inductor and two bidirectional thyristors.

Static Synchronous Series Compensator (SSSC)

Static Synchronous Series Compensator (SSSC) is based on solid-state voltage source converter designed to generate the desired voltage magnitude independent of line current. SSSC consists of a converter, DC bus (storage unit) and coupling transformer. The dc bus uses the inverter to synthesize an ac voltage waveform that is inserted in series with transmission line through the transformer with an appropriate phase angle and line current. If the injected voltage is in phase with the line current it exchanges a real power and if the injected voltage is in quadrature with line current it exchanges a reactive power. Therefore, it has the ability to exchange both the real and reactive power in a transmission line [12].

Static Synchronous Compensator (STATCOM)

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

Unified Power Flow Controller (UPFC)

It is designed by combining the series compensator (SSSC) and shunt compensator (STATCOM) coupled with a common DC capacitor. It provides the ability to simultaneously control all the transmission parameters of power systems, i.e. voltage, impedance and phase angle. It consists of two converters one connected in series with the transmission line through a series inserted transformer and the other one connected in shunt with the transmission line through a shunt transformer. The DC terminal of the two converters is connected together with a DC capacitor. The series converter control to inject voltage magnitude and phase angle in series with the line to control the active and reactive power flows on the transmission line. Hence the series converter will exchange active and reactive power with the line [13].

Interline Power Flow Controller (IPFC)

It is designed based on Convertible Static Compensator (CSC) of FACTS Controllers. IPFC consists of two series connected converters with two transmission lines. It is a device that provides a comprehensive power flow control for a multi-line transmission system and consists of multiple number of DC to AC converters, each provide series compensation for a different transmission line. The converters are linked together to their DC terminals and connected to the AC systems through their series coupling transformers. With this arrangement, it provides series reactive compensation in addition any converter can be controlled to supply active power to the common dc link from its own transmission line.

Phase Shifting Transformer

Phase shifting transformers (phase regulator) are used to control the flow of electric power over transmission lines. Both the magnitude and the direction of the power flow can be controlled by varying the phase shift across the series transformer. Phase shifting transformers (PSTs) present an economical and reliable solution as compared with flexible alternating current transmission system (FACTS) devices [14].

3.5 Phase Shifting Transformer technology

Phase Shifting Transformers exist in many different forms. They can be classified by the following characteristics [5].

- *Direct PST*: - have one three-phase core. The phase shift is obtained by connecting the windings in an appropriate manner to each other.
- *Indirect PST*: -are constructed using two separate transformers. One variable tap exciter to regulate the amplitude of the quadrature voltage and the other one series transformer to inject the quadrature voltage in the line.
- *Asymmetrical PST*: - create an output voltage with an altered phase angle and amplitude compared to the input voltage.
- *Symmetrical PST*: - create an output voltage with an altered phase angle compared to the input voltage, but with the same amplitude.

Each category is discussed in detail in the next paragraphs.

3.6 Basic Operating Principle of Phase Shifting Transformer

The phase shifting transformers are available in various designs and types; however, they use the same basic technique to create the quadrature voltage (ΔV). For a transmission line with Phase Shifting Transformer (PST), the power flow is controlled by changing the phase shift angle between the PST source- side voltage and load-side voltage. The phase shift is obtained by extracting the line-to-ground voltage of one phase and injecting a portion of it in series with another phase. This is accomplished by using two transformers: the regulating (or magnetizing) transformer, which is connected in shunt, and the series transformer. Therefore, under load conditions, a change in voltage (ΔV) can be obtained by using the on-load tap changer (OLTC).

3.7 Power Flow Control Using Phase Shifting Transformer

From having seen which parameter can be altered using PST to have an effect on the active power flow and how the changing of the phase angle at the sending and receiving ends have a significant influence on the active power flow, the review of how the phase shifting transformer influences the phase angle magnitude will be undertaken below. The phase shifting transformer controls the active power flow by injecting a voltage ΔV at 90^0 to the network voltage [4] as shown in Figure 3. 2

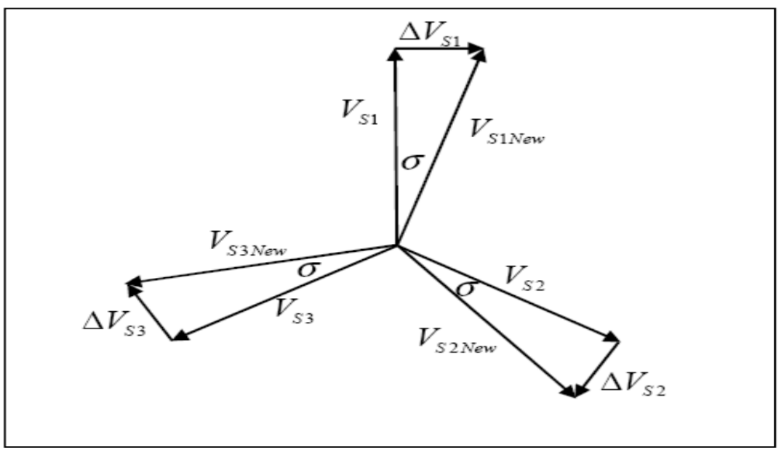


Figure 3. 2 Phasor diagram of a phase shifting transformer

The resulting output voltage $|V_{S1New}|$ is always larger than the input voltage $|V_{S1}|$, and the new output voltage $|V_{S1New}|$ is shifted by the angle σ with respect to the system voltage $|V_{S1}|$. The active power flow transfer formula (3.1) becomes

$$P = \frac{|V_i||V_j|\sin(\delta_1 \pm \sigma)}{X_L + X_{PST}} \quad \text{(3. 2)}$$

Where,

σ = the phase shift angle introduced by the phase shifting transformer

X_{PST} = the phase shifting transformer reactance

X_L = the impedance of the transmission line reactance

In order to illustrate how the phase shifting transformer controls the power flow in a transmission power network, an example of a transmission network with two parallel lines and in one of the lines a phase shifting transformer is installed as shown in Figure 3. 3.

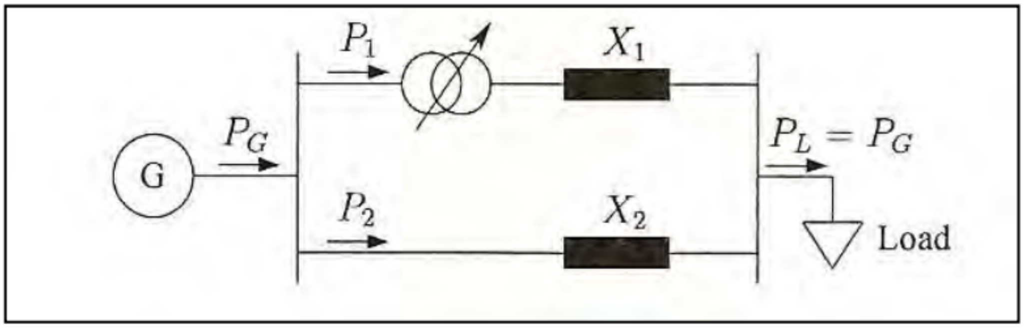


Figure 3. 3 Two parallel lines with one having a phase shifting transformer

From equation (3.1) and $P_G = P1 + P2$, it can be shown that if line 1 has a larger reactance than line 2 (X1>> X2) and their line resistances are neglected, then without the power flow control by the phase shifting transformer, line 2 will carry more power than line 1 as shown by the following:

$$\frac{P_1}{P_G} = \frac{X_2}{X_1 + X_2} \quad \text{.......... (3. 3)}$$

$$P_1 = P_G \frac{X_2}{X_1 + X_2} \quad \text{.......... (3. 4)}$$

$$P_1 = P_G \frac{X_2}{X_1\,(1+\frac{X_2}{X_1})} \quad \text{.......... (3. 5)}$$

$$P_1 = P_G \frac{X_2}{X_1} \sim 0 \quad \text{If } X_1 \gg X_2 \quad \text{.......... (3. 6)}$$

And

$$\frac{P_2}{P_G} = \frac{X_1}{X_1 + X_2} \quad \text{.......... (3. 7)}$$

$$P_2 = P_G \frac{X_1}{X_1 + X_2} \quad \text{(3. 8)}$$

$$P_2 = P_G \frac{X_1}{X_1\ (1+\frac{X_2}{X_1})} \quad \text{(3. 9)}$$

$$P_2 = P_G \frac{X_1}{X_1} = P_G \text{ If } X_1 \gg X_2 \quad \text{(3. 10)}$$

Equation (3.6) indicates that P_1 is approximately zero and equation (3.10) shows that P_2 is approximately equal to P_G, indicating that P_2 is far larger than P_1 .

Similarly, when the phase shifting transformer is installed on line 1, the power through each line can be represented as follows:

$$P_1 = \frac{|V1||V2|\ \sin(\delta \pm \sigma)}{X_1 + X_{PST}} \quad \text{(3. 11)}$$

And

$$P_2 = \frac{|V1||V2|\ \sin\delta}{X_2} \quad \text{(3. 12)}$$

The relationship between the powers transmitted through each line can be plotted as follows:

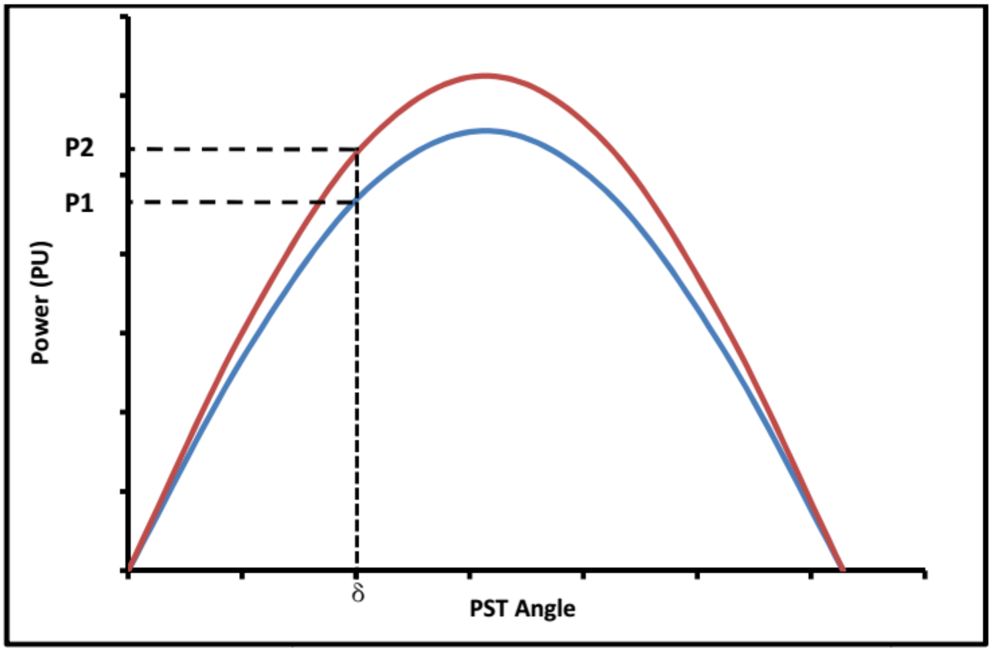


Figure 3. 4 P-δ Graphs for parallel lines without phase shifting transformer

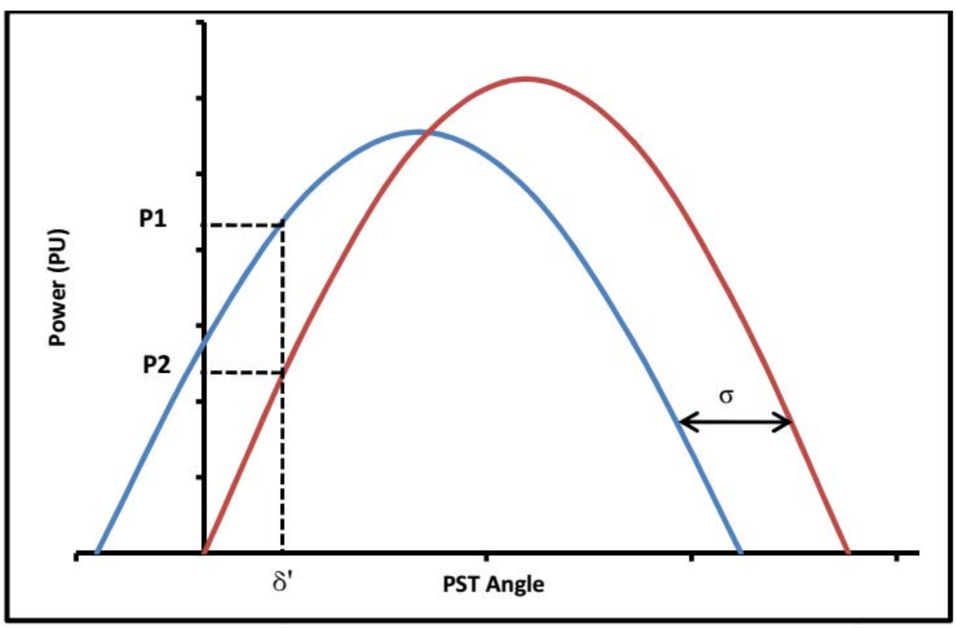


Figure 3. 5 P-δ Graphs for parallel lines with phase shifting transformer

3.8 Types of Phase Shifting Transformers

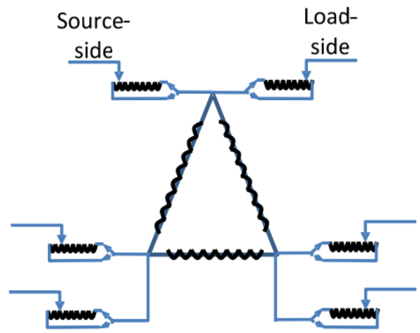
Phase shifting transformers are mainly categorized into four types, each with a different design and construction. Each design uses the same basic methodology to create the quadrature voltage by simply subtracting the other two phases from each other at the exciting winding, whereas the source and load sides are connected to the series winding.

A PST can be constructed as two-core (indirect) or single-core (direct). Both types of constructions have advantages and disadvantages. According to [15], a symmetrical design alters the phase angle with equal magnitudes of source- side and load-side voltages, whereas an asymmetrical design alters the phase shift and voltage magnitude, which can cause changes in the reactive power flow. The advantage of a symmetrical design over asymmetrical is that the phase shift angle is the only parameter that influences the active power flow. However, it uses two single-phase OLTCs per phase and therefore, it is more costly than the asymmetrical design.

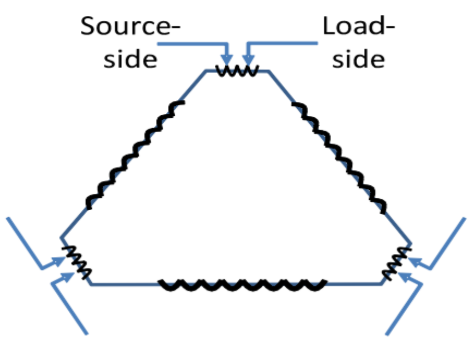
Asymmetrical design alters both phase shift and voltage magnitude. It is known from the aforementioned discussion that a variation in voltage has greater influence on reactive power than active power.

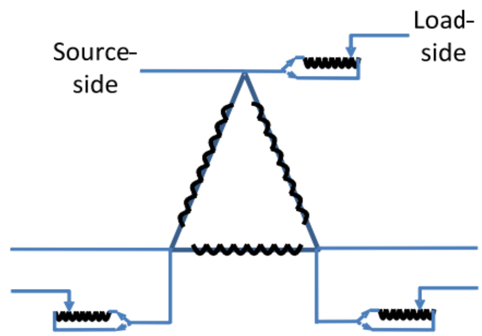
Figure 3. 6show three single-core design types. The single-core design can be constructed as standard-delta symmetrical (Figure 3. 6(a)), delta-hexagonal symmetrical (Figure 3. 6(b)) and squashed-delta asymmetrical (Figure 3. 6(c)).

The single-core design is simple and economical. An on-load tap changer(s) is installed on the series winding that is connected with the system source and load sides. The two main disadvantages of this type of construction are: OLTC(s) exposure to over-voltages and through-faults; secondly, to prevent the OLTC from system over-voltages and through-fault currents, the OLTC must be selected with higher specifications; however, it's not an economical solution. Moreover, the short-circuit impedance of the PST varies between maximum and zero, therefore influencing the contribution of fault currents in the system [16].



(a) Standard-delta symmetrical





(b) Delta-hexagonal symmetrical (c) squashed-delta asymmetrical

Figure 3. 6 Schematic diagrams of single-core PSTs

Figure 3. 7 and Figure 3. 8show two types of commonly used two-core designs: symmetrical (Figure 3. 7) and asymmetrical (Figure 3. 8), [17]. These types consist of series and exciting units. The source and load sides are connected to the series unit primary winding, whereas primary windings of the exciting unit are connected to the system voltage level. The secondary windings of the series unit are connected with the other two phases of the secondary of the exciting unit, therefore making a delta connection to create the quadrature voltage. Quadrature voltage can be controlled or changed by the OLTC installed at the secondary of the exciting unit.

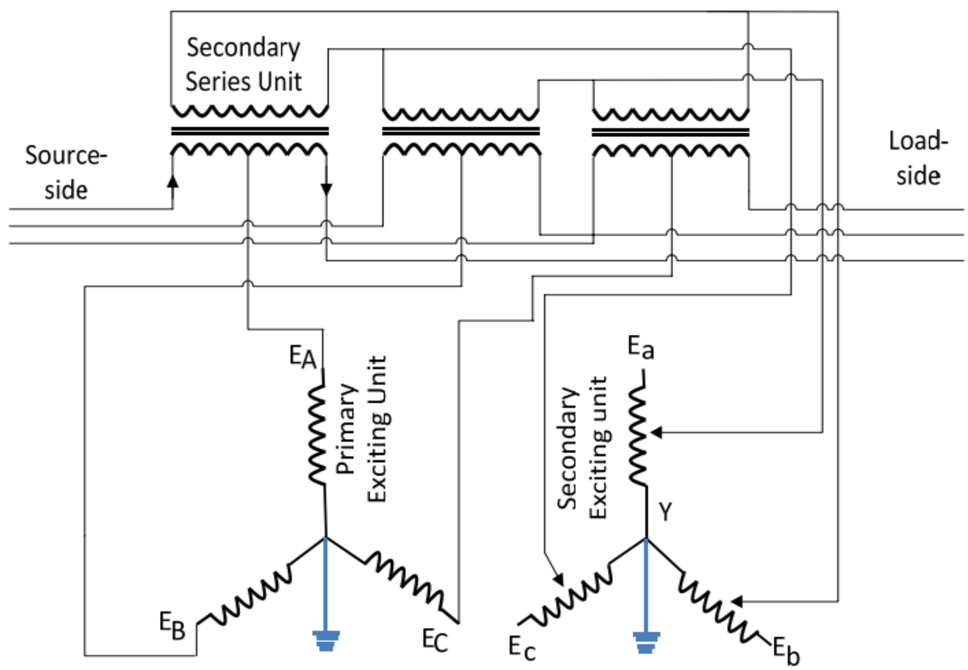


Figure 3. 7   Schematic diagram of a two-core symmetrical PST.

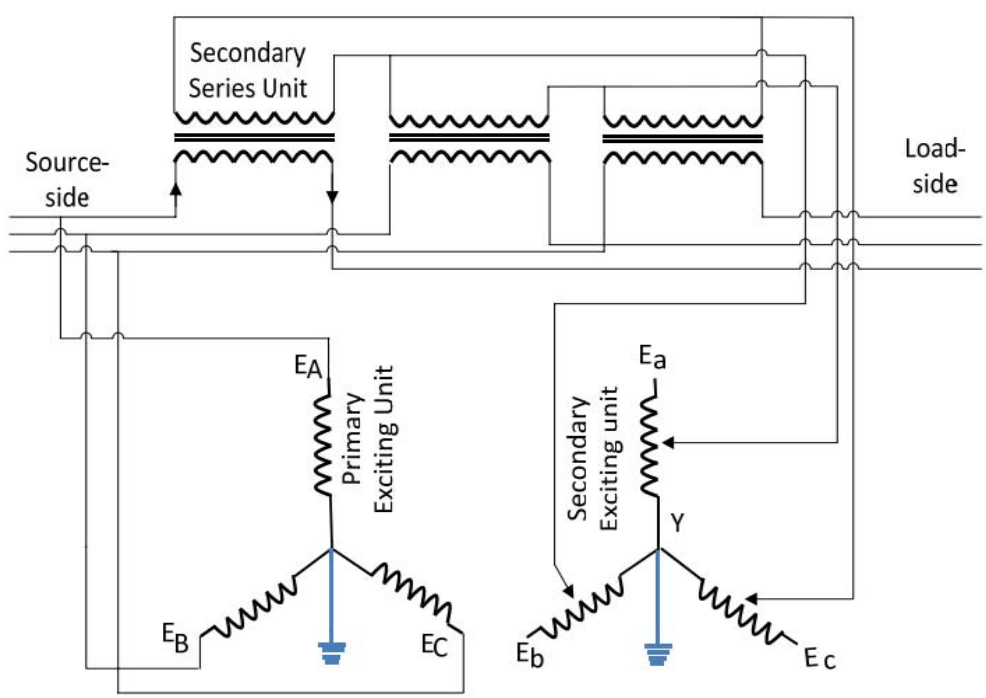
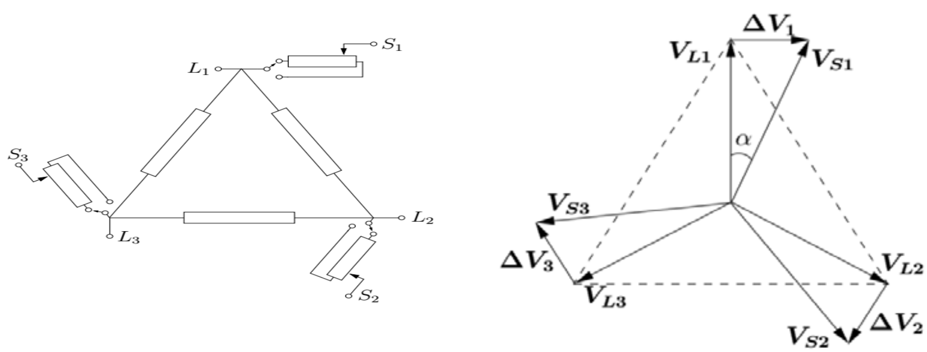


Figure 3. 8   Schematic diagram of a two-core asymmetrical PST.

The two-core construction is not as economical as the single-core, but has the advantages of a non-direct connection between the exciting unit and the system neutral grounding. Moreover, it offers greater flexibility in selecting the step voltage and the current of the regulating winding.

Direct Asymmetrical PST

Figure 3. 9 show the configuration of a direct asymmetrical PST. The input terminals are L_1 to L_3. The winding with a variable tap connected to the input terminal is magnetically coupled with the winding between the other two terminals. By doing so, a quadrature voltage that can be regulated by means of the variable tap is added to the input voltage in order to obtain a phase shift α. The direction of the phase shift can be changed by using switches. In this way, the power flow in the line can be increased or decreased. The relation between the tap position and the angle α is nonlinear and can be derived from the phasor diagram Figure 3. 9b



(a) (b)

Figure 3. 9 Phasor and Circuit diagram of direct asymmetrical PST

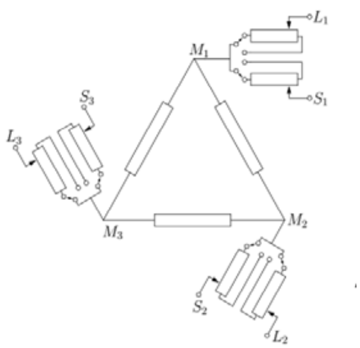
$$\alpha = \tan^{-1}\frac{\Delta V_1}{V_{L1}} \quad \text{(3. 13)}$$

The relation between the secondary voltage and the injected voltage is given by:

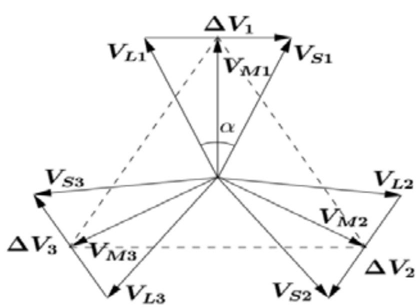
$$V_{S1} = \frac{\Delta V_1}{\sin\alpha} \quad \text{(3. 14)}$$

Direct Symmetrical PST

With some modifications, the direct asymmetrical PST can be made symmetrical as shown in (Figure 3. 10a) an additional tap changer is needed, which increases the total cost of the device. The advantages are that the voltage amplitudes remain unchanged and that the maximum attainable angles are larger. The relation between the quadrature voltage and the angle α is again nonlinear and can be derived from the phasor diagram Figure 3. 10(b):



$$\alpha = 2\tan^{-1}\frac{\Delta V_1}{2\,V_{L1}} \quad \text{......... (3. 15)}$$

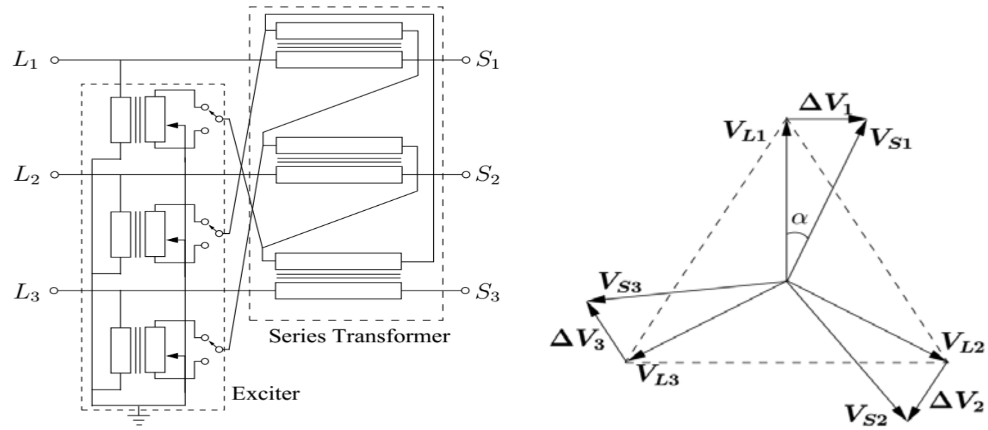


(a) (b)

Figure 3. 10 Phasor and Circuit diagram of direct symmetrical PST

Indirect asymmetrical PST

The indirect asymmetrical PST consists of an exciter and a series transformer. Depending on the rating of the system, these two transformers are housed in separate tanks or in a single tank. The two-tank system has the advantage of an easier transport. Figure 3. 11show the phasor diagram and the configuration of the system.

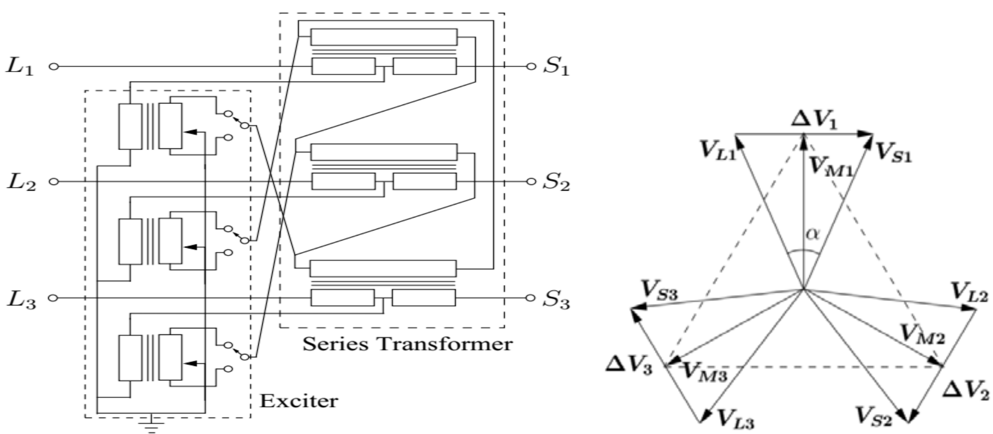


(a) (b)

Figure 3. 11 Phasor diagram and configuration indirect asymmetrical PST

Indirect Symmetrical PST

The indirect asymmetrical PST can be made symmetrical by splitting the series winding in two and tapping the voltage for the exciter from the middle. Figure 3. 12show the phasor diagram and the configuration of the system.



(a) (b)

Figure 3. 12 Phasor diagram and configuration of indirect symmetrical PST

3.9 Operation and Economic Benefits of PST

Phase Shifting Transformer is a special transformer used in power system network to control active power by regulating the voltage phase angle difference between two nodes of the system [14]. It is a mature technology solution for efficient power flow control and economic power-flow management

Transmission networks are usually loaded close to their transmission limits. The PST is proposed as one of the most cost-effective solution that efficiently controls the flows of active power through network.

Areas of Application

- *Increase transmission capacity*

In an uncontrolled grid, the impedance of the lines will determine the natural load distribution. It is vulnerable to transmission bottlenecks, which in turn can cause individual lines to overload. By changing the phase angle between source and load, a phase shifter can control the load flow between parallel lines and network segments, effectively preventing overloads.

- *Improve grid stability*

The rising number of interconnected networks creates more complex power flows. As a trend, the utilities are forced to consider expensive grid upgrade. Phase shifters are a versatile and more cost-efficient alternative. It blocks unwanted power flow from adjacent grids, eliminate loop flows, and are fast to reconnect after blackouts – even to grids with a large phase-angle difference.

- *Cross-network trading*

A cross-network energy trading between countries or power companies is governed by agreed contract power flow. But actual power flow is not quite as easy to control. It is the result of many factors, from in-feed to grid characteristics. A gap between physical power flow and contract obligations can affect both profits and grid stability. PST can be used actively to close the gap.

Advantage of PST during operation*:*

- Allow to control the power flow in the transmission grid independent of the generation,
- Rebalance the power flows in parallel lines,
- Increase transmission capacities without violation of n-1 safety criterion,
- Prevent line overloads,
- Increase system reliability,
- Block – or even reveres – power
- Eliminating unwanted power flows,
- Remove bottlenecks in the network caused by concentrated power injection, etc...

Apart from operational benefits, PSTs has the following economical benefits

- Minimize the electrical losses in the system by improve the system operating performance ,
- Save the investment cost for the construction of new transmission lines,
- Reduce Operating costs by avoiding system overloads and instabilities, etc…

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Chapter 4

Phase Shifting Transformer Modeling and Simulation Studies

4.1 Introduction

In this chapter, selection of effective location of phase shifting transformers (PST) is discussed. Power System Simulator for Engineering (PSS/E) software is utilized to model phase shifting transformers (PSTs) and carry out simulation studies. Implementation of PST into 400 kV Ethiopian transmission networks is investigated under various operating conditions with the aim of enhancing the regulation effect. Finally, the simulation results are analyzed.

4.2 Selection of effective locations of PSTs

The ‘strength’ of the power system is determined by its impedance and mechanical inertia, i.e. kinetic energy, stored in the rotating parts of the connected generators. Alternatively it can be measured by the three-phase short circuit capacity (SCC) at a specific bus and it is equal to the reciprocal of the magnitude of the Thevenin impedance as seen from this bus multiplied by the system three-phase MVA base [18].

The system, consisting of numerous generators and transmission lines will have different value of the Short Circuit Ratio (SCR) at each specific bus. The SCR of a bus is an indication of the strength of the bus. In per-unit terms, the SCR at bus n is the reciprocal of the driving point impedance of the network observed from bus “n” [19].The smaller the magnitude of the driving point impedance the stronger the system.

Mathematically, SCR at bus n is:-

$$SCR=\frac{1}{Z_{eq}}$$

A 3phase short circuit was imposed at each bus and the result of driving point impedance of the buses is attached in Appendix 2:

Table 4. 1 Driving Point Impedance from Short Circuit Result

Substation Name	**Driving Point Impedance (Zeq) in p.u**	**|Z|**
SULULTA 400 kV	Z= 0.006357+j0.023455	0.024301
GELAN 400 kV	Z= 0.004764+j0.021538	0.0220585
GEBRE-GURCH 400 kV	Z= 0.006232+j0.032890	0.03347521
BAHIRDAR-II 400 kV	Z= 0.004448+j0.028420	0.0287659
BELES 400 kV	Z= 0.003587+j0.031273	0.031478
DEBRE MARKO 400 kV	Z= 0.005453+j0.027926	0.028453
WOLAYTA 400 kV	Z= 0.002861+j0.021248	0.021439
SEBETA-2 400 kV	Z= 0.004825+j0.020991	0.021538
HOLETA 400 kV	Z= 0.004965+j0.022682	0.023219
GI GIBE-2 400 kV	Z= 0.002735+j0.019806	0.019999
G.GIBE NEW 400 kV	Z= 0.003173+j0.022333	0.022557
G-GIBE3 400 kV	Z= 0.002593+j0.022149	0.0223

In order for the PST to have a strong power flow control capability through the line, the driving point impedances as seen from each of these buses back into the network better to be small. The driving point impedances of WOLAYTA 400 kV substation is Zthev = 0.00286 +j0.021248and GILGEL GIBE-2 400 kV substation isZthev= 0.002735+j0.019806.

Thus, WOLAYTA 400 kV and GILGEL GIBE-2 400 kV buses have a very small Driving Point Impedance (Zeq) as seen from each of these buses back into the network. Therefore it is recommended to install the Phase Shifting Transformer (PST) in series with the line connecting these two substations.

4.3 Calculation of Phase Shifting Transformer Size and Angle

After determining the location of Phase Shifting Transformer, we can calculate the power rating of the Phase Shifting Transformer. For this very reason, the maximum phase angle has to be known. The actual data of the transmission line were PST is proposed to install is:

Transmission Line Name	WOLAYTA 400 kV to GI GIBE-2 400 kV
Transmission Line Length	119.0 km
+ve Sequence Resistance	0.002500 (p.u)
-ve Sequence Reactance	0.020700 (p.u)
Zero Sequence Resistance	0.022500 (p.u)

Line angle can be calculates as

$$\alpha_{+}= tan^{-1}\left(\frac{X_1}{R_1}\right) = \angle 83.1^{0} \quad \ldots\ldots (4.1)$$

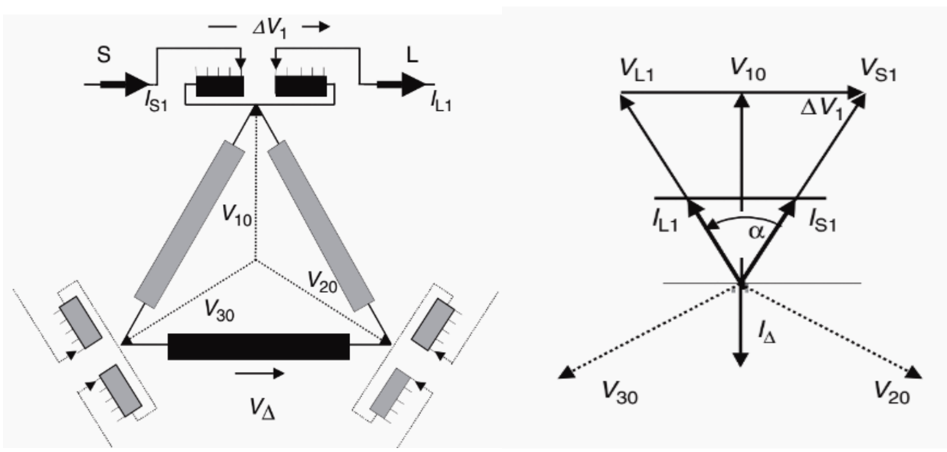
Now, the maximum inclination angle limit for the PST is 83º.For the study, a phase shifting angle range of -20^{0} to$+20^{0}$ is selected.

MVA Rating

Phase-shifting transformers built for transmission grids are generally a three-phase; two-terminal pair designs [20]. The most prevalent phase-shifting transformer designs in power systems applications are symmetric phase-shifting transformers and asymmetric phase-shifting transformers.

A direct symmetric phase-shifting transformer with a complex transformer voltage ratio $1.0*e^{\pm j\varphi}$ is selected for the study.

To obtain a 90° additional voltage ΔV, the use of delta-connected winding offers the simplest solution. Figure 4. 1 shows a possible arrangement where the secondary winding of phase V_2 - V_3 is split up into two halves and is connected in series with phase V_1. By designing this winding as a regulating winding and using on-load tap changers (OLTC), ΔV and the phase-shift angle can be changed under load. The phasor diagram has been plotted for no load conditions, i.e., without considering the voltage drops in the unit.



(a) Configuration (b) Phasor diagram

Figure 4. 1 Symmetric PST configuration and phasor diagram

From the configuration diagram the following equation can be derived

$$V_{S1} = V_{10} + \left(\Delta V_1/2\right) \quad \text{(4. 2)}$$

$$V_{L1} = V_{10} - \left(\Delta V_1/2\right) \quad \text{(4. 3)}$$

$$\Delta V_1 = \vec{V}_{S1} - \vec{V}_{L1} \quad \text{(4. 4)}$$

From the phasor diagram follows ($V_{S1}=V_{L1}=V$)

$$V_0 = V * \cos\left(\frac{\alpha}{2}\right) \quad \text{(4. 5)}$$

$$\Delta V = V * 2 * \sin\left(\frac{\alpha}{2}\right) \quad \text{(4. 6)}$$

$$V_{\Delta} = V * \cos\frac{\alpha}{2} * \sqrt{3} \quad \text{(4. 7)}$$

And with $I_S = I_L = I$, the part of the current that is transferred to the exciting winding becomes

$$I_{\Delta} = \frac{\Delta V}{V_{\Delta}} * I * \cos\frac{\alpha}{2} = I * \frac{2\alpha}{\sqrt{3}} * \sin\frac{\alpha}{2} \quad \text{(4.8)}$$

Where,

$\vec{V}_{SL}$ - Source terminal voltage

$\overrightarrow{V_{LL}}$ - Load terminal voltage

α - The change in phase angle between the terminal voltages of the transformer unit is ΔV- Quadrature voltage

The throughput power can be calculated from

$$S_{SYS} = 3 * V * I \quad \text{(4. 8)}$$

$$I = S_{SYS}\left(\frac{1}{3 * V}\right) \quad \text{(4. 9)}$$

And the rated power which determine the size of PST, becomes

$$S_{PST} = 3 * \Delta V * I \quad \text{(4. 10)}$$

By substituting eq (4.6) and (4.10) in to eq (4.11)

$$S_{PST} = 3 * V * 2 * \sin\left(\frac{\alpha}{2}\right) * P_{SYS}\left(\frac{1}{3 * V}\right) \quad \text{(4. 11)}$$

Finally,

$$S_{PST} = 2 * S_{SYS} * \sin\left(\frac{\alpha}{2}\right) \quad \text{(4. 12)}$$

Now using eq (4.13) and considering the MVA rating of WOLAYTA - Gibe II 400kV transmission line which is 1973 MVA, the size of the PST becomes:

$S_{PST} = 2 * 1973 * \sin\left(\frac{20^0}{2}\right)$ =685 MVA

Power flow step size

A quadrature tap-changer has a discrete number of steps to control the flow with the range of angle. In order to determine the magnitude of the MW change per step, a number of load flow studies were performed .Varying power transfers through the PST showed that, on average a 16MW change in power flow would require a 1^o change in phase angle across the PST.

Voltage rating

PST is installed in series with the line from WOLAYTA –GIBE II 400kV transmission line. Therefore, the voltage rating of the PST is 400/400 kV.

4.4 Phase Shifting Transformer Modeling using PSS/E

The program contains a set of modules which handle different power system analysis and operate from the same set of data. PSS/E Power Flow module is basic, powerful and easy-to-use for basic power flow network analysis. Besides analysis tool it is also used for Data handling, updating, and manipulation. To calculate a steady state solution in PSS/E, one can use either the Gauss-Seidel or the Newton-Raphson algorithm.

Phase-shifting transformers are modeled in PSS/E as two-winding transformers. Users have multiple choices to enter the model data in PSS/E. The choices of data codes for entering each winding's leakage impedance and magnetization branch are the same as those for conventional voltage control transformers. These parameters can be entered in per unit or can be from data collected in the short circuit and no-load tests. Only winding- 1 is allowed to have an under-load tap changer; winding -2 has an off-load tap changer.

Tap position and maximum and minimum phase-shift angles are specified in electrical degrees. The transformer control band is specified in MW. The following parameters are used in the modeling of phase-shifting transformers:

- Phase shift angle range [α_{max},α_{min}] in electrical degrees
- Number of tap positions

- Nominal tap position: 1.0*$e^{+j0^{\circ}}$ (per unit on bus voltage base)
- Winding connection angle "α" in degrees
- The transformer control band in MW

The phase-shifting transformers circuit model used in PSSE is shown in Figure 4. 2

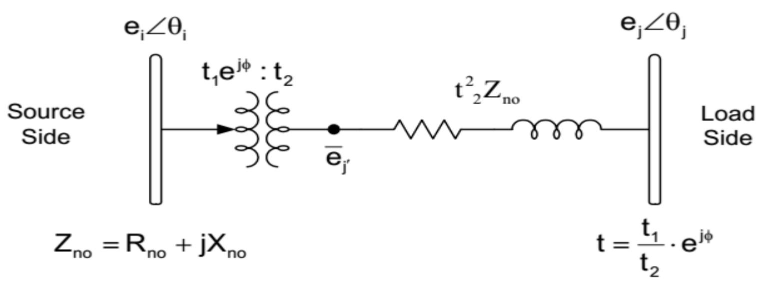


Figure 4. 2 General Equivalent Circuit Model of PST in PSS/E

4.5 Simulation Studies and Analysis of Results

Findings of effective active power flow control capability by using Phase Shifting Transformer were examined and discussed in the next paragraphs following the stipulated methodology.

The load flows were performed using Full Newton Raphson Method with and without Phase Shifting Transformer and the following results were observed.

Power Flow Results without PST

The results are for the base case, in which a phase shifting transformer is not included in the network, the bus connected to Belese Power Plant is selected as a swing bus and the loading of each power plant(Appendix 1:),overloaded transmission lines and under loaded transmission lines were identified.

Table 4. 2 Load flow iteration

Iteration	DELTA "P"	BUS	DELTA "Q"	BUS	DELTA/V/	BUS
0	0.0000	807015	0.0001	915007		
			0.0003	215003		
					0.05736	911008
1	0.0109	208002	1.1888	208005		
					0.07195	911008

2	0.0215	208001	0.0906	208005		
			0.2064	215003		
					0.01091	811016
3	0.0003	208001	0.0418	814015		
			0.0837	414002		
					0.0355	908004
4	0.0039	208004	0.2061	908003		
			0.8244	208001		
					0.03146	908001
5	0.0025	208001	0.0217	814038		
			0.0863	208001		
					0.00362	908001
6	0.0000	208001	0.0014	814038		
			0.0036	208001		
					0.00016	807015
7	0.0000	807015	0.0001	915005		
			0.0003	215003		

SWING BUS SUMMARY								
BUS #	BUS NAME	BASE KV	PGEN	PMAX	PMIN	QGEN	QMAX	QMIN
907001	BELES-1	15	104.1	117	0	-26.3	87.8	-127.6
907004	BELES-2	15	104.1	117	0	-26.3	87.8	-127.6
907007	BELES-3	15	104.1	117	0	-26.3	87.8	-127.6
907009	BELES-4	15	104.1	117	0	-26.3	87.8	-127.6

Table 4. 3 Loading of Generators

POWER PLANT	Generation (MW)
G-GIB3	1074
G-GIB2-1	276.6
G-GIB2-2	128
BELES	419
NESHE	89
FINCHA	100
TIS- ABA2	29
TEKEZE	175
ASHEGODA-WF	8
AWASH2	13
AWASH3	13
KOKA	12
M-WAKENA	30
ADAMA WF-1	28

ADAMA WF-2	86

Diagrammatic representation of the loading of all generators is given below:

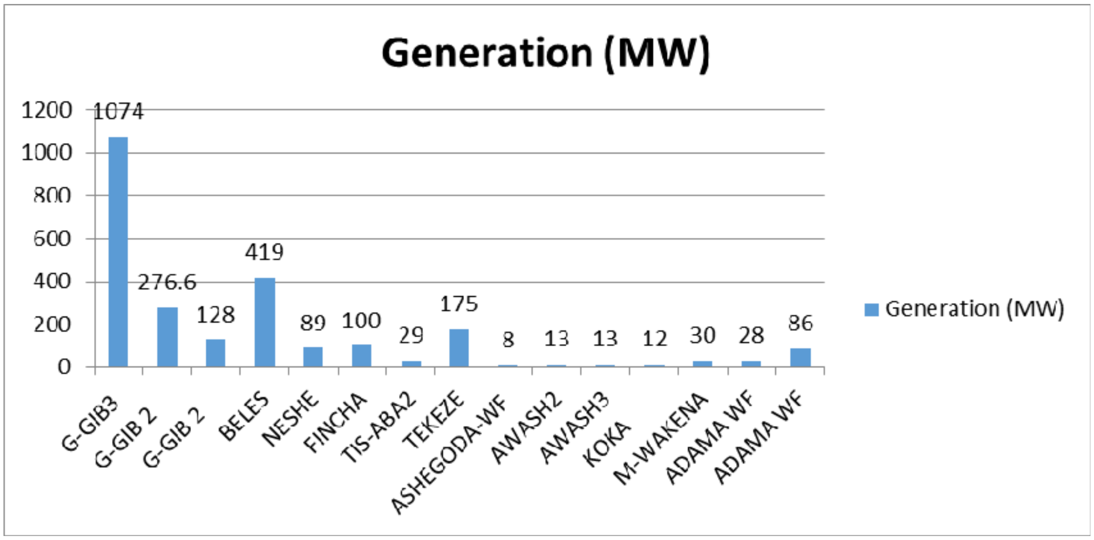


Figure 4. 3 Generators Loading

From power flow result shown in Figure 4. 4a 132 kV transmission lines located around southern part of the network are loading more than 100% their rated capacity where as the newly constructed 400kV high voltage transmission lines found in the same region are loading less than30% of their rated capacity.

Table 4. 4 Loading of Transmission Lines without PST in MVA and Percent

FROM		TO				
BUS NAME	BASE KV	X-- NAME --X	BASE KV	LOADING MVA	RATING MVA	PERCENT
ARBA MINCH	132.00*	W SODO-I	132	13.4	89	15
ALABA	132.00*	HOSAINA	132	11.4	89	12.8
ALABA	132.00*	SHASHEMENE	132	106.5	89	119.6
ALABA	132	W SODO-II	132.00*	112	89	125.8
ALABA	132	AWASA MOBILE	132.00*	14.7	82	17.9
AWASA	132.00*	SHASHEMENE	132	88.1	82	107.4
AWASA	132	YIRGALEM	132.00*	51.1	82	62.4
DILLA	132.00*	HAGER MARIAM	132	14.6	91	16.1
DILLA	132.00*	YIRGALEM	132	25.3	91	27.8
HOSAINA	132.00*	G.GIBE NEW	132	24	89	27
SAWLA	132	KEY AFER	132.00*	10.7	115	9.3
SAWLA	132.00*	W SODO-I	132	10.3	91	11.3
SHAKISO	132.00*	YIRGALEM	132	17.4	82	21.2

W SODO-II	132	W SODO-I	132.00*	27.6	89	31
ALABA	230.00*	HOSAINA	230	30.6	402	7.6
HOSAINA	230.00*	WOLKITE	230	23.5	402	5.9
GELAN	400	WOLAYTA 400	400.00*	527.5	1973	26.7
WOLAYTA 400	400.00*	GI GIBE-2	400	409.4	1973	20.7
WOLAYTA 400	400	G-GIBE3	400.00*	538.5	1973	27.3
WOLAYTA 400	400	G-GIBE3	400.00*	538.5	1973	27.3
ADAMI TULU	132	BUTAJIRA	132.00*	13.3	91	14.6
HOSAINA	230.00*	WOLKITE	230	23.5	402	5.9
SEBATA-1	230	WOLKITE	230.00*	118	402	29.3
WOLKITE	230	G.GIBE NEW	230.00*	144.2	280	51.5

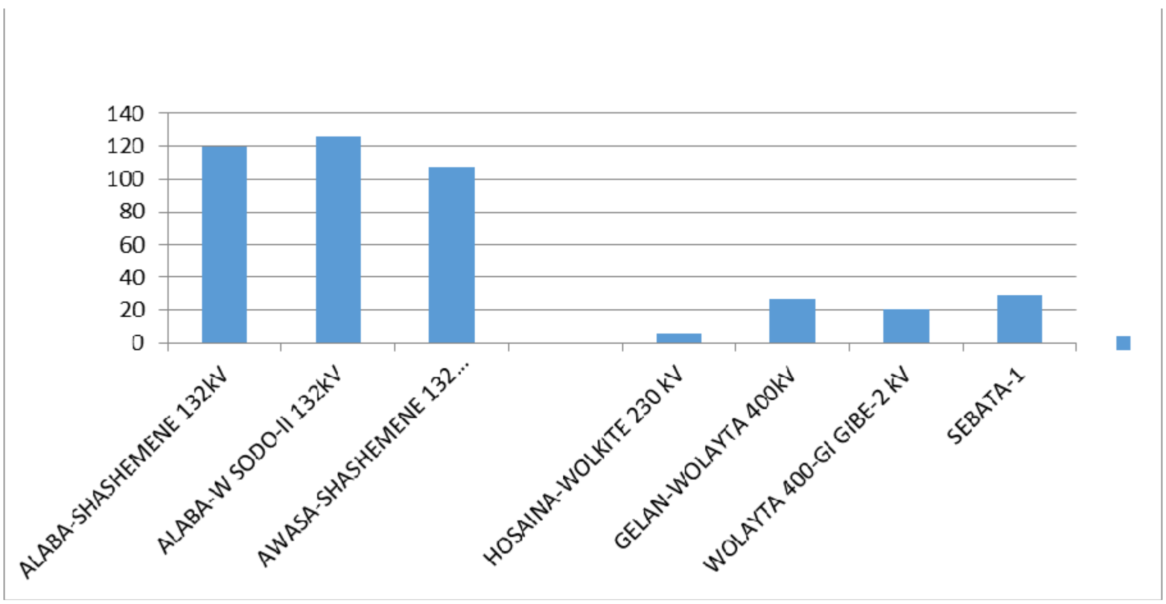


Figure 4. 4 Transmission Line loading without PST in percent

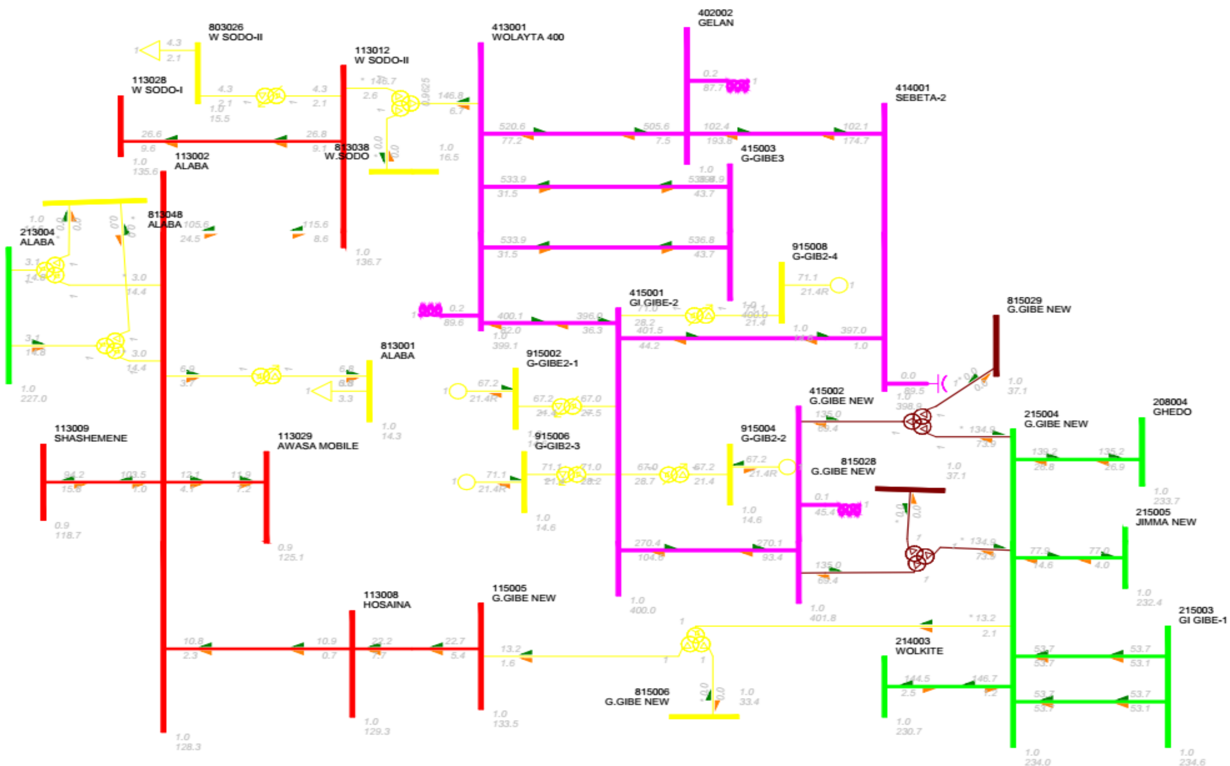


Figure 4. 5 Power flow scenario without PST

Power Flow Results with PST

As shown in Figure 4. 3 from a total generation of 2480 MW, 59.6 % is covered by cascaded Gigle Gibe Power Plants. And the implementation of the phase shifting transformer in this region resulted in moving power flow from the lower voltage transmission lines to the higher voltage transmission lines as the phase shifting transformer angle altered.

The details of results of load flow analysis are contained in Appendix 3. Positive values indicate the active power flow out of bus and power flowing into the bus is indicated as negative values.

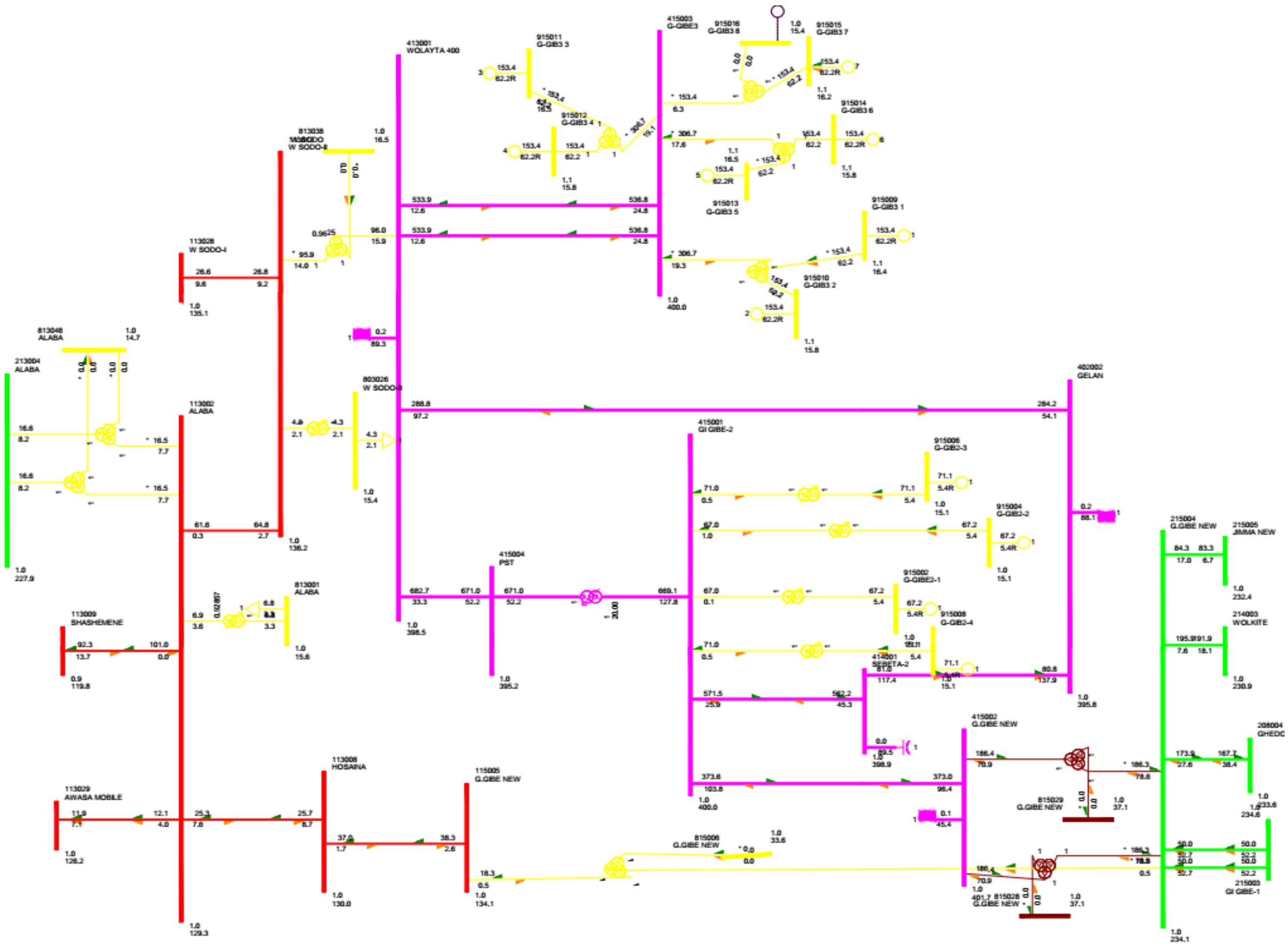


Figure 4. 6 Power flow scenario with PST

Figure 4. 7 show the impact of phase shifting transformer on the power flowing via 132 kV transmission lines. The phase shifting transformer set at various angles and the following observations can be made:

Table 4. 5 Loading of 132kV Transmission Lines

PHASE SHIFTING ANGLE	FROM		TO		LOADING (MVA)	RATING (MVA)	%
	BUS NAME	BASE KV	BUS NAME	BASE KV			
-20	ALABA	132.00*	HOSAINA	132	20.5	89	23
	ALABA	132	W SODO-II	132.00*	-185.5	89	208
	HOSAINA	132.00*	G.GIBE NEW	132	23.7	89	26.6
-19	ALABA	132.00*	HOSAINA	132	19.5	89	21.9
	ALABA	132	W SODO-II	132.00*	-182.4	89	204
	HOSAINA	132.00*	G.GIBE NEW	132	23.1	89	25.9

-18	ALABA	132.00*	HOSAINA	132	18.5	89	20.8
	ALABA	132	W SODO-II	132.00*	-179.3	89	201
	HOSAINA	132.00*	G.GIBE NEW	132	22.5	89	25.3
-17	ALABA	132.00*	HOSAINA	132	17.5	89	19.7
	ALABA	132	W SODO-II	132.00*	-176.2	89	197
	HOSAINA	132.00*	G.GIBE NEW	132	22	89	24.7
-16	ALABA	132.00*	HOSAINA	132	16.6	89	18.6
	ALABA	132	W SODO-II	132.00*	-173.1	89	194
	HOSAINA	132.00*	G.GIBE NEW	132	21.5	89	24.2
-15	ALABA	132.00*	HOSAINA	132	15.6	89	17.6
	ALABA	132	W SODO-II	132.00*	-170	89	191
	HOSAINA	132.00*	G.GIBE NEW	132	21.1	89	23.7
	SEBETA-2	400	GI GIBE-2	400.00*	-205.6	1341	15.3
-14	ALABA	132.00*	HOSAINA	132	14.7	89	16.6
	ALABA	132	W SODO-II	132.00*	-166.9	89	187
	HOSAINA	132.00*	G.GIBE NEW	132	20.8	89	23.3
-13	ALABA	132.00*	HOSAINA	132	13.9	89	15.6
	ALABA	132	W SODO-II	132.00*	-163.8	89	184
	HOSAINA	132.00*	G.GIBE NEW	132	20.5	89	23
-12	ALABA	132.00*	HOSAINA	132	13	89	14.6
	ALABA	132	W SODO-II	132.00*	-160.7	89	180
	HOSAINA	132.00*	G.GIBE NEW	132	20.2	89	22.7
-11	ALABA	132.00*	HOSAINA	132	12.2	89	13.7
	ALABA	132	W SODO-II	132.00*	-157.6	89	177
	HOSAINA	132.00*	G.GIBE NEW	132	20	89	22.5
-10	ALABA	132.00*	HOSAINA	132	11.4	89	12.8
	ALABA	132	W SODO-II	132.00*	-154.4	89	173
	HOSAINA	132.00*	G.GIBE NEW	132	19.9	89	22.3
-9	ALABA	132.00*	HOSAINA	132	10.7	89	12
	ALABA	132	W SODO-II	132.00*	-151.3	89	170
	HOSAINA	132.00*	G.GIBE NEW	132	19.8	89	22.2
-8	ALABA	132.00*	HOSAINA	132	10.1	89	11.3
	ALABA	132	W SODO-II	132.00*	-148.2	89	166.6
	HOSAINA	132.00*	G.GIBE NEW	132	19.8	89	22.2
-7	ALABA	132.00*	HOSAINA	132	9.5	89	10.7
	ALABA	132	W SODO-II	132.00*	-145.1	89	163
	HOSAINA	132.00*	G.GIBE NEW	132	19.8	89	22.3
-6	ALABA	132.00*	HOSAINA	132	9	89	10.2
	ALABA	132	W SODO-II	132.00*	-142	89	159
	HOSAINA	132.00*	G.GIBE NEW	132	19.9	89	22.4
-5	ALABA	132.00*	HOSAINA	132	8.7	89	9.8
	ALABA	132	W SODO-II	132.00*	-138.9	89	156
	HOSAINA	132.00*	G.GIBE NEW	132	20.1	89	22.6
-4	ALABA	132.00*	HOSAINA	132	8.5	89	9.6
	ALABA	132	W SODO-II	132.00*	-135.8	89	152

	HOSAINA	132.00*	G.GIBE NEW	132	20.3	89	22.9
-3	ALABA	132.00*	HOSAINA	132	8.5	89	9.5
	ALABA	132	W SODO-II	132.00*	-132.7	89	149
	HOSAINA	132.00*	G.GIBE NEW	132	20.6	89	23.2
-2	ALABA	132.00*	HOSAINA	132	8.6	89	9.6
	ALABA	132	W SODO-II	132.00*	-129.6	89	145
	HOSAINA	132.00*	G.GIBE NEW	132	21	89	23.6
-1	ALABA	132.00*	HOSAINA	132	8.8	89	9.9
	ALABA	132	W SODO-II	132.00*	-126.5	89	142
	HOSAINA	132.00*	G.GIBE NEW	132	21.4	89	24.1
0	ALABA	132.00*	HOSAINA	132	9.2	89	10.3
	ALABA	132	W SODO-II	132.00*	-123.4	89	138
	HOSAINA	132.00*	G.GIBE NEW	132	21.9	89	24.6
1	ALABA	132.00*	HOSAINA	132	9.6	89	10.8
	ALABA	132	W SODO-II	132.00*	-120.3	89	135
	HOSAINA	132.00*	G.GIBE NEW	132	22.4	89	25.2
2	ALABA	132.00*	HOSAINA	132	10.2	89	11.5
	ALABA	132	W SODO-II	132.00*	-117.3	89	131
	HOSAINA	132.00*	G.GIBE NEW	132	23	89	25.8
3	ALABA	132.00*	HOSAINA	132	10.9	89	12.2
	ALABA	132	W SODO-II	132.00*	-114.2	89	128
	HOSAINA	132.00*	G.GIBE NEW	132	23.6	89	26.5
4	ALABA	132.00*	HOSAINA	132	11.6	89	13
	ALABA	132	W SODO-II	132.00*	-111.1	89	124
	HOSAINA	132.00*	G.GIBE NEW	132	24.2	89	27.2
5	ALABA	132.00*	HOSAINA	132	12.4	89	13.9
	ALABA	132	W SODO-II	132.00*	-108	89	121
	HOSAINA	132.00*	G.GIBE NEW	132	24.9	89	27.9
6	ALABA	132.00*	HOSAINA	132	13.2	89	14.9
	ALABA	132	W SODO-II	132.00*	-104.9	89	117
	HOSAINA	132.00*	G.GIBE NEW	132	25.6	89	28.7
7	ALABA	132	HOSAINA	132.00*	-14.2	89	15.9
	ALABA	132	W SODO-II	132.00*	-101.9	89	114
	HOSAINA	132.00*	G.GIBE NEW	132	26.3	89	29.6
8	ALABA	132	HOSAINA	132.00*	-15.1	89	17
	ALABA	132	W SODO-II	132.00*	-98.8	89	111
	HOSAINA	132.00*	G.GIBE NEW	132	27.1	89	30.4
9	ALABA	132	HOSAINA	132.00*	-16.1	89	18.1
	ALABA	132	W SODO-II	132.00*	-95.8	89	107
	HOSAINA	132.00*	G.GIBE NEW	132	27.8	89	31.3
10	ALABA	132	HOSAINA	132.00*	-17.1	89	19.2
	ALABA	132	W SODO-II	132.00*	-92.7	89	104
	HOSAINA	132.00*	G.GIBE NEW	132	28.7	89	32.2
11	ALABA	132	HOSAINA	132.00*	-18.1	89	20.4
	ALABA	132	W SODO-II	132.00*	-89.7	89	100
	HOSAINA	132.00*	G.GIBE NEW	132	29.5	89	33.1

12	ALABA	132	HOSAINA	132.00*	-19.2	89	21.5
	ALABA	132	W SODO-II	132.00*	-86.6	89	97.3
	HOSAINA	132.00*	G.GIBE NEW	132	30.3	89	34.1
13	ALABA	132	HOSAINA	132.00*	-20.2	89	22.7
	ALABA	132	W SODO-II	132.00*	-83.6	89	93.9
	HOSAINA	132.00*	G.GIBE NEW	132	31.2	89	35.1
14	ALABA	132	HOSAINA	132.00*	-21.2	89	23.8
	ALABA	132	W SODO-II	132.00*	-80.6	89	90.6
	HOSAINA	132.00*	G.GIBE NEW	132	32.1	89	36
15	ALABA	132	HOSAINA	132.00*	-22.3	89	25
	ALABA	132	W SODO-II	132.00*	-77.6	89	87.2
	HOSAINA	132.00*	G.GIBE NEW	132	33	89	37
16	ALABA	132	HOSAINA	132.00*	-23.3	89	26.2
	ALABA	132	W SODO-II	132.00*	-74.6	89	83.8
	HOSAINA	132	G.GIBE NEW	132.00*	-33.9	89	38.1
17	ALABA	132	HOSAINA	132.00*	-24.4	89	27.4
	ALABA	132	W SODO-II	132.00*	-71.6	89	80.5
	HOSAINA	132	G.GIBE NEW	132.00*	-34.9	89	39.2
18	ALABA	132	HOSAINA	132.00*	-25.4	89	28.6
	ALABA	132	W SODO-II	132.00*	-68.7	89	77.2
	HOSAINA	132	G.GIBE NEW	132.00*	-35.8	89	40.3
19	ALABA	132	HOSAINA	132.00*	-26.5	89	29.7
	ALABA	132.00*	W SODO-II	132	65.8	89	73.9
	HOSAINA	132	G.GIBE NEW	132.00*	-36.8	89	41.4
20	ALABA	132	HOSAINA	132.00*	-27.5	89	30.9
	ALABA	132.00*	W SODO-II	132	62.9	89	70.7
	HOSAINA	132	G.GIBE NEW	132.00*	-37.8	89	42.5

Power flowing on ALABA to WOLAYITA SODO II 132 kV Line (Red)

The carrying capacity of this line is 89 MVA. Practically this line is out of service due to overloading. On inclusion of the phase shifting transformer and as a phase shifting angle increased beyond 14^0, more power forced to move on to the higher voltage lines, and the line start to load below the rated capacity. This enables to put the line in service.

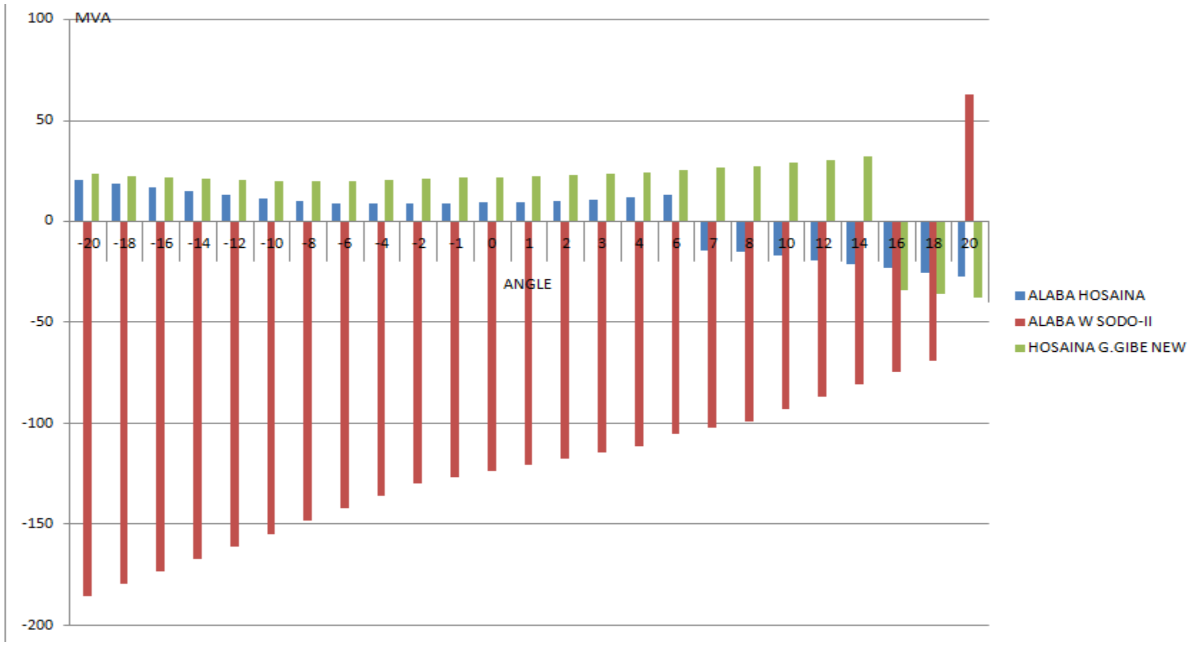


Figure 4. 7 Impact of phase shifting transformer on 132kV lines power flow

Power flowing on ALABA to HOSAINA 132 kV Line (Blue)

Without the phase shifting transformer, this line takes a relatively small amount of power. Once the phase shifting transformer angle increased beyond 10° and decreased beyond -10°the power transferred increased in proportion.

As the phase shifting transformer becomes 7° the power flowing via this line is reversed.

Power flowing on HOSAINA to GIGEL GIBE NEW 132 kV Line (Green)

As the phase shifting transformer angle is increased, power flowing through this line increases in proportion. At a phase shifting angle of 16°, the power flow direction is reversed.

Figure 4. 8show the impact of phase shifting transformer on the power flowing via 230 kV transmission lines. The phase shifting transformer set at various angles and the following observations can be made:

Table 4. 6 Loading of 230kV Transmission Lines

PHASE SHIFTING ANGLE	FROM		TO		LOADING (MVA)	RATING (MVA)	%
-20	BUS NAME	BASE KV	BUS NAME	BASE KV			
	ALABA	230.00*	HOSAINA	230	61.9	402	15.4

	HOSAINA	230.00*	WOLKITE	230	55.8	402	13.9
	SEBATA-1	230	WOLKITE	230.00*	-85.4	402	21.2
	WOLKITE	230.00*	G.GIBE NEW	230	79.6	280	28.4
-19	ALABA	230.00*	HOSAINA	230	60.3	402	15
	HOSAINA	230.00*	WOLKITE	230	54.1	402	13.5
	SEBATA-1	230	WOLKITE	230.00*	-86.8	402	21.6
	WOLKITE	230.00*	G.GIBE NEW	230	82	280	29.3
-18	ALABA	230.00*	HOSAINA	230	58.6	402	14.6
	HOSAINA	230.00*	WOLKITE	230	52.4	402	13
	SEBATA-1	230	WOLKITE	230.00*	-88.2	402	21.9
	WOLKITE	230.00*	G.GIBE NEW	230	84.4	280	30.1
-17	ALABA	230.00*	HOSAINA	230	56.9	402	14.2
	HOSAINA	230.00*	WOLKITE	230	50.6	402	12.6
	SEBATA-1	230	WOLKITE	230.00*	-89.7	402	22.3
	WOLKITE	230.00*	G.GIBE NEW	230	86.9	280	31
-16	ALABA	230.00*	HOSAINA	230	55.3	402	13.7
	HOSAINA	230.00*	WOLKITE	230	48.9	402	12.2
	SEBATA-1	230	WOLKITE	230.00*	-91.1	402	22.7
	WOLKITE	230.00*	G.GIBE NEW	230	89.4	280	31.9
-15	ALABA	230.00*	HOSAINA	230	53.7	402	13.3
	HOSAINA	230.00*	WOLKITE	230	47.3	402	11.8
	SEBATA-1	230	WOLKITE	230.00*	-92.5	402	23
	WOLKITE	230.00*	G.GIBE NEW	230	91.9	280	32.8
-14	ALABA	230.00*	HOSAINA	230	52	402	12.9
	HOSAINA	230.00*	WOLKITE	230	45.6	402	11.3
	SEBATA-1	230	WOLKITE	230.00*	-93.9	402	23.4
	WOLKITE	230.00*	G.GIBE NEW	230	94.5	280	33.8
-13	ALABA	230.00*	HOSAINA	230	50.5	402	12.6
	HOSAINA	230 *	WOLKITE	230	43.9	402	10.9
	SEBATA-1	230	WOLKITE	230.00*	-95.3	402	23.7
	WOLKITE	230.00*	G.GIBE NEW	230	97.2	280	34.7
-12	ALABA	230.00*	HOSAINA	230	48.9	402	12.2
	HOSAINA	230.00*	WOLKITE	230	42.3	402	10.5
	SEBATA-1	230	WOLKITE	230.00*	-96.7	402	24
	WOLKITE	230.00*	G.GIBE NEW	230	99.8	280	35.6
-11	ALABA	230.00*	HOSAINA	230	47.4	402	11.8
	HOSAINA	230.00*	WOLKITE	230	40.7	402	10.1
	SEBATA-1	230	WOLKITE	230.00*	-98.1	402	24.4

	WOLKITE	230.00*	G.GIBE NEW	230	102.5	280	36.6
-10	ALABA	230.00*	HOSAINA	230	45.9	402	11.4
	HOSAINA	230.00*	WOLKITE	230	39.1	402	9.7
	SEBATA-1	230	WOLKITE	230.00*	-99.5	402	24.7
	WOLKITE	230.00*	G.GIBE NEW	230	105.2	280	37.6
-9	ALABA	230.00*	HOSAINA	230	44.4	402	11
	HOSAINA	230.00*	WOLKITE	230	37.6	402	9.4
	SEBATA-1	230	WOLKITE	230.00*	-100.8	402	25.1
	WOLKITE	230.00*	G.GIBE NEW	230	107.9	280	38.5
-8	ALABA	230.00*	HOSAINA	230	42.9	402	10.7
	HOSAINA	230.00*	WOLKITE	230	36.1	402	9
	SEBATA-1	230	WOLKITE	230.00*	-102.2	402	25.4
	WOLKITE	230.00*	G.GIBE NEW	230	110.6	280	39.5
-7	ALABA	230.00*	HOSAINA	230	41.5	402	10.3
	HOSAINA	230.00*	WOLKITE	230	34.6	402	8.6
	SEBATA-1	230	WOLKITE	230.00*	-103.6	402	25.8
	WOLKITE	230.00*	G.GIBE NEW	230	113.4	280	40.5
-6	ALABA	230.00*	HOSAINA	230	40.2	402	10
	HOSAINA	230.00*	WOLKITE	230	33.2	402	8.3
	SEBATA-1	230	WOLKITE	230.00*	-105	402	26.1
	WOLKITE	230 *	G.GIBE NEW	230	116.2	280	41.5
-5	ALABA	230 *	HOSAINA	230	38.9	402	9.7
	HOSAINA	230.00*	WOLKITE	230	31.8	402	7.9
	SEBATA-1	230	WOLKITE	230.00*	-106.3	402	26.4
	WOLKITE	230.00*	G.GIBE NEW	230	119	280	42.5
-4	ALABA	230.00*	HOSAINA	230	37.6	402	9.4
	HOSAINA	230.00*	WOLKITE	230	30.5	402	7.6
	SEBATA-1	230	WOLKITE	230.00*	-107.7	402	26.8
	WOLKITE	230.00*	G.GIBE NEW	230	121.8	280	43.5
-3	ALABA	230.00*	HOSAINA	230	36.5	402	9.1
	HOSAINA	230.00*	WOLKITE	230	29.3	402	7.3
	SEBATA-1	230	WOLKITE	230.00*	-109	402	27.1
	WOLKITE	230.00*	G.GIBE NEW	230	124.6	280	44.5
-2	ALABA	230.00*	HOSAINA	230	35.3	402	8.8
	HOSAINA	230.00*	WOLKITE	230	28.1	402	7
	SEBATA-1	230	WOLKITE	230.00*	-110.4	402	27.5
	WOLKITE	230.00*	G.GIBE NEW	230	127.5	280	45.5

-1	ALABA	230.00*	HOSAINA	230	34.3	402	8.5
	HOSAINA	230.00*	WOLKITE	230	27	402	6.7
	SEBATA-1	230	WOLKITE	230.00*	-111.7	402	27.8
	WOLKITE	230.00*	G.GIBE NEW	230	130.4	280	46.6
0	ALABA	230.00*	HOSAINA	230	33.3	402	8.3
	HOSAINA	230.00*	WOLKITE	230	26.1	402	6.5
	SEBATA-1	230	WOLKITE	230.00*	-113	402	28.1
	WOLKITE	230.00*	G.GIBE NEW	230	133.2	280	47.6
1	ALABA	230.00*	HOSAINA	230	32.4	402	8.1
	HOSAINA	230 *	WOLKITE	230	25.2	402	6.3
	SEBATA-1	230	WOLKITE	230.00*	-114.3	402	28.4
	WOLKITE	230.00*	G.GIBE NEW	230	136.1	280	48.6
2	ALABA	230.00*	HOSAINA	230	31.7	402	7.9
	HOSAINA	230.00*	WOLKITE	230	24.5	402	6.1
	SEBATA-1	230	WOLKITE	230.00*	-115.7	402	28.8
	WOLKITE	230	G.GIBE NEW	230.00*	-139.1	280	49.7
3	ALABA	230.00*	HOSAINA	230	31	402	7.7
	HOSAINA	230.00*	WOLKITE	230	23.9	402	5.9
	SEBATA-1	230	WOLKITE	230.00*	-117	402	29.1
	WOLKITE	230	G.GIBE NEW	230.00*	-142	280	50.7
4	ALABA	230.00*	HOSAINA	230	30.4	402	7.6
	HOSAINA	230.00*	WOLKITE	230	23.4	402	5.8
	SEBATA-1	230	WOLKITE	230.00*	-118.3	402	29.4
	WOLKITE	230	G.GIBE NEW	230.00*	-145	280	51.8
5	ALABA	230.00*	HOSAINA	230	30	402	7.5
	HOSAINA	230.00*	WOLKITE	230	23.1	402	5.7
	SEBATA-1	230	WOLKITE	230.00*	-119.6	402	29.7
	WOLKITE	230	G.GIBE NEW	230.00*	-148	280	52.8
6	ALABA	230.00*	HOSAINA	230	29.6	402	7.4
	HOSAINA	230.00*	WOLKITE	230	22.9	402	5.7
	SEBATA-1	230	WOLKITE	230.00*	-120.8	402	30.1
	WOLKITE	230	G.GIBE NEW	230.00*	-150.9	280	53.9
7	ALABA	230.00*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230.00*	WOLKITE	230	22.9	402	5.7
	SEBATA-1	230	WOLKITE	230 *	-122.1	402	30.4
	WOLKITE	230	G.GIBE NEW	230.00*	-153.9	280	55
8	ALABA	230.00*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230.00*	WOLKITE	230	23.1	402	5.8

	SEBATA-1	230	WOLKITE	230.00*	-123.4	402	30.7
	WOLKITE	230	G.GIBE NEW	230.00*	-156.9	280	56
9	ALABA	230.00*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230.00*	WOLKITE	230	23.5	402	5.8
	SEBATA-1	230	WOLKITE	230.00*	-124.7	402	31
	WOLKITE	230	G.GIBE NEW	230.00*	-159.9	280	57.1
10	ALABA	230.00*	HOSAINA	230	29.6	402	7.4
	HOSAINA	230.00*	WOLKITE	230	23.9	402	6
	SEBATA-1	230	WOLKITE	230.00*	-125.9	402	31.3
	WOLKITE	230	G.GIBE NEW	230.00*	-162.9	280	58.2
11	ALABA	230.00*	HOSAINA	230	29.9	402	7.4
	HOSAINA	230.00*	WOLKITE	230	24.6	402	6.1
	SEBATA-1	230	WOLKITE	230.00*	-127.2	402	31.6
	WOLKITE	230	G.GIBE NEW	230.00*	-165.9	280	59.2
12	ALABA	230.00*	HOSAINA	230	30.3	402	7.5
	HOSAINA	230.00*	WOLKITE	230	25.3	402	6.3
	SEBATA-1	230	WOLKITE	230.00*	-128.4	402	32
	WOLKITE	230	G.GIBE NEW	230.00*	-168.8	280	60.3
13	ALABA	230.00*	HOSAINA	230	30.9	402	7.7
	HOSAINA	230.00*	WOLKITE	230	26.2	402	6.5
	SEBATA-1	230	WOLKITE	230 *	-129.7	402	32.3
	WOLKITE	230	G.GIBE NEW	230.00*	-171.8	280	61.4
14	ALABA	230.00*	HOSAINA	230	31.5	402	7.8
	HOSAINA	230.00*	WOLKITE	230	27.2	402	6.8
	SEBATA-1	230	WOLKITE	230.00*	-130.9	402	32.6
	WOLKITE	230	G.GIBE NEW	230.00*	-174.8	280	62.4
15	ALABA	230.00*	HOSAINA	230	32.3	402	8
	HOSAINA	230.00*	WOLKITE	230	28.3	402	7
	SEBATA-1	230	WOLKITE	230.00*	-132.1	402	32.9
	WOLKITE	230	G.GIBE NEW	230.00*	-177.8	280	63.5
16	ALABA	230.00*	HOSAINA	230	33.2	402	8.2
	HOSAINA	230.00*	WOLKITE	230	29.4	402	7.3
	SEBATA-1	230	WOLKITE	230.00*	-133.4	402	33.2
	WOLKITE	230	G.GIBE NEW	230.00*	-180.8	280	64.6
17	ALABA	230.00*	HOSAINA	230	34.1	402	8.5
	HOSAINA	230.00*	WOLKITE	230	30.7	402	7.6
	SEBATA-1	230	WOLKITE	230.00*	-134.6	402	33.5
	WOLKITE	230	G.GIBE	230.00*	-183.8	280	65.6

			NEW				
18	ALABA	230.00*	HOSAINA	230	35.1	402	8.7
	HOSAINA	230.00*	WOLKITE	230	32	402	8
	SEBATA-1	230	WOLKITE	230 *	-135.8	402	33.8
	WOLKITE	230	G.GIBE NEW	230.00*	-186.7	280	66.7
19	ALABA	230.00*	HOSAINA	230	36.2	402	9
	HOSAINA	230.00*	WOLKITE	230	33.3	402	8.3
	SEBATA-1	230	WOLKITE	230.00*	-137	402	34.1
	WOLKITE	230	G.GIBE NEW	230.00*	-189.7	280	67.8
20	ALABA	230.00*	HOSAINA	230	37.4	402	9.3
	HOSAINA	230.00*	WOLKITE	230	34.8	402	8.6
	SEBATA-1	230	WOLKITE	230.00*	-138.2	402	34.4
	WOLKITE	230	G.GIBE NEW	230.00*	-192.7	280	68.8

Power flowing on GIGEL GIBE I to WOLKITE 230 kV Line (Purple)

This line brings more power into the load area. As the phase shifting transformer angle increased, the power flowing through this line increase and at 2° the power flow direction is reversed. Further increasing of the angle leads to a progressive increase of reversed power flow.

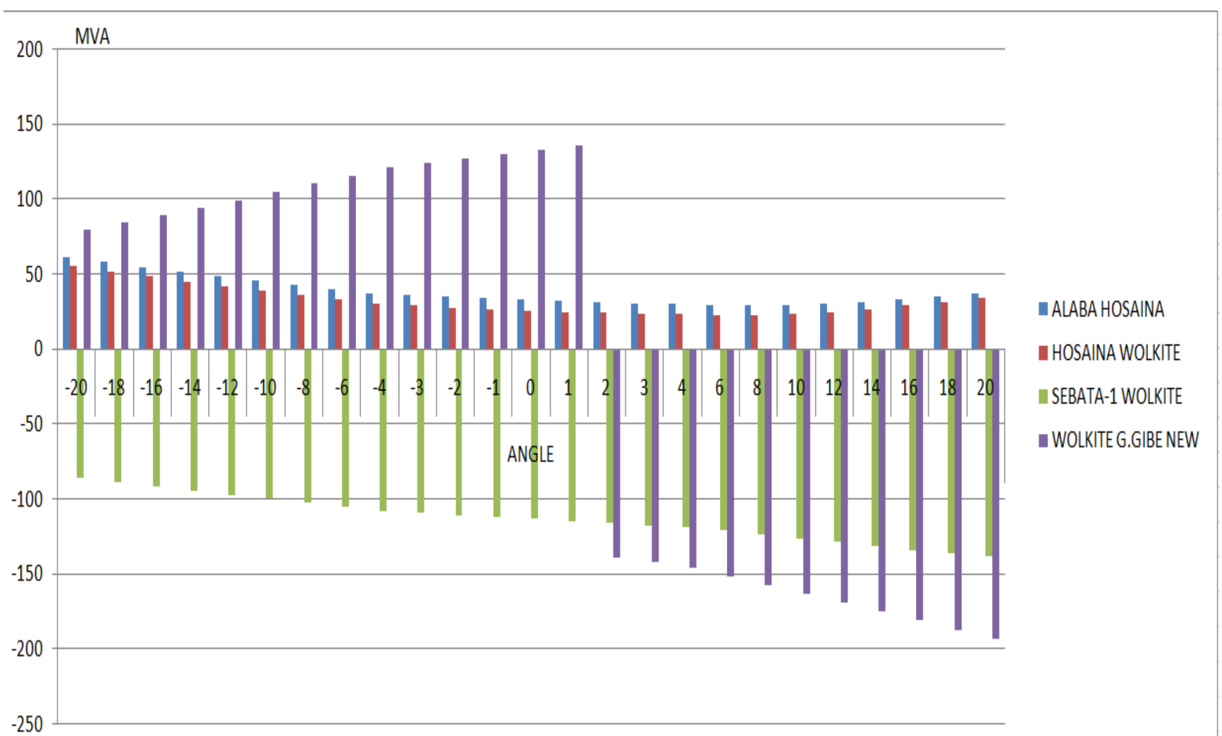


Figure 4. 8 Impact of phase shifting transformer on 230kV lines power flow

Power flowing on SEBETA- I to WOLKITE 230 kV Line (Green)

Increasing the angle of the phase shifting transformer leads to bring more power into the load area via this line. Whereas, decreasing the phase shifting angle serves only to reduce the power flow through this line.

Figure 4. 9show the impact of phase shifting transformer on the power flowing via 400 kV transmission lines. The phase shifting transformer set at various angles and the following observations can be made:

Table 4. 7 Loading of 400kV Transmission Lines

PHASE SHIFTING ANGLE	FROM		TO		LOADING (MVA)	RATING (MVA)	%
	BUS NAME	BASE KV	BUS NAME	BASE KV			
-20	GELAN	400	WOLAYTA 400	400.00*	-856.2	1973	43.4
	WOLAYTA 400	400.00*	GI GIBE-2	400	71.9	1973	3.6
	SEBETA-2	400	GI GIBE-2	400.00*	-154.7	1341	11.5
-19	GELAN	400	WOLAYTA 400	400.00*	-842.3	1973	42.7
	WOLAYTA 400	400.00*	PAR	400	73.2	1973	3.7
	SEBETA-2	400	GI GIBE-2	400.00*	-161.6	1341	12.05
-18	GELAN	400	WOLAYTA 400	400.00*	-828.4	1973	42
	WOLAYTA 400	400.00*	PAR	400	78.1	1973	4
	SEBETA-2	400	GI GIBE-2	400.00*	-172.8	1341	12.8
-17	GELAN	400	WOLAYTA 400	400.00*	-814.5	1973	41.3
	WOLAYTA 400	400.00*	PAR	400	86.2	1973	4.4
	SEBETA-2	400	GI GIBE-2	400.00*	-182.3	1341	13.5
-16	GELAN	400	WOLAYTA 400	400.00*	-800.6	1973	40.6
	WOLAYTA 400	400.00*	PAR	400	96.5	1973	4.9
	SEBETA-2	400	GI GIBE-2	400.00*	-203	1341	15.1
-15	GELAN	400	WOLAYTA 400	400.00*	-786.7	1973	39.9
	WOLAYTA	400.00	PAR	400	108.5	1973	5.5

	400	*					
	SEBETA-2	400	GI GIBE-2	400.00*	-205.6	1341	15.3
-14	GELAN	400	WOLAYTA 400	400.00*	-772.8	1973	39.2
	WOLAYTA 400	400.00 *	PAR	400	121.7	1973	6.2
	SEBETA-2	400	GI GIBE-2	400.00*	-218.7	1341	16.3
-13	GELAN	400	WOLAYTA 400	400.00*	-758.9	1973	38.5
	WOLAYTA 400	400.00 *	PAR	400	135.7	1973	6.9
	SEBETA-2	400	GI GIBE-2	400.00*	-227.9	1341	16.9
-12	GELAN	400	WOLAYTA 400	400.00*	-745.1	1973	37.8
	WOLAYTA 400	400.00 *	PAR	400	150.4	1973	7.6
	SEBETA-2	400	GI GIBE-2	400.00*	-239.6	1341	17.8
-11	GELAN	400	WOLAYTA 400	400.00*	731.2	1973	37.1
	WOLAYTA 400	400.00 *	PAR	400	165.5	1973	8.4
	SEBETA-2	400	GI GIBE-2	400.00*	-251	1341	18.7
-10	GELAN	400	WOLAYTA 400	400.00*	-717.3	1973	36.4
	WOLAYTA 400	400.00 *	PAR	400	180.9	1973	9.2
	SEBETA-2	400	GI GIBE-2	400.00*	-258.2	1341	19.2
-9	GELAN	400	WOLAYTA 400	400.00*	-703.5	1973	35.7
	WOLAYTA 400	400.00 *	PAR	400	196.7	1973	10
	SEBETA-2	400	GI GIBE-2	400.00*	-269	1341	20
-8	GELAN	400	WOLAYTA 400	400.00*	-689.6	1973	35
	WOLAYTA 400	400.00 *	PAR	400	212.6	1973	10.8
	SEBETA-2	400	GI GIBE-2	400.00*	-281	1341	20.9
-7	GELAN	400	WOLAYTA 400	400.00*	-675.8	1973	34.3
	WOLAYTA 400	400.00 *	PAR	400	228.7	1973	11.6
	SEBETA-2	400	GI GIBE-2	400.00*	-291	1341	21.7
-6	GELAN	400	WOLAYT	400 *	-661.9	1973	33.5
	WOLAYTA 400	400.00 *	PAR	400	244.9	1973	12.4
	SEBETA-2	400	GI GIBE-2	400.00*	-303.3	1341	22.6
-5	GELAN	400	WOLAYTA 400	400.00*	-648.1	1973	32.8

	WOLAYTA 400	400.00 *	PAR	400	261.3	1973	13.2
	SEBETA-2	400	GI GIBE-2	400.00*	-311.1	1341	23.2
-4	GELAN	400	WOLAYTA 400	400.00*	-634.3	1973	32.1
	WOLAYTA 400	400.00 *	PAR	400	277.8	1973	14.1
	SEBETA-2	400	GI GIBE-2	400.00*	-324.2	1341	24.2
-3	GELAN	400	WOLAYTA 400	400.00*	-620.4	1973	31.4
	WOLAYTA 400	400.00 *	PAR	400	294.3	1973	14.9
	SEBETA-2	400	GI GIBE-2	400.00*	-333	1341	24.8
-2	GELAN	400	WOLAYTA 400	400.00*	-606.6	1973	30.7
	WOLAYTA 400	400.00 *	PAR	400	310.9	1973	15.8
	SEBETA-2	400	GI GIBE-2	400.00*	-344.6	1341	25.7
-1	GELAN	400	WOLAYTA 400	400.00*	-592.8	1973	30
	WOLAYT	400.00 *	PAR	400	327.6	1973	16.6
	SEBETA-2	400	GI GIBE-2	400.00*	-354.4	1341	26.4
0	GELAN	400	WOLAYTA 400	400.00*	-579	1973	29.3
	WOLAYTA 400	400.00 *	PAR	400	344.4	1973	17.5
	SEBETA-2	400	GI GIBE-2	400.00*	-365.2	1341	27.2
1	GELAN	400	WOLAYTA 400	400.00*	-565.2	1973	28.6
	WOLAYTA 400	400.00 *	PAR	400	361.2	1973	18.3
	SEBETA-2	400	GI GIBE-2	400.00*	-376.4	1341	28
2	GELAN	400	WOLAYTA 400	400.00*	-551.4	1973	27.9
	WOLAYT	400 *	PAR	400	378	1973	19.2
	SEBETA-2	400	GI GIBE-2	400.00*	-385	1341	28.7
3	GELAN	400	WOLAYTA 400	400.00*	-537.6	1973	27.2
	WOLAYTA 400	400.00 *	PAR	400	394.9	1973	20
	SEBETA-2	400	GI GIBE-2	400.00*	-396.1	1341	29.5
4	GELAN	400	WOLAYTA 400	400.00*	-523.8	1973	26.6
	WOLAYTA 400	400.00 *	PAR	400	411.8	1973	20.9
	SEBETA-2	400	GI GIBE-2	400.00*	-405.8	1341	30.2
5	GELAN	400	WOLAYTA 400	400.00*	-510.1	1973	25.9

	WOLAYTA 400	400.00 *	PAR	400	428.8	1973	21.7
	SEBETA-2	400	GI GIBE-2	400.00*	-416.2	1341	31
6	GELAN	400	WOLAYTA 400	400.00*	-496.3	1973	25.2
	WOLAYTA 400	400.00 *	PAR	400	445.8	1973	22.6
	SEBETA-2	400	GI GIBE-2	400.00*	-428	1341	31.9
7	GELAN	400	WOLAYTA 400	400.00*	-482.6	1973	24.5
	WOLAYTA 400	400.00 *	PAR	400	462.8	1973	23.5
	SEBETA-2	400	GI GIBE-2	400.00*	-437.4	1341	32.6
8	GELAN	400	WOLAYTA 400	400.00*	-468.9	1973	23.8
	WOLAYTA 400	400.00 *	PAR	400	479.9	1973	24.3
	SEBETA-2	400	GI GIBE-2	400.00*	-448.1	1341	33.4
9	GELAN	400	WOLAYTA 400	400.00*	-455.2	1973	23.1
	WOLAYTA 400	400.00 *	PAR	400	497	1973	25.2
	SEBETA-2	400	GI GIBE-2	400.00*	-457.7	1341	34.1
10	GELAN	400	WOLAYTA 400	400.00*	-441.5	1973	22.4
	WOLAYTA 400	400.00 *	PAR	400	514.1	1973	26.1
	SEBETA 2	400	GI GIBE-2	400 *	-469	1341	34.9
11	GELAN	400	WOLAYTA 400	400.00*	-427.8	1973	21.7
	WOLAYTA 400	400.00 *	PAR	400	531.2	1973	26.9
	SEBETA-2	400	GI GIBE-2	400.00*	-480	1341	35.7
12	GELAN	400	WOLAYTA 400	400.00*	-414.1	1973	21
	WOLAYTA 400	400.00 *	PAR	400	548.3	1973	27.8
	SEBETA-2	400	GI GIBE-2	400.00*	-489	1341	34.6
13	GELAN	400	WOLAYTA 400	400.00*	-400.5	1973	20.3
	WOLAYTA 400	400.00 *	PAR	400	565.5	1973	28.7
	SEBETA-2	400	GI GIBE-2	400.00*	-498.9	1341	37.2
14	GELAN	400	WOLAYTA 400	400.00*	-386.9	1973	19.6
	WOLAYTA 400	400.00 *	PAR	400	582.7	1973	29.5
	SEBETA-2	400	GI GIBE-2	400.00*	-509	1341	37.9
15	GELAN	400	WOLAYTA	400.00*	-373.3	1973	18.9

			400				
	WOLAYTA 400	400.00 *	PAR	400	599.9	1973	30.4
	SEBETA-2	400	GI GIBE-2	400.00*	-520.7	1341	38.8
	GELAN	400	WOLAYTA 400	400.00*	-359.8	1973	18.2
16	WOLAYTA 400	400.00 *	PAR	400	617.1	1973	31.3
	SEBETA-2	400	GI GIBE-2	400.00*	-531	1341	39.5
	GELAN	400	WOLAYTA 400	400.00*	-346.3	1973	17.5
17	WOLAYTA 400	400.00 *	PAR	400	634.4	1973	32.2
	SEBETA-2	400	GI GIBE-2	400.00*	-540.4	1341	40.2
	GELAN	400	WOLAYTA 400	400.00	-332.8	1973	16.9
18	WOLAYTA 400	400.00	PAR	400	651.6	1973	33
	SEBETA-2	400	GI GIBE-2	400.00	-551.7	1341	41.1
	GELAN	400	WOLAYT	400 *	-319.3	1973	16.2
19	WOLAYTA 400	400.00 *	PAR	400	668.9	1973	33.9
	SEBETA-2	400	GI GIBE-2	400.00*	-560.6	1341	41.8
	GELAN	400	WOLAYTA 400	400.00*	-305.9	1973	15.5
20	WOLAYTA 400	400.00	PAR	400	686.2	1973	34.8
	SEBETA-2	400	GI GIBE-2	400.00	-572.1	1341	42.6

Power flowing on WOLAYTA to GIBE-II 400 kV Line (Red)

Without the phase shifting transformer, this line carries 20.7 % of its rated capacity as shown in Figure 4. 3. On inclusion of the phase shifting transformer and as the phase shifting transformer angle increased, power flowing through this line increases proportionally.

As the phase shifting transformer angle decreased, the power flowing through this line decreases and a further reduction of the angle leads to a decrease power flow.

Power flowing on GIBE-II to SEBETA –II 400 kV Line (Green)

As the phase shifting transformer angle increased, the flowing power increases in the reverse direction. As the phase shifting transformer angle decreased, the power flowing through this line decreases and a further reduction of the angle leads to a decrease power flow.

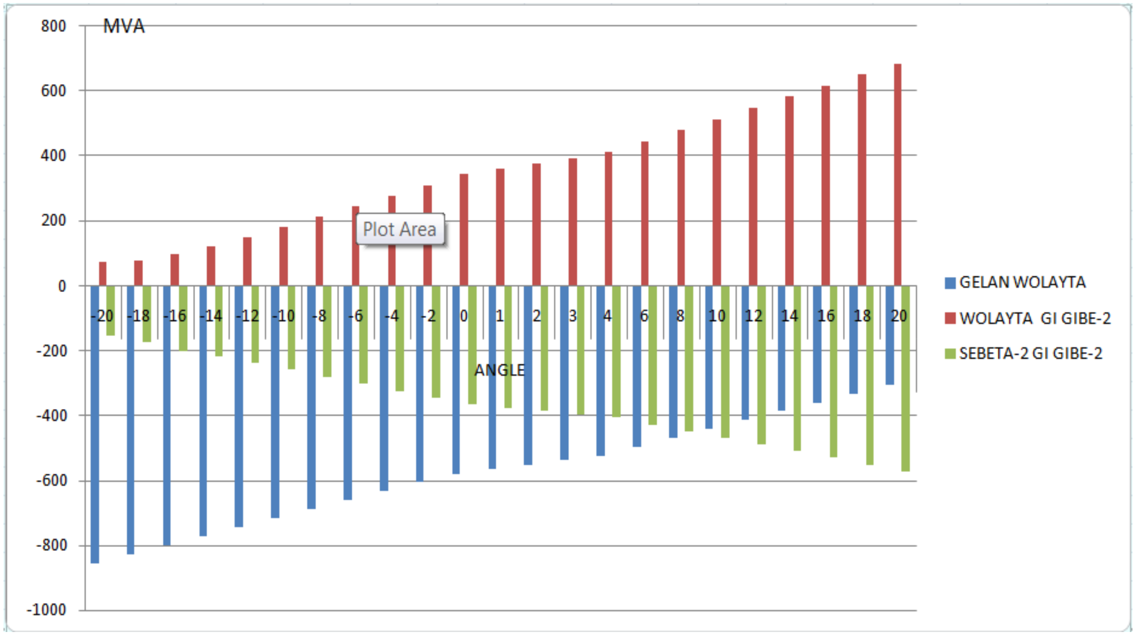


Figure 4. 9 Impact of phase shifting transformer on 400kV lines power flow

Power flowing on WOLAYTA to GELAN 400 kV Lines (blue)

As the phase shifting angle increased the power flowing through this line distributed to the other two 400kV transmission lines. (i.e Gibe II to Wolayta and Gibe II to Sebeta II) as shown in Figure 4. 9and lead to a decrease power flow.

Utilization of 400 kV transmission lines

Figure 4. 10 show the utilization of 400 kV transmission lines as the phase shifting transformer angle altered. As the Phase shifting transformer angle increased from -20° to +20°, the loading of Wolayta - Gibe II and Sebeta II- Gibe II 400kV transmission lines vary from 4% to 35% and 11% to 42% respectively.

Similarly Gelan- Wolayta 400kV transmission line loads 15% to 43% as the Phase shifting transformer angle decrease from +20° to -20°

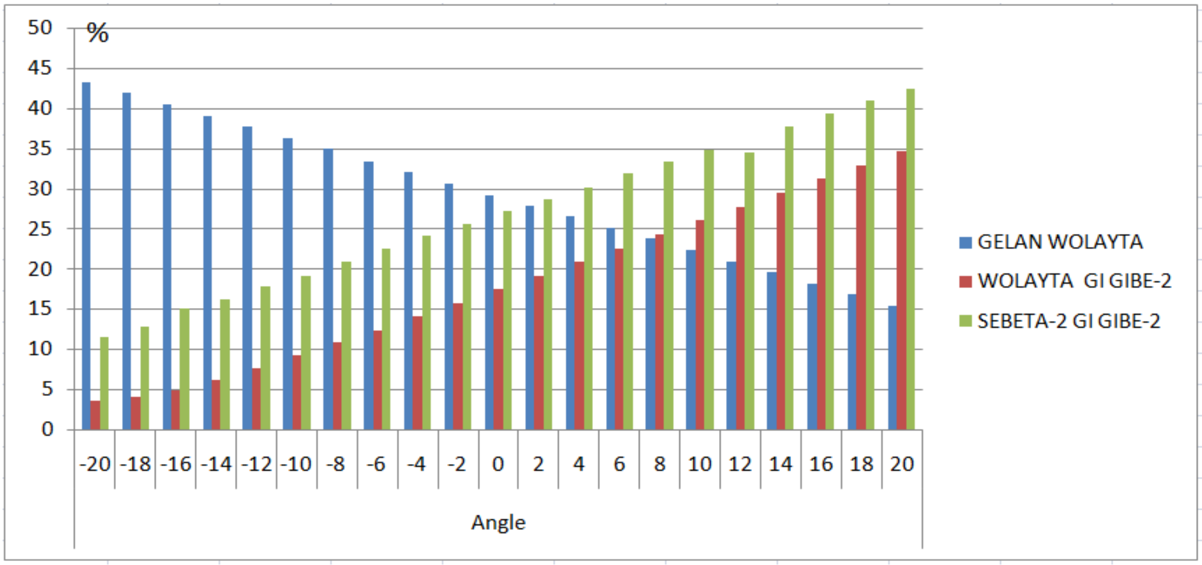


Figure 4. 10 Utilization of 400 kV transmission lines as a function of phase shifting angle

Impact of Phase Shifting Transformer on Bus Voltage

While performing the load flow simulations for different phase shift angle setting of the phase shifting transformer, voltage for buses exceeding their emergency limit were also recorded. The study was performed for the peak load of the system and during this time some 132 kV substations located around southern part of the network were operating lower than their emergency limit.

The results recorded from the load flow solution at different phase angles are tabulated in Table 4.8. The emergency voltage limit is 0.9 p.u

Table 4. 8 Buses exceeding emergency voltage limit at different phase shifting angle of PST

	PST Angle								
	20	15	10	5	0	-5	-10	-15	-20
BUS NAME	V(PU)	V(PU)	V(PU)	V(PU)	V(PU)	V(PU)	V(PU)	V(PU)	V(PU)
AWASA 132kV	0.866	0.8642	0.8618	0.8588	0.8551	0.8509	0.846	0.8402	0.8335
DILLA 132kV	0.8182	0.816	0.8131	0.8095	0.8051	0.8	0.7941	0.7871	0.7789
YIRGALEM 132kV	0.8327	0.8307	0.8279	0.8245	0.8205	0.8157	0.8101	0.8035	0.7959
BUTAJIRA 132kV	0.8976	0.8966	0.8951	0.8933	0.891	0.8884	0.8853	0.8817	0.8775

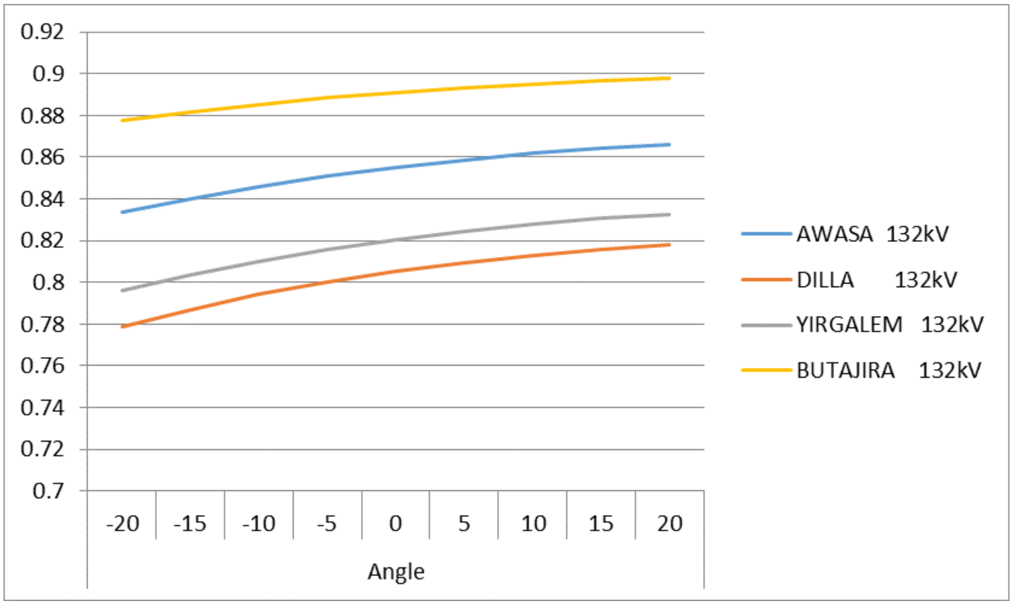


Figure 4. 11 Voltage Profile at different phase shifting angle

From Figure 4. 11 as the phase shifting angle increased the 132kV bus voltages increase relatively. This is because of the phase shifting transformer forced to move more power on to the higher voltage transmission lines.

Chapter 5

Conclusions, Recommendations and Future Work

5.1 Conclusions

When higher voltage transmission lines are operated in parallel with a lower voltage network having lower impedance, the power flows in the lower voltage network as dictated by the network impedances. This may lead to inefficient utilization of high voltage transmission lines.

This thesis presents an alternative solution which would enable to control the active power flows in the transmission network in order to enhance the transmission capacity of high voltage transmission lines. The simulation results show that a phase shifting transformer enables to control the distribution of active power flow over the transmission lines rather than a natural active power flow as dictated by network impedances. It is concluded that the active power flow in the network can be controlled by varying the phase shifting transformer angle. It is further observed that use of phase shifting transformer avoids overloading of transmission lines and increases the utilization capacity of high voltage transmission lines. Moreover, the voltage drop due to overloading of a specific transmission line can be reduced slightly by varying the angle of the phase shifting transformer.

It is concluded that the active power flow in the network could be controlled both in magnitude and direction by using phase shifting transformers. Thus, by redirecting active power flow towards the alternate high voltage paths would result in alleviating the congestion problem in the high voltage transmission network.

5.2 Recommendations

Due to an increased penetration of high capacity hydro power plants in to Ethiopian grid, electrical energy transmission has increased over the last years. Conventional ways of solving the network bottlenecks based on reinforcement and building new transmission lines cannot be taken as sufficient and fast due to the problems of acquiring new corridors and environmental limitations.

Thus, effective utilization of existing transmission networks is crucial to facilitate integration of high amount of power plants. Installation of phase shifting transformers in the network would be a better option for controlling the active power flow and improving the utilization of high voltage transmission networks. It is recommended that Ethiopian Electric Power may install phase shifting transformers in its existing high voltage transmission networks for its effective utilization

5.3 Suggestions for Future Work

In this thesis, control of active power flow in Ethiopian high voltage transmission network using phase shifting transformers is investigated. The following research work related to the use of phase shifting transformers in high voltage transmission network may be carried out.

1. The impact of phase shifting transformers on transient stability of the system may be analyzed.
2. N-1 contingency analysis of the system using phase shifting transformers may be carry out.
3. Protection of lines and transformers in the network with phase shifting transformers may be investigated.

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Appendix 1: Loading of Generators

Bus Number	Bus Name	P_{Gen} (MW)	Q_{Gen} (Mvar)
812006	ABA SAMUEL 6.3000	3.3	0.3
907001	BELES-1 15.000	104.7	-26.2
907004	BELES-2 15.000	104.7	-26.2
907007	BELES-3 15.000	104.7	-26.2
907009	BELES-4 15.000	104.7	-26.2
908001	FINCHA1 13.800	30	12.6
908002	NESHE-1 13.800	44.6	-13.7
908003	FINCHA2 13.800	30	12.6
908004	NESHE-2 13.800	44.6	-13.7
908005	FINCHA3 13.800	30	12.6
908006	FINCHA4 13.800	10.6	12.6
909001	TEKEZE1 13.800	58.4	-4.6
909002	TEKEZE4 13.800	58.4	-4.6
909005	TEKEZE3 13.800	58.4	-4.6
909006	ASHEGODA-WF 33.000	8.3	57.5
911003	AWASH2-1 10.500	6.4	8
911004	AWASH3-1 10.500	6.4	12
911005	KOKA1 10.500	6.1	10
911007	M-WAKENA1 13.800	8.7	5.4
911008	AWASH2-2 10.500	6.4	12
911009	AWASH3-2 10.500	6.4	12
911010	KOKA2 10.500	6.1	10
911012	M-WAKENA3 13.800	10.5	5.4
911013	M-WAKENA4 13.800	10.5	5.4
911015	ADAMA WF-I 33.000	26.7	8.3
911016	ADAMA WF-II 33.000	87.5	2.5
915002	G-GIBE2-1 15.000	67.2	-22.6
915003	G-GIBE1-1 13.800	57.1	44.4
915004	G-GIB2-2 15.000	67.2	-22.6
915005	G-GIBE1-2 13.800	14.3	44.4
915006	G-GIB2-3 15.000	71.1	-22.6
915007	G-GIBE1-3 13.800	57.1	44.4
915008	G-GIB2-4 15.000	71.1	-22.6
915009	G-GIB3 1 15.000	153.4	59.4
915010	G-GIB3 2 15.000	153.4	59.4
915011	G-GIB3 3 15.000	153.4	59.4

915012	G-GIB3 4 15.000	153.4	59.4
915013	G-GIB3 5 15.000	153.4	59.4
915014	G-GIB3 6 15.000	153.4	59.4
915015	G-GIB3 7 15.000	153.4	59.4
Total Generation		**2,456.00MW**	

Appendix 2: Driving Point Impedance Result

```
 - IMPEDANCE CORRECTIONS NOT APPLIED TO TRANSFORMER ZERO SEQUENCE IMPEDANCES

    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
402001 [SULULTA     400.00] 3PH      45.27   11.8406 -43.6898  24.3580 -89.8773  28.4902-105.1246   17.1813    45.2659    48.4169
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.006357+j0.023455, 3.68985

-----------------------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
402002 [GELAN       400.00] 3PH      49.87   10.7704 -48.6904  23.2236-104.9882  26.9345-121.7645   26.5648    49.8417    56.4791
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.004764+j0.021538, 4.52076

-----------------------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
402003 [GEBRE-GURCHA400.00] 3PH      32.86    6.1177 -32.2852  13.6271 -71.9144  14.9881 -79.0970   14.1188    32.8597    35.7645
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.006232+j0.032890, 5.27730

-----------------------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
407001 [BAHIRDAR-II 400.00] 3PH      38.24    5.9129 -37.7792  13.6535 -87.2362  14.3655 -91.7852   24.7053    37.9332    45.2690
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.004448+j0.028420, 6.38928
```

```
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
407002 [BELES       400.00] 3PH      34.94    3.9818 -34.7170   9.6556 -84.1870   9.9297 -86.5769   28.4494    34.2341    44.5123
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.003587+j0.031273, 8.71901

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    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
407003 [DEBRE MARKOS400.00] 3PH      38.66    7.4095 -37.9427  16.4042 -84.0035  18.0243 -92.2997   17.6865    38.6594    42.5131
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.005453+j0.027926, 5.12084

-----------------------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
407004 [GRAN RENAIS 400.00] 3PH      14.21    1.5775 -14.1176   3.8391 -34.3578   3.9207 -35.0884    6.9742    14.2054    15.8251
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.008599+j0.076956, 8.94943

-----------------------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,    NOMINAL FREQUENCY=50.0 Hz,    BREAKING CURRENT at TIME= 0.050 seconds
                                    <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                 RE(I)     IM(I)     RE(I)     IM(I)     RE(I)     IM(I)          /I/        /I/        /I/
X---------- BUS ----------X           PU            PU                  PU                  PU                   PU         PU         PU
413001 [WOLAYTA 400 400.00] 3PH      51.31    6.8476 -50.8470  16.2136-120.3954  17.6056-130.7315   40.7360    51.3060    65.5113
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.002861+j0.021248, 7.42557
```

```
    VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.050 seconds
                                   <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                RE(I)    IM(I)     RE(I)    IM(I)     RE(I)    IM(I)        /I/       /I/       /I/
X---------- BUS ----------X           PU          PU                PU                PU                PU        PU        PU
414002 [HOLETA-400  400.00] 3PH      47.37   10.1312 -46.2789   21.8951-100.0155   25.2932-115.5378    24.6508   47.3639   53.3948
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.004965+j0.022682, 4.56794

---------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.050 seconds
                                   <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                RE(I)    IM(I)     RE(I)    IM(I)     RE(I)    IM(I)        /I/       /I/       /I/
X---------- BUS ----------X           PU          PU                PU                PU                PU        PU        PU
415001 [GI GIBE-2   400.00] 3PH      55.02    7.5269 -54.4986   17.7506-128.5235   19.3515-140.1148    46.0823   54.1388   71.0957
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.002735+j0.019806, 7.24053

---------------------------------------------------------------------------------------------------------
    VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.050 seconds
                                   <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                RE(I)    IM(I)     RE(I)    IM(I)     RE(I)    IM(I)        /I/       /I/       /I/
X---------- BUS ----------X           PU          PU                PU                PU                PU        PU        PU
415002 [G.GIBE NEW  400.00] 3PH      48.77    6.8589 -48.2804   16.1012-113.3383   17.5112-123.2637    37.7026   48.2675   61.2474
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.003173+j0.022333, 7.03913

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    VOLTAGE FACTOR C= 1.10,   NOMINAL FREQUENCY=50.0 Hz,   BREAKING CURRENT at TIME= 0.050 seconds
                                   <-SCMVA-> <-Sym I''k rms--> <-----ip(B)------> <-----ip(C)------> <DC Ib(C)> <Sym Ib-> <Asym Ib>
                                                RE(I)    IM(I)     RE(I)    IM(I)     RE(I)    IM(I)        /I/       /I/       /I/
X---------- BUS ----------X           PU          PU                PU                PU                PU        PU        PU
415003 [G-GIBE3     400.00] 3PH      49.33    5.7358 -48.9912   13.8687-118.4579   14.8595-126.9205    42.7276   49.3258   65.2586
THEVENIN IMPEDANCE, X/R  (PU)      Z+:0.002593+j0.022149, 8.54136
```

Appendix 3: Load Flow Results

LINE LOADINGS FOR DIFFERENT SETTINGS OF PHASE SHIFTING TRANSFORMER ANGLE							
PHASE SHIFTING ANGLE	FROM		TO		LINE LOADING (MVA)	LINE RATING (MVA)	(%)
	BUS NAME	BASE KV	BUS NAME	BASE KV			
-20	ALABA	132*	HOSAINA	132	20.5	89	23
	ALABA	132*	SHASHEMENE	132	110.6	89	124.3
	ALABA	132	W SODO-II	132*	-185.5	89	208.4
	HOSAINA	132 *	G.GIBE NEW	132	23.7	89	26.6
	ALABA	230*	HOSAINA	230	61.9	402	15.4
	HOSAINA	230*	WOLKITE	230	55.8	402	13.9
	GELAN	400	WOLAYTA	400*	-856.2	1973	43.4
	WOLAYTA	400*	GI GIBE-2	400	71.9	1973	3.6
	HOSAINA	230*	WOLKITE	230	55.8	402	13.9
	SEBATA-1	230	WOLKITE	230*	-85.4	402	21.2
	WOLKITE	230*	G.GIBE NEW	230	79.6	280	28.4
	SEBETA-2	400	GI GIBE-2	400*	-154.7	1341	11.5
-19	ALABA	132*	HOSAINA	132	19.5	89	21.9
	ALABA	132*	SHASHEMENE	132	110.4	89	124.1
	ALABA	132	W SODO-II	132*	-182.4	89	204.9
	HOSAINA	132 *	G.GIBE NEW	132	23.1	89	25.9
	ALABA	230*	HOSAINA	230	60.3	402	15
	HOSAINA	230*	WOLKITE	230	54.1	402	13.5
	GELAN	400	WOLAYTA	400*	-842.3	1973	42.7
	WOLAYTA	400*	GI GIBE-2	400	73.2	1973	3.7
	HOSAINA	230*	WOLKITE	230	54.1	402	13.5
	SEBATA-1	230	WOLKITE	230*	-86.8	402	21.6
	WOLKITE	230*	G.GIBE NEW	230	82	280	29.3
	SEBETA-2	400	GI GIBE-2	400*	-161.6	1341	12.05
-18	ALABA	132*	HOSAINA	132	18.5	89	20.8
	ALABA	132*	SHASHEMENE	132	110.3	89	123.9
	ALABA	132	W SODO-II	132*	-179.3	89	201.4
	HOSAINA	132 *	G.GIBE NEW	132	22.5	89	25.3
	ALABA	230*	HOSAINA	230	58.6	402	14.6
	HOSAINA	230*	WOLKITE	230	52.4	402	13
	GELAN	400	WOLAYTA	400*	-828.4	1973	42
	WOLAYTA	400*	GI GIBE-2	400	78.1	1973	4

	HOSAINA	230*	WOLKITE	230	52.4	402	13
	SEBATA-1	230	WOLKITE	230*	-88.2	402	21.9
	WOLKITE	230*	G.GIBE NEW	230	84.4	280	30.1
	SEBETA-2	400	GI GIBE-2	400*	-172.8	1341	12.8
-17	ALABA	132*	HOSAINA	132	17.5	89	19.7
	ALABA	132*	SHASHEMENE	132	110.1	89	123.7
	ALABA	132	W SODO-II	132*	-176.2	89	197.9
	HOSAINA	132 *	G.GIBE NEW	132	22	89	24.7
	ALABA	230*	HOSAINA	230	56.9	402	14.2
	HOSAINA	230*	WOLKITE	230	50.6	402	12.6
	GELAN	400	WOLAYTA	400*	-814.5	1973	41.3
	WOLAYTA	400*	GI GIBE-2	400	86.2	1973	4.4
	HOSAINA	230*	WOLKITE	230	50.6	402	12.6
	SEBATA-1	230	WOLKITE	230*	-89.7	402	22.3
	WOLKITE	230*	G.GIBE NEW	230	86.9	280	31
	SEBETA-2	400	GI GIBE-2	400*	-182.3	1341	13.5
-16	ALABA	132*	HOSAINA	132	16.6	89	18.6
	ALABA	132*	SHASHEMENE	132	109.9	89	123.5
	ALABA	132	W SODO-II	132*	-173.1	89	194.5
	HOSAINA	132 *	G.GIBE NEW	132	21.5	89	24.2
	ALABA	230*	HOSAINA	230	55.3	402	13.7
	HOSAINA	230*	WOLKITE	230	48.9	402	12.2
	GELAN	400	WOLAYTA	400*	-800.6	1973	40.6
	WOLAYTA	400*	GI GIBE-2	400	96.5	1973	4.9
	HOSAINA	230*	WOLKITE	230	48.9	402	12.2
	SEBATA-1	230	WOLKITE	230*	-91.1	402	22.7
	WOLKITE	230*	G.GIBE NEW	230	89.4	280	31.9
	SEBETA-2	400	GI GIBE-2	400*	-203	1341	15.1
-15	ALABA	132*	HOSAINA	132	15.6	89	17.6
	ALABA	132*	SHASHEMENE	132	109.8	89	123.3
	ALABA	132	W SODO-II	132*	-170	89	191
	HOSAINA	132 *	G.GIBE NEW	132	21.1	89	23.7
	ALABA	230*	HOSAINA	230	53.7	402	13.3
	HOSAINA	230*	WOLKITE	230	47.3	402	11.8
	GELAN	400	WOLAYTA	400*	-786.7	1973	39.9
	WOLAYTA	400*	GI GIBE-2	400	108.5	1973	5.5
	HOSAINA	230*	WOLKITE	230	47.3	402	11.8
	SEBATA-1	230	WOLKITE	230*	-92.5	402	23
	WOLKITE	230*	G.GIBE NEW	230	91.9	280	32.8
	SEBETA-2	400	GI GIBE-2	400*	-205.6	1341	15.3

-14	ALABA	132*	HOSAINA	132	14.7	89	16.6
	ALABA	132*	SHASHEMENE	132	109.6	89	123.1
	ALABA	132	W SODO-II	132*	-166.9	89	187.5
	HOSAINA	132 *	G.GIBE NEW	132	20.8	89	23.3
	ALABA	230*	HOSAINA	230	52	402	12.9
	HOSAINA	230*	WOLKITE	230	45.6	402	11.3
	GELAN	400	WOLAYTA	400*	-772.8	1973	39.2
	WOLAYTA	400*	GI GIBE-2	400	121.7	1973	6.2
	HOSAINA	230*	WOLKITE	230	45.6	402	11.3
	SEBATA-1	230	WOLKITE	230*	-93.9	402	23.4
	WOLKITE	230*	G.GIBE NEW	230	94.5	280	33.8
	SEBETA-2	400	GI GIBE-2	400*	-218.7	1341	16.3
-13	ALABA	132*	HOSAINA	132	13.9	89	15.6
	ALABA	132*	SHASHEMENE	132	109.4	89	123
	ALABA	132	W SODO-II	132*	-163.8	89	184
	HOSAINA	132 *	G.GIBE NEW	132	20.5	89	23
	ALABA	230*	HOSAINA	230	50.5	402	12.6
	HOSAINA	230*	WOLKITE	230	43.9	402	10.9
	GELAN	400	WOLAYTA	400*	-758.9	1973	38.5
	WOLAYTA	400*	GI GIBE-2	400	135.7	1973	6.9
	HOSAINA	230*	WOLKITE	230	43.9	402	10.9
	SEBATA-1	230	WOLKITE	230*	-95.3	402	23.7
	WOLKITE	230*	G.GIBE NEW	230	97.2	280	34.7
	SEBETA-2	400	GI GIBE-2	400*	-227.9	1341	16.9
-12	ALABA	132*	HOSAINA	132	13	89	14.6
	ALABA	132*	SHASHEMENE	132	109.3	89	122.8
	ALABA	132	W SODO-II	132*	-160.7	89	180.5
	HOSAINA	132 *	G.GIBE NEW	132	20.2	89	22.7
	ALABA	230*	HOSAINA	230	48.9	402	12.2
	HOSAINA	230*	WOLKITE	230	42.3	402	10.5
	GELAN	400	WOLAYTA	400*	-745.1	1973	37.8
	WOLAYTA	400*	GI GIBE-2	400	150.4	1973	7.6
	HOSAINA	230*	WOLKITE	230	42.3	402	10.5
	SEBATA-1	230	WOLKITE	230*	-96.7	402	24
	WOLKITE	230*	G.GIBE NEW	230	99.8	280	35.6
	SEBETA-2	400	GI GIBE-2	400*	-239.6	1341	17.8
-11	ALABA	132*	HOSAINA	132	12.2	89	13.7
	ALABA	132*	SHASHEMENE	132	109.1	89	122.6
	ALABA	132	W SODO-II	132*	-157.6	89	177
	HOSAINA	132 *	G.GIBE NEW	132	20	89	22.5

	ALABA	230*	HOSAINA	230	47.4	402	11.8
	HOSAINA	230*	WOLKITE	230	40.7	402	10.1
	GELAN	400	WOLAYTA	400*	731.2	1973	37.1
	WOLAYTA	400*	GI GIBE-2	400	165.5	1973	8.4
	HOSAINA	230*	WOLKITE	230	40.7	402	10.1
	SEBATA-1	230	WOLKITE	230*	-98.1	402	24.4
	WOLKITE	230*	G.GIBE NEW	230	102.5	280	36.6
	SEBETA-2	400	GI GIBE-2	400*	-251	1341	18.7
-10	ALABA	132*	HOSAINA	132	11.4	89	12.8
	ALABA	132*	SHASHEMENE	132	108.9	89	122.4
	ALABA	132	W SODO-II	132*	-154.4	89	173.5
	HOSAINA	132 *	G.GIBE NEW	132	19.9	89	22.3
	ALABA	230*	HOSAINA	230	45.9	402	11.4
	HOSAINA	230*	WOLKITE	230	39.1	402	9.7
	GELAN	400	WOLAYTA	400*	-717.3	1973	36.4
	WOLAYTA	400*	GI GIBE-2	400	180.9	1973	9.2
	HOSAINA	230*	WOLKITE	230	39.1	402	9.7
	SEBATA-1	230	WOLKITE	230*	-99.5	402	24.7
	WOLKITE	230*	G.GIBE NEW	230	105.2	280	37.6
	SEBETA-2	400	GI GIBE-2	400*	-258.2	1341	19.2
-9	ALABA	132*	HOSAINA	132	10.7	89	12
	ALABA	132*	SHASHEMENE	132	108.8	89	122.2
	ALABA	132	W SODO-II	132*	-151.3	89	170
	HOSAINA	132 *	G.GIBE NEW	132	19.8	89	22.2
	ALABA	230*	HOSAINA	230	44.4	402	11
	HOSAINA	230*	WOLKITE	230	37.6	402	9.4
	GELAN	400	WOLAYTA	400*	-703.5	1973	35.7
	WOLAYTA	400*	GI GIBE-2	400	196.7	1973	10
	HOSAINA	230*	WOLKITE	230	37.6	402	9.4
	SEBATA-1	230	WOLKITE	230*	-100.8	402	25.1
	WOLKITE	230*	G.GIBE NEW	230	107.9	280	38.5
	SEBETA-2	400	GI GIBE-2	400*	-269	1341	20
-8	ALABA	132*	HOSAINA	132	10.1	89	11.3
	ALABA	132*	SHASHEMENE	132	108.6	89	122
	ALABA	132	W SODO-II	132*	-148.2	89	166.6
	HOSAINA	132 *	G.GIBE NEW	132	19.8	89	22.2
	ALABA	230*	HOSAINA	230	42.9	402	10.7
	HOSAINA	230*	WOLKITE	230	36.1	402	9
	GELAN	400	WOLAYTA	400*	-689.6	1973	35
	WOLAYTA	400*	GI GIBE-2	400	212.6	1973	10.8

	HOSAINA	230*	WOLKITE	230	36.1	402	9
	SEBATA-1	230	WOLKITE	230*	-102.2	402	25.4
	WOLKITE	230*	G.GIBE NEW	230	110.6	280	39.5
	SEBETA-2	400	GI GIBE-2	400*	-281	1341	20.9
-7	ALABA	132*	HOSAINA	132	9.5	89	10.7
	ALABA	132*	SHASHEMENE	132	108.4	89	121.8
	ALABA	132	W SODO-II	132*	-145.1	89	163.1
	HOSAINA	132 *	G.GIBE NEW	132	19.8	89	22.3
	ALABA	230*	HOSAINA	230	41.5	402	10.3
	HOSAINA	230*	WOLKITE	230	34.6	402	8.6
	GELAN	400	WOLAYTA	400*	-675.8	1973	34.3
	WOLAYTA	400*	GI GIBE-2	400	228.7	1973	11.6
	HOSAINA	230*	WOLKITE	230	34.6	402	8.6
	SEBATA-1	230	WOLKITE	230*	-103.6	402	25.8
	WOLKITE	230*	G.GIBE NEW	230	113.4	280	40.5
	SEBETA-2	400	GI GIBE-2	400*	-291	1341	21.7
-6	ALABA	132*	HOSAINA	132	9	89	10.2
	ALABA	132*	SHASHEMENE	132	108.2	89	121.6
	ALABA	132	W SODO-II	132*	-142	89	159.6
	HOSAINA	132 *	G.GIBE NEW	132	19.9	89	22.4
	ALABA	230*	HOSAINA	230	40.2	402	10
	HOSAINA	230*	WOLKITE	230	33.2	402	8.3
	GELAN	400	WOLAYTA	400*	-661.9	1973	33.5
	WOLAYTA	400*	GI GIBE-2	400	244.9	1973	12.4
	HOSAINA	230*	WOLKITE	230	33.2	402	8.3
	SEBATA-1	230	WOLKITE	230*	-105	402	26.1
	WOLKITE	230*	G.GIBE NEW	230	116.2	280	41.5
	SEBETA-2	400	GI GIBE-2	400*	-303.3	1341	22.6
-5	ALABA	132*	HOSAINA	132	8.7	89	9.8
	ALABA	132*	SHASHEMENE	132	108	89	121.4
	ALABA	132	W SODO-II	132*	-138.9	89	156.1
	HOSAINA	132 *	G.GIBE NEW	132	20.1	89	22.6
	ALABA	230*	HOSAINA	230	38.9	402	9.7
	HOSAINA	230*	WOLKITE	230	31.8	402	7.9
	GELAN	400	WOLAYTA	400*	-648.1	1973	32.8
	WOLAYTA	400*	GI GIBE-2	400	261.3	1973	13.2
	HOSAINA	230*	WOLKITE	230	31.8	402	7.9
	SEBATA-1	230	WOLKITE	230*	-106.3	402	26.4
	WOLKITE	230*	G.GIBE NEW	230	119	280	42.5
	SEBETA-2	400	GI GIBE-2	400*	-311.1	1341	23.2

-4	ALABA	132*	HOSAINA	132	8.5	89	9.6
	ALABA	132*	SHASHEMENE	132	107.9	89	121.2
	ALABA	132	W SODO-II	132*	-135.8	89	152.6
	HOSAINA	132 *	G.GIBE NEW	132	20.3	89	22.9
	ALABA	230*	HOSAINA	230	37.6	402	9.4
	HOSAINA	230*	WOLKITE	230	30.5	402	7.6
	GELAN	400	WOLAYTA	400*	-634.3	1973	32.1
	WOLAYTA	400*	GI GIBE-2	400	277.8	1973	14.1
	HOSAINA	230*	WOLKITE	230	30.5	402	7.6
	SEBATA-1	230	WOLKITE	230*	-107.7	402	26.8
	WOLKITE	230*	G.GIBE NEW	230	121.8	280	43.5
	SEBETA-2	400	GI GIBE-2	400*	-324.2	1341	24.2
-3	ALABA	132*	HOSAINA	132	8.5	89	9.5
	ALABA	132*	SHASHEMENE	132	107.7	89	121
	ALABA	132	W SODO-II	132*	-132.7	89	149.1
	HOSAINA	132 *	G.GIBE NEW	132	20.6	89	23.2
	ALABA	230*	HOSAINA	230	36.5	402	9.1
	HOSAINA	230*	WOLKITE	230	29.3	402	7.3
	GELAN	400	WOLAYTA	400*	-620.4	1973	31.4
	WOLAYTA	400*	GI GIBE-2	400	294.3	1973	14.9
	HOSAINA	230*	WOLKITE	230	29.3	402	7.3
	SEBATA-1	230	WOLKITE	230*	-109	402	27.1
	WOLKITE	230*	G.GIBE NEW	230	124.6	280	44.5
	SEBETA-2	400	GI GIBE-2	400*	-333	1341	24.8
-2	ALABA	132*	HOSAINA	132	8.6	89	9.6
	ALABA	132*	SHASHEMENE	132	107.5	89	120.8
	ALABA	132	W SODO-II	132*	-129.6	89	145.6
	HOSAINA	132 *	G.GIBE NEW	132	21	89	23.6
	ALABA	230*	HOSAINA	230	35.3	402	8.8
	HOSAINA	230*	WOLKITE	230	28.1	402	7
	GELAN	400	WOLAYTA	400*	-606.6	1973	30.7
	WOLAYTA	400*	GI GIBE-2	400	310.9	1973	15.8
	HOSAINA	230*	WOLKITE	230	28.1	402	7
	SEBATA-1	230	WOLKITE	230*	-110.4	402	27.5
	WOLKITE	230*	G.GIBE NEW	230	127.5	280	45.5
	SEBETA-2	400	GI GIBE-2	400*	-344.6	1341	25.7
-1	ALABA	132*	HOSAINA	132	8.8	89	9.9
	ALABA	132*	SHASHEMENE	132	107.3	89	120.6
	ALABA	132	W SODO-II	132*	-126.5	89	142.2
	HOSAINA	132 *	G.GIBE NEW	132	21.4	89	24.1

	ALABA	230*	HOSAINA	230	34.3	402	8.5
	HOSAINA	230*	WOLKITE	230	27	402	6.7
	GELAN	400	WOLAYTA	400*	-592.8	1973	30
	WOLAYTA	400*	GI GIBE-2	400	327.6	1973	16.6
	HOSAINA	230*	WOLKITE	230	27	402	6.7
	SEBATA-1	230	WOLKITE	230*	-111.7	402	27.8
	WOLKITE	230*	G.GIBE NEW	230	130.4	280	46.6
	SEBETA-2	400	GI GIBE-2	400*	-354.4	1341	26.4
0	ALABA	132*	HOSAINA	132	9.2	89	10.3
	ALABA	132*	SHASHEMENE	132	107.1	89	120.4
	ALABA	132	W SODO-II	132*	-123.4	89	138.7
	HOSAINA	132 *	G.GIBE NEW	132	21.9	89	24.6
	ALABA	230*	HOSAINA	230	33.3	402	8.3
	HOSAINA	230*	WOLKITE	230	26.1	402	6.5
	GELAN	400	WOLAYTA	400*	-579	1973	29.3
	WOLAYTA	400*	GI GIBE-2	400	344.4	1973	17.5
	HOSAINA	230*	WOLKITE	230	26.1	402	6.5
	SEBATA-1	230	WOLKITE	230*	-113	402	28.1
	WOLKITE	230*	G.GIBE NEW	230	133.2	280	47.6
	SEBETA-2	400	GI GIBE-2	400*	-365.2	1341	27.2
1	ALABA	132*	HOSAINA	132	9.6	89	10.8
	ALABA	132*	SHASHEMENE	132	106.9	89	120.2
	ALABA	132	W SODO-II	132*	-120.3	89	135.2
	HOSAINA	132 *	G.GIBE NEW	132	22.4	89	25.2
	ALABA	230*	HOSAINA	230	32.4	402	8.1
	HOSAINA	230*	WOLKITE	230	25.2	402	6.3
	GELAN	400	WOLAYTA	400*	-565.2	1973	28.6
	WOLAYTA	400*	GI GIBE-2	400	361.2	1973	18.3
	HOSAINA	230*	WOLKITE	230	25.2	402	6.3
	SEBATA-1	230	WOLKITE	230*	-114.3	402	28.4
	WOLKITE	230*	G.GIBE NEW	230	136.1	280	48.6
	SEBETA-2	400	GI GIBE-2	400*	-376.4	1341	28
2	ALABA	132*	HOSAINA	132	10.2	89	11.5
	ALABA	132*	SHASHEMENE	132	106.8	89	119.9
	ALABA	132	W SODO-II	132*	-117.3	89	131.7
	HOSAINA	132 *	G.GIBE NEW	132	23	89	25.8
	ALABA	230*	HOSAINA	230	31.7	402	7.9
	HOSAINA	230*	WOLKITE	230	24.5	402	6.1
	GELAN	400	WOLAYTA	400*	-551.4	1973	27.9
	WOLAYTA	400*	GI GIBE-2	400	378	1973	19.2

	HOSAINA	230*	WOLKITE	230	24.5	402	6.1
	SEBATA-1	230	WOLKITE	230*	-115.7	402	28.8
	WOLKITE	230*	G.GIBE NEW	230	-139.1	280	49.7
	SEBETA-2	400	GI GIBE-2	400*	-385	1341	28.7
3	ALABA	132*	HOSAINA	132	10.9	89	12.2
	ALABA	132*	SHASHEMENE	132	106.6	89	119.7
	ALABA	132	W SODO-II	132*	-114.2	89	128.3
	HOSAINA	132 *	G.GIBE NEW	132	23.6	89	26.5
	ALABA	230*	HOSAINA	230	31	402	7.7
	HOSAINA	230*	WOLKITE	230	23.9	402	5.9
	GELAN	400	WOLAYTA	400*	-537.6	1973	27.2
	WOLAYTA	400*	GI GIBE-2	400	394.9	1973	20
	HOSAINA	230*	WOLKITE	230	23.9	402	5.9
	SEBATA-1	230	WOLKITE	230*	-117	402	29.1
	WOLKITE	230*	G.GIBE NEW	230	-142	280	50.7
	SEBETA-2	400	GI GIBE-2	400*	-396.1	1341	29.5
4	ALABA	132*	HOSAINA	132	11.6	89	13
	ALABA	132*	SHASHEMENE	132	106.4	89	119.5
	ALABA	132	W SODO-II	132*	-111.1	89	124.8
	HOSAINA	132 *	G.GIBE NEW	132	24.2	89	27.2
	ALABA	230*	HOSAINA	230	30.4	402	7.6
	HOSAINA	230*	WOLKITE	230	23.4	402	5.8
	GELAN	400	WOLAYTA	400*	-523.8	1973	26.6
	WOLAYTA	400*	GI GIBE-2	400	411.8	1973	20.9
	HOSAINA	230*	WOLKITE	230	23.4	402	5.8
	SEBATA-1	230	WOLKITE	230*	-118.3	402	29.4
	WOLKITE	230*	G.GIBE NEW	230	-145	280	51.8
	SEBETA-2	400	GI GIBE-2	400*	-405.8	1341	30.2
5	ALABA	132*	HOSAINA	132	12.4	89	13.9
	ALABA	132*	SHASHEMENE	132	106.2	89	119.3
	ALABA	132	W SODO-II	132*	-108	89	121.4
	HOSAINA	132 *	G.GIBE NEW	132	24.9	89	27.9
	ALABA	230*	HOSAINA	230	30	402	7.5
	HOSAINA	230*	WOLKITE	230	23.1	402	5.7
	GELAN	400	WOLAYTA	400*	-510.1	1973	25.9
	WOLAYTA	400*	GI GIBE-2	400	428.8	1973	21.7
	HOSAINA	230*	WOLKITE	230	23.1	402	5.7
	SEBATA-1	230	WOLKITE	230*	-119.6	402	29.7
	WOLKITE	230*	G.GIBE NEW	230	-148	280	52.8
	SEBETA-2	400	GI GIBE-2	400*	-416.2	1341	31

6	ALABA	132*	HOSAINA	132	13.2	89	14.9
	ALABA	132*	SHASHEMENE	132	106	89	119.1
	ALABA	132	W SODO-II	132*	-104.9	89	117.9
	HOSAINA	132 *	G.GIBE NEW	132	25.6	89	28.7
	ALABA	230*	HOSAINA	230	29.6	402	7.4
	HOSAINA	230*	WOLKITE	230	22.9	402	5.7
	GELAN	400	WOLAYTA	400*	-496.3	1973	25.2
	WOLAYTA	400*	GI GIBE-2	400	445.8	1973	22.6
	HOSAINA	230*	WOLKITE	230	22.9	402	5.7
	SEBATA-1	230	WOLKITE	230*	-120.8	402	30.1
	WOLKITE	230*	G.GIBE NEW	230	-150.9	280	53.9
	SEBETA-2	400	GI GIBE-2	400*	-428	1341	31.9
7	ALABA	132*	HOSAINA	132	-14.2	89	15.9
	ALABA	132*	SHASHEMENE	132	105.8	89	118.9
	ALABA	132	W SODO-II	132*	-101.9	89	114.5
	HOSAINA	132 *	G.GIBE NEW	132	26.3	89	29.6
	ALABA	230*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230*	WOLKITE	230	22.9	402	5.7
	GELAN	400	WOLAYTA	400*	-482.6	1973	24.5
	WOLAYTA	400*	GI GIBE-2	400	462.8	1973	23.5
	HOSAINA	230*	WOLKITE	230	22.9	402	5.7
	SEBATA-1	230	WOLKITE	230*	-122.1	402	30.4
	WOLKITE	230*	G.GIBE NEW	230	-153.9	280	55
	SEBETA-2	400	GI GIBE-2	400*	-437.4	1341	32.6
8	ALABA	132*	HOSAINA	132	-15.1	89	17
	ALABA	132*	SHASHEMENE	132	105.6	89	118.6
	ALABA	132	W SODO-II	132*	-98.8	89	111
	HOSAINA	132 *	G.GIBE NEW	132	27.1	89	30.4
	ALABA	230*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230*	WOLKITE	230	23.1	402	5.8
	GELAN	400	WOLAYTA	400*	-468.9	1973	23.8
	WOLAYTA	400*	GI GIBE-2	400	479.9	1973	24.3
	HOSAINA	230*	WOLKITE	230	23.1	402	5.8
	SEBATA-1	230	WOLKITE	230*	-123.4	402	30.7
	WOLKITE	230*	G.GIBE NEW	230	-156.9	280	56
	SEBETA-2	400	GI GIBE-2	400*	-448.1	1341	33.4
9	ALABA	132*	HOSAINA	132	-16.1	89	18.1
	ALABA	132*	SHASHEMENE	132	105.4	89	118.4
	ALABA	132	W SODO-II	132*	-95.8	89	107.6
	HOSAINA	132 *	G.GIBE NEW	132	27.8	89	31.3

	ALABA	230*	HOSAINA	230	29.4	402	7.3
	HOSAINA	230*	WOLKITE	230	23.5	402	5.8
	GELAN	400	WOLAYTA	400*	-455.2	1973	23.1
	WOLAYTA	400*	GI GIBE-2	400	497	1973	25.2
	HOSAINA	230*	WOLKITE	230	23.5	402	5.8
	SEBATA-1	230	WOLKITE	230*	-124.7	402	31
	WOLKITE	230*	G.GIBE NEW	230	-159.9	280	57.1
	SEBETA-2	400	GI GIBE-2	400*	-457.7	1341	34.1
10	ALABA	132*	HOSAINA	132	-17.1	89	19.2
	ALABA	132*	SHASHEMENE	132	105.2	89	118.2
	ALABA	132	W SODO-II	132*	-92.7	89	104.2
	HOSAINA	132 *	G.GIBE NEW	132	28.7	89	32.2
	ALABA	230*	HOSAINA	230	29.6	402	7.4
	HOSAINA	230*	WOLKITE	230	23.9	402	6
	GELAN	400	WOLAYTA	400*	-441.5	1973	22.4
	WOLAYTA	400*	GI GIBE-2	400	514.1	1973	26.1
	HOSAINA	230*	WOLKITE	230	23.9	402	6
	SEBATA-1	230	WOLKITE	230*	-125.9	402	31.3
	WOLKITE	230*	G.GIBE NEW	230	-162.9	280	58.2
	SEBETA-2	400	GI GIBE-2	400*	-469	1341	34.9
11	ALABA	132*	HOSAINA	132	-18.1	89	20.4
	ALABA	132*	SHASHEMENE	132	105	89	117.9
	ALABA	132	W SODO-II	132*	-89.7	89	100.7
	HOSAINA	132 *	G.GIBE NEW	132	29.5	89	33.1
	ALABA	230*	HOSAINA	230	29.9	402	7.4
	HOSAINA	230*	WOLKITE	230	24.6	402	6.1
	GELAN	400	WOLAYTA	400*	-427.8	1973	21.7
	WOLAYTA	400*	GI GIBE-2	400	531.2	1973	26.9
	HOSAINA	230*	WOLKITE	230	24.6	402	6.1
	SEBATA-1	230	WOLKITE	230*	-127.2	402	31.6
	WOLKITE	230*	G.GIBE NEW	230	-165.9	280	59.2
	SEBETA-2	400	GI GIBE-2	400*	-480	1341	35.7
12	ALABA	132*	HOSAINA	132	-19.2	89	21.5
	ALABA	132*	SHASHEMENE	132	104.8	89	117.7
	ALABA	132	W SODO-II	132*	-86.6	89	97.3
	HOSAINA	132 *	G.GIBE NEW	132	30.3	89	34.1
	ALABA	230*	HOSAINA	230	30.3	402	7.5
	HOSAINA	230*	WOLKITE	230	25.3	402	6.3
	GELAN	400	WOLAYTA	400*	-414.1	1973	21
	WOLAYTA	400*	GI GIBE-2	400	548.3	1973	27.8

	HOSAINA	230*	WOLKITE	230	25.3	402	6.3
	SEBATA-1	230	WOLKITE	230*	-128.4	402	32
	WOLKITE	230*	G.GIBE NEW	230	-168.8	280	60.3
	SEBETA-2	400	GI GIBE-2	400*	-489	1341	34.6
13	ALABA	132*	HOSAINA	132	-20.2	89	22.7
	ALABA	132*	SHASHEMENE	132	104.6	89	117.5
	ALABA	132	W SODO-II	132*	-83.6	89	93.9
	HOSAINA	132 *	G.GIBE NEW	132	31.2	89	35.1
	ALABA	230*	HOSAINA	230	30.9	402	7.7
	HOSAINA	230*	WOLKITE	230	26.2	402	6.5
	GELAN	400	WOLAYTA	400*	-400.5	1973	20.3
	WOLAYTA	400*	GI GIBE-2	400	565.5	1973	28.7
	HOSAINA	230*	WOLKITE	230	26.2	402	6.5
	SEBATA-1	230	WOLKITE	230*	-129.7	402	32.3
	WOLKITE	230*	G.GIBE NEW	230	-171.8	280	61.4
	SEBETA-2	400	GI GIBE-2	400*	-498.9	1341	37.2
14	ALABA	132*	HOSAINA	132	-21.2	89	23.8
	ALABA	132*	SHASHEMENE	132	104.3	89	117.2
	ALABA	132	W SODO-II	132*	-80.6	89	90.6
	HOSAINA	132 *	G.GIBE NEW	132	32.1	89	36
	ALABA	230*	HOSAINA	230	31.5	402	7.8
	HOSAINA	230*	WOLKITE	230	27.2	402	6.8
	GELAN	400	WOLAYTA	400*	-386.9	1973	19.6
	WOLAYTA	400*	GI GIBE-2	400	582.7	1973	29.5
	HOSAINA	230*	WOLKITE	230	27.2	402	6.8
	SEBATA-1	230	WOLKITE	230*	-130.9	402	32.6
	WOLKITE	230*	G.GIBE NEW	230	-174.8	280	62.4
	SEBETA-2	400	GI GIBE-2	400*	-509	1341	37.9
15	ALABA	132*	HOSAINA	132	-22.3	89	25
	ALABA	132*	SHASHEMENE	132	104.1	89	117
	ALABA	132	W SODO-II	132*	-77.6	89	87.2
	HOSAINA	132 *	G.GIBE NEW	132	33	89	37
	ALABA	230*	HOSAINA	230	32.3	402	8
	HOSAINA	230*	WOLKITE	230	28.3	402	7
	GELAN	400	WOLAYTA	400*	-373.3	1973	18.9
	WOLAYTA	400*	GI GIBE-2	400	599.9	1973	30.4
	HOSAINA	230*	WOLKITE	230	28.3	402	7
	SEBATA-1	230	WOLKITE	230*	-132.1	402	32.9
	WOLKITE	230*	G.GIBE NEW	230	-177.8	280	63.5
	SEBETA-2	400	GI GIBE-2	400*	-520.7	1341	38.8

16	ALABA	132*	HOSAINA	132	-23.3	89	26.2
	ALABA	132*	SHASHEMENE	132	103.9	89	116.8
	ALABA	132	W SODO-II	132*	-74.6	89	83.8
	HOSAINA	132 *	G.GIBE NEW	132	-33.9	89	38.1
	ALABA	230*	HOSAINA	230	33.2	402	8.2
	HOSAINA	230*	WOLKITE	230	29.4	402	7.3
	GELAN	400	WOLAYTA	400*	-359.8	1973	18.2
	WOLAYTA	400*	GI GIBE-2	400	617.1	1973	31.3
	HOSAINA	230*	WOLKITE	230	29.4	402	7.3
	SEBATA-1	230	WOLKITE	230*	-133.4	402	33.2
	WOLKITE	230*	G.GIBE NEW	230	-180.8	280	64.6
	SEBETA-2	400	GI GIBE-2	400*	-531	1341	39.5
17	ALABA	132*	HOSAINA	132	-24.4	89	27.4
	ALABA	132*	SHASHEMENE	132	103.7	89	116.5
	ALABA	132	W SODO-II	132*	-71.6	89	80.5
	HOSAINA	132 *	G.GIBE NEW	132	-34.9	89	39.2
	ALABA	230*	HOSAINA	230	34.1	402	8.5
	HOSAINA	230*	WOLKITE	230	30.7	402	7.6
	GELAN	400	WOLAYTA	400*	-346.3	1973	17.5
	WOLAYTA	400*	GI GIBE-2	400	634.4	1973	32.2
	HOSAINA	230*	WOLKITE	230	30.7	402	7.6
	SEBATA-1	230	WOLKITE	230*	-134.6	402	33.5
	WOLKITE	230*	G.GIBE NEW	230	-183.8	280	65.6
	SEBETA-2	400	GI GIBE-2	400*	-540.4	1341	40.2
18	ALABA	132*	HOSAINA	132	-25.4	89	28.6
	ALABA	132*	SHASHEMENE	132	103.5	89	116.3
	ALABA	132	W SODO-II	132*	-68.7	89	77.2
	HOSAINA	132 *	G.GIBE NEW	132	-35.8	89	40.3
	ALABA	230*	HOSAINA	230	35.1	402	8.7
	HOSAINA	230*	WOLKITE	230	32	402	8
	GELAN	400	WOLAYTA	400*	-332.8	1973	16.9
	WOLAYTA	400*	GI GIBE-2	400	651.6	1973	33
	HOSAINA	230*	WOLKITE	230	32	402	8
	SEBATA-1	230	WOLKITE	230*	-135.8	402	33.8
	WOLKITE	230*	G.GIBE NEW	230	-186.7	280	66.7
	SEBETA-2	400	GI GIBE-2	400*	-551.7	1341	41.1
19	ALABA	132*	HOSAINA	132	-26.5	89	29.7
	ALABA	132*	SHASHEMENE	132	103.3	89	116
	ALABA	132	W SODO-II	132*	65.8	89	73.9
	HOSAINA	132 *	G.GIBE NEW	132	-36.8	89	41.4

	ALABA	230*	HOSAINA	230	36.2	402	9
	HOSAINA	230*	WOLKITE	230	33.3	402	8.3
	GELAN	400	WOLAYTA	400*	-319.3	1973	16.2
	WOLAYTA	400*	GI GIBE-2	400	668.9	1973	33.9
	HOSAINA	230*	WOLKITE	230	33.3	402	8.3
	SEBATA-1	230	WOLKITE	230*	-137	402	34.1
	WOLKITE	230*	G.GIBE NEW	230	-189.7	280	67.8
	SEBETA-2	400	GI GIBE-2	400*	-560.6	1341	41.8
20	ALABA	132*	HOSAINA	132	-27.5	89	30.9
	ALABA	132*	SHASHEMENE	132	103.1	89	115.8
	ALABA	132	W SODO-II	132*	62.9	89	70.7
	HOSAINA	132 *	G.GIBE NEW	132	-37.8	89	42.5
	ALABA	230*	HOSAINA	230	37.4	402	9.3
	HOSAINA	230*	WOLKITE	230	34.8	402	8.6
	GELAN	400	WOLAYTA	400*	-305.9	1973	15.5
	WOLAYTA	400*	GI GIBE-2	400	686.2	1973	34.8
	HOSAINA	230*	WOLKITE	230	34.8	402	8.6
	SEBATA-1	230	WOLKITE	230*	-138.2	402	34.4
	WOLKITE	230*	G.GIBE NEW	230	-192.7	280	68.8
	SEBETA-2	400	GI GIBE-2	400*	-572.1	1341	42.6

Appendix 4 : Load Data

Bus Name	Type	Pload (MW)	Qload (Mvar)
WONJPULP 132.00	Industrial	0	0
DJIB-PK12 230.00	Interconnection	55.46	26.84
DJIB-PK12 230.00	Interconnection	0	0
SUDAN-GADARE230.00	Interconnection	94.64	45.8
SUDAN-GADARE230.00	Interconnection	94.64	45.8
SULULTA 66.000	Industrial	12.64	6.12
W SODO I 66.00	Industrial	1.71	0.1
MEKELE MB 45.000	Residential	0	0
ASSOSA 33.000	Residential	0.19	0.41
GHIMBI 15.000	Residential	3.83	0.81
MENDI 33.000	Residential	1.31	-0.3
ASSOSA 15.000	Residential	2.57	0.59
GHIMBI 33.000	Residential	3.62	0
ADDIS-E1 15.000	Residential	5.65	2.73
B.WRGENU 15.000	Residential	53.11	25.72
COTOBIE-15B1	Residential	24.67	11.94
D.BERHAN 33.000	Residential	6.02	2.91
D.BERHAN 15.000	Residential	2.67	1.29
FICHE 15.000	Residential	3.53	1.71
FICHE 33.000	Residential	0.92	0.44
SULULTA-15 15.000	Residential	23.16	6.34
ADDIS-EAST 2 15.0	Residential	38.26	3.62
COTOBIE-15B215.000	Residential	0	0
SULULTA-33 33.000	Residential	5.13	1.21
Bole Lemi 15.000	Industrial	3.42	0.51
CHANCHO 33.00	Residential	0	0
SHEGOLE 15.000	Residential	0	0
LEGETAFO 15.000	Residential	55.81	10.25
COTTEBEI 33	Residential	7.87	3.81
Ayat GIS 15.000	Industrial(Traction Station)	0.39	-0.35
BOLE ARABSA15	Residential	0	0
BOLE-LEMI MB33.000	Residential	0	0
A.TEFERI 15.000	Residential	4.81	2.52
ADIGALA 33.000	Residential	0.42	-0.87

ALEMAYA 15.000	Residential	3.81	1.85
ALEMAYA-33 33.000	Residential	3.31	1.6
ASEBE-33 33.000	Residential	0.91	0.6
BABILE 15.000	Residential	1.88	0.91
BEDESSA 15.000	Residential	2.01	0.4
CHELENKO 15.000	Residential	1.71	0.83
D.DAWA1- 15.000	Residential	20.94	7.05
D.DAWA-2 15.000	Residential	0	0
D.DAWA3 15.000	Residential	0	0
FIK 33.000	Residential	0	0
HARAR 15.000	Residential	4.43	2.14
HARAR3 33.000	Residential	0.41	0.2
HURSO 33.000	Residential	0	0
CHELENKO-33	Residential	0	0
HARAR3 15.000	Residential	9.03	2.2
HURSO 15.000	Residential	0.42	0.2
BEDESSA 33.000	Residential	0.6	0.1
DEGEHABUR 33.000	Residential	0	0
W SODO II	Residential	4.03	1.95
DIREDAWA III 33.000	Residential	5.24	2.53
AFDEM TS	Industrial(Traction Station)	2	0.97
GOTA TS	Industrial(Traction Station)	2	0.97
MIESO TS	Industrial(Traction Station)	2	0.97
LONNIS TS	Industrial(Traction Station)	2	0.97
ADIGALA TS	Industrial(Traction Station)	2	0.97
AYISHA TS	Industrial(Traction Station)	2	0.97
DAWANLE TS	Industrial(Traction Station)	2	0.97
ALISABIETH TS	Industrial(Traction Station)	2	0.97
HOL HOL TS	Industrial(Traction Station)	2	0.97
NIGAD TS	Industrial(Traction Station)	2	0.97
HURSO TS	Industrial(Traction Station)	2	0.97
MILO TS	Industrial(Traction Station)	2	0.97

DEMBI DO 15	Residential	2.48	1.2
GAMBELA1 15.000	Residential	3.52	1.71
GAMBELA II (New) 33.00	Residential	0.81	0.39
METU 33.000	Residential	0.68	0.33
METU 15.000	Residential	6.24	3.02
DEMBI DO 33	Residential	1.21	0.58
JIJIGA 15.000	Residential	10.69	5.17
JIJIGA 33	Residential	1.01	1.24
A-KETEMA 33.000	Residential	1.51	0.73
AKSTA 33.000	Residential	9.97	0.59
COMBOL-1 15.000	Residential	10.2	4.94
DESSIE 15.000	Residential	13.63	6.6
LALIBELA 15.000	Residential	3.11	1.51
SEKOTA 15.000	Residential	1.98	0.96
SHWA-RBT 15.000	Residential	3.43	0.1
WOLDIA 15.000	Residential	4.04	1.95
WOLDIA 33.000	Residential	1.78	0.86
SHWA-RBT 33.000	Residential	3.22	0
WOLDIYA 15	Residential	0	0
WOLDIYA 33	Residential	0	0
BAHIR DAR1 15.0	Residential	4.83	2.82
BAHIR DAR1 15.0	Residential	0	0
B.DAR2-1 15.000	Residential	15.09	7.31
BITCHENA 15.000	Residential	1.27	0.62
DABAT 15.000	Residential	2.97	1.44
DB-MRKOS 15.000	Residential	9.58	4.64
FNOT-SLM 15.000	Residential	1.29	0.63
GASHENA 33.000	Residential	3.47	-0.91
GONDER1 15.000	Residential	4	1.94
METEMA 33.000	Residential	1.92	0.93
MOTA 33.000	Residential	2.43	1.18
N-MEWCHA 33.000	Residential	4.51	0.49
PAWIE 15.000	Residential	2.38	1.15
WORETA	Residential	1.14	0.55
GONDAR2 15.000	Residential	12.83	6.21
PAWIE 33.000	Residential	2.38	1.15
WORETA 15.000	Residential	3.13	1.52
GONDER 15.000	Residential	3.63	1.75
DANGILA 33.000	Residential	2.51	1.21

DANGLA 15.000	Residential	1.55	0.75
BAHIRDAR 33.000	Residential	0.54	0.4
BICHENA 33.000	Residential	7.56	3.66
DEBRE MARKOS 33.000	Residential	0.44	0.21
FINOTE SELAM 33.000	Residential	0	0
DABAT 33.000	Residential	0.45	0.22
ADDIS ALEM 15.000	Residential	7.44	3.6
ADDIS NORTH 15.000	Residential	46.61	15.46
Derba Cement 33.000	Industrial	2.03	0.08
FINCHAA 15.000	Industrial	1.86	0.9
FNCH-SG1 15.000	Industrial	0	0
FNCH-SG2 15.000	Industrial	0.4	0.19
GEFERSA 15.000	Residential	46.36	22.44
GHEDO 15.000	Residential	0.6	0.29
GINCHI 15 15.000	Residential	2.1	1.02
HORMAT 15.000	Residential	9	4.36
MUGER 15.000	Industrial	11.92	5.77
DERBA CEMENT 6.6 00	Industrial	27.18	15.5
MUGER 33.000	Industrial	6.57	3.18
GEBRE GURACHA 33	Residential	6.54	3.17
HABESHA CEM 6.6	Industrial	15.1	7.31
TORHAYILOCH 15.000	Industrial(Traction Station)	5.29	2.19
MINILIK GIS 15.000	Industrial(Traction Station)	6.04	2.92
HORMAT 33.000	Residential	0.46	0.22
DANGOTE 11.500	Industrial	42.16	20.41
GHEDO	Residential	0.1	0.05
FINCHAA 33.000	Industrial	0	0
ADIGRAT 15.000	Residential	11.5	1.82
ADWA 15.000	Residential	19.49	9.43
ALAMATA1 15.000	Residential	8.28	4.01
HUMERA 33.000	Residential	8	3.87
MAYCHEW 15.000	Residential	4.51	2.18
MEKELE 15.000	Residential	25.17	12.18
MESOBO 6.3000	Industrial	16.11	6.04
SHIRE ENDASI15.000	Residential	7.84	3.8
TEKEZE 33.00	Residential	1.95	0.94
TEKEZE 6	Industrial	0.32	0.2
WUKRO 15.000	Residential	6.2	3

SHIRE ENDASI33.000	Residential	5.32	2.57
MEHONI33 33.000	Residential	0	0
MEHONI 15.000	Residential	4.02	1.58
HUMERA 15.000	Residential	2.3	1.11
ADWA 33.000	Residential	0.48	0.23
ADIGRAT 33.000	Residential	0.94	0.46
WUKRO 33.000	Residential	0	0
MEKELE 33.000	Residential	1.61	0.78
ALAMATA 33.000	Residential	0	0
MESOBO 6.000	Industrial	14.09	5.03
ABIADI MB 15.000	Residential	0	0
ABIADI MB 33.000	Residential	0	0
MEKELE MB 15.000	Residential	0	0
AMIBARA 15.000	Residential	1.41	0.68
AWASH-7D	Residential	0	0
AWSH-7KL 15.000	Residential	2.87	1.39
DITCHETO 33.000	Residential	0	0
SEMERA 33.000	Residential	5.63	2.72
AMIBARA 33.000	Residential	1	0.48
SIRBA TS	Industrial (Traction Station)	2	0.97
AWASH TS	Industrial (Traction Station)	2	0.97
ADAMI TULU 15.000	Residential	0.71	0.34
ASSELA 15.000	Residential	4.23	2.05
AWASH II 15.000	Power plant auxiliary	15.78	7.64
AWASH-2 15.000	Power plant auxiliary	5.03	2.44
AWASH-3 15.000	Power plant auxiliary	2.59	1.25
BALEROBE 15.000	Residential	6.04	1.21
ELALA-GEDA 15.000	Residential	7.65	3.71
GOBESSA 33.000	Residential	5.08	2.46
KOKA 15.000	Residential	5.92	2.87
KOKA2 15 15.000	Residential	2.59	1.25
M.WK-YUG 15.000	Residential	0.67	0.33
METAHARA 15.000	Residential	3.39	1.64
MODJO 15.000	Residential	0	0
NAZERET-II 15.000	Residential	18.12	8.77
NURAERA 15.000	Residential	3.88	1.88
WONJIPUL 15.000	Industrial	4.65	2.25
NURAERA 33.000	Residential	2.01	0.97
BALE ROBE 33.000	Residential	1.81	0.88

ADAMITULU 33.000	Residential	4.14	2
ASELA 33.0000	Residential	0.25	0.12
MODJO II(Mobile) 15.000	Residential	6.92	3.35
METEHARA TS	Industrial (Traction Station)	2	0.97
MODJO TS	Industrial (Traction Station)	2	0.97
MELKA JIL TS	Industrial (Traction Station)	2	0.97
NAZRETH2 MB 15.000	Residential	0	0
WON SUG 11.000	Industrial	0.12	0.06
MODJO 15.000	Residential	6.21	3.01
ADDIS CENTER 15.000	Residential	64.43	31.19
ADDIS SOUTH	Residential	34.63	8.46
AKAKI 15.000	Residential	3.83	1.85
AKAKI-SP 15.000	Industrial	20.34	9.84
DEBRE-ZEIT 1 15.000	Residential	4.5	2.18
DEBRE-ZEIT2 15.000	Residential	35.48	21.96
DUKEM 15.000	Industrial	4.33	2.1
KALITI1 15.000	Residential	8.1	3.92
KALITI2- 15.000	Residential	26.68	5.44
KALTI-NORTH 15.000	Residential	52.57	25.33
MEKANISA 15.000	Residential	45.4	21.98
NEFASILK 15.000	Residential	16.67	8.07
YESU 15.000	Industrial	31.49	15.24
GELAN 15.000	Residential	25.71	12.45
KALITI GIS 15.000	Industrial (Traction Station)	0.22	0.11
KNORIA TEX 11.000	Industrial	8.05	3.9
EIZ 33.000	Industrial	22.58	10.93
INDODE TS	Industrial (Traction Station)	2	0.97
ALABA 15.000	Residential	6.44	3.12
ARBA MINCH 15.000	Residential	8.36	4.04
AWASA 15.000	Residential	24.69	11.95
BOCULUGUMA 33.000	Residential	3.87	1.87
DILLA 33.000	Residential	1.21	0.58
DILLA-1 15.000	Residential	7.05	3.22
HAGER MARIAM 33.000	Residential	7.15	3.46
HOSAINA 15.000	Residential	5.84	2.83

NEG-BORE 33.000	Residential	1.51	0.73
SHASHEMENE-1 15.000	Residential	18.83	4.63
SAWLA 33.000	Residential	2.32	3.52
SHAKISO 15.000	Residential	5.6	2.01
W.SODO 15.000	Residential	6.59	3.19
YADOT 33.000	Residential	0.28	0.14
YIRGALEM 15.000	Residential	0	0
NEG-BORE 15.000	Residential	1.97	0.96
YIRGALEM 15.000	Residential	5.44	1.01
YIRGALEM 33.000	Residential	2.01	0.97
KEY AFER 33.00	Residential	1.55	0.75
SHAKISO 33.00	Residential	3	1.45
WOLAYTA SODO 33.000	Residential	1.29	0.62
SHASHEMENE 33.000	Residential	1.41	1.61
HOSSANA 33.0000	Residential	0.34	0.17
AWASA INDUST 33	Industrial	0	0
A.MINCH 33.000	Industrial	2.72	1.32
AWASA MOBILE 33	Industrial	10.15	4.91
AWASA MOBILE 15	Industrial	8.05	3.9
ADDIS-W2 15.00	Residential	15.47	7.49
BUTAJIRA 15.000	Residential	6.17	2.99
GEDJA 15.000	Residential	2.62	1.21
SEBETA1	Residential	84.46	40.91
WOLISO 15.000	Residential	7.02	3.4
WOLKITE 33.000	Residential	5.7	2.76
BUTAJIRA33 33.000	Residential	3.16	1.53
SABATA-II 33.000	Residential	11.68	5.65
WOLISO-33 33.000	Residential	2.38	1.15
WOLKITE 15.000	Residential	4.71	2.28
BLACK-LION	Residential	0	0
HOLETA-33 33.000	Residential	0	0
SEBETA TS	Industrial (Traction Station)	2	0.97
ABA 33	Residential	1.71	0.83
AGARO 15.000	Residential	1.31	0.63
B.BEDELE 15.000	Residential	3.71	1.8
BONGA 15.000	Residential	2.14	1.03
G.GIBE 15.000	Residential	2.01	0.97
GIDA-AYANA 33.000	Residential	4.1	1.98

JIMMA 15.000	Residential	0	0
MIZAN 33.000	Residential	0.97	0.47
NEKEMPTE 15.000	Residential	7.55	3.65
TEPI 15.000	Residential	2.69	0.9
BONGA 33.000	Residential	0	0
TEPI 33.000	Residential	0	0
JIMMA OLD 15.000	Residential	13.39	6.48
GIDAMI 33	Residential	0	0
AGARO 33.000	Residential	0.41	0.2
BEDELE 33.000	Residential	2.01	0.97
JIMMA 33.000	Residential	4.03	1.95
MIZAN 15.000	Residential	2.97	1.44
WULNCH TS	Industrial (Traction Station)	2	0.97
D.DAWA I	Industrial	11.58	5.6
GRAN RENAIS 15.00	Industrial	18.12	8.77
GONDAR2 33.000	Residential	1.5	0.73
AWASA 33.000	Residential	2.21	1.07
YADOT 15.00	Residential	0.57	0.28
RAMO 33.00	Residential	0.91	0.44
GODE 33.00	Residential	1.01	0.49

Appendix 5 : Transmission Line Data

From Bus Name	To Bus Name	Line R (ohms)	Line X (ohms)	Charging B (uF)	MVA Rate
ASSOSA 132.00	MENDI 132.00	18.73036	35.44358	0.72253	63
GHIMBI 132.00	MENDI 132.00	27.71287	55.44822	1.117848	91
GHIMBI 132.00	NEKEMPTE 132.00	18.93797	35.6441	0.72398	89
MENDI 132.00	GIDAMI 132.00	33.9564	63.97875	1.28986	115
ADD EAST-II 132.00	COTEBEI-I 132.00	1.163728	2.328404	0.04695	91
ADD EAST-II 132.00	ADDIS-NORTH 132.00	2.118114	4.237953	0.085496	91
B.WGN-TP 132.00	COTEBEI-I 132.00	0.638412	1.039615	0.020826	82
B.WGN-TP 132.00	WERGENU 132.00	1.172592	1.909496	0.038364	82
B.WGN-TP 132.00	KALITI1 132.00	4.690399	7.638539	0.153008	82
COTEBEI-I 132.00	ADDIS-E1 132.00	1.278845	2.558647	0.051593	100
COTEBEI-I 132.00	ADDIS-E1 132.00	1.278845	2.558647	0.051593	100
COTEBEI-I 132.00	AYAT 132.00	1.824031	2.970335	0.05972	82
COTEBEI-I 132.00	BOLE-LEMI TP132.00	1.823658	2.97005	0.059671	82
DEBRE BERHAN132.00	LEGETAFO 132.00	26.05759	42.43336	0.853138	82
DEBRE BERHAN132.00	SHOWA-ROBIT 132.00	14.98051	24.39482	0.490509	82
SULULTA-132 132.00	DANGOTE CEM 132.00	12.9112	24.3166	0.490084	115
LEGETAFO 132.00	AYAT 132.00	1.042304	1.697446	0.008531	82
SHEGOLE 132.00	GEFERSA 132.00	1.17259	1.90958	0.038399	82
SHEGOLE 132.00	MINILIK TS 132.00	0.680103	1.107558	0.022271	82
BOLE-LEMI TP132.00	BOLE-LEMI MB132.00	1.042204	1.69744	0.034099	82
BOLE-LEMI TP132.00	KLT.N-TP 132.00	3.035542	4.943751	0.099325	82
ASEBETEFIR 132.00	AFDEM TS 132.00	12.71412	23.93677	0.48269	115
ASEBETEFIR 132.00	AWASH-7KL 132.00	52.3759	85.2912	1.71503	115
ASEBETEFIR 132.00	MIESSO TS 132.00	4.34903	8.187886	0.165118	402
DIRE DAWA 1 132.00	DIRE DAWA 3 132.00	0.956836	1.55815	0.031239	82
DIRE DAWA 1 132.00	NATIONAL CEM132.00	0.782155	1.27369	0.025536	82
DIRE DAWA 3 132.00	D.DAWA-2 132.00	3.238703	5.274036	0.105957	82
DIRE DAWA 3 132.00	D.DAW-DS 132.00	0.814954	1.53549	0.030957	115
FIK 132.00	HARAR-3 132.00	32.8073	65.64127	1.323368	91
HARAR-3 132.00	D.DAWA-2 132.00	9.960569	18.76722	0.378358	115
HARAR-3 132.00	JIJIGA I 132.00	21.5054	40.51986	0.816937	115
HURSO 132.00	GOTA 132.00	8.88833	16.73399	0.337444	115
AFDEM TS 132.00	GOTA 132.00	7.506608	14.13263	0.284988	115
ALEM KETEMA 132.00	AKISTA 132.00	32.01747	64.06108	1.291581	91
AKISTA 132.00	COMBOLCHA-I 132.00	22.59666	45.21162	0.911414	91
COMBOLCHA-I 132.00	COMBOLCHA-II132.00	1.492231	2.985672	0.060103	91
SHOWA-ROBIT 132.00	KEMISSIE 132.00	18.13424	33.93608	0.696858	115
COMBOLCHA-II132.00	KEMISSIE 132.00	7.159345	13.39787	0.275115	115
B.DAR2 132.00	T-ABAY2 132.00	6.182332	12.28486	0.252288	91
B.DAR2 132.00	T-ABAY2 132.00	6.182332	12.28486	0.252288	91
ADDIS-NORTH 132.00	MINILIK TS 132.00	1.042304	1.697272	0.034144	82
DERBA-CEMENT132.00	DERBA-TAP 132.00	10.54156	21.09175	0.42529	91
GEFERSA 132.00	MINILIK TS 132.00	1.85269	3.01714	0.06067	82

GEFERSA 132.00	HABESHA TP 132.00	5.541848	11.08821	0.223518	91
GEFERSA 132.00	KALITI1 132.00	6.44925	10.50225	0.211184	82
GEFERSA 132.00	SEBATA -I 132.00	2.809098	4.574323	0.09189	82
GHEDO 132.00	HORMAT 132.00	7.63673	14.37353	0.29193	89
GHEDO 132.00	NEKEMPTE 132.00	26.03773	49.00692	0.995449	89
MUGER 132.00	DANGOTE TP 132.00	1.279038	2.559121	0.051578	91
DERBA-TAP 132.00	HABESHA TP 132.00	7.675058	15.35637	0.309556	91
DERBA-TAP 132.00	DANGOTE TP 132.00	2.131681	4.26525	0.085963	91
HABESHA CEM 132.00	HABESHA TP 132.00	0.053293	0.10663	0.002149	91
HABESHA CEM 132.00	HOLETA-132 132.00	2.984354	5.97135	0.120356	91
ADIGRAT 132.00	WUKRO-TP 132.00	12.70542	23.91357	0.485759	89
ADWA 132.00	ABIADI MB TP132.00	8.183355	15.40231	0.31286	89
MEKELE 132.00	MESOBO 132.00	1.13686	2.139754	0.043479	89
MEKELE 132.00	WUKRO-TP 132.00	6.973939	13.12604	0.26672	89
MEKELE 132.00	ABIADI MB TP132.00	18.04535	33.96407	0.689897	89
WUKRO 132.00	WUKRO-TP 132.00	0.262421	0.493918	0.010048	89
ABIADI MB TP132.00	ABIADI MB 132.00	2.246755	4.228728	0.085898	89
AWASH-7KL 132.00	SIRBA OUNKUR132.00	7.822506	12.73852	0.256146	115
AWASH-7KL 132.00	AWASH TS 132.00	0.625383	1.018403	0.020478	115
AWASH-7KL 132.00	METAHARA 132.00	6.517304	10.61301	0.213238	82
SIRBA OUNKUR132.00	MIESSO TS 132.00	10.97027	17.86448	0.359218	115
AWASH TS 132.00	METEHARA-TS 132.00	7.598409	12.3736	0.248807	115
ADAMI TULU 132.00	ASSELA 132.00	13.28	21.62562	0.43479	82
ADAMI TULU 132.00	SHASHEMENE 132.00	20.02	32.60152	0.655473	82
ADAMI TULU 132.00	BUTAJIRA 132.00	9.972383	19.95292	0.402272	91
ASSELA 132.00	WON SUG TP 132.00	9.432432	15.36015	0.308817	82
AWASH2 132.00	AWASH-3 132.00	0.378273	0.611914	0.012605	82
AWASH2 132.00	KOKA 132.00	6.605596	10.75685	0.216299	82
AWASH2 132.00	WONJI-TP 132.00	4.429791	7.213693	0.145052	82
AWASH2 132.00	WON SUG TP 132.00	3.909057	6.365664	0.127982	82
AWASH2 132.00	WULENCHTI TS132.00	7.257053	11.81772	0.23763	82
ELALA-GEDA 132.00	ELALA-TP 132.00	1.276822	2.079223	0.041835	82
ELALA-TP 132.00	KOKA 132.00	6.199111	10.09487	0.202963	82
ELALA-TP 132.00	GELAN 132.00	9.966529	18.78307	0.377792	115
KOKA 132.00	NAZRETH2 132.00	2.992712	4.873458	0.097919	82
KOKA 132.00	WONJI-TP 132.00	1.917843	3.123095	0.062844	82
KOKA 132.00	MOJO II MOB 132.00	4.542101	8.566455	0.172723	115
KOKA 132.00	DBZT2-TP 132.00	10.0452	16.35804	0.328833	82
METAHARA 132.00	NAZRETH2 132.00	23.98368	39.05587	0.784717	82
METAHARA 132.00	MELKAJILO TS132.00	11.50184	18.73013	0.376624	82
NAZRETH2 132.00	MODJO TS 132.00	3.882589	6.322585	0.127134	82
NAZRETH2 132.00	ADAM-I WIND 132.00	1.251323	2.037698	0.040942	82
WONJI-TP 132.00	WONJIPULP 132.00	0.148528	0.241869	0.004932	82
M WAK-YUGO 132.00	SHASHEMENE 132.00	26.77912	50.40241	1.023765	89
M WAK-YUGO 132.00	YADOT 132.00	21.31757	42.65256	0.859897	91
METEHARA-TS 132.00	MELKAJILO TS132.00	11.74939	19.13325	0.38473	115

MODJO TS 132.00	WULENCHTI TS132.00	10.40742	16.94792	0.340788	82
MOJO II MOB 132.00	KNORIA TEX 132.00	3.405589	6.42298	0.129505	115
WON SUG TP 132.00	WON SUG 132.00	1.302901	2.121682	0.042656	82
ADDIS CENTER132.00	KALITI1 132.00	3.73926	6.089183	0.122399	82
GOFA 132.00	MEKANISA 132.00	0.426351	0.85305	0.017172	91
DB-ZEIT2 132.00	DBZT2-TP 132.00	0.013029	0.021217	0.000365	82
DBZT2-TP 132.00	GELAN 132.00	6.115827	11.51726	0.232192	115
KALITI1 132.00	KALITI TWO 132.00	1.818822	2.961854	0.059555	82
KALITI1 132.00	KLT.N-TP 132.00	0.390864	0.636499	0.012788	82
KALITI1 132.00	MEKANISA 132.00	4.210911	6.857215	0.137927	82
KALITI1 132.00	YESU 132.00	2.077766	3.918666	0.079011	115
KALITI1 132.00	GELAN 132.00	2.26512	4.18176	0.08586	115
KALITI1 132.00	INDODE TS 132.00	1.060076	1.995797	0.040247	115
KALITI1 132.00	KALITI GIS 132.00	0.781815	1.272997	0.025594	82
KALTI-NORTH 132.00	KLT.N-TP 132.00	0.114653	0.186707	0.003836	82
KALITI TWO 132.00	NEFASILK 132.00	0.099317	0.620294	0.527776	100
KALITI TWO 132.00	NEFASILK 132.00	0.099317	0.620294	0.527776	100
KALITI TWO 132.00	KALITI GIS 132.00	1.042304	1.697446	0.034126	100
MEKANISA 132.00	ADDIS-EFW 132.00	1.585584	2.979504	0.060103	115
YESU 132.00	GELAN 132.00	1.812096	3.415104	0.068872	115
GELAN 132.00	INDODE TS 132.00	7.955101	14.99231	0.301547	115
GELAN 132.00	KNORIA TEX 132.00	4.995722	9.421928	0.189973	115
DANGOTE CEM 132.00	DANGOTE TP 132.00	0.426346	0.85304	0.017193	91
ARBA MINCH 132.00	W SODO-I 132.00	24.51888	46.14833	0.937355	89
ALABA 132.00	HOSAINA 132.00	8.897165	16.74586	0.340159	89
ALABA 132.00	SHASHEMENE 132.00	14.20626	26.73835	0.543122	89
ALABA 132.00	W SODO-II 132.00	13.88722	26.13792	0.530882	89
ALABA 132.00	AWASA MOBILE132.00	17.97425	33.83009	0.687191	82
AWASA 132.00	SHASHEMENE 132.00	5.62844	9.1656	0.184329	82
AWASA 132.00	YIRGALEM 132.00	9.143609	14.88984	0.29942	82
BOCULUGUMA 132.00	HAGER MARIAM132.00	51.31932	96.69325	1.949391	115
DILLA 132.00	HAGER MARIAM132.00	19.18591	38.38734	0.773853	91
DILLA 132.00	YIRGALEM 132.00	8.527045	17.06101	0.343995	91
HOSAINA 132.00	G.GIBE NEW 132.00	15.86663	29.86352	0.606696	89
SAWLA 132.00	KEY AFER 132.00	25.12774	47.34428	0.954496	115
SAWLA 132.00	W SODO-I 132.00	26.43377	52.88916	1.066331	91
SHAKISO 132.00	YIRGALEM 132.00	34.71139	56.52538	1.136299	82
W SODO-II 132.00	W SODO-I 132.00	3.370138	6.343124	0.12884	89
SEBATA -I 132.00	ADDIS WEST 2132.00	0.231739	1.449677	1.231295	100
SEBATA -I 132.00	ADDIS WEST 2132.00	0.231739	1.449677	1.231295	100
SEBATA -I 132.00	ADDIS-EFW 132.00	1.563475	2.546001	0.051227	82
ADDIS WEST 2132.00	BLACK-LION 132.00	0.165528	1.034986	0.879444	100
ADDIS WEST 2132.00	BLACK-LION 132.00	0.198634	1.242331	1.05537	100
ABA 132.00	JIMMA NEW 132.00	10.01927	20.04666	0.404099	91
AGARO 132.00	B.BEDELE 132.00	18.28858	34.42199	0.699134	89
B.BEDELE 132.00	NEKEMPTE 132.00	24.72849	49.47684	0.997459	91

BONGA 132.00	MIZAN 132.00	18.8235	37.66215	0.759238	91
BONGA 132.00	JIMMA OLD 132.00	21.83245	43.38297	0.890771	91
G.GIBE NEW 132.00	GI GIBE-1 132.00	0.584227	1.099454	0.022288	89
G.GIBE NEW 132.00	JIMMA OLD 132.00	16.02389	30.15938	0.612542	89
GIDA-AYANA 132.00	NEKEMPTE 132.00	19.951	39.91804	0.804726	91
JIMMA NEW 132.00	JIMMA OLD 132.00	1.635245	3.249375	0.066719	91
LEGETAFO 230.00	SULULTA 230.00	2.3805	6.6654	0.243456	402
LEGETAFO 230.00	SULULTA 230.00	2.3805	6.6654	0.243456	402
LEGETAFO 230.00	COTOBEI-I 230.00	0.8993	2.5392	0.092785	402
LEGETAFO 230.00	COTOBEI-I 230.00	0.8993	2.5392	0.092785	402
LEGETAFO 230.00	BOLEARABSTP 230.00	0.39731	1.1109	0.040579	402
LEGETAFO 230.00	COMBOL-II 230.00	30.59911	93.54466	3.216675	318
SULULTA 230.00	CHANCHO230 230.00	1.6928	4.761	0.173897	402
SULULTA 230.00	CHANCHO230 230.00	1.6928	4.761	0.173897	402
SULULTA 230.00	SHEGOLE 230.00	0.8993	2.5921	0.089716	402
SULULTA 230.00	GEFERSA 230.00	1.789242	5.309838	0.193994	318
SHEGOLE 230.00	GEFERSA 230.00	1.0051	2.8566	0.0979	402
BOLEARABSTP 230.00	BOLE ARABSE 230.00	0.022703	0.06348	0.002319	402
BOLEARABSTP 230.00	KALITI1 230.00	4.019443	11.23534	0.410442	402
ADIGALA 230.00	DJIB-PK12 230.00	16.69982	48.07812	1.653232	402
ADIGALA 230.00	HURSO 230.00	14.83679	42.71439	1.468799	402
ADIGALA 230.00	ADIGALA-TS 230.00	0.9522	2.7508	0.099705	402
ADIGALA 230.00	MILO TS 230.00	13.59096	39.12768	1.345464	402
DIRE DAWA3 230.00	HURSO 230.00	19.88763	5.65452	0.202601	255
DIRE DAWA3 230.00	HURSO 230.00	19.88763	5.65452	0.202601	255
DIRE DAWA3 230.00	AWSH-7KL 230.00	18.82884	83.8811	1.835197	353
DJIB-PK12 230.00	HURSO 230.00	32.05215	92.27666	3.173053	402
DJIB-PK12 230.00	NIGAD TS 230.00	0.215013	0.621149	0.022514	402
HURSO 230.00	HURSO TS 230.00	0.136187	0.393428	0.01426	402
HURSO 230.00	KOKA 230.00	39.96912	111.719	4.081232	402
HURSO 230.00	KOKA 230.00	39.9689	111.7188	4.081234	402
LONNIS TS 230.00	HURSO TS 230.00	24.2282	69.7751	2.398636	402
LONNIS TS 230.00	MILO TS 230.00	4.077288	11.7383	0.403639	402
ADIGALA-TS 230.00	AYISHA TS 230.00	0.9522	2.7508	0.099705	402
AYISHA TS 230.00	DAWALE TS 230.00	0.9522	2.7508	0.099705	402
DAWALE TS 230.00	ALISABIEH TS230.00	0.324567	0.937638	0.033985	402
ALISABIEH TS230.00	HOL HOL TS 230.00	0.649134	1.875276	0.067971	402
HOL HOL TS 230.00	NIGAD TS 230.00	0.602036	1.739215	0.063039	402
GAMBELA2 230.00	METU 230.00	15.85612	45.64896	1.569708	402
GAMBELA2 230.00	METU 230.00	15.85612	45.64896	1.569708	402
METU 230.00	BEDELLE 230.00	9.651607	29.50587	1.01462	318
METU 230.00	BEDELLE 230.00	9.651607	29.50587	1.01462	318
COMBOL-II 230.00	WOLDIYA MOB 230.00	11.37147	33.74656	1.232812	318
COMBOL-II 230.00	SEMERA 230.00	18.13185	55.43073	1.906068	318
WOLDIYA MOB 230.00	ALAMATA 230.00	6.681346	19.82791	0.724343	318
BAHIR DAR2 230.00	GONDAR 2 230.00	15.51295	44.66098	1.535735	402

BAHIR DAR2 230.00	GONDAR 2 230.00	15.51293	44.66083	1.535734	402
BAHIR DAR2 230.00	MOTA 230.00	6.761043	35.1411	0.722425	280
BAHIR DAR2 230.00	NIFAS MEW TP230.00	14.54813	44.47514	1.529331	318
DEBRE-MARKOS230.00	MOTA 230.00	9.103719	47.31773	0.972741	280
DEBRE-MARKOS230.00	FINCHA 230.00	7.750749	40.28526	0.828147	280
GASHENA 230.00	GASHENA-TAP 230.00	0.106658	0.326064	0.011192	318
GASHENA-TAP 230.00	NIFAS MEW TP230.00	10.9111	33.35636	1.146999	318
GASHENA-TAP 230.00	ALAMATA 230.00	10.9111	33.35636	1.146999	318
GONDAR 2 230.00	METEMA 230.00	17.64643	52.3682	1.913049	318
GONDAR 2 230.00	METEMA 230.00	18.68757	53.80057	1.850013	402
METEMA 230.00	SUDAN-GADARF230.00	21.54683	60.306	2.202935	402
METEMA 230.00	SUDAN-GADARF230.00	21.54683	60.306	2.202935	402
NIFAS MEW TP230.00	N.MEWCHA 230.00	0.106658	0.326064	0.011192	318
FINCHA 230.00	FINCHA-II 230.00	0.88526	2.706332	0.093086	318
FINCHA 230.00	GHEDO 230.00	5.311901	28.48771	0.583909	284
FINCHA-II 230.00	GHEDO 230.00	7.436735	22.73483	0.781755	318
FINCHA-II 230.00	NESHE 230.00	3.119428	9.536388	0.327937	318
GEFERSA 230.00	GHEDO 230.00	10.83715	56.32739	1.15795	280
GEFERSA 230.00	GHEDO 230.00	15.10189	42.21194	1.542057	402
GEFERSA 230.00	GHEDO 230.00	15.10189	42.21194	1.542057	402
GEFERSA 230.00	TORHAYILOCH 230.00	7.561173	14.24421	0.031089	402
GHEDO 230.00	G.GIBE NEW 230.00	11.16153	54.32142	1.134844	274
TORHAYILOCH 230.00	SEBATA-1 230.00	5.016349	9.453442	0.020645	402
ALAMATA 230.00	MEHONI 230.00	0	0.0529	0.481151	318
ALAMATA 230.00	ASHEGODA WF 230.00	14.0185	40.3098	1.386844	402
ENDASILASIE 230.00	HUMERA 230.00	24.56359	72.89567	2.662972	318
ENDASILASIE 230.00	TEKEZE 230.00	17.05734	50.62006	1.849206	318
ENDASILASIE 230.00	WELKAYT 230.00	18.16768	50.78128	1.855106	402
HUMERA 230.00	WELKAYT 230.00	18.05413	50.46389	1.843512	402
MEKELE 230.00	TEKEZE 230.00	11.22956	33.3252	1.2174	318
MEKELE 230.00	TEKEZE 230.00	11.22956	33.3252	1.2174	318
MEKELE 230.00	MEHONI 230.00	11.09928	31.95427	1.098795	402
MEKELE 230.00	ASHEGODA WF 230.00	2.1689	6.1893	0.213009	402
AWSH-7KL 230.00	KOKA 230.00	11.87779	52.91466	1.157696	353
DITCHETO 230.00	SEMERA 230.00	5.866187	17.93352	0.616643	318
KOKA 230.00	MELKA-WAKNA 230.00	15.70564	67.60673	1.454117	257
KOKA 230.00	MELKA-WAKNA 230.00	15.70564	67.60673	1.454117	257
KOKA 230.00	ADAMA II WF230.00	1.1638	3.4385	0.117757	402
KOKA 230.00	GELAN 230.00	5.828011	23.51746	0.505826	331
KOKA 230.00	EIZ TAP 1 230.00	2.842883	13.50283	0.295445	274
MELKA-WAKNA 230.00	M WAK-YUGO 230.00	0.479235	2.062941	0.044371	257
MELKA-WAKNA 230.00	RAMO 230.00	26.61557	76.62512	2.634866	402
KALITI1 230.00	GELAN 230.00	0.8563	4.067184	0.088991	331
KALITI1 230.00	GELAN 230.00	0.8563	4.067184	0.088991	331
KALITI1 230.00	SEBATA-1 230.00	1.224333	5.958656	0.124496	274
GELAN 230.00	EIZ TAP 1 230.00	6.543873	26.40557	0.567946	331

RAMO 230.00	GODE 230.00	33.60533	93.93172	3.431448	402
ALABA 230.00	HOSAINA 230.00	4.462366	12.84692	0.441761	402
HOSAINA 230.00	WOLKITE 230.00	10.11394	29.11751	1.001249	402
SEBATA-1 230.00	SEBETA-2 230.00	1.227857	6.228869	0.134063	280
SEBATA-1 230.00	SEBETA-2 230.00	1.227857	6.228869	0.134063	280
SEBATA-1 230.00	WOLKITE 230.00	16.10541	46.36632	1.594378	402
SEBETA-2 230.00	SEBETA TS 230.00	0.114264	0.580842	0.012498	280
SEBETA-2 230.00	SEBETA TS 230.00	0.114443	0.580597	0.012496	280
WOLKITE 230.00	G.GIBE NEW 230.00	5.702038	29.63707	0.609241	280
BEDELLE 230.00	AGARO 230.00	9.254161	25.86671	0.944945	402
BEDELLE 230.00	AGARO 230.00	9.254161	25.86671	0.944945	402
GI GIBE-1 230.00	G.GIBE NEW 230.00	0.43074	2.045881	0.044768	274
GI GIBE-1 230.00	G.GIBE NEW 230.00	0.43074	2.045881	0.044768	274
G.GIBE NEW 230.00	JIMMA NEW 230.00	7.448749	20.82032	0.760593	402
G.GIBE NEW 230.00	JIMMA NEW 230.00	7.44875	20.82032	0.760593	402
JIMMA NEW 230.00	AGARO 230.00	4.394307	12.28272	0.448704	402
JIMMA NEW 230.00	AGARO 230.00	4.394307	12.28272	0.448704	402
SULULTA 400.00	GEBRE-GURCHA400.00	3.2	43.36	1.488696	1341
SULULTA 400.00	DEBRE MARKOS400.00	5.336319	70.976	2.440721	1341
SULULTA 400.00	HOLETA-400 400.00	0.96	8	0.439765	1973
SULULTA 400.00	HOLETA-400 400.00	0.96	8	0.439765	1973
GELAN 400.00	WOLAYTA 400 400.00	8.8	69.12	3.787669	1973
GELAN 400.00	WOLAYTA 400 400.00	8.8	69.12	3.787669	1973
GELAN 400.00	SEBETA-2 400.00	1.12	9.12	0.439228	1973
GELAN 400.00	HOLETA-400 400.00	1.6	12.64	0.694314	1973
GELAN 400.00	HOLETA-400 400.00	1.6	12.64	0.694314	1973
GEBRE-GURCHA400.00	DEBRE MARKOS400.00	2.24	28.8	0.990541	1341
BAHIRDAR-II 400.00	BELES 400.00	1.532856	19.45408	0.750276	1341
BAHIRDAR-II 400.00	BELES 400.00	1.532856	19.45408	0.750276	1341
BAHIRDAR-II 400.00	DEBRE MARKOS400.00	4.795008	63.77632	2.193135	1341
BELES 400.00	GRAN RENAIS 400.00	7.120658	73.64551	2.890549	543
WOLAYTA 400 400.00	GI GIBE-2 400.00	4	33.12	1.583453	1973
WOLAYTA 400 400.00	G-GIBE3 400.00	1.6	12.96	0.709294	1973
WOLAYTA 400 400.00	G-GIBE3 400.00	1.6	12.96	0.709294	1973
WOLAYTA 400 400.00	G-GIBE3 400.00	1.76	13.28	0.723479	1973
SEBETA-2 400.00	HOLETA-400 400.00	0.45094	5.40998	0.20645	1205
SEBETA-2 400.00	HOLETA-400 400.00	0.45094	5.40998	0.20645	1205
SEBETA-2 400.00	GI GIBE-2 400.00	4.541856	60.40928	2.07735	1341
GI GIBE-2 400.00	G.GIBE NEW 400.00	0.690182	9.179791	0.315684	1341
FITCHE 66.000	GEFERSA 66.000	59.21808	40.0756	0.831581	24
ALEMAYA2 66.000	CHELENKO 66.000	25.00749	20.86842	0.43479	27
ALEMAYA2 66.000	HARAR3 66.000	9.537201	7.95863	0.165878	27
ASEBE-TEFERI66.000	BEDDESA 66.000	14.80456	10.01889	0.20753	24
HARAR1 66.000	HARAR3 66.000	1.727199	1.16887	0.024212	24
DEMBI DOLO 66.000	GAMBELA1 66.000	39.47887	26.71705	0.554631	24
GAMBELA1 66.000	GAMBELA2 66.000	9.252842	6.261794	0.130072	24

GAMBELA1 66.000	METU 66.000	90.06117	60.94828	1.264909	24
METU 66.000	SOR 66.000	14.80456	10.01889	0.20753	24
COMB0LCHA-1 66.000	DESSIE 66.000	7.827906	5.297506	0.109611	24
COMB0LCHA-1 66.000	DESSIE 66.000	7.827906	5.297506	0.109611	24
DESSIE 66.000	WOLDIA 66.000	54.2836	36.73598	0.762161	24
LALIBELA 66.000	ALAMATA 66.000	52.6353	43.92329	0.915616	27
SEKOTA 66.000	ALAMATA 66.000	40.15657	33.5101	0.698587	27
BAHIR DAR1 66.000	BAHIR DAR2 66.000	2.788193	1.886893	0.03946	24
BAHIR DAR1 66.000	WORETA 66.000	31.84214	21.54896	0.447212	24
BAHIR DAR2 66.000	DANGLA 66.000	42.31641	28.63735	0.594091	24
BITCHENA 66.000	DEBRE MARKOS66.000	40.52753	27.42673	0.569246	24
DABAT 66.000	GONDER1 66.000	36.03061	24.3835	0.505671	24
DANGLA 66.000	PAWIE 66.000	67.23748	45.50234	0.944115	24
DEBRE MARKOS66.000	FINOTE SELAM66.000	49.34869	33.39632	0.69274	24
GONDAR2 66.000	GONDER1 66.000	2.658654	1.799228	0.037268	24
GONDAR2 66.000	WORETA 66.000	53.66679	36.3185	0.753392	24
FINCHAA 66.000	FINCHA-SUG 166.000	4.709707	4.551497	0.097188	30
FINCHA-SUG 166.000	FINCHA-SUG 266.000	6.593634	6.372087	0.135918	30
ADWA 66.000	SHIRE 66.000	21.01273	26.84285	0.601398	36
ALAMATA 66.000	MAYCHEW 66.000	24.09395	20.10603	0.418713	27
AMIBARA 66.000	AWASH-7KILO 66.000	26.27809	17.78354	0.369023	24
AWASH-7KILO 66.000	NURAERA 66.000	37.62825	25.4647	0.528413	24
BALEROBE 66.000	M WAKENA YUG66.000	35.58177	30.15284	0.639397	28
GOBESSA 66.000	M WAKENA YUG66.000	37.2452	31.08058	0.648165	27
NEGELE BORNA66.000	SHAKISO 66.000	57.17294	47.70996	0.994536	27
WOLISO 66.000	WOLKITE 66.000	19.66163	16.40735	0.341986	27
MIZAN 66.000	TEPI 66.000	15.13401	12.62913	0.263066	27
ADDIS-EAST 145.000	COTOBIE 45.000	3.576211	2.508287	0.051873	17
BABILE 45.000	HARAR I 45.000	14.80407	9.893199	0.210635	17
BAHIR DAR1 45.000	TIS-ABAY1 45.000	9.331079	11.81654	0.276655	25
ADDIS ALEM 45.000	GEFERSA 45.000	17.78507	12.4741	0.257792	17
ADDIS ALEM 45.000	GINCHI 45.000	21.00127	14.72989	0.304949	17
KOKA 45.000	MODJO 45.000	10.4526	7.331306	0.155168	17
AKAKI 1 45.000	ABA SAMUEL 45.000	10.80064	7.575363	0.15719	17
AKAKI 1 45.000	DUKEM 45.000	9.000538	6.312816	0.130468	17
AKAKI 1 45.000	KALITI1 45.000	1.800108	1.262561	0.026722	17
AKAKI-SP 45.000	KALITI1 45.000	3.700809	2.516245	0.051873	17
AKAKI-SP 45.000	KALITI1 45.000	3.700809	2.516245	0.051873	17
DEBRE-ZEIT1 45.000	DUKEM 45.000	5.040306	3.535184	0.072307	17
GEDJA 45.000	SEBETA1 45.000	14.18723	9.480989	0.202775	17
AWASH-7 D 15.000	AWASH-7KL 15.000	0	0.000001	0	0
ADAMI TULU 15.000	ALT-LANG 15.000	0.64998	1.68048	0.297089	6