ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

Voltage and Reactive Power Control for Power loss Minimization of Distribution Networks

Case Study- (Sebeta I Substation Outgoing Feeder)

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Electrical Engineering (Electrical Power Stream)

By Mihret Desta
Advisor: Dr. Getachew Bekele

Date: March 2019
ADDIS ABABA, ETHIOPIA

ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING

Voltage and Reactive Power Control for power loss minimization of Distribution Network
(Case Study: Sebeta-I Substation)

APPROVAL BY BOARD OF EXAMINERS

______________________________ ______________________

Chairman **Signature**

Department Of Graduate Committee

Dr.Getachew Bekele ______________________

Advisor **Signature**

______________________ ______________________

Internal Examiner **Signature**

______________________ ______________________

External Examiner **Signature**

Declaration

I hereby declare that the work which is being presented in this thesis entitled 'Voltage and Reactive Power Control for power loss minimization of Distribution Networks' has not been presented for a degree in this or other universities and all sources of materials used for this thesis work have been fully acknowledged.

Name: Mihret Desta

Signature: ______________

Place: Addis Ababa

Date of Submission: February, 2019

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

Dr. Getachew Bekele ____________________

Advisor's Name Signature

Acknowledgment

First and above all, I praise Father **Almighty God,** for providing me this opportunity and granting me the capability to proceed successfully.I would like to express my special appreciation to my supervisor, Dr. Getachew Bekele; you have been a tremendous mentor for me. I would like to thank you for encouraging my thesis and for allowing me in the field of Power engineering. Your advice on research as well as on my career has been priceless.

I would like to give my regards to Mr. Gulilat Engida for his difficult time support during my career may God give you all the best in return.

Lastly, I would like to express my appreciation to my family and friends.

Abstract

With the rapid growth of electrical power consumption, the expansion and complexity of power transmission and distribution networks also increase, this expansion leads to frequently changes in loading conditions to operate on overloaded or to operate with under loaded conditions. Electricity distribution networks form the backbone by which electricity is effectively delivered to the consumers. In Ethiopia most of distribution network have problem of operating on overloaded condition that result on voltage drop and most of them supply to factory that cause the reactive power increment on the system.

This thesis studies on a comparative analysis of the problem of voltage drop and reactive power solving methods that can be implemented power loss minimization of distribution networks Sebeta I substation.Voltage drop which is caused by system overloading and Reactive power in distribution networks is fundamental issue for power loss and maximum transmission of power in the distribution network. There are different methods for solving voltage drop and reactive power problem for power loss minimizations.Basically this thesis studies on comparatively application of mechanisms for voltage drop and reactive power like, shunt capacitors, distributed generation, load sharing, and use of additional transformer in substation level. The system network is modeled using DIgSILENT Power Factory software and all four methods mentioned above are simulated using this Package. Load flow calculations are carried out and the results obtained are used to compare the impact of the four methods on the performance of the system. The methods are compared based on the improvement of voltage profile, reduction in the total real power losses, power factor correction and future load capacity is implemented.

From methods that are implemented comparatively, use of additional transformer with rating of 50MVA 132/15kV 1.25%, with 4MVAR capacitor bank is recommended based on reduction of over load by 78%, which improving the voltage profile from 0.87 per unit to 0.98 per unit at the last bus bar of distribution network of feeder 02 and, power loss also minimized by 97% of feeder 02 and over all power loss reduced by 20%.

Key words: Over Current, Power Distribution, Reactive Power Compensation, Voltage Drop, Nominal Current, Distributed Generation, Current Carrying Capacity

Contents

List of Figures

List of tables

Acronyms and Abbreviations

FACTS	Flexible Alternating Current Transmission System
PSS	Power System Software
HVL	High Voltage Level
LV	Low Voltage
VSPP	Very Small Power Producer
VAR	Volt –Ampere Reactive
AC	Alternating Current
DG	Distributed Generation
MVA	Mega Volt-Ampere
MW	Megawatt
MVAR	Mega Volt Ampere Reactive
KV	Kilo Volt
SEB I	SEBETA I substation
AASR	All Aluminum Silicon Reinforced
p.u.	Per Unit
C.C.C	Current Carrying Capacity
CT	Current Transformer
DIgSILENT	DIgital SImuLation of Electrical NeTwork
AC-DC	Alternating Current to Direct Current
DC-AC	Direct Current to Alternating Current
DC-DC	Direct Current to Direct Current
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility

Chapter one
Introduction

1.1 Background

Distribution system is the largest portion of network in electrical power system. It can be defined as the part of power system which distributes power to various customers in ready to use form at their place of consumption. Hence, utilities have to ensure reliable and efficient cost effective service, while providing service voltages and power quality within the specified range.

There are two different distribution network arrangement meshed or a ring and radial.However, most electric distribution feeders are configured radials, for effective coordination of their protective systems. The feeders must remain radial and satisfy all load requirements and voltage constraints. Power supply reliability and power quality directly affects the development of the national economy and people's daily life also it is necessary to ensure the safe operation of the distribution network [6].

In electric power distributions networks there are a lot of problems which are observable due to different types of load available in different ranges of power consumption, over and under loading, equipment failure and insulation failure**.** Distribution systems are also increasingly being automated in recent times. Utilities can save significant operating and maintenance cost by increasing the knowledge and capacity of distributed generation.

Reactive power compensation in distribution systems improves the stability of the ac system by increasing the maximum active power that can be distributed, it also helps to maintain a substantially smooth voltage profile, increases efficiency, controls steady-state and temporary over voltages, and can avoid unfortunate system interruption. If there is a group of capacitors rather than the power line, this system is called reactive power correction [5]. Also Series and shunt VAR compensation are used to modify the natural electrical characteristics of ac power systems. Series compensation modifies the distribution system parameters, while shunt compensation changes the equivalent impedance of the load. In both cases, the reactive power that flows through the system can be effectively controlled improving the performance of the overall ac power system. Traditionally, rotating synchronous condensers, fixed or mechanically switched capacitors or reactors have been used for reactive power compensation [12].

Most of the time capacitor bank used for reactive power compensation and voltage control for factories capacitor bank has an advantage of increase power distribution capability, reduce system losses, improve voltage profile on the lines, and optimize power flow between parallel lines [9].

In Ethiopia electric power distribution system is labeled as LV for 45kV, 33kV and 15kV. Mostly 33kV and 15kV overhead conductors are used for feeding up to 80 distribution step down transformers on each of 33kV and 15kV feeder. The voltage reaches to the customer reduced as to 380 volts three-phase or 220 volts single-phase.

Addis Ababa is the capital city of the country and is a preferred location for most of the industries in the country and also has a large number of customers which have problems of electric power distributions interruption. Sebeta I substation is located at Western side of Addis Ababa which is the high voltage level substation having 230kV, 132kV incoming lines, three of 132 kV incoming, one of 45 kV and thirteen 15KV outgoing feeders. Most of the outgoing lines are supplying the factories which have high reactive power consumption capability and overloading, this result a problem of voltage drop on both sides. And this thesis studies and suggests how to regulate voltage profile and reactive power reduction by using different mechanisms.

In this thesis the voltage control and reactive power compensation are studied and analyzed by using DigSILENT software and the appropriate selection and allocation are studied that used to achieve load balance, voltage control and power loss minimization.

1.2 Statement of the Problem and motivation

In Ethiopia like many other countries, the overall grid system has generation, transmission, substation and distribution. But most of distributions networks have problems have high power loss due to voltage drop which is caused by system overloading and reactive power. This problem results in poor voltage regulation, and poor efficiency, under and over loading of lines thought out the system.

Since Addis Ababa is the capital city of the country and is a preferred location for most of the industries in the country, considerable share of the electric power supply which takes 45% of overall generated power is directed towards the city [data from national load dispatch center]. Due to this fact, Addis Ababa has already been the load center of Ethiopian electric power system. But, electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems.

Sebeta I substation is located at western side of Addis Ababa, which is having 230kV, 132kV incoming lines, three 132kV, one 45kV outgoing lines and thirteen 15kV outgoing lines which supplies one-third of Addis Ababa city.

This thesis study, analysis and suggests how to regulate voltage and reactive power problem reduction by using different mechanism for over load minimization to bring load balance and reactive power compensation of sebeta I substation outgoing line 2.

1.3 Objective

1.3.1 General objective

The main objective of this thesis is to study about how to control voltage and reactive power for power loss minimization in distribution networks of outgoing feeder 2.

1.3.2 Specific objective

- ✓ To explore and identify the possible cause of voltage drop.
- ✓ To study the significant ways for resolving voltage drop and reactive power consumption for continuity of power supply.
- ✓ Implement voltage and reactive compensation methods for the chosen distribution network,
- ✓ Collect data from substation data log, customer center, regional maintenance office, and distribution control center.
- ✓ To make applicable conclusions and recommendation

1.4 Methodology

The methods employed to achieve the objectives of this thesis are:

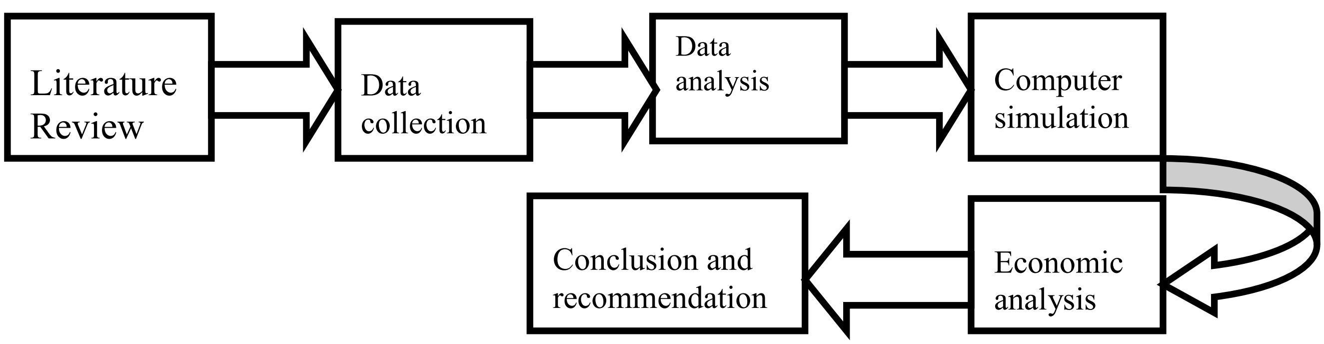


Figure 1.1 methodology

Under the topic called literature review the work of different authors; articles, journals, books, thesis done in similar topics and others have been reviewed and it has been considered one of the methodology used to do this Thesis.

The total task of data collection is accomplished through

- Conducting interviews with the respective personnel of the substations.
- Direct measurement

- From recorded data and equipment specifications
- Physical observation in the substations.
- Data from Ethiopian Electric Utility (EEU) engineering offices, sebeta 1 substation and distribution design and planning office.

Computer analysis or Simulation

There are different types of software which can be applicable on electrical power distributions simulation Power world, PSS, MAT-LAB, and DIgSILENT. From software mentioned above the DIgSILENT is most recent, highly compatible and combined reliability and flexible system modeling capability with state of the art algorithms and unique database concept [2].The data is organized using EXCEL sheet and the single layout diagram and analysis using Power Factory Software the preferable solution, use of distributed generation micro turbine), capacitor bank and other recommended will be suggested.

Data analysis: Analysis has been done using power factory software load profile. Comparison has been done between the system with no compensation, with the proposed overload reduction methods and shunt compensators.

1.5 Organization of the Thesis

The thesis is organized into six chapters.

Chapter one presents the introduction, background, statement of the problem, objectives of the study, methodology followed in the thesis work and the outline of the thesis. Chapter two deals the theoretical background and literature review of the study topic. Chapter three discusses the data collection and analysis of the distribution system of selected area. Chapter four discusses about computer simulation, results and detailed discussion. Chapter five cost analysis. Chapter six is about conclusions and recommendation.

Chapter two

Theoretical Notes and Literature Review

2.1 Introduction

Electric power distribution is the final stage in the delivery of electric power, it carries electricity from the transmission system to individual consumers. Primary distribution lines carry this medium voltage power to distribution transformers located near the customer's premises. Electricity supplies the power for industry, agriculture and our homes. Its use requires wiring, lighting fixtures, power distribution equipment, and other advanced technology and related equipment.

Distribution systems can be defined as the sequential flow of procedures, systems, and activities which are designed and linked to facilitate and monitor the movement of goods and services from the source to the consumer. The primary distribution system is that part of the electric distribution system between the distribution substation and distribution transformers. It is made up of circuits called primary feeders or distribution feeders. A typical power distribution feeder provides power for both primary and secondary circuits. A distribution board (also known as panel board, breaker panel, or electric panel) is a component of an electricity supply system that divides an electrical power feed into subsidiary circuits, while providing a protective fuse or circuit breaker for each circuit in a common enclosure.

An electrical grid is an interconnected network for delivering electricity from producers to consumers. It consists of generating stations that produce electrical power, high voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers. The transition from transmission to distribution happens in a power substation, which has the following functions:

- Circuit breakers and switches enable the substation to be disconnected from the transmission grid or for distribution lines to be disconnected.
- Transformers step down transmission voltages.

From the transformer, power goes to the bus bar that can split the distribution power off in multiple directions. The bus distributes power to distribution lines, which fan out to customers. A distribution transformer steps the primary distribution power down to a low-voltage secondary circuit, usually 380/220 volts in the Ethiopia for residential customers. The power comes to the customer via a service drop and an electricity meter.

2.2 Distribution network arrangement

Distribution systems are divided into two types in Ethiopia, which are called section based distribution (radial) and network power distribution (switching distribution systems).

A radial system is arranged like a tree where each end user has one source of supply and breaks. Radial systems usually include emergency connections where the system can be reconfigured in case of problems, such as a fault or planned maintenance. This can be done by opening and closing switches to isolate a certain section from the grid. Long feeders experience voltage drop (power factor distortion) requiring capacitors or voltage regulators to be installed.

Advantages and disadvantages of section based distribution:

Advantages of the section based distribution

- Simplest as fed at only one end, initial cost is low.
- It is useful when the generating is at low voltage.
- Preferred when the station is located at the center of the load.
- More economical for some areas which have a low load requirement
- require less amount of cables, low maintenance

Disadvantages of section based distribution

- The end of distributor near to the substation gets heavily loaded.
- When load on the distributor changes, the clients will face voltage fluctuation.
- As users are dependent on single feeder and distributor, a fault on any of these two causes Interruption in supply to all the users connected to that distributor

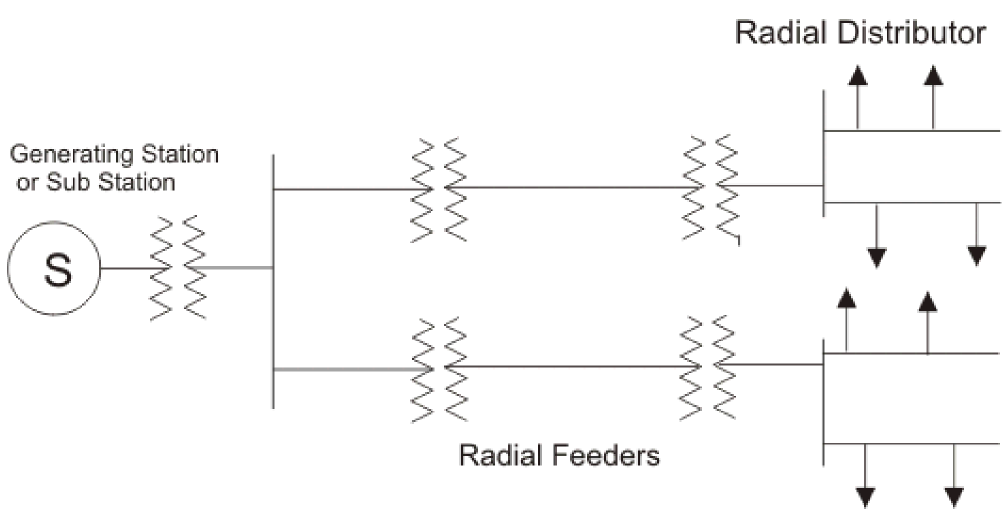


Figure 2.1 radial distribution networks

Switching distribution systems has multiple sources of supply operating in parallel. Spot networks are used for concentrating loads. In this case, we have a switch stations consisting of a breaker, dispensary switch. In our project This switching power supply system have two parallel, but having same generating station or substation sharing load, which divide power to two different routes. Thus independent routs have their own breaker, switch and provide power to customers efficiently and effectively**.**

Advantages of the switching distribution systems:

- In switch power is supplied from both ends as compared to radial.
- In case of a fault in the circuit the entire system goes off unlike in ring where by incase one end gets a fault the other end still keeps on supplying power.
- Compared to the section based system, the voltage drop is less along the distribution line.
- More subscribers can be installed to the system than the section based system.
- Less voltage fluctuations can be seen at client's terminals.

Disadvantages of the switching distribution systems:

- This system is very expensive and requires more materials than section based system.
- Section based circuit is more economical.
- High maintenance cost.
- It is not usable when the client is located at the center of the load.

2.3 Reactive Power and voltage drop in Power distribution System

In general power system can have sub division power generation, transmission and distribution, from this all distribution part is highly affected by problem of voltage drop due to overloading and most distribution lines supply different type of loads that result on load unbalance. These different types of loads can be factors that used more reactive power that also another result for voltage drop. There are different literatures which describe mechanisms of solution for voltage drop and reactive power.

From the literature review there are different methods as a solution;

- ❖ distributed generation,
- ❖ FACT devices,
- ❖ Disconnector or section opening ,
- ❖ Developing of load sharing.

For the analysis of these problems, most researchers use different algorithms and software.

Reactive power compensation mainly refers to the effective use of reactive power compensation devices and equipment. In order to obtain the required reactive power, it reduces the energy consumption of grid operation and promote the power system effectively improve the power factor, and ultimately improved grid voltage quality goals [6]. An effective way to improve the power factor is to take the appropriate means of reactive power compensation. Researcher T.Xu, P.C. Taylor use distributed generation as power loss minimization mechanisms by implementing the DG for reactive power reduction by increasing the real or active power that leads to improve the voltage regulation[14].

2.4 Distribution System Voltage Control

Distribution system voltage control is sometimes referred to as volt/var control (VVC), which Grainger and Civanlar (1985) specify as follows to minimize the peak power and energy losses while keeping the voltage within specified limits for a variety of nominal load patterns which is formulated as an optimization problem that is solved off-line, based on nominal load patterns.

The optimization variables are the locations, sizes and control dead bands of capacitors and tap changer voltage regulators. Tap changers are normally automatically controlled by a relay controller that measures and regulates the secondary side voltage of the transformer. The control of transformers operating in parallel in the same substation must be coordinated to minimize circulating reactive power flows [1].

The control of voltage and reactive power is a major issue in power system operation. This is because of the topological differences between distribution and transmission systems, different strategies have evolved. A particular interest is taken to the development of control schemes to avoid so called voltage collapse, which can result in widespread outages. In order to achieve efficient and reliable operation of power system, the control of voltage and reactive power should satisfy the following objectives;

- Voltages at all terminals of all equipment in the system are within acceptable limits
- System stability is enhanced to maximize utilization of the transmission system
- The reactive power flow is minimized so as to reduce $R I^2$ and $X I^2$losses.

This ensures that the transmission system operates mainly for active power. Thus the power system supplies power to a vast number of loads and is feeding from many generating units, there is a problem of maintaining voltages within required limits. As load varies, the reactive power requirements of the transmission system vary. Since the reactive power cannot be transferred or transported over long distances, voltage control has to be effected by using special devices located through the system which possess difficulties in keeping sufficient levels of voltage in the power system network. This has been occurring practically since the first power systems started.

The proper selection and coordination of equipment for controlling reactive power and voltage stability are among the major challenges of power system engineering. These challenges gave birth to some selected devices to control or compensate reactive power. In order to cover the additional demand for reactive power and maintain the ability to control voltage stability within the target range, various sources of reactive power is required. In recent decades, there has been significant progress in terms of equipment designed to improve the stability of voltage in power systems. This is mainly due to the development of power supply systems in the world, which requires seeking better ways of adjusting and controlling power Flows and voltage levels [12].

As the expansion in power distribution system leads to voltage drop and reactive power increment from the desired value if there is no sufficient power generation. The idea of developing a new generation station is not possible because of economic and environmental considerations. So, this problem solved by achieving improving the performance of the existing power system set-up through effective overloading reduction mechanisms and reactive power control mechanisms. As far as, effective power system control is made, it is possible to run power system parameters within their normal operating ranges. However, the consistency of these parameters is dependent on the amount and type of load the system provides.

The theory of reactive power increment depends on type of loads. For example, a load characterized with inductive load and other with resistive load consumes different amount of reactive power. The characteristic of inductive loads reflects with under voltage, reduction in operating power factor which further results in increased power losses. This in turn results in degradation in the power system performance and also the consumer getting frequent electrical power interruption. Specially, industrial zone areas which are characterized with high demand of reactive power for their operation of induction machines, they shall be connected to a power system of strong reactive power profile or be connected to shunt reactive power compensator with faster switching controls.

In electrical power system, the reactive power is the power that supplies the stored energy in operating power factor which further results in increased power losses. And voltage drop also results of overloading of the line.

Distributed generation is power generation that placed nearby to customer which have small scale power generation capability, the output will be DC form and required a storage for generated power storage also it required converted DC-AC if they are needed to be connected to grid it's possible the time of grid power outage. In general terms, Distributed Generation is any type of electrical generator or static inverter producing alternating current that (a) has the capability of parallel operation with the utility distribution system, or (b) is designed to operate separately from the utility system and can feed a load that can also be fed by the utility electrical system [14]. Distributed generation is emerging as an important option for the future development and restructuring of electricity infrastructure [5].

There are different types of distributed generation

- Gas turbine the efficiency of 21-40% 1-20KW CHP peak power supply units gas kerosin
- Micro turbine with the efficiency of 25-30% 30KW -1MW power CHP
- Fuel cell with the efficiency of 35-60% 50-5MW PEMFC MCFC SOFC CHP UPS methanol Hydrogen or natural gas reforming of CH4 to leads to decreased efficiency
- Photovoltaic 1-20KW nature dependent output is not predicted
- Wind on shore, off shore 200W-3 MW

2.5 Reactive Power Control

2.5.1 Elements of System that Produces and Absorbs Reactive Power

Loads: normally absorb a reactive power. A typical load bus supplied by a power system is composed of a large number of devices. The composition changes depending on the day, season and weather conditions. The composite characteristics are normally such that a load bus absorbs reactive power. Both active and reactive of the composite loads vary as a function of voltage magnitude. Load low-lagging power factors leads to excessive voltage drops in the transmission network.

Underground cables: owning to their high capacitance, have high natural loads. They are always loaded below their natural loads, and hence generate reactive power under all operating conditions.

Overhead line: depending on the load current either absorb or supply reactive power. At loads below the natural load, the lines produce net reactive power. On the contrary, at loads above natural load lines absorb reactive power [12].

2.5.2 Importance of Reactive Power

Voltage control in an electrical power system is important for proper operation of electrical power equipment to prevent damage by overheating, to reduce transmission losses and to maintain the ability of the system to prevent voltage collapse. In general terms, decreasing reactive power, causing voltage to fall while increasing it causing voltage to rise. A voltage collapse occurs when the system try to serve much more load than the voltage can support. When reactive power supply lower voltage, as voltage drops current must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further. If the current increases too much, transmission lines go off line, overloading other lines and potentially causing cascading failures. If the voltage drops too low, some generators will disconnect automatically to protect themselves. Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and still there further voltage reductions. If voltage reduction continues, these will cause additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demands [1].

2.5.3 Reactive Power in Operations

Reactive power affects power system operation in numerous ways:

- Loads consume reactive power, so this must be provided by some source.
- The delivery system (transmission lines and transformers) consumes reactive power, so this must be provided by some source (even if the loads do not consume reactive power). Note however that all transmission lines do provide some reactive power from their shunt line charging which offsets their consumption of reactive power in their series line losses.
- The flow of reactive power from the supplies to the sinks causes additional heating of the lines and voltage drops in the network.
- The generation of reactive power can limit the generation of real power.

So, one primary dilemma with reactive power is that a sufficient quantity of it is needed to provide the loads and losses in the network, but having too much reactive power flowing around in the network causes excess heating and undesirable voltage drops. The normal answer to this dilemma is to provide reactive power sources exactly at the location where the reactive power is consumed. And, since strictly speaking it does not take any fuel to provide reactive power, it should be possible to distribute reactive power sources (such as capacitors) all around the network to avoid the problem of heating the conductors and causing voltage drops. Unfortunately, this is not practical in the extreme since there are literally millions of lines and loads connected to the grid and so this would require millions of reactive power sources which controlled to provide exactly the right amount of reactive power at the right time in every second of every day. The best we can do in most cases is work with some type of aggregation of load at the terminal of feeder leaving a substation and at terminals of major lines and transformers. This also brings up the issue of the difference between power factor control (trying to exactly provide the right amount of reactive power needed to equal that which is consumed) and voltage control (trying to keep voltage levels at exactly the right level no matter how much reactive power it takes).

Reactive power is both the problem and the solution to network voltage control. There are many authors and researchers who have worked voltage and reactive power control for power loss minimization using different techniques [1].

2.5.4 Problems of Reactive Power

Though reactive power is needed to run many electrical devices, it can cause harmful effects on appliances and other motorized loads, as well as electrical infrastructure. Since the current flowing through electrical system is higher than that necessary to do the required work, excess power dissipates in the form of heat as the reactive current flows through resistive components like wires, switches and transformers. Keep in mind that whenever energy is expended, it has payment. It makes no difference whether the energy is expended in the form of heat or useful work. A power factor of 1 or 100% ideally means that all electrical power is applied towards real work. Homes typically have overall power factors in the range of 70% to 85%, depending upon which appliances may be running. Newer homes with the latest in energy efficient appliances can have an overall power factor in the nineties.

The typical residential power meter only reads real power, i.e. which would have with a power factor of 100%. While most electric companies do not charge residences directly for reactive power, it's a common misconception to say that reactive power correction has no economic benefit. To begin with, electric companies correct for power factor around industrial complexes, or they will request the offending customer to do so at his expense, or they will charge more for reactive power. Clearly electric companies benefit from power factor correction, since transmission lines carrying the additional (reactive) current to heavily industrialized areas costs them money.

In an electrical power system, balanced reactive power is the carrier of the true power. If it is Consumed, the voltage decreases, and hence its ability to transport the true power decreases. So, reactive power in power system is required to deliver the active power through transmission lines, and to produce magnetic fields in Electric motors and transformers for their operation. If the reactive power of the system is not sufficient to support the terminal voltage of bus terminals, it can be supported using shunt reactive compensation system, so that, the reactive power which has to come from the system is to be provided by the compensation system and therefore the main equipment of the power system which were forced to deliver the reactive power to the load are getting relaxed and utilized the reactivity for their own operation. The Shunt reactive compensation can modify the parameters of the system to give enhanced VAR compensation.

It can do quite satisfactorily job of generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS).This allows an increase in transfer of apparent power through a transmission line, and much better stability by the adjustment of parameters that govern the power system i.e. current, voltage, phase angle, frequency and impedance. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. The terminal voltage at bus bar of the substations is influenced by loading [1].

Flexible Alternating Current Transmission Systems (FACTS)

These devices are applicable for the controlling of voltage drop and reactive power. Most literature uses different types; SVC -static var compensator, STATCOM- static compensator, UPFC unified power flow controller, SSSC-Static Synchronous series compensator and so on. Shunt capacitor bank is one of reactive power compensation because of low cost and low area of placement. Shunt capacitors, reactors and series capacitors provide passive compensation. They are either permanently connected to the transmission and distribution system or switched. They contribute to voltage control by modifying the network characteristics. Synchronous condensers, SVC and STATCOM provide active compensation for the voltages of the buses to which they are connected together with the generating units; they establish voltages at specific points in the system.

Voltages at other locations in the system are determined by active and reactive power flows through various elements, including the passive compensating devices [1, 13].The primary purposes of transmission system shunt compensation near load areas are voltage control and load stabilization.

Mechanically switched shunt capacitor banks are installed at major substations in load areas for producing reactive power and keeping voltage within required limits.

For voltage stability shunt capacitor banks are very useful in allowing nearby generators to operate near unity power factor this maximizes fast acting reactive reserve. Compared to SVCs, mechanically switched capacitor banks have the advantage of much lower cost. Like inductors, capacitor banks are discrete devices, but they are often configured with several steps to provide a limited amount of variable control. If voltage collapse results in a system, the stable parts of the system may experience damaging over voltages immediately following separation. Shunt capacitors banks are always connected to the bus rather than to the line. They are effective if they connected to near to load.

Shunt capacitor banks are breaker-switched either automatically by a voltage relays or manually [9].

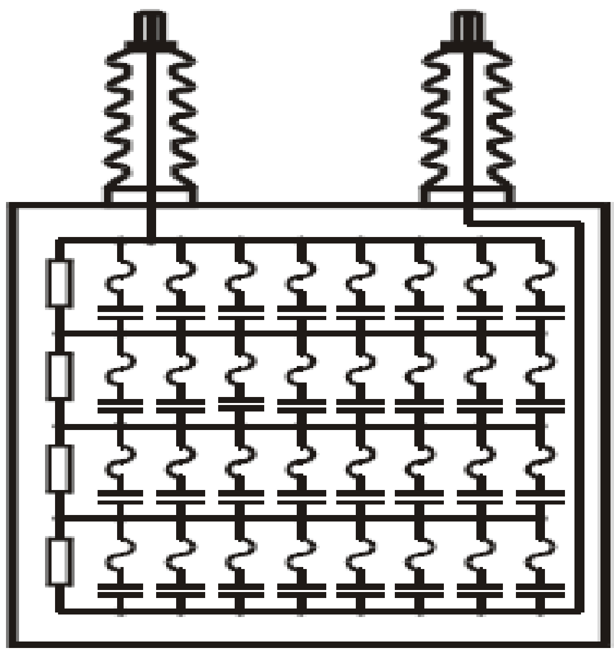


Figure 2.2 shunt capacitor bank arrangements

Shunt capacitors are used to compensate for X I^2 and R I^2 losses in power distribution system and to ensure satisfactory voltage levels during heavy load conditions. Shunt capacitors are used in power system for power factor correction. The objective of power factor correction is to provide reactive power close to point where it is being consumed, rather than supply it from remote sources.

Power factor correction based on power capacitors is the biggest group of the devices used the industry and by the private users, mainly from economic reasons. On the hand, they may be a reason for unwanted distortions at the spot of operation. That is why they should be carefully selected, in accordance actual standards. In order to achieve the voltage stability, the power system needs to be operated within an acceptable voltage range even under disturbances [8]. The much known disturbances in power system are sudden changes in loads, switches in loads, changes or losses in supply. Besides that, disturbances also occur when reactive power flow through the transmission lines and modify the line and bus voltages.

This thesis studies on the advantage of different methods of solving voltage drop problem and reactive power problems, by using capacitor bank, using micro turbine, switching by load sharing, and use of additional transformer. Which is previously not worked in the selected distribution network and the simulation is done by using software DIgSILENT.

Chapter Three

Distribution System Data Analysis and Modeling

In Ethiopia most 15kV outgoing feeders are connected in radial fashion. Mostly those feeders are used to feeding 60 to 80 distribution transformer. As the distance increase the voltage is then further reduced, by distribution transformers to the utilization voltage of 380 volts three-phase or 220 volts single-phase supply required by end users. While doing the research different data have been collected from different sources and for ease of this study form Sebeta I substation outgoing feeder line 02.

The primary data: own studies of the Problem. It includes the collection of Information through direct observation of the substations and distribution lines within the distribution line route such as loading of transformers and feeders and through conducting personal conversations and interviews.

Secondary data: the result of other peoples research in the same problem area, web-sites and other historical and documentary records relevant for the research.

The necessary data for this thesis work are collected from different sources through,

- Conducting interviews with the respective personnel of the substations.
- Physical observation in the substations.
- Data from Ethiopian Electric Utility (EEU) engineering offices, sebeta 1 substation and distribution design and planning office.

The data include:

- Distribution line, transformers, parameters.
- Substation transformer rating
- Active and reactive power demand at bus bar terminals.

3.1 Direction for outgoing feeder for Sebeta I substation

Sebeta I substation supply electric power for one third of Addis Ababa customers through 400V low voltage transformer. Currently, the substation is connected to the neighboring substation system through 132kV outgoing line such as Kality-I, Gefersa Substation, Addis West. There is another two winding transformer of capacity 50MVA which operate parallel to feed about 13 outgoing lines. From this feeders outgoing line 02 supply more customer by 124 distribution transformers. The one line diagram of the overall system 132kV side is model by using DIgSILENT power factory software.

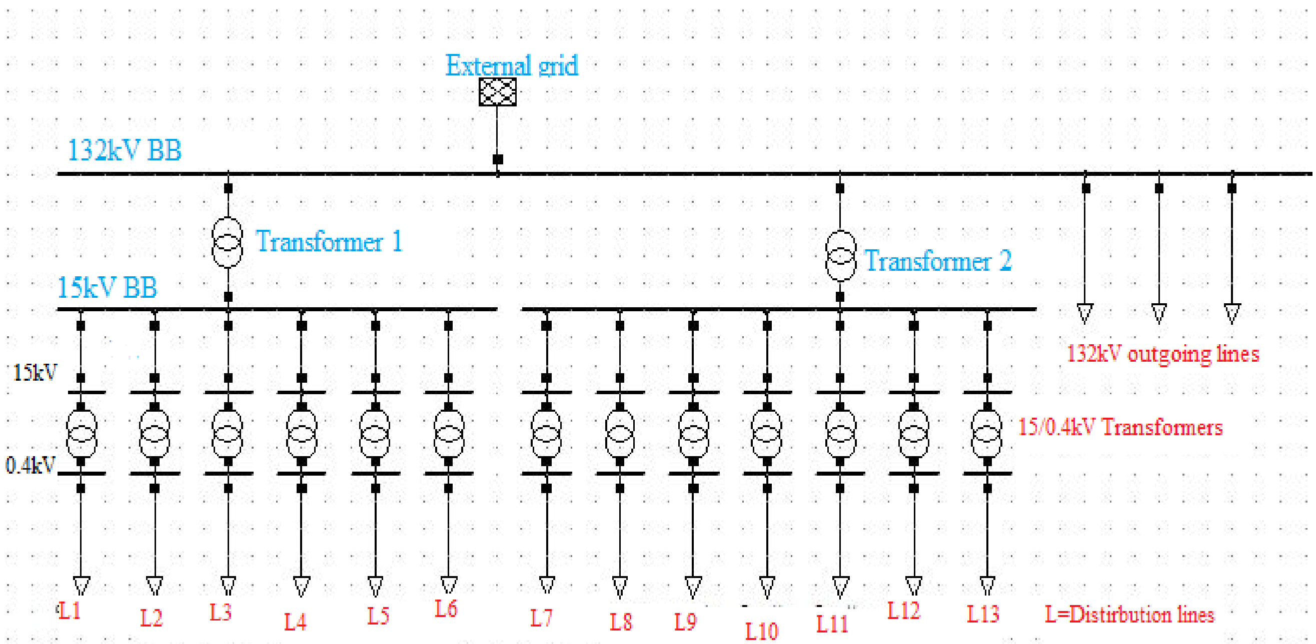


Figure 3.1: Sebeta I substation single line diagram

Direction of outgoing feeders;

- ✓ L1-supplies to residential, starting from the substation area up to Jemo condominium
- ✓ L2-it goes through underground cable from substation and supply to area Welete, Wechecha Mariam Church, Yes Water Factory, Meta Brewery Factory, Berchiko Fabrica, up to Bethel.
- ✓ L3- supply to residential, starting from Holland Embassy and Torhiloch Hospital up to Keranyo.
- ✓ L4- goes with underground cable supply to half of Bethel area and Berchuko Fabrica
- ✓ L5- it supply to Waliya Metal Factory
- ✓ L6 –gives to Ayka Addis Factory
- ✓ L7 – it supply to residence and Furi radio station and industry around there
- ✓ L8- it supply to residential around Jemo and for Fana water storage
- ✓ L9- it supply to Welete condominium and to Gelan area
- ✓ L10- it supply to Girar condominium and area around there.
- ✓ L11- it supply to Ayer Tena condominium and Mark Food Processing Complex.
- ✓ L12-supply to condominium in front of the substation and to Zenebework Hospital
- ✓ L13- supplies to jemo 2 condominium up to Sebeta industrial zones and Delete area

Where; L –outgoing lines

3.2 General distribution network root line of sebeta I substation (AUTOCAD layout)

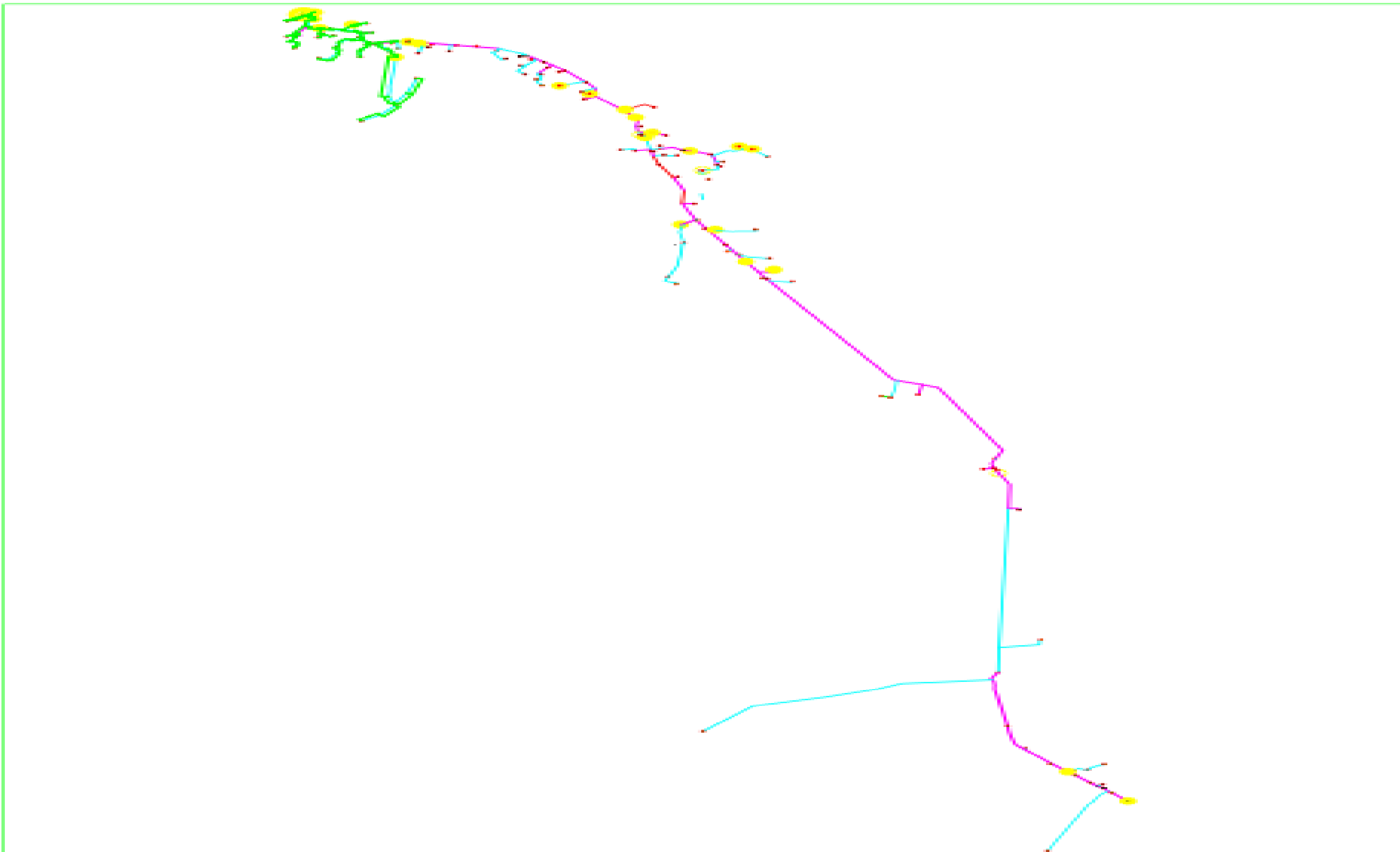


Figure 3.2 general distribution network root line of sebeta I substation (AUTOCAD layout)

Distribution Cable Type

Pole mounted transformer

1 AAC 95 all aluminum cable	9 UGCU 120 underground copper
2 AAC 50	10 UGCU 70
3 AAC25	11 CU 16 copper
4 ACSR 129	12 CU 25
5 ACSR 65	13 CU 10
6 ACSR 46	
7 ACSR 30	
8 ACSR 18	

3.3 Data Analysis

The collected data are analyzed quantitatively and qualitatively using DIgSILENT power factory software. This program is a computer aided engineering tool which is designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of power system operation. The name DIgSILENT stands for "Digital Simulation and Electrical Network calculation program".

The Power Factory package was designed and developed by qualified engineers and programmers with many years of experience in both electrical power system analysis and programming fields. The accuracy and validity of the results obtained with this package has been confirmed in a large number of implementations, by organizations involved in operation of power systems. In order to meet today's power system analysis requirements, the DIgSILENT power system calculation package was designed as an integrated engineering tool.

3.4 Load Flow Analysis

In this part, Load flow analysis is used to analyze the selected power systems under steady-state using power factory software. The load flow calculates the active and reactive power flows for all branches, loading of transmission and distribution lines and transformers, voltage magnitude at each bus bar of the substations in terms of kilo Volt (kV) and per unit.

Under normal operating conditions the in feed power as well as the loads is known, and it is Sufficient for the load flow calculation to represent these in feed power and to provide the active and reactive power of all loads. The results of the load flow calculation should represent a system condition in which none of the branch limits are exceeded. The calculation methods and the options provided by Power Factory’s load flow analysis function allow the accurate representation of any 3 phase AC systems. For very fast and reliable analysis of complex transmission networks, only the flow of active and reactive power through the branches and voltage profile at bus bar of substations is considered.

As a general concept, DIgSILENT Power Factory software is implemented as a single executable program a special feature of the DIgSILENT Power Factory software is the unique vertically integrated model concept. This allows models to be shared for all analysis functions and more importantly, for categories of analysis, such as generation, transmission, distribution and industrial. No longer are separate software engines required to analyze separate aspects of the power system, as

DIgSILENT Power Factory can accommodate all within one integrated frame and one integrated database [2].

Distribution line coverage distance used for evaluating power loss is measured as follows

Table3.1 Coverage distance of distribution line

Line name	distance(km)	Line name	Distance (km)	Line name	Distance (km)
1	10.8	5	19.8	9	24.4
2	40.12	6	20.1	10	1.3
3	25.7	7	19.5	11	24.2
4	27.3	8	16.9	12	13.3
				13	27.9

Maximum and minimum load for computer simulation

Table 3.2 minimum and maximum load in active power and current

Peak (max)					Minimum				
bay/line	Power(MW)	Current(A)	date	Time(hr)	bay/line	Power(MW)	Current(A)	date	Time(hr)
trafo132/15	57.6	1678	2/9/2018	19:00	trafo 132/15	8	39	30/9/18	8:00
line 1	9.4	394	16/9/18	20:00	line 1	1	44	5/9/2018	3:00
line2	15.2	640	2/9/2018	11:00	line2	2	90	11/9/2018	0:00
line 3	13.2	573	7/9/2018	13:00	line 3	2.5	107	11/9/2018	4:00
line 4	9.6	416	8/9/2018	12:00	line 4	0.01	1	16/9/18	2:00
line 5	1.9	74	3/9/2018	12:00	line 5	0.09	4	22/9/18	2:00
line 6	6.2	260	4/9/2018	9:00	line 6	3	13	24/9/18	18:00
line 7	6.1	274	21/9/18	11:00	line 7	1.1	45	9/9/2018	5:00
line 8	4.9	206	3/9/2018	8:00	line 8	0.64	27	30/9/18	3:00
line9	6.6	296	5/9/2018	10:00	line9	1.2	50	8/9/2018	21:00
line 10	3	140	7/9/2018	10:00	line 10	0.45	19	9/9/2018	16:00
line11	10.5	452	3/9/2018	13:00	line11	1.6	69	9/9/2018	2:00
line12	9.8	461	7/9/2018	14:00	line12	1.5	64	4/9/2018	3:00
line 13	8.8	442	2/9/2018	20:00	line 13	1.1	47	13/9/18	4:00

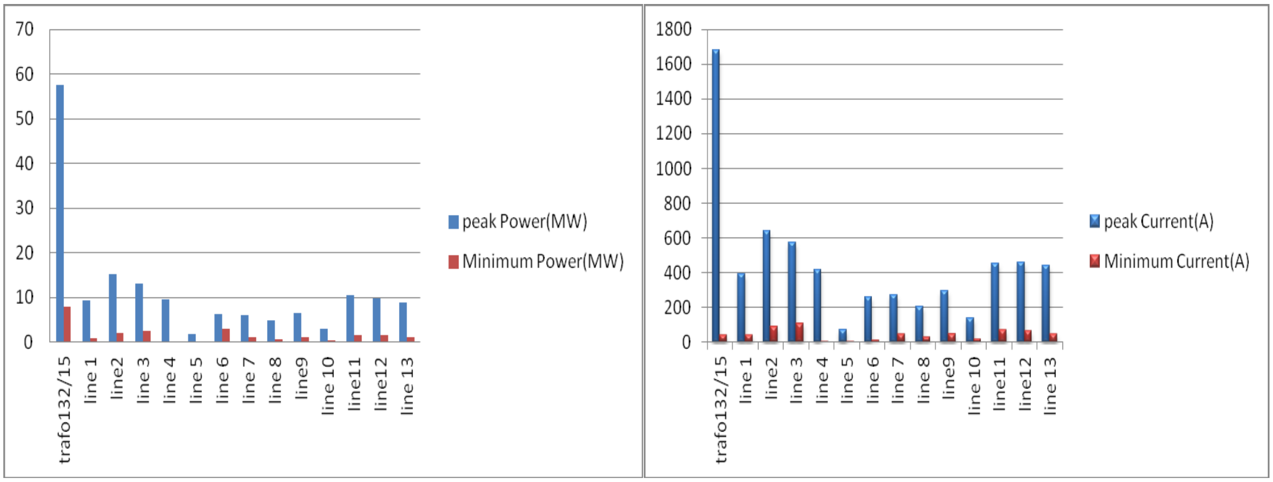


Figure 3.3: real power and load variation for peak and minimum value

Distribution Line Voltage Variation and Power Factor

In general Voltage measurement involves determination of the electric potential difference between two points. The potential difference is the amount of work needed to move a unit charge located in an electric field from a reference point to another point.

Voltage at electrical distribution system is conducted from the relay on the control panel at substation level and also measurement will carried out at the distribution transformer cable using different devices. For this thesis voltage measurement is taken from the sebeta I substation all outgoing feeders control panel.

Table 3.3 Distribution line voltage (kV) variation for peak time (8:00-21:00)

Line 1 (kV)	Line 2 (kV)	Line 3 (kV)	Line 4 (kV)	Line **6** (kV)	Line 7 (kV)	Line 8 (kV)	Line 10 (kV)	Line 11 (kV)	Line 12 (kV)	Line 13 (kV)
14.8	14.7	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
14.8	14.5	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
14.8	14.6	14.7	14.7	14.7	15	14.7	14.7	14.7	14.7	14.7
14.7	14.2	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7	14.7
15	14.5	15	15	15	15	15	15	15	15	15
15	14.68	15	15	15	15	15	15	15	15	15
15	14.65	15	15	15	15	15	15	15	15	15
15	14.6	15	15	15	15	15	15	15	15	15
14.8	14.7	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8	14.8
15.1	14.67	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1	15.1
15	14.75	15	15	15	15	15	15	15	15	15
15	14.7	15	14.9	15	15	15	15	15	14.8	15
14.9	14.7	14.9	14.8	14.9	15	14.9	14.9	14.9	14.9	0.9

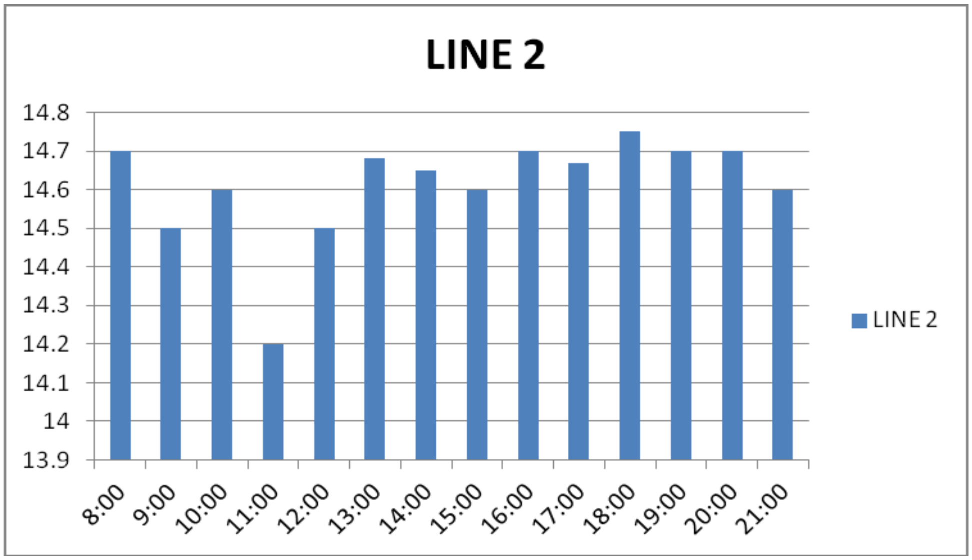


Figure 3.4: voltage variation for line 2 from substation control panel

Power factor compares the real power (watts) required to the apparent power (Volts-Amps) being consumed. A completely efficient system would have a power factor of 1.0. However, in this facility, inductive loads including motors, transformers, and high-intensity lighting were consuming significant reactive nonworking power in addition to real power. That was causing a low power factor. And since utilities start charging higher fees for power factors less than .95, this facility was getting higher power bills in addition to the voltage drops and overheating issues. For this thesis power factor measurement is taken from the sebeta I substation all outgoing feeders control panel.

Table 3.4 Power factor for the distribution line of 13 feeders (8:00-21:00)

L1	L2	L3	L4	L6	L7	L8	L10	L11	L12	L13
0.9	0.87	0.9	0.9	0.73	0.9	0.9	0.9	0.9	0.9	0.9
0.9	0.8	0.9	0.8	0.7	0.9	0.8	0.8	0.8	0.8	0.8
0.9	0.85	0.9	0.9	0.73	0.9	0.9	0.9	0.9	0.9	0.9
0.9	0.86	0.9	0.8	0.74	0.9	0.8	0.8	0.8	0.8	0.8
0.9	0.88	0.9	0.9	0.71	0.9	0.9	0.9	0.9	0.9	0.9
0.9	0.87	0.9	0.9	0.79	0.9	0.9	0.9	0.9	0.9	0.9
0.94	0.8	0.94	0.8	0.8	0.9	0.8	0.8	0.8	0.8	0.8
0.9	0.84	0.9	0.84	0.8	0.8	0.84	0.84	0.84	0.84	0.84
0.9	0.87	0.9	0.87	0.81	0.9	0.87	0.87	0.87	0.87	0.87
0.9	0.89	0.9	0.96	0.71	0.9	0.96	0.96	0.96	0.96	0.96
0.9	0.89	0.9	0.95	0.704	0.9	0.95	0.95	0.95	0.95	0.95
0.9	0.8	0.9	0.9	0.7	0.9	0.94	0.94	0.94	0.8	0.94
0.95	0.81	0.95	0.8	0.706	0.95	0.91	0.91	0.91	087	0.9

One of the critical reason for voltage drop is overloading of distribution line due to long distance coverage .The following table shows the maximum current carrying capacity, the over current setting value and the corresponding value in amperes for all outgoing lines.

Table 3.5 cable type, nominal current and over current setting

Outgoing Feeders	Type	CT Ratio	Nominal current(A)	Relay Setting	Over current (A)
Line-1	AL	400-800/1/1	800	0.5XIn	400
Line-2	"	"	800	0.6XIn	480
Line-3	"	"	800	0.68XIn	544
Line-4	"	"	800	0.81XIn	648
Line-6	CU	400-800/1/1	800	0.4XIn	320
Line-7	"	"	800	0.5XIn	400
Line-8	"	"	800	0.4XIn	320
Line-10	AL	"	800	0.6XIn	480
Line-11	"	"	800	0.6XIn	480
Line-12	"	"	800	0.5XIn	400
Line-13	"	"	800	0.4XIn	320
Line-5	CU	75-150/5/5	150	0.10XIn	81
Line-9	"	"	150	0.91XIn	137

Table 3.6 distribution cable type with rating for line 02

Cable type	R (Ω/km)	X (Ω/km)	I_{Sc} (kA)	I_{Rated}(kA)
XLPE AAAC95	0.307	0.34	8	1.012
AAC95	0.578	0.46	4.3	1.381
UG Al 240mm ^{2}	0.122	0.103	19.2	1.012
XLPE AAAC46	0.65	0.34	3.8	1.12

Where,

AL: ALMUNIUM **CU**: COPPER

R: Positive sequence resistance of conductor (O/km)

X: positive sequence reactance of conductor (O/km)

Isc (kA): short circuit capability

I Rated (kA): Thermal Limit

Monthly Peak Load Analysis

For the power system distribution network analysis the average value of the monthly peak load must be conducted in order to determine the cause of voltage drop problem. From the data of interruption Sebeta I substation line 02 have highly around 40 times per year interruption due to line overloading.

Table 3.7 Monthly peak load for four months

peak load	Average Current(A)			Average Power(MW)		
Bay	Max	Min	average	Max	Min	Average
132/15 TR 1	1730	1655	1692	56	52	54
132/15 TR2	1940	1502	1615	50	46	49
LINE 1	394	378	387	9	9	9.2
LINE 2	640	617	628	15	14	15
LINE 3	573	553	562	14	13	14
LINE 4	416	375	390	10	8.9	9.5
LINE 5	80	60	72.5	2	1.4	1.7
LINE 6	260	188	207	6	4.5	5
LINE 7	274	258	265	7	6.1	6.3
LINE 8	206	132	152	5	3.2	3.7
LINE 9	296	260	275	7	6.2	6.6
LINE 10	140	122	128	3	2.9	3.1
LINE 11	452	439	445	11	10	11
LINE 12	461	379	414	11	9	9.9
LINE 13	442	300	361	10	7.1	8.6

3.5 Distribution line power loss analysis

At the substations level, the incoming line power is lowered in voltage for distribution of local area using step down transformer. Each substation feeds its local load area by means of primary distribution feeders, some operating at 15kV. Ordinarily, primary feeders are one to five miles in length in rural sections where demands for electricity are relatively light and scattered, they are sometimes as long as 10 or 12 miles. These circuits are usually carried on poles; but in the more densely built-up sections, underground conduits convey the cables, or the cable may be buried directly in the ground.

Distribution transformers connect to the primary distribution lines. These transformers step down the primary voltage from 15kV to approximately 400 volts or 380 volts. A line which carries the energy at utilization voltage from the transformer to consumer's services are called secondary distribution mains and may be found overhead or underground. In the case of transformers supplying large amounts of electrical energy to individual consumers, no secondary mains are required. Such consumers are railroads, large stores, and factories.The service wires or cables are connected directly to these transformers.Transformers may also serve a number of consumers and secondary mains.

Services and meters link the distribution system and the consumer's wiring. Energy is tapped from the secondary mains at the nearest location and carried by the service wires to the consumer's building. As it passes on to operate the lights, motors, and various appliances supplied by the house wiring, it is measured by a highly accurate device known as the watt-hour meter. The watt-hour meter represents the cash register of the utility company. Through this electric power distribution processes, power energy distribution and supply cannot achieve 100% efficiency, there is a distribution loss that caused by different reasons.

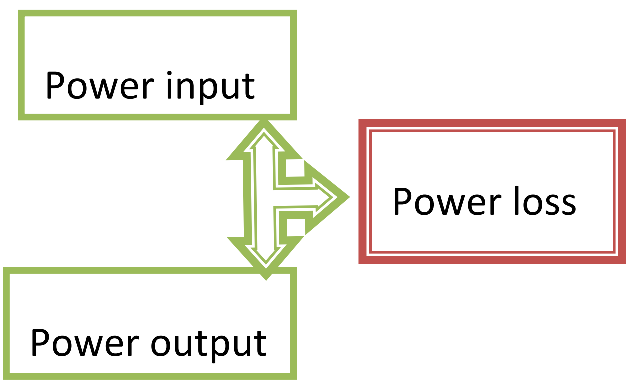


Figure 3.5 Electric power transfers

Distribution loss can be divided in to two

I. Technical loss; conductor or load loss, core loss or no load loss
II. Nontechnical loss; illegal connection, meter error, billing irregularity

Technical loss is energy loss due to the physics of the system

It is the physical properties of the components of the network that induces energy losses.

Conductor Loss or Load Loss

• Wires (conductors) have electrical resistance –a property of materials to resist the current.

$$Resistance = Resistivity * \frac{Length}{Area} \quad (3.1)$$

Resistivity depends on wire material.

- ✓ Length depends on distance between source and load.
- ✓ Area (cross-sectional) depends on wire size.

Conductor loss is energy lost to overcome this resistance, and manifests as heat.

$$Conductor\ Loss = current^2 * resistance \quad (3.2)$$

Current depends mostly on characteristics of the load (hence, load loss). The distribution network also has effects on the current.

No-Load Loss: When a transformer is energized, even when no load is connected, it already uses energy, energy loss here is associated with the transformer core.

Mostly technical loss can be obtained at

- ✓ Sub transmission lines
- ✓ Substation and Distribution power transformer
- ✓ Primary distribution line, Secondary distribution line
- ✓ Service drop, Voltage regulator capacitor, reactor

This distribution technical loss can be obtained through technical simulations depending on the conductor type and covering distance resistance will vary.

Table 3.8 power loss

Line	Distance(km)	Power(MW)	Current(A)	Line power loss (MW)
Line 1	10.8	9.4	394	0.23
Line 2	40.12	15.2	640	0.43
Line 3	25.7	13.1	573	0.1396
Line 4	27.3	9.6	416	0.1207
Line 5	19.8	1.9	74	0.0541472
Line 6	20.1	6.2	260	0.1437
Line 7	19.5	6.1	274	0.243777
Line 8	16.9	4.9	206	0.1542688
Line 9	24.4	6.6	296	0.207
Line 10	1.3	3	140	0.00006
Line 11	24.2	10.5	452	0.1543
Line 12	13.3	9.8	461	0.00154
Line 13	27.9	8.8	442	0.291

Total power loss = 2.1679MW

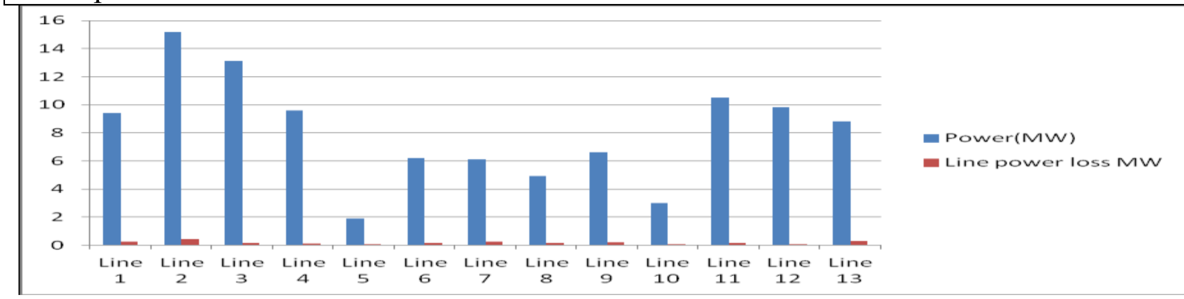


Figure 3.6 Power loss analysis

Line overload analysis is performed by comparative analysis of maximum load registered with the line nominal current setting, those loads (both in Mega Watts and Amperes) registered is shown so that we can compare the maximum load with maximum threshold value and current capacity of the installed Current Transformer.

Table 3.9 Maximum power registered for the 6 distribution lines

	Line 1	Line 2	Line 3	Line 4	Line 5	Line 6	Sum
Nominal current (A)	400A	480A	544A	648A	81A	320A	2792A
Max load current (A)	393A	640A	553A	375A	79A	188A	2228A
Max power(MW)	9.4MW	15.2MW	13.2MW	9.6MW	1.9MW	6.2MW	55.5MW
% of loading	393/400= 98.25%	640/480= 134.36%	553/544= 101.65%	375/648= 57.87%	79/81= 97.31%	188/320 =59.2%	
Power factor	0.94	0.89	0.9	0.94	0.899	0.78	

In order to limit further the scope the study area, one feeder of Sebeta-I substation is selected as a case study network among the total 13 feeders of the substation based on their vulnerability to frequent power interruption and long duration outage of a feeder. Among the 13 feeders of the substation, a feeder which has more frequent power interruption with long duration outage of the feeder is preferred as a base case study network.

Table 3.10: Sebeta-I substation outgoing feeder power interruption frequency due to overload

Feeder	Power Interruption due to Overload Freq(Interruption /Year) >1hr/day	Feeder	Power Interruption due to Overload Freq(Interruption /Year) >1hr/day
1	10	7	0
2	40	8	1
3	7	9	5
4	8	10	6
5	1	11	8
6	12	12	25
		13	35

Chapter Four

Network modeling and Simulation studies

4.1 Introduction

In this chapter modeling and simulation of Sebeta I substation and outgoing feeder 02distribution system by using DigSILENT Power Factory 14.1.7 simulation software was performed. In addition, the Impact of overloading on technical parameters of distribution system and the mitigation techniques is also implemented comparatively conducted under different scenarios.

4.2 DIgSILENT Power Factory software

Is computer aided engineering tool for the analysis of transmission, distribution, and industrial electrical power systems. **DigSILENT** is an acronym for **Dig**ital **SI**mu**L**ation of **E**lectrical **N**e**T**works. To address user's power system analysis requirements, **Power Factory** was designed as an integrated engineering tool to provide a comprehensive suite of power system analysis functions within a single executable program. Key features include:

- Power Factory core functions: definition, modification and organization of cases; core numerical routines output and documentation functions.
- Integrated interactive single line graphic and data case handling.
- Power system element and base case database.
- Integrated calculation functions (e.g. line and machine parameter calculation based on geometrical or nameplate information).
- Power system network configuration with interactive or on-line SCADA access.

The software provides an environment to implement operations of a real-life power system with all the calculations. Its huge single database supports all power system functions load flow, time domain RMS simulation, modal analysis, fault calculation/analysis(IEC, ANSI, and VDE), protective relay coordination, reliability, etc.

Power Factory is primarily intended to be used and operated in a graphical environment.That is, data is entered by drawing the network elements, and then editing and assigning data to these objects. Data is accessed from the graphics page by double-clicking on an object. An input dialogue is displayed and the user may then edit the data for that object.

4.3 Inputs parameters for software simulation

To simulate the overall Sebeta I Substation distribution network, the following points has been considered as an inputs parameters:

- Active, reactive and apparent power of transmission and distribution network
- Load in ampere
- Voltage and power factor at substation and distribution network
- Transmission and distribution network parameters
- Distribution line coverage distance
- Distribution line parameters with transformer ratings
- Current transformer relay and circuit breakers ratings from EEU and EEP

4.4 Ethiopia Electric Power (EEP) Network Model

The power system is made of more than a few parts: generators, transmission lines, distribution transformers, loads, and shunt components.In this thesis however, main objective is on controlling of voltage and reactive power for power loss minimization on only distribution network of sebeta I substation design with the data that is obtained from EEP. These parts of the power system are implemented by way of modeling simulation on mechanisms of how to reduce the power loss.

There are many possibilities to model electrical component, either in detail or in simple form in Power Factory, but only basic modeling component and those options that are necessary for load flow are considered here. The power system component models of the EEP network in the Power Factory software are designed with its simulation result.

This simulation performed without any distribution network voltage and reactive power control for power loss minimization technique. In farther more studies cause of voltage drop is overloading of the system and reactive power due to different type of loads. As voltage drop more from the permissive value leads to power loss increment and as power supply networked for long distance the problem will increase further.

Currently, Sebeta-I Substation has 13 feeders of 15kV lines which supply power to 15/0.4kV transformers, which feed different consumers such as residential, commercial and industrial. The whole distribution system has an average power factor of 0.871. To limit the scope of the study the single line diagram of figure below which shows only the two transformers of capacity 50MVA, 132/15 kV which supply power to the thirteen feeders and 15 kV line respectively.

Original network configuration using data from EEP and EEU

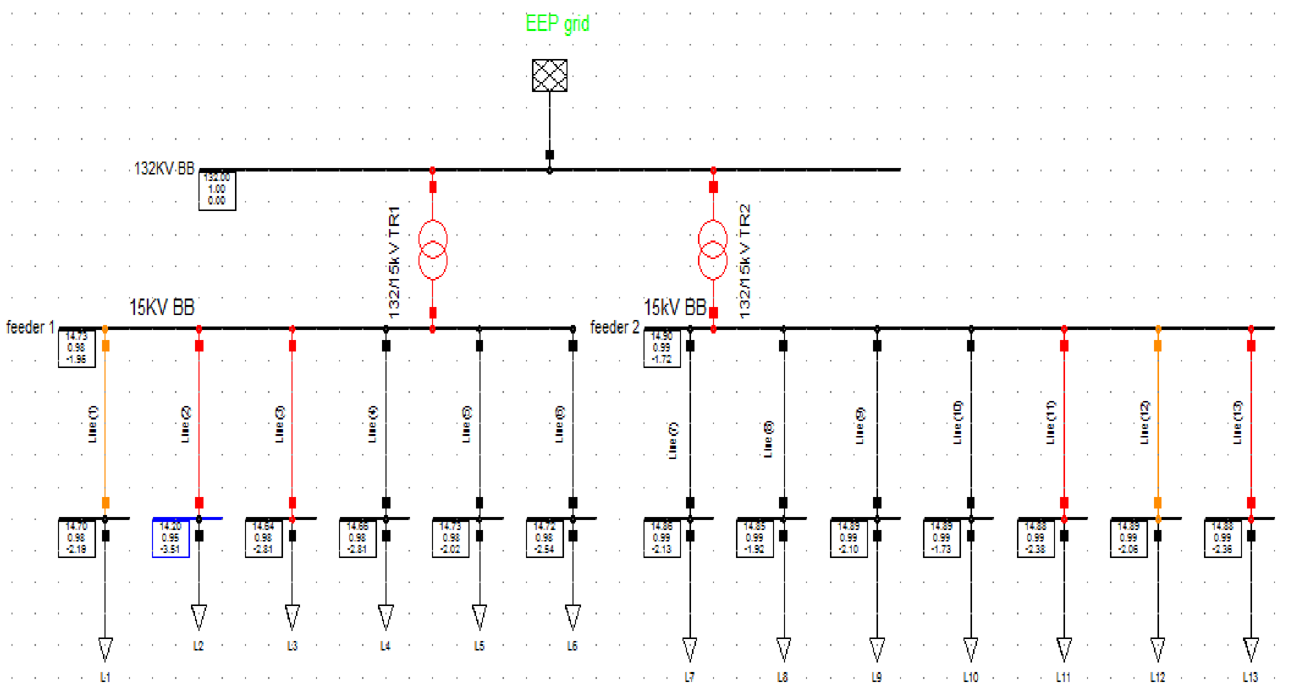


Figure 4.1 General diagram of substation and feeder 2

```
------------------------------------------------------------------------------------------------------------------
| Grid: Grid                  System Stage: Grid            | Study Case: Study Case              | Annex:          / 1  |
------------------------------------------------------------------------------------------------------------------
| Grid: Grid                  Summary                                                                              |
|                                                                                                                  |
| No. of Substations     0         No. of Busbars         263        No. of Terminals      2          No. of Lines          139   |
| No. of 2-w Trfs.       125       No. of 3-w Trfs.       0          No. of syn. Machines  0          No. of asyn.Machines  0     |
| No. of Loads           453       No. of Shunts          0          No. of SVS            0                                      |
|                                                                                                                  |
| Generation             =      0.00  MW          0.00  Mvar      0.00  MVA                                      |
| External Infeed        =    107.05  MW         31.85  Mvar    111.69  MVA                                      |
| Inter Grid Flow        =      0.00  MW          0.00  Mvar                                                     |
| Load P(U)              =    104.85  MW         23.48  Mvar    107.44  MVA                                      |
| Load P(Un)             =    104.85  MW         23.49  Mvar    107.45  MVA                                      |
| Load P(Un-U)           =      0.00  MW          0.00  Mvar                                                     |
| Motor Load             =      0.00  MW          0.00  Mvar      0.00  MVA                                      |
| Grid Losses            =      2.21  MW          8.37  Mvar                                                     |
| Line Charging          =                        0.00  Mvar                                                     |
| Compensation ind.      =                        0.00  Mvar                                                     |
| Compensation cap.      =                        0.00  Mvar                                                     |
```

Figure 4.2 Grid summary report

Sebeta I substation there are two 132/15kV power transformers which having the rating of 50MVA capacity of apparent power. The apparent power S is related to line voltage, V and line current, I:

$$S = \sqrt{3} * V * I \tag{4.1}$$

From the above equation I = 50000VA/ (√3*15V) = 1924.5A

This is the maximum possible current to be delivered to the feeder that is why the over current setting is 0.96*nominal current (2kA) = 0.96*2000A=1920A.

If the transformer is able to supply more power than this value, upgrading the Current transformer and cable of the feeder and changing the over current setting of the feeder and the lines to a higher value is the easiest option to give solution to the problem.

Power factor (P.F) is the ratio between actual powers (MW) to the apparent power (MVA)

$$P.F = \frac{MW}{MVA} \quad (4.2)$$

For a purely resistive load the power factor is unity. Active and reactive powers are designated by P &Q respectively. The average power in a circuit is called active power (MW) and the power that supplies the stored energy in reactive elements is called reactive power (MVAR).

Power factor of outgoing line 02 ($P.F = \frac{MW}{MVA}$) =15.2MW/16.6MVA=0.91.

Apparent power (S) are directly related to the active (P) and reactive power (Q) and when variation of those power can cause the variation of voltage on which reactive power is directly related to the reactive power.

$$S = P + jQ \quad (4.3)$$

Sum of power at peak load hours which is registered is 55.5MW+ j23.54MVAR = 58.9 MVA. But maximum power to be supplied by the feeder, $S_{FeedMax}$ is 50MVA.on this case power transformer I 132/15kV is overloaded by 8.9MVA so external system should be able to supply this amount to overcome problem of overloading. Also the voltage at the bus bar of end terminal of line 02 is measured with in 4 km for the last ten transformers.

Table 4.1: Voltage measurement

bas bar(BB)	Name	Voltage(kV)	Per unit
BB124	TR0034	13.02	0.868
BB 120	TR0058	13.05	0.87
BB116	TR0046	13.09	0.872667
BB112	TR001	13.14	0.876
BB108	TR0023	13.2	0.88
BB104	TR0107	13.38	0.892
BB100	TR1001	13.49	0.899333
BB96	TR008	14.2	0.946667
BB92	TR098	14.27	0.951333
BB88	TR1004	14.44	0.962667

4.5 Techniques used to control voltage drop and reactive power problem

From the literature reviewed there are different mechanisms that are used for reduction of voltage drop and reactive power control:

- Using capacitor bank
- Use of distributed generation(micro turbine)
- by load sharing
- Using additional transformers

These thesis works on this mechanism comparatively to select the best way of reduction of voltage drop and reactive power problems for real power loss minimizations.

4.5.1 Distributed generation

In general terms,Distributed Generation is any type of electrical generator or static inverter producing alternating current that (a) has the capability of parallel operation with the utility distribution system, or (b) is designed to operate separately from the utility system and can feed a load that can also be fed by the utility electrical system.

Distributed generation is emerging as an important option for the future development and restructuring of electricity infrastructure. Possible benefits of distributed generation include lower electricity costs, higher flexibility, improved power quality, higher system efficiency and greater reliability. Micro-turbines are one of the most promising DG technologies and they are the best technologies for peak shaving applications.

The use of micro turbines for power generation has increased in recent years and is likely to continue to increase due to small scale and other properties of advantages. Micro turbines are low-power versions of traditional gas turbines used in power plants and one of the best short-term distributed power production options because of their simplicity, no major technological breakthroughs are required for deployment and Low emissions also characterize modern micro turbines [5, 10].

But there are some disadvantages from using micro-turbines:

- Noisy operation needs additional equipment and soundproofing for control of noise levels.
- Low fuel efficiency; efficiency is dependent on the inlet fuel parameters [10].

Micro-turbine generators are designed to operate at full rated efficiency only under full load conditions.The fractional load performance of micro-turbines is lower than full load performance because the mechanical power output is reduced proportionally with the decrease in electric load demand.So micro-turbines are the most promising technologies for peak-shaving applications. Micro-turbine technology is based on the design of much larger combustion turbines employed in the electric power and aviation industries.

Micro turbine design character; prime mover is a simple Brayton cycle with or without recuperation.They are operated at much lower pressure ratios (3/4) than larger gas turbines (10/15) larger gas turbines (10/15).

In a recuperated system, pressure ratio is in direct proportion to temperature spread between inlet and exhaust.With recuperator,net cycle efficiency increases to as much as 30%and unrecuperated average 17% net efficiency.

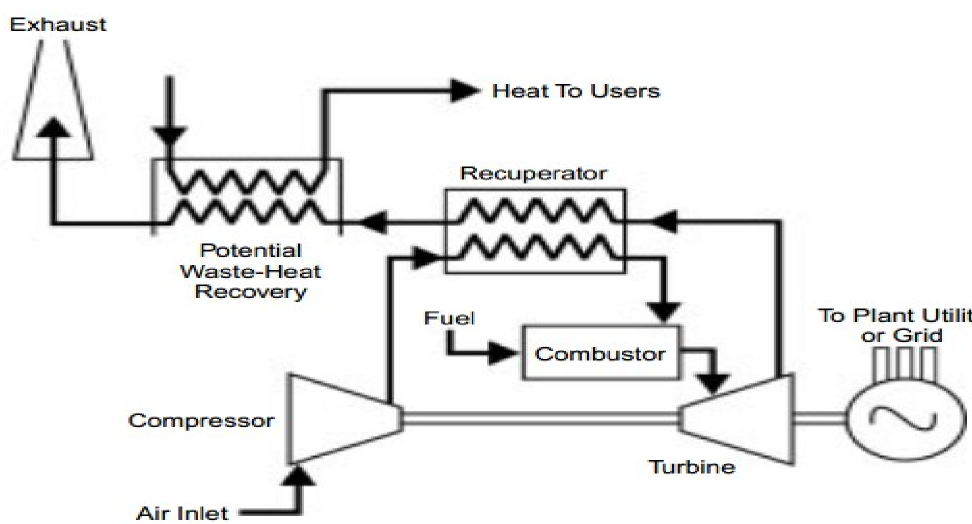


Figure 4.3 a general schematic of micro turbine process

Micro-turbines generally work as follows:

Fuel is supplied to the combustor section of the micro-turbine under 70 to 80 pounds per square inch gauge (psig) of pressure. Air and fuel are burned in the combustor, releasing heat that causes the combustion gas to expand. The expanding gas powers the gas turbine that in turn operates the generator, the generator then produces electricity [10].The output of micro turbine is DC form to make them to operate with grid interconnected it must be converter to AC so high power transistors can be configured into various topologies (e.g. DC-to-DC, AC-to-DC, OR DC-to-AC).For power levels up to~500 kW, insulated gate bipolar transistor (IGBT) is the most commonly used today switching frequencies up to 20 KHz can be obtained using these devices transistors are controlled to be only on or off and waveforms produced consist of pulses with very high harmonic content.

Selection of micro turbine

From the grid summary rating, we have:

Total power factor of load (pf) =0.97 at transformer 01

Power rating of TR- 01, apparent power (S) = 50MVA Active power (P) =48.15MW

Reactive power (Q) =13.47MVAR

But currently this substation is loaded at P=55.5MW; Q=19.6MVAR, S=58.9MVA

So 58.9-50=8.9 MVA capacity external supply is required from Distributed Generation in order to reduce transformer overloading problem.

Capstone C1000, which is Fie C200 power modules in one package, is selected for this thesis. The fuel flexibility of Capstone micro turbines is a critical competitive advantage. It micro-turbines operate faultlessly across wide variety of fuels.

Specification of

- ✓ Rating: 1000kW
- ✓ Electrical Efficiency LHV: 33%
- ✓ Voltage: 400-480 VAC
- ✓ Frequency: 50/60 Hz,
- ✓ Compatible Fuels: Natural Gas, Liquid Fuels Low Sulfur Diesel

4.5.2 Load sharing between line 2 of transformer one with line 9 of transformer two

The problem of overloads, voltage difference and heating effects is very common in power distribution. It takes lot of time to its repair and also involves lot of payments also causes system interruption feeder transformer outage under overload condition. In high voltage power transformer overload cause the efficiency to be gets reduced and the secondary winding gets overheated or it may be burnt. So, by reducing the extra load, the transformer can be protected. This problem can be reduced by operating another transformer in parallel with main transformer through comparator and change over relay or by making two transformer outgoing feeders to share loads. The comparator compares the load on the first transformer with a reference value. When the load exceeds the reference value, the second transformer will automatically be connected in parallel with first transformer and share the extra load. Therefore, two transformers work efficiently under overload condition and the damage can be prevented.

In Sebeta I substation there are two 132/15kV power transformers that supply power through 13 outgoing line. From these lines, line 02 of transformer one and line 09 of transformer two supplies the same area, but line 09 is loaded 57%below its loading capability so after 9km from the substation area line 02 and line 09 can share their loads around bethel area. For load sharing there are different types of pole; Wood, Concrete and Steel.

From different type of poles mentioned above, concert pole is more advantageous based on cost and easily maintenance capability. Concrete pole with accessories for 10Km and also there is aluminum conductor cables 2/1xlpe with disconnector and bushings is selected.

4.5.3 Additional 50MVA 132/15 kV transformer

Parallel operation of existing transformer with additional transformer means two or more transformers are connected to the same Supply bus bars on the primary side and to a common bus bar/load on the secondary side. Such requirement is frequently encountered in practice. The reasons that necessitate parallel operation are as follows.

1. Non-availability of a single large transformer to meet the total load requirement.
2. The power demand might have increased over a time necessitating augmentation of the capacity. More transformers connected in parallel will then be pressed into service.
3. To ensure improved reliability. Even if one of the transformers gets into a fault or is taken out for maintenance/repair the load can continue to be serviced.
4. To reduce the spare capacity. If many smaller size transformers are used one machine can be used as spare. If only one large machine is feeding the load, a spare of similar rating has to be available. The problem of spares becomes more acute with fewer machines in service at a location.
5. When transportation problems limit installation of large transformers at site, it may be easier to transport smaller ones to site and work them in parallel.

Certain conditions have to be met before two or more transformers are connected in parallel and share a common load satisfactorily. They are,

Same voltage ratio-Generally the turns ratio and voltage ratio are taken to be the same. If the ratio is large there can be considerable error in the voltages even if the turn's ratios are the same. When the primaries are connected to same bus bars, if the secondaries do not show the same voltage, paralleling them would result in a circulating current between the secondaries. This reflected circulating current will be there on the primary side. Thus even without connecting a load considerable current can be drawn by the transformers and they produce copper losses. In two identical transformers with percentage impedance of 5 percent, a no-load voltage difference of one percent will result in a circulating current of 10 percent of full load current. This circulating current gets added to the load current when the load is connected resulting in unequal sharing of the load. In such cases the combined full load of the two transformers can never be met without one transformer getting overloaded.

Per unit impedance Transformers of different ratings may be required to operate in parallel. If they have to share the total load in proportion to their ratings the larger machine has to draw more current. The voltage drop across each machine has to be the same by virtue of their connection at the input and the output ends. Thus the larger machines have smaller impedance and smaller machines must have larger ohmic impedance. Thus the impedances must be in the inverse ratios of the ratings. As the voltage drops must be the same as per unit impedance of each transformer on its own base, must be equal. In addition if active and reactive power is required to be shared in proportion to the ratings the impedance angles also must be the same. Thus we have the requirement that per unit resistance and per unit reactance of both the transformers must be the same for proper load sharing.

Polarity of connection -The polarity of connection in the case of single phase transformers can be either same or opposite. Inside the loop formed by the two secondaries the resulting voltage must be zero. If wrong polarity is chosen the two voltages get added and short circuit results. In the case of poly phase banks it is possible to have permanent phase error between the phases with substantial circulating current. Such transformer banks must not be connected in parallel. The turn's ratios in such groups can be adjusted to give very close voltage ratios but phase errors cannot be compensated. Phase error of 0.6 degree gives rise to one percent difference in voltage. Hence poly phase transformers belonging to the same vector group alone must be taken for paralleling.

Transformers having -30^{o} angle can be paralleled to that having $+30^{o}$ angle by reversing the phase sequence of both primary and secondary terminals of one of the transformers. This way one can overcome the problem of the phase angle error.

Phase sequence: The phase sequence of operation becomes relevant only in the case of poly phase systems.The poly phase banks belonging to same vector group can be connected in parallel. A transformer with $+30^{o}$ phase angle however can be paralleled with the one with -30^{o}

phase angle.The phase sequence is reversed for one of them both at primary and secondary terminals. If the phase sequences are not the same then the two transformers cannot be connected in parallel even if they belong to same vector group. The phase sequence can be found out by the use of a phase sequence indicator.

By considering the criteria for connecting transformer in parallel for overloading problem reduction the following specification help to select the appropriate additional transformer on-load tap changer.

Specification; 50MVA, 132/15kV Transformer reactance =1.25%

Table 4.2: Transformer specification

Rated voltage (132±7*1.43%)/15kV)
Mounting position 2500m
Type of cooling ONAN/ONAF 80/100%
Rated frequency 50 Hz
Load loss 175.4 kW
No load loss 31.67kW
No load current 0.12%
Impedance -min taping 11.50%
-Rated taping 11.70%
- Max taping 12.42%

The above specification is taken from the transformers that are currently working in sebeta I substation. For parallel operation of additional transformer with the existing, selected based on this specification.

4.5.4 Design of capacitor bank

Most of distribution systems have problems such as poor voltage regulation, poor power factor, high power losses and poor efficiency, overloading. It is needed to be improving the working of the power distribution systems to reduce the poor conditions and reduce power losses, improve voltage regulation, etc. On a power line, moreover the active power and reactive power must also be existing for inductive loads. An alternator can produce the reactive power for the line, but the reactive power can be supplied from any source that can be either an alternator or capacitor groups connected near the load. The reactive power source must be very close to the load for efficient operation of the system. If the reactive power of any load is supplied from a synchronous motor or a group of capacitors rather than the power line, this system is called reactive power compensation.

So, this compensator make power factor of the system kept at a critical value. The voltage control is achieved by regulating the reactive output of the generating plants, tap changing on the transformers and switching on or out reactors or capacitors to achieve target system voltages.

Shunt capacitors are relatively inexpensive to install and maintain. Installing shunt capacitors in the load area or at the point that they are needed will increase the voltage stability. However, shunt capacitors have the problem of poor voltage regulation and, beyond a certain level of compensation; a stable operating point is unattainable. Furthermore, the reactive power delivered by the shunt capacitor is proportional to the square of the terminal voltage, during low voltage conditions reactive power support drops, thus compounding the problem.

To design the rating of capacitor bank for feeder 02 voltage profile improvement the following data are consider;

Voltage = 15 kV /400V

Present maximum active power P (MW) =15.2MW

Present maximum apparent power S (MVA) = 16.64MVA

Present maximum reactive power Q (MVAR) =6.76MVAR

Power factor (maximum load) = 91.3%

Desired power factor = 97%

If the power factor is raised to (pf_2) =97%

$$MVA_2 = \frac{MW}{pf_2} \tag{4.4}$$

= 15.2/.97

=15.67 MVA

The size of the capacitor bank required to accomplish this is determined from the MVAR at the two values of power factor as follows:

$$\text{Capacitor rating MVAR} = \text{MW}\left((\tan \cos^{-1}(\text{pf1}) - \tan \cos^{-1}(\text{pf2})\right) \tag{4.5}$$

=15.2 ($\tan\cos^{-1}0.91 - \tan\cos^{-1}0.97$)

=15.2(0.445-0.25)

= 2.95MVAR

For the maximum load condition the capacitor rating for power factor of 0.97 is increased to multiplier of 0.205 of active power =15.2MW*0.205 = 3.116MVAR then capacitor bank rating will be around 4MVAR

$$\text{MVAR2} = \text{MVAR1} - \text{capacitor rating} \tag{4.6}$$

=6.76-2.95

=3.81

$MVA_{2} = (3.81^2+15.2^2)^{.5}$

=15.67MVA

$$\text{Power factor}_2 = \frac{\text{MW}}{\text{MVA2}} \tag{4.7}$$

=15.2/15.67=0.97

Advantages of capacitor bank

Voltage rise

The approximate voltage change due to capacitors at a transformer primary bus is determined by using the following equation:

Capacitor Rating = 3.11MVAR

Transformer Reactance = 1.255%

$$\%\ \text{voltage rise} = 100 * \frac{[\text{capacitor MVAR} * \text{transformer reactance}\%]}{\text{transformerMVA}} \tag{4.8}$$

% Voltage Rise = (3.11*1.25)/50=7.375%

Line current reduction

The percentage of line current reduction may be approximated from this equation

$$\%\ \text{current loss} = 100 \times \left[1 - \frac{[\text{present power factor}]}{\text{improvedpowerfactor}}\right] \tag{4.9}$$

. I_L=100[1-0.913/0.97]=4.02%

Power Losses reduction

An estimate of reduction of power losses can be made using following equations.

$$\%\ \text{loss reduction} = 100 \times [1 - \frac{[\text{present power factor}^2\ ]}{\text{improved power factor}^2} \tag{4.10}$$

$=100[1-[0.913/0.97]^2]$

=14.4 %

Capacitor bank is used in the distribution systems for voltage drop and reactive power problem, act to improve power factor. In these installations, reactive output rating of capacitor bank is chosen at 4MVAR.The single phase discharge coil is connected so as to bridge each phase leg of a capacitor bank.The secondary windings of the discharge coil are used for protecting relay system.The series reactor is connected in series with capacitors at neutral side of the bank.

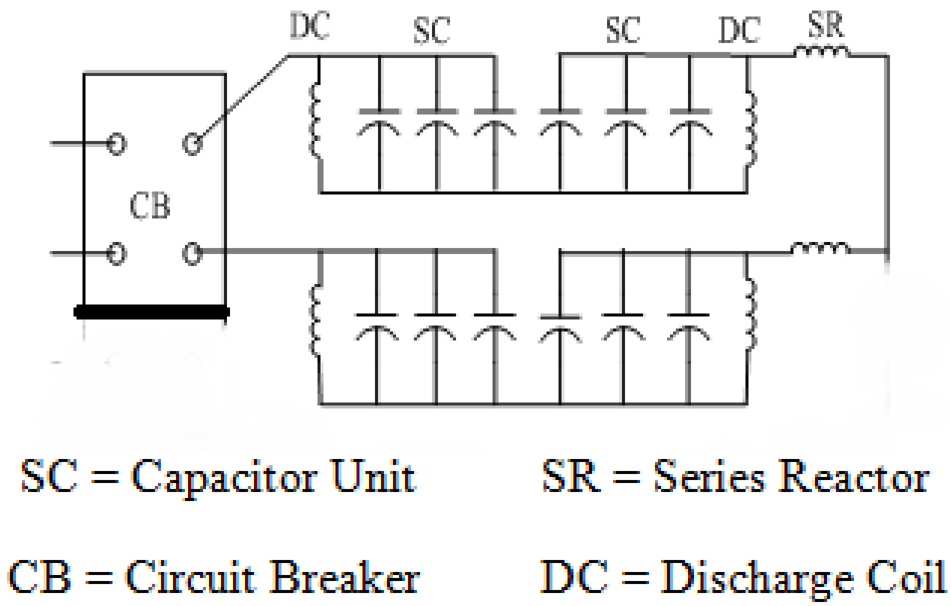


Figure 4.4: Capacitor bank configuration and internal component

China General Electric Capacitors Bank 400V 50Hz Metal Case Outdoor parallel connected units having 10*400kVAR rating has been selected.

With Specifications of

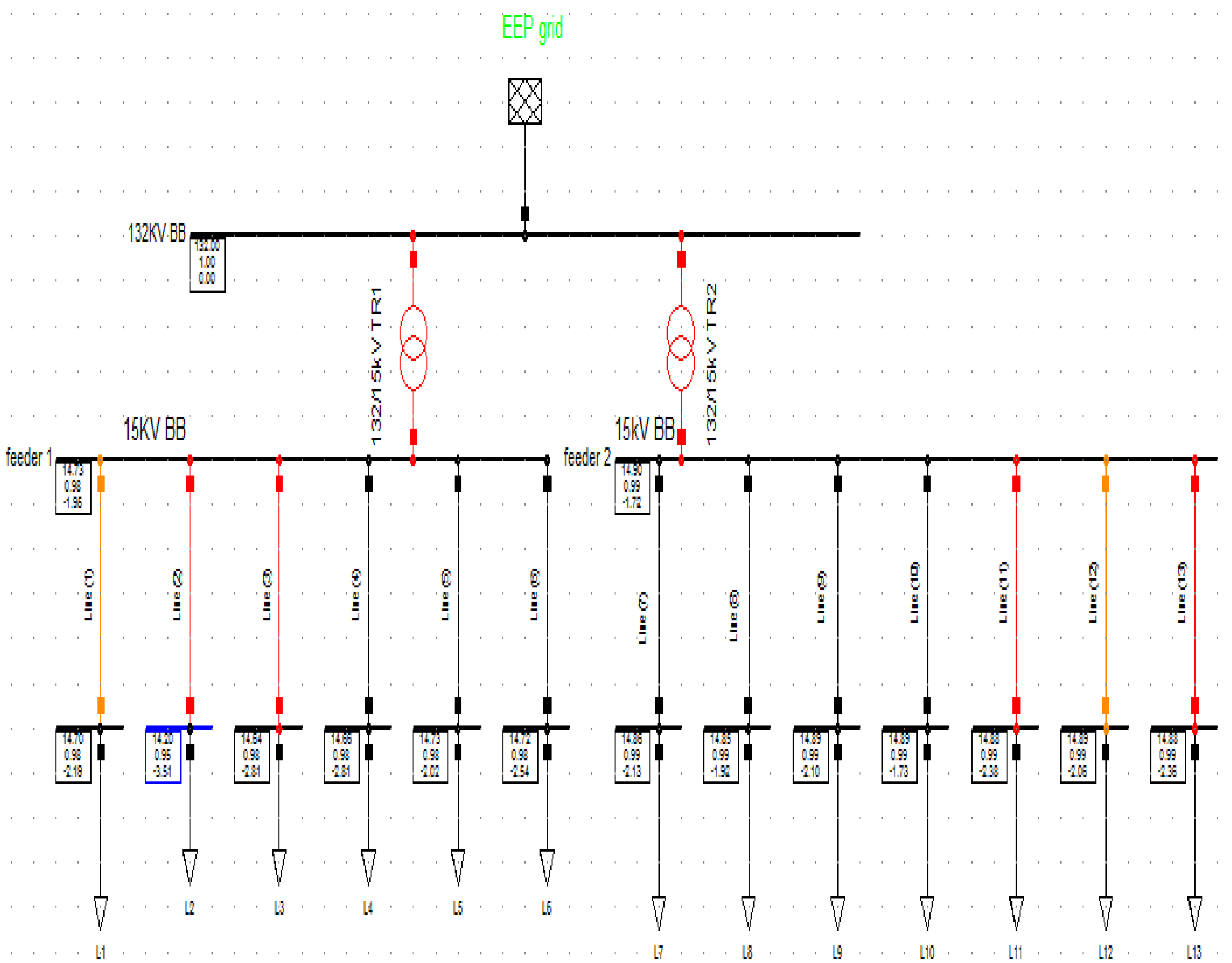
- 400kVAR general electric capacitors bank 400V 50 Hz metal case outdoor;
- Series GGD0.4-400kVAR/10step Over Current Tolerance 30% permanently
- Rated Voltage Range From 220-1000 VAC Max.
- Capacitor Connection 3 phase Dielectric Loss =0.2 W / kVAR
- Capacitor Frequency 50/60 Hz.
- Maximum Ambient Temperature 25 °C-50°C Max. Altitude = 2000m
- Standard IEC60831 / GBT12747
- FOB price US $24 - 120 / P

The optimal placement of a capacitor bank is based on the load type.But most preferable allocation for capacitor bank is if it is placed near to load because the load highly dependent on the voltage variation most capacitor bank is connected in parallel.

4.6 Computer Simulation results of Distribution Network

Computer simulation analysis is taken place by using DIgSILENT software with the condition of different techniques that are used for voltage drop and reactive power problems. In a very simplified way which has an equal amount of load and power factor to the actual network which is shown below.

Original network without any technique of power loss reduction



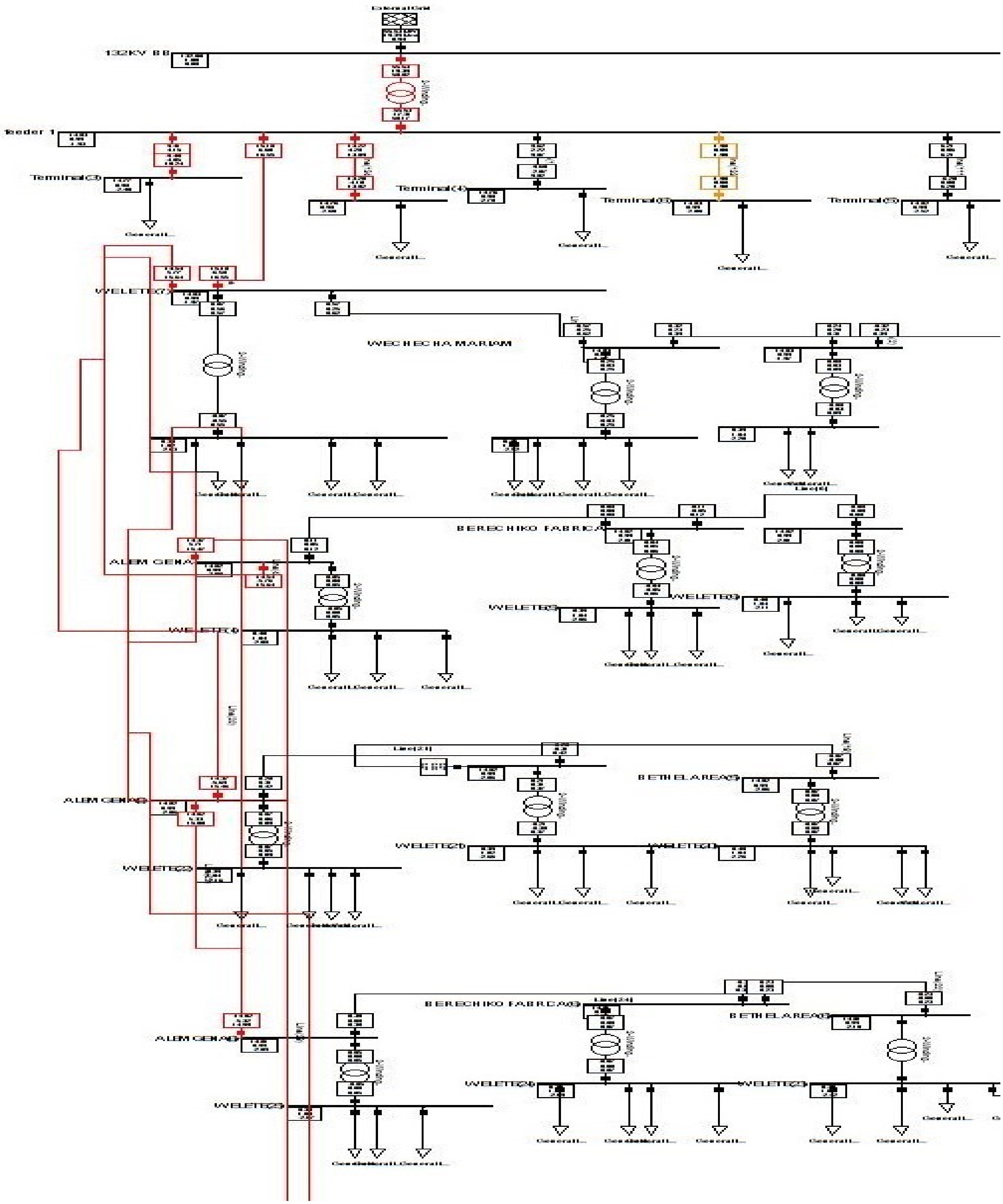


Figure 4.5 Load flow analysis for sebeta I substation and distribution line 02

```
---------------------------------------------------------------------------------------------------------------
| Grid: Grid                System Stage: Grid          | Study Case: Study Case            | Annex:            / 1  |
---------------------------------------------------------------------------------------------------------------
| Grid: Grid                Summary                                                                           |
|                                                                                                             |
| No. of Substations      0        No. of Busbars       263       No. of Terminals     2        No. of Lines          139   |
| No. of 2-w Trfs.      125        No. of 3-w Trfs.       0       No. of syn. Machines 0        No. of asyn.Machines  0     |
| No. of Loads          453        No. of Shunts          0       No. of SVS           0                      |
|                                                                                                             |
| Generation          =      0.00  MW          0.00  Mvar        0.00  MVA                                    |
| External Infeed     =    107.05  MW         31.85  Mvar      111.69  MVA                                    |
| Inter Grid Flow     =      0.00  MW          0.00  Mvar                                                     |
| Load P(U)           =    104.85  MW         23.48  Mvar      107.44  MVA                                    |
| Load P(Un)          =    104.85  MW         23.49  Mvar      107.45  MVA                                    |
| Load P(Un-U)        =      0.00  MW          0.00  Mvar                                                     |
| Motor Load          =      0.00  MW          0.00  Mvar        0.00  MVA                                    |
| Grid Losses         =      2.21  MW          8.37  Mvar                                                     |
| Line Charging       =                        0.00  Mvar                                                     |
| Compensation ind.   =                        0.00  Mvar                                                     |
| Compensation cap.   =                        0.00  Mvar                                                     |
|                                                                                                             |
| Installed Capacity  =      0.00  MW                                                                         |
| Spinning Reserve    =      0.00  MW                                                                         |
|                                                                                                             |
| Total Power Factor:                                                                                         |
|   Generation        =        0.00  [-]                                                                      |
|   Load/Motor        =  0.98 / 0.00  [-]                                                                     |
---------------------------------------------------------------------------------------------------------------
```

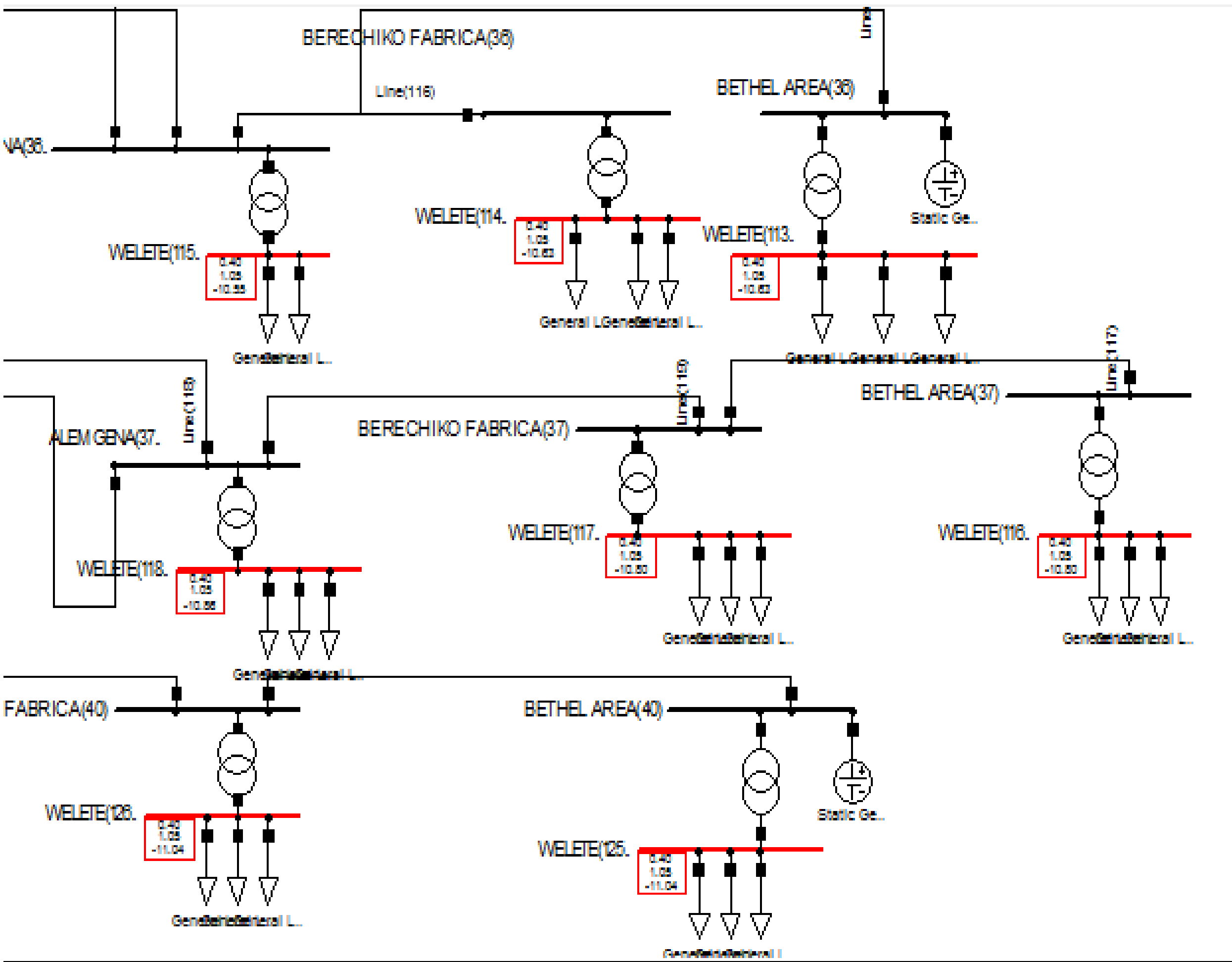
Figure4.6 grid summary for original network

```
-----------------------------------------------------------------------------------------------------
|                       rtd.V     Bus - voltage                      Voltage - Deviation [%]        |
|                        [kV]   [p.u.]     [kV]   [deg]        -10      -5       0       +5     +10  |
-----------------------------------------------------------------------------------------------------
|                        0.38    0.916     0.35 -24.49                                              |
|BERECHIKO FABRICA(37)                                                                              |
|                       15.00    0.869    13.04 -24.52                                              |
|BETHEL AREA(37)                                                                                    |
|                       15.00    0.869    13.04 -24.52                                              |
|WELETE(116)                                                                                        |
|                        0.38    0.915     0.35 -24.82                                              |
|WELETE(117)                                                                                        |
|                        0.38    0.915     0.35 -24.82                                              |
|ALEM GENA(37)                                                                                      |
|                       15.00    0.869    13.04 -24.52                                              |
|WELETE(118)                                                                                        |
|                        0.38    0.915     0.35 -24.90                                              |
|BERECHIKO FABRICA(38)                                                                              |
|                       15.00    0.869    13.03 -24.79                                              |
|WELETE(119)                                                                                        |
|                        0.38    0.914     0.35 -25.18                                              |
|WELETE(120)                                                                                        |
|                        0.38    0.915     0.35 -25.18                                              |
|ALEM GENA(38)                                                                                      |
|                       15.00    0.869    13.03 -24.79                                              |
|WELETE(121)                                                                                        |
|                        0.38    0.914     0.35 -25.28                                              |
|BERECHIKO FABRICA(39)                                                                              |
|                       15.00    0.868    13.03 -25.00                                              |
|BETHEL AREA(39)                                                                                    |
|                       15.00    0.868    13.03 -25.01                                              |
|WELETE(122)                                                                                        |
|                        0.38    0.914     0.35 -25.39                                              |
|WELETE(123)                                                                                        |
|                        0.38    0.914     0.35 -25.40                                              |
|ALEM GENA(39)                                                                                      |
```

Figure 4.7 grid summary for voltage profile report

4.6.1 Load flow simulation with different technique for reduction of voltage drop and reactive power problems

Use of micro turbine (9MVA) with 18*.5 MVA placed different area within outgoing line two




```
| Grid: Grid            System Stage: Grid       | Study Case: Study Case          | Annex:          / 1  |
| Grid: Grid            Summary                                                                         |
|                                                                                                       |
| No. of Substations    0      No. of Busbars     255     No. of Terminals     2     No. of Lines       132  |
| No. of 2-w Trfs.      124    No. of 3-w Trfs.   0       No. of syn. Machines 0     No. of asyn.Machines 0  |
| No. of Loads          446    No. of Shunts      0       No. of SVS           0                          |
|                                                                                                       |
| Generation          =    6.60  MW      5.60  Mvar     8.66  MVA                                        |
| External Infeed     =   48.76  MW      8.32  Mvar    49.47  MVA                                        |
| Inter Grid Flow     =    0.00  MW      0.00  Mvar                                                     |
| Load P(U)           =   54.35  MW     11.15  Mvar    55.48  MVA                                        |
| Load P(Un)          =   54.35  MW     11.15  Mvar    55.48  MVA                                        |
| Load P(Un-U)        =    0.00  MW      0.00  Mvar                                                     |
| Motor Load          =    0.00  MW      0.00  Mvar     0.00  MVA                                        |
| Grid Losses         =    1.01  MW      2.78  Mvar                                                     |
| Line Charging       =                  0.00  Mvar                                                     |
| Compensation ind.   =                  0.00  Mvar                                                     |
| Compensation cap.   =                  0.00  Mvar                                                     |
|                                                                                                       |
```

Figure 4.8 grid summary report using micro turbine at end of eight bus bar of line 2

| Grid: Grid | System Stage: Grid | Study Case: Study Case | Annex: / 1 |

	rtd.V [kV]	Bus - voltage [p.u.]	[kV]	[deg]
WECHECHA MARIAM	15.00	0.995	14.93	-1.71
META BERWEY	15.00	0.995	14.93	-1.71
YES WATER AND AROUND	15.00	0.995	14.93	-1.71
WELETE(1)	0.38	1.047	0.40	-2.25
WELETE(2)	0.38	1.046	0.40	-1.93
WELETE(3)	0.38	1.043	0.40	-2.05
BERECHIKO FABRICA(2)	15.00	0.999	14.98	-6.51
WELETE(12)	0.38	1.049	0.40	-7.23
ALEM GENA(2)	15.00	0.999	14.98	-6.44

Voltage - Deviation [%]: -10, -5, 0, +5, +10

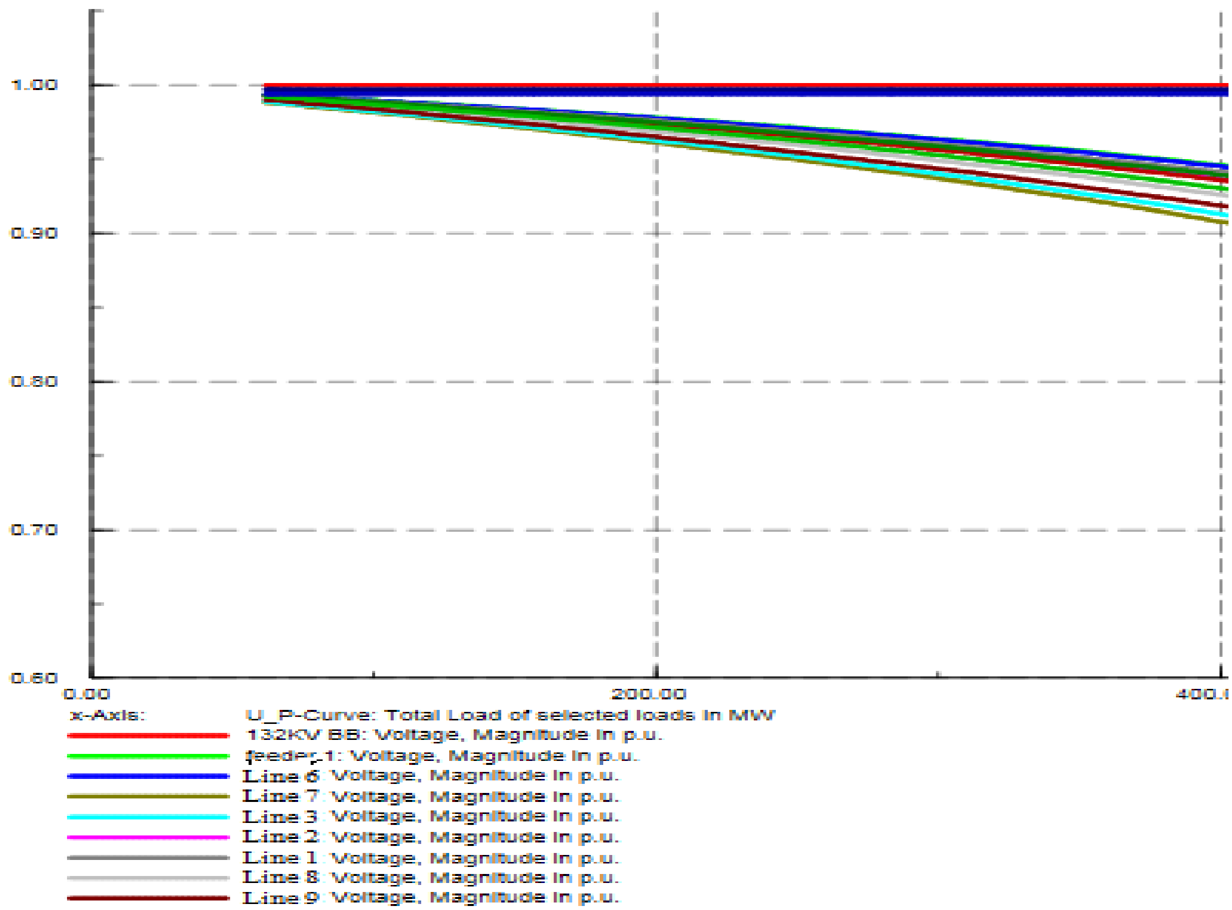
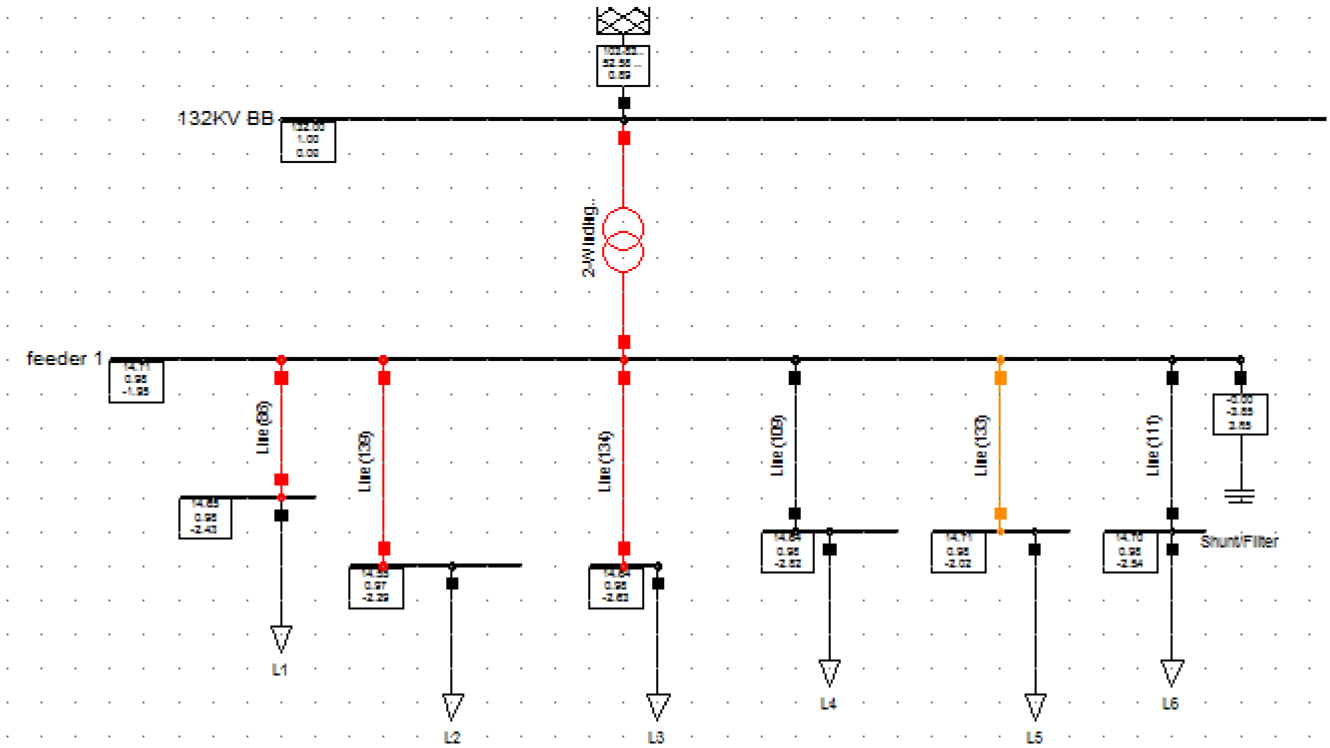


Figure 4.9 Grid voltage profile

Capacitor bank 4Mvar



Grid: Grid	System Stage: Grid	Study Case: Study Case	Annex: / 1

Grid: Grid — Summary

No. of Substations	0	No. of Busbars	255	No. of Terminals	2	No. of Lines	132
No. of 2-w Trfs.	124	No. of 3-w Trfs.	0	No. of syn. Machines	0	No. of asyn.Machines	0
No. of Loads	446	No. of Shunts	1	No. of SVS	0		

Generation	=	0.00 MW	0.00 Mvar	0.00 MVA
External Infeed	=	56.47 MW	14.86 Mvar	58.39 MVA
Inter Grid Flow	=	0.00 MW	0.00 Mvar	
Load P(U)	=	55.15 MW	13.15 Mvar	56.69 MVA
Load P(Un)	=	55.15 MW	13.15 Mvar	56.70 MVA
Load P(Un-U)	=	0.00 MW	0.00 Mvar	
Motor Load	=	0.00 MW	0.00 Mvar	0.00 MVA
Grid Losses	=	1.32 MW	5.64 Mvar	
Line Charging	=		0.00 Mvar	

Figure 4.10 Grid summary report with capacitor bank

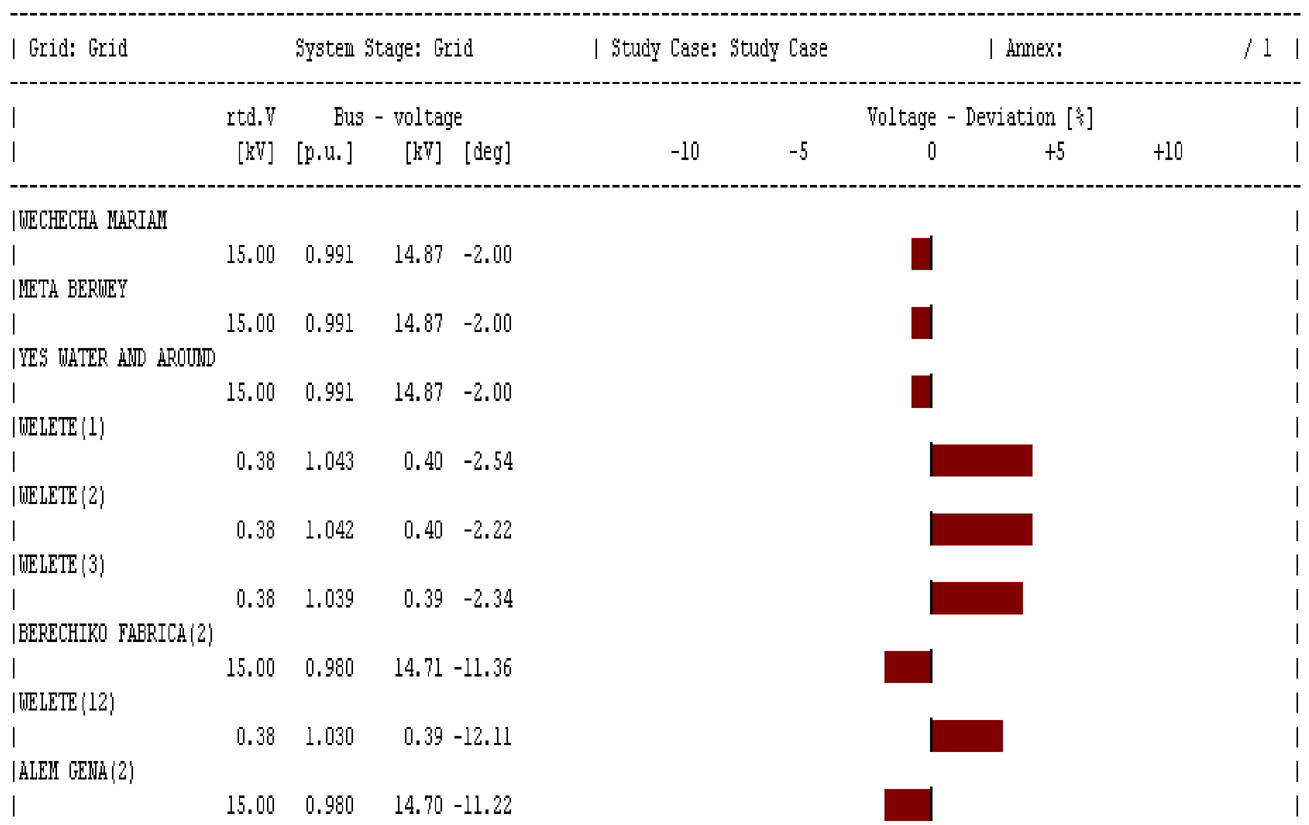
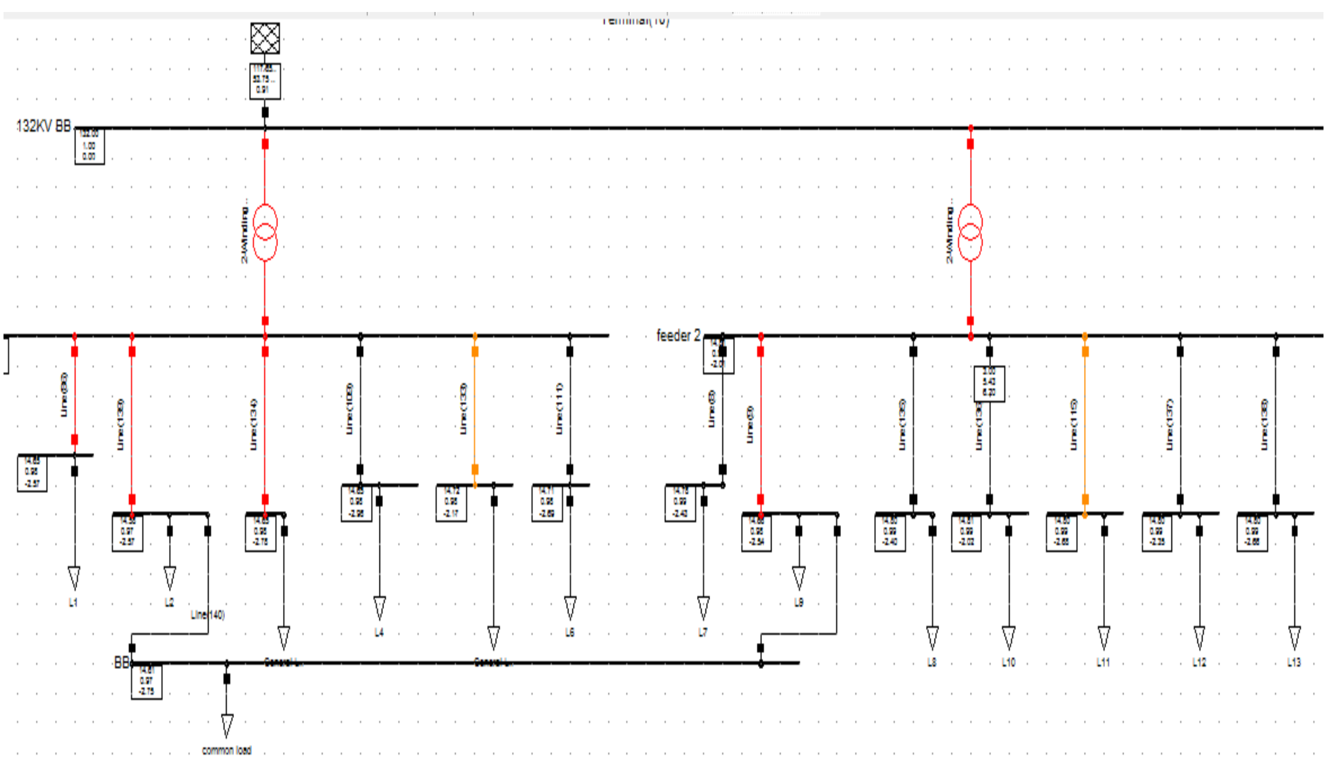


Figure 4.11 Voltage profile with capacitor bank

<u>Load sharing between line 2 of transformer one with line 9 of transformer two</u>



```
---------------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case              | Annex:            / 1  |
---------------------------------------------------------------------------------------------------------------
| Grid: Grid              Summary                                                                               |
|                                                                                                               |
| No. of Substations    0        No. of Busbars       263       No. of Terminals      2        No. of Lines         139  |
| No. of 2-w Trfs.      125      No. of 3-w Trfs.     0         No. of syn. Machines  0        No. of asyn.Machines  0   |
| No. of Loads          453      No. of Shunts        0         No. of SVS            0                                  |
|                                                                                                               |
| Generation          =      0.00  MW          0.00  Mvar        0.00  MVA                                     |
| External Infeed     =    106.94  MW         29.56  Mvar      110.95  MVA                                     |
| Inter Grid Flow     =      0.00  MW          0.00  Mvar                                                      |
| Load P(U)           =    104.85  MW         23.49  Mvar      107.45  MVA                                     |
| Load P(Un)          =    104.85  MW         23.49  Mvar      107.45  MVA                                     |
| Load P(Un-U)        =      0.00  MW          0.00  Mvar                                                      |
| Motor Load          =      0.00  MW          0.00  Mvar        0.00  MVA                                     |
| Grid Losses         =      2.09  MW          6.08  Mvar                                                      |
```

Figure 4.12 Grid summary report for load sharing

```
---------------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case              | Annex:            / 2  |
---------------------------------------------------------------------------------------------------------------
|                     rtd.V     Bus - voltage                          Voltage - Deviation [%]                  |
|                      [kV]  [p.u.]    [kV]  [deg]        -10       -5         0          +5         +10       |
---------------------------------------------------------------------------------------------------------------
|WELETE(6)                                                                                                      |
|                      0.38   1.042    0.40  -1.95                                                              |
|WELETE(4)                                                                                                      |
|                      0.38   1.042    0.40  -1.92                                                              |
|ALEM GENA(5)                                                                                                   |
|                     15.00   0.990   14.85  -1.88                                                              |
|BERECHIKO FABRICA(5)                                                                                           |
|                     15.00   0.990   14.85  -1.88                                                              |
|BETHEL AREA(5)                                                                                                 |
|                     15.00   0.990   14.85  -1.88                                                              |
|WELETE(21)                                                                                                     |
|                      0.38   1.027    0.39  -2.48                                                              |
|WELETE(20)                                                                                                     |
|                      0.38   1.042    0.40  -2.08                                                              |
|WELETE(22)                                                                                                     |
|                      0.38   1.041    0.40  -1.98                                                              |
|ALEM GENA(6)                                                                                                   |
|                     15.00   0.990   14.85  -1.90                                                              |
|WELETE(24)                                                                                                     |
|                      0.38   1.042    0.40  -2.00                                                              |
```

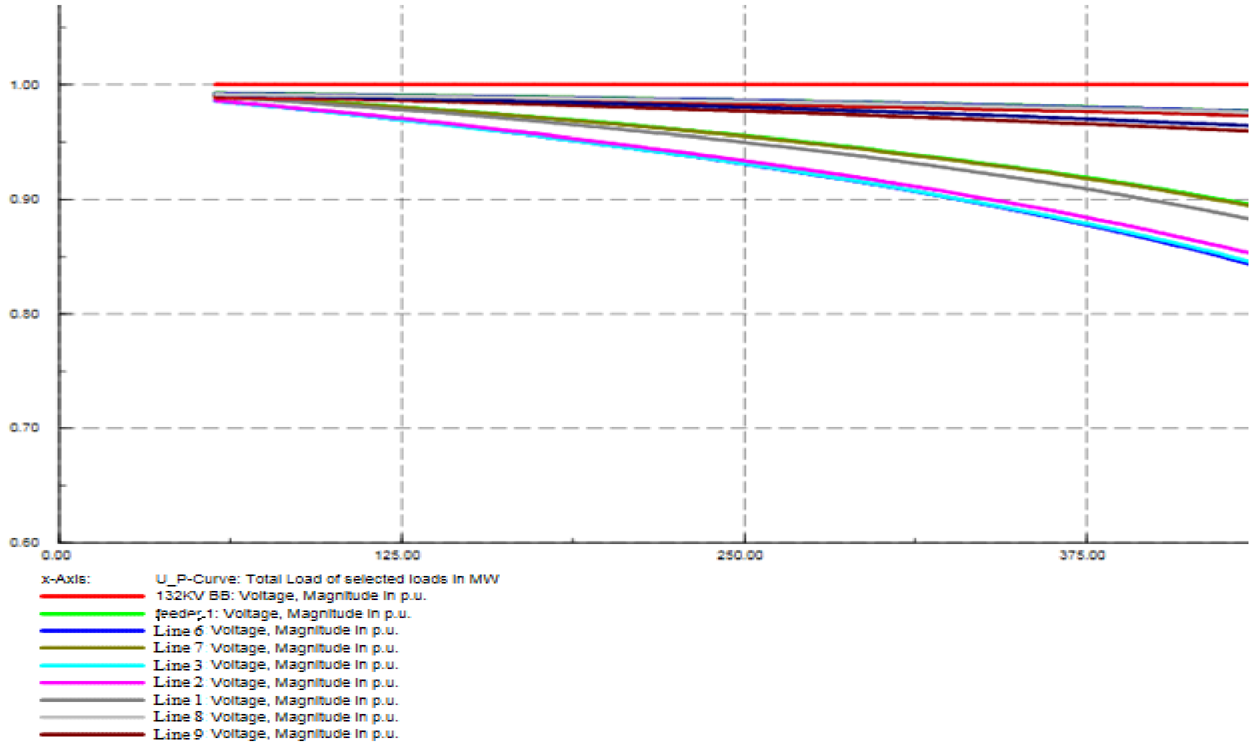
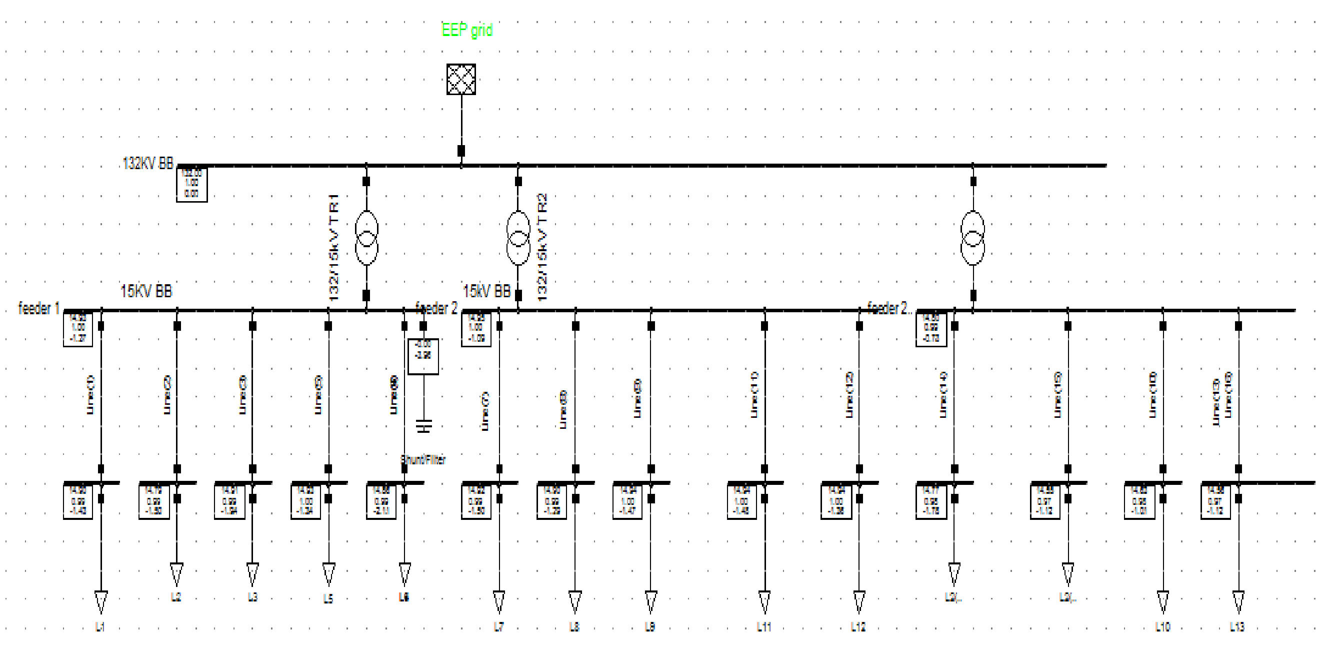


Figure 4.13 Voltage profile of load sharing mechanisms

Additional transformer 3 with 132/15kv 50 MVA with capacitor bank 4Mvar



```
-------------------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case              | Annex:               / 1  |
-------------------------------------------------------------------------------------------------------------------
| Grid: Grid              Summary                                                                                  |
|                                                                                                                  |
| No. of Substations     0         No. of Busbars       265       No. of Terminals      2         No. of Lines          140   |
| No. of 2-w Trfs.       126       No. of 3-w Trfs.     0         No. of syn. Machines  0         No. of asyn.Machines  0     |
| No. of Loads           453       No. of Shunts        0         No. of SVS            0                                    |
|                                                                                                                  |
| Generation          =      0.00  MW         0.00  Mvar      0.00  MVA                                              |
| External Infeed     =    106.66  MW        28.22  Mvar    110.33  MVA                                              |
| Inter Grid Flow     =      0.00  MW         0.00  Mvar                                                             |
| Load P(U)           =    104.85  MW        23.49  Mvar    107.45  MVA                                              |
| Load P(Un)          =    104.85  MW        23.49  Mvar    107.45  MVA                                              |
| Load P(Un-U)        =      0.00  MW         0.00  Mvar                                                             |
| Motor Load          =      0.00  MW         0.00  Mvar      0.00  MVA                                              |
| Grid Losses         =      1.81  MW         4.73  Mvar                                                             |
| Line Charging       =                       0.00  Mvar                                                             |
| Compensation ind.   =                       0.00  Mvar                                                             |
| Compensation cap.   =                       0.00  Mvar                                                             |
|                                                                                                                  |
| Installed Capacity  =      0.00  MW                                                                               |
| Spinning Reserve    =      0.00  MW                                                                               |
|                                                                                                                  |
| Total Power Factor:                                                                                              |
|   Generation        =        0.00  [-]                                                                           |
|   Load/Motor        =  0.98 / 0.00  [-]                                                                           |
|------------------------------------------------------------------------------------------------------------------|
```

Figure 4.14 Grid summary for additional transformer

```
-------------------------------------------------------------------------------------------------------------------
| Grid: Grid              System Stage: Grid          | Study Case: Study Case              | Annex:               / 2  |
-------------------------------------------------------------------------------------------------------------------
|                      rtd.V      Bus - voltage                          Voltage - Deviation [%]                  |
|                      [kV]  [p.u.]    [kV]  [deg]          -10        -5         0         +5        +10         |
-------------------------------------------------------------------------------------------------------------------
|WELETE(6)                                                                                                        |
|                      0.38   1.045    0.40  -1.46                                                                |
|WELETE(4)                                                                                                        |
|                      0.38   1.045    0.40  -1.42                                                                |
|ALEM GENA(5)                                                                                                     |
|                     15.00   0.993   14.90  -1.37                                                                |
|BERECHIKO FABRICA(5)                                                                                             |
|                     15.00   0.993   14.89  -1.37                                                                |
|BETHEL AREA(5)                                                                                                   |
|                     15.00   0.993   14.89  -1.37                                                                |
|WELETE(21)                                                                                                       |
|                      0.38   1.030    0.39  -1.97                                                                |
|WELETE(20)                                                                                                       |
|                      0.38   1.045    0.40  -1.57                                                                |
|WELETE(22)                                                                                                       |
|                      0.38   1.044    0.40  -1.47                                                                |
|ALEM GENA(6)                                                                                                     |
|                     15.00   0.993   14.89  -1.39                                                                |
|WELETE(24)                                                                                                       |
|                      0.38   1.045    0.40  -1.49                                                                |
|BERECHIKO FABRICA(6)                                                                                             |
|                     15.00   0.993   14.89  -1.39                                                                |
|BETHEL AREA(6)                                                                                                   |
|                     15.00   0.993   14.89  -1.39                                                                |
|WELETE(23)                                                                                                       |
|                      0.38   1.045    0.40  -1.71                                                                |
```

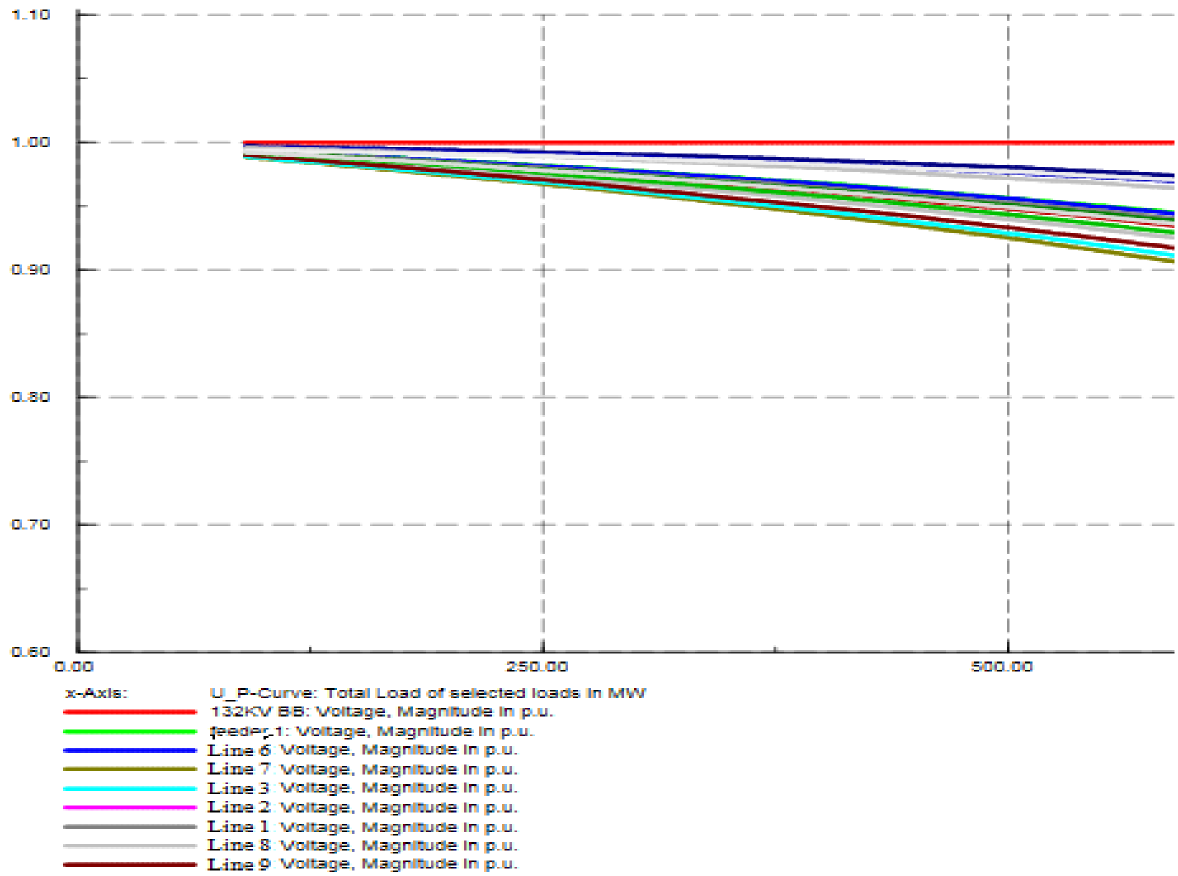


Figure 4.15 Voltage profile for use of additional transformer

4.7 Simulation Result and Discussion

Result of simulation from Dig silent software for four different technique that are used for problem of voltage drop and reactive power is tabulated as follows;

Table 4.3: Simulation result

	capacitor bank	Use of micro turbine	additional transformer 50 MVA
	Transformer one	Transformer one	Transformer one Transformer three
Active power	55.49MW	48.67MW	37.43MW 36.5 MW
Reactive power	12.79MVAR 114.84%	8.39MVAR 99.39%	10.59MVAR78.3% 4.52MVAR73.8%
Apparent power	56.9MVA	49.38MVA	38.89MVA 36.78 MVA
	Line 2	Line 2	Transformer two
Active power	15.14MW	8.32MW	31.12MW
Reactive power	2.07MVAR 123%	2.32MVAR 69.64%	10.58MVAR 66.18% loaded
Apparent power	15.28MVA	8.64MVA	32.87MVA
Cost	18000$	8,180,000$	2,800,000 $
Efficiency	Good	high	high efficiency ,25 years
Space	Small	Medium	Medium
power loss	15% of line 2 and 3.17% of overall	79% of line 2 and 13.58% overall	94.12% of line 2 and 18.9% of overall system
	Load sharing line 2 to line 9		
	Line 2 line 9		
MW	10.35MW 9.52 MW		
MVAR	3.83MVAR89.31% 4.28MVAR101%		
MVA	11.03MVA 10.44MVA		
	Transformer 1 Transformer 2		
MW	50.7MW 54.37MW		
MVAR	14.59MVAR106.7% 11.3MVAR110%		
MVA	52.74 MVA 55.52MVA		
COST	51,320$		
EFFICIENCY	Good		
SPACE	Small		
power loss	76.48% line2 5.43%overall system		

Voltage variation

Voltage which are evaluated at the last terminal point of distribution line 02 in different conditions.

Table 4.4: Voltage variation at the load terminal point

	Normal operation	Using capacitor bank	Using Microturbine	By Load sharing	additional transformer
voltage	13.02kV 0.87 p.u	14.51kV 0.97 p.u	14.95 kV 1 p.u	TR1 14.58kV 0.97 p.u.	TR1 14.7kV 0.98 p.u.
				TR214.37Kv 0.94 p.u.	TR2 14.88kV 0.99 p.u.
					TR 3 14.45kV 0.96 p.u.

4.8 Load Forecast of 2019-2023

To implement the study of this work, it is vital to show its importance for the future time. Thus, a short period of load forecast has been made for the incoming five years and out of many load forecast methodology, gross domestic product (GDP) growth rates of countries is one of the familiar one and normally EEP uses this to forecast electrical load in substation/ distribution levels.

Let's see the following load forecast made by EEP for its power system master plan study for the next 21 years of the main developmental sectors in Table below.

Table 4.5 Load forecast made by EEP

sector	2012-2015(%)	2016-2020(%)	2021-2025(%)	2026-2037(%)
agriculture	8.1	6.3	5.4	3.9
Industry	20	15.6	13.9	10.7
Services	10.9	9.3	8.4	6.9
Total	11.2	9.6	8.6	7.6

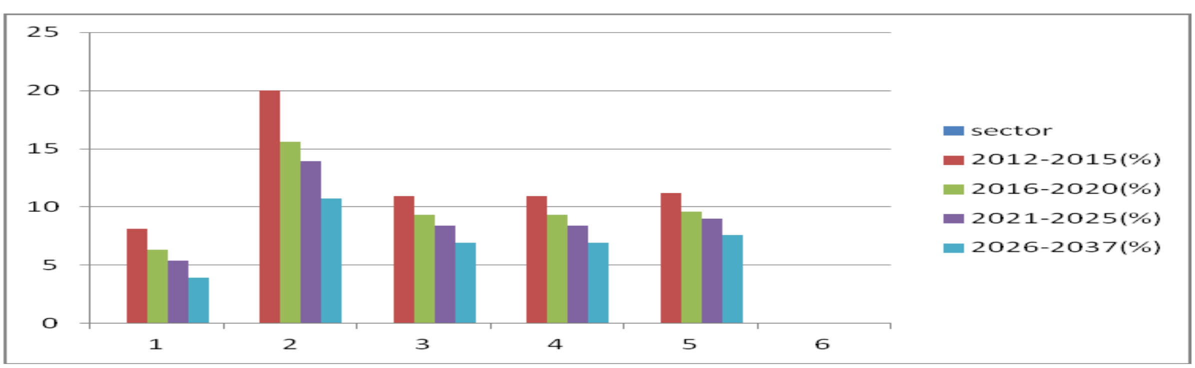


Figure 4.16 Load forecast made by EEP for its power system master plan study

The average GDP growth in 2016-2020 GC is 9.6% and 2021-2025 9%.According to independent study of World Bank on the GDP growth of Ethiopia 8% of growth rate (press released) is expected and the electrical power demand at substation/distribution level is expected to grow with the same rate. (From Ethiopia electric power national load dispatch center planning office)

Table4.6 Load forecasting using the power distribution master plane made by EEP

	2018		2023	
Bay/line	Power(MW)	Current(A)	Power (MW)	Current (A)
FEEDER 1	57.9	2476	73.89713	3160.092
FEEDER 2	49.7	2125	63.43156	2712.114

4.8.1 Load forecasting using regression method on Microsoft excel

Electric load forecasting is principal to the economic and efficient provision of electric power to meet various load demands for a specified period of time. This thesis focus on loss minimization using different mechanisms by making forecasting on the medium-term load forecast of sebeta I substation. Electrical load forecasting is usually made by constructing models. This model are based on relative information and previous load demand data's All forecasts should be based on previous data. Therefore, an electrical load forecast should be based on the previous load data of the region to be forecasted. Regression Analysis is a very important statistical tool for medium term forecasting which is very useful in determining the statistical relationship or dependence between a change in one variable and the change in another when compared to it [15]. From literature reviewed to carry out a medium term forecast of the electrical load consumed, literature "Covenant University researcher IsaacA. Samuel Felly-Njoku Chihurumanya.F, Adewale Adeyinka.A, and Ayokunle.A, Awelewa"used as a reference.

The following steps have to be taken using the collated load data:

- ✓ Collection of data
- ✓ Building of the Forecast Models
- ✓ Carrying out the forecast and Implementation of the Models

In medium term load forecasting there are three types of modeling

1) The Linear Regression Model: This is the simplest model of regression analysis. It comprises of an independent and dependent variable. It is denoted by the formula;

$$Y = a + bX \tag{4.13}$$

Where; Y is the value of the load

X is the number of years

The values of *a* and *b* are derived by simultaneously.

$$\sum Y = n\,a + b\sum X \tag{4.14}$$

$$\sum X\,Y = a\sum X + b\sum X^2$$

2) The Compound-Growth Model: This is another model of regression analysis. It is denoted by the formula:

$$Y = \text{antilog}(c + dX) \tag{4.15}$$

Like the linear regression model, the values of *c* and *d* are also derived by solving simultaneously

$$\sum \log Y = nc + d\sum X \tag{4.16}$$

$$\sum X\,(log)Y = c\sum X + d\sum X \tag{4.17}$$

For this thesis linear regression method is using on Microsoft word excel

Table 4.7 Load forecasting using Microsoft excel Linear Regression method

	Y	X1	X2	X1*X1	X2*X2	X1*X2	X1*Y	X2*Y	
YEAR	Peak load (MW)	GDP	number of customer						
2013	33.33	10.3	630000	106.09	3.969E+11	6489000	343.29	20997900	
2014	38.1	10.3	630000	106.09	3.969E+11	6489000	392.43	24003000	
2015	45.57	10.21	741000	104.241	5.491E+11	7565610	465.27	33767370	
2016	48.5	8.33	794857	69.3889	6.318E+11	6621159	404.00	38550565	
2017	55.4	7.98	880000	63.6804	7.744E+11	7022400	442.09	48752000	
2018	57.2241603	7.96	900000						
2019	62.1718231	7.92	957142						
2020	69.6376934	7.91	1042857						
2021	71.9383473	7.68	1071571						
2022	72.8326441	7.49	1072285						
2023	73.6700961	7.27	1090999	449.493	2.749E+2	34187169	2047.1	1.66E+08	
SUM	626.974764		Y mean	125.395		A	-28.29		
			X1mean	1.454		b1	0.8844		
			X2mean	2181998		b2	8.7E-05		
	SUMMARY OUTPUT								
	Regression Statistics								
	Multiple R	0.981							
	R Square	0.962							
	Adjusted R	0.924							

	Square								
	Standard Error	2.388							
	Observations	5							
	ANOVA								
		Df	*SS*	*MS*	*F*	*Significa F*			
	Regression	2	289.7678	144.8839	25.409203	0.037866			
	Residual	2	11.40405	5.702024					
	Total	4	301.1718						
		Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
	Intercept	-28.3	34.62855	-0.81715	0.4997019	-177.291	120.698	-177.291	120.6981
	X Variable 1	0.884	2.027382	0.436048	0.7053551	-7.83908	9.60716	-7.83908	9.607158
	X Variable 2	9E-05	2.26E-05	3.86574	0.0608707	-9.9E-06	0.00018	-9.9E-06	0.000184

Chapter Five

Cost Analysis

5 Cost Analysis of Different Techniques

Basically economic analysis is considering the cost of components of techniques which are suggested for voltage drop and reactive power minimization and the analysis help to perform the best solution. To perform this cost analysis the cost of individual must be evaluated from different markets.

Cost of capacitor bank-1800$/400kVAR from capacitor bank which is selected by considering labor, shipping, installation and maintenance cost is around **23,000$ for 4Mvar.**

Cost of micro turbine-the micro turbine of 1000 kW was selected to estimate the cost of DG capacity of 9MVA. The generators should be integrated to provide the modular packages of 9MVA unit comprised of nine 1000 kW. Cost for a single micro turbine is 900$/kW so 9*1000*900$/kW =8,100,000$ =8100000$*27.6birr/$ =**218,700,000birr**

Cost For load sharing-according to Ethiopia electric utility most of the distribution network is design by considering wood pole as distribution line, but currently all those wood pole are changing by concrete pole due to more advantage of concert over wood pole. For effective distribution line load sharing with all accessories 15kV distribution line for 10km,because line 2 and line 9 are design to supply in the same area after 9km.

= 4100$/Km for 10Km=51320$

For aluminum conductor over headline 1$/meter

=10*1000meter*1$/meter

=10000$; Total cost =51320+10000=**61320$**

Cost of Additional transformer 50MVA

The existing power supply configuration of sebeta I substation have two 50 MVA transformer. When additional transformer is needed to increase load ability of system, all parameters must be equal with existing system. By parallel operation with additional transformer, all transformers are connected to the same Supply bus bars on the primary side and to a common bus bar/load on the secondary side.

Additional transformer 50MVA with all accessories including labor, shipping, and installation cost.

=**2,980,000 $=82,248,000 birr**

In general all cost is taken from china different electrical equipment market, mostly Alibaba .com, ABB.com.

5.1 Comparison between techniques

From the simulation result and numerical analysis of cost the following comparison are prepared. The comparisons are executed by considering line and transformer overloading reduction, power loss reduction, cost analysis, space requirement and effectiveness of devices.

From table above (Table 4.7) and simulation results the mechanisms that are used to solve the problem of voltage drop and reactive power are compared graphically as follows

Table 5.1: Power loss reduction

	capacitor bank	**use of micro turbine**
Power loss reduction	15% of line 2 and 3.17% of overall	79% of line 2 and 13.58% overall
	load sharing line 2 to line 9	**additional transformer 50 MVA**
Power loss reduction	76.48% line2 5.43%overall system	94.12% of line 2 and 18.9% of overall system

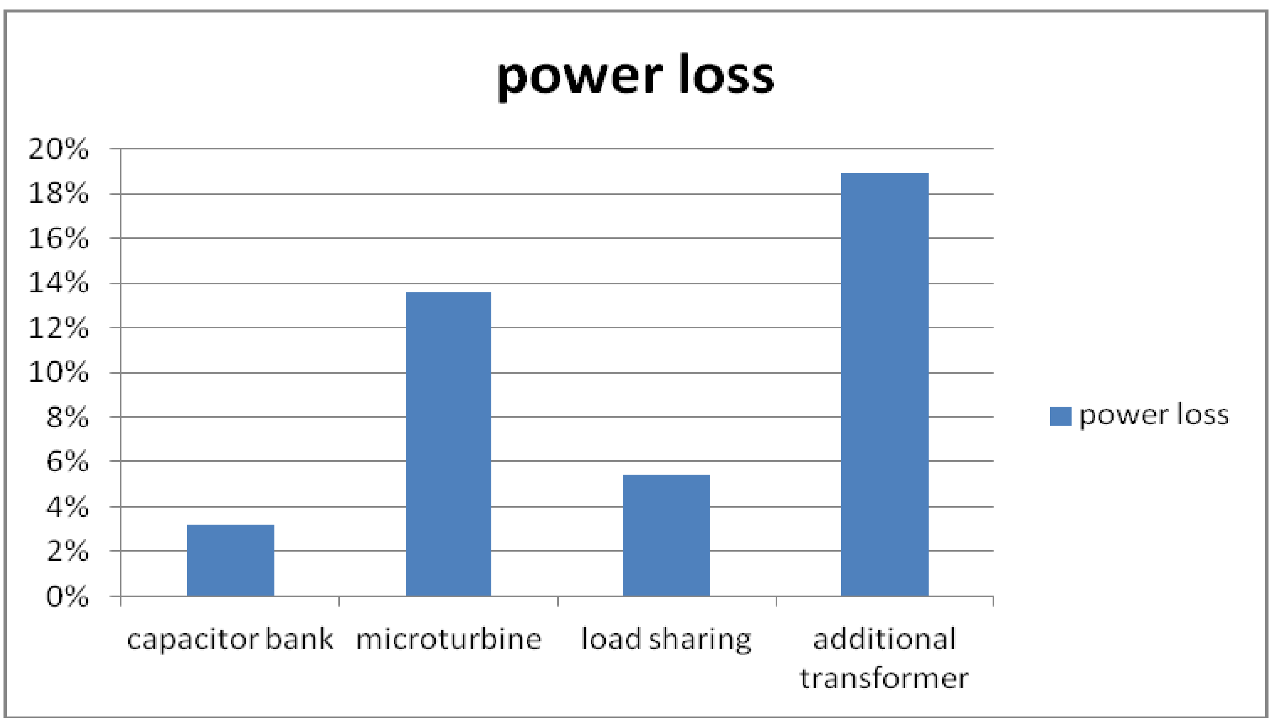


Figure 5.1: Graphical representation for power loss reduction overall system

Voltage increment by considering different technique

Voltage which are evaluated at the last terminal of distribution line 02 in different case ;normal operating condition ,using capacitor bank, distributed generation, using load sharing technique and by additional extra transformer .

Table 5.2 :Voltage variation at end load bus bar

	Normal operation	capacitor bank	Micro turbine	Load sharing	additional transformer
voltage	13.02kV0.87 p.u	14.51kV0.97p.u	14.95 kV 1p.u	TR1 14.58kV0.97 p.u.	TR1 14.7kV 0.98 p.u.
				TR2 14.4kV0.94 p.u.	TR2 14.8kV0.99 p.u.
					TR 3 14.5kV 0.96p.u.

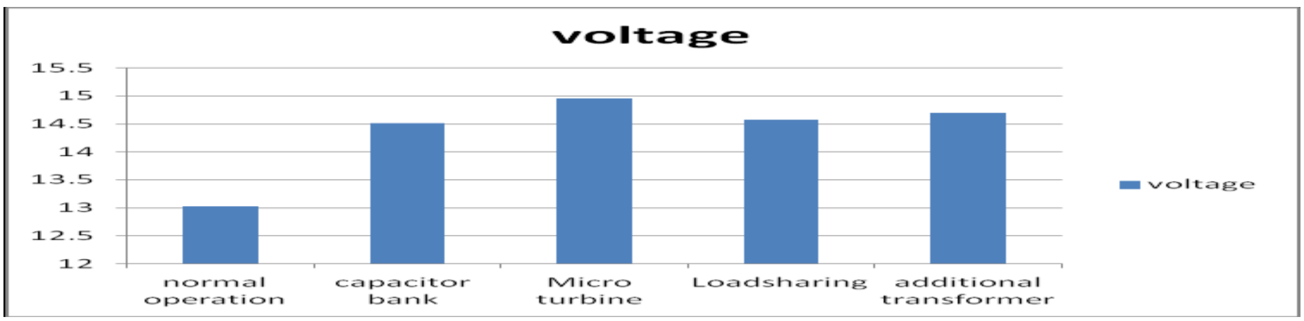


Figure 5.2: Graphical representation of voltage comparison

Overload reduction for outgoing line 02 and transformer one are computed by using suggested techniques as a voltage drop and reactive power problem solution comparatively to select best one. The original overloading of line 02 is about 134.34% and transformer one loaded by 117.1% is defined as reference.

Table 5.3: System overloads reduction in percentage

	capacitor bank	use of micro turbine
line 2 loading	123%	69.64%
transformer 1 loading	114.84%	99.39%
	load sharing line 2 to line 9	additional transformer 50 MVA
line 2 loading	89.31%	78.31%
transformer 1 loading	106.47%	78.31%

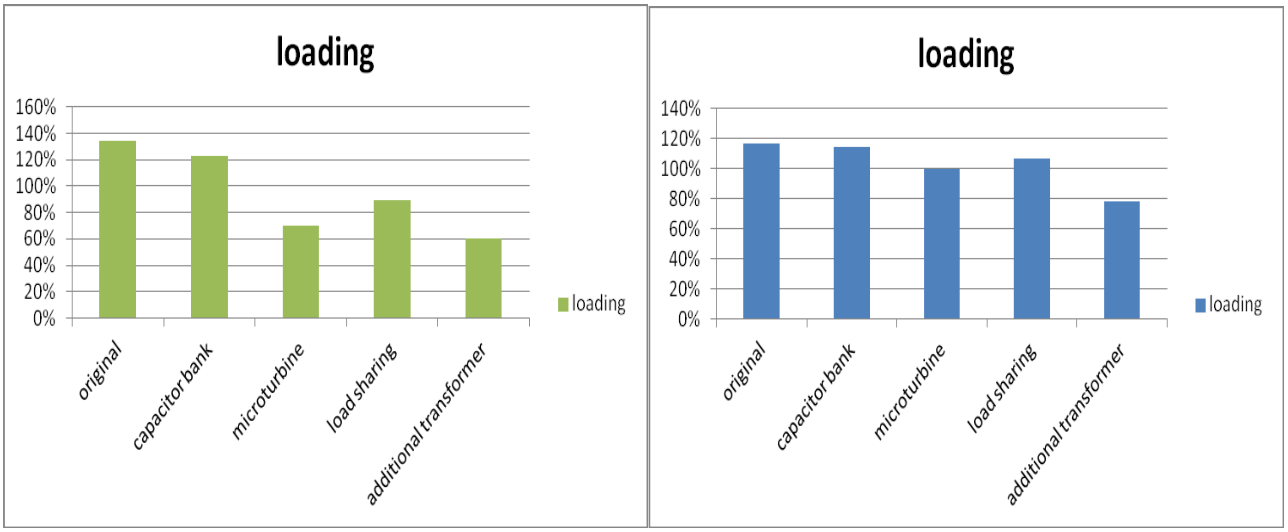


Figure 5.3: Overloading analysis line 02 and transformer one

Costs of four techniques that are comparatively evaluated for power loss reduction by controlling voltage and reactive power are described as follows

Table 5.4: Cost comparison

Cost	capacitor bank	use of micro turbine
	$23000	$8,100,000
	load sharing line 2 to line 9	additional transformer 50 MVA
	$61,320	$2,980,000

Effectiveness and space requirment are compared as follows in order to select best solution from the technique that are used as solution for power loss reduction that caused by voltage drop and reactive power problem.

Table 5.5: Efficiency and placement space require

	capacitor bank	Use of micro turbine
EFFICIENCY	Good	high
SPACE	SMALL	MEDIUM
	load sharing line 2 to line 9	additional transformer 50 MVA
EFFICIENCY	Good	high efficiency ,25 years
SPACE	Small	Medium

Chapter six

6.1 Conclusion and Recommendation

As an electrical power consumption increase rapidly, the expansion and complexity of power transmission and distribution networks also increase, this expansion leads to frequently changes in loading conditions to operate on overloaded or to operate with under loaded conditions. Electricity distribution networks form the backbone by which electricity is effectively delivered to the consumers. In Ethiopia most of distribution network have problem of operating on overloaded condition that result on voltage drop and most of them supply to factory that cause the reactive power increment on the system overall result on high power loss, also this type of problem typically observed in Sebeta I substation.

This thesis studies on a comparative analysis of voltage drop and reactive power problem compensation methods that can be implemented in distribution network for power loss minimization. Power loss which is caused by voltage drop and reactive power in distribution networks is therefore fundamental issue to be ensured for maximum transmission of power within the distribution networks. There are different methods for solving the above mentioned problems. From different types of techniques this thesis focuses on use of shunt capacitors, distributed generation, load sharing and use of additional transformer in substation level comparatively to select the best solution.

The network of Sebeta I substation is modeled using DIgSILENT Power Factory software and all four options are simulated using this Package. Load flow calculations are carried out and the results obtained are used to compare the impact of the four methods on the behavior of the system. Those methods are compared based on the improvement of the voltage profile, reduction in the total real power losses, power factor correction as well as the net present value of implementing the method also the load forecasting is also implemented.

From overall techniques which are applicable for power loss minimization by controlling voltage drop reactive power problems, use of additional transformer rated at 50MVA 132/15kV 1.25%, with 4MVAR capacitor bank is recommended based on reduction of power loss by 97% for line 02 and overall system power loss reduced by 20% and over load reduced by 78%, which improving voltage profile from 0.87 p.u to 0.98 p.u at the last bus bar of outgoing line.

References

[1] Akwukwaegbu I. O, Okwe Gerald Ibe 'concepts of Reactive Power control and Voltage Stability Methods in Power System Network'Department of Electrical/Electronic Engineering Federal University of Technology Owerri Imo State

[2] DIgSILENT software application (February 2018). Available: https://www.digsilent.de

[3] Flavio Caresana1, Gabriele Comodi1,Leonardo Pelagalli1andSandr Vagni2 Micro Gas Turbines

[4] Ling Wang," Research on Reactive Power Compensation Based on Distribution Network," Benxi Power Supply Branch, State Grid Liaoning Electric Power Supply Co. Ltd Benxi, China, 2015

[5] Lagoon D.W. Williams, Micro turbine Operation with Biogas from a Covered Dairy Manure

[6] MD. Shakib Hasan Reactive Power Control for Voltage Management

[7] Noppatee Sabpayakom, Somporn Sirisumrannuku," Power losses reduction and reliability improvement in distribution system with Very Small Power Producers," 3rd International Conference on Power and Energy Systems Engineering,CPESE 2016, 8-12 September 2016, Kitakyushu, Japan

[8] Omid Alizadeh Mousavi and Rachid Cherkaoui," Literature Survey on Fundamental Issues of Voltage and Reactive Power Control," EPF Lausanne – Power System Group, 10. June 2011

[9] phanikrishnagomatom(pxgomatom@wichita.edu)wardjewell(Ward.Jewell@wichita.edu) Fuel parameter and quality constraints for microturbine distributed generators

[10] Prof. P. S. R. MURTY," Operation and Control in Power Systems," B.Sc. Engg.(Hans.)ME., Dr. - lng (Berlin),F.I.E.(India) Life member -ISTE 2008 Lakervi and Holmes, 1989

[11] P.A Pilavachi Mini- and micro-gas turbines for combined heat and power

[12] Samawha creative technology provider .capacitor bank pdf.
Available:http://www.samwha.co.kr/SWCatalogue/cat/121/capacitor bank.pdf

[13] T. Xu, P. C. Taylor," Voltage Control Techniques for Electrical Distribution Networks Including Distributed Generation,"Proceedings of the 17th World Congress The International Federation of Automatic Control Seoul,Korea, July 6-11,2008

[14] X.L.Dai," Reactive power compensation in distribution network applications," Grid technology ,july 2009

[15] Samuel Felly Isaac A. -Njoku Chihurumanya F., Adewale Adeyinka A. and Ayokunle A. Awelewa "medium term forecast of the electrical load consumed" Covenant University researcher

Appendix A

Distribution transformer rating and load for sebeta I substation 15kV outgoing lines 02.

Table 7.1 distribution transformer with ratings

Name	Size(kVA)	Load(kW)	NAME	kVA	kW
SEB 02 - T 001	315	252	SEB 02 - T 062	800	640
SEB 02 - T 002	315	252	SEB 02 - T 063	315	252
SEB 02 - T 003	315	252	SEB 02 - T 064	200	160
SEB 02 - T 004	315	252	SEB 02 - T 065	315	252
SEB 02 - T 005	630	504	SEB 02 - T 066	200	160
SEB 02 - T 006	315	252	SEB 02 - T 067	315	252
SEB 02 - T 007	630	504	SEB 02 - T 068	200	160
SEB 02 - T 008	315	252	SEB 02 - T 069	315	252
SEB 02 - T 009	315	252	SEB 02 - T 070	315	252
SEB 02 - T 010	630	504	SEB 02 - T 071	200	160
SEB 02 - T 011	315	252	SEB 02 - T 072	315	252
SEB 02 - T 012	200	160	SEB 02 - T 073	315	252
SEB 02 - T 013	315	252	SEB 02 - T 074	315	252
SEB 02 - T 014	200	160	SEB 02 - T 075	315	252
SEB 02 - T 015	200	160	SEB 02 - T 076	315	252
SEB 02 - T 016	315	252	SEB 02 - T 077	315	252

SEB 02 - T 017	315	252	SEB 02 - T 078	315	252
SEB 02 - T 018	200	160	SEB 02 - T 080	315	252
SEB 02 - T 019	630	504	SEB 02 - T 081	1250	1000
SEB 02 - T 020	315	252	SEB 02 - T 082	1250	1000
SEB 02 - T 021	315	252	SEB 02 - T 083	200	160
SEB 02 - T 022	200	160	SEB 02 - T 084	315	252
SEB 02 - T 023	315	252	SEB 02 - T 085	315	252
SEB 02 - T 024	315	252	SEB 02 - T 086	315	252
SEB 02 - T 025	315	252	SEB 02 - T 087	200	160
SEB 02 - T 026	315	252	SEB 02 - T 088	200	160
SEB 02 - T 027	315	252	SEB 02 - T 089	315	252
SEB 02 - T 028	315	252	SEB 02 - T 090	200	160
SEB 02 - T 029	200	160	SEB 02 - T 091	315	252
SEB 02 - T 030	200	160	SEB 02 - T 092	200	160
SEB 02 - T 031	315	252	SEB 02 - T 093	630	504
SEB 02 - T 032	630	504	SEB 02 - T 094	200	160
SEB 02 - T 033	315	252	SEB 02 - T 095	200	160
SEB 02 - T 034	800	640	SEB 02 - T 096	200	160
SEB 02 - T 035	315	252	SEB 02 - T 097	630	504

SEB 02 - T 036	315	252	SEB 02 - T 098	315	252
SEB 02 - T 037	630	504	SEB 02 - T 099	315	252
SEB 02 - T 038	315	252	SEB 02 - T 100	315	252
SEB 02 - T 039	315	252	SEB 02 - T 101	200	160
SEB 02 - T 040	315	252	SEB 02 - T 102	315	252
SEB 02 - T 041	315	252	SEB 02 - T 103	200	160
SEB 02 - T 042	200	160	SEB 02 - T 104	315	252
SEB 02 - T 043	315	252	SEB 02 - T 105	315	252
SEB 02 - T 044	200	160	SEB 02 - T 106	315	252
SEB 02 - T 045	315	252	SEB 02 - T 107	200	160
SEB 02 - T 046	315	252	SEB 02 - T 114	315	252
SEB 02 - T 047	200	160	SEB 02 - T 115	200	160
SEB 02 - T 048	200	160	SEB 02 - T 116	315	252
SEB 02 - T 049	630	504	SEB 02 - T 117	315	252
SEB 02 - T 050	200	160	SEB 02 - T 118	200	160
SEB 02 - T 051	315	252	SEB 02 - T 119	315	252
SEB 02 - T 052	315	252	SEB 02 - T 120	800	640
SEB 02 - T 053	315	252	SEB 02 - T 121	1250	1000
SEB 02 - T 054	315	252	SEB 02 - T 122	1250	1000

SEB 02 - T 055	200	160	SEB 02 - T 123	315	252
SEB 02 - T 056	200	160	SEB 02 - T 124	200	160
SEB 02 - T 057	200	160			
SEB 02 - T 058	315	252			
SEB 02 - T 059	315	252			
SEB 02 - T 060	200	160			
SEB 02 - T 061	315	252			

Appendix B

Table 7.2 Yearly power interruption frequency due to overloading

Feeder	Region	Date(G.C)	Int.time	Rec.time	Interaval(hr)	fault type
SEB-2	WAAR	10/1/2017	19:20	20:20	1:00	OVER LOAD
SEB-9	WAAR	10/2/2017	19:30	21:20	1:50	OVER LOAD
SEB-13	WAAR	10/3/2017	19:20	19:36	1:16	OVER LOAD
SEB-2	WAAR	10/4/2017	19:00	20:25	1:25	OVER LOAD
SEB-13	WAAR	10/5/2017	19:20	20:25	1:05	OVER LOAD
SEB-13	WAAR	10/6/2017	10:45	12:40	1:55	OVER

						LOAD
SEB-01	WAAR	10/7/2017	11:30	13:50	2:55	OVER LOAD
SEB-02	WAAR	10/8/2017	13:50	14:55	3:55	OVER LOAD
SEB-04	WAAR	10/9/2017	19:10	19:15	4:55	OVER LOAD
SEB-04	WAAR	10/10/2017	19:27	19:32	5:55	OVER LOAD
SEB-04	WAAR	10/11/2017	19:36	20:30	6:55	OVER LOAD
SEB-1	WAAR	10/12/2017	19:19	20:37	7:55	OVER LOAD
SEB-02	WAAR	10/13/2017	19:19	20:32	8:55	OVER LOAD
SEB-03	WAAR	10/14/2017	19:00	20:15	9:55	OVER LOAD
SEB-9	WAAR	10/15/2017	19:00	20:15	10:5	OVER LOAD
SEB-13	WAAR	10/16/2017	19:15	20:55	1:40	OVER LOAD
SEB-09	WAAR	10/17/2017	19:30	20:55	1:25	OVER LOAD
SEB-13	WAAR	10/18/2017	19:26	21:10	:44	OVER

						LOAD
SEB-02	WAAR	10/19/2017	19:15	20:15	1:00	OVER LOAD
SEB-10	WAAR	10/20/2017	11:20	12:20	1:00	OVER LOAD
SEB-13	WAAR	10/21/2017	19:40	20:50	1:10	OVER LOAD
SEB-02	WAAR	10/22/2017	19:25	20:30	1:05	OVER LOAD
SEB-07	WAAR	10/23/2017	19:25	20:30	1:05	OVER LOAD
SEB-07	WAAR	10/24/2017	19:15	20:30	1:15	OVER LOAD
SEB-01	WAAR	10/25/2017	19:22	21:05	1:43	OVER LOAD
SEB-07	WAAR	10/26/2017	19:35	20:35	1:00	OVER LOAD
SEB-13	WAAR	10/27/2017	19:25	21:10	1:45	OVER LOAD
SEB-01	WAAR	10/28/2017	19:25	21:10	1:45	OVER LOAD
SEB-04	WAAR	10/29/2017	13:25	14:30	1:05	OVER LOAD
SEB-10	WAAR	10/30/2017	19:31	21:15	1:44	OVER

						LOAD
SEB-12	WAAR	10/31/2017	19:31	21:15	0:44	OVER LOAD
SEB-07	WAAR	11/1/2017	19:30	21:20	1:50	OVER LOAD
SEB-13	WAAR	11/2/2017	19:40	21:20	1:40	OVER LOAD
SEB-01	WAAR	11/3/2017	19:32	21:20	1:48	OVER LOAD
SEB-13	WAAR	11/5/2017	19:40	20:15	1:35	OVER LOAD
SEB-01	WAAR	11/6/2017	19:20	20:10	0:50	OVER LOAD
SEB-9	WAAR	11/7/2017	19:20	20:10	0:50	OVER LOAD
SEB-13	WAAR	11/8/2017	19:25	20:25	1:00	OVER LOAD
SEB-02	WAAR	11/9/2017	19:25	20:10	0:45	OVER LOAD
SEB-01	WAAR	11/10/2017	19:20	20:20	1:00	OVER LOAD
SEB-10	WAAR	11/11/2017	19:20	20:35	1:15	OVER LOAD
SEB-13	WAAR	11/12/2017	19:25	20:50	1:25	OVER

						LOAD
SEB-02	WAAR	11/13/2017	19:15	20:16	1:01	OVER LOAD
SEB-12	WAAR	11/14/2017	18:00	20:19	2:19	OVER LOAD
SEB-04	WAAR	11/15/2017	11:50	12:55	1:05	OVER LOAD
SEB-13	WAAR	11/16/2017	19:00	20:10	1:10	OVER LOAD
SEB-11	WAAR	11/17/2017	19:10	20:15	1:05	OVER LOAD
SEB-13	WAAR	11/18/2017	19:25	20:20	0:55	OVER LOAD
SEB-01	WAAR	11/19/2017	19:35	20:20	0:45	OVER LOAD
SEB-09	WAAR	11/20/2017	19:20	20:15	0:55	OVER LOAD
SEB-02	WAAR	11/21/2017	19:25	20:25	1:00	OVER LOAD
SEB-09	WAAR	11/22/2017	11:15	12:10	0:55	OVER LOAD
SEB-2	WAAR	11/23/2017	19:24	20:15	0:51	OVER LOAD
SEB-2	WAAR	11/24/2017	19:50	21:25	1:35	OVER

						LOAD
SEB-13	WAAR	11/25/2017	11:05	12:00	0:55	OVER LOAD
SEB-13	WAAR	11/26/2017	19:30	20:30	1:00	OVER LOAD
SEB-13	WAAR	11/27/2017	11:25	14:00	2:35	OVER LOAD
SEB-02	WAAR	11/28/2017	19:10	20:45	1:35	OVER LOAD
SEB-02	WAAR	11/29/2017	19:20	20:25	1:05	OVER LOAD
SEB-04	WAAR	11/30/2017	19:00	19:50	0:50	OVER LOAD
SEB-01	WAAR	12/1/2017	19:30	20:00	0:30	OVER LOAD
SEB-13	WAAR	12/2/2017	12:00	12:20	0:20	OVER LOAD
SEB-02	WAAR	12/3/2017	12:20	13:00	0:40	OVER LOAD
SEB-13	WAAR	12/4/2017	19:25	20:32	1:07	OVER LOAD
SEB-13	WAAR	12/5/2017	19:20	20:10	0:50	OVER LOAD
SEB-10	WAAR	12/10/2017	19:15	19:55	0:40	OVER

						LOAD
SEB-13	WAAR	12/11/2017	19:25	20:10	0:45	OVER LOAD
SEB-07	WAAR	12/12/2017	19:32	20:10	1:38	OVER LOAD
SEB-01	WAAR	12/13/2017	7:30	9:30	2:00	OVER LOAD
SEB-09	WAAR	12/14/2017	10:00	12:30	2:30	OVER LOAD
SEB-03	WAAR	12/15/2017	19:50	21:05	1:15	OVER LOAD
SEB-02	WAAR	12/16/2017	19:00	20:00	1:00	OVER LOAD
SEB-13	WAAR	12/17/2017	19:30	20:20	0:50	OVER LOAD
SEB-11	WAAR	12/18/2017	19:10	20:30	1:20	OVER LOAD
SEB-13	WAAR	12/19/2017	18:55	20:15	1:20	OVER LOAD
SEB-13	WAAR	12/20/2017	19:20	20:15	0:55	OVER LOAD
SEB-02	WAAR	12/21/2017	19:45	20:15	1:30	OVER LOAD

SEB-13	WAAR	12/22/2017	19:14	21:00	1:46	OVER LOAD
SEB-13	WAAR	12/23/2017	19:14	21:00	1:46	OVER LOAD
SEB-13	WAAR	12/24/2017	19:14	21:00	1:46	OVER LOAD
SEB-02	WAAR	12/25/2017	16:40	18:35	1:55	OVER LOAD
SEB-11	WAAR	12/26/2017	16:45	18:05	1:20	OVER LOAD
SEB-13	WAAR	12/27/2017	17:00	19:55	2:55	OVER LOAD
SEB-10	WAAR	12/28/2017	21:30	22:35	1:05	OVER LOAD
SEB-01	WAAR	12/29/2017	20:05	21:15	1:10	OVER LOAD
SEB-02	WAAR	12/30/2017	20:05	8:20	12:15	OVER LOAD
SEB-03	WAAR	12/31/2017	20:05	21:10	1:05	OVER LOAD
SEB-02	WAAR	1/1/2018	15:45	16:40	0:55	OVER LOAD
SEB-01	WAAR	1/2/2018	16:27	17:32	1:05	OVER LOAD

SEB-02	WAAR	1/3/2018	16:27	17:32	1:05	OVER LOAD
SEB-03	WAAR	1/4/2018	16:27	17:32	1:05	OVER LOAD
SEB-01	WAAR	1/5/2018	11:20	12:25	1:05	OVER LOAD
SEB-02	WAAR	1/6/2018	11:20	12:25	2:05	OVER LOAD
SEB-03	WAAR	1/7/2018	11:20	12:25	1:05	OVER LOAD
SEB-02	WAAR	1/8/2018	15:15	16:20	1:05	OVER LOAD
SEB-01	WAAR	1/9/2018	19:10	20:15	1:05	OVER LOAD
SEB-03	WAAR	1/10/2018	19:10	20:15	1:05	OVER LOAD
SEB-02	WAAR	1/11/2018	19:10	21:30	2:20	OVER LOAD
SEB-02	WAAR	1/19/2018	14:40	16:00	1:20	OVER LOAD
SEB-04	WAAR	1/22/2018	18:41	19:35	0:54	OVER LOAD
SEB-01	WAAR	1/23/2018	18:55	19:55	1:00	OVER LOAD

SEB-10	WAAR	1/26/2018	18:35	19:30	0:55	OVER LOAD
SEB-13	WAAR	1/27/2018	18:56	20:03	1:07	OVER LOAD
SEB-11	WAAR	1/29/2018	18:30	19:50	1:20	OVER LOAD
SEB-01	WAAR	1/30/2018	19:00	19:05	0:05	OVER LOAD
SEB-01	WAAR	1/31/2018	19:05	19:10	0:05	OVER LOAD
SEB-13	WAAR	2/1/2018	19:30	21:05	1:35	OVER LOAD
SEB-01	WAAR	2/2/2018	18:55	19:55	1:00	OVER LOAD
SEB-13	WAAR	2/3/2018	18:40	19:50	1:10	OVER LOAD
SEB-11	WAAR	2/4/2018	19:20	20:00	0:40	OVER LOAD
SEB-02	WAAR	2/5/2018	18:30	19:55	1:25	OVER LOAD
SEB-10	WAAR	2/6/2018	18:50	19:10	0:20	OVER LOAD
SEB-02	WAAR	2/7/2018	8:30	8:35	0:05	OVER LOAD

SEB-02	WAAR	2/8/2018	11:20	12:35	1:15	OVER LOAD
SEB-05	WAAR	2/9/2018	13:19	15:30	2:11	OVER LOAD
SEB-09	WAAR	2/10/2018	13:19	15:30	2:11	OVER LOAD
SEB-02	WAAR	2/17/2018	14:34	16:39	2:05	OVER LOAD
SEB-02	WAAR	2/18/2018	8:25	10:30	2:05	OVER LOAD