Analysis and Minimization of Power Loss in EEU Distribution Network Using UPFC

(Case Study: Adama Town Distribution System)

By

Tesfaye Dulla Wada

A Thesis Submitted to the Department of Electrical Power and Control Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfilment of the Requirement for the Degree of Master of Science in Electrical Power and Control Engineering
(Electrical Power Engineering)

Office of Post Graduate Studies

Adama Science and Technology University

October, 2020

Adama, Ethiopia

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Approval sheet

We, the undersigned, members of the board of Examiners of the final open defense by Tesfaye Dulla Wada have read and evaluated his thesis entitled "Analysis and Minimization of Power Loss in EEU Distribution Network Using UPFC" and Examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment for the requirement of the degree of Master of Science in Electrical Power Engineering.

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Declaration

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

Tesfaye Dulla Wada ------------------------- ---------------------

Signature Date

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

Dr. Molla Biweta ________________

Advisor Signature

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List of Symbols

t	Time
$\Delta\omega_r$	Per unit angular velocity
δ	Angular position of the rotor
$\Delta\varpi_r$	Per unit change in rotor speed
$\Delta\bar{P}_e$	Per unit change in electrical load power
$\Delta\bar{P}_m$	Per unit change in ballast load
$\Delta\bar{P}_D$	Per unit change in demand power
V_{ll}	Line voltage
R_{ll}	Ballast load resistance
D	Load damping constant
f	Frequency
ω_m	Angular velocity
ω_{om}	Rated angular velocity
$\sum$	Summation Function
S_{ij}	Power injection from bus i to the line between bus i and bus j
S_{ji}	Power injection from bus j to the line between bus j and bus i
S_{Lij}	Apparent power loss in the line between bus i and bus j
$I_{ij}{}^*$	Complex conjugate of current I_{ij}

List of Abbreviations

AEP ....American Electric Power

AAAC ……………………………...…. All Aluminum Alloy Conductors

AC ....Alternating Current

ACAR ....Aluminum conductor alloy reinforced

ACSR ....Aluminum Cable Steel Reinforced

ANSI …..American national standard institutes

CB...Circuit Breaker

CSC …..Convertible Static Compensator

DC ....Dirrect Current

DFC …..Dynamic Flow Controller

DG’s …...Distributed Generators

DNOs …...Distribution Network Operators

DNOs …...Distribution Network Operators

EEP...…....Ethiopia Electric Power

EEU..Ethiopia Electric Utility

EHV…...Extra high voltage

FACTS …..Flexible AC Transmission System

GA-Fuzzy…..Genetic Fuzzy Algorithm

HP ....Horsepower

GTO ……………………………...…...…..Gate turn offs

IEEE …………………………….........…....Institute of Electrical and Electronics Engineer

IGBT…..Insulated gate bipolar transistors

IGCT ………………………….......................Insulated Gate Commutated thyristor

IPFC …..Interline Power Flow Controller

LTL…..Low Tension Line

OH …..Overhead

PWM …..Pulse Width Modulation

SSSC …..Static Synchronous Series Compensators

SSR ....Subsynchronous Resonance

STATCOM …...Static Synchronous Compensators

SVC…..Static Var Compensators

TCSC …...Thyristor Controlled Series Compensators

THD ....…....Harmonic Distortion

TSC ……………......………....…………..…...Thyristor Switched Capacitor

TSR ....Thyristor Switched Reactor

UG ....Underground

UPFC ....Unified Power Flow Controller

VSC ....Voltage source converters

Abstract

Minimization of line losses and the improvement of power quality in distribution system is the most challenging problems, particularly when it needs capital cost to upgrade the entire feeder systems. A simplified loop distribution system is taken as the object and the main reasons leading to the power loss in the feeder are analysed in this thesis. This thesis work presents a method to achieve the line loss minimization condition and improve power quality in a loop distribution system using Unified Power Flow Controllers (UPFC), one of the most important FACTS devices. First, the line loss minimization conditions in distribution system is present for regulating voltage and to minimize losses in distribution system then this load voltage regulation is applied in the system to improve the power quality.

Thinking about the power control function of the unified power flow controller, the control system for the series side of the unified power flow controller is designed based on the voltage control method. Reference voltage of the controlled node is determined based on the assumptions that this voltage can subsequently improve all node voltages to be with in the permissible range and it control that the system insets a series voltage into the controller line and produces a power, which is in the same direction with the power of the controlled line and equals to the loop power of the loop system in quantity. Then the power loss is decreased by eliminating the loop current in the distribution system. Simulations in the loop distribution systems take place by two feeders with different line loss values and the results verified the function of UPFC designed in this thesis for reducing the power loss of the distribution system.

Key words: Distribution line loss, FACTS controller, loss reduction, UPFC.

CHAPTER ONE

1. INTRODUCTION

1.1 Background

The distribution system is the most visible part of the supply chain, and as such the most exposed to the critical observation of its users. It is, in many cases, the largest investment, maintenance and operation expense, and the object of interest to government, financial agencies and associations of concerned citizens. About 30 to 40 % of total investments in the electrical sector go to distribution systems, but nevertheless, they have not received the technological impact in the same manner as the generation and transmission systems [1]. Many of the distribution network work with minimum monitoring systems, mainly with local and manual control of capacitors, sectionalizing switches and voltage regulators; and without adequate computation support for the system's operators. Nevertheless, there is an increasing trend to automate distribution systems to improve their reliability, efficiency and service quality. Ideally, losses in an electric system should be around 3 to 6%. In developed countries, it is not greater than 10%.However, in developing countries, the percentage of active power losses is around 20% [1]; therefore, utilities in the electric sector are currently interested in reducing it in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses. To manage a loss reduction program in a distribution system it is necessary to use effective and efficient computational tools that allow quantifying the loss in each different network element for system losses reduction.

Power Transmission and Distribution is a complex process, wherever power is to be transferred, the two main components are active and reactive power. In a three phase ac power system active and reactive power flows from the generating station to the load through different transmission lines and networks buses. The active and reactive power flow in transmission line is called power flow or load flow. Power flow studies provide a systematic mathematical approach for determination of various bus voltages, there phase angle, active and reactive power flows through different lines, generators and loads at steady state condition. Power flow analysis is also used to determine the steady state operating condition of a power system. For the planning and operation of power distribution system, Power flow analysis is used. It is very important to control the power flow along the transmission line. Thus to control and improve the performance of AC power systems, we need the various different types compensators. The continuing rapid development of high-power semiconductor technology now makes it possible to control electrical power systems by means of power electronic devices [2]. These devices constitute an emerging technology called FACTS (flexible alternating current transmission systems).The FACTS technology opens up new opportunities for controlling both types of powers and enhancing the usable capacity of present transmission systems. The possibility that power through a line can be controlled enables a large potential of increasing the capacity of lines. This opportunity arises through the ability of FACTS controllers to adjust the power system electrical parameters including series and shunt impedances, current, voltage, phase angle, and the damping oscillations etc. The implementation of such equipment's requires the different power electronics-based compensators and controllers [3].The FACTS devices use various power electronics devices such as Thyristor, Gate turn offs(GTO), Insulated gate bipolar transistors(IGBT), Insulated Gate Commutated thyristor (IGCT),they can be controlled very fast as well as different control algorithms adapted to various situations. FACTS technology has a lots of benefits, such as greater power flow control ability, increased the loading of existing transmission circuits, damping of power system oscillations, has less bed impact on environmental and, has the less cost than other alternative techniques of transmission system is used.

This thesis presents minimum conditions for the losses in distribution systems by modeling the system using unified power flow controllers (UPFC). Among the FACTS components, Unified Power Flow Controller (UPFC) is the most complete. It is able to control independently the throughput active and reactive powers. The UPFC is capable to act over three basic electrical system parameters: line voltage, line impedance, and phase angle, which determine the power.

Generally, FACTS devices and technology could be divided into two generations

Dynamic devices and fixed capacitance devices: This is the first generation of the FACTs devices. In this period, the typical devices are including tap changing and phase changing transformer, synchronous generator and series capacitors. Except the series capacitors, which could also be called capacitor bank, others are dynamic devices. These devices are mainly controlled at the generation side of the power grid and the cost is typically expensive. When talk about the series capacitors, the drawback of this device could hardly be omitted. Since the device is made up of many fixed-capacitance capacitors, it could hardly be controlled to give the real not-fixed capacitance to the grid.

Static state compensator: This is the second generation of the FACTS devices. It could be classified into two categories i.e. thyristor-based devices and fully-controlled devices based compensator. The thyristor is called half-controlled device, because it can only be controlled to switch on but not to cut off. Static Var Compensator (SVC) and Thyristor-Controlled Series Capacitor (TCSC) are included in this category. The fully controlled devices mainly involve GTO etc. The Static Compensator (STATCOM), Solid State Series Compensator (SSSC), Unified Power Flow Controller (UPFC) and HVDC-Voltage Source Converter (HVDC-VSC) are included in this group. The UPFC can simultaneously control the active and reactive power flow and voltage magnitude. However it has little effect on voltage angle.

1.2. Problem Formulation

The quality of electric distribution systems was critically important for both utilities and customers. Electric power quality affects public health and safety, economic growth and development as well as societal well-being.

The frequent power interruption of Adama town was become a serious problem due to many factors. These factors that cause failures of electricity in the town distribution system such as Human error factors, External factors and Intrinsic factors are the main motivating factors to study on this area. The rapid increase in the population on the town and people migrating from the rural areas to here; However, the power system facilities, particularly the distribution network has not experienced a proportionate expansion and not adequate enough for maintenance thus leading to; overloading of the system, system losses due to mismatches between the power supply and demand received, unreliable power supply to consumers, transient behaviour of the systems, overloading of feeder (conductors, resulting to over-heating and insulation breakdown), constant power outages leading to shutdown of production activities and eventual loss of revenue and gross profits, overloading of the system result to overheating of the system which has caused deficiency of the system to supply a reliable power to the consumer.

In order to overcome and minimize these effects, loss minimization on distribution system is the main important way to overcome with rapidly increasing demand of consumers of electricity on the town.

Technology reveals up new opportunities for controlling power and enhancing the usable capacity of present, as well as new and upgraded lines. The high power switching devices applied at the transmission and distribution level is bringing utilities new opportunities as well as new challenges for controlling the main parameters related to power flow and voltage control. UPFC has the advantage over other FACTS controller devices and also the phase shifter can control not only real power but also reactive power flow on transmission or distribution lines simultaneously.

Thus, the state of transmission and distribution losses in the existing grid network of EEU should have to be critically analyzed and technology based measures towards loss reduction should have to be implemented. Analyzing some loss reduction methods i.e. FACTS controller on the existing network and designing UPFC injection model for EEU's distribution grid network is the first aim of this thesis work.

1.3. Significance of the Study

The UPFC by means of angularly unconstrained series voltage injection is able to control concurrently or selectively, the distribution line voltage, impedance, and angle or, alternatively, the real and reactive power flow in the line. The UPFC may also provide independently controllable shunt-reactive compensation. And also, enable to get accurate reflection of its operation. Specifically, the proposed study will contribute the following advantages.

1. Improved Power System Stability and Reliability
2. Increased System Security and power flow
3. Increase the power transfer capability
4. Compensate reactive power

1.4. Objectives of the Thesis

1.4.1 General objective:

The General objective of this thesis is to analyze and minimize power loss in EEU distribution network using UPFC.

1.4.2 The specific objectives:

- Analyze distribution line losses of distribution-feeders as a function of line loading and length
- Model distribution system of the two most highest loss share feeders

- Design the UPFC system and simulate the performance of the controlling system in terms of power reliability and output power using UPFC.
- Compare the distribution system loss with and without the installation of UPFC
- Make relevant conclusions and recommendations for practical implementation of the model.

1.5. Thesis Methodology

In order to attain the above general and specific objectives of the study, the following tools, methods and techniques will be followed.

Tools used

- MATLAB Simulation
- Unified power flow controller (UPFC)
- Bus bar
- Transmissions lines
- Transformer
- Capacitor

a) Literature Review

A number of published ideas about power loss problems in books, papers, articles, journals, note lectures, materials have been reviewed. The situation of increased demand of electric power has necessitated a review of the traditional power system concepts and practices to achieve greater operating flexibility and better utilization of existing power systems. The technologies of FACTS device and UPFC have been well identified in the broad application in distribution system.

b) Data Collection

Data of primary feeder lines and other parameters have been collected from Ethiopian electric utility concerned offices and substation regarding the following Ethiopian electric utility components: distribution lines, loads and transformers in accordance to their parameters and ratings.

c) Data Analysis

The aforementioned collected data have been analyzed and organized to make suitable for selecting the highest load share feeders and modeling distribution system.

d) **Modeling of Unified Power Flow Controller (UPFC)**

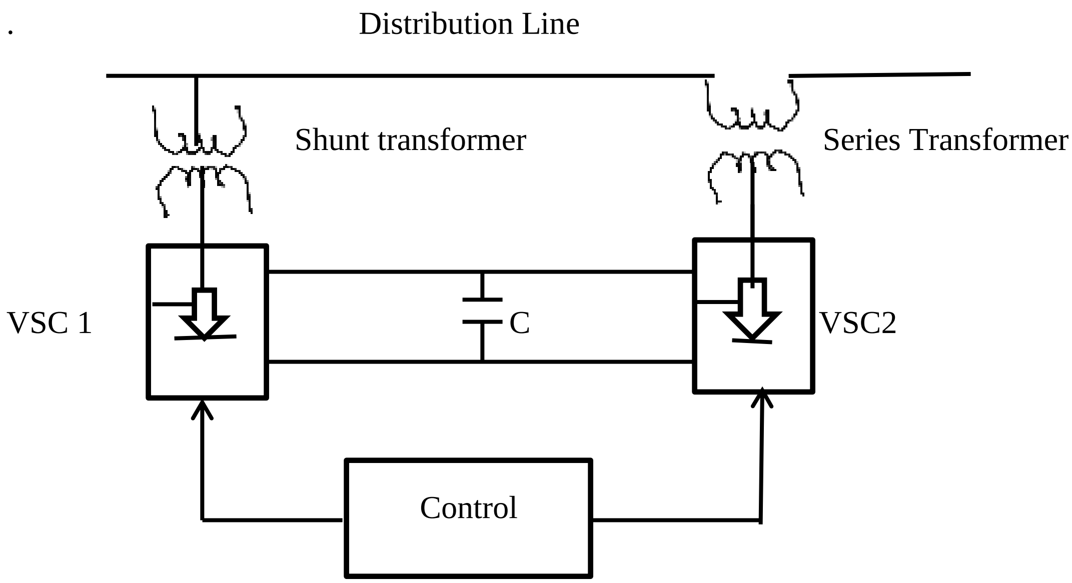


Figure 1. 1The Schematic diagram of UPFC

e) Design of distribution system using UPFC

To verify the performance of the proposed model of distribution system, Adama District, Adama-132 kv Substation is selected as a case study in this thesis.

f) Simulation of the proposed scheme

The actual distribution network, which was modelled using real data for system study, has been used and the performance of the proposed schemes were simulated by employing different events using Matlab simulation software

g) Analysis of the result:

Based on the simulation results obtained, analysis of the system which is currently working and the results obtained by using upfc was compared.

h) Recommendation:

Necessary recommendation for power loss minimization technique have been made

CHAPTER TWO

2. THEORETICAL BACKGROUND AND LITERATURE REVIEW

2.1 Theoretical Background

The distribution system is defined as the part of the power system located between the distribution substation and the point of entry of customer service [4]. The distribution system is that part which connects the distribution substation to the consumer's service entrance equipment. The primary distribution lines are usually in the range of 4 to 34.5kv and supplies the load in a well-defined geographical area. Some small industrial customers are served directly by the primary feeders. The secondary distribution network reduces the voltage by the utilization by commercial and residential consumers. The secondary distribution serves most of the customers of 140/120v. Single phase, three wire; 208Y/120v, three phase, four wire; or 480Y/277v, three phase, four wire. The power for a typical home is derived from a transformer that reduces the primary feeder voltage from 240/120v using a three wire line.

In distribution line, sending end power and receiving end power was not same. It goes on decreasing due to consumption at each load center. The voltage at each node (load center point) was different and also power flow in each branch between two nodes was different and hence power loss was different in different branches [5].

Low cost, simplification, and standardization were all important design characteristics of distribution systems. Few components or installations were individually engineered on a distribution circuit. Standardized equipment and standardized designs were used wherever possible [5].

Primary distribution system

The part of the electrical service system that lies between the distribution substation and the distribution transformer is called the primary distribution system. Electric power from the generating station is transmitted at high voltage to the substation located in or near the city. At this substation voltage is stepped down to 15kv with the help of step down transformer. Power is supplied to various substations for distributions or to big consumers at this voltage. This forms the high voltage distribution or primary distribution. The voltage used for primary distribution depends up on the amount of power to be conveyed and a distance of the substation required to be fed. The most commonly used primary distribution voltages are

15kv, 6.6kv and 3.3kv. Due to economic consideration, primary distribution is carried out by 3-phase, 3-wire system.

Secondary distribution system

The part that lies between the distribution transformer and the service load drop point is called the secondary distribution system. The primary distribution circuit delivers power to various substations called distribution transformer substations. The substations are situated near the consumers' localities and contain step down transformers. Therefore, it is that part of ac distribution which includes the range of voltages at which the ultimate consumers utilize the electrical energy delivered to them. The secondary distribution employs 400/230v, 3-phase, 4-wire system.

2.2 Classification of distribution system

In a broad definition, the AC-distribution system is that part of the electric utility system between the bulk power source and the consumer's service switches. This definition of the distribution system includes the following components:

1. Sub-transmission system
2. Distribution substations
3. Distribution or primary feeders
4. Distribution transformers
5. Secondary mains
6. Consumer services

Distribution systems are both overhead and underground.

2.2.1 Overhead Distribution Line Systems

Overhead circuits consist of aerial cables or open-wire conductors carried on poles or towers. The purpose of an overhead transmission network is to transfer electric energy from generating units at various locations to the distribution system which ultimately supplies the load. Aluminum conductors have, to a large degree, replaced copper in overhead installations. Conductor sizes most commonly used Aluminum Cable Steel Reinforced (ACSR) or stranded aluminum alloy. An overhead line was the structure of distribution system that transmits the electrical energy over a large distance which consists of one or more conductors suspended by towers or poles. The overhead (OH) lines were mainly bare conductors [5], [6].

2.2.2 Underground Line of Distribution System

In older areas, transmission circuits were often 3-conductor lead-covered cables. Cross-linked polyethylene and ethylene-propylene rubber were replacing lead. Ordinarily, a conductor copper cable varying was installed in underground conduits. Aluminum cable was seldom used in underground installations because these cables were larger than copper cables of equal capacity [6].

The underground (UG) systems mainly use power cables to transmit electrical energy. The UG lines were used due to the reasons; Extreme weather condition (snow, wind) in distribution areas, densely populated urban areas having right of way problem, can be used near submarine crossings [6].

2.3 Electrical Power Loss

Losses in transmission and distribution networks represent the single largest consumption in any power system. Due to the rapid increase in the demand for electricity, environmental constraints and competitive energy market scenario, the transmission and distribution systems are often being operated under heavily loaded conditions and the distribution system loss has become more and more of a concern. The requirement to provide acceptable power quality and enhanced efficiency to achieve all possible economic benefits will create a very favourable climate for the need of loss minimization techniques and innovative operating practices. The total power delivered to the distribution system has been calculated according to the total power generation and power loss of the transmission system. To enhance the efficiency of distribution system loss minimization is the only alternative. Thus it is found that, since last three decades research in distribution systems has been focused on line loss minimization and voltage regulation.

There are two types of Transmission and Distribution Losses:

- **Technical Losses**
- **Non-Technical Losses (Commercial Losses)**

Technical Losses

The technical losses are due to energy or power dissipated in the conductors, equipment used for transmission line, transformer, sub transmission line and distribution line and magnetic losses in transformers. Technical losses are normally 22.5%, and directly depend on the network characteristics and the mode of operation.

The major amount of losses in a power system is in primary and secondary distribution lines. While transmission and sub-transmission lines account for only about 30% of the total losses. Therefore the primary and secondary distribution systems must be properly planned to ensure within limits. The unexpected load increase was reflected in the increase of technical losses above the normal level. Technical losses are typically divided into load losses (e.g. copper losses) and no-load losses (e.g. iron losses). Load losses are a function of current and no-load losses are a function of voltage.

Load Losses

Load losses are system load dependent and occur in any system element through which the electric current flows. Variable losses vary with the amount of electricity distributed and are proportional to the square of the current. They are simply copper or I^2R losses of a branch or equipment. Between 2/3and 3/4 of technical losses are variable [7].

No-load losses

No-load losses are the result of the readiness state. $i.e$ presence of electric voltage on element. The share of the constant losses in the total peak load losses is small. It should nevertheless be remembered that constant losses are load-independent and occur throughout the element operation. Fixed losses are present all the time. This means 8760 hours a year. The only problem affecting the calculation accuracy is determination of the scope of the power losses [8].

Sources of no-load losses include the iron cores of transformers due to hysteresis and eddy-current losses, resistive losses in the primary winding of transformers, corona discharges and voltage coils of energy meters.

There are two types of Technical Losses.

1. Permanent / Fixed Technical losses

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

- Corona Losses
- Leakage Current Losses
- Dielectric Losses

- Open-circuit Losses
- Losses caused by continuous load of measuring elements
- Losses caused by continuous load of control elements

2. Variable Technical losses

Variable losses vary with the amount of electricity distributed and are, more precisely, proportional to the square of the current. Consequently, a 1% increase in current leads to an increase in losses of more than 1%.

Between 2/3 and 3/4 of technical (or physical) losses on distribution networks are variable Losses. By increasing the cross sectional area of lines and cables for a given load, losses will fall. This leads to a direct trade-off between cost of losses and cost of capital expenditure.

Main Reasons for Technical Losses

- **Lengthy Distribution lines**

In practically 15 KV and 380 volts lines, in rural areas are extended over long distances to feed loads scattered over large areas. Thus the primary and secondary distributions lines in rural areas are largely radial laid usually extend over long distances. This results in high line resistance and therefore high I^2Rlosses in the line.

- **Inadequate Size of Conductors of Distribution lines**

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

- **Installation of Distribution transformers away from load centers**

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

- **Low Power Factor of Primary and secondary distribution system**

In most LT distribution circuits, the Power Factor ranges from 0.65 to 0.75. A low Power Factor contributes towards high distribution losses. For a given load, if the Power Factor is low, the current drawn is high and the losses proportional to square of the current will be more. Thus, line losses owing to the poor PF can be reduced by improving the Power Factor. This can be done by application of shunt capacitors. Shunt capacitors can be connected either in secondary side (15 KV side) of the 33/15 KV power transformers or at various point of Distribution Line.

The optimum rating of capacitor banks for a distribution system is $2/3^{rd}$ of the average KVAR requirement of that distribution system. The vantage point is at 2/3rd the length of the main distributor from the transformer. A more appropriate manner of improving this PF of the distribution system and thereby reduce the line losses is to connect capacitors across the terminals of the consumers having inductive loads. By connecting the capacitors across individual loads, the line loss is reduced from 4 to 9% depending upon the extent of PF improvement.

- **Bad Workmanship**

Bad Workmanship contributes significantly role towards increasing distribution losses. Joints are a source of power loss. Therefore the number of joints should be kept to a minimum. Proper jointing techniques should be used to ensure firm connections. Replacement of deteriorated wires and services should also be made timely to avoid any cause of leaking and loss of power.

- **Feeder Phase Current and Load Balancing**

One of the easiest loss savings of the distribution system is balancing current along three-phase circuits. Feeder phase balancing also tends to balance voltage drop among phases giving three-phase customers less voltage unbalance. Amperage magnitude at the substation doesn’t guarantee load is balanced throughout the feeder length. Feeder phase unbalance may vary during the day and with different seasons. Balancing load among distribution feeders will also lower losses assuming similar conductor resistance. This may require installing additional switches between feeders to allow for appropriate load transfer.

- **Transformer Sizing and Selection**

Distribution transformers use copper conductor windings to induce a magnetic field into a grain-oriented silicon steel core. Therefore, transformers have both load losses and no-load core losses. Transformer copper losses vary with load based on the resistive power loss equation

$$P_{loss} = I^2 R$$

For some utilities, Economic transformer loading means loading distribution transformers to capacity-or slightly above capacity for a short time-in an effort to minimize capital costs and still maintain long transformer life. Transformer no-load excitation loss (iron loss) occurs from a changing magnetic field in the transformer core whenever it is energized. Core loss varies slightly with voltage but is essentially considered constant. Fixed iron loss depends on transformer core design and steel lamination molecular structure. Improved manufacturing of steel cores and introducing amorphous metals (such as metallic glass) have reduced core losses.

Non-technical Losses

Non-technical losses are not related to the physical characteristics and functions of the electrical system. These losses are not actually losses in terms of consumption loss. What makes them to be grouped under losses is that the consumption is not paid for. They can be evaluated on the basis of the difference between the generated and sold energy on one hand and the calculated technical losses on the other hand. Illegal energy consumption (theft), incorrect meter reading, energy meter failures and shortfalls in billing are known sources of non-technical losses [9].Non-technical losses are at 16.6%, and related to meter reading, defective meter and error in meter reading, billing of customer energy consumption, lack of administration, financial constraints, and estimating unmetered supply of energy as well as energy thefts.

Main Reasons for Non-Technical Losses

- **Power Theft**

Theft of power is energy delivered to customers that is not measured by the energy meter for the customer. Customer tempers the meter by mechanical jerks, placement of powerful magnets or disturbing the disc rotation with foreign matters, stopping the meters by remote control.

- **Metering Inaccuracies**

Losses due to metering inaccuracies are defined as the difference between the amount of energy actually delivered through the meters and the amount registered by the meters. All energy meters have some level of error which requires that standards be established.

- **Unmetered Losses for very small Load**

Unmetered losses are situations where the energy usage is estimated instead of measured with an energy meter. This happens when the loads are very small and energy meter installation is economically impractical. Examples of this are streetlights and cable television amplifiers.

- **Unmetered Supply**

Unmetered supply to agricultural pumps is one of the major reasons for commercial losses. In most states, the agricultural tariff is based on the unit horsepower (HP) of the motors. Such power loads get sanctioned at the low load declarations. Once the connections are released, the consumers increase their connected loads without obtaining necessary sanction for increased loading from the utility. Further, estimation of the energy consumed in unmetered supply has a great bearing on the estimation of T&D losses on account of inherent errors in estimation.

Error in Meter Reading

Proper Calibrated Meter should be used to measure electrical energy. Defective Energy Meter should be replaced immediately. The reason for defective meter are burning of meters, burn out terminal box of meter due to heavy load, improper C.T ratio and reducing the recording, Improper testing and calibration of meters.

- **Billing Problems**

• Faulty and untimely serving bill should be main part of non-technical losses.

• Normal complaint regarding billing are not receipt of bill, late receipt of bill, receiving wrong bill , wrong meter reading, wrong tariff, wrong calculations.

2.4 Power Loss Minimization Techniques

When electricity is transmitted over transmission and distribution lines, some portion of the energy is consumed by joule heating losses (resistive losses) in the conductor. These line losses are a function of the line’s resistance and the square of the current flowing through the line. Therefore, reducing line losses requires either reduction in the resistance of the line or in the current flowing through the line. Reducing the currents flowing in a given transmission and distribution line can significantly reduce losses because the losses change with the square of the current flow. There are many of loss reduction strategies within the electric power distribution industry. In the majority of cases, these modifications have been implemented for reasons other than reducing transmission losses; whereas may be implemented to increase transmission capacity, keep stability of the system or improve the power quality. However, these distribution constraints as well as distribution losses can be improved simultaneously being two sides of a coin. Losses in transmission and distribution networks represent the single largest consumption in any power system. Due to the rapid increase in the demand for electricity, environmental constraints and competitive energy market scenario the transmission and distribution systems are often being operated under heavily loaded conditions and the distribution system loss has become more and more of a concern. The requirement to provide acceptable power quality and enhanced efficiency to achieve all possible economic benefits will create a very favourable climate for the need of loss minimization techniques and innovative operating practices. The total power delivered to the distribution system has been calculated according to the total power generation and power loss of the transmission or distribution system. Some distribution loss reduction techniques used in present day utility companies are described below [10].

2.4.1. Capacitor placement

This section contains those publications which are related to Distribution Network Loss Reduction by using Capacitor Placement Technique which was found to be feasibly applicable in high voltage distribution systems. The application of capacitors to electric power systems can be used for:

1. The control of power flow
2. Stability improvement
3. Voltage profile management
4. Power factor correction
5. Power and energy loss reduction

The capacitor is a source of reactive power as by reducing the inductive reactance portion of the line loading, it can reduce the reactive losses which can be done by the addition of shunt capacitors.

Loss equation

Consider a single line diagram of a uniformly loaded feeder as shown in Fig.2.1. The basic reactive loss given by equation

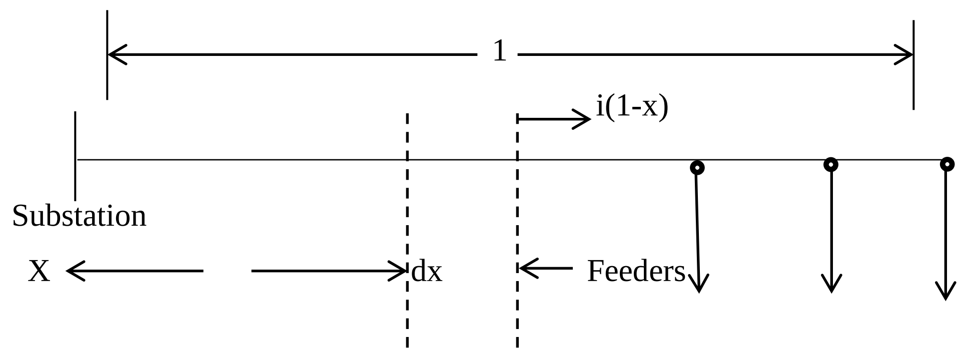


Figure 2. 1Single line diagram of uniformly loaded feeder

Total Losses (due to reactive current) $= \min \int I^2 R dx = \min \int \left[I\left(1-x\right)\right]^2 R dx$ (2.1)

Where *i* is the reactive current at feeder; *R* is the total resistance and *x* is the distance from source.

This formula is used in the literature, in various forms for siting and sizing the capacitors so as to achieve minimum losses.

2.4.2 Network reconfiguration

This was found to be generally applicable in low voltage Distribution networks. It is a very imperative approach to save the electrical energy. Distribution systems consist of groups of interconnected radial circuits. The configuration may be varied via switching operations to transfer loads among the feeders. Two types of switches are used in primary distribution systems. They are normally closed switches (sectionalizing switches) or normally open switches (tie switches).

2.4.3 DG allocation

DG can be defined as “The generation of electricity from facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system”[11].Recently the penetration of Distributed Generators (DG's) into distribution systems has been increasing rapidly in many parts of the world. Integration of DG into an existing utility can result in several benefits such as:

- reduced environmental impacts
- increased overall energy efficiency

- relieved transmission and distribution congestion
- voltage support
- exploitation of the renewable resources, such as wind, solar, hydro, biomass, geothermal and ocean energy and
- Line loss reduction.

Distributed generators are very much beneficial in reducing the losses effectively compared to other methods of loss reduction except the use of modern electronic devices. The main reasons for continuous growth in the penetration of DG in power network are:

2.4.4 High voltage distribution system

A high voltage distribution system or HVDS will use 20 kV voltage lines longer than the 380 V voltage line. In other words, this HVDS system will distribute in the voltage 20 kV; then it will be lowered to 380 V at certain positions. This HVDS system is basically the location change and the capacity of the adjusted distribution transformer.

The proposed change of the system into the new configuration is done by replacing a large-capacity distribution transformer with some smaller-capacity distribution transformers and installed them in positions that closest to the load. The use of high voltage distribution systems will result in better voltage profiles and fewer power losses. From the non-technical side, the annual savings and payback periods on high voltage distribution systems will also be the advantage.

2.4.5. Conductor grading

The size of conductor in a distribution system is an important parameter as it determines the current density and the resistance of the line. A lower conductor size can cause highI^2R losses and high voltage drop which causes a loss of revenue as consumer's consumption lower and hence revenue is reduced.

In most of the distribution systems planning methods the distribution feeders have been assumed to be of uniform cross section. But in practical systems current carrying capacity of the feeders are varied in different sections of the system and thus cross section of sections of the feeders also will vary.

The main reason for having high losses in developing countries like Ethiopia is stretching of distribution lines beyond the limits of load centers, increase of load abnormally without considering the current carrying capacity of the conductors and imbalance of generation and load causing reactive power generation, etc. Hence proper selection of conductors in the distribution system is important as it determines the current density and the resistance of the line. A lower conductor size can cause high I^2R losses and high voltage drop which causes a loss of revenue as consumer's consumption lowered and hence revenue is reduced. Increasing the size of conductors will require additional investment, which may not pay back for the reduction in losses [11].

2.5. Radial and loop distribution system for loss minimum conditions

This thesis presents minimum conditions for the losses in distribution systems and experimentally achieved them by using unified power flow controllers (UPFC). Among the FACTS components, Unified Power Flow Controller (UPFC) is the most complete. It is able to control independently the throughput active and reactive powers. The UPFC is capable to act over three basic electrical system parameters: line voltage, line impedance, and phase angle, which determine the power. There are three basic types of distribution system designs: Radial, Loop, or Network. The Radial distribution system is the cheapest to build, and is widely used in sparsely populated areas. A radial system has only one power source for a group of customers. A power failure, short-circuit, or a downed power line would interrupt power in the entire line which must be fixed before power can be restored.

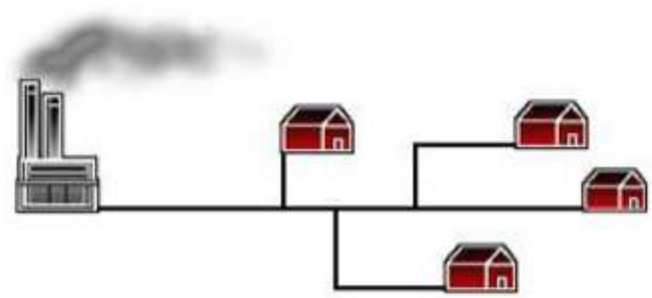


Figure 2. 2Radial distribution system

A loop system, as the name implies, loops through the service area and returns to the original point. The loop is usually tied into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction. If one source of power fails, switches are thrown (automatically or manually), and power can be fed to customers from the other source. The loop system provides better continuity of service than the radial system, with only short interruptions for switching. In the event of power failures due to faults on the line, the utility has only to find the fault and switch around it to restore service. The fault itself can then be repaired with a minimum of customer interruptions. The loop system is more expensive than the radial because more switches and conductors are required, but the resultant improved system reliability is often worth the price.

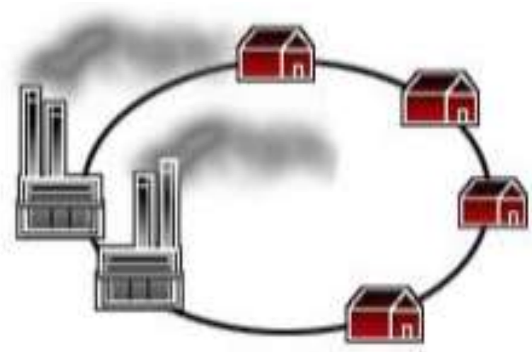


Figure 2. 3loop distribution system

Network systems are the most complicated and are interlocking loop systems. A given customer can be supplied from two, three, four, or more different power supplies. Obviously, the big advantage of such a system is added reliability. However, it is also the most expensive. For this reason it is usually used only in congested, high load density municipal or downtown areas.

2.6 FACTS Devices

The concept of Flexible AC Transmission System was first introduced by N.G.Hingorani in April 19, 1988. Since then different kind of FACTS controllers have been recommended. FACTS controller are based on voltage source converters and includes devices such as Static Var Compensators (SVC), static Synchronous Compensators (STATCOM), Thyristor Controlled Series Compensators (TCSC), Static Synchronous Series Compensators (SSSC) and Unified Power Flow Controllers (UPFC) [12]. The basic idea of FACTS is installing the power electronic devices at the high-voltage side of the power grid to make the whole system electronically controllable. The advances achieved in high power semiconductor devices and control technology makes the foundation of the development of FACTS. These devices are able to provide active and reactive power to the power grid rapidly. The power compensation achieved by FACTS devices could adjust the voltage of the whole system and the power flow could be satisfactorily controlled.

Power generated in power stations pass through large and complex networks like transformers, overhead lines, cables and other equipment and reaches at the end users. It is fact that the unit of electric energy generated by Power Station does not match with the units distributed to the consumers. Some percentage of the units is lost in the distribution network. This difference in the generated and distributed units is known as Transmission and Distribution loss. Transmission and Distribution loss are the amounts that are not paid for by users.

Power losses can be divided into two categories, real power loss and reactive power loss: The resistance of lines causes the real power loss, while reactive power loss is produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers. Nevertheless, reactive power loss is obviously not less important. This is due to the fact that reactive power flow in the system needs to be maintained at a certain amount for sufficient voltage level. Consequently, reactive power makes it possible to transfer real power through transmission and distribution lines to customers. The total real and reactive power losses in a distribution system can be calculated using equation 1 and 2.

$$P_{loss} = \sum_{i=1}^{n_{br}} |I_i|^2 R_i \qquad 2.2$$

$$Q_{loss} = \sum_{i=1}^{n_{br}} |I_i|^2 X_i \qquad 2.3$$

Where n_{br} is total number of branches in the system, $|I_i|$ is the magnitude of current flow in branch I, r_i and x_i are the resistance and reactance of branch i, respectively. Different types of loads connected to distribution feeders also affect the level of power losses. The problems which may be found in the distribution network affect both consumers and utilities. One of these problems is the problem of voltage drop that must be reduced to keep the voltages at load points within standard limits. The voltage drop problem may arise when using lateral radial feeders with long distance or feeding large loads. Therefore, the solution of this problem becomes imperative, that is, the voltage at different nodes of the system must be controlled. The voltage control means actually reactive power control. Consequently, controlling the reactive power and regulating the node

Voltages result in a reduction of power loss which has a great concern by utilities.

Flexible AC Transmission System (FACTS): Alternating current transmission systems incorporating power electronic-based and other static controllers to enhance controllability and increase power transfer capability.

The various basic applications of FACTS-devices are:

- Power flow control
- increase of transmission capability
- voltage control
- reactive power compensation,
- stability improvement
- Power quality improvement
- Power conditioning.

Figure 2.4 is classification of FACTS Controllers Based on power electronic devices. In this figure, left hand side column of FACTS-devices employs the use of thyristor valves or converters. This valves or converters are well known since several years. They have low switching frequency and low losses. The devices of the right hand side column of the figure has more advanced technology of voltage source converters based mainly on Insulated Gate Bipolar Transistors (IGBT) or Insulated Gate Commutated thyristor (IGCT). Pulse width modulation technique is used to control the magnitude and phase of the voltage. They have high modulation frequency.

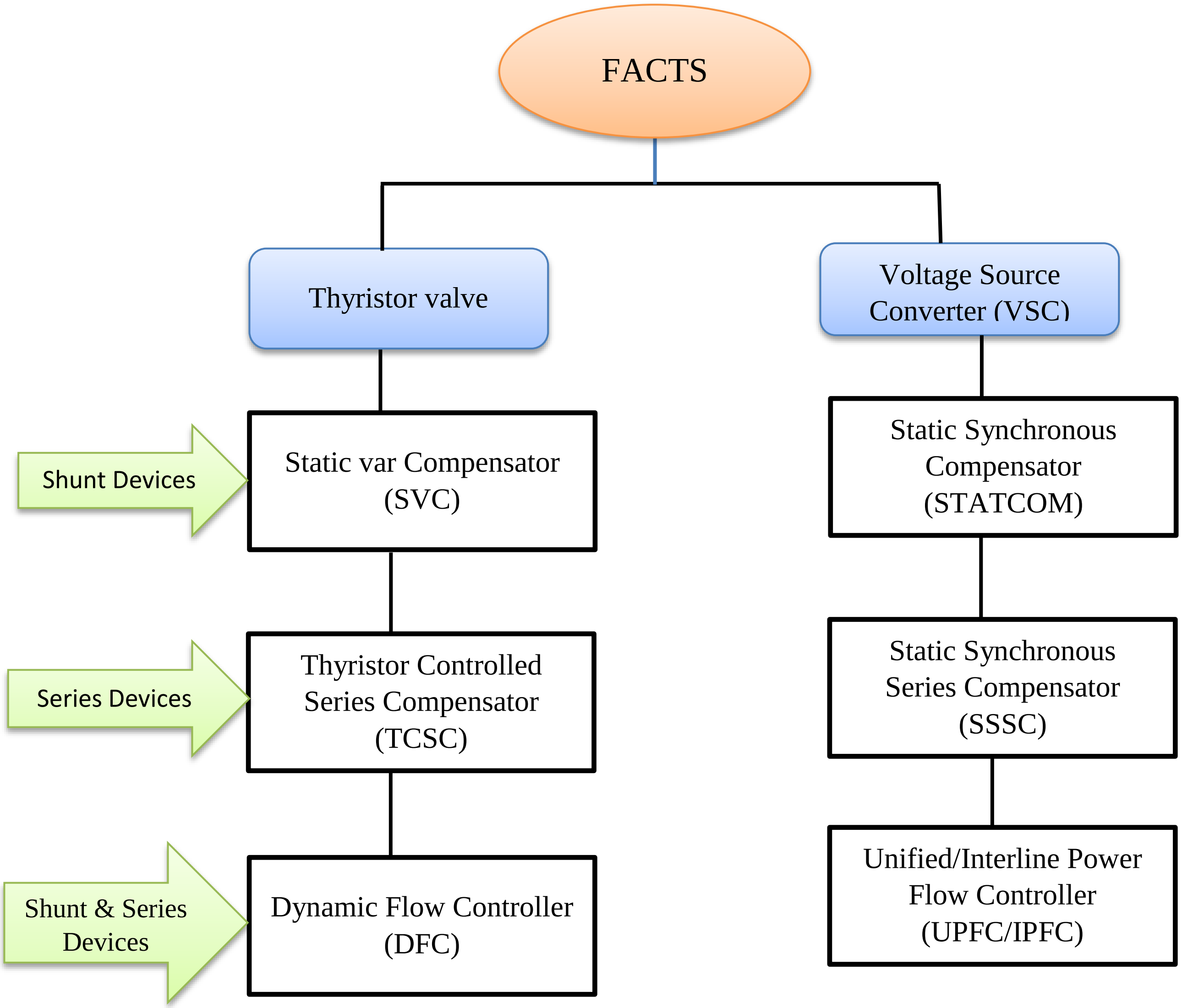


Figure 2. 4Overview Of major FACTS devices in terms of on power electronic devices

2.6.1 Thyristor Based Facts Devices:

2.6.1.1 SVC

A shunt- connected static var generator or absorber whose output is adjusted to exchange capacitive or inductive current so as to maintain or control specific parameters of the electrical power system (typically bus voltage).This is a general term for a Thyristor Controlled Reactor (TCR) or Thyristor Switched Reactor (TSR) and/or Thyristor Switched Capacitor (TSC). The term, “SVC” has been used for shunt connected compensators, which are based on thyristors without gate turn-off capability. It includes separate equipment for leading and lagging vars;

the thyristor –controlled or thyristor – switched reactor for absorbing reactive power and thyristor – switched capacitor for supplying the reactive power [13], [14].

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

2.6.2 Voltage Source Converter Based FACTS Devices

2.6.2.1 Static Synchronous Series Compensator (SSSC):

Static Synchronous Series Compensator is based on solid-state voltage source converter designed to generate the desired voltage magnitude independent of line current. SSSC consists of a converter, DC bus (storage unit) and coupling transformer. The dc bus uses the inverter to synthesize an ac voltage waveform that is inserted in series with transmission line through the transformer with an appropriate phase angle and line current. If the injected voltage is in phase with the line current it exchanges a real power and if the injected voltage is in quadrature with line current it exchanges a reactive power. Therefore, it has the ability to exchange both the real and reactive power in a transmission line [15].

2.6.2.2 Static Synchronous Compensator (STATCOM):

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

2.6.2.3 Unified Power Flow Controller (UPFC):

The UPFC is the most powerful and versatile FACTS equipment used to control the power flow and stability of the power system. UPFC can be act static as well as dynamic condition also. Static is an analysis at the steady state condition and dynamic is an analysis at the transient condition such as faults occurs in transmission system.

Operation of UPFC

The UPFC is a device which can control simultaneously all three parameters of line power flow (line impedance, voltage and phase angle).It is a one of the FACTS family that used to optimum power flow in transmission. The UPFC is a combination of static synchronous compensator (STATCOM) and static synchronous compensator (SSSC).Both converters are operated from a common dc link with a dc storage capacitor. The real power can freely flow in either direction between the two-ac branches. Each converter can independently generate or absorb reactive power at the ac output terminals [16]. The controller provides the gating signals to the converter valves to provide the desired series voltages and simultaneously drawing the necessary shunt currents, In order to provide the required series injected voltage, the inverter requires a dc source with regenerative capabilities. The possible solution is to use the shunt inverter to support the dc bus voltage.

Theory of UPFC:

The Unified Power Flow Controller (UPFC) was proposed first time for real turn-off time control and dynamic compensation of ac transmission systems. The Unified Power Flow Controller is consists of two switching converters, which are considered as voltage sourced inverters using gate thyristor valves, as illustrated in fig 2.5.These inverters, labeled "VSC1" and "VSC2" in the figure are operated with a common dc link provided by a dc storage capacitor. With this arrangement the ac power converter in which the real power can freely flow in either direction between the ac terminals of the two inverters and each inverter can independently generate as well as absorb the reactive power at its own ac output terminal .Since the series converter of the UPFC can inject a voltage with variable magnitude and phase angle it can exchange real power with the transmission line with the help of series transformer. However a UPFC as a whole (both converter) cannot supply or absorb real power in steady state (except for the power drawn to compensate for the losses).Unless it has a power source at DC terminals. Thus the shunt branch is required for compensate (from the system for any real power drawn/supplied by the series branch and the losses. when the power balance is not maintained, at that situation the capacitor cannot remain at a constant voltage. Shunt branch also can independently exchange reactive power with the system.

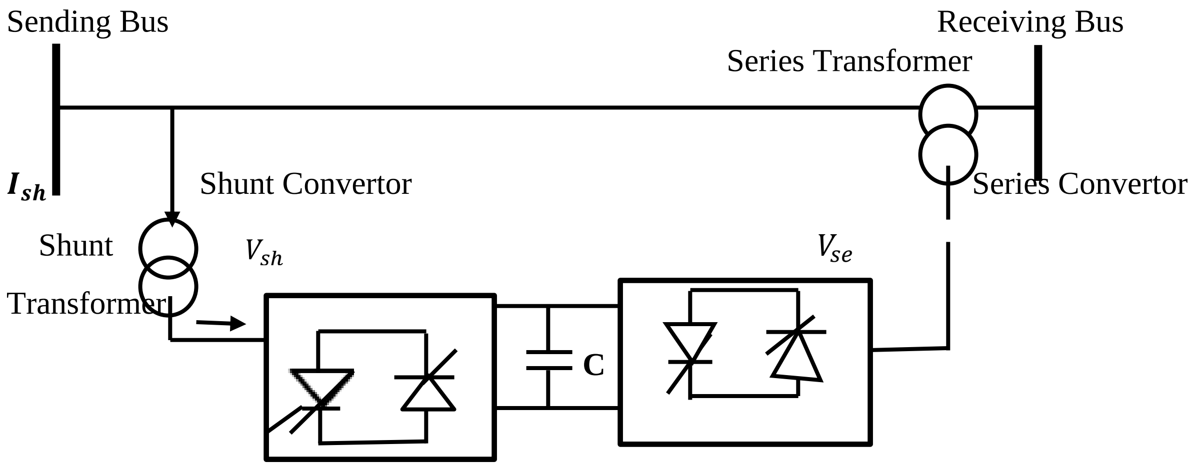


Figure 2. 5Basic Structure of an UPFC[17]

The function of converter1 is to supply or absorb the real power demanded by converter 2 at the common dc link. The power of the dc link is converted back to ac and coupled to the transmission line via a shunt-connected transformer. If reactive power is required then inverter 1 can also generate or absorb controllable reactive power, so it can provide independent shunt reactive compensation for the line. It is also important to note that whereas there is a closed "direct" path for the real power negotiated by the action of series voltage injection through Inverters 1 and 2 back to the line, corresponding the reactive power exchanged is supplied or absorbed locally by Inverter 2 and therefore the reactive power does not flow through the line. So the Inverter 1 can be operated at a unity power factor or be controlled to have a reactive power exchange with the line independently of the reactive power exchanged by Inverter 2. That means there is no continuous reactive power flow through the UPFC.

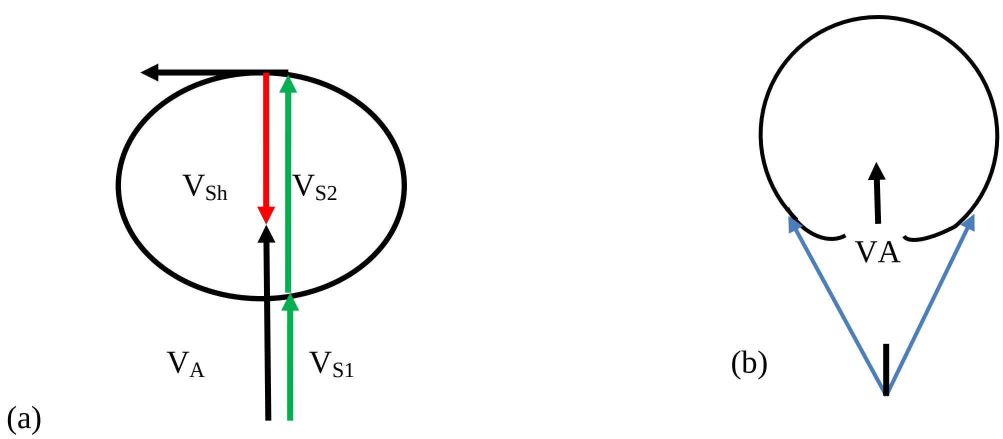


Figure 2. 6Power exchange of the Shunt Converter [17]

Figure 2.6(a) shows the exchange of the reactive power between the UPFC and the electrical system. The shunt converter generates a voltage Vs_1 in phase with VA but with variable magnitude. If Vs=Vs1. The UPFC injects some reactive power, if Vs=Vs_2 the UPFC absorbs some reactive power and no reactive power is exchanged for Vs=VA. In order to compensate the series converter losses, Figure 2.6(b) shows very clearly that the active power is exchanged between UPFC and the electrical system. The Voltage generated by shunt converter is no it in phase with the voltage of the system but of the same magnitude. Whereas the series converter of the UPFC controls the transmission line real/reactive power flows by injecting a series voltage of adjustable magnitude and phase angle. The UPFC can provide multiple power flow control functions by adding the injected voltage phasor with appropriate magnitude V_{se} and phase angle θ to the sending-end voltage phasor.

It can be seen that the UPFC consists of a series and a shunt converter is connected back-to-back through a common dc link. The shunt converter is connected also in parallel with the line of distribution by transformer and allows controls the UPFC bus Voltage/shunt reactive power and the dc capacitor voltage.

The Unified Power Flow Controller from the stand point of conventional power transmission based on reactive series compensation, shunt compensation, and phase shifting, the UPFC is the only device which can fulfill all these functions and thereby meet multiple control objectives by adding the injected voltage$V_{p\,q}$, with appropriate amplitude and phase angle, to the terminal voltage V_0Using phasor representation, the basic UPFC power flow control functions are illustrated in Fig.2.7.

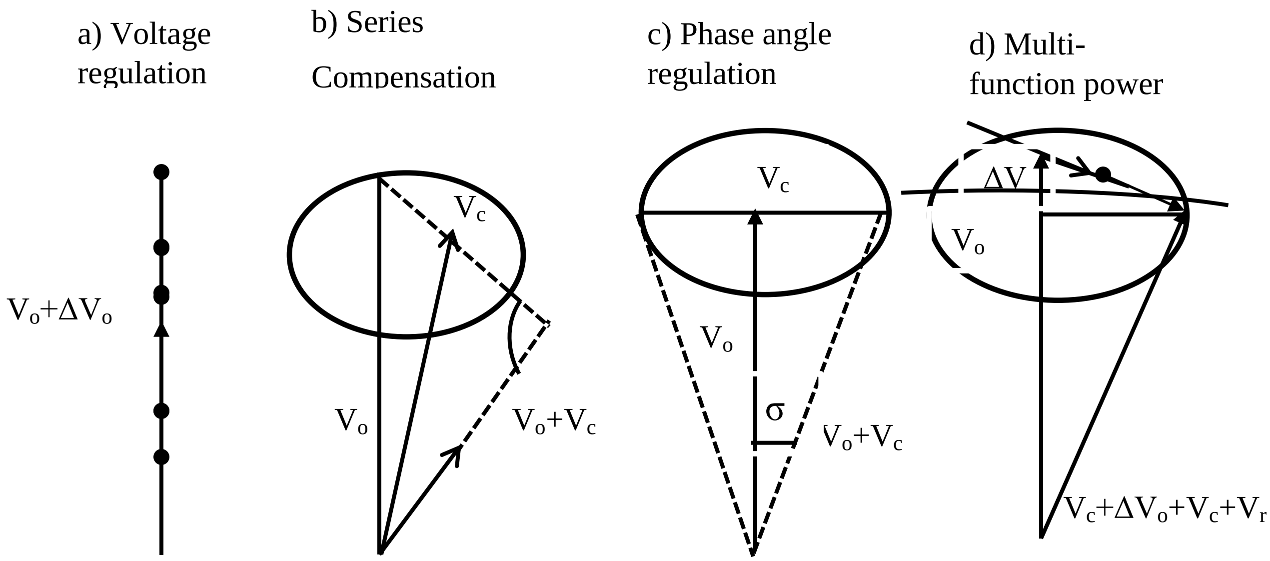


Figure 2. 7Basic UPFC control function. (a) Voltage Regulation (b) Series compensation (c) Angle regulation (d) Multi-function power flow controller [17]

Terminal voltage regulation, similar to that obtainable with a transformer tap-changer having infinitely small steps is shown at (a) where $V_m = \Delta V$ (boldface letters represent phasors) is injected in-phase (or anti-phase) withV_0. Series capacitive compensation is shown at (b) where V_m=V_c is injected in quadrature with the line current I. Transmission angle regulation (Phase shifting) is shown at (c) where $V_{p\,q}$= Vσ is injected with an angular relationship with respect to V_0 that achieves the desired σ phase shift (advance or retard) without any change in magnitude.

Fig 2.7 (d) shows that Multi power flow control, executed by simultaneous terminal voltage regulation; series capacitive line compensation, and phase shifting, where

$V_{p\,q}$=ΔV+ V_c + V_0.

2.6.2.4 Interline Power Flow Controller (IPFC):

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

2.7 Previous Works on Power loss minimization

1. Capacitor bank in distribution substation:

In 1996, Grainger and Lee [18] by eliminating many previous shortcomings of capacitor allocation set forth procedures for sizing and locating fixed shunt capacitors on primary distribution single radial feeder having possibly many sections of different wire sizes and for any known reactive-load distribution along the feeder which may not necessarily either uniformly distributed or concentrated feeders. Where as in [19] They extend their concepts and modeling procedures to account for both fixed and switched capacitors. After that in 1998 [20] they had proposed voltage dependent methodology for shunt capacitors which allows incorporation of an a.c. load flow program into the procedure for radial feeder compensation. In 2003 Grainer et al.[21] presented continuously controllable, capacitive compensation scheme for primary distribution feeders which assist distribution automation schemes being considered for implementation by electric utilities which rely heavily on substation-based computers for control

of reactive power on primary feeders. But none of the above approaches have accounted for the benefits due to either capacity release, effects of the growth factors, load growth, growth in load factor, and voltage rise problems during off-peak period and Solutions obtained under these assumptions may be far from real circumstances and methods were practically not compatible.

2. Use of High Speed Circuit Breaker:

The best method of improving power loss in distribution system is the use of high-speed circuit breakers. The quicker a breaker operates, the faster the fault is removed from the system and better is the tendency of the system to minimize power loss. The use of high-speed breakers has materially improved the power loss in distribution system. However this method occurs when a circuit is attempting to draw an electrical load than it is intended to carry.

3. Static Synchronous Series Compensator:

SSSC is connected in series with a power system. It has a voltage source converter serially connected to distribution line through a transformer. It can be considered as a voltage source that can inject an almost sinusoidal voltage of variable and controllable amplitude and phase angle in series with a distribution line. A small part of the injected voltage that is in phase with the line current provides the losses in the inverter.

Most of the injected voltage, which is in quadrature with the line current, provides the effect of inserting an inductive or capacitive reactance in series with the distribution line. However the variable reactance influences the electric power flow in the distribution line.

4. Thyristor Controlled Series Capacitor (TCSC):

TCSC consists of a number of capacitors in series each shunted by a switch in which two thyristors connected in anti-parallel. The TCSC is used to increase power transfer capability which intern reduces loss in the distribution system. Capacitor is inserted by turning off the thyristor switch. If all the switches are off the effective capacitance becomes C_{eq}=C/m where‟m‟ is the total number of capacitors.Similarly when simultaneously all the switches turned on Ceq is zero. Therefore the series compensation and effective capacitance are controlled in a stepped manner by changing the number of capacitors inserted in the circuit.

The configuration using TCSC is not common because of its SSR Characteristic. Although continuous control of the capacitor is possible, it is not yet to be applied in practice. TCSC is a mature technology available for increasing the power transferred to the system however this device has better performance in the transmission line of high voltage than in distribution system [22].

.**Unified Power Flow Controller (UPFC):**

In the unified power flow controller the shunt and series controllers are unified. It is combined by static synchronous series compensator (SSSC) and static synchronous compensator (STATCOM).With a common DC link. Between the shunt output terminals of STATCOM and the series output terminals of the SSSC, the DC link allows bi-directional flow of real power. For series line compensation UPFC is controlled to provide concurrently reactive and active power. It can control the transmission or distribution line Voltage, Impedance and angle and therefore the active and reactive power flow in the line it is highly capable[23].Both voltage and power flow control can be achieved by the use of combined series and shunt connected. The main advantages of using UPFC controllers in distribution lines are:

1. They help in system operation by reducing power losses and improving voltage profile.
2. UPFC has a unique capability to control real and reactive power flow simultaneously on a transmission system as well as to regulate the voltage at the bus where it's connected.
3. UPFC can also increase the capability of the power flow to the load demand until it reaches its limit in the short period.

CHAPTER THREE

3. METHODOLOGY AND DATA ANALYSIS

3.1Research Methods of Data Collection

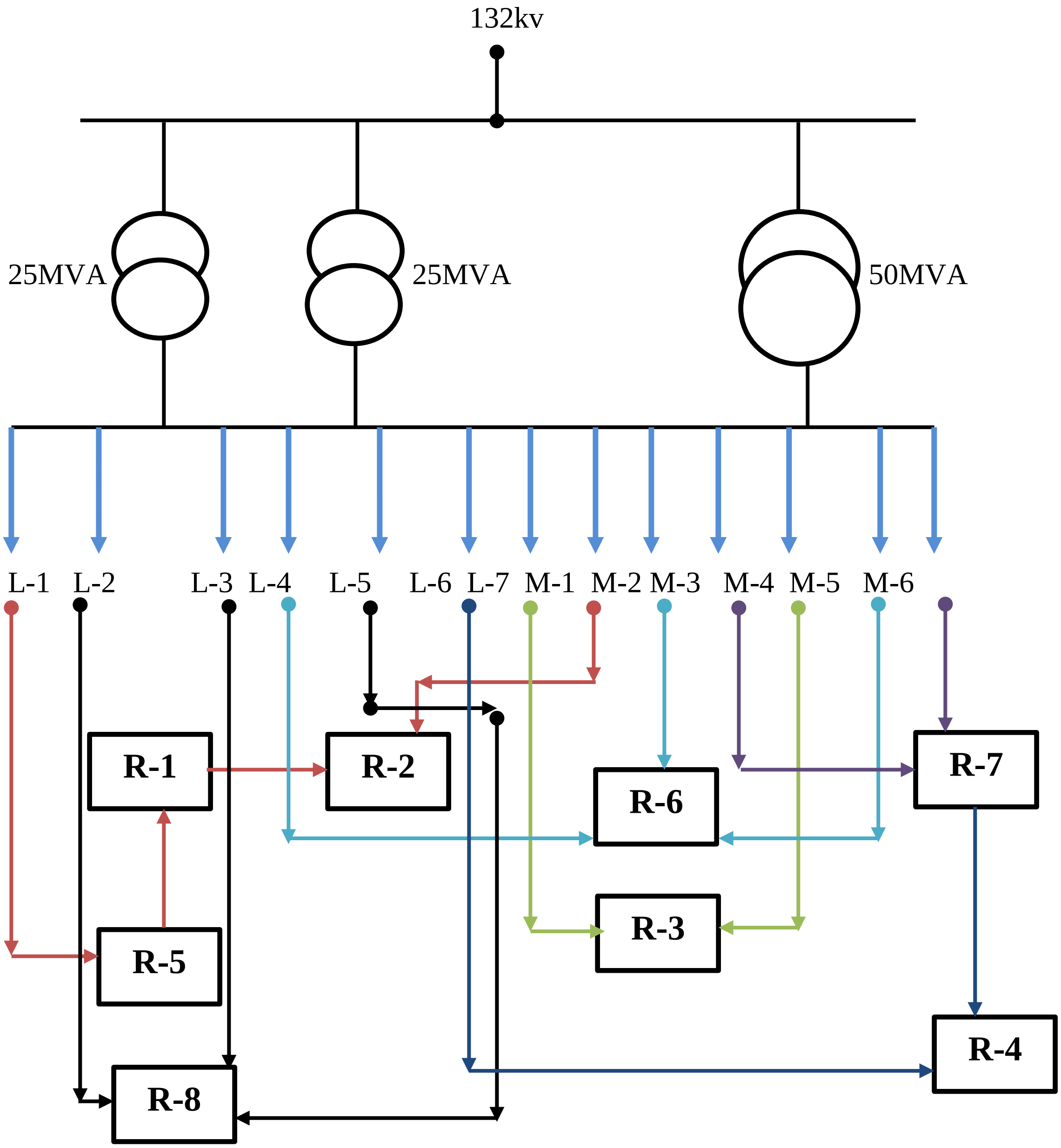
In order to identify power loss problem as the problem of power quality in distribution network of the adama town distribution system, the data collected were one year monthly power interruption duration and frequency of fault which was used from April 2019 up to March 2020. These data were collected from EEU Adama Distribution Substation. The distribution substation has thirteen of 15kv feeder lines those were Wonji, Nazereth, Wolenchity, Berta, Turk textile, Adama metal, M-1 up to M-6 mobile substation. The evaluation was done for two high loss sharing feeder lines these are L-7 and M-4(mobile substation-4). These data are located on Appendix part

The power of substation is 15kVA, the power factor is 0.85, the impedance of lines and other parameters are listed in the following table

Table 3. 1 distribution system line parameters

ID		Line parameters (Z)	(km)	X(ohm/km)	R(ohm) load	X(ohm) load
Line 1 (L-7 in this case)	L_1 R_1	6.0mH 20.7Ω	11	1.06	125	95Ω
L-2 (M-4) in this case	L_2 R_2	6.0mH 16.7Ω	9	1.62	120	125Ω
Grid voltage			132kv			
Capacitor C			3000µF			
DC link Voltage Vdc			400v			
Rated power			100MVA			
System frequency			50Hz			

3.1.1 Description of the Study Area



L-existing feeder line

M-Mobile substation line

R-switching stations (express feeder)

Figure 3. 1 Adama substation express feeder interconnection system

3.1.2 Analysis of Annual energy loss for the existing Network of Adama substation

Once the annual peak load loss is determined from the data acquired from the concerned offices, then it is possible to calculate the annual energy loss. The summary of annual power loss and unsold energy is determined in the following table.

Table 3. 2 Annual Unsold energy and load loss in a year 2019/2020

Feeder	L-1	L-2	L-3	L-4	L-5	L-7	M-1	M-2	M-3	M-4	M-5	M-6
Line loss (kw)	54500	49650	73300	54400	6400	75315	56950	52530	61300	72600	27700	41950
Unsold energy (kwh)	43643	49085	75733	69618	99099	159032	129543	57594	143027	232042	25041	58832

In table 3.2, one year fault remark summary is listed and as adama town is known as one of the eight towns having the substation interloped lines in Ethiopia, comparatively we will see which two interlopes have maximum loss share or having highest unsold energy in a year. From the table above, in one year data of loss due to fault records, maximum loss recorded in feeder (L-7 & M-4). This means in a selected year 2019/2020 the maximum unsold energy due to fault in each feeder are:

Line load of (L-7) = 75315kw　　　　Line load of (M-4) = 72600kw

Unsold Energy of (L-7) = 159032 kWh　　　　Unsold Energy of (M-4) = 232042 kWh

Adama substation was designed with three transformers which steps down 132kv/15kv and the decreased voltage goes through various control rooms towards distribution feeders then the 13 distribution feeders contained eight switching stations which are located at various places under the city and these switching stations interconnect the express feeders for the purpose of power stability and reliability.

3.2 Design of Distribution Network

One of the main tasks in the design of distribution networks is to find such a network form and dimensioning, that the total costs incurred by the investments and by operation of the network will minimize. Also, distribution has to be technically acceptable, safe and effects on nature and the environment must be limited.

The design of a network often involves finding several alternative solutions, and then comparing them with each other. These alternatives include different line routes, different transformer locations, and different number of feeders or circuits, different number of transformer substations. To assure proper functioning of the protection system, the checking of short circuit currents has to be carried out. To guarantee the fault current protection of conductors in all fault conditions, the rated current of protection should be considerably lower than the lowest fault current in the line. On the other hand, the protection should not operate under normal load currents. The minimum short-circuit current can be increased, for example, by strengthening the network starting from the feeding point. The aim of short-circuit and earth-fault calculations was to check whether the conductors can stand for maximum (3-phase) short-circuit current and whether the minimum fault current (1-phase short-circuit) was high enough for the protective relays or fuses to operate properly [24].

3.2.1. The Design Procedures in Electrical Distribution

Distribution system analysis and design has experienced a gradual development. The increasing power of computers now allows for managing the large volumes of data and other obstacles inherent to distribution systems. A variety of sophisticated optimization methods, which were impossible to conduct in the past, have been developed and successfully applied to distribution systems [24].

3.2.1.1 Design of Medium Voltage Network System

Medium voltage networks have the highest impact on reliability in electricity distribution because more than 90% of the customer experienced outages occur on MV networks. A challenge with the MV network was that it is usually very large, and the line length of a single feeder may be even more than 100 km. MV distribution networks constitute the backbone of power distribution systems and for this reason utilities justifiably strive to improve their performance. Distribution Automation provides a means of enhancing feeder performance in the event of a fault by automatically restoring supply, after the fault has been cleared by a circuit breaker, to as many customers as possible, while isolating the faulted section of the line or cable [25]. The primary distribution system was that portion of the power network between the distribution substation and the utilization transformers. The primary distribution system consists of circuits, referred to as primary or distribution feeders that originate at the secondary bus of the distribution substation. The distribution substation was usually the delivery point of electric power in large industrial or commercial applications.

As for the LV-network, different alternatives for line routes must be checked for the Network. The location of MV/LV transformer substations must also be re-considered in view of accessibility by the MV-line. The main MV-line shall be constructed with AAAC 95 mm^2 and the T-offs with AAAC 50 mm^2 [26].

3.2.1.2 Design of Conductors and Cables

The overhead line conductors must have an adequate current carrying capacity. Besides the loading current, also the short-circuit and earth-fault currents and their duration shall be taken into account. Short-time exceptional operation and switching situations were not necessary to take into account, when defining the short-circuit and earth-fault current [26], [28].

The overhead conductors must be mechanically strong and conform to the up-to-date standards for overhead lines. Each conductor size has its own economic range of use. The economic dimensioning means that it was worth choosing a conductor with greater cross-section, if saving in the loss cost was greater during the expected operating time than the difference between the investment costs of the two conductors [26].

3.2.1.3 Design of Low-voltage network

The secondary distribution system is that portion of the network between the primary feeders and utilization equipment. The secondary system consists of step-down transformers and secondary circuits at utilization voltage levels. Residential low voltage secondary systems were predominantly single-phase; but commercial and industrial systems generally use three-phase power. After the voltage drop constraint was met, the design continues with checking of the functioning of the protection. The network obtained in this way was the economical optimum based on the given criteria and cost parameters. However, it may not be practically acceptable. After the economic and technical criteria have been fulfilled, the network shall be checked from practical point of view (available space, right-of-ways) [26].

The dimensioning of LV and MV networks shall be calculated according to the defined/set criteria, to determine the optimum cross-sections and transformer sizes. The practical aspects of network construction must be kept in mind when designing distribution networks. The schemes must be reasonably easy to implement.

Design Low-voltage network required information

A) **A map including**

Houses, shops, schools, hospitals, other special consumers, load data, average load of consumers, street lighting data, estimate of load growth, increase in consumer amount, and increase in load of "average consumer".

B) Estimation of the loads

As all the loads were not 100% at the same time, the peak load of the network was smaller than the sum of individual peak loads. This coincidence effect was taken into account by a diversity factor, which shows the relation of the real maximum network load to the sum of the maximum consumer loads connected to the network. The estimation coincidence effect must be considered when defining the loads of the lines and transformers, in order not to get too big cross-sections and transformer sizes. The diversity factor varies depending on the number and type of consumers, being normally 0.7...0.85[27], [28].

3.2.1.4 Location of the Transformers

The transformer density should be defined so that the line distance from the MV/LV transformer to the furthest consumer should not be longer than 600m, to avoid problems in protection and voltage level. In special cases upon 900m distance may be approved after detailed analyses of the voltage drops, short-circuit currents and functionality of fuse protection.

3.2.1.5 Determination of Line Routes

The MV-line routes should approximately follow roads, in order to make the line construction and maintenance works easier. However, angles should be avoided when reasonably possible. The LV-line routes should be defined so that all consumers requiring electricity were considered. The straightest routes were preferred in order to save cable and facilitate the installation work.

3.2.1.6 Loads and Measurements

Two of the most important parameters in distribution network design were the average consumer load and the annual load growth percentage in each consumer category. Correct load information was essential for accurate and reliable network analysis [26]. The best way to achieve consumer load information was to carry out load measurements. Homogenous consumers like households were measured in large groups, by measuring the load of a single feeder at transformer. Bigger consumers must be analyzed individually [26]. In case of electrification of new areas, consumer load information of similar consumers in other areas should be used when estimating the future loads in the new network [25], [29].

3.2.2 Simplified model of distribution network

Taking account of the long transmission lines and multi-load nodes, the distribution network is often designed as a loop in order to ensure the reliability of power supply usually operated in the radiation way. Adama town simplified distribution system model is adopted as shown in *Figure 3. 2.*

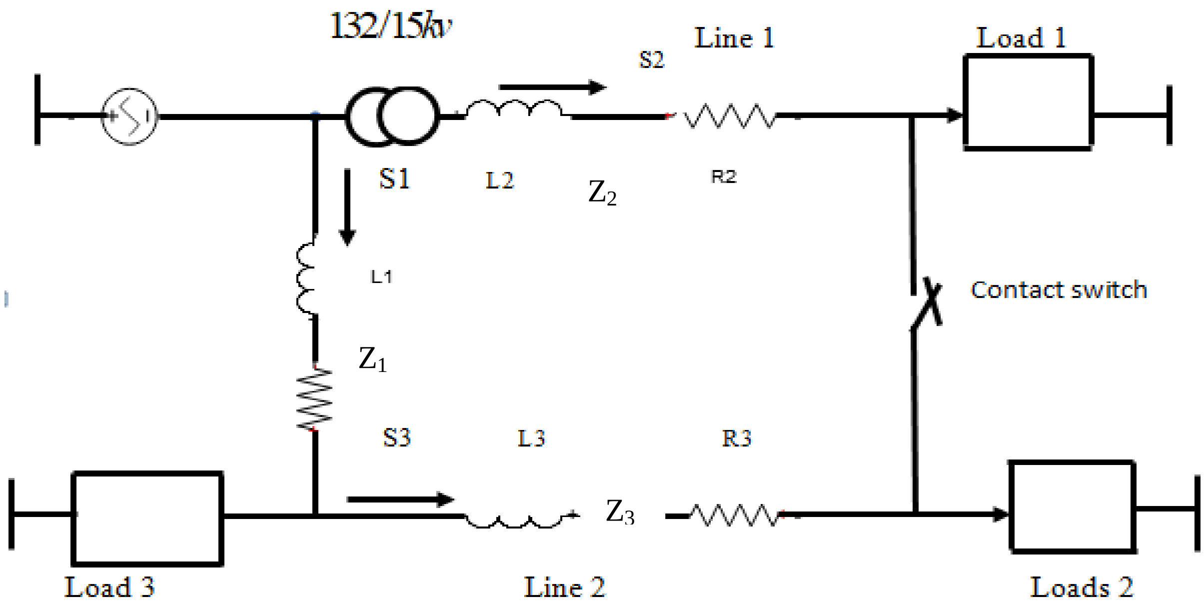


Figure 3. 2Simplified distribution system model

In *Figure 3. 2,* two lines are led from substation. The first line supplies power to load 1 and load 3 by line 1 and line 3 respectively, and the second one line 2 supplies the load 2 directly. To ensure the reliability of power supply, a switch is set between the end of line 3 and line 2. Under normal circumstances, the switch is off. When it is on, the grid in Figure 3.1 forms a loop. Substation terminal bus voltage is V_s . The node voltage of load 1 is V_1 , load 2; V_2 and load 3; V_3 The resistance and reactance of line 1, line 2 and line 3 are R_1, L_1; R_2, L_2; R_3, L_3 respectively and the power flow of which are S_1, S_2, S_3.

To facilitate the analysis, the load uses constant power model. The load 1 is expressed as S_{L1}, load 2 as S_{L2}, load 3 as S_{L3} so that the *Figure 3. 2*can be equivalent to *Figure 3. 3*

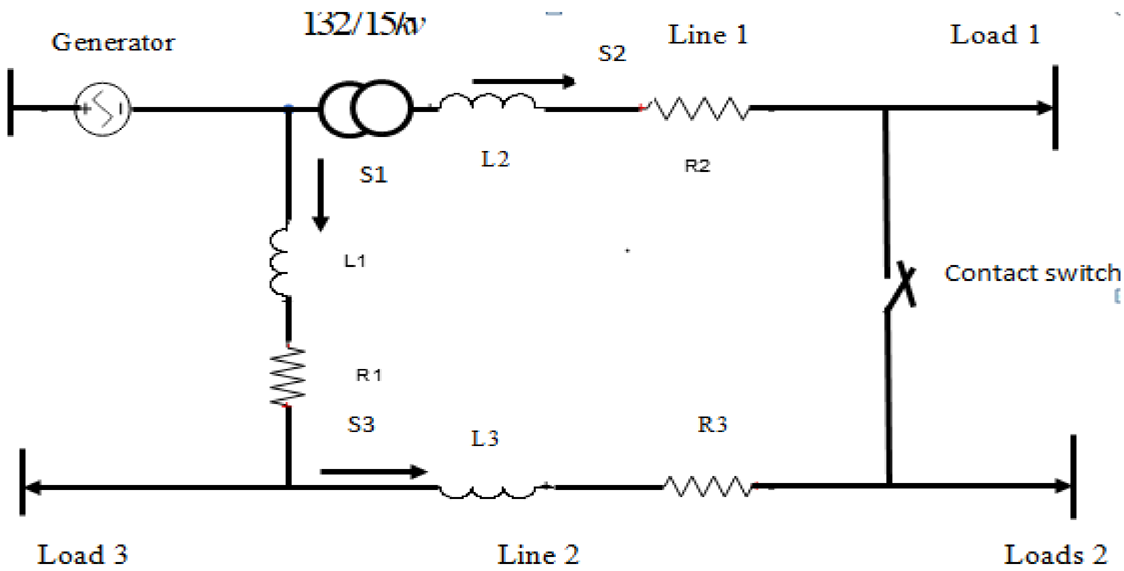


Figure 3. 3Equivalent model of distribution network

Loads: -loads of power systems are divided into industrial, commercial and residential. Very large industrial loads may be served from the transmission system. Large industrial loads are served directly from the sub transmission network, and small industrial loads are served from the primary distribution network. The industrial loads are composite loads, and induction motors from a high proportion of these load, these composite loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating and cooling. These loads are independent of frequency and consume negligibly small reactive power.

3.3. Distribution Substation Design Considerations

Substations are the points in the power network where transmission lines and distribution feeders are connected together through circuit breakers or switches via bus-bars and transformers. This allows for the control of power flows in the network and general switching operations for maintenance purposes. The electrical and physical arrangement of the switching and bussing at the sub-transmission voltage level are determined by the selected substation schemes or diagrams. On the other hand the selection of particular substations scheme is based up on Safety, Reliability, Economy, Simplicity, and Other considerations.

Security of supply: In ideal situations all circuits and substation equipment's will be duplicated such that following a fault or during maintenance a connection remains available.

This would involve very high cost and methods have been adopted to achieve a compromise between complete security of supply and capital investments.

Extendibility: The design should allow for future extendibility. Adding bays of switch gear to a substation is normally possible and care must be taken to minimize the outages and outage duration for construction and commissioning where future extension is likely to involve major changes or such as from a single to double bus-bar arrangement, then it is best to install the final arrangement at the outset because of the disruption involved.

Maintainability: The design must take into account the electricity supply company system planning and operations procedures together with knowledge of reliability and maintenance requirements for the proposed substation equipment. In a similar way the lay out must allow easy access for winching gear mobile cranes or other lifting devices if maintenance down times are to be kept to a minimum

Operational flexibility: The physical layout of individual circuits and groups of circuits must permit the required power flow control. In a two transformers substations operation, either restore to service without loss of supply, would be a normal design considerations

Protection arrangement: The design must allow for the protection of each system element by provision of suitable city locations to insure overlapping of protection zones. The number circuit breakers that require to be tripped following a fault, the auto reclose arrangements, the type of protection and extent type of mechanical or electrical interlocking must be considered.

Cost: A satisfactory cost comparison between different substation layout designs is extremely difficult because of the differences in performances in performance and maintainability. It is preferable to base a decision for a particular layout on technical grounds and then to determine the most economical means of achieving these technical requirements.

Distribution Feeders: - The part of the electric utility system which is between the distribution substation and the distribution transformers is called *the primary system*. It is made of circuits known as primary feeders or primary distribution feeders. A given feeder is sectionalized by reclosing devices at various locations in such a manner as to remove as little as possible of the faulty circuit so as to hinder service to few consumers as possible. This can be achieved through the coordination of the operation of all the fuses and re-closers.

There are various and yet interrelated factors affecting the selection of a primary feeder rating. The most common factors taken in to consideration include the following:

1. The nature of the load connected
2. The load density of the area served
3. The growth rate of the load
4. The need for providing spare capacity for emergency operations
5. The type and cost of circuit construction employed
6. The design and capacity of the substation involved
7. The continuity of service required

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are proper voltage, availability of power on demand and reliability.

Good voltage regulation of a distribution network is probably the most important factor responsible for delivering good service to the consumers. Therefore, a good distribution system should ensure that the voltage variations at consumer's terminals are within permissible limits (i.e. ± 5%). For this purpose, design of feeders and distributers requires careful consideration. A feeder is designed from the point of view of its current carrying capacity while the voltage drop consideration is relatively unimportant. It is because; voltage drop in a feeder can be compensated by means of voltage regulation equipment at the substation.

Distribution Transformer: - The distribution transformer is a step-down transformer that serves to lower the voltage from the primary distribution system (15 kV) into a voltage for the secondary distribution system (220/380 V).

3.4. Unified Power Flow Controller (UPFC)

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

3.4.1 Working principle of UPFC

The unified power flow controller consists of two voltage source converters (VSC).These converters are operated from a common dc link provided by a dc storage capacitor as shown in fig 3.4.

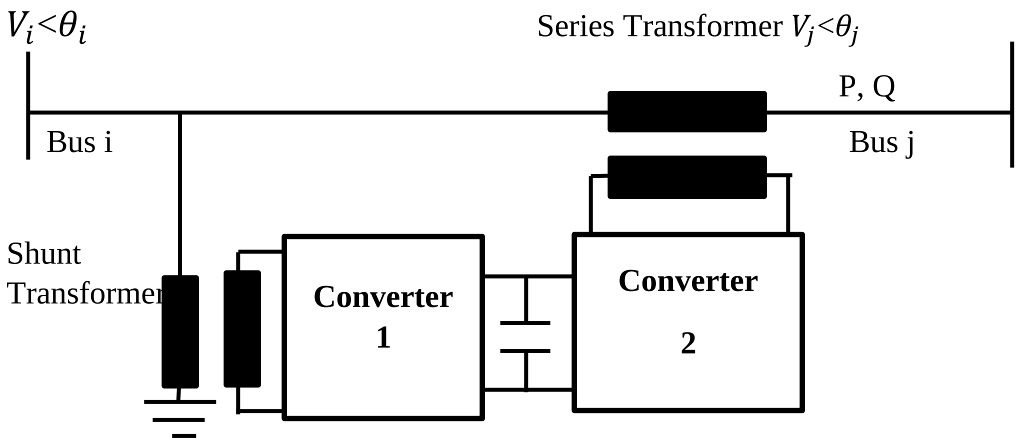


Figure 3. 4 Basic UPFC circuit arrangement

Converter 2(Series converter) provides the main function of the UPFC by injecting an ac voltage with controllable magnitude and phase angle in series with the transmission line via a series transformer. The basic function of converter 1 is to supply or absorb the real power demand by converter 2 at the common dc link. It can also generate or absorb controllable reactive power and provide independent shunt reactive compensation for the line. Converter 2 supplies or absorbs locally the required reactive power and exchanges the active power as a result of the series injection voltage. Here $V_i < \theta_i$ and $V_j < \theta_j$ are bus voltage magnitude and phase angles at bus i & j respectively. P and Q are real and reactive power flow in the line. Converter 1(shunt converter) maintains constant voltage of the DC bus. It functions like a STATCOM & independently regulates the terminal voltage of the interconnected bus by generating/absorbing a requisite amount of reactive power.

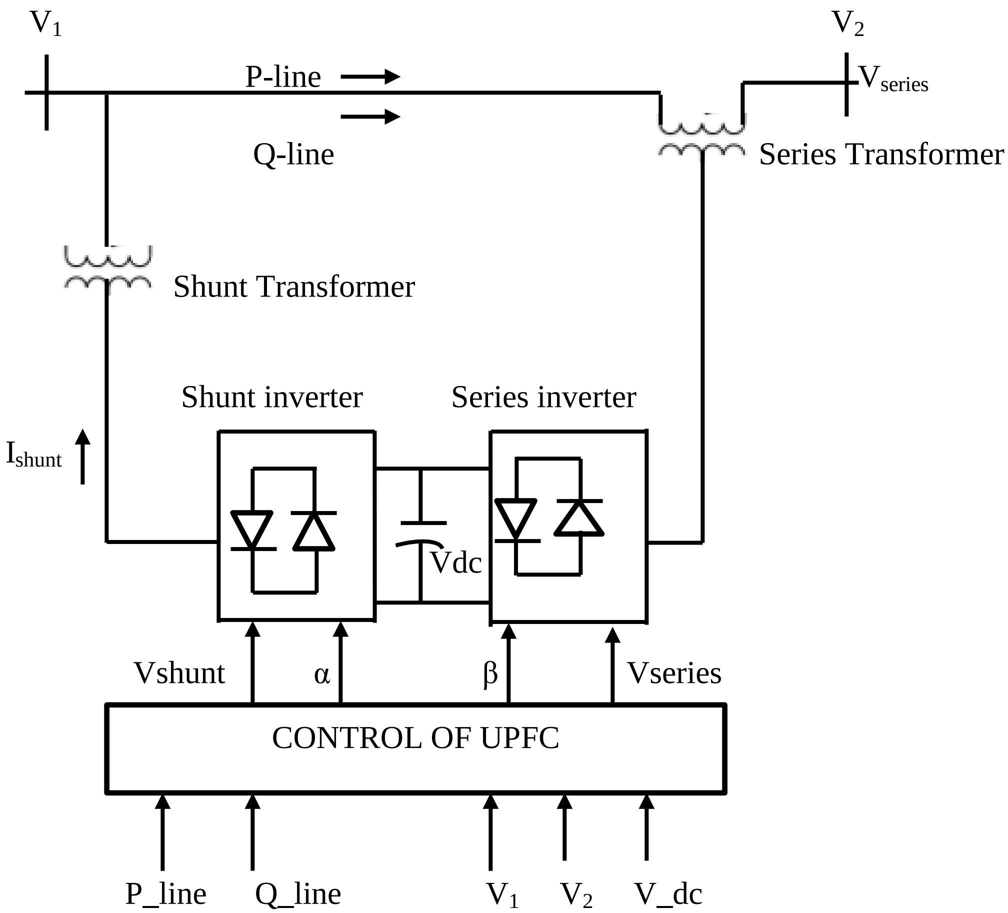


Figure 3. 5UPFC functional model [17]

The branches can work independently of each other by separating the dc side, i.e., by supplying each branch with its own dc capacitor. In that case, the shunt-connected branch becomes a STATCOM that generates/absorbs reactive power to regulate the voltage magnitude at the ac terminal. The series branch corresponds then to a SSSC that generates/absorbs reactive power to regulate the current flow, and hence the power, of the transmission line. If these two devices are merged together through a common dc capacitor, real power can be exchanged at the ac terminals; the UPFC behaves then as an ideal ac to ac power converter in which the real power can flow freely in either direction between the controller terminals. This basically results in a controllable phase shift between the terminal voltages V_1 and V_2, as the twovoltage-source inverters can interchange power. It should be noted that the real power is typically negotiated by the action of the series connected branch, whereas the shunt-connected branch is primarily used to feed real power from the ac system to the common dc link. The reactive power is generated or absorbed locally and independently from the real power by each branch and, therefore, it does not flow through the UPFC.

3.4.2 UPFC design for the proposed system

The designing capacity of UPFC is 15kVA, in which both of the series and parallel converter capacity is 7.5kVA. According to the system requirements, the total capacity of series and parallel converters have to be 15kVA and the compensation capacity is 50%, which is 7.5kVA. From the aspect of current switching device ratings and the coordination of voltage relationship between serial and parallel side, the voltage rating of DC capacitor is set as 400V. Considering a certain redundancy, the coupling transformer capacity of series and parallel side are both taken as 10kVA. The transformer on the parallel side adopts Y/Δ-11 connection and the turn ratio is 2.5:1.

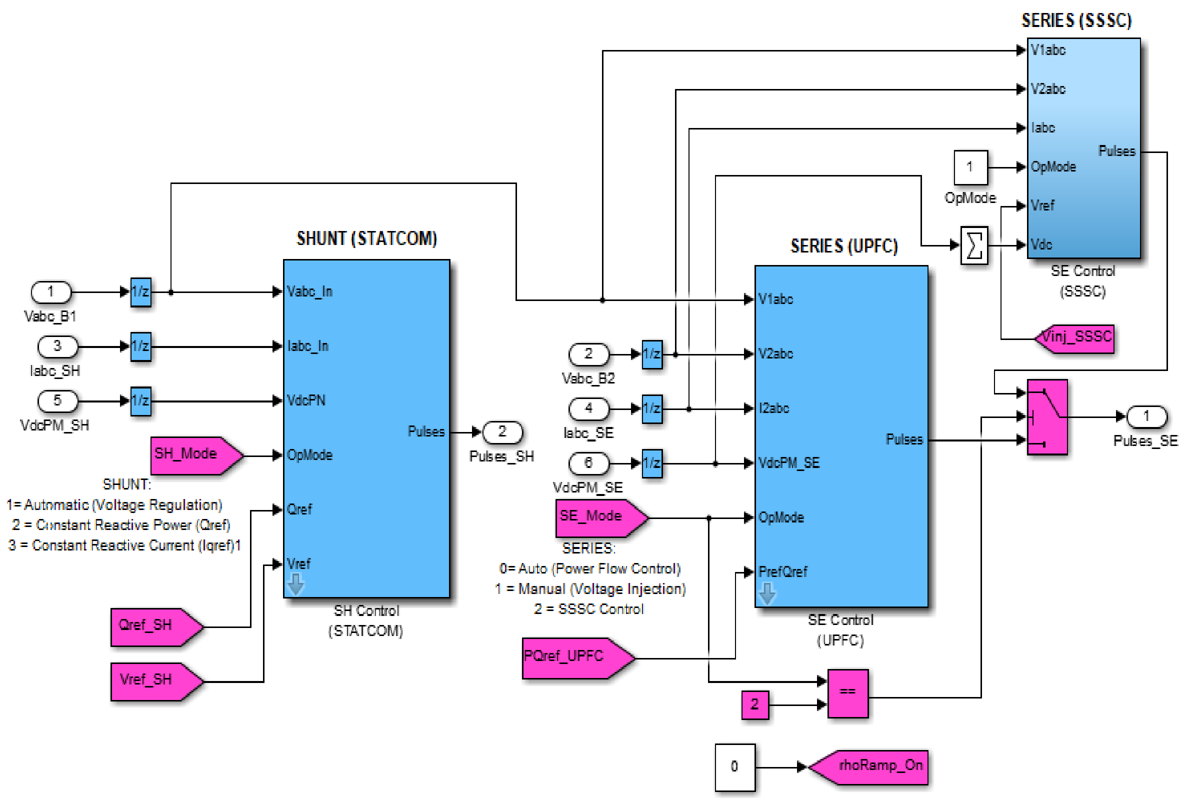


Figure 3. 6The internal structure of UPFC

3.5 Distribution System loss Expressions

3.5.1 Model of the distribution system

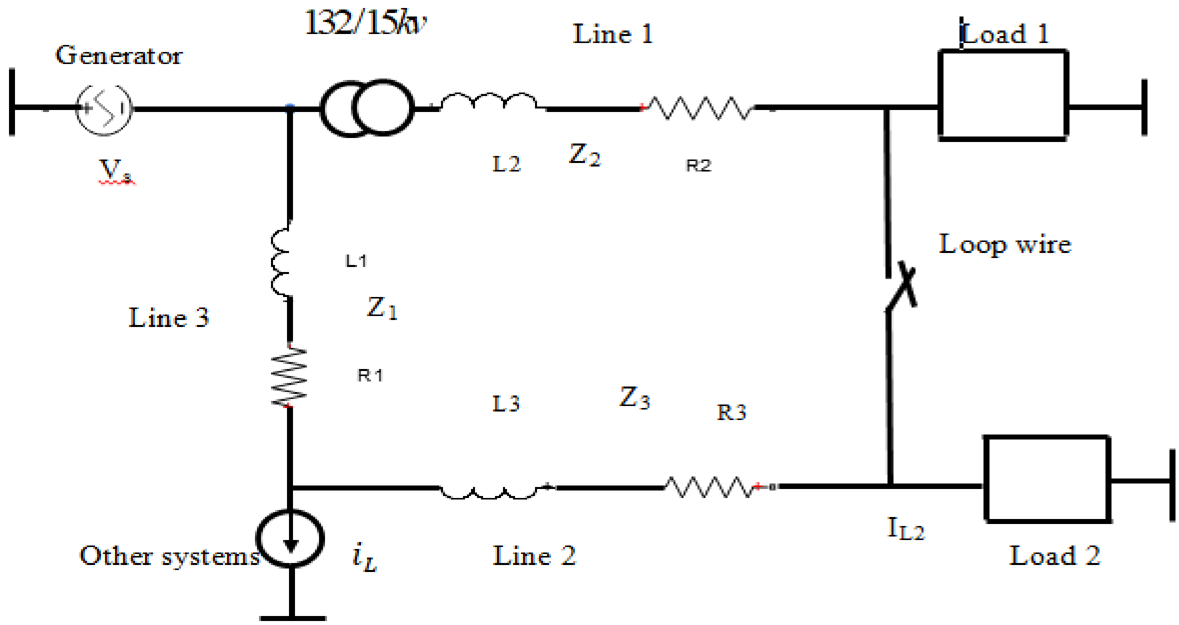


Figure 3. 7Model of distribution system

Figure 3.7 shows a simple model of the distribution system. In this model, impedances of lines 1, 2, and 3 are $Z_1 = R_1 + j\omega L_1$, $Z_2 = R_2 + j\omega L_2$, and $Z_3 = R_3 + j\omega L_3$, respectively. The load impedances are Z_{L1} and Z_{L2}. The other systems, connected to this system, are represented by a current source. The system is reconfigured to be loop system by connecting the adjacent ends of line 2 and line 3, using loop wire. The load currents $\acute{I}_{L1}$ and $\acute{I}_{L2}$ and the other systems current $\acute{I}_L$ are assumed to be constant. Also, the line currents $\acute{I}_{0i}$ (i=1, 2, 3, and 4) flow in each line in the same direction (counter clockwise). According to the line currents and the system parameters, the total line loss P_L in the loop system can be formulated as follows:

$$P_l = \sum_{i=1}^{3} R_i \left| \dot{I}_{oi} \right|^2 \tag{3.1}$$

$$= R_{loop}\left|I_{oi} - \frac{R_2\dot{I}_{L1} + R_2\dot{I}_{L2} + (R_2 + R_3)\dot{I}_L}{R_{loop}}\right| - \frac{\left|R_2\dot{I}_{L1} + R_2\dot{I}_{L2} + \left(R_2 + R_3\right)\dot{I}_L\right|^2}{R_{looop}}$$

$$+R_2\left|\dot{I}_{L1} + \dot{I}_{L2} + \dot{I}_L\right|^2 + R_3\left|\dot{I}\right|^2 \tag{3.2}$$

Where $R_{loop} = \sum_{i=1}^{3} R_i$

Since the second, third, and fourth parts in eqn. (3.2) are constants, because the currents $\acute{I}_{L1}$, $\acute{I}_{L2}$ and I_L are assumed to be constants, the first part is the only part that can be used to obtain the line loss minimum conditions. These conditions can be obtained by equating the first part in (3.1) with zero. In this case, the total line loss P_{lmin} in loop system can be formulated as follows:

$$P_{lmin=} = \sum_{i=1}^{3} R_i\left|\dot{I}_{mi}\right|^2 \tag{3.3}$$

Where $\acute{I}_{mi}$ (i = 1, 2, and 3) is the line current that flows in the loop lines in case of line loss minimization. The loss minimum line currents can be formulated as follows:

$$\left.\begin{aligned}
\dot{I}_{m1} &= \frac{R_2\dot{I}_{L1} + R_2\dot{I}_{L2} + (R_2 + R_3)I_L}{R_{loop}} \\
\dot{I}_{m2} &= \frac{(R_1 + R_3)\dot{I}_{L1} + (R_1 + R_3)\dot{I}_{L2} + R_1\dot{I}_L}{R_{loop}} \\
\dot{I}_{m3} &= \frac{R_2\dot{I}_{L1} + R_2\dot{I}_{L2} - R_1\dot{I}_L}{R_{loop}}
\end{aligned}\right\} \tag{3.4}$$

The difference between the currents $\acute{I}_{0i}$ and $\acute{I}_{mi}$ is defined as the loop current I_{loop} that circulates in loop system in the same direction, and can be formulated as follows:

$$I'_{loop} = I'_{0i} - I'_{mi} = \sum_{i=1}^{3} j\omega L_i I''_{0i} \tag{3.5}$$

The line loss minimum conditions in loop systems can be realized by eliminating the loop current I_{loop} from the system, which can be achieved if any of the following conditions, is realized:

$$\frac{R_1}{L_1} = \frac{R_2}{L_2} = \frac{R_3}{L_3} \tag{3.6}$$

$$\sum_{i=1}^{3} j\omega L_i \dot{I}_{oi} = 0 \tag{3.7}$$

3.5.2 Minimization Condition of Loss under Line Loss Minimum Condition

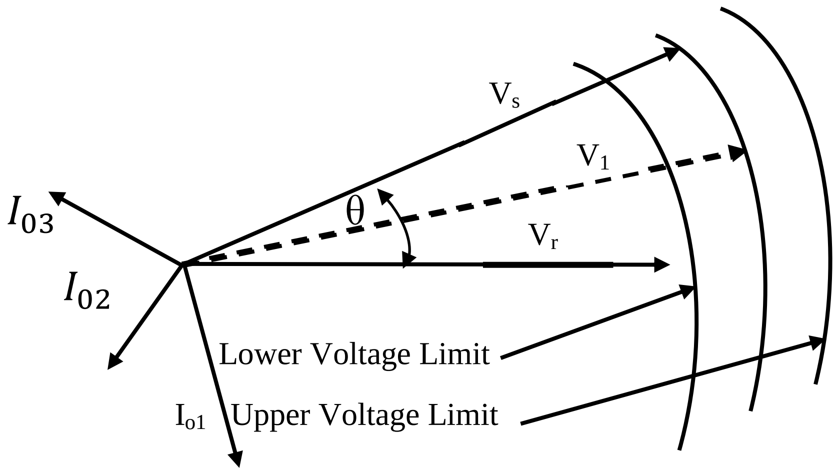
To improve the power quality voltage regulation is the main important one. Load voltage regulation problems in distribution systems are commonly solved by using STATCOM, which has the ability to control voltage magnitude by compensating reactive power. However, STATCOM cannot control the line loss in loop distribution systems. On the other hand, series compensators, such as UPFC, have the ability to regulate load voltage, to minimize line loss and improve power quality simultaneously in the radial and loop distribution system. The main object of this paper is to minimize the total line loss and to regulate the load voltages in loop distribution system, simultaneously. The line loss minimum conditions can be achieved if the loop current is eliminated from the loop system. Under this condition, the load voltages can be controlled in order to keep it within the permissible voltage range, ±5% of the nominal source voltage.

Installing a series voltage source in a loop distribution system affects the power flow and hence changes all the node voltages. Based on the superposition theorem, the change in node 1 and node 2 voltages due to the installation of the controlled series voltage $\ddot{V}_c$ the loop system shown in Fig. 3 above can be formulated as follows:

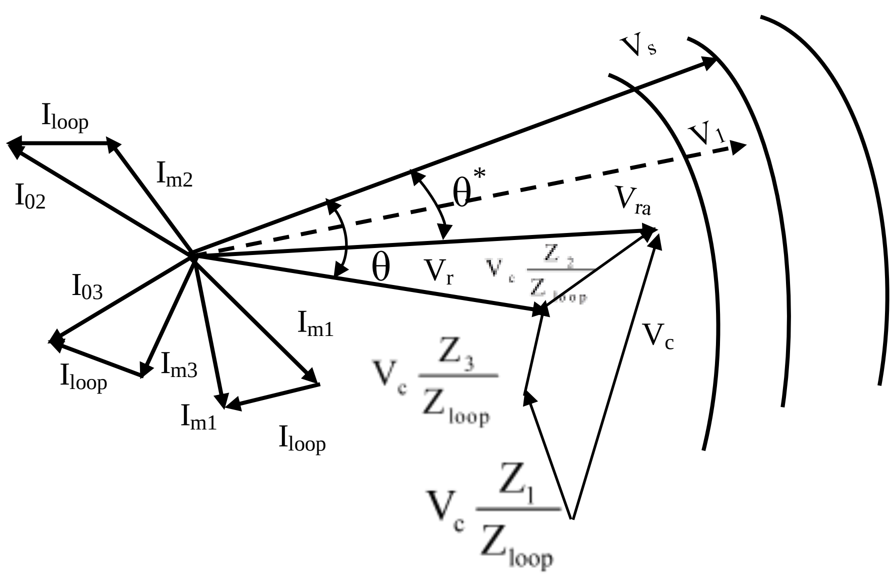
$$\left.\begin{aligned} \Delta \ddot{V}_1 &= -\ddot{V}_c \frac{\dot{Z}_1}{\dot{Z}_{loop}} \\ \Delta \ddot{V}_r &= \ddot{V}_c = \ddot{V}_c \frac{\dot{Z}_2}{\dot{Z}_{loop}} \end{aligned}\right\} \tag{3.8}$$

Where $\ddot{V}_c$ the series is injected voltage and $\dot{Z}_{loop}$ is the summation of the loop impedances.*(c)*

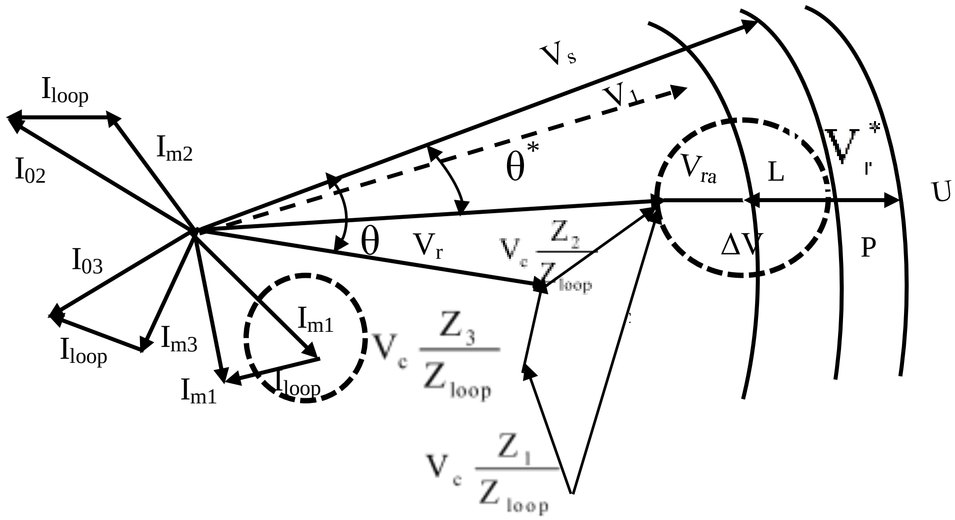
Figure 3. 8(b) and (c) shows the phasor diagrams of all line currents and node voltages after installing the controlled series voltageV_c. The phasor diagrams are drawn based on the change in each node voltage due to the installation ofV_c. The value of the controlled series voltage V_c is determined according to its function in the loop distribution system, and the change in each node voltage can be calculated based on (3.8).



(a)



(b)



(c)

Figure 3. 8Phasor diagram of the loop distribution system. (a)Before installing $\boldsymbol{V_c}$ *(b) After installing*$\boldsymbol{V_c}$*to achieve line loss minimization. (c) After installing Vc to achieve voltage regulation under line loss minimization [17]*

Since the controlled series voltage V_c realize its function by controlling the node 2 voltage, the phasor lines, representing the change in each node voltage, are drawn to show the overall change related to node 2 voltage. Also, the line currents I_{0i} and their components (I_{mi} and I_{loop}) are drawn in the phasor diagrams based on (3.4) and (3.5). The focus of the phastor diagrams shown in 3.8*(c)*

Figure 3. 8(b) and (c), is the relation between the change in the node 2 voltages and the loop current. In the system shown in *(c)*

Figure 3. 8,if the controlled series voltage Vc is installed to achieve loss minimum condition, node 2 voltage changes to be Vra , which is still less than the lower voltage limit and lags behind source voltage Vs by the angle θ^* , as shown in *(c)*

Figure 3. 8(b). In this case, node 2 voltage can be formulated as follows:

$$\dot{V}_{ra} = V''_{r} + V''_{c} V'' \frac{\dot{Z}_2}{Z_{loop}} \tag{3.9}$$

Where V_r is the load voltage before installingV_c , and V_{ra} is the load voltage after installingV_c. Inserting a controlled series voltage in loop system to achieve line loss minimization affects all voltages in the system. However, (c)

Figure *3. 8*(b) shows that this method cannot guarantee all node voltages to be within the permissible voltage range. (c)

Figure *3. 8*(c) shows the phasor diagram of the distribution system, shown in Figure 3.7, with the effect of using Vc to achieve load voltage regulation under line loss minimum condition. Based on the loop current, total power loss shown in (3.1) can be formulated as follows:

$$P_l = \sum_{i=1}^{3} R_i \left| I_{oi}^{'} \right|^2 = \sum_{i=1}^{3} R_i \left| I_{mi}^{'} \right|^2 + R_{loop} \left| I^{'} \right| \qquad (3.10)$$

Equation (3.10) shows that any circle centered by the current I_{mi}, due to the change in loop current, has constant power loss. The change in loop current will change the node 2 voltage by ΔV, as shown in *(c)*

Figure 3. 8(c) the resultant node 2 voltage can be formulated as follows:

The resultant node 2 voltage can be formulated as follows:

$$\begin{aligned} \dot{V}_r &= \dot{V}_{ra} + \Delta V^{"} \\ \Delta V^{"} &= \dot{Z}_2 \, I_{loop} \end{aligned} \qquad (3.11$$

Equation (3.11) shows that changing the loop current to draw a circle around its center I_{mi} causes the node 2 voltage to draw a similar circle around its center V_{ra} that also has constant power loss. In case of line loss minimization, the loop current is zero and hence the radius of both circles is zero. As the loop current increases, the radius of these circles and hence total line loss increase, too. The tangential point, point (P), between the circle centered by $V_{ra}$and the circle of source voltage loci, represents the point, at which node 2 voltage equals in magnitude to source voltage under loss minimum condition.

In general, controlling node 2 voltage to be lag behind Vs by the angle θ^*, means controlling the voltage under line loss minimum condition. However, controlling the node 2 voltage to be equal in magnitude to source voltage under line loss minimum condition cannot guarantee all node voltages to be within the permissible voltage range. According to eqn (3.8), the change in node 2 voltages causes an opposite change in the node 1 voltage that may cause the node 1 voltage to be less than the lower voltage limit.

In this thesis, the reference magnitude of node 2 voltages is controlled to be in between points L and U, as shown in *(c)*

Figure 3. 8(c), in order to achieve all node voltages within the permissible voltage range under line loss minimum condition. The reference magnitude will start at point (p), then changes toward point (L) or (U) according to the voltage at node 1 in order to realize all node voltages in between the permissible voltage limit.

3.6 Proposed Control Scheme

The proposed control scheme has been developed to meet the following objectives, simultaneously: 1) minimize total power loss in loop distribution systems; and 2) compensate reactive to improve power quality. The line here determined i.e Line 1 shows feeder line-7 and Line 2 shows the mobile substation feeder M-4 in my case.

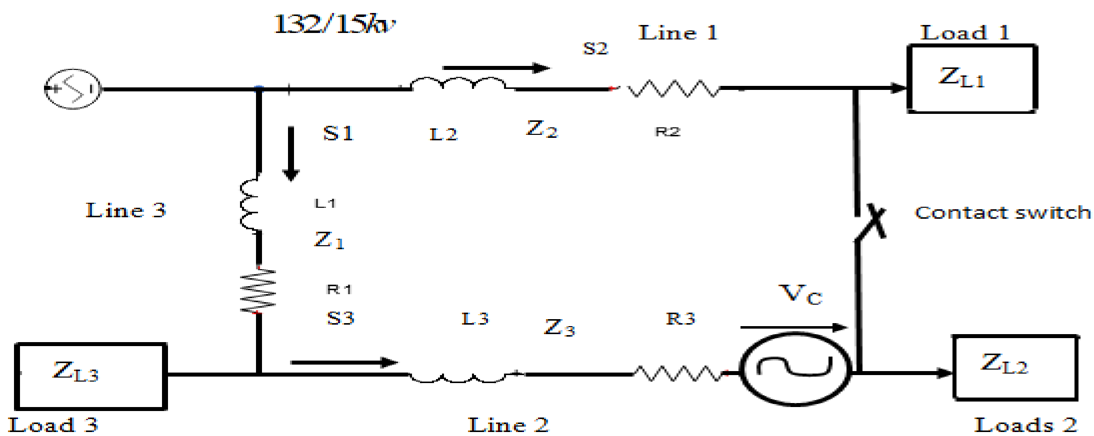


Figure 3. 9Model of the system in case study

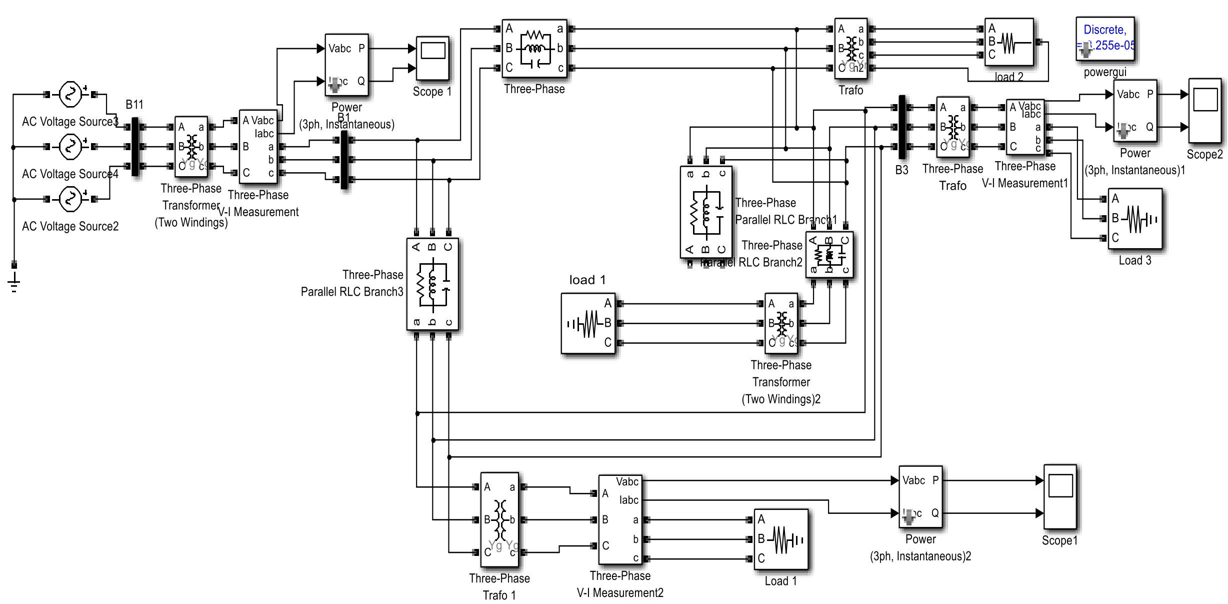


Figure 3. 10Matlab model of the distribution system currently working

(3.12)

$$V_r^* = \left|V_{ra}\right| < \theta^*$$

Reference voltage for loss minimization can be calculated by using the line currents that flow in loop lines under loss minimum condition (Imi, (i = 1, 2, 3, and 4)) and the line parameters. In order to calculate these currents, first the UPFC circulating current, I_{UPFC}, is calculated as follows:

$$\dot{I}_{UPFC} = \left| \frac{\dot{V}_c}{\dot{Z}_{loop}} \right| \tag{3.13}$$

The line currents that flow in the loop system lines before installing UPFC (I_{0i}, [i = 1, 2, 3, and 4)] can be estimated by subtracting the UPFC circulating current, as shown in (13), from the loop system line currents as follows:

$$\dot{I}_{oi} = \dot{I}_i - \dot{I}_{UPFC} \tag{3.14}$$

By using the currents I_{0i} , shown in (3.14), the loop current can be calculated as in (5). The line currents that flow in loop lines under loss minimum condition [I_{mi}, (i = 1, 2, 3, and 4)] can be calculated as follows:

$$\dot{I}_{mi} = \dot{I}_{0i} - \dot{I}_{loop} \tag{3.15}$$

By using the currents I_{mi}, shown in (3.15), and the line parameters, the load voltage V_{ra} , and hence, the phase shift angle θ^*can be calculated from the p–q axes components of V_{ra} as follows:

$$\begin{aligned} \dot{V}_{ra} &= \dot{V}_s - \dot{Z}_1 \dot{I}_{mi} + \dot{V}_c - \dot{Z}_2 \dot{I}_{m2} \\ &= \dot{V}_s + \dot{Z}_4 \dot{I}_{m4} + \dot{Z}_3 \dot{I}_{m3} \end{aligned} \tag{3.16}$$

$$\theta^* = \tan^{-1}\left(\frac{V_{raq}}{V_{rap}} \right) \tag{3.17}$$

If the series injected voltage, for line loss minimization, cannot guarantee all node voltages to be within the permissible voltage limit, node 2 voltage magnitude should be controlled in order to achieve all node voltages within the limit. First, node 2 reference voltages is controlled to be equal in magnitude to source voltage and lag behind it by the angle θ^*as follows

$$V_r^* = \left|V_s\right| \angle \theta^* \tag{3.18}$$

$$V_c^* = \left(V_r^* - V_r\right) \frac{Z_{loop}}{Z_3 + Z_4} \tag{3.19}$$

$$I_{UPFC} = \frac{V_c^*}{Z_{loop}} \tag{3.20}$$

In the node 2 voltage before installing UPFC, V_r, is calculated using line currents [I_{0i}, (i = 1, 2, 3, and 4)], shown in (3.14). The estimated currents that flow in the loop system lines in case of controlling node 2 voltage, as in (18), are calculated by adding the circulating current shown in to the line currents [I_{0i}, (i = 1, 2, 3, and 4)], and the resultant line currents are used to calculate the estimated voltages at nodes 1 and 3. If the series injected voltage still cannot guarantee voltages at nodes 1 and 3 to be within the permissible voltage limit, an additional block diagram can be used in order to keep all node voltages within the limit, as shown in *(c) Figure **3. 8*** (b). The inputs of this additional block diagram can be node-1 or node-3 voltage, depending on which one of them is out of the limit. The reference values of nodes 1 and 3 voltages can be the lower or the upper voltage limits according to the value of node voltage. In this case, node 2 reference voltage can be formulated as follows:

$$V_r^* = |V_s|(1-\alpha)\angle\theta \tag{3.21}$$

Where α is the voltage limit controller.

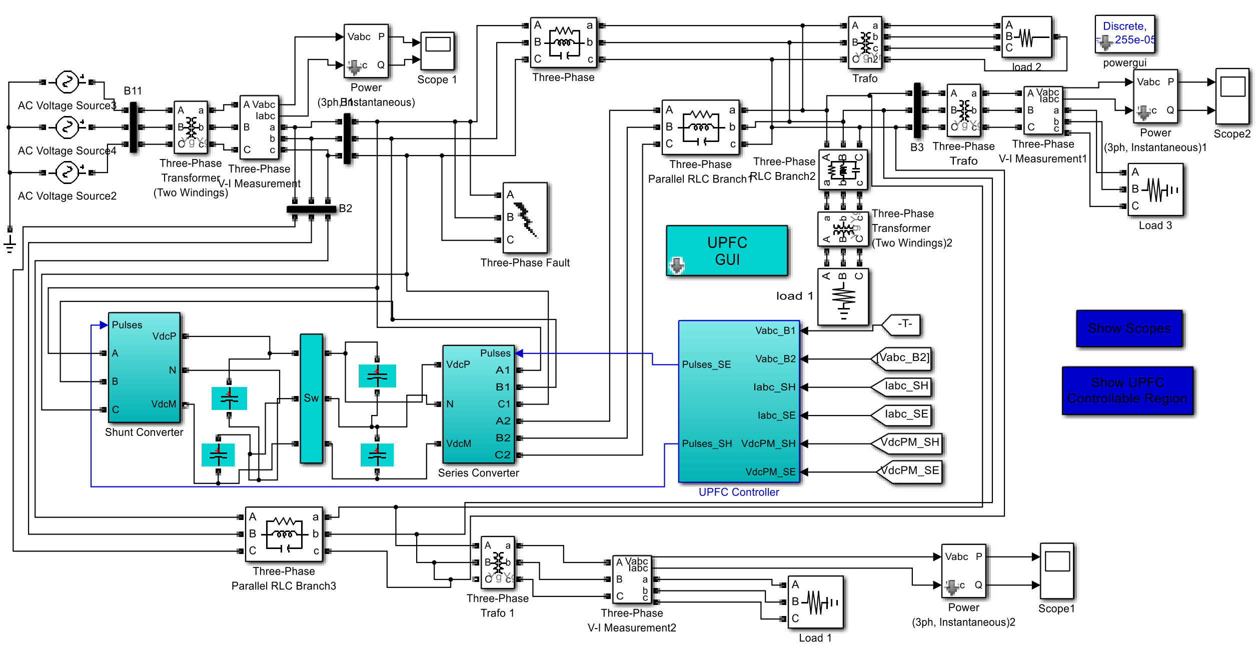


Figure 3. 11overall matlab simulink model of distribution system with UPFC system

CHAPTER FOUR

4. RESULTS AND DISCUSSION

The simulation results of the model for a distribution system of Adama substation are tested for three different cases.

1. When the distribution system is without fault
2. When the three phase fault is applied for the distribution system without UPFC
3. When the UPFC device is installed for the distribution line when three phase fault is applied on it.

When the system is with no fault like; no application of large loads, no load is removed, and no fault occurs on the system, the power system is stable. The simulation results shown below are the real power and the reactive power wave forms without the application of the three phase faults as shown in fig4.1

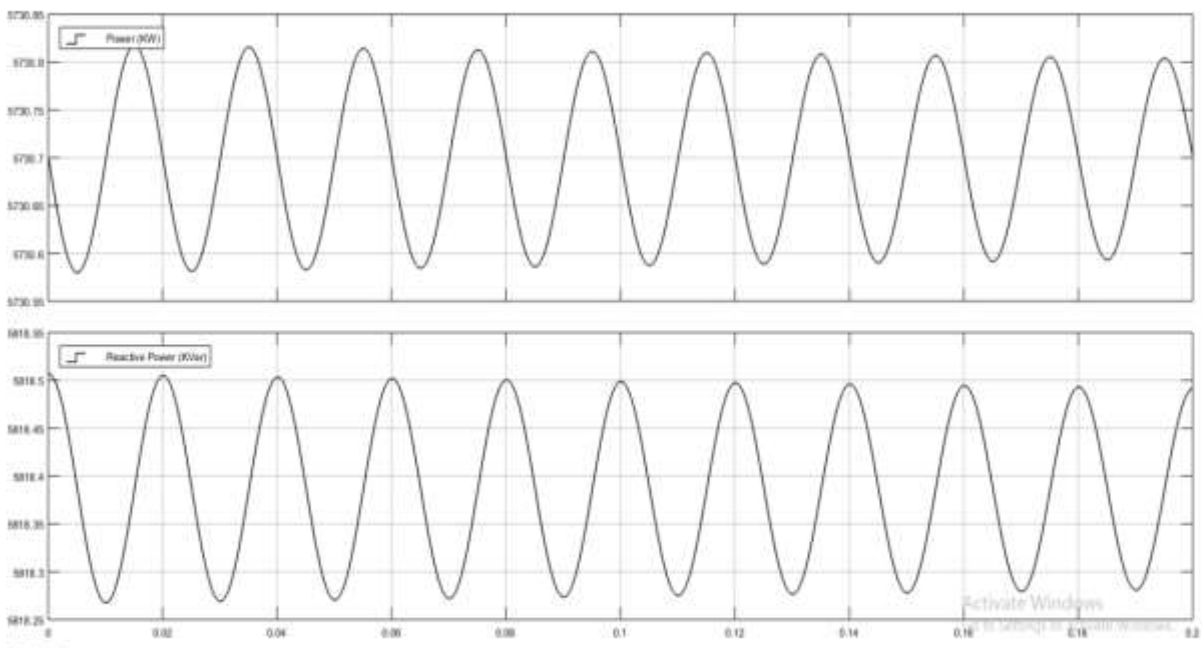


Figure 4. 1 The MATLAB simulation results of active and reactive power without Fault

From the simulation Results of the active and reactive power shown above in figure 4.1, no fault happens on the system. As shown in the Fig.4.1, the system has no stability on real and reactive power due to a frequent change of loads i.e when a very large loads added or connected to the system or disconnected from the system, there will be a disturbance on the distribution system and hence oscillation of the real power and reactive power drawn on the results.

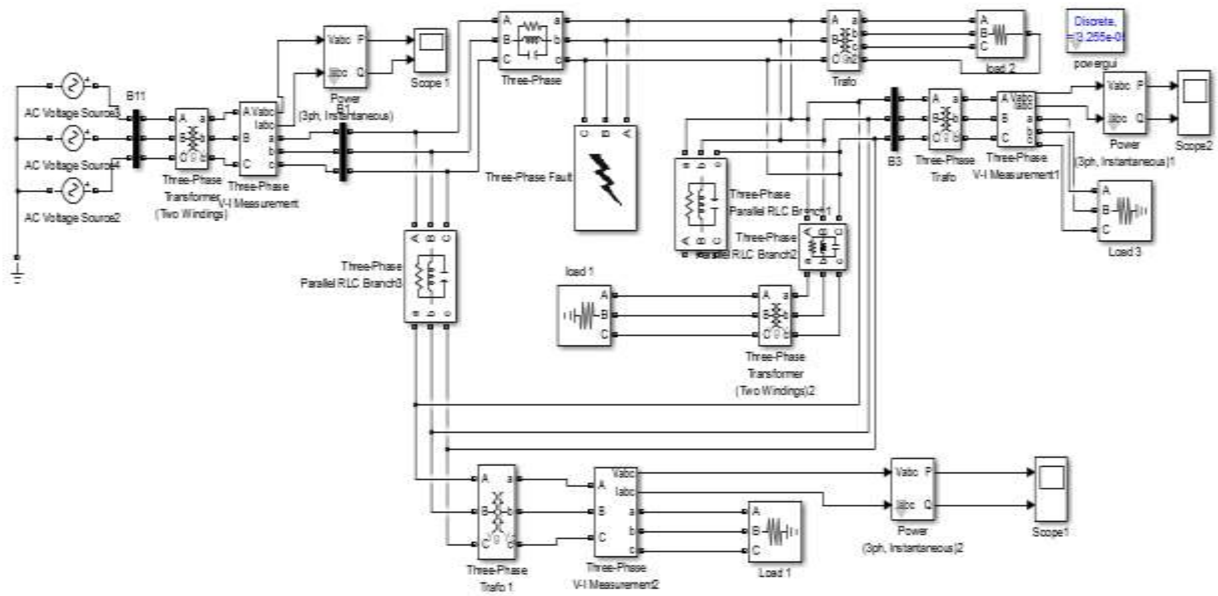


Figure 4. 2 When the three phase fault is applied for the distribution system without UPFC

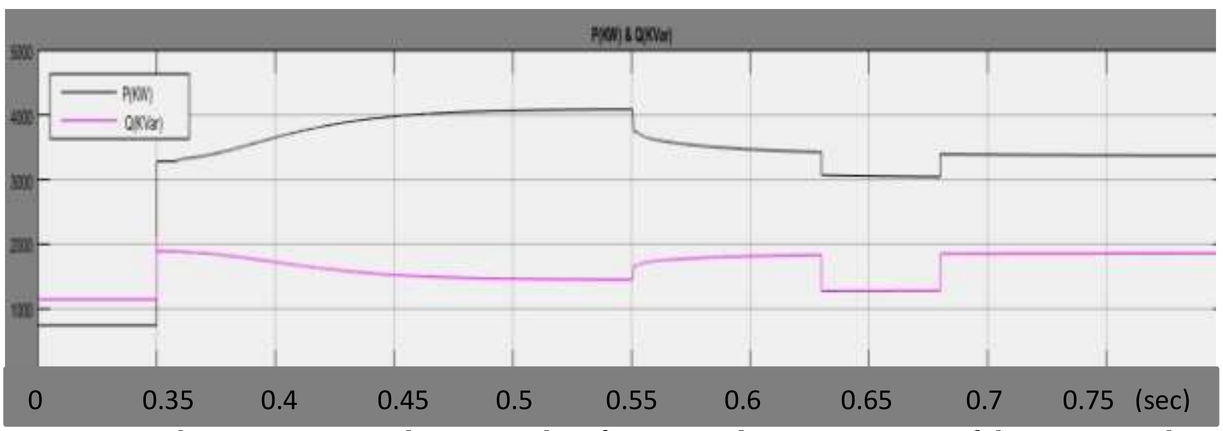


Figure 4. 3 The MATLAB simulation results of active and reactive power of the system without UPFC

From the simulation Results shown above, the active power decreases due the application of fault on the system. The active power decrements were due to the power lost until the system return to its normal condition. As shown in the Fig.4.3, the active power delivered to the load decreases below 1000KW when the system connected to the UPFC device. Whenever the system is back to its healthy condition the performance of the whole system is better even though there was no injection of UPFC and power loss is also minimized as shown.

When three phases fault is applied on the distribution system, the system is disturbed and even the flow of energy stops until the fault is cleared.

The voltage sag happens and the current increase which creates some disturbance on the system. If this disturbance is not avoided by using some devices like UPFC which reduces the voltage regulation, the system becomes unstable. This disturbance on the voltage and current as well as real power and reactive power is shown in Fig4.4.

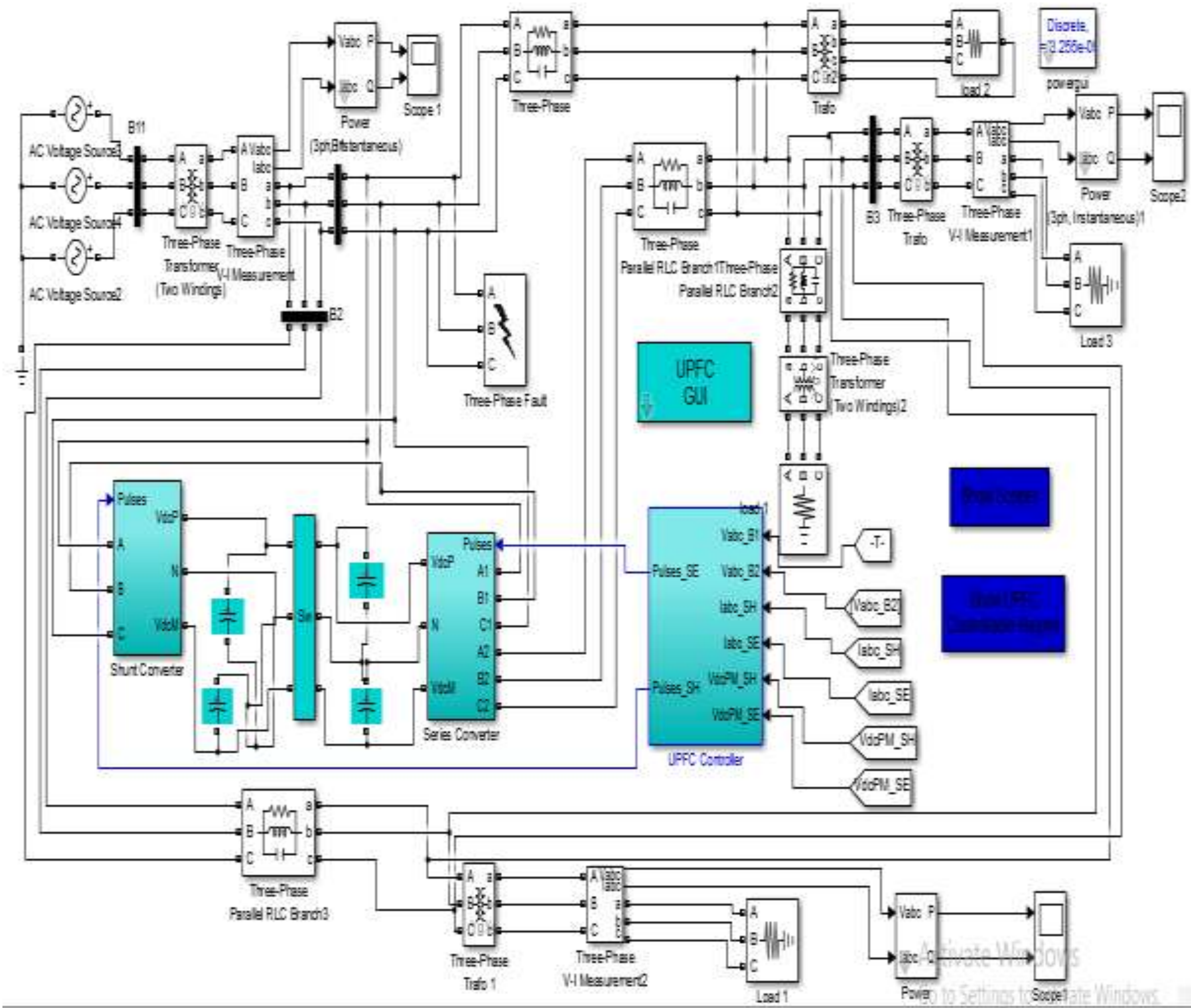


Figure 4. 4 When the UPFC device is installed for the distribution line when three phase fault is applied on it.

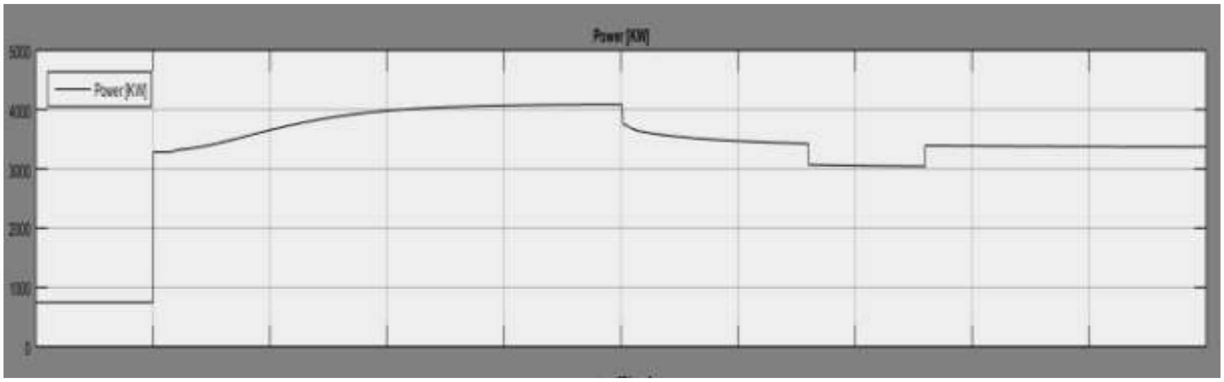


Figure 4. 5 The MATLAB simulation results of active power with UPFC

The Real power at the same time decreases with fault happen on the system. The simulation Results shows that the active and reactive power decreases due the application of fault on the system. The active and reactive power decrement leads the power to be lost until the system return to its healthy condition. As shown in the Fig.4.3 the active and reactive power delivered to the load decreases. However the decrement of active and reactive power is less as compared to the system without UPFC in which the power loss is also minimized. Whenever the system back to normal operation, the active and reactive power delivered to the load with UPFC is better as can be shown below.

From the simulation results shown in fig 4.5 with UPFC, the active and reactive power of the system oscillations are effectively damped out as compared to the simulation results obtained without UPFC. The Power transfer capability is also increased due to the reduction of loss.

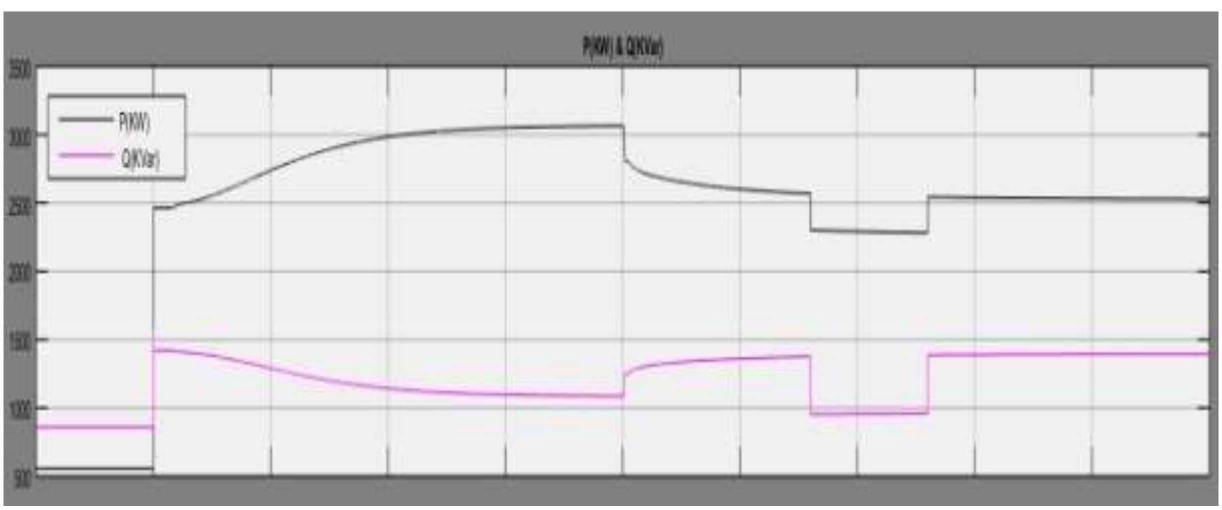


Figure 4. 6 The MATLAB simulation results of active power and reactive power with UPFC

From the simulation results shown above in fig 4.6, the real power and reactive power are improved due to installation of UPFC device on the system. As we have seen in fig 4.3, when fault generated on the system the value of real power falls below 800kw and after clearance of fault it raised up to 3500kw but in the case when we installed UPFC device, due to the performance of this device we improved the power quality to about 3500kw and this power is the rated power that the line carries to feed all customers on that line. The Power transfer capability is also increased due to the reduction of loop current flowing through the line. With reference to the size, the maximum UPFC series voltage can be up to 0.5pu of the line voltage [30] or even more. This determines the series converter MVA. Also, the series and shunt converters may or may not have the same size. Determination of converter MVA is a matter of UPFC allocation. In this paper, however, we would like to find some areas as candidate points for UPFC installation by performing as sensitivity analysis. Once the promising candidate points are determined by this approach, more precise UPFC allocation algorithms such as [31] would be necessary to select the final points. So with regard to the purpose of this paper, the UPFC series and shunt converters are sized into the relatively small fixed value of 4MVA, equal to 0.04pu with S_{base} 100MVA. Since the current ratings of the test system lines are 0.4pu on average, the UPFC maximum series voltage would be typically 0.1pu. Also, the assumption of constant sized converters removes the need to calculate the UPFC investment cost. Apart from the size of converters, other UPFC ratings may vary at different points. The maximum voltage magnitude of the shunt converter, Umax p , is always a bit more than the line nominal voltage. Here, it is chosen 1.2pu in all cases. Since Up is normally about 1.0pu, the maximum current of the shunt converter,I_p^{max}, will be the same as the converter apparent power rating, 0.04pu, in all cases. The maximum current of the series part, I_s^{max}, is practically selected to be equal to the line current thermal limit [31].

From a computational point of view, the differencing method needs much more calculations, that is in my cases, In order to assess how much saving can be obtained through UPFC installation; the cost of UPFC installation must be calculated. The cost of installation of UPFC is taken from Siemens database and reported in [32] given by

$$C_{UPFC} = 0.0003S^2 - 0.2691S + 188.22 \tag{4.1}$$

Where C_{UPFC} is the cost of UPFC in US$/KVA and S is the operating range of UPFC in MVA. Therefore, based on the supposed size of UPFC in my case studies, the cost of UPFC installation will be about 749,000 $. This cost will have to be compared with the revenue (or benefit) that can be derived from UPFC. The revenue derived from UPFC has the unit of "$/hr" depending on the utilization and level of congestion. In order to compare the cost of FACTS against the anticipated benefits, they have to be converted to a common unit. In this thesis, the comparison is made by converting the cost, as well as the benefit (revenue) into annuity ("$/year"). To compute the annual capital cost and benefit (revenue) of FACTS, the following assumptions have been made:

Project lifetime (n): 5 years

Discount rate (r): 10%

Average utilization (u): 40%

Operational cost of UPFC device is neglected

Annual capital cost of FACTS in $/year can be found as [31]:

$$C_{UPFC}^{Annual} = C_{UPFC} \times S \times 1000 \times \frac{r \times (1+r)^n}{(1+r)^n - 1} \tag{4.2}$$

Thus, the annual capital cost of UPFC in our test case is 197,000$/year. Annual revenue from use of UPFC in $/year can be determined as [33]:

$$R_{UPFC}^{Annual} = R_{UPFC}^{hour} \times 8760 \times u \tag{4.3}$$

The average utilization u gives the percentage of time the UPFC device is considered 100% effective. Since, the demand and supply patterns change during different time period, leading to different price quantity relationship and consequently different setting for FACTS devices. At low load period, the effectiveness of UPFC devices decreases and hence the revenue (benefit) from use of UPFC decreases. So, to evaluate the benefit of UPFC a utilization factor is considered. Considering the best case, UPFC installation at the sending end of line L-7 and M-4 loop system feeder, the annual revenue generated due to UPFC is 217,000$/year. Consequently, about US$20,000 can be saved each year.

CHAPTER FIVE

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This thesis has presented the line loss minimum conditions and the control schemes of UPFC for the improvement of power quality. Regulating node voltage under line loss minimization has been achieved by controlling the phase angle of the controlled voltage. The UPFC can perform the function of STATCOM and SSSC and phase angle regulator. Besides that the UPFC also provides an additional flexibility by combining some of the function above.

Installing UPFC is used to minimize the total line losses or to regulate the load voltage to be equal in magnitude to the nominal source voltage under loss minimization. Node voltage estimation has been proposed and the estimated voltages at each node agree well with their actual values.

Thus it is seen that UPFC reduces the distribution line losses and regulates the bus voltages very well. It was shown that a UPFC can be controlled in a power system to satisfy the following objectives simultaneously.

- Regulating power flow through a distribution line.
- Minimisation of power losses without generation rescheduling.
- Control terminal voltage by locally generating or absorbing reactive power.
- Allow secure loading of transmission lines to their full thermal capability where desirable.

From the control point of view, it is important to distinguish between the two basic types of voltage-source inverters that can be used in the UPFC [47]. One type is based on a phase control scheme, involving multi-connected out-of-phase six-pulse inverters. The other type of inverters operate based on Pulse With Modulation (PWM) switching techniques, where active and reactive components of the variables can be independently controlled provided that the dc voltage is kept sufficiently high.

5.2 Recommendation

The Ethiopian Electric Utility should work a lot on the whole power system, from generation to distribution, to enhance the power system stability problem, voltage variation and frequency variation of its electric power supply. Most of the distribution systems designed were not capable of handling the present load due to increasing demand of electricity time by time.

Since Building new distribution substations is difficult due to different factors like cost, availability of resource, environmental factors and land use; so the existing capacity should be enhanced. The UPFC can perform the function of STATCOM and SSSC and phase angle regulator. Besides that the UPFC also provides an additional flexibility by combining some of the function above. UPFC has also a unique capability to control real and reactive power flow simultaneously on a transmission system as well as to regulate the voltage at the bus where it's connected. At the same time the UPFC also can increase the security system by increasing the limit of transient stability, fault and the over load demand. The Ethiopian Electric Utility should work a lot in order to install these newly emerging FACTS like UPFC device technology. Because it is technology transfer and they are effective and efficient in

- ✓ Controlling Voltage profile
- ✓ Changing the impedance
- ✓ Compensating reactive power

Power System loss minimization with the help of Matlab/Simulink/SimPower Systems has been investigated in this research work. Power loss problem is real time issue, so there is a need to focus on this topic with more attention in order to avoid loss and instability in the system during further study.

- Since power systems are Non-linear and complex, the modeling has to be further analyzed with other worldwide utilizing software.
- The load model used in this paper is only the static, there are more works should be made in the future, such as used for the dynamic load.
- Giving attention for preventive maintenance and operation to improve random power interruptions, sustainability of equipment's and deliver reliable power to with at least minimum loss to the end users' needs special attention from the Ethiopian electric utility.
- The performance of the existing Adama town distribution network was not good. Therefore, the Ethiopian electric utility should work to improve power quality of distribution system.

Finally due to the natural pandemic disease named, covid-19, I faced a lot of challenges in this year which hindered easy mobility in collecting data from the sites.

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APPENDIX I

Monthly Interruption Duration of Substation Fault Data of 2019/2020

Based on the collected data, one year monthly power interruption and interruption duration was listed in the following table.

Table I Annual substation feeders fault duration table

Month: 09/05/19—07/06/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	0.04	4000	267
2	Line2 Nazereth	o.p	Request	00.50	4200	3500
3	Line3 wolenchity	o.p	Request	00.47	6600	5170
4	Line4 Berta	o.p	Request	00.48	5000	4000
5	Line5 turk textile	o.c	E.F& request	01.22	5000	6833
7	Line7 Adama metal	o.p & o.c	I>>& Request	02.38	7550	19882
8	M 1	o.p & o.c	I>>& Request	3.45	4800	18000
9	M 2	o.p & o.c	E.F & request	01.32	4000	6133
10	M 3	o.p & o.c	E.f & request	02.37	5500	14392

11	M 4	o.p & o.c	I>>& request	04.09	5800	24070
12	M 5	o.p	Request	00.36	1900	1140
13	M 6	o.c&o.p	I>>& request	01.19	3000	3950

Month: 08/06/19—07/07/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p & o.c	I>>& Request	01.33	5500	8525
2	Line2 Nazereth	o.p & o.c	I>>& Request	1.45	4400	7700
3	Line3 wolenchi ty	o.p & o.c	Request	00.36	3700	2220
4	Line4 Berta	o.p & o.c	E.f & request	02.55	5000	14583
5	Line5 turk textile	o.p & o.c	I>>& request	02.19	5400	12510
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.56	7000	13533
8	M 1	o.p & o.c	I>>& Request	3.45	4000	15000
9	M 2	o.p & o.c	I>>& req.	01.00	4350	4350
10	M 3	o.p & o.c	E.f & request	02.37	5700	14915
11	M 4	o.p & o.c	I>>& request	02.24	6500	15600
12	M 5	o.p	Request	00.36	2000	1200

13	M 6	o.c&o.p	I>>& request	01.42	3400	5780

Month: 08/07/19—06/08/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	0.08	4500	600
2	Line2 Nazereth	o.c	I>>	00.28	4600	2147
3	Line3 wolenchity	o.p	Request	01.45	6500	11375
4	Line4 Berta	o.p	Request	00.38	5500	3483
5	Line5 turk textile	o.c	E.F& request	00.21	4000	1400
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.02	6200	6407
8	M 1	o.p & o.c	I>>& Request	01.59	4600	9123
9	M 2	o.p & o.c	I>>& req.	00.51	4300	3655
10	M 3	o.p & o.c	E.f & request	02.55	5800	16917
11	M 4	o.p & o.c	I>>& request	02.49	6300	17745
12	M 5	o.p	Request	00.56	2500	2333
13	M 6	o.c&o.p	I>>& request	01.19	3000	3950

Month: 07/08/19—05/09/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	01.25	6000	8500
2	Line2 Nazereth	o.c & o.p	I>>& request	01.02	5350	5528
3	Line3 wolenchity	o.p	Request	01.45	6200	10850
4	Line4 Berta	o.p	Request	00.30	4800	2400
5	Line5 turk textile	o.c	E.F& request	01.48	5600	10080
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.05	6500	7042
8	M 1	o.p & o.c	I>>& Request	00.55	4000	3667
9	M 2	o.p o.c	Request	00.15	3880	970
10	M 3	o.p & o.c	E.f & request	02.57	5000	14750
11	M 4	o.p & o.c	I>>& request	01.54	5800	11020
12	M 5	o.p	Request	00.32	1800	960
13	M 6	o.c&o.p	I>>& request	01.40	4000	6667

Month: 12/09/19—11/10/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1	o.p	Request	00.43	4500	3225

	wonji					
2	Line2 Nazereth	o.c & o.c	Request	00.29	4100	1982
3	Line3 wolenchity	o.p	Request	00.56	6000	5600
4	Line4 Berta	o.p	Request	00.40	3800	2533
5	Line5 turk textile	o.c	E.F& request	02.51	6000	17100
7	Line7 Adama metal	o.p & o.c	I>>& Request	03.22	6000	20200
8	M 1	o.p & o.c	I>>& Request	03.25	4900	16742
9	M 2	o.p o.c	Request	02.24	4200	10080
10	M 3	o.p & o.c	E.f & request	03.15	5000	16250
11	M 4	o.p & o.c	I>>& request	04.13	5800	24457
12	M 5	o.p	Request	01.32	4000	6133
13	M 6	o.c&o.p	I>>& request	01.25	4150	5879

Month: 12/10/19—10/11/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	01.28	4000	5867
2	Line2 Nazereth	o.c	I>>	02.18	5000	11500

3	Line3 wolenchi ty	o.p	Request	00.59	6600	6490
4	Line4 Berta	o.p	Request	00.47	3500	2742
5	Line5 turk textile	o.c	E.F& request	01.55	6000	11500
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.57	6500	12675
8	M 1	o.p & o.c	I>>& Request	00.34	4850	2748
9	M 2	o.p o.c	E.F & request	01.26	5600	8027
10	M 3	o.p & o.c	E.f & request	01.37	5500	8892
11	M 4	o.p & o.c	I>>& request	02.47	5800	16143
12	M 5	o.p	Request	00.50	2500	2083
13	M 6	o.c&o.p	I>>& request	01.19	3000	3950

Month: 11/11/19—10/12/19

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	00.47	5000	3917
2	Line2 Nazereth	o.c & o.p	I>>	00.31	4600	2377
3	Line3 wolenchi ty	o.p	Request	01.45	6600	11550

4	Line4 Berta	o.p	Request	01.43	4900	8412
5	Line5 turk textile	o.c	E.F& request	01.28	5700	8360
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.36	5500	8800
8	M 1	o.p & o.c	I>>& Request	00.45	4800	3600
9	M 2	o.p & o.c	Request	00.09	3500	525
10	M 3	o.p & o.c	E.f & request	01.28	5600	8213
11	M 4	o.p & o.c	I>>& request	03.42	5900	21830
12	M 5	o.p	Request	00.42	2800	1960
13	M 6	o.c&o.p	I>>& request	01.28	3200	4693

Month: 11/12/2019—09/01/2020

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.c & o.p	Request	0.49	4500	3675
2	Line2 Nazereth	o.c & o.p	I>>	00.36	4200	2520
3	Line3 wolenchity	o.p	Request	01.47	6200	5170
4	Line4 Berta	o.p	Request	01.46	5000	8833
5	Line5	o.c	E.F&	00.50	5500	4583

	turk textile		request			
7	Line7 Adama metal	o.p & o.c	I>>& Request	01.53	6080	11451
8	M 1	o.p & o.c	I>>& Request	3.45	4800	18000
9	M 2	o.p & o.c	I>>	01.06	4950	5445
10	M 3	o.p & o.c	E.f & request	02.03	5500	11275
11	M 4	o.p & o.c	I>>& request	04.19	7200	31080
12	M 5	o.p	Request	01.36	2700	4320
13	M 6	o.c&o.p	I>>& request	01.19	3000	3950

Month: 10/01/2020—08/02/2020

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	0.25	4000	1667
2	Line2 Nazereth	o.p	Request	00.47	2500	1958
3	Line3 wolenchi ty	o.p	Request	00.47	6600	5170
4	Line4 Berta	o.p	Request	00.51	5500	4675
5	Line5 turk textile	o.c	E.F& request	01.41	4900	8248
7	Line7 Adama	o.p & o.c	I>>&	02.29	6500	16142

	metal		Request			
8	M 1	o.p & o.c	I>>& Request	3.47	5800	21943
9	M 2	o.p o.c	Request	00.55	3700	3392
10	M 3	o.p & o.c	E.f & request	02.00	5500	11000
11	M 4	o.p & o.c	I>>& request	03.27	6000	20700
12	M 5	o.p	Request	00.36	1800	1080
13	M 6	o.c&o.p	I>>& request	01.19	2600	3423

Month: 09/02/2020—09/03/2020

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	0.24	4500	1800
2	Line2 Nazereth	o.c & o.p	Request	00.30	4100	2050
3	Line3 wolenchity	o.p	Request	00.47	6600	5170
4	Line4 Berta	o.p	Request	01.56	5000	9667
5	Line5 turk textile	o.c	E.F& request	00.53	5000	4417
7	Line7 Adama metal	o.p & o.c	I>>& Request	03.39	5980	21827
8	M 1	o.p & o.c	I>>& Request	00.45	4800	3600

9	M 2	o.p o.c	I>>	01.55	5000	9583
10	M 3	o.p & o.c	E.f & request	02.37	3200	8373
11	M 4	o.p & o.c	I>>& request	01.01	5800	5897
12	M 5	o.p	Request	00.36	1900	1140
13	M 6	o.c&o.p	I>>& request	01.19	3600	4740

Month: 10/03/2020—08/04/2020

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	01.13	4000	4867
2	Line2 Nazereth	o.c & o.p	I>>& request	02.25	2000	4833
3	Line3 wolenchity	o.p	Request	00.30	5600	2800
4	Line4 Berta	o.p	Request	00.59	4200	4130
5	Line5 turk textile	o.c	E.F& request	01.39	5900	9735
7	Line7 Adama metal	o.p & o.c	I>>& Request	00.30	5900	2950
8	M 1	o.p & o.c	I>>& Request	01.49	4800	8720
9	M 2	o.p o.c	Request	02.05	5250	10937
10	M 3	o.p & o.c	E.f & request	01.37	5500	8892

11	M 4	o.p & o.c	I>>& request	04.40	5700	26600
12	M 5	o.p	Request	00.36	1900	1140
13	M 6	o.c&o.p	I>>& request	01.19	5200	6847

Month: 11/04/2020—08/05/2020

No	Feeder	Type of fault	Cause of fault	Interruption hour d/ce (Hr)	Line load (kw)	Unsold Energy (kwh)
1	Line 1 wonji	o.p	Request	0.11	4000	733
2	Line2 Nazereth	o.p & o.c	I>>	00.39	4600	2990
3	Line3 wolenchi ty	o.p	Request	00.41	6100	4168
4	Line4 Berta	o.p	Request	00.48	5200	4160
5	Line5 turk textile	o.c	E.F& request	00.52	5000	4333
7	Line7 A	o.p & o.c	I>>&	03.14	5605	18123
8	M 1	o.p & o.c	I>>& Request	01.45	4800	8400
9	M 2	o.p o.c	Request	01.11	3800	4497
10	M 3	o.p & o.c	E.f & request	02.37	3500	9158
11	M 4	o.p & o.c	I>>& request	02.49	6000	16900
12	M 5	o.p	Request	00.49	1900	1552
13	M 6	o.c&o.p	I>>& request	01.19	3800	5003

Two-winding distribution transformer Data (Name plate)

KVA rating,nameplate percentage impedance $\%Z_{np,}$ nameplate X_{np}, R_{np} ratio are the necessary data to be fed in modeling two winding transformer

$$\%Z_{np} = \sqrt{\left(\%R_{np}\right)^2 + \left(\%X_{np}\right)^2}$$

$$X/R = \%X_{np}/\%R_{np}$$

Table II Distribution Transformer Data

ID	$\%Z_{np}$	KVA	X/R	%R	%X	%Z
0408614	7.43	200	11.92	10.35	123.4	123.8
19989	6.15	315	7.63	53.38	406.5	410
00547	7.5	500	17.22	5.79	99.4	99.6
0408614	9	100	27.30	0.82	22.5	22.5
14463	10.33	100	29.50	0.7	20.6	20.7
17652	7.5	200	18.60	3.36	62.4	62.5
27564	9	315	27.30	0.82	22.5	22.5
09565	9	500	27.30	0.82	22.5	22.5
156987	7.5	200	18.60	3.36	62.4	62.5
17308	7.5	50	18.60	2.24	41	41.3
25558	7.5	315	23.4	1.32	31.2	31.3
81236	11.88	500	28.95	0.16	4.7	4.8
120896	11.88	400	28.95	0.16	4.7	4.8
569802	7.5		18.6	3.36	62.4	62.5

The collected EEU Data consists of line length (km), resistance of a line (ohm/km), reactance of a line(ohm/km), resistance of loads(ohm), reactance of loads(ohm)

Table III Distribution line Data (loading and length)

ID	(km)	R(ohm/km)	X(ohm/km)	R(ohm) load	X(ohm) load
Line-7	11	20.7	1.06	125	95
Mobile-4	9	16.7	1.62	120	125

Table IV Substation transformer I data (25MVA)

Transformer Id	2005-53-69
Rated power	25MVA
Rated voltage	132kv/15kv
Rated current	109.3A/962.3A
Frequency	50Hz

Table V Substation transformer II Data (25MVA)

Transformer Id	2005-53-67
Rated power	25MVA
Rated voltage	132kv/15kv
Rated current	109.3A/962.3A
Frequency	50Hz

Table VI Substation transformer III Data (50MVA)

Transformer Id	2016-12
Rated power	50MVA
Rated voltage	132kv/15kv
Rated current	218.7A/1925A
Frequency	50Hz
No-load current	0.16%
No-Load Loss	30.56kw
Load Loss	186.56
Impedance	10.75%