

**INVESTIGATION AND MITIGATION OF UNDER VOLTAGE  
PROBLEMS IN DISTRIBUTION NETWORK BY OPTIMAL  
PLACEMENT OF CAPACITOR BANKS  
(A Case study at Adama Distribution System)**

By : **GENET LEMMA AWOKE**



A Thesis Submitted to  
The Department of Electrical Power and Control Engineering School of  
Electrical Engineering and Computing  
**Presented In Partial Fulfillment of the Requirements for Degree Of  
Master's In Electrical Power Engineering and Control Engineering  
(Specialization In Power System Engineering)**

**Office Of Graduate Studies  
Adama Science And Technology University**

Adama, Ethiopian

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## Approval of Board of Examiners

We, the undersigned, members of the Board of Examiners of the final open defense by Genet Lemma have read and evaluated his thesis entitled “**the investigation and mitigation of under voltage problem in distribution system by optimal placement of capacitor banks**” (Case Study of Adama distribution Network ) and examine the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power Engineering.

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## **DECLARATION**

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

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## ABSTRACT

*Distribution feeders are components of distribution system which transfer power from distribution substation to distribution transformers located near to customer's premises. Distribution substation feeders which have poor power factor, large loads beyond it's' carrying capacity and which travel long distance to feed costumers are not efficient in transferring electrical power to the connected costumers. To improve the efficiency of distribution feeders voltage profile improvement techniques are required.*

*Adama distribution substation is one of the distribution substations found in Oromia electric utility which has Eleven (11) outgoing feeders that feed different areas of Adama town. Among these feeders, feeder four F1 has been selected as test system after investigation has been done through distribution interruption due to over load regarding all outing feeders from 2018 to 2020 years recorded data. The selected feeder has been modeled in ETAP software with built in a genetic algorithm and load flow analysis has been simulated using Newton-Raphson method that is built in ETAP software.*

*The proposed method was tested on distribution system of Adama outgoing Feeder-1. In the tested distribution system it was found that by placing total of 9000kvar at a location (bus-4, bus-8 and bus-13). After capacitor bank installed on the feeder -1 near bus -4; bus 8 and bus 13 the voltage drop improvement from 14.085 to 15.005 with a percentage increment of 6.13%; from 14.050 to 15.020 with a percentage increment of 6.46% and from 14.090 to 15.011 with a percentage increment of 6.12% consecutively. And also total power loss to decrease from 0.253MW to 0.137MW. Due to this, the Ethiopian Electric Utility can save 143,731.68 Birr per annum with the payback period of Eighteen months. In general, Optimal Capacitor Placement in Adama distribution network feeder -1 averagely improves voltage profile of the feeder with 6.10% and as a result it enhanced the power quality of the distribution network.*

**Keywords:** Genetic Algorithm, Optimal capacitor placement, ETAPs software Feeders, power loss, Voltage drop.

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## **LIST OF ABBREVIATIONS**

|           |                                                       |
|-----------|-------------------------------------------------------|
| OCP       | Optimal Capacitor Placement                           |
| DLOL      | Distribution Line over Load                           |
| DPET      | Distribution permanent earth fault                    |
| DPSC      | Distribution permanent short circuit                  |
| EEP       | Ethiopian Electric Power                              |
| EEU       | Ethiopian Electric Utility                            |
| PFC       | Power Factor Correction                               |
| IEC       | International Electro technical Commission            |
| IEEE      | International of Electrical and Electronics Engineers |
| DNOs      | Distribution Network Operators                        |
| OLTC      | on Load Tap Changer                                   |
| VVC       | Volt/Var Control                                      |
| AVR       | Automatic Voltage Regulator                           |
| OPF       | Optimal Power Flow                                    |
| SVC       | Static var Compensator                                |
| KVAR      | Kilovolt Ampere Reactive                              |
| KVA       | Kilovolt Ampere                                       |
| MW        | Mega watt                                             |
| MVA       | Mega volt Ampere                                      |
| KV        | Kilovolt                                              |
| PF        | Power factor                                          |
| GA        | Genetic Algorithm                                     |
| DPEF      | Distribution permanent fault                          |
| DPSC      | Distribution Permanent Short Circuit                  |
| DTEF      | Distribution Temporarily Fault                        |
| DTSC      | Distribution Temporarily Short Circuit                |
| DLOL      | Distribution Line Over Load                           |
| SOL (LDC) | System Over Load ; Load Dispatch Center               |

# CHAPTER ONE

## INTRODUCTION

### 1.1. Background

The Ethiopian Electric Utility (EEU), the state-owned electric power distribution company, is established as a separate entity, pursuant to Council of Ministers Regulation No. 303/2013, on December 27, 2013. The Regulation stated that EEU is established to construct and maintain electric distribution networks; contract out the distribution networks construction to contractors as required; administer electric distribution networks, to purchase bulk electric power and sell electric energy to customers; initiate electric tariff amendments and, upon approval, to implement same, in line with directives and policy guidelines issued by the Ministry of Finance and Economic Development, to sell and pledge bonds and to negotiate and sign loan agreements with local and international financial sources; and undertake any other related activities necessary for the attainment of its purposes.

EEU currently provides electricity to a total of about 3.2 million customers in approximately 7000 towns and communities in Ethiopia. According to current figures only about 58.4% of the population is estimated to have access to electricity and the per capita energy consumption is 100 kWh, which is the lowest in the world.

Since July 8, 2018 EEU is reorganized with a decentralized local administration structure which composed of regional offices in nine regional government states and two city administrations. [1]

The Ethiopian transmission and distribution system consists of 500kV (where it is under construction), 400kV, 230kV, 132kV primary transmission systems and 66kV, 45kV as sub transmission system and 33kV and 15kV as distribution system. The power distribution system is made up of sub-transmission lines, power transformers, 33kV lines, 15kV lines, distribution transformers, LV lines, etc.

Currently in Ethiopia there are 144 functional substation exist which are divided in to eight (8) zones, such as zone-1 is Addis Ababa region it contains 22 substation, zone-2 is central region 27 substation, zone-3 Eastern region 13 substation, zone-4 north eastern region 11 substation, zone-5 northern region 8 substation, zone-6 north eastern region 14 substation, zone-7 western

region 15 substation and the last zone-8 southern region 16 substation. Adama substation is categorized in zone two central regions.

The power supply to Adama substation is coming from koka and Adama wind generation through 1x132kV transmission line. The substation has two, 2\*25MVA power transformers and mobile substation one 50 MVA power transformer. The medium voltage side (15kV) has five has 11 outgoing feeders.[2]

Electric Power distribution system in Adama town is something of a major poor state of electric power distribution concern. According to annual report of 2020G.C of distribution medium voltage interruption data, Most of the time distribution feeders are interrupted due to over loads condition.

It is known that electric energy to end users transfer with required standards of efficiency, quality and reliability, which requires minimizing energy losses and improving transport processes [3]. Reactive power compensation is one of the well-recognized methods for its contribution to the reduction of energy losses, along with other benefits; Such as power factor correction, increase of the transport and operation capacity of lines and devices of the distribution system, voltage stability and improvement of the voltage profile, all of them subject to different operating restrictions [4].

The distribution circuits, in spite of the typical nature of their loads, are predominantly inductive due to their short distances and medium voltage levels, predominating the aerial type of construction [5].The reactive power flows are consumed in the grid and the reactive components of the currents that demand these inductive loads normally circulate throughout the distribution circuit, causing high losses due to the Joule effect. For this reason, the reactive power compensation, subject to the proper selection and location of compensating devices, is of great importance in minimizing losses of power and for voltage profile improvement.

Ensuring the reliability and stability of medium voltage distribution system is one of the biggest challenges for energy distribution companies, since energy must reach end users with quality standards that demand constant improvement to maintain the levels of stable voltages within the parameters governed by the standards established in each country for the different voltage levels [6]. The improvement of the voltage profiles in distribution system, seeking to

increase stability and reliability, has been achieved through the insertion reactive power compensators. [7].

This thesis focuses on the investigation and mitigation of under voltage problems on Adama distribution network by capacitor bank placement.

## **1.2. Problem Statement**

Ethiopian Government is currently making all rounded effort to change the country's economic status from the current least developed level to a medium income level. Of the many aspects of this effort, expanding and strengthening of the electric power supply sector is one among the most emphasized economic dimensions. In Ethiopia like many other countries, the overall grid system has generation, transmission, substation and distribution. But most of distributions networks have problems have high power loss due to voltage drop which is caused by system overloading and reactive power. This problem results in poor voltage regulation, and poor efficiency, under and over loading of lines thought out the system. Nowadays, demand of electrical power is increasing from time to time. As a result, the distribution feeders which transfer power from substation to the customers are overloaded beyond their carrying capacity. Overloaded distribution feeders that travel long distances have large losses and voltage drop problems. Utility and connected customers both suffer from these loss and voltage drop problems. The equipment used by utility and customers are designed to operate at a certain voltage level. If they operate below that level, it will draw large current. This has dangerous effect on the life time of the connected equipment's and devices. Since adama town is the capital city of the oromia regional state and is a preferred location for most of the industries in the country, and currently new industrial zone are developing that need reliable and quality power supply. But, in adama town distribution network electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems

In this regard, finding loss reduction and voltage profile improvement mechanisms for the distribution networks is a pressing issue. There are different such mechanisms as shunt capacitor placement, Distributed Generation (DG) placement, conductor upgrading and feeder reconfiguration, to list a few. Loss reduction and voltage profile improvement mechanism for

distribution feeders need feasibility analysis. In addition to the feasibility issue, proper sizing and locating of the selected mechanism in the distribution system is another problem.

Therefore, finding feasible mechanism for loss reduction and voltage profile improvement of distribution feeders with appropriate size and location of capacitor placement is a challenging problem for especially Ethiopian electric utility company.

To solve this challenging problem, investigation and mitigation of under voltage problem in Adama distribution network are done using ETAP software.

### **1.3.Research Objective**

#### **1.3.1. General Objective**

The general objective of this thesis is investigation of under voltage problem and to provide mitigation mechanism by optimal placement of capacitor bank in Adama distribution outgoing feeder F1.

#### **1.3.2. Specific Objective**

The specific objectives of this thesis are:

- ◆ Investigate the drawbacks and strengths of the existing network.
- ◆ Implementation of optimal placement of capacitor placing.
- ◆ Implementing the algorithm to obtain the optimal size of capacitor bank and thereby reducing the losses.
- ◆ Model the existing network on ETAPS software and simulate for the network performance for different scenarios.
- ◆ Evaluate and compare the result before and after OCP
- ◆ Draw relevant conclusions and recommendations based on the research result.

### **1.4.Methodology**

Raw data of the existing network is collected from the respective work units of Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). For instance, data from Adama distribution substation and central EEP office that include fault statistics (interruption), peak load, power transformer rating and other equipment ratings. And also 15kV feeder data from the

distribution network such as number of 15kV transformer in each outgoing feeder's conductor length, size and type, distribution transformers data, and number customer in each feeder. Specifically, the following methodologies have been followed in this thesis work:

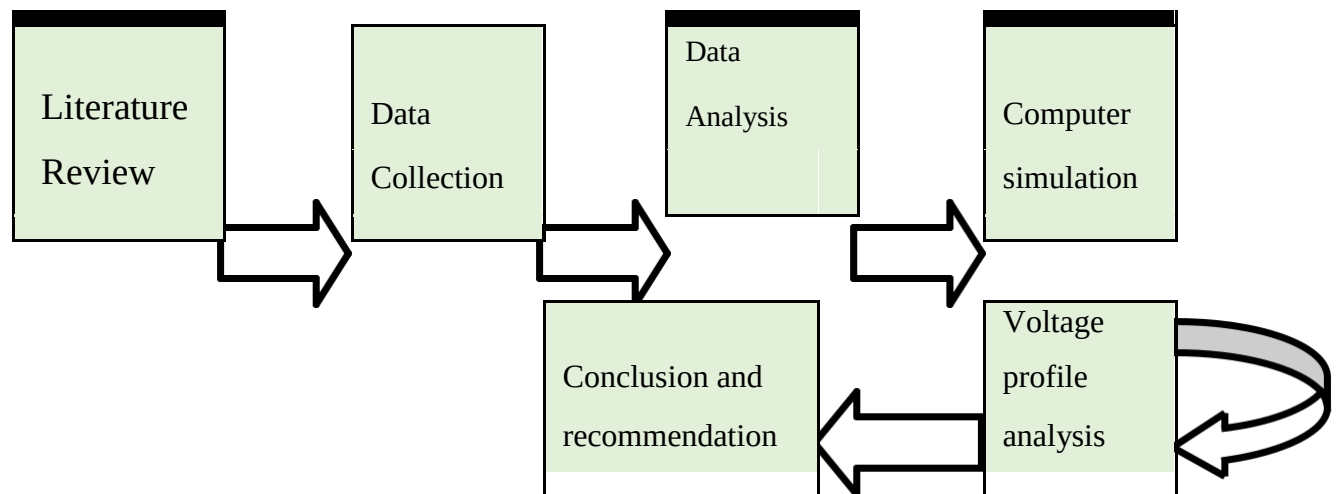


Fig 1,1: Block diagram of the overall methodology utilized on this thesis

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

The total task of data collection is accomplished through

- ❖ Conducting interviews with the respective personnel of the substations.
- ❖ Direct measurement
- ❖ From recorded data and equipment specifications
- ❖ Physical observation in the substations.
- ❖ Data from Ethiopian Electric Utility (EEU) engineering offices.
- ❖ Adama substation operation department section unit.
- ❖ Adama district distribution operation and maintenance office.

#### Computer analysis or Simulation

There are different types of software which can be applicable on electrical power distributions simulation ETAPs, Power world, PSS, MATLAB, and DigSILENT. From the software

mentioned above ETAP version 19.1 the most comprehensive power system enterprise solution in the market ,highly compatible , combined reliability and flexible system modeling capability with built in Genetic algorithms (GA).The data is organized using EXCEL sheet and modeling of the single layout diagram and newton raphson power flow analysis is done using ETAP Software for optimal placement of capacitor bank .Comparison voltage profile has been done on each bus of the system before and after capacitor bank placement,

### **1.5. Scope of the study**

The scope of this research is limited to the Existing Distribution networks as per EEP and EEU standard voltages definition and it focus on distribution system that is only supplied from the 33kv Feeder system. Although there are many ways of solving this research problem, this research investigates the use of ETAP Software to solve the above mentioned optimization problem. ETAP Software has been specifically chosen due to their reliability, robustness and versatility of consistently finding solutions to the objective optimization problems. In this case an optimal capacitor position needs to be located for various levels of network dynamics (i.e. different loading conditions and different network configurations).

### **1.6.Organization of the Thesis**

The thesis is organized into five chapters. Chapter one presents the introduction, background, statement of the problem, research objectives, methodology and scope followed in the thesis work and the organization of the thesis. Chapter two deals the theoretical background and literature review of the study, mainly on importance voltage stability, reactive power control in electrical systems, the aim of power factor correction, voltage and reactive power control method, ways of improving voltage profile. Chapter three discusses techniques of optimization, choice of optimization, optimal capacitor placement. Chapter four collections of data and analysis of the distribution line of the selected area. In this chapter all main data's that are needed for power flow analysis are provided and analyzed. Chapter five discusses about simulation results and detailed discussion of the gain in forms of, tables and column charts for comparison of the system before and after OCP. Conclusion and recommendations are incorporated under chapter six.

## CHAPTER TWO

### THREORETICAL BACKGROUND AND LITERATURE REVIEW

#### 2.1. Introduction

Improving voltage profile is one of the biggest challenges in electric power utility of developing countries. The electricity demand has been grown rapidly. As a result, a poor voltage profile with higher loss has not reliability if no proper measures are put in place. While the utilities have no sufficient funds for expansion their grid and source, it is necessary to reduce power loss. This chapter presents overview of distribution system and different voltage profile improvement technique in distribution system [8].

#### 2.2. Electrical Power Distribution System

Electrical distribution substation networks consist of primary distribution feeder, distribution transformer, distributors and service mains.

The transmitted electric power is stepped down in substations, for primary distribution purpose. Now these stepped down electric power is fed to the distribution transformer through primary distribution feeders.

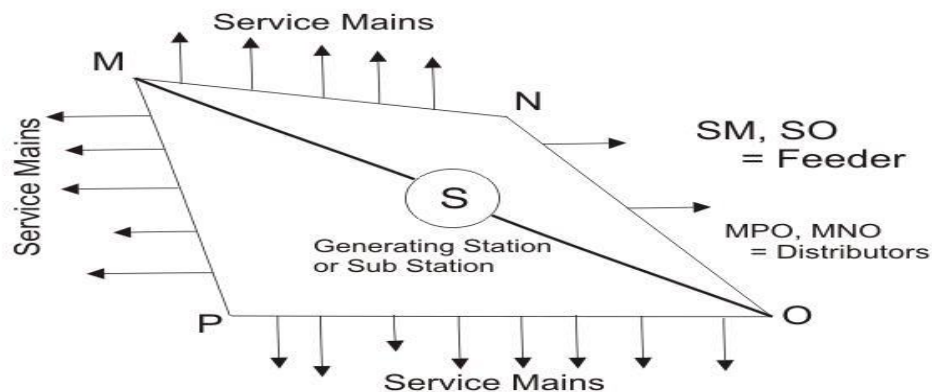


Fig 2.1: Electric Power Distribution Network [8]

Distribution transformers are mainly three phase pole mounted type. The secondary of the transformer is connected to distributors. Different consumers are fed electric power by means of the service mains. These service mains are tapped from different points of distributors. The distributors can also be re-categorized by distributors and sub distributors. Distributors are directly connected to the secondary of distribution transformers whereas sub distributors are tapped from distributors. Service mains of the consumers may be either connected to the distributors or sub distributors depending upon the position and agreement of consumers. In this discussion of electrical power distribution system, we have already mentioned about both feeders and distributors. Both feeder and distributor carry the electrical load, but they have one basic difference. Feeder feeds power from one point to another without being tapped from any intermediate point. As because there is no tapping point in between, the current at sending end is equal to that of receiving end of the conductor. The distributors are tapped at different points for feeding different consumers; and hence the current varies along their entire length.[8]

## 2.3 Distribution System Network Configuration

### 2.3.1. Radial Electrical Power Distribution System

In early days of electrical power distribution system, different feeders came out in radial from the substation and connected to the primary of distribution transformer.

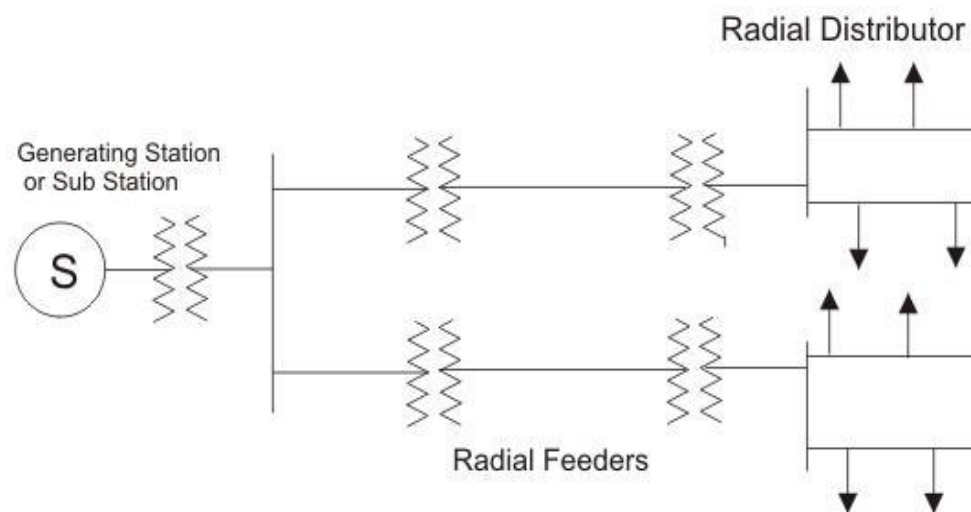


Fig 2.2: Radial Electric Power Distribution system [8]

But radial electrical power distribution system has one major drawback that in case of any feeder failure, the associated consumers would not get any power as there was no alternative path to feed the transformer. In case of transformer failure also, the power supply is interrupted. In other words the consumer in the radial electrical distribution system would be in darkness until the feeder or transformer was rectified [8].

### 2.3.2 Ring Main Electrical Power Distribution System

The drawback of radial electrical power distribution system can be overcome by introducing a ring main electrical power distribution system. Here one ring network of distributors is fed by more than one feeder. In this case if one feeder is under fault or maintenance, the ring distributor is still energized by other feeders connected to it. In this way the supply to the consumers is not affected even when any feeder becomes out of service. In addition to that the ring main system is also provided with different section isolates at different suitable points. If any fault occurs on any section, of the ring, this section can easily be isolated by opening the associated section isolators on both sides of the faulty zone transformer directly.

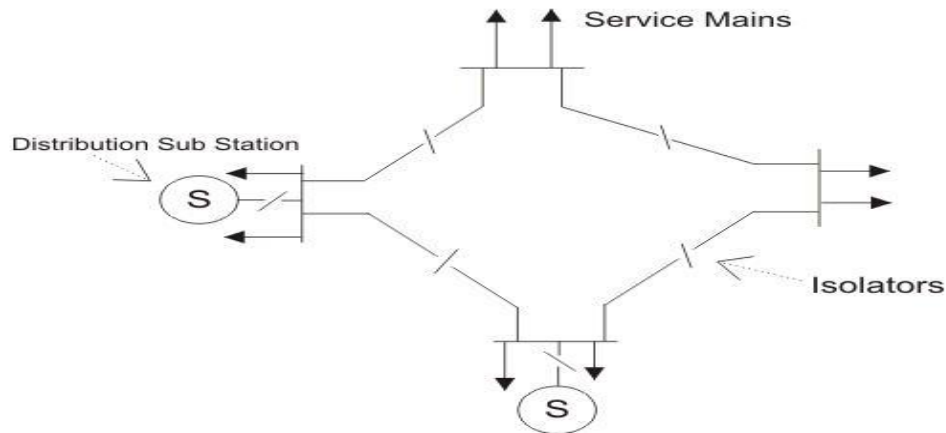


Fig 2.3: Ring Electric Power Distribution system [8]

In this way, supply to the consumers connected to the healthy zone of the ring, can easily be maintained even when one section of the ring is under shutdown. The number of feeders connected to the ring main electrical power distribution system depends upon the maximum demand of the system, the total length of the ring main distributor and the voltage regulation required. The sub distributors and service mains are taken off may be via distribution transformer at different suitable points on the ring depending upon the location of the

consumers. Sometimes, instead of connecting service main directly to the ring, sub distributors are also used to feed a group of service mains where direct access of ring distributor is not possible [8].

### **2.3. Power Quality, Reliability and Availability**

Power quality problem from a customer perspective might be defined as any electric supply condition that causes appliances to malfunction or stops their use. Power quality problem from a utility perspective might be perceived as non-fulfillment of various standards such as RMS voltage or harmonics. Power is equivalent to the instantaneous product of current and voltage, and formulating a meaningful definition of power quality is difficult. The best a utility can do is to supply customers with a perfect sinusoidal voltage source with constant frequency and amplitude. Less than perfect power quality occurs when a voltage waveform was distorted by transients or harmonics, changes its amplitude, or deviates in frequency [9].

Reliability is primarily concerned with customer interruptions, therefore a subsection of power quality [9]. Sustained interruptions have continuously been categorized as a reliability issue, but many utilities have categorized momentary interruptions as a power quality issue. Momentary interruptions are an important customer issue and most distribution engineers consider them a reliability issue. Therefore, reliability is all aspects of customer interruptions, together with momentary interruptions [10].

Availability is defined as the proportion of time a voltage source was uninterrupted. Its complement, unavailability, is the fraction of time a voltage source was interrupted. Since availability and unavailability deal strictly with interruptions, they are classified as a subsection of reliability [10].

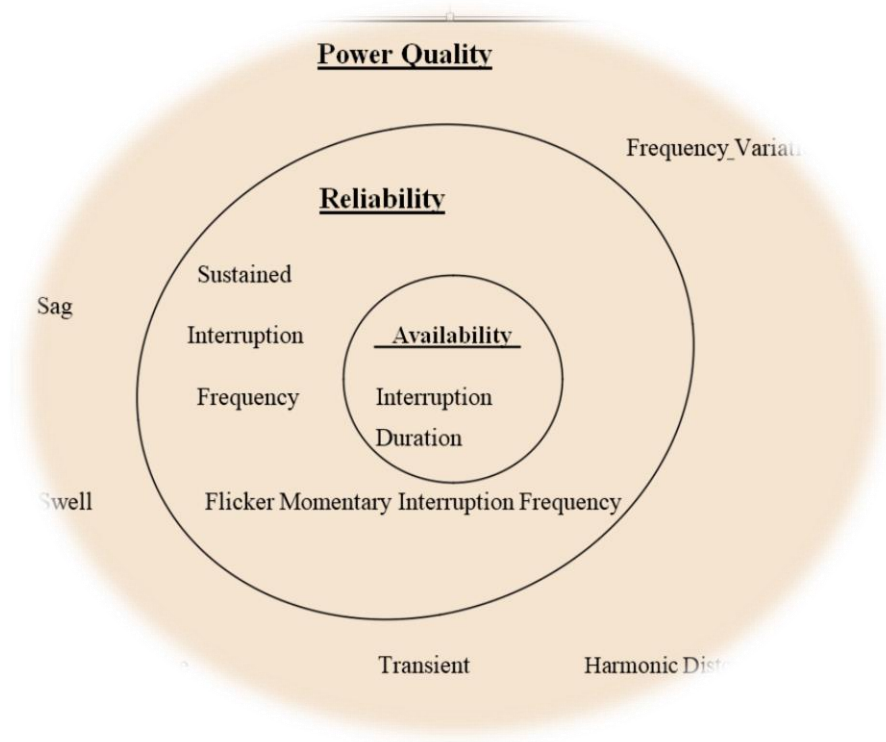


Fig 2.4: The grading of power quality, reliability, and availability [11]

### 2.3.1 Overview of power quality

The quality of delivered electricity, like quality of other goods and services, is difficult to define and quantify. There is not one accepted definition of quality electricity. The quality is mainly determined by the quality of the voltage waveform, as it is impossible to control the currents drawn by customer loads. Voltage quality is not only the responsibility of the network operator but also, in certain respects, depends on producers and customers.

**Power quality** is the combination of current quality and voltage quality, involving the interaction between the system and the load. **Voltage quality** concerns the deviation of the voltage waveform from the ideal sinusoidal voltage of constant magnitude and constant frequency. *Current quality* is a complementary term and it concerns the deviation of the current waveform from the ideal sinusoidal current of constant magnitude and constant frequency. Voltage quality involves the performance of the power system towards the load, while current quality involves behavior of the load towards the power system.

There is always close relationship between voltage and current in any practical power system.

Although the generators may provide a near-perfect sinusoidal voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage. To understand the basis of many power quality problems is necessary to deal with the interaction between the load and the power system. The power system can only control the quality of the supply voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits.[12]

**Quality of supply** is a combination of voltage quality and the non-technical aspects of the interaction between the utility and its customers. Quality of service in electricity supply has a number of different dimensions, which can be grouped under three general headings: commercial relationships between a supplier and an end-user, continuity of supply, and voltage quality.

**Continuity of supply** (also referred to as *Reliability of delivery*) is characterized by the number and duration of interruptions. Several indicators are used to evaluate the continuity of supply in transmission and distribution systems (e.g. SAIDI, SAIFI).

**Voltage quality** is concerned with deviations of the voltage from the ideal. The ideal voltage is a single-frequency sine wave of constant frequency and constant magnitude. Voltage quality is described according to the European standard EN 50160 by the characteristics of the supply voltage concerning: frequency, magnitude, waveform and symmetry of the phases.

**Quality of service** (also referred to as *Commercial quality*) concerns the quality of relationships between a supplier and a customer. It covers many aspects of the relationship (e.g. transparency of the tariff structure, information supply, responses on customers' complaints, metering, reading and billing), but only some of them can be measured and regulated through standards or other instruments.[12]

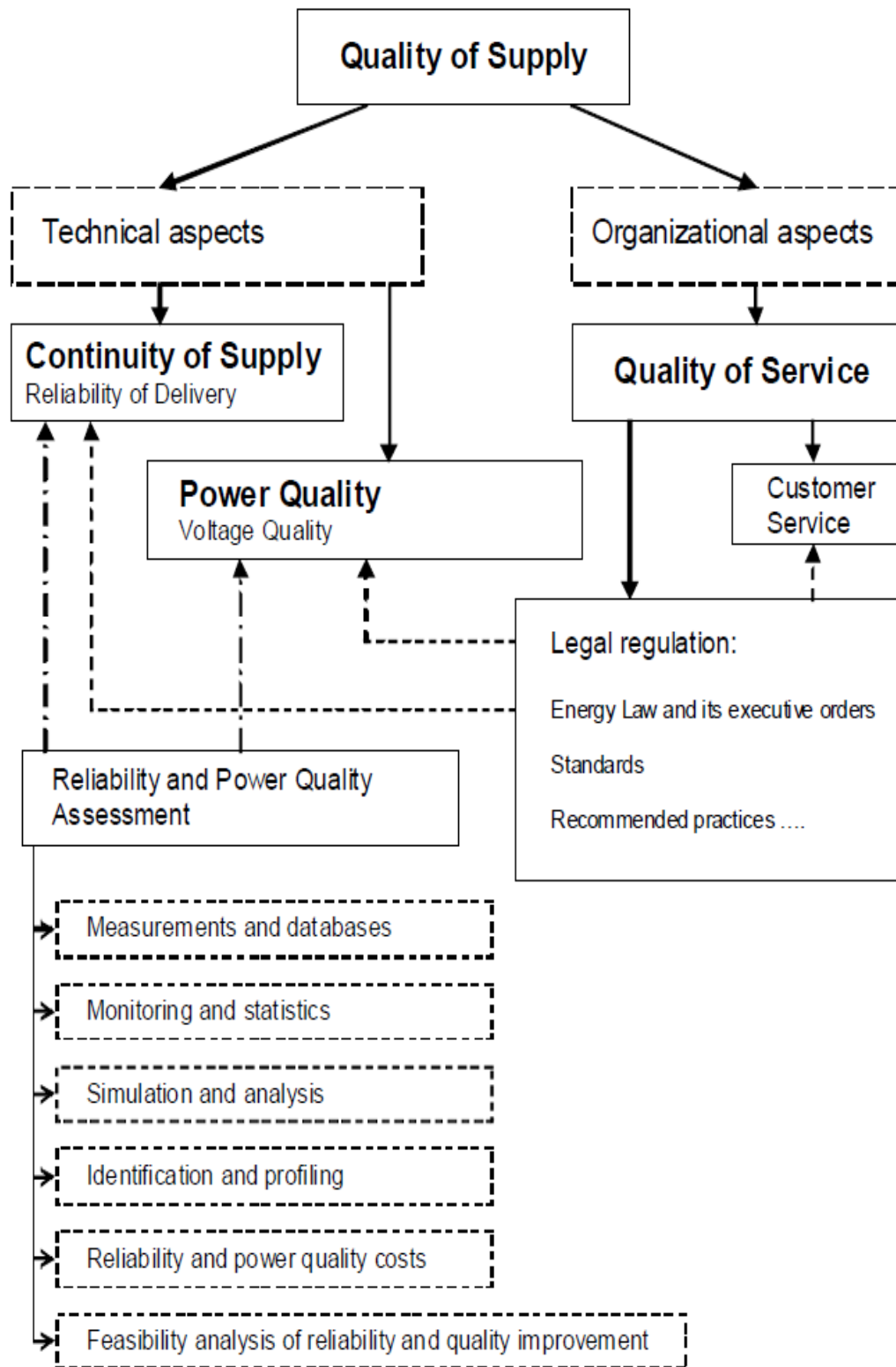
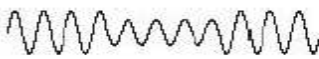
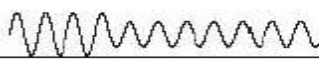
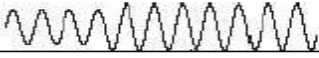
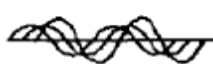
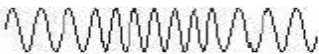


Fig 2.5: Dimensions of the Quality of Supply [12]

Table 2.1: Summary of power quality disturbances [12]

|                     | PQ Disturbance                                                                                                                              | Frequency / Rise Time                                 | Duration               | Magnitude     |
|---------------------|---------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|------------------------|---------------|
| Amplitude           | <b>INTERRUPTION</b><br>                                    | collapse                                              | 10 ms to 3 min         | 0             |
|                     | <b>VOLTAGE DIP</b><br>                                     | power frequency                                       | 10 ms to 1 min         | 0.1 to 0.9 pu |
|                     | <b>VOLTAGE SWELL</b><br>                                   | power frequency                                       | 10 ms to 1 min         | 1.1 to 1.8 pu |
|                     | <b>UNDERVOLTAGE</b><br>                                    | power frequency                                       | > 1 min                | 0.8 to 0.9 pu |
|                     | <b>OVERVOLTAGE</b><br>                                     | power frequency                                       | > 1 min                | 1.1 to 1.2 pu |
|                     | <b>TRANSIENT OVERVOLTAGE (Impulsive Transients)</b><br>    | rise time: ns to ms                                   | 50 ns to 1 ms          | 0 to 10 pu    |
|                     | <b>TRANSIENT OVERVOLTAGE (Oscillatory Transients)</b><br> | 1 kHz to 10 MHz                                       | 1 $\mu$ s to 50 ms     | 0 to 6 pu     |
| Waveform distortion | <b>VOLTAGE FLUCTUATIONS (FLICKER)</b><br>                | modulation frequency < 50 Hz                          | steady-state variation | +/- 0.1 pu    |
|                     | <b>HARMONICS</b><br>                                     | harmonic orders: 0 to 50                              | steady-state variation | < 0.1 pu      |
|                     | <b>NOTCHING</b><br>                                      | broad-band                                            | steady-state variation | < 0.1 pu      |
| Balance             | <b>VOLTAGE UNBALANCE</b><br>                             | power frequency                                       | steady-state variation | ---           |
| Frequency           | <b>FREQUENCY VARIATION</b><br>                           | 49.5 to 50.5 Hz (47 to 52 Hz) for synchronous systems | < 10 s                 | ---           |

## 2.4. The concepts of Reliability in Distribution System

The function of an electric power system is to satisfy the system load requirement with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term reliability. The concept of power-system reliability is extremely broad and covers all aspects of the ability

of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as system reliability which is shown in Figure 2.6.

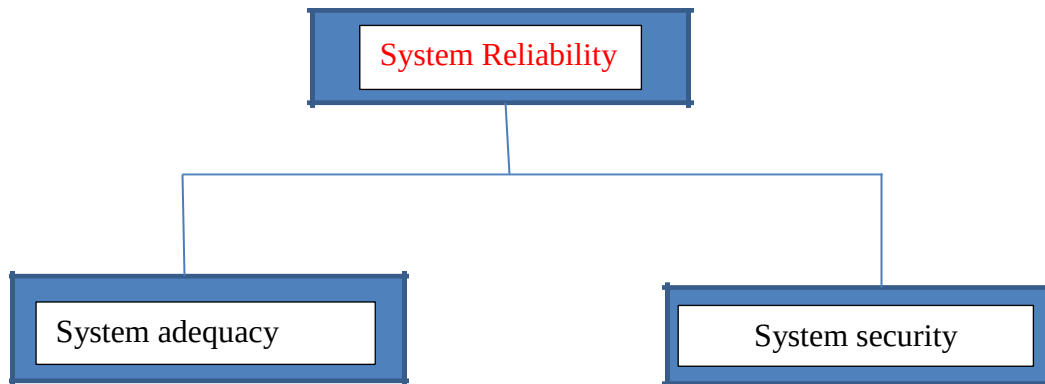


Fig 2.6: System Reliability Subdivisions [13]

**Adequacy:** Relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include

- ❖ The facilities necessary to generate sufficient energy and
- ❖ The associated transmission and distribution facilities required to transport the energy to the actual consumer load points.

**Security:** Relates to the ability of the system response to disturbances arising within that system. Security is therefore associated with the response of the system to whatever perturbations it is subject to [33].

## 2.5. Reliability Indices for Distribution system

To measure system performance, the electric utility industry has developed several performance measures of reliability. These reliability indices include measures of outage duration, frequency of outages, system availability, and response time.

A common way of defining reliability is in terms of

1. customer-oriented indices and
2. Energy or load-oriented indices.

### 2.5.1. Customer-Oriented Indices

These indices are directly related to customers. Some of these indices are listed below.

### 1. System Average Interruption Duration Index (SAIDI)

The most often used performance measurement for a sustained interruption is the System Average Interruption Duration Index (SAIDI). This index measures total duration of interruption, for the average customer during a given time period. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period. The formula is

$$SAIDI = \frac{\sum(r_i * N_i)}{NT} \dots\dots\dots 2.1$$

Where,

$r_i$  = Restoration time, minutes.

$N_i$  = Total number of customers interrupted

$NT$  = Total number of customers served

### 2. Customer Average Interruption Duration Index (CAIDI)

Once an outage occurs, the average time to restore service is found from Customer Average Interruption Duration Index (CAIDI). CAIDI is calculated similar to SAIDI except that the denominator is the number of customers interrupted versus the total number of utility customers. CAIDI is,

$$CAIDI = \frac{\sum(r_i * N_i)}{\sum N_i} \dots\dots\dots 2.2$$

Where

$r_i$  = Restoration time, minutes.

$N_i$  = Total number of customers interrupted

### 3. System Average Interruption Frequency Index (SAIFI)

The System Average Interruption Frequency Index (SAIFI) is the average number of times that a system customer experiences an outage during the year (or time period under study) and it is a dimensionless number.

$$SAIFI = \sum\left(\frac{N_i}{N_T}\right) ; \quad \text{or} \quad SAIFI = \frac{SAIDI}{CAIDI} \dots\dots\dots 2.3$$

$N_i$  = Total number of customers interrupted

$N_T$  = Total number of customers

SAIFI can also be found by dividing the SAIDI value by the CAIDI value,

#### 4. Customer Average Interruption Frequency Index (CAIFI)

Similar to SAIFI is CAIFI, which is the Customer Average Interruption Frequency Index. The CAIFI measures the average number of interruptions per customer interrupted per year. The CAIFI is,

$$\text{CAIFI} = \frac{\sum N_0}{\sum N_i} \dots\dots\dots 2.4$$

Where

$N_0$  = Number of interruptions

$N_i$  = Total number of customers interrupted

#### 5. Customer Interrupted per Interruption Index (CIII)

Customer Interrupted per Interruption Index (CIII) gives the average number of customers interrupted during an outage.

It is the reciprocal of the CAIFI and is,

$$\text{CIII} = \frac{\sum N_i}{\sum N_0} \dots\dots\dots 2.5$$

Where

$N_0$  = Number of interruptions

$N_i$  = Total number of customers interrupted

#### 6. Average Service Availability Index (ASAI)

The Average Service Availability Index (ASAI) is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes called the service reliability index. The ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. The ASAI is found as,

$$\text{ASAI} = \left[ 1 - \sum \left[ \frac{N_i \cdot r_i}{NT \cdot T} \right] \right] \dots\dots\dots 2.6$$

Where,

T = Time period under study, hours.

$r_i$  = Restoration time, hours

$N_i$  = Total number of customers interrupted

NT = Total number of customers served

In this calculation, the restoration time,  $r_i$ , is in hours instead of minutes.

Another way of looking at ASAI on an annual basis is,

$$ASAI = \left[ \frac{8760 - SAIDI}{8760} \right] \times 100\% \dots\dots\dots 2.7$$

## 2.5.2. Load or Energy-Oriented Indices

### 1. Total energy not supplied (ENS)

The ENS (Total energy not supplied) is the sum of each load times its outage duration:

$$ENS = L \times r_i (kwh / yr) \dots\dots\dots 2.8$$

Where

$L$  = Load (KW)

$r_i$  = Outage Duration

### 2. Average Energy Not Supplied (AENS)

AENS (Average Energy Not Supplied) can be calculated by dividing the ENS and the total number of customers:

$$AENS = \frac{\text{Total Energy not supplied (kWh/ customer yr)}}{\text{Number of customers}} \dots\dots\dots 2.9$$

**Note:** A customer here is defined as an electric meter, which can be an individual customer, a commercial entity or organization etc.

## 2.6. Factors Affecting Voltage Drop and Power Loss of Distribution Feeders

Voltage deviation and loss of the distribution feeders are increasing in distribution network due to various factors. Some of them are listed below [14].

**A. Poor jointing and termination:** poor jointing and termination on the distribution networks are resulted from loose contact; there will be high opposition to current flow which generates heat at that point. This lead to an increase in resistance and subsequently result to voltage drop at that point.

**B. Use of undersized conductors:** voltage can be considered as the pressure pushing charges along a conductor, while resistance of the conductor is a measure of how difficult it is to push the charges along. The small size conductors have high resistance consequently large voltage drop.

- C. Use of different types of conductor material:** corrosion is an important factor to be considered in the selection of conductor materials. The two types of corrosion which exhibit greatest influence on the electrical properties of a metal are oxidation and galvanic corrosion. Galvanic corrosion, which is caused by the difference in electrical potential between two or more metals, has to be given careful consideration when selecting conductor materials
- D. Hot spots:** whenever a mechanically joint or termination is made, high resistance point is created. Thus, the joint or termination will undergo a progressive failure. High resistance creates localized heating and since heating increases oxidation and creep, the connection become less tight and further heating occurs, until the contact tends glow.
- E. Loads on the main feeder:** the currents in a feeder segment along the distribution feeder are function of the loads connected to the downstream portion of the feeder. Although the current will not affect the feeder impedance, it does affect voltage deviation [14].
- F. Length of distribution feeder:** the series impedance of a feeder is linearly proportional to the length of the feeder. Therefore, the length of the feeder has a significant effect on voltage deviation.
- G. Phase imbalance:** a network which does not have its load evenly distributed across all three phases will have higher currents in at least one phase meaning it is not optimized for losses [6]. There will also be currents flowing in the neutral conductors if they are present. Therefore, due to the quadratic dependence of losses on current, this load imbalance across the three phases will increase losses.
- H. Harmonics:** harmonic effects are essentially distortions to an AC current profile. They can occur in transformer windings because the AC magnetizing current is not perfectly sinusoidal. However, this usually occurs on the triple harmonics (3<sup>rd</sup>, 6<sup>th</sup>, 9<sup>th</sup>). So, on normal three phase system they are all in phase and do not result in any real harmonics. However, if other equipment connected to the network produces harmonics they will not cancel in the neutral conductor. Therefore, these can cause additional loss the distribution system.

- I. Power factor:** the power factor is the ratio of real power to apparent power. For two power factor systems distributing the same amount of real power, the system with the lower power factor will have the higher reactive power current which should cause the higher voltage drop and produce the higher loss.
- J. Rated capacity of substation transformer:** the variance of node voltage along the feeder can be lessened by increasing the rated capacity of their feeding substation transformer. The larger the transformer capacity has minimum voltage variation effect on the system. However, one of the major disadvantages for increasing rated capacity of substation transformer is the rise in the short-circuit fault current level on the secondary side of a substation transformer.
- K. Location of distribution transformer:** in appropriate location of distribution transformer may leads to energy loss in the distribution system. The farthest consumer will get an extremely low voltage as compared to the consumer nearer to distribution transformer.

## **2.7.Distribution Network Power Loss and Voltage Drop Minimization Techniques**

There are different techniques to reduce loss and voltage deviation of a distribution feeder. Some of the power loss and voltage drop reduction techniques are: network reconfiguration, network re conducting (conductor grading), distribution transformer locating and sizing, reactive power compensation, using highly efficient transformer, using high voltage distribution system, using distributed generation and building new substation. The power loss and voltage drop reduction techniques have been discussed in the following section.

- A. Network Reconfiguration:** Network reconfiguration is the process of operating switches to change the circuit topology so that operating costs are reduced while satisfying the specified constraints [15].

Network reconfiguration is one of the possible methods in distribution system for reducing loss in which the power flow is altered by the formation of new links with a feeder to form tree structure or by opening or closing the appropriate switches on the feeder. Feeder reconfiguration allows the transfer of loads from heavily-loaded feeders to relatively lightly-loaded feeders and form higher-resistance routs to lower resistance routs to obtain the least loss, where the resistance route is the total resistance from the source to the load

point. Such transfers are effective not only in terms of altering the level of loads on the feeder being switched, and reducing the losses, but also in improving the voltage profile along the feeders and affecting reductions in the overall system power losses [16].

But feeder reconfiguration is effective if distribution feeders are automated and not far apart to each other. For un automated and far apart feeders, feeder reconfiguration may not be cost effective.

**B. Conductor Grading:** Conductor grading is the technique of replacing the existing conductor on the feeder by conductor of optimal size for optimal (in terms of cost) length of feeder to reduce the resistance. This can be achieved by replacing the small size conductors with a larger cross-sectional area, or by installing auxiliary conductors to work in parallel with the existing ones. So that the equivalent resistance is reduced. Although these methods could give a large loss reduction, it is not cost effective, and it is not used unless there is a special need, as the cost of conductors and their installation are usually in excess of the cost of the energy saved [16].

This technique is used when existing conductor is no more optimal because of rapid growth of load [17]. This technique is also good for the developing countries where annual Population (energy demand) growth rates are high and the conductors are chosen to minimize power loss and voltage drop of the distribution system.

**C. Distribution Transformer Locating and Sizing:** If distribution transformers are not located centrally with respect to consumers, the farthest consumers will obtain extremely low voltage even though a reasonably good voltage level is maintained at secondary of transformer.

This leads to higher losses in distribution system. So, distribution transformers should be located nearer to the load center as possible and replace large transformers by the transformers of small rating such that it serves small number of consumers so that optimum voltage level is maintained.

**D. Reactive Power Compensation:** Reactive power compensation is defined as the management of reactive power to improve the performance of ac power system.

The beer mug analogy [18] is useful to understand the theory of reactive power compensation. If the mug capacity is the apparent power (kVA) that we can transmit through a system, then the foam is the reactive power (kVAr) and the beer is the real

power (kw). If we use capacitors to provide the foam (KVA<sub>r</sub>) when we drink the beer, then we free up mug capacity so you don't have to buy a bigger mug and/or so you can pay less for your beer.

The benefits of reactive power compensation in the transmission and distribution system include [19]: voltage profile improvement, increase power flow capacity (by decreasing feeder impedance), increase system capacity (the distribution system capacity can be increased by controlling reactive power flow using capacitors) and reduce power losses.

In general, reactive power compensation is an important method to improve voltage profile and loss of a distribution network if the size and location has done optimally.

- E. Using Highly Efficient Transformers:** The use of highly efficient transformers will reduce losses of the distribution system. Like amorphous core transformers which have high magnetic susceptibility and high electrical resistance. The high resistance in transformers leads to low losses by eddy currents.
- F. High Voltage Distribution System:** Using high voltage distribution system will reduce the loss and voltage deviation of the distribution system. This technique aims extending high voltage lines as nearer to the load as possible and replacing large transformers with various small rating transformers. Also, conversion of existing low voltage distribution systems to high voltage distribution system is done. This technique is most effective and efficient in reducing the technical losses and improving the power quality in distribution system. Because the current is low in high voltage system. But the initial investment cost is very high for this reason it may not be feasible.

### **2.8.Reactive Power and voltage drop in distribution System**

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

- ❖ distributed generation,
- ❖ FACT devices,

- ❖ Dis-connector or section opening ,
- ❖ Developing of load sharing.

For the analysis of these problems, most researchers use different algorithms and software. Reactive power compensation mainly refers to the effective use of reactive power compensation devices and equipment. In order to obtain the required reactive power, it reduces the energy consumption of grid operation and promote the power system effectively improve the power factor, and ultimately improved grid voltage quality goals [20]. An effective way to improve the power factor is to take the appropriate means of reactive power compensation. Researcher T.Xu, P.C. Taylor use distributed generation as power loss minimization mechanisms by implementing the DG for reactive power reduction by increasing the real or active power that leads to improve the voltage regulation[21].

The voltage drop along a distribution feeder can be calculated in two methods [22]:

#### **Approximate Method**

$$V_{drop} = |V_S - V_R| = I \cdot R \cdot \cos\theta + I \cdot X \cdot \sin\theta \dots\dots\dots 2.10$$

Where

$V_{drop}$  = Voltage drop, line-to-neutral, V

$V_R$  = Receiving end voltage, V

$V_S$  = Source voltage, line-to-neutral, V

$I$  = Line (Load) current, A

$R$  = Circuit (branch, feeder) resistance,

$X$  = Circuit (branch, feeder) reactance,

$\cos\theta$  = Power factor of load, decimal

$\sin\theta$  = Reactive factor of load, decimal

$\theta$  = angle between the voltage and the current

#### **Exact Method 1**

- i. **If sending end voltage and load PF are known.**

$$v_{drop} = |V_S| + IR \cos\theta + IX \sin\theta - \sqrt{V_S^2 - (IX \cos\theta - IR \sin\theta)^2} \dots\dots\dots 2.11$$

Where:-

$V_{drop}$  = Voltage drop, line-to-neutral, V

$V_S$  = Source voltage, line-to-neutral, V

I = Line (Load) current, A

R = Circuit (branch, feeder) resistance,

X = Circuit (branch, feeder) reactance,

Cosθ = Power factor of load, decimal

Sinθ = Reactive factor of load, decimal

θ = angle between the voltage and the current

**ii. If the receiving end voltage, load current and power factor (PF) are known.**

$$V_{drop} = (V_R * \cos\theta + I_R)^2 + \sqrt{(V_R * \sin\theta + I_x)^2} \dots\dots\dots 2.12$$

**Exact Method 2**

If receiving or sending MVA and its power factor are known at a known sending or receiving voltage.

$$V_s^2 = V_R^2 + \frac{(Z * MVA_R)^2}{V_R^2} + 2 * Z * MVA_R * \cos(\gamma - \theta_R) \dots\dots\dots 2.13$$

or

$$V_R^2 = V_s^2 + \frac{(Z * MVA_s)^2}{V_s^2} + 2 * Z * MVA_s * \cos((\gamma - \theta_s)) \dots\dots\dots 2.14$$

Where:

V<sub>R</sub> = Receiving line-line voltage in kV

V<sub>S</sub> = Sending line-line voltage in kV

MVA<sub>R</sub> = Receiving three-phase, MVA

MVA<sub>S</sub> = Sending three-phase, MVA

Z = Impedance between sending and receiving ends

γ = the angle of impedance Z

θ<sub>R</sub> = Receiving end PF ; θ<sub>S</sub> = Sending end PF, positive when lagging

In electric power distribution system, voltage drop depends upon numerous factors. The type and nature of conductor, the size of conductor and the length of circuit are the few out of many. The supply conductor, if not of reasonable size, will cause excessive voltage drop in an electrical circuit. The voltage drop is in direct proportion to the circuit length. Proper starting and running of motors, lighting equipment, and other loads having inrush currents should be considered. The NEC recommends that the steady-state voltage

drop in power, heating, or lighting feeder be no more than 3%, and the total drop including feeders and branch circuits be no more than 5% overall.

Poor performance of equipment's, overheating; nuisance tripping of over current protective devices and excessive burnouts are the sign of unsatisfactory voltage at customer's terminals. When the voltage at the terminals of utilizing equipment deviates from the value of nameplate of electrical appliances, the performance and the operating life of the equipment is affected. The effect may be minor or prominent depending on the characteristics of the equipment and amount of the voltage drop deviation from the nameplate rating. Generally performance conforms to the utilization voltage limits specified in American National Standard Institute (ANSI) but it may vary for specific items of voltage sensitive equipment [23].

## **2.9. Reactive Power Control**

### **2.9.1. Elements of System that Produces and Absorbs Reactive Power**

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

Underground cables: owing to their high capacitance, have high natural loads. They are always loaded below their natural loads, and hence generate reactive power under all operating conditions. Overhead line: depending on the load current either absorb or supply reactive power. At loads below the natural load, the lines produce net reactive power. On the contrary, at loads above natural load lines absorb reactive power [24].

### **2.9.2. Importance of Reactive Power**

Voltage control in an electrical power system is important for proper operation of electrical power equipment to prevent damage by overheating, to reduce transmission losses and to maintain the ability of the system to prevent voltage collapse. In general terms, decreasing reactive power causes voltage to fall while increasing it causing voltage to rise. A voltage collapse occurs when the system try to serve much more load than the voltage can support. When reactive power supply is lower in a lower voltage condition, as voltage drops current

must increase to maintain power supplied, causing system to consume more reactive power and the voltage drops further. If the current increases too much, transmission lines go off line, overloading other lines and potentially causing cascading failures. If the voltage drops too low, some generators will disconnect automatically to protect themselves. Voltage collapse occurs when an increase in load or less generation or transmission facilities causes dropping voltage, which causes a further reduction in reactive power from capacitor and line charging, and still there further voltage reductions. If voltage reduction continues, these will cause additional elements to trip, leading further reduction in voltage and loss of the load. The result in these entire progressive and uncontrollable declines in voltage is that the system unable to provide the reactive power required supplying the reactive power demand [25].

### **2.9.3. Problems of Reactive Power**

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

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

In an electrical power system, balanced reactive power is the carrier of the true power. If it is Consumed, the voltage decreases, and hence its ability to transport the true power decreases. So, reactive power in power system is required to deliver the active power through transmission lines, and to produce magnetic fields in Electric motors and transformers for their operation. If the reactive power of the system is not sufficient to support the terminal voltage of bus terminals, it can be supported using shunt reactive compensation system, so that, the reactive power which has to come from the system is to be provided by the compensation system and therefore the main equipment of the power system which were forced to deliver the reactive power to the load are getting relaxed and utilized the reactivity for their own operation. The Shunt reactive compensation can modify the parameters of the system to give enhanced VAR compensation [26].

It can do quite satisfactorily job of generating reactive power with a faster time response and come under Flexible AC Transmission Systems (FACTS). This allows an increase in transfer of apparent power through a transmission line, and much better stability by the adjustment of parameters that govern the power system i.e. current, voltage, phase angle, frequency and impedance. Unnecessary voltage drops lead to increased losses which needs to be supplied by the source and in turn leading to outages in the line due to increased stress on the system to carry this imaginary power. Thus we can infer that the compensation of reactive power not only mitigates all these effects but also helps in better transient response to faults and disturbances. In recent times there has been an increased focus on the techniques used for the compensation and with better devices included in the technology, the compensation is made more effective. The terminal voltage at bus bar of the substations is influenced by loading [27].

#### **2.9.4. Reactive Power in Operations**

Reactive power affects power system operation in numerous ways:

- ❖ Loads consume reactive power, so this must be provided by some source.
- ❖ The delivery system (transmission lines and transformers) consumes reactive power, so this must be provided by some source (even if the loads do not consume reactive power). Note however that all transmission lines do provide some reactive power from their shunt line charging which offsets their consumption of reactive power in their series line losses.

- ❖ The flow of reactive power from the supplies to the sinks causes additional heating of the lines and voltage drops in the network.
- ❖ The generation of reactive power can limit the generation of real power.

So, one primary dilemma with reactive power is that a sufficient quantity of it is needed to provide the loads and losses in the network, but having too much reactive power flowing around in the network causes excess heating and undesirable voltage drops. The normal answer to this dilemma is to provide reactive power sources exactly at the location where the reactive power is consumed. And, since strictly speaking it does not take any fuel to provide reactive power, it should be possible to distribute reactive power sources (such as capacitors) all around the network to avoid the problem of heating the conductors and causing voltage drops [27].

Unfortunately, this is not practical in the extreme since there are literally millions of lines and loads connected to the grid and so this would require millions of reactive power sources which controlled to provide exactly the right amount of reactive power at the right time in every second of every day. The best we can do in most cases is work with some type of aggregation of load at the terminal of feeder leaving a substation and at terminals of major lines and transformers. This also brings up the issue of the difference between power factor control (trying to exactly provide the right amount of reactive power needed to equal that which is consumed) and voltage control (trying to keep voltage levels at exactly the right level no matter how much reactive power it takes).

Reactive power is both the problem and the solution to network voltage control. There are many authors and researchers who have worked voltage and reactive power control for power loss minimization using different techniques [28].

## **2.10. Capacitor Placement for Loss Reduction and Voltage Profile**

### **2.10.1. Voltage Profile Improvement**

Capacitors have been very commonly used to provide reactive power compensation in distribution systems. Also, capacitors have been provided to minimize power and energy loss and to maintain the voltage profile within the acceptable limits. The amount of compensation provided is very much linked to the placement of capacitors in the distribution system, which is essentially determination of the location, size, number and

type of capacitors to be placed in the system. The capacitor placement problem is a well-researched topic and has been addressed by many authors in the past [28].

### 2.10.2. Concept of fixed and switched capacitors

Fixed and switched capacitors play a large role in line-loss reduction and voltage-profile improvement because they depend on the optimal reactive power flow that is controlled by fixed and switched capacitors. The use of fixed and on/off switched capacitors provides considerable reduction in power losses and improvement in the voltage profile when the capacitors are controlled to respond to daily, weekly, or seasonal changes in feeder reactive loads [29]. The power factor during off-peak hours is normally high; therefore, heavy capacitor compensation may lead to over-voltage problems during this time. This situation poses certain limitations regarding capacitor compensation and hence leads to the concept of fixed and switched capacitor applications. The minimum size of capacitors connected at all load levels can be considered as fixed capacitors, and others are considered as switched capacitors[30].

### 2.10.3. Capacitor Operating Mode

**Fixed mode** – the capacitor is permanently put in service and is only taken out of service during either planned or unplanned maintenance.

**Switched mode** – the capacitor is only put in service when needed or during predefined times. Switched banks require a switch and control circuit/ device, which makes it more costly compared to the fixed bank.

#### Capacitor Voltage Limit

After knowing the capacitance value in micro Farads, the standard capacitor bank rating can be determined using the following expression:

$$KVar_{perphase} = \frac{2\pi f C V^2}{1000} \dots\dots\dots 2.14$$

Where:  $f$  is the grid frequency in Hertz (Hz),  $C$  is the capacitance in micro Farads (F) and  $V$  is the network voltage where the capacitor is connected in (kV)

The above formula indicates that the relationship between the voltage applied across the capacitor bank and the reactive power produced by the Capacitor. Let ignore the variation of the frequency on the grid and therefore assume that  $f$  and  $C$  are constant, there is a parabolic relationship between the Capacitor MVARs and the system kV, i.e. as the voltage varies, the VAr output of the capacitor varies by a voltage squared factor. It is because of

this mathematical relationship that Capacitors need to be switched into service shortly before the network voltages are depressed due to the rising load profile [31].

### 2.11. Installation of capacitor bank to distribution feeder

Shunt capacitor are connected in parallel with the primary distribution feeder of a system .distribution capacitors can be **pole mounted or pad mounted**.

**Pole mounted capacitor** are the least expensive way for providing the reactive power from the point of view of installation.

Pad mounted capacitors are used where the power distribution circuit is placed underground. The disadvantage of this kind of capacitors can be the big size and aesthetics.

In the figure 2.7: and figure 2.8: below an example of installed pole mounted and pad mounted capacitors bank in distribution system are shown.



Fig 2.7: A pole-mounted capacitor bank with switch (photo credit: Power cap Capacitors Pvt. Ltd)



Fig 2.8: Custom pad mounted capacitor bank (photo credit: Scott Manufacturing and Engineering Power cap Capacitors Pvt. Ltd)

The figure above shows that the Rear View of customer pad mounted capacitor bank (Including Capacitor Control, Current Sensors, a Transformer Capacitor Switches and Fuses)

## 2.12. Literature Review on Power Loss and Voltage Drop reduction of a Distribution System

Different researchers have proposed different ways for solving the problem of voltage drop and power loss in distribution systems.

In [32] the author proposed feeder reconfiguration with addition of new distribution transformer for reduction of voltage drop and distribution loss. In this method, the loss and voltage drop are reduced to some extent but the cost of the added transformers and tie switches is not considered. The payback period may be very large due to the cost of transformers. Therefore, it may not cost effective.

In [33] the author studied impact of distributed generation (diesel generator, wind turbine and photovoltaic) on distribution networks' voltage profile and power loss. He used NEPLAN software and the extended Newton Raphson method in the analysis. He concludes that different types of DG influence the distribution network differently and their precise location and size are vital in reducing power losses and improving the

voltage stability. But he did not consider the intermittent nature of the loads and the wind turbine.

In [34] the author studied effects of distribution generation on distribution loss and voltage profile. Voltage stability index-based approach is used to identify the candidate buses. The author tried to show distribution losses are reduced and voltage profile is improved more by type 2 DG (generating both real and reactive power) than type 1 DG (generating real power only). The objective functions has not written clearly and not include voltage deviation, he did not use optimizing tool, feasibility issue of the type of DG did not considered and during candidate bus selection loss sensitivity index was not used.

In [35] the author presented a GA-IPSO based approach which utilizes combined sensitivity factor analogy to locate and size multi-type DG in IEEE 57-bus test system .with the aim of reducing power loss and improving voltage profile. The author showed that the system power loss and voltage drop is reduced with the introduction of DGs in to the network up to an optimal number where any further DG inclusion resulted to an increase in system loss and voltage deviation outside the acceptable limits. Even though, the loss and voltage drop are reduced, the effect of DG on the protection coordination, the type of DG and feasibility issue have not considered yet.

In [36], the author proposed capacitor placement with feeder reconfiguration to reduce distribution loss and voltage deviation. The author showed that by using DlgSILENT simulation tools, capacitor placement with feeder reconfiguration improve the loss and voltage drop of the distribution system. But the cost of tie switches and the separation distance between each feeder have not considered. This has significant impact on the initial investment cost of the suggested solution.

In [37], the author studied the improvement of voltage profile of radial distribution system by capacitor placement using plant growth simulation algorithm. Loss sensitivity factor is used to identify the candidate buses then plant growth simulation algorithm is used to select the size of the capacitors. The author tested his solution on IEEE 9 bus system and got a considerable voltage profile improvement. The author assumed a constant load model but in reality, the distribution load is variable. Switchable type capacitors are not also considered. If the compensating capacitor is not switchable type, the voltage rise problem may be occurred during off peak periods.

## **CHAPTER THREE**

### **DATA COLLECTION AND ANALYSIS**

#### **3.1. DATA COLLECTION**

The required data from Adama distribution substation regarding distribution network are collected from respective office of Adama district distribution maintenance and operation office and also from Adama substation work unit section. The collected data are a recorded data that includes peak load, type of faults, frequency and duration of interruption of all medium voltage (15kV) outgoing feeders of the distribution system. The collected data is a recorded data of two consecutive years from 2018 to 2020G.C.

Adama substation has 11 outgoing feeders, around 80MW peak load, it provides electric supply for about 55,772 customers with different tariff categories such as industrial, commercial and residential. Currently there is one dedicated outgoing feeder line that for industrial park. The collected data for Adama town Substation are shown in Table 3.1. The frequency of interruption and duration of interruption for the Adama town distribution network for 24 Months are analyzed and interpreted as shown in Tables 3.2 and 3.3 and Figures 3.1 and 3.2 respectively.

#### **3.2. Description of the study area**

Adama city had electric supply dated back to 1929 E.C which was generated from diesel generator After Awash river has been dammed in three places in the vicinity of Adama city ,the city was supplied with power generated from the nearby domestic hydropower plants of koka Dam and connected with national interconnected electric transmission lines , since 1963 E.C. And currently renewable energy that is wind power currently supply to Adama substation.

Adama that situated in strategic position of along the vibrant transport corridor that leads to the eastern and southeastern parts of the country was established beneath of kechema ridge as a railways station in 1916 E.c At a distance of 99 k m via old road and now 84.7 km via express ways from southeast of addis abeba in economically and geographically strategic position at the junction of major routes to addis abeba ,Arsi,Harar and other areas of economic importance.

Table 3.1: Socio economic profile of Adama city 2019

| <b>Types of industries</b>                    | <b>Quantity in number</b> |
|-----------------------------------------------|---------------------------|
| <b>1. Agro processing</b>                     | <b>67</b>                 |
| <b>2. Chemicals</b>                           | <b>5</b>                  |
| <b>3. Metal ;plastic and wood engineering</b> | <b>66</b>                 |
| <b>4. Textile</b>                             | <b>6</b>                  |

Industrial Development Park is also on the verge of launching its product. Thus this indicates there is high demand of electric power for such industries and micro enterprises.

Adama 132kV distribution substation is one of the existing substation in the EEP power system network that are found in the oromiya region of the country and the power supply is coming from koka substation through 1x132kV transmission line. In this substation it has two 132/15 KV, 2\*25MVA transformers and mobile substation one 132/15 KV, 50 MVA transformer. The 15kV side has five (5) (L1.L3.L4.L5.L7) out-going feeders and also the 15kV sides have six (6)(M1.M2.M3.M4.M5.M6) outgoing feeders.

At Adama and surrounding area there is industry zone which has a big contribution on earning of foreign currency for the country. The government has a plan to expand the industry zone around the area and the high demand together with the small and large scale industries power demand increases from the last two consecutive years on ward according to the power service sector reports on 2011 E.C due to this facts the load growth of the area will be high in near future.

Table 3.2: Overview of Adama substation Incoming transmission lines to Adama substation

| No. | Voltage (kV) | From          | To    | Assumed Conductor Type | Tower Configuration | Line Rating (MVA) | Length (KM) |
|-----|--------------|---------------|-------|------------------------|---------------------|-------------------|-------------|
| 1   | 132          | Koka          | Adama | Tiger                  | Single              | 100               | 13.2        |
| 2   | 230          | Awash         | Adama | Tiger                  | Single              | 100               | 35          |
| 3   | 132          | Adama wind G. | adama | Tiger                  | single              | 50                | 7           |

Table 3.3: Transmission line parameter

|                      |                  | Transmission Line parameter |                   |        |        |               |        |        |                   |                        |    |
|----------------------|------------------|-----------------------------|-------------------|--------|--------|---------------|--------|--------|-------------------|------------------------|----|
| Voltage<br>e<br>(KV) | From             | To                          | Positive Sequence |        |        | Zero Sequence |        |        | Current<br>rating | power<br>deli.capacity |    |
|                      |                  |                             | R                 | X      | B      | R0            | X0     | B0     |                   | MVA                    | MW |
|                      |                  |                             | Ω/km              | Ω/km   | μS/km  | Ω/km          | Ω/km   | μS/km  |                   |                        |    |
| 132                  | koka             | adama                       | 0.2132            | 0.4265 | 2.7015 | 0.4777        | 1.1958 | 1.6615 | 438               | 100                    | 80 |
| 230                  | awash            | adama                       | 0.3158            | 0.5681 | 3.8501 | 0.7166        | 1.7937 | 2.4923 | 251               | 100                    | 80 |
| 132                  | adama<br>wind G. | adama                       | 0.2390            | 0.4781 | 3.0284 | 0.5355        | 1.3405 | 1.8625 | 219               | 50                     | 40 |

Table 3.4: Power transformer data of Adama substation

| No | Voltage (KV) | Location                | Transformer Parameter |             |             |             |             |             |                  |                 |                 |                  |
|----|--------------|-------------------------|-----------------------|-------------|-------------|-------------|-------------|-------------|------------------|-----------------|-----------------|------------------|
|    |              |                         | W1 - 2R (%)           | W1 - 2X (%) | W2 - 3R (%) | W2 - 3X (%) | W3 - 1R (%) | W3 - 1X (%) | W1 - 2 MVA based | W2 - 3MVA based | W3 - 1MVA based | RATING 1/2/3 MVA |
| 1  | 132/15       | Adama Power T1          | 0.82                  | 10.1        | 2.5         | 7.1         | 0.78        | 15          | 8                | 8               | 8               | 2*8/8/8          |
| 2  | 132/15       | Adama Power T2          | 0.82                  | 10.1        | 2.5         | 7.1         | 0.78        | 15          | 8                | 8               | 8               | 2*8/8/8          |
| 3  | 132/15       | adama Mobile substation | 0.52                  | 10.5        | 0.41        | 8.2         | 0.3         | 6.1         | 20               | 12              | 8               | 2*20/12/8        |

Where: W1-2R; W1-2X; per winding percentage reactance and resistance value written on the Nameplate of power transformer and three winding power transformer per winding MVA value.

Table 3.5: The no of customer and transformer data in each outgoing feeder of Adama substation

| Feeder Name  | No of customer | average active power | Average reactive power | Adama Distribution transformer Capacity in (KVA) |           |            |            |            |          |          |          |          |          |          |
|--------------|----------------|----------------------|------------------------|--------------------------------------------------|-----------|------------|------------|------------|----------|----------|----------|----------|----------|----------|
|              |                |                      |                        | 25                                               | 50        | 100        | 200        | 315        | 500      | 630      | 800      | 1250     | 3000     | 8000     |
| Line-1       | 6,542          | 10.4295              | 8.0260                 | 1                                                | 1         | 2          | 4          | 2          | 1        | 1        | 1        | 2        |          |          |
| Line-2       | 2,896          | 4.5581               | 3.4642                 | 9                                                | 8         | 11         | 15         | 20         |          |          | 1        |          |          |          |
| Line-3       | 12,227         | 7.5055               | 6.0795                 | 13                                               | 9         | 19         | 21         | 7          |          |          |          |          |          |          |
| Line-4       | 6,221          | 7.7860               | 5.2945                 | 8                                                | 10        | 14         | 12         | 19         |          |          |          |          |          |          |
| Line-5       | 3,325          | 4.3279               | 2.5535                 |                                                  |           |            |            |            |          | 1        |          |          |          | 1        |
| Line-6       | 4,290          | 3.7389               | 2.5799                 | 7                                                | 7         | 16         | 4          | 11         |          | 2        |          |          | 1        |          |
| Line-7       | 6,757          | 9.6263               | 6.4496                 | 9                                                | 5         | 15         | 9          | 11         | 1        | 2        |          |          | 1        |          |
| Line-8       | 2,896          | 3.8964               | 2.2209                 | 8                                                | 14        | 9          | 15         | 20         |          |          |          |          |          |          |
| Line-9       | 2,681          | 2.8976               | 2.2312                 | 7                                                | 5         | 17         | 5          | 11         |          |          | 2        | 2        |          |          |
| Line-10      | 3,861          | 9.2905               | 4.4594                 | 9                                                | 15        | 8          | 20         |            |          | 1        |          | 2        | 1        |          |
| Line-11      | 4,076          | 8.0325               | 4.3376                 | 8                                                | 16        | 12         | 15         | 15         | 1        |          |          |          |          |          |
| <b>Total</b> | <b>55,772</b>  | <b>72</b>            | <b>48</b>              | <b>79</b>                                        | <b>90</b> | <b>123</b> | <b>120</b> | <b>116</b> | <b>3</b> | <b>7</b> | <b>4</b> | <b>6</b> | <b>3</b> | <b>1</b> |

Table 3.6: Overhead MV conductor Data

| No | Conductor type | Nominal Area (mm <sup>2</sup> ) | Actual Area (mm <sup>2</sup> ) | Stranding and wire Diameter | overall Diameter (mm) | Actual Diameter | GMR (mm) | Resistance (u/km) |
|----|----------------|---------------------------------|--------------------------------|-----------------------------|-----------------------|-----------------|----------|-------------------|
| 1  | AAC            | 50                              | 49.48                          | 7/3.00                      | 9                     | 7.9377          | 2.88     | 0.5786            |
| 2  | AAC            | 95                              | 93.27                          | 19/2.5                      | 12.5                  | 10.8975         | 4.129    | 0.3084            |

### 3.3. Reliability of distribution network

The term reliability in the utility context usually refers to the amount of time end users are totally without power for an extended period of time (i.e., a sustained interruption). Definitions of what constitutes a sustained interruption vary among utilities in the range of 1 to 5 min. This is what many utilities refer to as an “outage.” Current power quality standards efforts are leaning toward calling any interruption of power for longer than 1 min, a sustained interruption. In any case, reliability is affected by the permanent faults on the system that must be repaired before service can be restored.

Types of voltage Disturbances in distribution system

- ❖ Long-Duration Voltage Variations
- ❖ Short-Duration Voltage Variations
  - A. Long-Duration Voltage Variations

When the rms value of voltage deviates for duration more than 1 minute, it is termed as long duration voltage variation. This condition occurs due to Load variations, System switching operation in distribution substation.

It may be categorized into following types.

1. Over Voltage: An overvoltage is an increase in the rms ac voltage greater than 110 percent at the power frequency for duration longer than 1 min.

(a) Overvoltage is usually the result of load switching (e.g., switching off a large load or energizing a capacitor bank).

(b) Incorrect tap settings on transformers can also result in system over voltages.

2. Under Voltage: An under voltage is a decrease in terms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min. This condition occurs due to a load switching on or a capacitor bank switching off.

3. Sustained Interruptions: excess of 1 min, the interruption.

When the supply voltage becomes zero for a period of time in long-duration voltage variation is considered a sustained

#### **A. Short-Duration Voltage Variations**

When the rms value of voltage deviates for duration less than 1 minute, it is termed as long duration voltage variation. Each type of variation can be designated as instantaneous, momentary, or temporary, depending on its duration.

It may be categorized into following types.

1. **Interruption:** An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min. Such Interruptions can be the result of power system faults, equipment failures, and control malfunctions.

2. **Voltage Sags (dips):** Voltage sags are probably the most problematic of all power quality problems. At this time, a number of standards-making bodies, including IEEE, ANSI, and IEC, are working on standards related to voltage sags. In most cases, sags are generally agreed to be more severe and outside of the scope of ANSI C84.1 and they are temporary in nature due to the operation of system protection elements. Because the electrical system is a continuous electrical circuit, faults in any location will have some impact on voltages throughout the network. Of course, areas closer to the faulted area will see a greater voltage sag due to the fault than other, more (electrically) remote areas. Sags can originate anywhere in a system, but are more pronounced in utility distribution systems because of the greater exposure of low-voltage

systems to the causes of short circuits. Voltage sag occurs when the RMS voltage value decreases over a limited time period before it settles and returns to its average value. There are several types of sags including the following (Caramia et al., 2009):

- ❖ Instantaneous sags lasting typically from 0.5 cycles to 30 cycles,
- ❖ Momentary sags that can last 30 cycles to 3 s, and
- ❖ Temporary sags that last 3 s to 1 min.

If the sag lasts for more than a minute, it is then classified as an **under voltage**. Voltage sag is generally caused by a short circuit fault or by a sudden change in the characteristics of a power source or a load such as the case during a large motor starting in industries. If the voltage does sag, some equipment may not be supplied by the amount of voltage they require and their performance may be affected (Kusko and Thompson, 2007). Voltage sags are the most common power quality problem that is “given” to the customer of electric utility company of adama district.

### 3. Voltage Swells

A voltage swell refers to the case when the RMS voltage increases during a time period before it comes back to its average value. Similar to the sag events, several swell types have been identified:

- ❖ Instantaneous swells lasting from 0.5 cycles to 30 cycles,
- ❖ Momentary swells that can last 30 cycles to 3 s, and
- ❖ Temporary swells that last 3 s to 1 min.

Again, if the swell lasts for more than a minute it is then classified as an overvoltage event. Voltage swells occur mostly due to faults in the electrical distribution systems. It is also occurring from temporary voltage rise on the not faulted phases during Single Line Ground fault. Swells can also be caused by switching off a large load. They do not occur as often as voltage sags, but they can cause more damage to select devices that are sensitive to higher voltages than their rating levels (Kusko and Thompson, 2007).

#### **A. Detection of voltage sag—downstream event restored after 1.2 s**

This is a very common type of event observed in adama distribution network where the likely cause is a short circuit due to a dry tree branch falling on a distribution feeder causing a temporary short circuit. The branch might fall on the ground by itself or burn due to the short

circuit, thus clearing the fault in the next reclosure (if there is a trip event, which is not the case in this particular event); also, the protection relay may survive the overcurrent for the said period (as per the protection logic) and normalcy will thus be restored after 1.2 s

### **B. Equipment Sensitivity to Voltage Sags**

The equipment's within an end user facility that are sensitive to voltage sags are very dependent on specific load type, control settings, and applications.

The most commonly used characteristics are the duration and magnitude of the sag.

Generally, equipment sensitivity to voltage sags can be divided into following three categories:

**1. Equipment sensitive to only the magnitude of voltage sag:** Devices in this group are sensitive to the minimum (or maximum) voltage magnitude experienced during a sag (or swell). This group includes devices such as under-voltage relays, process controls, motor drive controls, and many types of automated machines (e.g., semiconductor manufacturing equipment). The duration of the disturbance is usually of secondary importance for these devices.

**2. Equipment sensitive to both the magnitude and duration of a voltage Sag:** This group includes all equipment that uses electronic power supplies. Such equipment not properly operates or fails when the power supply output voltage drops below specified values. Thus, the important characteristic for this type of equipment is the duration that the rms voltage is below a specified threshold at which the equipment trips.

**3. Equipment sensitive to characteristics other than magnitude and Duration:** Some devices are affected by other sag characteristics such as the phase unbalance during the sag event, the point-in-the wave at which the sag is initiated, or any transient oscillations occurring during the disturbance. These characteristics are more subtle than magnitude and duration, and their impacts are much more difficult to generalize. As a result, the rms variation performance indices defined here are focused on the more common magnitude and duration characteristics.

For end users with sensitive processes, the voltage sag ride-through capability is usually the most important characteristic to consider.

### **Fault-Induced Voltage Sags**

The majority of voltage sags are caused by faults on the power systems and the subsequent operations of protective devices. Consider a customer that is supplied from the feeder supplied

by circuit breaker. If there is a fault on the same feeder, the customer will experience voltage sag during the fault followed by an interruption when the breaker opens to clear the fault. If the fault is temporary in nature, a reclosing operation on the breaker should be successful and the interruption will only be temporary. It will usually require about 5 or 6 cycles for the breaker to operate, during which time a voltage sag occurs. The breaker will remain open for typically a minimum of 12 cycles up to 5 s depending on utility reclosing practices. Sensitive equipment will almost surely trip during this interruption.

A much more common event would be a fault on one of the other feeders from the substation, that is, a fault is on a parallel feeder, or a fault somewhere on the transmission system. In either of these cases, the customer will experience voltage sag during the period that the fault is actually on the system. As soon as breakers open to clear the fault, normal voltage will be restored at the customer. In case of two lines supplying the distribution substation and only one has a fault. Therefore, customers supplied from the substation should expect to see only voltage sag and not an interruption. The distribution fault on the other feeder may be cleared either by the lateral fuse or the breaker, depending on the utility fuse saving practice. Any of these fault locations can cause equipment not properly operate in customer facilities.

### **3.4. Reliability assessment of Adama distribution network**

The analytical method uses mathematical solutions to evaluate mathematical models; this technique has been used for many years. In this approach, the impact to all load points due to each component failure will be considered as well as the average failure rate of the component. Then, the interruption frequency and duration at each load point is calculated to eventually calculate the system reliability indices such as SAIFI and SAIDI [38]. When calculations are performed, the mean values are the results produced and they represent the reliability indices, which prove to be very useful however, that does not give a realistic picture. The reliability indices are in fact variable [39]; therefore, it is beneficial to be able to look at its distribution. The probability distribution offers a way for the variations in the reliability indices to be shown.

Table 3.7: Adama substation medium voltage line (15 kv ) outgoing feeders frequency and duration of interruption data for the year 2018 to 2019 G.C

| No.   | Feeder Name | Ferquency and duration of MV line interruption of adama substaion outgoing feeders for the year from 2018 - 2019 G.C |          |      |          |      |        |      |        |      |        |     |         |            |        | Frequenc y Of Intrrupti on(No.) | Duration Of Intrrupti on (Hr.) |
|-------|-------------|----------------------------------------------------------------------------------------------------------------------|----------|------|----------|------|--------|------|--------|------|--------|-----|---------|------------|--------|---------------------------------|--------------------------------|
|       |             | DPEF                                                                                                                 |          | DPSC |          | DTEF |        | DTSC |        | DLOL |        | OP  |         | SOL (LDC ) |        |                                 |                                |
|       |             | F                                                                                                                    | D(Hr)    | F    | D(Hr)    | F    | D(Hr)  | F    | D(Hr)  | F    | D(Hr)  | F   | D(Hr)   | F          | D(Hr)  |                                 |                                |
| 1     | LINE1       | 61                                                                                                                   | 155.8323 | 59   | 186.4146 | 17   | 7.4249 | 8    | 3.4997 | 32   | 79     | 15  | 73.3316 | 2.6        | 10.4   | 205.6                           | 415.9031                       |
| 2     | LINE3       | 12                                                                                                                   | 43.67    | 8    | 11.58    | 11   | 3.33   | 4    | 5.80   | 9    | 21.00  | 25  | 25.67   | 2          | 5.60   | 74                              | 103.65                         |
| 3     | LINE4       | 8                                                                                                                    | 29.91    | 28   | 62.08    | 9    | 1.42   | 7    | 4.33   | 8    | 24.44  | 18  | 28.92   | 5          | 11.85  | 108                             | 177.76                         |
| 4     | LINE5       | 17                                                                                                                   | 23.42    | 24   | 67.58    | 38   | 6.25   | 7    | 7.17   | 2    | 5.44   | 23  | 29.67   | 1          | 1.45   | 113                             | 142.78                         |
| 5     | LINE7       | 17                                                                                                                   | 28.58    | 32   | 81.92    | 18   | 3.35   | 5    | 1.25   | 10   | 39.50  | 16  | 46.00   | 3          | 10.53  | 114                             | 224.30                         |
| 6     | MOBILE1     | 62                                                                                                                   | 105.00   | 33   | 79.75    | 26   | 12.17  | 9    | 3.17   | 10   | 42.13  | 13  | 60.33   | 3          | 11.23  | 189                             | 327.81                         |
| 7     | MOBILE2     | 39                                                                                                                   | 110.33   | 48   | 179.83   | 15   | 7.02   | 4    | 10.92  | 6    | 33.75  | 13  | 42.58   | 2          | 9.00   | 169                             | 404.68                         |
| 8     | MOBILE3     | 43                                                                                                                   | 101.08   | 37   | 113.92   | 22   | 23.67  | 2    | 1.67   | 9    | 38.25  | 14  | 63.75   | 2          | 10.20  | 172                             | 365.28                         |
| 9     | MOBILE4     | 34                                                                                                                   | 173.16   | 40   | 90.17    | 20   | 9.75   | 3    | 0.50   | 5    | 22.25  | 13  | 47.58   | 5          | 11.27  | 159                             | 388.76                         |
| 10    | MOBILE5     | 27                                                                                                                   | 74.67    | 16   | 56.83    | 11   | 4.75   | 1    | 0.17   | 7    | 37.31  | 14  | 81.50   | 2          | 9.95   | 120                             | 277.61                         |
| 11    | MOBILE6     | 19                                                                                                                   | 42.58    | 7    | 28.42    | 15   | 5.17   | 1    | 0.42   | 7    | 36.37  | 18  | 27.50   | 2          | 9.70   | 71                              | 162.28                         |
| TOTAL |             | 339                                                                                                                  | 888.23   | 332  | 958.48   | 202  | 84.29  | 51   | 38.88  | 104  | 379.44 | 182 | 526.82  | 28         | 101.18 | 1493                            | 2990.80                        |

For the above table Feeder that interruption due to line over loaded exhibited mainly on feeder -1 (Line – 1 ) this implies that there is also voltage drop on this distribution feeder line . More clearly seen on the figure below .more over this data of frequency and duration of interruption shows low performance of the distribution network as a result the power quality , reliability and availability of electric supply on the year of 2018 – 2019 G.C have a worse performance .

| Types of fault          | DPEF  | DPSC   | DTEF  | DTSC  | DLOL  | OP    | SOL (LDC) |
|-------------------------|-------|--------|-------|-------|-------|-------|-----------|
| Maximum value           | 61    | 59     | 38    | 9     | 32    | 25    | 5         |
| Frequency Minimum value | 8     | 7      | 9     | 1     | 2     | 13    | 1         |
| Maximum value           | 155.8 | 186.71 | 23.67 | 10.92 | 79.00 | 73.33 | 11.85     |
| Duration Minimum value  | 23.42 | 11.58  | 1.42  | 0.5   | 5.44  | 25.67 | 5.60      |

This assessment interruption duration due to distribution permanent earth fault (DPEF) is highest compared to the other types of fault and distribution line overload(DLOL) shows a significant amount that indicates the redundant occurrence of overload condition especially for Line feeder -1.

## Ferquency and duration of MV line interruption of adama substaion outgoing feeders for the year from 2018 - 2019 G.C

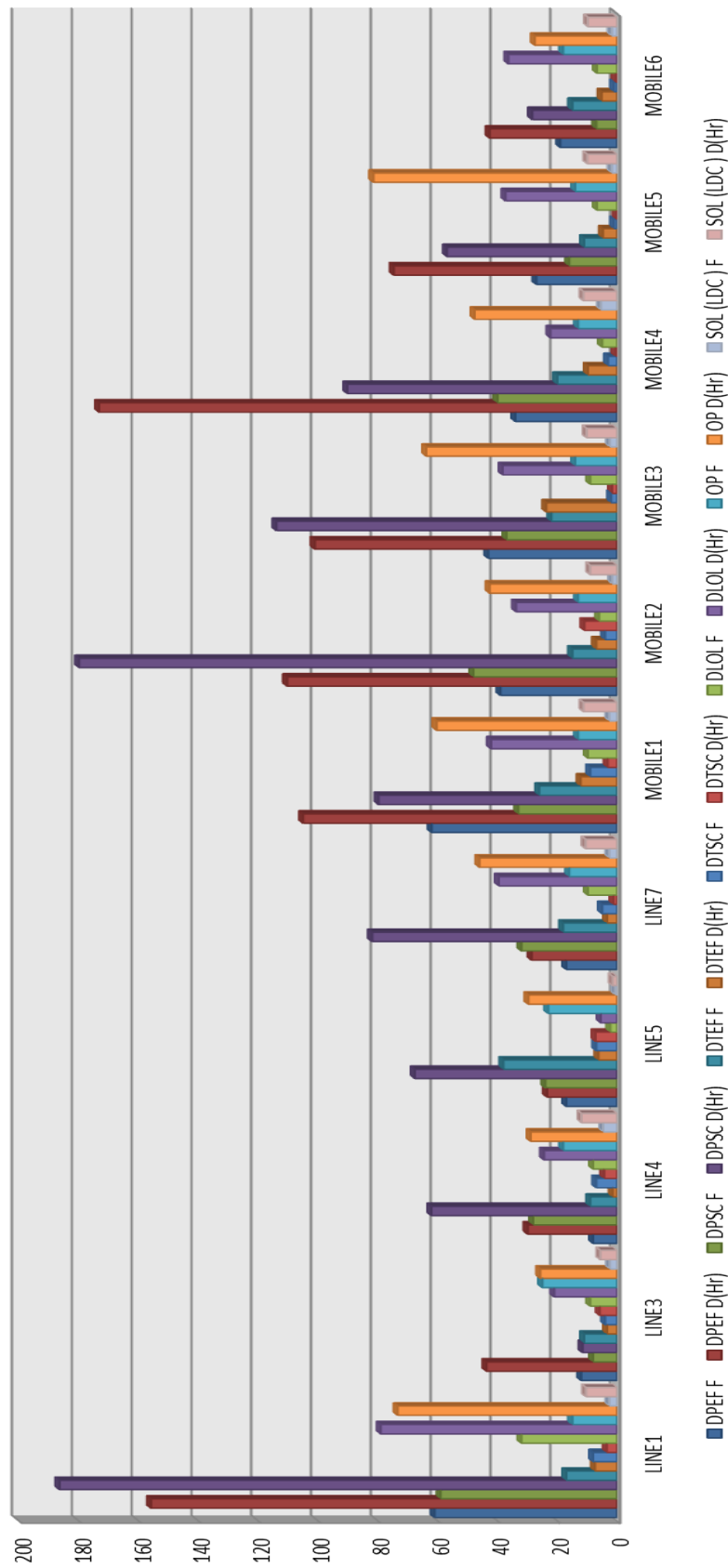


Fig 3.1: Adama distribution network frequency and duration of interruption based on fault type of the year 2018-2019 G.C

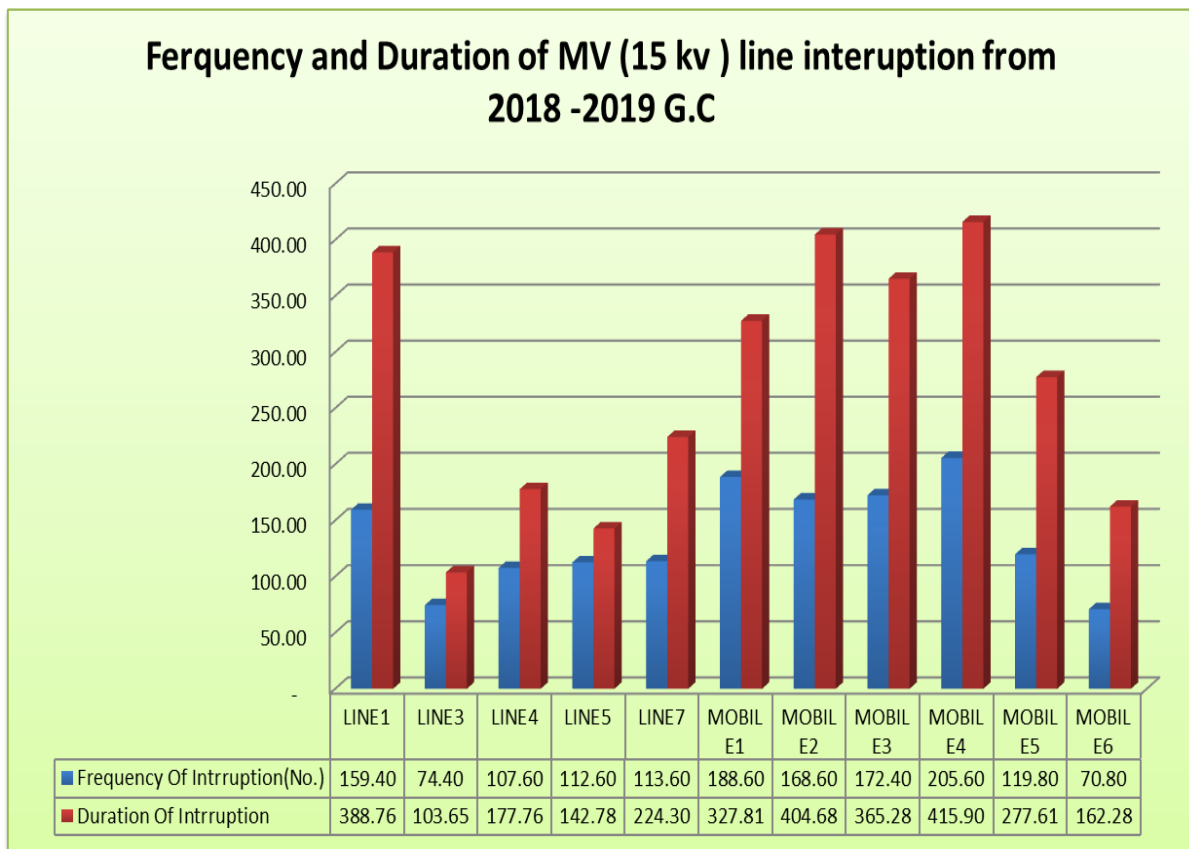


Fig 3.2: Frequency and duration of interruption on Adama substation of MV line (15kv) outgoing feeder for the year of 2018 – 2019 G.C

The Figure above shows that the yearly majority of frequency interruption and duration of interruption falls is distribution Permanent short circuit faults ( DPSCF) that is mainly occurred due to Line to Line contact of mv line and it contributes the major fault for the stated year respectively. So the main contributors for this outage ranked accordingly

1. Distribution Permanent short circuit faults ( DPSCF)
2. Distribution Permanent Earth faults ( DPEF)
3. Distribution line over load ( DLOL)
4. Distribution operational work (DOP)

From the figure 3.2: the highest frequency of interruption occurred on the M-4 line which is 202.60 and the lowest value happened on the line no M- 6 .this means that preventive maintenance and rehabilitation work and planed interruption is properly done on line no M-6.

And also line no 1 ranked five as compared to the rest distribution feeders that need to be focused and different mitigation measure should need to be taken by respective office.

Table 3.8: Frequency and duration of Adama substation outgoing MV line feeder for the year of 2019 – 2020 G.C

| Item No. | Feeder Name | Frequency and Duration of Interruption for the year of 2019 -2020G.C |         |      |         |      |         |      |         |      |         |          |         |     |         | Frequency Of Interruption | Duration Of Interruption |
|----------|-------------|----------------------------------------------------------------------|---------|------|---------|------|---------|------|---------|------|---------|----------|---------|-----|---------|---------------------------|--------------------------|
|          |             | DPEF                                                                 |         | DPSC |         | DTEF |         | DTSC |         | DLOL |         | SOL(LDC) |         | OP  |         |                           |                          |
|          |             | F                                                                    | D [Hr.] | F    | D [Hr.] | F    | D [Hr.] | F    | D [Hr.] | F    | D [Hr.] | F        | D [Hr.] | F   | D [Hr.] | F                         | D(Hr)                    |
| 1        | LINE1       | 3                                                                    | 2.67    | 5    | 8.33    | 2    | 0.58    | 7    | 2.5     | 25   | 21.083  | 1.6      | 3       | 26  | 28.347  | 120                       | 163.798                  |
| 2        | LINE3       | 7                                                                    | 9.38    | 2    | 1.167   | 9    | 2.434   | 2    | 2.75    | 14   | 34.499  | 3.2      | 5.28    | 7   | 13.586  | 41                        | 63.816                   |
| 3        | LINE4       | 3                                                                    | 2.917   | 23   | 48.414  | 8    | 1.67    | 18   | 6.346   | 20   | 27.917  | 2.2      | 6.12    | 15  | 14.247  | 87                        | 101.511                  |
| 4        | LINE5       | 6                                                                    | 30.33   | 1    | 1.667   | 18   | 2.103   | 1    | 0.083   | 10   | 23.583  | 4        | 6.86    | 15  | 30.084  | 51                        | 87.85                    |
| 5        | LINE7       | 3                                                                    | 2.67    | 5    | 8.33    | 2    | 0.58    | 7    | 2.517   | 13   | 22.918  | 1.6      | 2.63    | 22  | 37.873  | 52                        | 74.888                   |
| 6        | MOBILE1     | 42                                                                   | 133.717 | 7    | 13.33   | 46   | 15.667  | 1    | 0.12    | 12   | 29.084  | 5.4      | 7.79    | 16  | 45.999  | 124                       | 237.917                  |
| 7        | MOBILE2     | 17                                                                   | 47.303  | 51   | 122.915 | 11   | 4.331   | 1    | 0.42    | 10   | 26.501  | 1.4      | 0.84    | 37  | 31.666  | 127                       | 233.136                  |
| 8        | MOBILE3     | 30                                                                   | 70.484  | 24   | 58.08   | 14   | 4.836   | 6    | 2.5     | 13   | 28.918  | 3.8      | 6.5     | 27  | 27.87   | 114                       | 192.688                  |
| 9        | MOBILE4     | 22                                                                   | 77.464  | 39   | 151.933 | 16   | 5.17    | 2    | 2.087   | 10   | 25.001  | 5.4      | 10.88   | 32  | 27.83   | 121                       | 289.485                  |
| 10       | MOBILE5     | 4                                                                    | 8.584   | 6    | 18.193  | 2    | 0.83    | 0    | 0       | 9    | 31.837  | 2        | 5       | 37  | 36.167  | 58                        | 95.611                   |
| 11       | MOBILE6     | 23                                                                   | 44.283  | 30   | 53.753  | 23   | 15.166  | 3    | 1.166   | 15   | 31.167  | 3        | 8       | 15  | 85.9497 | 23                        | 117.1167                 |
| Total    |             | 160                                                                  | 429.80  | 193  | 486.11  | 151  | 53.37   | 48   | 20.49   | 151  | 302.51  | 33.6     | 62.90   | 249 | 379.62  | 918.00                    | 1,657.82                 |

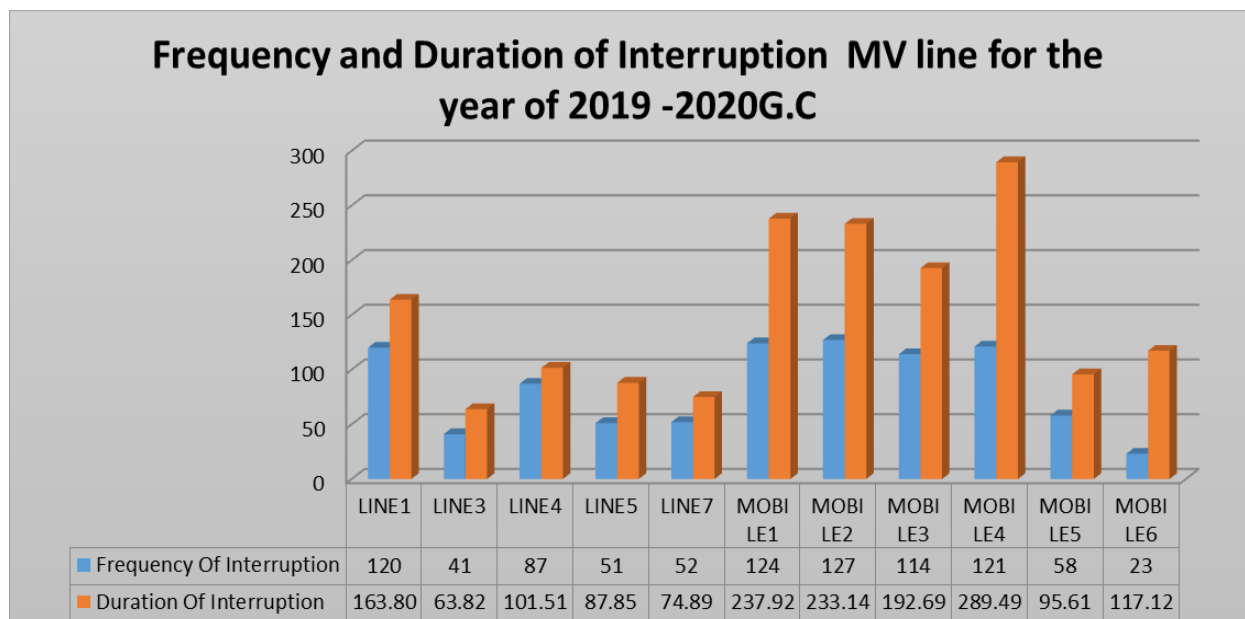


Fig 3.3: Adama distribution feeder frequency and duration of interruption for the year 2019-2020G.C

Even though there is a progress in some feeder regarding the data of the frequency and duration of interruption 2019 -2020 G.C compared to that of 2018-2019 G.C the reliability of power supplies are very low that no significant improvement is performed by the respective Adama district electric utilities office .such as preventive maintenance, load balancing, network

upgrading, upgrading of distribution transformer based on the identified loaded distribution transformer.

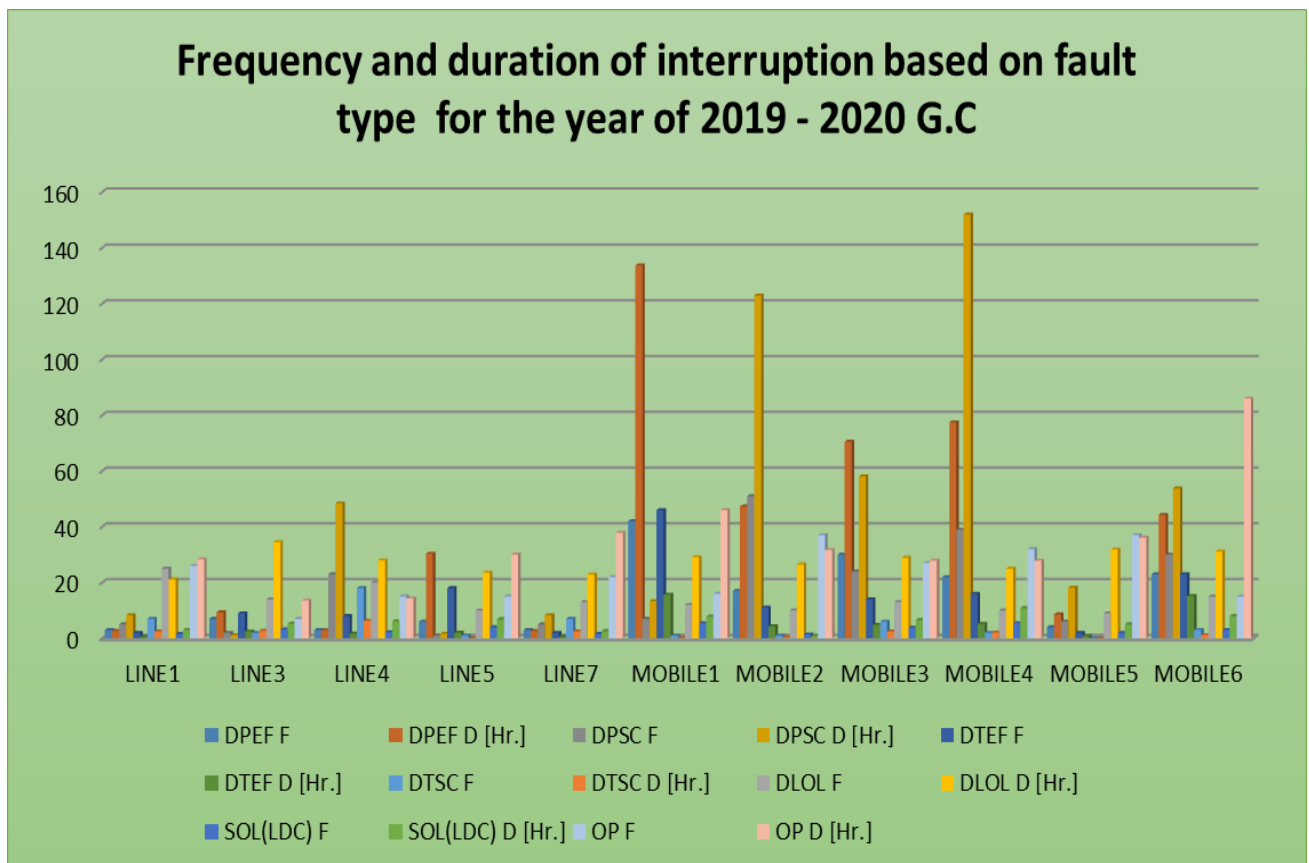


Fig 3.4: Frequency and duration of interruption on Adama substation of MV line (15kv) outgoing feeder based on fault type for the year of 2019 – 2020 G.C

The Figure above shows that the yearly majority of frequency interruption and duration of interruption falls is distribution Permanent short circuit faults (DPSCF) that is mainly occurred due to Line to Line contact of mv line and it contributes the major fault for the stated year respectively. So the main contributors for this outage ranked accordingly

1. Distribution Permanent short circuit faults ( DPSCF)
2. Distribution Permanent Earth faults ( DPEF)
3. Distribution line over load ( DLOL)

The other forced measured interruption like System over load in case of the interruption is done from direct order of the Ethiopian electric utility load dispatch center (LDC) respective work units to down size the maximum load which among the eleven feeders have carried. The

interruption for operational purposed is done through planned schedule based on the demand for new connection and for maintenance activities.

Table 3.9: Adama distribution outgoing feeders frequency and duration of interruption data of the year from 2018-2020G.C

|                                           |  |  |  |  | Year (G.C) |         |            |         |
|-------------------------------------------|--|--|--|--|------------|---------|------------|---------|
|                                           |  |  |  |  | 2018-2019  |         | 2019 -2020 |         |
|                                           |  |  |  |  | F          | D(Hr)   | F          | D(H)    |
| Distribution faults                       |  |  |  |  |            |         |            |         |
| Permanent short circuit faults ( DPSCF)   |  |  |  |  | 319        | 815.23  | 160        | 429.8   |
| Permanent Earth faults ( DPEF)            |  |  |  |  | 323        | 918.48  | 193        | 486.11  |
| Temporarily Earth faults ( DTEF)          |  |  |  |  | 202        | 84.29   | 151        | 53.37   |
| Temporarily short circuit faults ( DTSCF) |  |  |  |  | 51         | 53.37   | 48         | 20.49   |
| Distribution line over load ( DLOL)       |  |  |  |  | 107        | 38.88   | 151        | 303     |
| Total                                     |  |  |  |  | 1002       | 1910.25 | 703        | 1292.28 |
| Other forced measure out                  |  |  |  |  |            |         |            |         |
| Operation                                 |  |  |  |  | 182        | 379.44  | 168        | 62.9    |
| System Over Load (LDC)                    |  |  |  |  | 36         | 101.18  | 28         | 379.63  |
| Grand Total                               |  |  |  |  | 218        | 480.62  | 196        | 442.53  |
| Grand Total                               |  |  |  |  | 1220       | 2390.87 | 899        | 1734.81 |
| (% ) of distribution Faults               |  |  |  |  | 82.13%     | 79.90%  | 78.20%     | 74.49%  |
| (% ) Other Forced measure outage          |  |  |  |  | 58.71%     | 57.80%  | 21.80%     | 25.51%  |

From the analysis, it is observed that majority (82.13 %) of the faults in Adama distribution network are due to short circuit, earth fault and over load. The remaining faults are due to black out, operation and system over load (when generated power is below the total demand other than black out).

Generally from the result of the data of the interruption frequency and duration of Adama substation MV feeder outgoing line.

1. In the case of forced measure of interruption, for operational duties and planned interruption for new connection purposes result shows even though it has more significant impact on the interruption frequency and duration time, the rate of an additional new load introduced in the network is increased based on the interruption.
2. Distribution line overload shows that it has a significantly impact on interruption data therefore it is an indication of over load in Adama distribution network which results voltage drop on the networks.

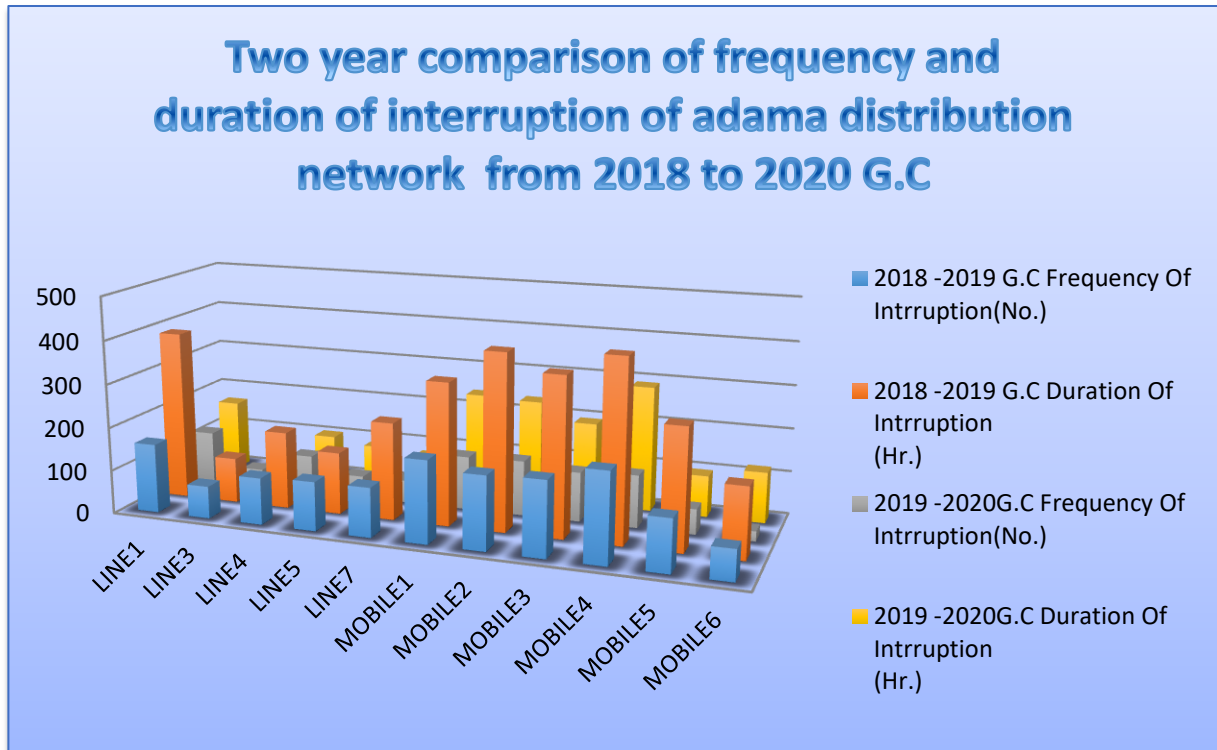


Fig 3.5: two year data of interruption regarding frequency and duration of Adama distribution network from 2018 -2020G.C

From the above figurative explanation it is clear that there is a few progress is seen in frequency of and duration of interruption of Adama distribution network. if plan preventive maintenance , trimming of trees, load balancing ;rehabilitation of distribution line and designed base upgrading of distribution transformer all this duties are done based on the area identified then the reliability ;availability and quality of electric supply will be enhanced.

### 3.5.Reliability Indices Evaluation of Adama Distribution network

As one object of this thesis work is to investigate under voltage problems of Adama distribution network using a more adopted method for determining distribution network reliability, this part of the thesis work used IEEE1366 indices to evaluate the reliability indices of Adama distribution system. The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers (15kV). The reliability is highly affected by outages occurred on the customer side secondary distribution lines which unable to collect data for analysis due to lack of resource, lack of organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network. The causes occurred on the secondary sides of customer transformers

that may affect the service reliability of the feeders. Reliability analysis and calculations for the Adama distribution system had been done using equation 2.1 -2.5 for the indices (such as SAIFI, SAIDI, CAIDI, and ASAI) and tabulated as follow

Table 3.10: Reliability indices of Adama substation outgoing feeders

| Feeder Name | SAIFI            |                  | SAIDI            |                  | CAIDI            |                  | ASAI             |                  | ASUI             |                  |
|-------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|------------------|
|             | 2018-2019<br>G.C | 2019-2020<br>G.C | 2018-2019<br>G.C | 2019-2020<br>G.C | 2018-2019<br>G.C | 2019-2020<br>G.C | 2018-2019<br>G.C | 2019-2020<br>G.C | 2018-2019<br>G.C | 2019-2020<br>G.C |
| LINE1       | 7.30             | 6.79             | 504.04           | 448.60           | 75.45            | 68.66            | 99.43            | 99.23            | 1.15             | 1.12             |
| LINE3       | 2.74             | 2.55             | 261.48           | 232.72           | 72.38            | 65.87            | 99.70            | 99.50            | 0.60             | 0.58             |
| LINE4       | 4.23             | 3.93             | 379.47           | 337.73           | 77.86            | 70.85            | 99.57            | 99.37            | 0.87             | 0.84             |
| LINE5       | 0.42             | 0.39             | 39.21            | 34.90            | 27.32            | 24.86            | 99.96            | 99.76            | 0.09             | 0.09             |
| LINE7       | 4.21             | 3.92             | 343.44           | 305.66           | 60.35            | 54.92            | 99.61            | 99.41            | 0.78             | 0.76             |
| MOBILE1     | 0.90             | 0.84             | 70.23            | 62.51            | 20.27            | 18.45            | 99.92            | 99.72            | 0.16             | 0.16             |
| MOBILE2     | 1.32             | 1.22             | 149.28           | 132.86           | 25.67            | 23.36            | 99.83            | 99.63            | 0.34             | 0.33             |
| MOBILE3     | 6.15             | 5.72             | 294.42           | 262.03           | 48.53            | 44.16            | 99.60            | 99.40            | 0.81             | 0.79             |
| MOBILE4     | 1.24             | 1.15             | 90.65            | 80.68            | 14.20            | 12.92            | 99.90            | 99.70            | 0.21             | 0.20             |
| MOBILE5     | 3.55             | 3.30             | 257.38           | 229.06           | 37.70            | 34.30            | 99.71            | 99.51            | 0.59             | 0.57             |
| MOBILE6     | 4.90             | 4.55             | 463.00           | 412.07           | 58.66            | 53.38            | 99.47            | 99.27            | 1.06             | 1.03             |

### 3.6.Comparison of Reliability Indices with Benchmarks

Reliability benchmarks are the standards against which analyzed or measured reliability is judged. The purposes of reliability benchmarks are to define minimum average reliability performance, by feeder type, for a distribution network and provide a basis against which a distribution network service provider’s reliability performance can be assessed.

The benchmarks were calculated using the IEEE Guide for electric power distribution reliability indices – IEEE Standard 1366-2012. Reliability analysis and calculations for the Adama distribution system had been done for the indices (such as SAIFI, SAIDI, CAIDI, and ASAI) using the equation 2.1-2.5.

A benchmark of SAIDI, CAIDI, SAIFI and ASAI for nine countries is shown in Table 3.11. From the calculation and analysis considered in reliability evaluation of Adama distribution system feeder 01 has an average value of SAIDI=504.04 minutes, SAIFI=7.3 interruptions/customer, CAIDI=75.45 minutes and ASAI=99.43%. A lower number for SAIDI, SAIFI and CAIDI index indicates better reliability performance; i.e., a lower frequency

of outages or shorter outage duration. A higher SAIDI, SAIFI and CAIDI index number indicates worse performance. Compare the average SAIDI, SAIFI, CAIDI and ASAI value of feeder of Adama distribution with the benchmarks shows that has worse performance.

Table 3.11: Benchmarks for Reliability Indices

| No | Country             |         | SAIDI        | SAIFI                    | CAIDI          | ASAI    |
|----|---------------------|---------|--------------|--------------------------|----------------|---------|
|    |                     |         | (Hours/year) | (Interruptions/Customer) | (Hours/outage) | (%)     |
| 1  | United States       |         | 4            | 1.5                      | 2.05           | 99.91   |
| 2  | Austria             |         | 1.2          | 0.9                      | 1.866          | 99.97   |
| 3  | Denmark             |         | 0.4          | 0.5                      | 1.166          | 99.981  |
| 4  | France              |         | 1.03         | 1                        | 0.966          | 99.97   |
| 5  | Germany             |         | 0.383        | 0.5                      | 0.833          | 99.9999 |
| 6  | Italy               |         | 0.966        | 2.2                      | 1.767          | 99.9991 |
| 7  | Netherlands         |         | 0.55         | 0.3                      | 1.25           | 99.97   |
| 8  | Spain               |         | 1.733        | 2.2                      | 1.90           | 99.968  |
| 9  | UK                  |         | 1.5          | 0.8                      | 1.67           | 99.964  |
| 10 | Adama<br>(Ethiopia) | Line -1 | 333.54       | 2.105                    | 42.26          | 99.24   |
|    |                     | Line -3 | 220.85       | 1.17                     | 61.13          | 99.495  |
|    |                     | Line -4 | 168.515      | 0.61                     | 34.575         | 99.615  |
|    |                     | Line -5 | 19.55        | 0.11                     | 13.625         | 99.96   |
|    |                     | Line -7 | 147.49       | 0.9                      | 25.915         | 99.66   |
|    |                     | M - 1   | 274.5        | 3.45                     | 41.09          | 99.375  |
|    |                     | M - 2   | 88.385       | 0.58                     | 15.2           | 99.795  |
|    |                     | M - 3   | 211.165      | 2.87                     | 28.835         | 99.52   |
|    |                     | M - 4   | 69.37        | 0.64                     | 10.865         | 99.84   |
|    |                     | M - 5   | 171.445      | 1.765                    | 25.11          | 99.61   |
|    |                     | M - 6   | 50.58        | 0.35                     | 14.16          | 99.89   |

A typical customer expects to have a power at all times. In reality a utility will be able to make power available between 99.9 and 99.999 percent of the time. To put it in another way, the average customer may be dissatisfied if there is no electricity for more than for less than an hour

in a year. (Source: APPA distribution system reliability and operations survey report, by Alex Hofmann, Nov 2018, published by American Public power association).

Outgoing Feeder 1 (L- 1) of adama substation has a deviation of 0.504% . Consequently, customers experienced life without electricity on average for about 5 hours per month

### **3.7. Modeling of Adama distribution network in ETAP software**

The above collected data is analyzed quantitatively and qualitatively using ETAPs software for load flow analysis and capacitor placement. ETAP software performs power flow analysis and voltage drop calculations with accurate and reliable result. Built-in features like automatic equipment evaluation, alerts and warnings summary, load flow result analyzer, and intelligent graphics make it the most efficient electrical power flow analysis tool available today.

ETAP load flow calculation program calculate bus voltages, brunch power factors, currents and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with unlimited power grids generator calculations. This load flow calculation software is capable of performing analysis on both radial and loop systems. ETAP allows to select from several different load flow calculation methods in order to achieve the most efficient and accurate results.

The modeling and simulation of this work is done based on real and valid data which represents real condition of the network ETAP is used to perform the load flow analysis. They are fully integrated suite of electrical software applications that provides intelligent power monitoring, energy management, optimal power flow.

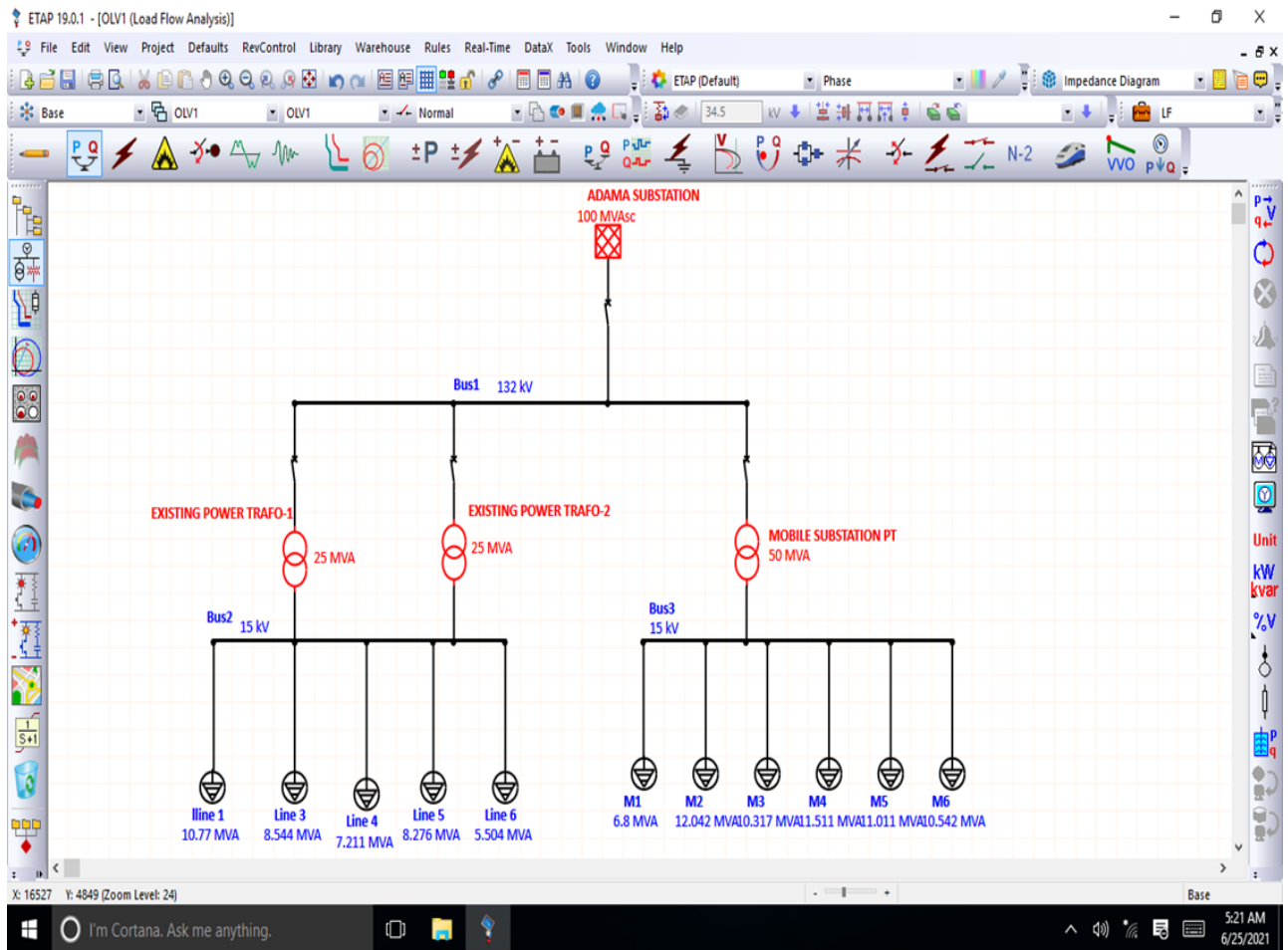


Fig 3.6: Modeling of Adama substation outgoing feeder

### 3.4. Load Flow Analysis of Adama distribution feeder 01

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

The main areas for the application of load flow calculations are: Calculation of branch loadings, voltage profiles for system planning and operation at normal conditions and compares with a system after introducing capacitor bank.

Under normal operating conditions the feed power as well as the loads is known, and it is therefore sufficient for the load flow calculation to represent these in feed power and to provide the active and reactive power of all loads. The results of the load flow calculation should represent a system condition in which none of the branch or generator limits are exceeded. The calculation methods and the options provided by ETAPs load flow analysis function allow the

accurate representation of any 3-phase AC systems. For very fast and reliable analysis of complex networks, only the flow of active and reactive power through the branches and voltage profile at bus bar of the system is considered.

As a general concept, ETAPs software is implemented as a single executable program. The programming method employed allows for a fast 'walk around' the execution environment, and eliminates the need to reload modules and update or transfer results between different program applications. As an example, the power flow, fault analysis, and harmonic load flow analysis tools can be executed sequentially without resetting the program, enabling additional software modules and engines or reading external data files.

These thesis works aimed at solving this problem by proposing optimize capacitor bank location and size while considering both real and reactive power losses. Both real and reactive power flow and power loss sensitivity factors were utilized in identifying the candidate buses for capacitor bank allocation. This reduced the search space for the algorithm and thus increased its rate of convergence [40].

### **3.5. Modeling of Distribution network components**

In power engineering, the load flow of a power network provides the steady state solution through which various parameters of interest like currents, voltages and losses can be calculated. The load flow study is an important part of distribution systems analysis and it is used in operational as well as planning stages. Many real time applications in the distribution automation system such as networks optimization, reactive power planning, switching, state estimation and so forth, need the support of a robust and efficient power flow method. Such a power flow solution method must be able to model the special features of distribution system [41].

Modeling of system elements and distribution load flow analysis are discussed in section. Power distribution system is the heart of power system, it constitutes of major portion of any power system. Distribution systems are mostly radial or near radial in structure, multi-phase, unbalanced, grounded or ungrounded operation. It has a larger R/X ratio, Distributed load are mostly unbalanced. It consists of large number of nodes and branches.

Power distribution network plays the role of providing energy to end users connected at low or medium voltage and still considered as a mere termination of the transmission grid. It is Characterizing by unidirectional power flow and simple protection ensuring safe and economical operation of the power system.

The inability of the conventional load flow techniques coupled with the above raised issues demands a power flow technique that gives the status of the distribution system for planning and operation purpose. To run a load flow, it is necessary with appropriately model the different components in the distribution system.

The following sections will show how lines, loads, transformer and capacitors can be modeled for load flow technique [40].

### **3.5.1. Line Model**

The overhead line models described in this thesis is applicable to both the line element for single circuits and the line coupling for multiple coupled circuits [41].

**Lumped parameters:** this model can be used with acceptable accuracy for short lines or relative long lines at low frequencies.

**Distributed parameters:** It should be preferred to model long lines or in calculations when high frequencies. The models are available for steady-state calculations (load flow, short circuit or frequency sweep calculations among others).

### **Line Models for Steady-State Analysis**

Line models for steady-state analysis are formulated in frequency domain. An accurate representation of the transmission line, including the effect of its distributed parameters is therefore possible [41].

### **3.5.2. Load Model**

The load model plays a significant role in customer load energy consumption, in reactive power compensation, in a voltage reduction program and in voltage stability analysis of a distribution network system. When shunt capacitors are connected to a feeder line to compensate the reactive power, current flowing through the line is reduced, and as a result, the line voltage drop ( $Z \cdot I$ ) decreases, resulting in an increase in node voltage ( $V_J = V_I - Z \cdot I$ ). Since the node voltage increases, voltage-dependent loads consume more power after the reactive power compensation. This energy consumption depends on the type of the load model. A balanced load can be represented either as constant power, constant current, constant impedance or as an exponential load [42].

In power systems, electrical load consists of various different types of electrical devices, from incandescent lamps and heaters to large arc furnaces and motors. It is often very difficult to identify the exact composition of static and dynamic loads in the network.

This load composition can also vary depending on factors such as the season, time of day etc. The general load model diagram is shown in Figure 3.7

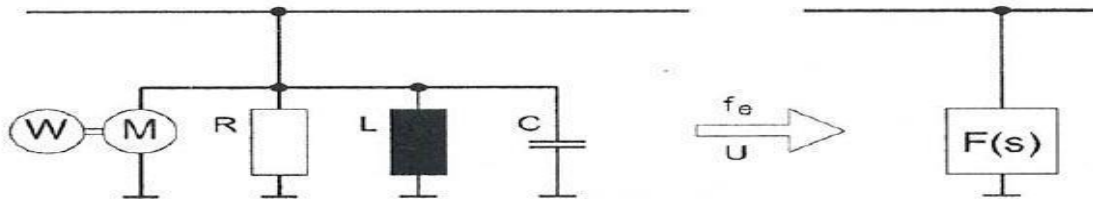


Figure 3.7 General Load Model

**Dynamic Load Model:** The active and reactive power of the dynamic load model at any instant of time can be represented by a function of the bus voltage magnitude and frequency at the past and present instant of time.

**Static Load Model:** The active and reactive power of a static load model at any instant of time can be represented by a function of the bus voltage magnitude and frequency at the same instant. This kind of load includes resistive and lighting loads. Three of the most common static load models are constant impedance, constant current, and constant power. These are explained below:

**Constant Impedance Load Model:** The active and reactive powers of this static load model are directly proportional to the square of the voltage magnitude:

$$P_{\text{Load}} = (V/V_r)^2 * P_{\text{Load}}^r \dots\dots\dots 3.1$$

$$Q_{\text{Load}} = (V/V_r)^2 * Q_{\text{Load}}^r \dots\dots\dots 3.2.$$

Where  $P_{\text{Load}}^r$  and  $Q_{\text{Load}}^r$  are the rated loads at voltage  $V_r$ , and  $P_{\text{Load}}$  and  $Q_{\text{Load}}$  are the loads at voltage  $V$ . Incandescent lighting, resistive water heaters, electric stoves, and clothes dryers are examples of constant impedance loads. In this thesis, most of the residential and commercial loads are modeled with this constant impedance load model.

**Constant Current Load Model:** The active and reactive power of this static load model is directly proportional to the voltage magnitude:

$$P_{Load} = (V/V_r) * P_{load}^r \dots\dots\dots 3.3$$

$$Q_{Load} = (V/V_r) * Q_{load}^r \dots\dots\dots 3.4$$

Welding units and electroplating processes are constant current loads. The small industries mainly use constant loads with big percentage, so our research use constant current load model for most of small industries.

**Constant Power Load Model:** The active and reactive powers of this static load model are constant, i.e., its power does not vary with voltage magnitude. An induction motor operating close to its rated voltage, fluorescent lighting, and washing machines are examples of constant power loads. The big industries are modeled with constant power load Model in ETAP Power factory Environment [43].

### 3.5.3. Transformer Model

#### 1. The Two winding transformer model

The two-winding transformer model is a very detailed model for various kinds of three-phase, two-winding transformers in power systems. It can represent e.g. network transformers, block transformers, phase shifters or MV-voltage regulators. The model makes special consideration for auto-transformers [44].

#### The Three winding transformer

Three winding transformer is a Three port element connecting Three cubicles in the network. Power factory comes with a built-in model for three-winding transformers. The sequence equivalent models of the three-winding transformer including generalized tap changers (for phase and magnitude). The Negative sequence models are identical to the positive sequence model. In this thesis paper the positive and zero sequence models are selected for both Two Winding and Three winding [44].

#### 3.5.4. Load Flow Analysis

Load flow calculations are used to analyze power systems under steady state conditions. The load flow calculates the active and reactive power flows for all branches, and the voltage magnitude and phase for all nodes [45].

##### Network Representation

A load flow calculation determines the voltage magnitude and the voltage angle of the nodes, and the active and reactive power flow on branches. Usually, the network nodes are represented by specifying two of these four quantities. Depending on the quantities specified, nodes can be classified as [45]:

**PV nodes:** constant active power and voltage magnitude are specified. This type of node is used to represent generators whose active power and voltage magnitude are controlled, and synchronous condensers. In order to consider equipment limits under abnormal conditions (as mentioned in the previous section), reactive power limits for the corresponding network components are also used as input information.

**PQ nodes:** active and reactive powers are specified. This type of node is used to represent loads and generators with fixed dispatch. Loads can also be set to change (from their original  $P_o$  and  $Q_o$  values at nominal voltage) as a function of the voltage of the node to which the load itself is connected.

**Slack bus:** voltage magnitude and angle are fixed. In traditional load flow calculations the slack node (associated with a synchronous generator or an external network) carries out the balancing of power in the system.

**Device nodes:** special nodes used to represent devices such as HVDC converters, SVSs, etc., with specific control conditions (for example the control of active power flow at a certain MW threshold in a HVDC converter).

In contrast to other power system calculation programs, Power factory does not directly define the node characteristic of each bus bar. Instead, more realistic control conditions for the network elements connected to these nodes are defined.

For example, synchronous machines are modeled by controlled power factor, controlled by constant active and reactive power (PQ), controlled by constant voltage, constant active power (PV) on the connected bus and by secondary controller ('slack', SL).

### **AC Load Flow**

In Power factory the nodal equations used to represent the analyzed networks are implemented using Newton-Raphson (Current Equations) and Newton-Raphson (Power Equations, classical). In both formulations, the resulting non-linear equation systems must be solved by an iterative method. The Newton-Raphson method is used as its non-linear equation solver. For large transmission systems, especially when heavily loaded, the standard Newton-Raphson algorithm using the "Power Equations" formulation usually converges best. Distribution systems, especially unbalanced distribution systems, usually converge better using the "Current Equations" formulation. This paper are assumed, the three-phase radial distribution networks are to be balanced and hence represented by their single-line diagram. The system is represented by its positive-phase sequence network. The operating conditions of the system are selected. The static operating state of the system is then specified by the constraints on voltage at the network buses [44].

## CHAPTER FOUR

### SIMULATION STUDIES AND ANALYSIS OF RESULTS

#### 4.1. Genetic Algorithm for Optimal Capacitor Placement

GA is a search algorithm based on the mechanic of natural selection. Basically, a GA makes a population that evolves through time using reproduction and mutation process. Only individuals representing good solutions of the capacitor placement problem will survive longer, and their genetic information will be present in the next generation. At the end, after several generations, the interaction between these high quality individuals will produce a final population which represent the best solutions set of the problem [45].

Three most important aspects of using GA are:

- Definition of objective function
- Definition and implementation of genetic representation
- Definition and representation of genetic operators

Before of the genetic algorithm procedure, the real parameters of the problem must be represented in genetic algorithm language. It means that location and size of the capacitors used are codified as a chromosome. The representation chosen for this application is a chromosome divided in two parts. First part is location of the capacitors. The second part indicates the size of the capacitors used. In reproduction process, first we randomly select a pair of chromosomes, with the same structure. In the next step, chromosomes are treated separately; one for binary part and another for integer part. In binary part, for a given position, if two parents share value, the chromosome produced by reproduction will keep it. If values are different, the result for new chromosome is selected at random. In integer part, for a given position, result will be the average of values found in the parents. If result is not an integer value, it will be approximated until closer value at random in mutation process, chromosome structure is modified. This change is performed at random, but there is a difference between binary and integer part. The GA was able to improve the quality of the randomly generated population very fast, and created good solutions in a very short time. In the selection of individuals for recombination, selection of a leader uniformly at random is required. The next step is to choose which one of the three supporters will take part in the recombination. This choice is also uniformly at random. Following this selection strategy, any pair of parents will belong to the same cluster. That makes

the population act similarly to a multiple-population approach with a high migration rate. After the parents were selected, following the criterion described before, they are utilized as input parameters in the recombination operator. The recombination returns a new individual the offspring. Since the chromosome is composed of two distinct parts, they should be treated separately during the recombination process. The mutation operator aims to add diversity to the population of individuals. Similarly to the crossover, the mutation is divided into two parts.

The first is modifies the binary portion of the chromosome by choosing a position of the individual at random. The second part acts on the integer values by adding or subtracting a unity from its value. The choice of whether to add or subtract is also decided at random. Mutation is applied to 10% of the offspring. In general, higher mutation rates may slow down evaluation speed and hence should be avoided. After recombination and mutation, GA submits all or some of the new individuals to a local search procedure for the purpose of improving their fitness function. This local search acts at the first part of the chromosome, i.e., trying to improve capacitor location. If a specific location already has a capacitor, the local search tests the possibility of dropping that capacitor ('drop'). In case of deterioration of the solution, the position returns to the original value and the local search proceeds to the next one. This local search acts on the second part of the chromosome. It adjusts the sizes of the capacitors already present in the solution, trying to find the best size for each location. Only the sizes immediately above and below the present capacitor's size are tested [45].

Calculation of the power losses requires the execution of a load-flow algorithm. The objective of optimal capacitor placement is to minimize the cost of the system. This cost is measured in four ways:

1. Fixed capacitor installation cost
2. Capacitor purchase cost
3. Capacitor bank operating cost (maintenance and depreciation)
4. Cost of real power losses

#### **4.2. Optimal Capacitor Placement**

The majority of power systems operate at a lagging power factor due to inductive loads and delivery apparatus (lines and transformers). Power systems are inductive in nature, and require additional reactive power flow from the power grid. But excessive reactive power demands result in reduced system capacity, increased losses, and decreased voltage, as well as higher

operating costs. Shunt capacitor banks are able to compensate for VAR requirements, but bank size, location, the capacitor control method, and cost considerations are important issues that need to be optimized during the design phase. An ideal solution would be a capacitor placement tool able to weigh all these factors and that considers load levels. This solution should also be able to place capacitors for voltage support and power factor correction, while minimizing the total cost of installation and operation. ETAP now provides just such an application in its Optimum Capacitor Placement (OCP) module [46].

As described in the IEEE Standard 1036-1992 (IEEE Guide for Application of Shunt Power Capacitors), the purposes of shunt capacitor applications are:

**Table 4.1: Application of capacitor bank**

| Purpose                     | Benefits                                                                                            |
|-----------------------------|-----------------------------------------------------------------------------------------------------|
| Var support                 | Yields a primary benefit for transmission systems and a Secondary benefit for distribution systems. |
| Voltage control             | Yields a primary benefit for both transmission and Distribution systems.                            |
| System capacity increase    | Yields a secondary benefit for transmission systems and a Primary benefit for distribution systems. |
| System power loss reduction | Yields a secondary benefit for transmission systems and a Primary benefit for distribution systems. |
| Billing charge reduction    | Does not apply to transmission systems, but yields a primary Benefit for distribution systems.      |

To place shunt capacitors in power systems, it is necessary to:

1. Determine bank size in KVAR
2. Determine connection location
3. Determine a control method
4. Determine a connection type (wye or delta)

The capacitor size and the appropriate location for voltage support and power factor correction can be determined in different ways. A common method applies “rules of thumb” techniques, and then runs multiple load flow studies to fine-tune the size and location. Unfortunately, this method may not yield the optimal solution. And it can also be very time consuming and impractical for large systems. It is also important to minimize cost, while mathematically determining the capacitor size and location. Because this is an optimization issue, an optimization approach should be employed. This is where the ETAP OCP module excels. It is an

extremely powerful simulation tool specifically designed for this application. The OCP module allows you to place capacitors for voltage support and power factor correction while minimizing total cost. The advanced graphic interface provides the flexibility to control the capacitor placement process, while allowing you to view the results instantly. The precise calculation approach automatically determines the best location and bank sizes. In addition, it reports the branch capacity release and savings during the planning period due to var loss reduction [46].

Optimal Capacitor Placement module in ETAP consist,

- ❖ Optimal location & bank size
- ❖ Minimize installation & operation costs
- ❖ Individual source or average energy cost
- ❖ Voltage & power factor objectives
- ❖ Minimum, maximum, & average loading
- ❖ Branch capacity release & cost savings
- ❖ Review capacitor impact on the system
- ❖ Capacitor control method To place shunt capacitors in power systems

The capabilities of the OCP module are summarized below:

#### **Key Features**

- ◆ Calculate the most cost-effective installation locations and best bank size
- ◆ Minimize total installation and operation cost
- ◆ Consider voltage support and power factor correction
- ◆ Evaluate Capacitor control method
- ◆ Allow review of capacitor impact on the system
- ◆ Employ most advanced optimum techniques

#### **Flexible Operation**

- ◆ Show available locations
- ◆ Apply user-selected load categories
- ◆ Utilize individual and global constraints
- ◆ Handle unlimited network configurations
- ◆ Use only user selected installation locations
- ◆ Constrain maximum capacitors installed at a location to user specified quantity

## **Capability**

- ◆ Advanced graphic user interface
- ◆ User friendly input and output
- ◆ Instantly view new capacitors
- ◆ Speed and precision control
- ◆ Integrated load flow results
- ◆ Standard Crystal reports

## **Plotting**

- ◆ Loss reduction savings during the planning period
- ◆ Capacitor operation cost during the planning period
- ◆ Profit during the planning period

## **Reporting**

- ◆ Capacitor properties
- ◆ Capacitor locations and sizes
- ◆ Load flow results for maximum, average and minimum loads
- ◆ Branch capacity release
- ◆ Cost summary

### **4.2.1. Calculation Method using ETAPs**

ETAP currently utilizes the genetic algorithm for optimal capacitor placement. The genetic algorithm is an optimization technique based on the theory of natural selection. A genetic algorithm starts with a generation of solutions with wide diversity to represent characteristics of the whole search space. By mutation and crossover, good characteristics are selected and carried to the next generation. The optimal solution can be reached through repeated generations. OCP uses the present worth method to perform alternative comparisons. It considers initial installation and operating costs, which include maintenance, depreciation, and loss reduction savings [47].

#### **4.2.1.1. Objective Function of OCP**

The objective of optimal capacitor placement is to minimize the cost of the system [47]. This cost is measured in four ways:

- ◆ Fixed capacitor installation cost
- ◆ Capacitor purchase cost
- ◆ Capacitor bank operating cost (maintenance and depreciation)

◆ Cost of real power losses

Cost can be represented mathematically as:

$$\text{MIN } F(x,u) = \sum_{i=1}^{N_{bus}} (X_i C_{0i} + Q_{ci} C_{1i} + B_i C_{2i} T) + C_2 \sum_{l=1}^{N_{load}} (T_l P_L^l) \dots \dots \dots 4.1$$

$N_{bus}$       => Number of bus candidates

$X_i -0/1$    => 0 means no capacitor installed at a bus i

$C_{0i}$         => Installation cost

$C_{1i}$         => Per KVar cost of capacitor banks

$Q_{ci}$         => capacitor bank size in KVar

$B_i$          => Number of capacitor banks

$C_{2i}$         => operating cost of capacitor bank ; per year

$T$           => planning period (years)

$C_2$         => cost of each kWh loss; in \$/kwh

$l$           => load levels ;maximum; average; minimum

$T_l$          => Time duration; in hours; of load level l

$P_L^l$         => Total system loss at load level l

#### 4.2.1.2 Constraints

The main constraints for capacitor placement are to meet the load flow constraints. In addition, all voltage magnitudes of load (PQ) buses should be within the lower and upper bars [48]. Load Power Factor (PF) should be greater than the minimum. It may be a maximum power factor bar.

Load flow :  $F(x ; u) = 0$

$$V_{\min} \leq V \leq V_{\max} ; PF_{\min} \leq PF_{\max} \text{ for all PQ bus} \dots \dots \dots 4.2$$

To simulate the distribution system, the following points has been considered as an inputs. In order to analysis the problem of the existing adama substation system and put the mitigation technique, simulations have been made under different scenarios.

To simulate the given system the following inputs are applied.

- ◆ Distributions line parameters
- ◆ Transformer ratings
- ◆ Bus bar rating
- ◆ Loads

It is necessary to determine bank size in KVAR, determine connection location, determine a control method and determine a connection type. The capacitor size and the appropriate location for voltage support and power factor correction can be determined in different ways. A common method applies “rules of thumb” techniques, and then runs multiple load flow studies to fine-tune the size and location Based on the investigation

Adama distribution feeder 1 has overload problems as result there existed voltage drop as compared to the other feeders therefore study only focus on 15kV outgoing line-1 in order to mitigate this under voltage problems.

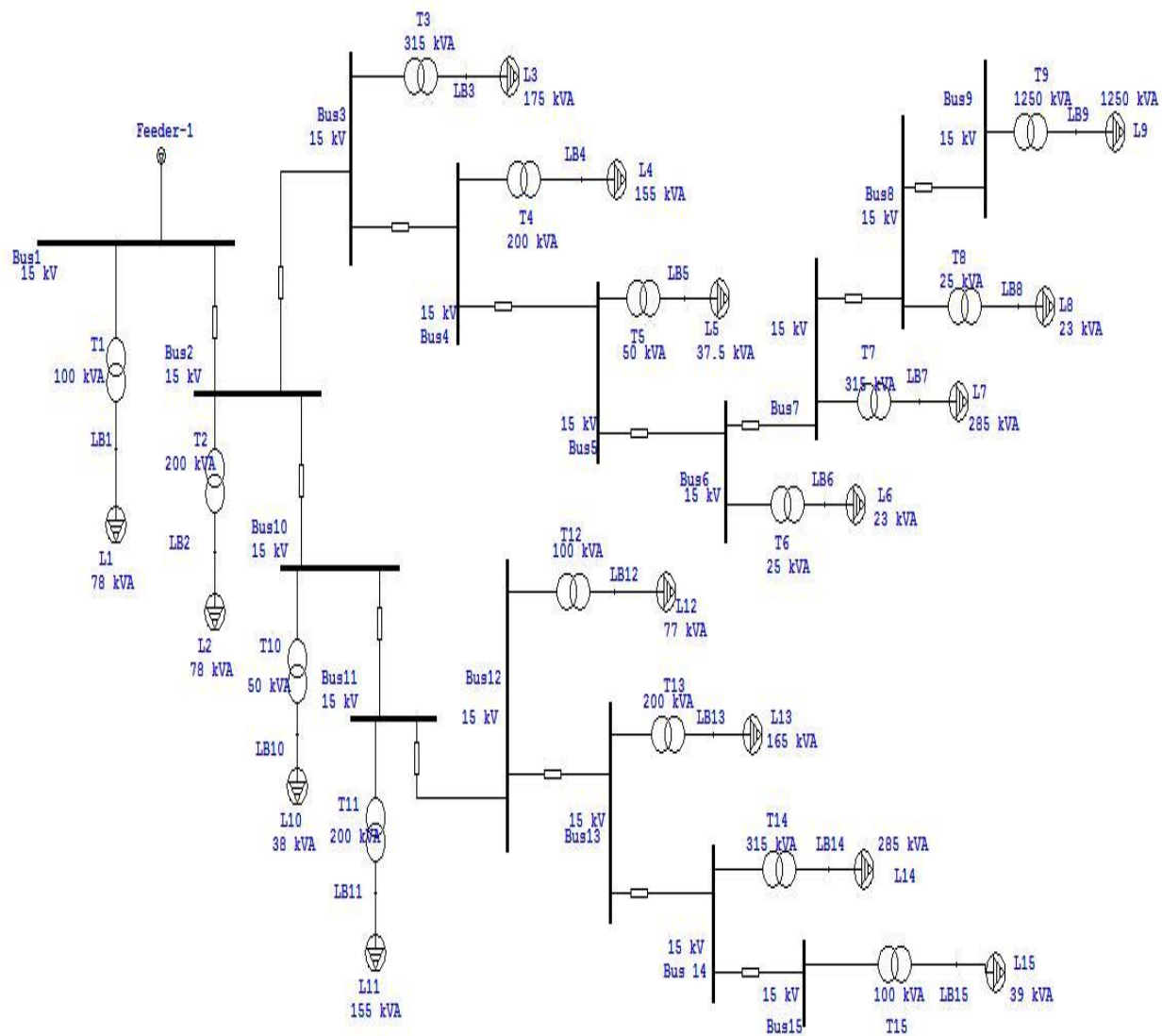


Figure 4: 1 Single Line Diagram of Outgoing Line-1

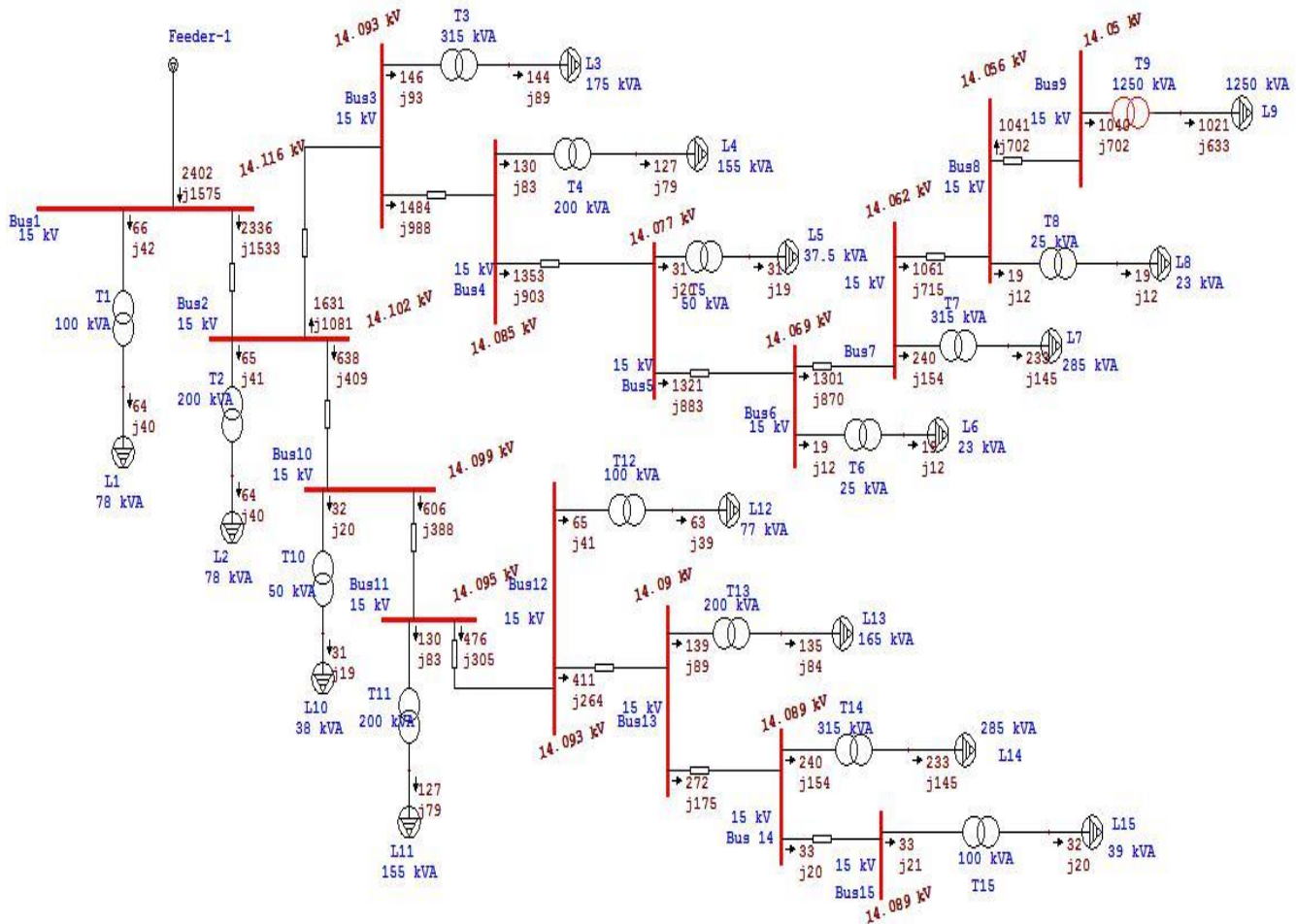


Figure 4: 2 Outgoing Line-1 load flow result before OCP

From the results of power flow analysis as shown above figure 4.1 and 4.2 the power system is Longley served line and mostly uncompensated in terms of reactive power. Due to inadequate planning most equipment's like distribution line, transformers and connecting node (bus bar) are overloaded during peak-hours.

As a result there are very high losses and serious voltage drops at the ends of lines in a system beside of other problems that cause many technical problems in the distribution system.

Table 4. 2: General load flow result before OCP for 2\*25MVA power transformer

| Study ID            | General Load flow |
|---------------------|-------------------|
| Study Case ID       | LF                |
| Data Revision       | Base              |
| Configuration       | Normal            |
| Loading Category    | Design            |
| Generation Category | Design            |
| Diversity Factor    | Normal Loading    |
| Buses               | 179               |
| Branches            | 178               |
| Generators          | 0                 |
| Power Grids         | 1                 |
| Loads               | 63                |
| Load-MW             | 37.434            |
| Load-Mvar           | 29.507            |
| Generation-MW       | 37.434            |
| Generation-Mvar     | 29.507            |
| Loss-MW             | 0.253             |
| Loss-Mvar           | 4.201             |

The above table shows that the power transformer with a capacity values of 2\*25 MVA /135/15KV the average active and reactive value and its associated loss. The overall capacity of the power transformer at a power factor 0.8 is about 40MW. It clearly indicates that the power transformer is almost working at full capacity. As a result transformer heats up; the high temperatures can gradually weaken the insulation system. The net result of small, incremental increases in loading capacity over time is a weakened insulation system. Overloading causes overheating, and eventually thermal degradation that acts through cracks in the insulation and lead to transformer to be burned.

Table 4.3: Bus voltages before OCP of Adama distribution Feeder -1

| Bus ID | Nominal<br>kV | Voltage at<br>Bus | % of bus<br>Voltage | Normal operating<br>Voltage |
|--------|---------------|-------------------|---------------------|-----------------------------|
| Bus1   | 15            | 14.116            | 94.1                | 98-102%                     |
| Bus2   | 15            | 14.102            | 94.02               | 98-102%                     |
| Bus3   | 15            | 14.093            | 93.95               | 98-102%                     |
| Bus4   | 15            | 14.085            | 93.9                | 98-102%                     |
| Bus5   | 15            | 14.077            | 93.85               | 98-102%                     |
| Bus6   | 15            | 14.069            | 93.79               | 98-102%                     |
| Bus7   | 15            | 14.069            | 93.74               | 98-102%                     |
| Bus8   | 15            | 14.050            | 93.66               | 98-102%                     |
| Bus9   | 15            | 14.056            | 93.7                | 98-102%                     |
| Bus10  | 15            | 14.099            | 93.99               | 98-102%                     |
| Bus11  | 15            | 14.095            | 93.97               | 98-102%                     |
| Bus12  | 15            | 14.093            | 93.95               | 98-102%                     |
| Bus13  | 15            | 14.09             | 93.94               | 98-102%                     |
| Bus14  | 15            | 14.065            | 93.92               | 98-102%                     |
| Bus15  | 15            | 14.062            | 93.92               | 98-102%                     |

The data shown in the above table indicate that from 15 buses on the Adama distribution outgoing feeder -1 there are voltage drop on five buses since as it is seen on figure 4.1: these feeders are far from the substation related to the remaining 10 buses. This voltage drop in the distribution networks. This Voltage drops occur throughout the distribution network. However, it is necessary to regulate the voltage in order to ensure that these drops stay within a permissible range. High voltage drops, below the permissible level, can have many negative consequences. These result in an increase in the system maintenance cost and a decrease in the safety and performance of the network. Operating electrical equipment below its rated voltage can be dangerous as well as reducing the expected lifetime of the equipment. When inductive loads are operated below their rated voltage, they tend to overheat and consume more power. Resistive

loads which are operated at a too low voltage will not be able to produce the desired output. Reducing the voltage by 10% will reduce the power output by 19%, since power output correlates to the voltage squared. A reduction in the network voltage can cause lights to flicker when other appliances are turned on. Therefore voltage improvements mechanisms need to be implement in the distribution network so as to avoid the effect of voltage drop in the network.

Thus this thesis tried to improve voltage profile by optimal placement of capacitor bank in the Adama distribution network of based on the analytical investigation done in chapter three to select the outgoing feeder that have a redundant voltage drop compared to the other remaining feeders and through reliability assessment feeder one is selected .

As shown above Table 4.2 the result of power flow analysis of Adama town distribution system the total load and power loss of the system is  $(37.434+j29.507)$  MVA and  $(0.253+j4.201)$  MVA respectively.

To compensate the distribution line loss and to improve voltage profile we are applying optimal capacitor placements for this works. From fifteen bus system select 9 candidate locations selects, such as bus4, bus5, bus6, bus7, bus8, bus9, bus13, bus14, and bus15 as shown table 4.3 out of nine minimum voltages occurs at bus-8.

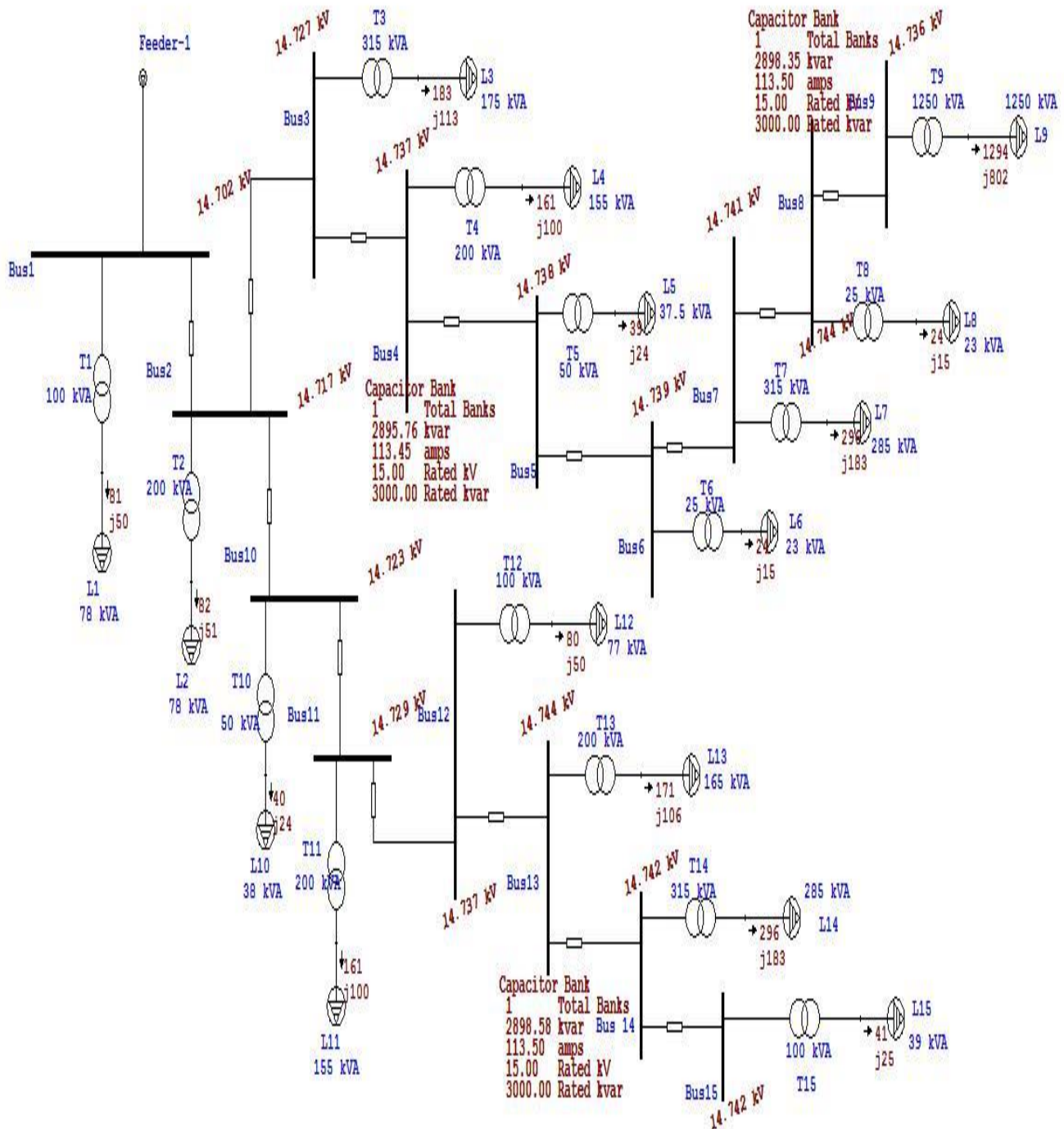


Fig 4.3: The load flow result After Optimal Capacitor Placement

From the result above figure 4.5 the optimal location s and size of the capacitors are bus-4 with 3000kVAr, bus-8 with 3000kVAr and bus-13 with 3000kVA a total 9000kVAr is installed this distribution systems.



Table 4.4: General load flow result after placement of capacitor bank

| Study ID         | General load flow |
|------------------|-------------------|
| Study Case ID    | LF                |
| Data Revision    | Base              |
| Configuration    | Normal            |
| Loading Cat      | Design            |
| Generation Cat   | Design            |
| Diversity Factor | Normal Loading    |
| Buses            | 179               |
| Branches         | 178               |
| Generators       | 0                 |
| Power Grids      | 1                 |
| Loads            | 53                |
| Load-MW          | 37.743            |
| Load-Mvar        | 20.158            |
| Generation-MW    | 37.743            |
| Generation-Mvar  | 10.158            |
| Loss-MW          | 0.137             |
| Loss-Mvar        | 2.065             |

As shown in the table the result of power flow analysis after placement of capacitor bank in the distribution feeder 1 of Adama distribution network indicates the reactive power reduction on the overall system compared to the value in table 4.2: this reactive power reduction on the network is useful to minimize power loss as compared to the value in the table 4.2: before placement of capacitor bank in the network. The total active power losses along the distributors and transformers are reduced by 45.849%. The increase in power factor, and the power losses reduction was as a result of the reactive power being compensated by optimally placed capacitor banks on the network. The leading reactive power injected into the network through the capacitor bank partly neutralized the lagging reactive power of the network which reduced the excessive lagging current drawn by the network inductive loads and subsequently reduced the losses in the distribution apparatus (distribution lines and transformers)..

Table 4.5: Bus voltage after OCP

| Bus ID | Nominal kV | Bus    | % of bus voltage | Nominal % Operating Voltage |
|--------|------------|--------|------------------|-----------------------------|
| Bus1   | 15         | 14.961 | 99.74            | 98-102%                     |
| Bus2   | 15         | 14.98  | 99.98            | 98-102%                     |
| Bus3   | 15         | 14.992 | 99.95            | 98-102%                     |
| Bus4   | 15         | 15.005 | 100.04           | 98-102%                     |
| Bus5   | 15         | 15.009 | 100.06           | 98-102%                     |
| Bus6   | 15         | 15.012 | 100.08           | 98-102%                     |
| Bus7   | 15         | 15.015 | 100.1            | 98-102%                     |
| Bus8   | 15         | 15.02  | 100.14           | 98-102%                     |
| Bus9   | 15         | 15.015 | 100.1            | 98-102%                     |
| Bus10  | 15         | 14.987 | 99.91            | 98-102%                     |
| Bus11  | 15         | 14.994 | 99.96            | 98-102%                     |
| Bus12  | 15         | 15.002 | 100.02           | 98-102%                     |
| Bus13  | 15         | 15.011 | 100.07           | 98-102%                     |
| Bus14  | 15         | 15.009 | 100.06           | 98-102%                     |
| Bus15  | 15         | 15.009 | 100.06           | 98-102%                     |

So as to be able to choose the optimal locations of the capacitor banks and their optimal sizes, results were obtained taking in to consideration all the candidate buses. From the result of power flow analysis by applying optimal capacitor placement, fifteen candidate locations have been selected. The capacitor banks are installed near bus 4; bus 8 and bus 13 with 3000KVA<sub>r</sub> from the load flow analysis after applying capacitor bank shows that there is improvement on the distribution voltage profiles and power loss reduction accordingly.

Table 4. 6: Comparison of terminal voltage before and after OCP

| Bus ID | Nominal Kv | Terminal Voltage | Terminal      | voltage enhanced after OCP |
|--------|------------|------------------|---------------|----------------------------|
|        |            | before OCP       | Voltage after |                            |
|        |            |                  | OCP           |                            |
| Bus1   | 15         | 14.116           | 14.961        | 0.845                      |
| Bus2   | 15         | 14.102           | 14.981        | 0.879                      |
| Bus3   | 15         | 14.093           | 14.992        | 0.899                      |
| Bus4   | 15         | 14.085           | 15.005        | 0.92                       |
| Bus5   | 15         | 14.077           | 15.009        | 0.932                      |
| Bus6   | 15         | 14.069           | 15.012        | 0.943                      |
| Bus7   | 15         | 14.062           | 15.015        | 0.953                      |
| Bus8   | 15         | 14.056           | 15.025        | 0.969                      |
| Bus9   | 15         | 14.056           | 15.015        | 0.959                      |
| Bus10  | 15         | 14.099           | 14.987        | 0.888                      |
| Bus11  | 15         | 14.095           | 14.994        | 0.899                      |
| Bus12  | 15         | 14.093           | 15.002        | 0.909                      |
| Bus13  | 15         | 14.093           | 15.011        | 0.918                      |
| Bus14  | 15         | 14.089           | 15.009        | 0.92                       |
| Bus15  | 15         | 14.116           | 15.009        | 0.893                      |

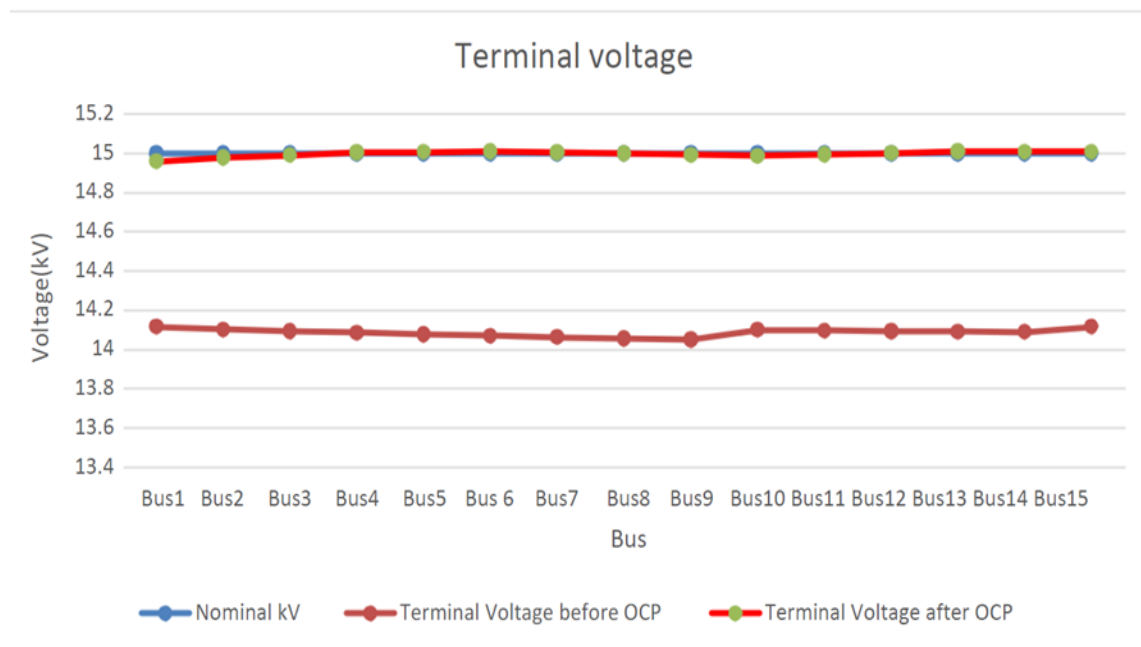


Fig 4.5: Comparison of terminal voltage before and after OCP

#### 4.4. Results Based on Capacitor Placements

The method of loss reduction by capacitor placement was tested on portion of the distribution system. The results obtained in this system are described as follows:-

The portion of adama town distribution system before OCP has a total load of  $(37.74+j29.507)$  MVA and active and reactive power loss is 253 kW and 4,201 KVAR respectively. After employing capacitor bank the power loss improved by 45.58% that is total load of  $(37.74+j20.158)$  MVA and active and reactive power loss is 137 kW and 2,065 KVAR. The loss reduced to by 116 kw and the voltage level at buses of the distribution feeder voltage profile is improved by on average 5.99%. Therefore optimal capacitor placement in distribution network of Adama outgoing feeder -1 made significant change regarding on power loss reduction and to improve voltage level on each buses as stated below.

1. Bus 1 from 14.116 to 14.961 with a percentage increment of 5.63%
2. Bus 2 from 14.102 to 14.980 with a percentage increment of 5.86%
3. Bus 3 from 14.093 to 14.992 with a percentage increment of 5.99%
4. Bus 4 from 14.085 to 15.005 with a percentage increment of 6.13%
5. Bus 5 from 14.077 to 15.009 with a percentage increment of 6.12%
6. Bus 6 from 14.069 to 15.012 with a percentage increment of 6.29%
7. Bus 7 from 14.062 to 15.015 with a percentage increment of 6.35%
8. Bus 8 from 14.050 to 15.020 with a percentage increment of 6.46%
9. Bus 9 from 14.056 to 15.015 with a percentage increment of 6.39%
10. Bus 10 from 14.099 to 14.987 with a percentage increment of 6.92%
11. Bus 11 from 14.095 to 14.994 with a percentage increment of 5.99%
12. Bus 12 from 14.093 to 15.002 with a percentage increment of 6.06%
13. Bus 13 from 14.090 to 15.011 with a percentage increment of 6.12%
14. Bus 14 from 14.089 to 15.009 with a percentage increment of 6.13%
15. Bus 15 from 14.089 to 15.009 with a percentage increment of 5.95%

From the above data after capacitor bank installed on the feeder -1 network near bus -4; bus 8 and bus 13 the average voltage profile improvement is about 6.10% with validating the voltage constraint maximum level .thus the installing capacitor bank on feeder 1 of Adama distribution network enhanced the under voltage problems and also reduce power loss in the system.

## 4.5. Optimal Capacitor Placements Cost Summary

**Table 4.7 :Cost summary**

|       | Cost(\$)                           |                           |                             | Saving(\$)                     |                     |
|-------|------------------------------------|---------------------------|-----------------------------|--------------------------------|---------------------|
| Month | Supply & Installation (\$ dollars) | Operation in dollars (\$) | Loss Reduction (in dollars) | Monthly Profit in dollars (\$) | Accumulation Profit |
| 1     | 290,700.00                         | 900                       | 15,928.05                   | 275,671.95                     | 275,671.95          |
| 2     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 260,643.90          |
| 3     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 245,615.85          |
| 4     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 230,587.80          |
| 5     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 215,559.75          |
| 6     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 200,531.70          |
| 7     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 185,503.65          |
| 8     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 170,475.60          |
| 9     | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 155,447.55          |
| 10    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 140,419.50          |
| 11    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 125,391.45          |
| 12    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 110,363.40          |
| 13    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 95,335.35           |
| 14    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 80,307.30           |
| 15    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 65,279.25           |
| 16    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 50,251.20           |
| 17    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 35,223.15           |
| 18    | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 20,195.10           |
|       | 0                                  | 900                       | 15,928.05                   | 15,028.05                      | 5,167.05            |

Purchasing cost and installation for 9000KVAR is about 290700 USA dollars and its' operational and maintenance cost per months is about 900 USA dollar.

Monthly saving in USA dollar is 15,928.05 with excluding of operational and maintenance cost.

Thus total monthly saving is 15,028.05 USA dollars.

## Rate of investment calculation

Total cost in Ethiopian Birr (taking currency rate 37Birr/\$)

$$=\text{Capacitor cost in USA Dollar} * 37$$

$$=291,600 * 37$$

$$=10,789,200$$

Therefore, power loss reduction due to capacitor placement is:

$$0.253\text{MW} - 0.137\text{MW} = 0.116\text{MW}$$

After capacitor placement total energy saved for one year is:

$$0.116\text{MW} * 24\text{hr/day} * 365\text{days} = 1016.1\text{MWH}$$

Saving in terms of Ethiopian Birr is:

$$=1016.1\text{MWH} * 1000(\text{K/W}) * 0.58 (\text{Birr/KWH})$$

$$=589,338 \text{ birr}$$

$$= (589,338/$$

$$= \$15,928.05) \text{ (taking currency rate 37Birr/\$)}$$

Return of investment (ROI) for capacitor placement is calculated as follows:

$$\text{ROI} = 10,789,200 / 589,338 = 18.31 \text{ months}$$

From this calculation the cost expenditure for capacitor installing and on the distribution system returned after 18 months.

## **CHAPTER FIVE**

### **CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORK**

#### **5.1. CONCLUSIONS**

Minimization of distribution feeder loss due to optimum reactive power compensation in the distribution networks is successfully achieved through identifying the optimal location and size of capacitors. Optimal placement of shunt capacitor in the distribution system reduces the current flows in each section of the feeder and hence the voltage drop in the section reduced. Therefore the voltage profile is improved after the feeder line is compensated and the quality of the supply is improved.

This thesis studies the existing power system of an area in Adama town distribution system voltage profile of bus terminals. The method first finds a sequence of candidate buses to be compensated through finding the highest loss saving by a single located capacitor. The proposed method was tested on distribution system of Adama outgoing line-1. In the tested distribution system it was found that by placing total 9000kvar, optimal capacitors at a location (bus-4, bus-8 and bus-13).

As results of the study shows an improvement of voltage profile at a bus terminal and also minimize the line losses of the distribution systems. For examples voltage at bus-1 is corrected from 14.116kV to 14.961kV. Thus after implemented OCP the system voltage profile improved by 6.10%. Conclusively, Optimal Capacitor Placement in Adama distribution network feeder -1 shows that placement of capacitor optimally in 15kv distribution network improve power quality of a network.

#### **5.2. RECOMMENDATION**

In the present energy crisis that is a society-wide economic problem caused by a constricted supply of energy, leading to diminished availability and increased price to consumers, implementing energy loss reduction techniques has a paramount effect in the development of country socially and economically. Capacitor for loss minimizations has a relatively low cost and shorter return period than other methods and it is advisable to implement this method in conjunction with other natural compensation methods such as phase balancing to satisfy the increased load demand. Distribution feeder having short length had lower line losses despite of

higher reactive current flow . Therefore it is recommended to compensate the high reactive power flow by the electric utility rather than company the consumers.

- ❖ The repeated simulation results could be used to develop a model using any artificial intelligence technique which can be accurately predict the location and size of capacitor for any load conditions which gives a great promise for practical implementation of the proposed technique.
- ❖ The study focuses only improving weak voltage profile and power transfer capability of the town, the impact of shunt capacitor to the rest system shall be examined.
- ❖ Detail economical and technical analysis shall be done for future works.

### **5.3. Suggestions for Future Work**

In this thesis the way of voltage profile improvement through active power loss reduction method with proper application of reactive power sources to the system is discussed and analyzed. However the method considers and the simulation has been done only for the peak hour operations, when the system is heavy loaded. During the rest of the time load is decreased and therefore the system is becoming able to transfer the needed power without overloading the system components. Accordingly the losses are becoming lower. In such a case, when the loads are lowered, the reactive power sources, which we applied to the system during the peak hour operations, become excessive and their injected reactive power can cause even more losses and destructive over voltages. Therefore it's very important the reactive power sources to be properly operated and switched to the system only in case when they will be needed, i.e. during the heavy loads of the system. Another issue to be considered is the transient on the system at the moment of connecting reactive power sources on the system. As it is essential to apply the reactive power sources to the system only during peak hours, the problem of transients becomes urgent for consideration while planning the locations and sizing of reactive sources. The other point is that the scope of this research is covered only on the optimal capacitor placement for voltage profile improvement in Adama distribution system only feeder -1 due to COVID -19 epidemics constraints and therefore researcher should need to cover more feeders on this regards.

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## Appendix A

### ETAPs Load Flow Result

|           |                                |           |          |
|-----------|--------------------------------|-----------|----------|
| Project:  | ETAP                           | Page:     | 1        |
| Location: | 12.6.0H                        | Date:     | 02.05.21 |
| Contract: |                                | SN:       |          |
| Engineer: |                                | Revision: | Base     |
| Filename: | Optimal Placement of capacitor | Config.:  | Normal   |
|           | Study Case: LF                 |           |          |

#### Line/Cable Input Data

| Line/Cable |        | Ohms or Siemens/1000 m per Conductor (Cable) or per Phase (Line) |        |        |   |        |          |          |           |   |
|------------|--------|------------------------------------------------------------------|--------|--------|---|--------|----------|----------|-----------|---|
|            |        | Library                                                          | Size   | Length |   | #Phase | T (°C)   | R        | X         | Y |
| Adj. (m)   | % Tol. |                                                                  |        |        |   |        |          |          |           |   |
| ID         |        |                                                                  |        |        |   |        |          |          |           |   |
| Line1      |        | 49.5                                                             | 1200.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line3      |        | 49.5                                                             | 1400.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line4      |        | 49.5                                                             | 2000.0 | 0.0    | 1 | 75     | 0.037624 | 0.037624 | 0.0000004 |   |
| Line6      |        | 49.5                                                             | 1150.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line8      |        | 49.5                                                             | 1800.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line10     |        | 49.5                                                             | 2200.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line12     |        | 49.5                                                             | 1050.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line14     |        | 49.5                                                             | 1050.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line16     |        | 49.5                                                             | 2300.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line18     |        | 49.5                                                             | 2000.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line20     |        | 49.5                                                             | 1900.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line22     |        | 49.5                                                             | 1100.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line24     |        | 49.5                                                             | 1800.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line26     |        | 49.5                                                             | 1800.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |
| Line28     |        | 49.5                                                             | 1800.0 | 0.0    | 1 | 75     | 0.060550 | 0.071450 | 0.0000006 |   |

Line / Cable resistances are listed at the specified temperatures.

|           |                 |           |          |
|-----------|-----------------|-----------|----------|
| Project:  | ETAP            | Page:     | 1        |
| Location: | 12.6.0H         | Date:     | 02.05.21 |
| Contract: |                 | SN:       |          |
| Engineer: |                 | Revision: | Base     |
| Filename: | My thises OCP   | Config.:  | Normal   |
|           | Study Case: OCP |           |          |

#### Optimal Capacitor Placement Cost Summary

| Year | Cost (\$)    |           | Saving (\$)    |               |                     |
|------|--------------|-----------|----------------|---------------|---------------------|
|      | Installation | Operation | Loss Reduction | Yearly Profit | Accumulative Profit |
| 1    | 290700.00    | 900.00    | 4784.64        | -286815.40    | -286815.40          |
| 2    | 0.00         | 900.00    | 4784.64        | 3884.64       | -282930.80          |
| 3    | 0.00         | 900.00    | 4784.64        | 3884.64       | -279046.10          |
| 4    | 0.00         | 900.00    | 4784.64        | 3884.64       | -275161.50          |
| 5    | 0.00         | 900.00    | 4784.64        | 3884.64       | -271276.90          |
| 6    | 0.00         | 900.00    | 4784.64        | 3884.64       | -267392.30          |
| 7    | 0.00         | 900.00    | 4784.64        | 3884.64       | -263507.60          |
| 8    | 0.00         | 900.00    | 4784.64        | 3884.64       | -259623.00          |
| 9    | 0.00         | 900.00    | 4784.64        | 3884.64       | -255738.30          |
| 10   | 0.00         | 900.00    | 4784.64        | 3884.64       | -251853.70          |

Project:  
Location:  
Contract:  
Engineer:  
Filename: Optimal Placement of capacitor

**ETAP**  
12.6.0H  
  
Study Case: LF

Page: 1  
Date: 02.05.21  
SN:  
Revision: Base  
Config.: Normal

**Line/Cable Input Data**

| Line/Cable |        | Ohms or Siemens/1000 m per Conductor (Cable) or per Phase (Line) |      |        |     |        |        |          |          |           |
|------------|--------|------------------------------------------------------------------|------|--------|-----|--------|--------|----------|----------|-----------|
|            |        | Library                                                          | Size | Length |     | #Phase | T (°C) | R        | X        | Y         |
| Adj. (m)   | % Tol. |                                                                  |      |        |     |        |        |          |          |           |
| ID         |        |                                                                  |      |        |     |        |        |          |          |           |
| Line1      |        |                                                                  | 49.5 | 1200.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line3      |        |                                                                  | 49.5 | 1400.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line4      |        |                                                                  | 49.5 | 2000.0 | 0.0 | 1      | 75     | 0.037624 | 0.037624 | 0.0000004 |
| Line6      |        |                                                                  | 49.5 | 1150.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line8      |        |                                                                  | 49.5 | 1800.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line10     |        |                                                                  | 49.5 | 2200.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line12     |        |                                                                  | 49.5 | 1050.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line14     |        |                                                                  | 49.5 | 1050.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line16     |        |                                                                  | 49.5 | 2300.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line18     |        |                                                                  | 49.5 | 2000.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line20     |        |                                                                  | 49.5 | 1900.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line22     |        |                                                                  | 49.5 | 1100.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line24     |        |                                                                  | 49.5 | 1800.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line26     |        |                                                                  | 49.5 | 1800.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line28     |        |                                                                  | 49.5 | 1800.0 | 0.0 | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |

Line / Cable resistances are listed at the specified temperatures.

Project:  
Location:  
Contract:  
Engineer:  
Filename: My thises OCP

**ETAP**  
12.6.0H  
  
Study Case: OCP

Page: 1  
Date: 02.05.21  
SN:  
Revision: Base  
Config.: Normal

**Optimal Capacitor Placement Cost Summary**

| Year | Cost (\$)    |           | Saving (\$)    |               |                     |
|------|--------------|-----------|----------------|---------------|---------------------|
|      | Installation | Operation | Loss Reduction | Yearly Profit | Accumulative Profit |
| 1    | 290700.00    | 900.00    | 4784.64        | -286815.40    | -286815.40          |
| 2    | 0.00         | 900.00    | 4784.64        | 3884.64       | -282930.80          |
| 3    | 0.00         | 900.00    | 4784.64        | 3884.64       | -279046.10          |
| 4    | 0.00         | 900.00    | 4784.64        | 3884.64       | -275161.50          |
| 5    | 0.00         | 900.00    | 4784.64        | 3884.64       | -271276.90          |
| 6    | 0.00         | 900.00    | 4784.64        | 3884.64       | -267392.30          |
| 7    | 0.00         | 900.00    | 4784.64        | 3884.64       | -263507.60          |
| 8    | 0.00         | 900.00    | 4784.64        | 3884.64       | -259623.00          |
| 9    | 0.00         | 900.00    | 4784.64        | 3884.64       | -255738.30          |
| 10   | 0.00         | 900.00    | 4784.64        | 3884.64       | -251853.70          |

|             |                                |           |          |
|-------------|--------------------------------|-----------|----------|
| Project:    | ETAP                           | Page:     | 1        |
| Location:   | 12.6.0H                        | Date:     | 02.05.21 |
| Contract:   |                                | SN:       |          |
| Engineer:   |                                | Revision: | Base     |
| Filename:   | Optimal Placement of capacitor | Config.:  | Normal   |
| Study Case: | LF                             |           |          |

#### Line/Cable Input Data

| Ohms or Siemens/1000 m per Conductor (Cable) or per Phase (Line) |         |        |          |       |        |        |          |          |           |
|------------------------------------------------------------------|---------|--------|----------|-------|--------|--------|----------|----------|-----------|
| Line/Cable                                                       |         | Length |          |       |        |        |          |          |           |
| ID                                                               | Library | Size   | Adj. (m) | % Tol | #Phase | T (°C) | R        | X        | Y         |
| Line1                                                            |         | 49.5   | 1200.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line3                                                            |         | 49.5   | 1400.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line4                                                            |         | 49.5   | 2000.0   | 0.0   | 1      | 75     | 0.037624 | 0.037624 | 0.0000004 |
| Line6                                                            |         | 49.5   | 1150.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line8                                                            |         | 49.5   | 1800.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line10                                                           |         | 49.5   | 2200.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line12                                                           |         | 49.5   | 1050.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line14                                                           |         | 49.5   | 1050.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line16                                                           |         | 49.5   | 2300.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line18                                                           |         | 49.5   | 2000.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line20                                                           |         | 49.5   | 1900.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line22                                                           |         | 49.5   | 1100.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line24                                                           |         | 49.5   | 1800.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line26                                                           |         | 49.5   | 1800.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line28                                                           |         | 49.5   | 1800.0   | 0.0   | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |

Line / Cable resistances are listed at the specified temperatures.

|             |               |           |          |
|-------------|---------------|-----------|----------|
| Project:    | ETAP          | Page:     | 1        |
| Location:   | 12.6.0H       | Date:     | 02.05.21 |
| Contract:   |               | SN:       |          |
| Engineer:   |               | Revision: | Base     |
| Filename:   | My thises OCP | Config.:  | Normal   |
| Study Case: | OCP           |           |          |

#### Optimal Capacitor Placement Cost Summary

|        | Year   | Cost (\$)    |           | Saving (\$)    |               |                     |
|--------|--------|--------------|-----------|----------------|---------------|---------------------|
|        |        | Installation | Operation | Loss Reduction | Yearly Profit | Accumulative Profit |
|        | 1      | 290700.00    | 900.00    | 4784.64        | -286815.40    | -286815.40          |
|        | 2      | 0.00         | 900.00    | 4784.64        | 3884.64       | -282930.80          |
|        | 3      | 0.00         | 900.00    | 4784.64        | 3884.64       | -279046.10          |
|        | 4      | 0.00         | 900.00    | 4784.64        | 3884.64       | -275161.50          |
|        | 5      | 0.00         | 900.00    | 4784.64        | 3884.64       | -271276.90          |
|        | 6      | 0.00         | 900.00    | 4784.64        | 3884.64       | -267392.30          |
|        | 7      | 0.00         | 900.00    | 4784.64        | 3884.64       | -263507.60          |
|        | 8      | 0.00         | 900.00    | 4784.64        | 3884.64       | -259623.00          |
|        | 9      | 0.00         | 900.00    | 4784.64        | 3884.64       | -255738.30          |
|        | 10     | 0.00         | 900.00    | 4784.64        | 3884.64       | -251853.70          |
| Bus 14 | 15.000 | 98.283       | -6.20     | 100.0          |               |                     |
| Bus15  | 15.000 | 98.281       | -6.20     | 100.0          |               |                     |
| Total  |        |              |           |                | 3             | 9000.000            |
|        |        |              |           |                | 2700.00       | 288000.00           |
|        |        |              |           |                |               | 900.00              |

Project:  
Location:  
Contract:  
Engineer:  
Filename: Optimal Placement of capacitor

ETAP  
12.6.0H  
  
Study Case: LF

Page: 1  
Date: 02.05.21  
SN:  
Revision: Base  
Config.: Normal

#### Line/Cable Input Data

| Line/Cable |  | Ohms or Siemens/1000 m per Conductor (Cable) or per Phase (Line) |      |          |        |        |        |          |          |           |
|------------|--|------------------------------------------------------------------|------|----------|--------|--------|--------|----------|----------|-----------|
|            |  | Library                                                          | Size | Length   |        | #Phase | T (°C) | R        | X        | Y         |
|            |  |                                                                  |      | Adj. (m) | % Tol. |        |        |          |          |           |
| ID         |  |                                                                  |      |          |        |        |        |          |          |           |
| Line1      |  |                                                                  | 49.5 | 1200.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line3      |  |                                                                  | 49.5 | 1400.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line4      |  |                                                                  | 49.5 | 2000.0   | 0.0    | 1      | 75     | 0.037624 | 0.037624 | 0.0000004 |
| Line6      |  |                                                                  | 49.5 | 1150.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line8      |  |                                                                  | 49.5 | 1800.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line10     |  |                                                                  | 49.5 | 2200.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line12     |  |                                                                  | 49.5 | 1050.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line14     |  |                                                                  | 49.5 | 1050.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line16     |  |                                                                  | 49.5 | 2300.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line18     |  |                                                                  | 49.5 | 2000.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line20     |  |                                                                  | 49.5 | 1900.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line22     |  |                                                                  | 49.5 | 1100.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line24     |  |                                                                  | 49.5 | 1800.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line26     |  |                                                                  | 49.5 | 1800.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |
| Line28     |  |                                                                  | 49.5 | 1800.0   | 0.0    | 1      | 75     | 0.060550 | 0.071450 | 0.0000006 |

Line / Cable resistances are listed at the specified temperatures.

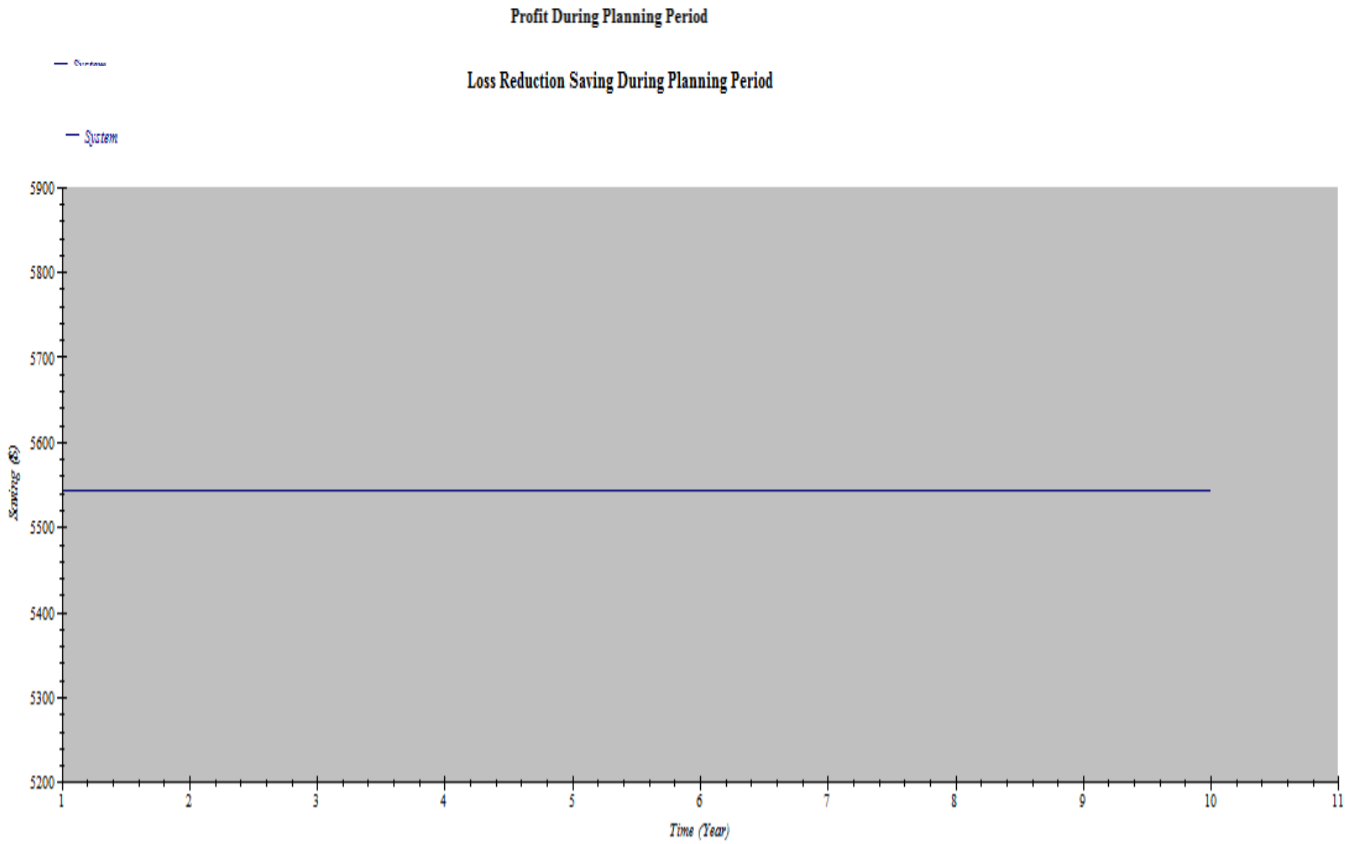
Project:  
Location:  
Contract:  
Engineer:  
Filename: My thises OCP

ETAP  
12.6.0H  
  
Study Case: OCP

Page: 1  
Date: 02.05.21  
SN:  
Revision: Base  
Config.: Normal

#### Optimal Capacitor Placement Cost Summary

| Year | Cost (\$)    |           | Saving (\$)    |               |                     |
|------|--------------|-----------|----------------|---------------|---------------------|
|      | Installation | Operation | Loss Reduction | Yearly Profit | Accumulative Profit |
| 1    | 290700.00    | 900.00    | 4784.64        | -286815.40    | -286815.40          |
| 2    | 0.00         | 900.00    | 4784.64        | 3884.64       | -282930.80          |
| 3    | 0.00         | 900.00    | 4784.64        | 3884.64       | -279046.10          |
| 4    | 0.00         | 900.00    | 4784.64        | 3884.64       | -275161.50          |
| 5    | 0.00         | 900.00    | 4784.64        | 3884.64       | -271276.90          |
| 6    | 0.00         | 900.00    | 4784.64        | 3884.64       | -267392.30          |
| 7    | 0.00         | 900.00    | 4784.64        | 3884.64       | -263507.60          |
| 8    | 0.00         | 900.00    | 4784.64        | 3884.64       | -259623.00          |
| 9    | 0.00         | 900.00    | 4784.64        | 3884.64       | -255738.30          |
| 10   | 0.00         | 900.00    | 4784.64        | 3884.64       | -251853.70          |



|                         |                |                 |
|-------------------------|----------------|-----------------|
| Project:                | <b>ETAP</b>    | Page: 1         |
| Location:               | 12.6.0H        | Date: 02.05.21  |
| Contract:               |                | SN:             |
| Engineer:               | Study Case: LF | Revision: Base  |
| Filename: My thises OCP |                | Config.: Normal |

#### Alert Summary Report

|                           | % Alert Settings |                 |
|---------------------------|------------------|-----------------|
|                           | <u>Critical</u>  | <u>Marginal</u> |
| <b><u>Loading</u></b>     |                  |                 |
| Bus                       | 100.0            | 95.0            |
| Cable                     | 100.0            | 95.0            |
| Reactor                   | 100.0            | 95.0            |
| Line                      | 100.0            | 95.0            |
| Transformer               | 100.0            | 95.0            |
| Panel                     | 100.0            | 95.0            |
| Protective Device         | 100.0            | 95.0            |
| Generator                 | 100.0            | 95.0            |
| Inverter/Charger          | 100.0            | 95.0            |
| <b><u>Bus Voltage</u></b> |                  |                 |
| OverVoltage               | 105.0            | 102.0           |
| UnderVoltage              | 95.0             | 98.0            |

|                        |                 |                 |
|------------------------|-----------------|-----------------|
| Project:               | ETAP            | Page: 1         |
| Location:              | 12.6.0M         | Date: 02.05.21  |
| Contract:              |                 | SN:             |
| Engineer:              | Study Case: OCP | Revision: Basic |
| Filename: My thins OCP |                 | Config: Normal  |

### Electrical Transient Analyzer Program

#### Optimal Capacitor Placement

Loading Category(1): Design

Generation Category(1): Design

Charger Loading: Design

|                     | <u>Swing</u> | <u>V-Control</u> | <u>Load</u>    | <u>Total</u>      |                  |               |              |
|---------------------|--------------|------------------|----------------|-------------------|------------------|---------------|--------------|
| Number of Buses:    | 1            | 0                | 34             | 35                |                  |               |              |
|                     | <u>XFMR2</u> | <u>XFMR3</u>     | <u>Reactor</u> | <u>Line/Cable</u> | <u>Impedance</u> | <u>Tic PD</u> | <u>Total</u> |
| Number of Branches: | 16           | 2                | 0              | 15                | 0                | 1             | 34           |

| OCP Objective   | Energy Based on     | Energy Cost (\$/kWh) | Planning Period (Years) | Interest Rate (%) |
|-----------------|---------------------|----------------------|-------------------------|-------------------|
| Voltage Support | Average Energy Cost | 0.08                 | 10                      | 0.00              |

| Load Stages | Time Distribution of Load (%) | Global Load Diversity Factor (%) |
|-------------|-------------------------------|----------------------------------|
| Maximum     | 25                            | 125                              |
| Average     | 55                            |                                  |
| Minimum     | 20                            | 80                               |

|                            |                                                            |
|----------------------------|------------------------------------------------------------|
| Method of Solution:        | Adaptive Newton-Raphson                                    |
| Maximum No. of Iterations: | 99                                                         |
| Precision of Solution:     | 0.000100                                                   |
| System Frequency:          | 50.00 Hz                                                   |
| Unit System:               | English                                                    |
| Project Filename:          | My thins OCP                                               |
| Output Filename:           | C:\ETAP 1260\Mod6\My thins OCP\Access Backup\Untitled6.CAT |