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# ADDIS ABABA UNIVERSITY

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

# GIS Based Modeling and Performance Improvement of Distribution Network

## (Case Study: Adama Town 15 kV Distribution Network)

A Thesis Submitted to Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Electrical and Computer Engineering (Electrical Power Engineering)

By
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**Advisor**
**KIROS TESFAYE (PhD Candidate)**

*December, 2021*
*Addis Ababa, Ethiopia*

# Declaration

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

| *Researcher's Name* | *Date* | *Signature* |
|---|---|---|
| **Tefera Derbe Jiru** | __________________ | ________________ |

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

***Kiros Tesfaye (PhD Candidate)*** ***Signature _________***

# Approval Sheet

## GIS Based Modeling and Performance Improvement of Distribution Network

## (Case Study: Adama Town 15 kV Distribution Network)

**By:**

Tefera Derbe Jiru

## Approved by:

**Advisor:** Kiros Tesfaye (PhD Candidate) Signature _________ Date: _________

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**Examiner 2:** ______________________ Signature ___________ Date: _________

# Acknowledgment

First and foremost, I would like to give special thanks and glory to Almighty God who is the source of my strength. He gave me the grace, wisdom, good health and guided me throughout my life.

Then, I would like to acknowledge and extend my sincere gratefulness to my advisor, **Kiros Tesfaye (PhD Candidate)**. His valuable and academically important supervision, hints, inspiration, ideas, support and productive comments were very important for me. Throughout this thesis work, I received continues assistance from him and finalizing of this thesis study would have been hard without his support.

As well as, I would like to acknowledge and extend my gratitude to **Mr. Adugnaw Lake** (lecturer at Addis Ababa University school of electrical and computer engineering) for his essential guidance and support that play great role for the success of this thesis.

I wish to express my sincere thanks to my mother **W/ro Tewabech Kura**, all my sisters and brothers and families for their motivation and lovely support in every step of my life.

I would like to thank my respected wife **W/ro Kidist Getahun** and my lovely Children, **Mekides Tefera** and **Natan Tefera** for all the joy, happiness and others they brought into my life.

# ABSTRACT

*Different Studies show that power distribution systems in Ethiopia is the weakest area compared to generation and transmission. In this thesis work, Geographic Information Systems (GIS) based modeling and performance improvement of Adama town 15kV distribution network was done that can enable operation and planning offices to take measurements based on the proposed methods.*

*The attribute and electrical data are obtained from the already available data base and also additional data was collected on field visit. Then database was created and the network was mapped using Geographic Information Systems (GIS). By integrating the GIS database with the Electrical Transient Analyzer Program (ETAP), modeling and power flow analysis were done by ETAP Software for all ten (10) 15kV feeders under the study. Line 1 was selected as it is experienced significance power loss and voltage drop compare to the others. This thesis was mainly concerned with the power losses and voltage drop of the distribution network. Optimal Capacitor Placement (OCP), Conductor Upgrading (CU), and the combined solution of OCP and CU techniques were used to reduce power loss and improve voltage profile for both the normal and design scenarios for distribution network.*

*The result shows that the combined solution of OCP and CU gives the maximum active power loss reduction (57.6%), followed by CU (42.9%) and OCP (32.9%). It also shows the highest bus voltage profile (≥ 0.971pu), followed by OCP (≥ 0.942pu) and CU (≥ 0.91pu). However, the combined solution of OCP and CU needs higher initial capital investment cost of Birr 8,652,573.61 with return of investment of 1.40 years, whereas CU and OCP needs initial capital investment cost of Birr 5,607,309.85 and Birr 3,045,263.76 with return of investment of 1.21 year and 0.86 year, respectively. Thus, among the three cases, OCP is selected for the current scenario due to its best active power loss minimization and minimum voltage drop with best return of investment. On the other hand, the result for the design scenario (10 years forecast) shows that the combined solution of OCP and CU gives the highest active power loss reduction (57.7%), followed by CU (46.3%) and OCP (22.3%). It also shows the highest bus voltage profile (≥ 0.894pu), while the maximum bus voltage for CU and OCP were 0.840pu and 0.835pu, respectively. Hence, among the three cases, the combined solution of OCP and CU is selected for the design scenario (10 years load forecast) due to its best power loss minimization and minimum voltage drop.*

*In general, the results of this study revealed that for short term solution, optimal capacitor placement (OCP) method is proposed, whereas for long term solution, the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size is proposed, to be implemented to improve the performance of distribution network on the bases of loss reduction and voltage profile improvement.*

**Keywords**: *GIS, distribution network, power flow analysis, ETAP, power loss, voltage drop, optimal capacitor placement, Conductor upgrading.*

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# List of Abbreviations

| | |
|---|---|
| CU | Conductor Upgrading |
| EEP | Ethiopian Electric Power |
| EEU | Ethiopian Electric Utility |
| ETAP | Electrical Transient Analyzer Program |
| FD | Fast Decoupled |
| GIS | Geographic Information Systems |
| GS | Gauss-Seidel |
| LV | Low Voltage |
| HV | High Voltage |
| kV | kilo Volt |
| kVA | kilo Volt Ampere |
| KVar | Kilo Var |
| kW | kilo Watt |
| KWh | Kilo Watt hour |
| MATLAB | Matrix Laboratory |
| MV | Medium Voltage |
| MVA | Mega Volt Ampere |
| NR | Newton-Raphson |
| OCP | Optimal Capacitors Placement |
| PF | Power Flow |
| PLI | Power Loss Index |
| VPI | Voltage Profile Index |

# CHAPTER ONE

# 1 INTRODUCTION

## 1.1 Background

Electric energy has become the most available form of energy used in industries, commercial centers, residential homes, etc. The economic growth and advancement of any people mainly depend on the efficient and cost effective control of the obtainable electrical energy [1].

Basically, electrical distribution network is developed to carry the electric power from transmission network to customer premises. Improving the performance of distribution networks to achieve the essential target is a burning issue for utility companies of electric energy. It can be achieved by implementing the most appropriate and effective technology with the right operating practices. Furthermore, distribution system may be modified in order to both improve its today's performance and determine the most possible solutions based on future demand forecast [2].

As all components of the distribution network have a geographical reference, it is useful to create digital map for electrical distribution network using GIS and shall be updated regularly based on field parameters. Regular updating and monitoring of GIS map of the electrical network and consumer database is useful to improve planning, load management, loss minimization, improving revenue collection, and asset management and in general to improve the performance of the operation [2, 3].

**Distribution Network in Ethiopia**: In 2013, the former Ethiopian Electric Power Corporation was split into two companies namely Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU). All electric power generation stations connected to the grid, and primary transmission systems 500 kV, 400 kV, 230 kV and 132 kV are under EEP while the sub-transmission systems 66 kV, 45 kV, distribution systems 33 kV, 15 kV and LV networks are under EEU.

At all the 66 kV or 45 kV substations, power transformers of various ratings like 25/12/6.3/3 MVA are installed for step down of voltage to 33 kV and 15 kV for feeding to distribution transformers. Most of the outgoing feeders are connected in radial fashion.

For feeding the distribution transformers, mostly, 33 kV and 15 kV overhead conductors and underground cables are used. The voltage is then further step down by distribution transformers to the utilizing of voltages level of 380 volts three-phase or 220 volts single-phase supply required by most users [14].

Once the voltage has been step down to low voltage level at the distribution substation, the electric power is then supplied to industrial, commercial, and residential end users through low voltage distribution networks. Currently, due to the increasing of power demand, the compact substation with rating of 630 up to 2500 KVA have been introduced to the distribution network in Addis Ababa city and some major towns of Ethiopia.

Article by [14] and different internal study reports confirmed that electric distribution network in Ethiopia is the weakest part of power system components compared to generation, transmission and substation. It directly affects power supply to the customers. Now a day's quality of electric power in the distribution system in Ethiopia is the major concern. Customers require quality service as their day to day life is depend on electric energy. The effectiveness of distribution network is measured in terms of efficiency, service continuity or reliability, and supply quality in terms of voltage drop and power loss.

**Power Distribution Network and GIS**: Geographical Information System (GIS) is a set of technological procedures developed to collect, store, manipulate, analyze, manage, present and disseminate spatial or geographic data for public or decision makers. Each component of the electric distribution network can be mapped spatially by using GIS. Moreover, the conceptual model of GIS can provide a useful way to visualize geographically the electrical distribution system as a set of map layers (themes), all components overlaid to a common geographic area [7, 4]

GIS provides an upgrade in method to collect, store, and handle the data more professionally in the electric power distribution system. GIS cover from the aspect of the database for inventory, map interacting viewing and several methods of analysis based on need. Based on this capability, the implementation of GIS in electrical distribution network system analysis and management is a suitable approach to increase the performance of electric utility companies serving to the end-users [4].

This thesis work focus on modeling and power flow analysis of 15 kV distribution network of Adama town using Geographical Information System (GIS) and Electrical Transient Analyzer Program (ETAP) software to improve its performance in terms of loss minimization and voltage profile improvement.

## 1.2 Problem Statement

The electric distribution network is the component of the power system that has the most disruptions. The electricity demand has been grown rapidly, and thus, distribution feeders, which transfer electrical power from the substations to end users, are overloaded beyond their carrying capacity. Overloaded distribution feeders that travel long distances have large power losses and voltage drop problems. Thus, both utility companies and their customers suffer from these problems and improving voltage profile and reducing power losses are the biggest challenges for electric power utility in developing countries [2, 5, 15].

In addition, finding efficient and effective techniques and mechanisms for loss reduction and voltage profile improvement together with feasibility analysis, and proper sizing and locating of the selected techniques in distribution network are also critical issues for loss reduction and voltage profile improvement in the power distribution network [5].

The present situation shows that electric distribution network in Ethiopia is the weakest area compared to generation, transmission and substation. It directly affects power supply to the customers. Reliability and power quality in terms of power losses and voltage drop are some common problems. In Adama town, power distribution network is faced with problems such as over loading of conductors and cables, and voltage drops due to the distance covered by the distribution line.

Analyzing power losses and voltage drop in the distribution network, and finding economical solution for loss reduction and voltage profile improvement of distribution networks with appropriate size and location of proposed mechanisms are challenging problems for the utility.

Therefore, this thesis address the problem of power loss reduction and voltage profile improvement in 15 kV distribution networks of Adama town using optimal capacitor placement, conductor upgrading and combination of both methods based on GIS based modeling and power flow analysis. The effectiveness of the proposed methods is tested through simulation studies using ETAP.

## 1.3 Objectives of the Study

**General objective**: The general objective of this thesis is GIS based modeling and performance improvement of Adama 15 kV distribution network by optimal allocation of capacitors and upgrading of conductors

**Specific objectives**: The specific objectives of this thesis are:

1. To collect data and develop GIS based model of the existing Adama15 kV distribution network
2. To carryout load flow analysis of the 15 kV distribution network using ETAP software
3. To analyze the simulation results and identify the weak buses for allocation of capacitors
4. To determine the optimal size and allocation of capacitors
5. To develop software model of the 15 kV distribution network with optimal placement of capacitors and upgrading of conductors using ETAP software
6. To carry out simulation studies of the distribution network using the models with optimal placement of capacitors, upgrading of conductors and the combination of both methods
7. To carry out cost benefit analysis of the proposed methods as noted above
8. To analyze the results,
9. Draw conclusions and make appropriate recommendations to Ethiopian Electric Utility (EEU)

## 1.4 Significance of the Study

As the demand of electricity consumption increases, the existing power distribution network leads to the problems of power loss and voltage drop. Hence, adequate power loss minimization and voltage profile improvement mechanisms shall be implemented.

The purpose of this research is to propose economical method to improve the performance of 15 kV distribution networks in terms of loss minimization and voltage profile improvement. The contribution of this thesis work presents power loss minimization and voltage profile improvement in 15kV distribution networks of Adama town through optimal capacitor placement, conductor upgrading and combination of both methods.

## 1.5 Scope of the Study

This thesis focuses only on two factors, power loss minimization and voltage profile improvement, that are more important for improving the performance of Adama town 15kV distribution network

Geographic Information System (GIS) is used to model the 15kV distribution network of Adama town. GIS is selected due to its ability to select the information needed depending upon the intended application and integrate the spatial data with ETAP software.

The power flow analysis 15kV distribution network is done by the Electrical Transient Analyzer Program (ETAP) software. ETAP is selected as its calculation is precise enough and trusted to be used as guidance to ensure proper network operation.

Power flow analysis was done for all ten (10) 15 kV lines currently supply power for the entire Adama town and among these, one (1) 15kV line ( Line 1) with significant power loss and voltage drop was selected for the simulation of proposed methods for the loss minimization and voltage profile improvement.

Cost benefit analysis was done for all proposed methods to select the economical method for better implementation.

**Limitations of the Study**: The followings are limitations this study:

- The study is limited to optimal capacitor placement, conductor upgrading and combination of these two methods to improve the performance of distribution networks

- The study is limited to loss minimization and voltage profile improvement to improve the performance of distribution networks

- The study size is limited to 15 kV Adama town distribution networks and the proposed methods are simulated and tested on one 15kV distribution line.

## 1.6 Methodology

The problem identification was the first step and reviewing of literatures related to distribution network analysis to come up with ideas for mitigating the problems. Then a detailed survey of published literature was done on techniques how loss reduction and voltage profile improvement can be achieved and better understanding on the capacitor placement, conductor upgrading and combination of capacitor placement and conductor upgrading methods employed on power distribution network to optimize power loss and voltage drop.

Recent and unpublished important information related to power quality problems in terms of power supply quality and losses of power distribution system in Ethiopia were collected from Ethiopian Electric Utility and other relevant sources.

Generally, the following methodology has been followed in conducting this thesis work.

**Site Selection**: Adama town 15kV distribution network was selected as case study area where power loss and voltage drop problems are highly identified and not to satisfy the demand for load growth from time to time.

**Data Collection**: The following steps have been followed for data collection.

- Perform site visiting and understanding about Adama town 15kV distribution networks.
- Collection of available data for the selected distribution network from EEU IFRI (International Financial Reporting Standards) and FAIR (Fixed Asset Inventory and Revaluation) Projects.
- The available data collected from EEU was verified with the actual network configuration on site.
- 
- The data collected for the distribution network was then organized in terms of spatial and non special data

**GIS based Modeling**: GIS based modeling of 15 kV distribution network of Adama town was done using the following steps.

- Using the collected and organized spatial and non spatial data, GIS based database was developed for 15kV distribution network of Adama town.
- Using the developed database, GIS based modeling of 15 kV distribution network of Adama town was developed and layers of distribution networks components (overhead lines, underground cables, distribution transformers and etc.) were created and displayed on common GIS map.
- GIS based database of the 15 kV distribution networks was exported to ETAP software to perform load flow analysis.

**Load flow Analysis using ETAP**: The engineering modeling of all the 15 kV networks, and transformers, etc. was done in the ETAP software using imported network data from GIS based database. And the following setting was applied to perform load flow analysis using ETAP.

- Conductor and cable parameters were used from EEU's existing technical data, and a separate ETAP library was developed.
- Transformers loading factor and load allocation was performed using the collected load data.

**Performing Load flow Analysis**: the load flow analysis was done with and without optimal capacitor placement, conductor upgrading and combination of optimal capacitor placement and conductor upgrading. The load flow analysis was done for the following two scenarios

- Perform the load flow analysis for current load scenario of the existing 15 kV distribution network (Case-1)
- Perform the load flow analysis for load forecasting after 10 years (Case-2).

Among the 10 distribution lines, a line that experiences significant amount of power loss and voltage drop was identified, and proposed solutions were simulated.

**Analysis of the Result:** the simulation results with and without optimal capacitor placement, conductor-upgraded, and combination of optimal capacitor placement and upgrading with optimal conductor size were compared and discussed. Finally conclusion and recommendation was forwarded.

## 1.7 Organization of the Thesis

Chapter One: In this chapter, power distribution system concepts related to the background of the study is described. It also describes problem statement, objectives, significance, scope, and methodology of the study. Chapter two introduces about power distribution network, power quality, reduction of power losses and voltage drop in the distribution networks and power flow analysis for distribution network are discussed. Literatures are also reviewed. Chapter three focuses on GIS based modeling and performance analysis of the existing 15 kV distribution networks of Adama town in terms of power loss and voltage drop. Chapter four presents performance improvement of 15kV distribution networks of Adama town in terms of power loss minimization and voltage profile improvement. And also describes proposed solutions to reduce power loss and improve voltage profile. Finally, Chapter five concludes the study results and forwards recommendations based on the findings of the study and suggested future works.

# CHAPTER TWO

# 2 POWER DISTRIBUTION NETWORK ANALYSIS AND LITERATURE REVIEW

## 2.1 Introduction

Electricity demand has been grown rapidly. As a result, improving power losses and voltage drop are becoming the biggest challenges for utility companies of developing countries. Thus, a poor voltage profile with higher loss has not reliable power system if no proper measures are put in place. In particular, for the utilities with lack of sufficient funds for the expansion of their power infrastructures, it is necessary to reduce power losses and voltage drops. Minimization of power losses and voltage profile improvement play significant role to enhance the performance of power distribution networks.

The load flow study is an important for electrical distribution systems analysis and it is very important to make ensure that the transfer of electrical power from supply units to end users is stable, reliable and cost effective.

GIS comes as perfect software that helps utilities to reduce the cost of manual maintenance and enables the simultaneous assessment of financial, technical, and environmental factors. Using GIS, the entire electrical distribution networks can be overlaid on the geo referenced base map or a vector base map with the feature of zooming, adjust the size and scrolling.

The structure of power distribution network is discussed in Section 2.2. Section 2.3 discusses about minimization of power loss and voltage drops in distribution networks. Power flow analysis is briefly discussed in Section 2.4. Section 2.5 presents applications of GIS in power distribution utilities. Lastly, literature review is presented in Section 2.6.

## 2.2 Structure of Power Distribution Network

The supply of electricity to customers requires various components including generating, transmission and distribution systems. These components are interrelated to each other and form an electric power system. Electric power system is a collection of electricity centers and substations (load centers) which are connected to one another by a transmission network. Distribution network is the integral part of the power system that has the most disruptions, so the main problem in operating the distribution network is to overcome the disruptions. Disturbances can also occur in the generator, transmission and distribution systems so that it will have a blackout on the customer [15].

Distribution networks are often radial which has advantage of easier fault current protection, lower fault current, easier voltage and power flow control and minimum cost. A radial distribution network might have different types of feeder such as single main line, branch main line, very brunched main line and express feeder.

Voltage levels of the distribution network ranges from 4kV up to 35 kV of which 5kV, 11kV, 15kV, 25kV, 35kV are the most common voltage level. 15 kV insulators are applicable for using any 15 kV class voltages such as 12.47, 13.2, 13.8 and these voltages are not actual system voltage. Most utilities use 15 kV voltages in North America among which 12.47 kV is widely used and it has line to ground voltage of 7.2 kV. Higher voltage primary distribution was widely used in the later part of twentieth century which carry more power for certain amount of current which in turns reduce the voltage drop, power loss. Higher voltage system needs fewer voltage regulators and capacitors for voltage support and more power or smaller currents can be carried for higher voltage for longer distribution circuits which reduce the number of distribution transformer [16].

Electrical distribution networks consist of primary distribution feeder, distribution transformer, distributors and main service lines. The transmitted electric power is step down at the substations, which is connected primary distribution feeders. Through the primary distribution feeders, the stepped down electric power is fed to the distribution transformers for further stepping down. Distribution transformers are mainly three phase and pole mounted or ground mounted type. The secondary (the low voltage side) of the transformer is connected to distributors. Different low voltage users are fed the electric power by means of the main low voltage service lines. These main low voltage service lines are tapped from different points of distributors. The distributors can also be categorized by distributors and sub-distributors. Distributors lines are directly connected to the secondary or low voltage side of distribution transformers whereas sub-distributors are tapped from distributors. The low voltage main service lines of the user may be either connected to the distributors or sub-distributors depending upon the location and accessibility of consumers.

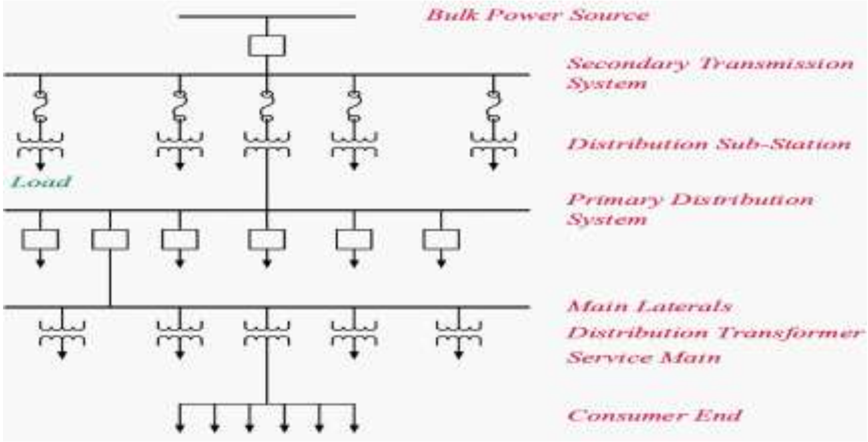

*Figure 2-1 General Diagram of Distribution Network*

Both feeders and distributors transmit electrical power to load, but they have one basic difference. Feeder feeds electrical power from one point to another without being tapped from any intermediate point. Since there is no tapping point in between, the current at sending end is equal to that of at the receiving end of the lines. In order feed the customers in between, the distributors needed to be tapped at different suitable points of the distributers; and hence the current varies along their entire length of the distributers. The electric distribution network is one of the sensitive parts of the power system components as it is connected to the load center. The finding of different studies have shown and confirmed that 80% of power supply failure of the electric power system resulting from the problems and breakdowns happened at the electrical distribution networks system [17].

## 2.3 Minimization of Power Loss and Voltage drop in Distribution Network

The need of voltage profile improvement is one of the major concerns and poor voltage profile leads to massive economic losses all over the world. Electric Utilities Companies must follow the minimum standard for the length of distribution network feeders and maximum loading of transformers. Transformers shall not be loaded more than 80%. Lengthy distribution feeders shall be connected with voltage booster to boost the supply voltage to standard ±5% nominal voltage value. This removes the critical voltage drops problem in low voltage electric distribution networks. When the distribution length extends beyond the minimum standard length, in order to improve the voltage profile from the beginning of the network to the end to the standard permissible range, utility companies of electricity distribution must provide an effective and efficient means of voltage booster connected along the feeder length [18].

According to [19], voltage problem might be defined as any electric supply that causes to malfunction or prevents their use or the level to which the utility voltage not approaches the ideal case of stable, continuous, pure signal and disturbance free power source. A best utility have to do its best to supply customers a perfect sinusoidal voltage source. Load current can affect voltage as it interacts with system impedances, but voltage is the ultimate measure of power quality. Perfect voltage profile is characterized by a perfect sinusoidal voltage source without waveform distortion, variation in amplitude or variation in frequency. To attain near perfect voltage profile, a utility could spend vast amounts of money.

Electrical distribution system carries electric power from substation transformer to distribution transformer and as it operates with large current as compared to transition system i.e. low voltage, voltage drop and loss problem is very high. Loss and voltage drop problem have its own impact on the distribution system. Both utility and customer equipment’s that are connected to the distribution system may not operate properly since they are designed to work at a certain rating [18, 20].

**Power Losses in Electrical Distribution Network**: In the process of delivering electric power to customers, loss has been occurred in generation system, transmission systems, and distribution networks system. The purpose of distribution network is to take electric power from the transmission part of the power system and deliver it to end-users or customers to serve their needs. However, a significant amount of the electric power can be lost at the distribution comments of the system and losses occur at each stage of the distribution network process. As compared with other, power loss in the distribution is very high, since it operates at low voltage [6, 21].

Distributing of electric power from transmission component of the power system to the end users is complemented with losses of power at all times. Power losses increases in distribution networks due to joule’s effect, which can be evaluated and approximately equal to 13% of the energy produced, has a direct impact on the economic development and the effectiveness of the power supply utilities [22].

Power losses in the components of distribution network can be shared into two: technical losses and non-technical losses. The causes for the technical losses are high resistance and reactance of the conductors and faults. Several factors which include unbalanced loading of transformers' outgoing feeders, leakage current inside transformers, aged transformer due to long service time, damaged accessories or lose of connections, inappropriate size of conductors were discovered to have significant contribution for power losses [21, 22].

Technical losses in power system are caused also by the physical characteristics of the lines and equipments of the power system. These losses occur naturally as they consist of dissipation of energy in electrical system components such as transformers, conductors, measuring systems/instruments and other equipment that can transmit energy to and from end users. On the other hand, non-technical losses are primarily related to energy flows like unidentified, misallocated, and inaccurate. They represent the amount of energy that is delivered but not accounted for. This type of losses is caused by actions that are external to the power system. These losses can be also viewed as undetected load of customers that the utilities don't know [20].

Technical losses occur in numerous small components in the distribution system, such as transformers and distribution lines. Transformers and power lines are major sources of losses in power distribution systems. Core (iron) losses and copper losses occur in transformers. As load increases, the copper losses become significant, until they are approximately equal to the core losses at peak load. It is very important for electric power suppliers to consider these losses and reduce them wherever practical. Technical losses mean losses that occur due to physical nature of the equipment and infrastructure of the power systems, that is, $\boldsymbol{I^2R}$ loss or copper loss in the conductor cables, transformers, switches and generators. Non-technical losses are losses happened due to individual errors and social issues. It is more difficult to measure non-technical losses because these losses are often unaccounted for by the operators and thus have no measured and recorded information [20, 21].

In distribution network, the grid is almost in radial so the level voltage, load density are the main factors concerning about the system loss. Technical loss has been consisting mostly dissipation of power in the electrical system components such as transmission lines/conductors, power/distribution transformers, measurement systems/instruments, etc. It is possible to analyze and manage the power system consists of known quantities of loads or measured loads. Using computation tools for calculating power flow, loss and equipment status in power systems has been developed in nearly years [21, 23].

Advancement in information technology and data acquisition has made the calculation and verification to be easier. Loss depends on various factors, such as load density, inadequate designs, and improper maintenance, etc. There may be significant proportion of unaccounted loss due to inaccuracy in meters, flat rate tariff structure, error of customer billing, pilferage of energy and unauthorized use of electricity. Most of them fall under non-technical loss. The reduction in system loss can result in substantial saving in energy has been increased in the power capacity supply [21].

The calculation of power losses for each of the 15 kV feeders, which are obtained on the basis of the average maximum loading on the feeders, resistance of conductors, size of each feeder conductor, route length of each feeder and maximum current drawn from each feeder conductor, is shown as follows:

The current drawn from the feeder line ($I_L$) *and* resistance ($R$) were determined by using equation (2-1) and (2-2).

$$I_L = \frac{P}{\sqrt{3}\, V(p.f)} \qquad \text{(Equation 2-1)}$$

$$R = \frac{\ell L}{A} \qquad \text{(Equation 2-2)}$$

Where, $\boldsymbol{P}$ is power in Watts,

$\boldsymbol{V}$ is voltage in Volts,

$\boldsymbol{\ell}$ is the resistivity of the conductor in Ω-m,

$\boldsymbol{L}$ is the length of each segment of the line, and

$\boldsymbol{A}$ is the cross sectional area of the conductor used.

Then, the power loss on each feeder is determined by equation (2-3).

$$Power\ Loss = I_L^2 R \qquad \text{(Equation 2-3)}$$

**Voltage Drop in Power Distribution Network**: From supply quality point of view, the most important parameters are the voltage level or amount of voltage at the load point compare to the system voltage [24]. To keep the voltage level in a certain range, voltage regulations is usually applied to a standard power distribution system. One knows that the slope of voltage profile is determined by type of a transmission line, its cross-section, and the power flowing through it [24, 25]. For the power distribution system that is not well installed in line to a high standard, it is possible to minimize the voltage drop by changing MV/LV transformers tap position and by placing shunt capacitor banks in the network, reactive power can be compensated, which causes a decrease in voltage drop. But compensation of reactive power and regulating of voltage does not help sufficiently to minimize power loss and voltage drop in the MV level of the power distribution system, because it does not deal with primary feeders and medium voltage level [18, 25].

**Minimization of Power Loss and Voltage Drop in Distribution Network**: Power loss reduction techniques on the power transmission system are not as effective as those on the power distribution networks. Hence, this thesis work focuses only on the minimization of power losses and voltage drop to improve the performance of power distribution networks. Power distribution network delivers electrical energy directly from suppliers to customers operating at different voltage levels. The importance of power loss reduction and voltage improvement in the distribution system is felt vital in the situation of increasing resource scarcity and escalating cost of electrical energy supply [21].

Minimization of power loss and voltage drop and maximization of power quality are the major aspects in power distribution networks, which have drawn serious attention of researchers, planners and designers. Therefore, several techniques were being proposed to reduce power losses, minimize voltage drop and maximize power quality in distribution system. Some of the power loss and voltage drop reduction techniques are: network re-conducting (conductor grading), reactive power compensation, network reconfiguration, locating and sizing of distribution transformer, using highly efficient transformer, and using high voltage distribution system [26, 22].

The major power losses and voltage drop reduction techniques are discussed as follows.

**Conductor Upgrading:** Conductor upgrading is the technique of replacing the existing conductor of the feeder lines by conductor of optimal size for optimal length of feeder to reduce the resistance. This can be obtained by replacing a conductor having larger cross-sectional area for the small size conductors, or installing auxiliary conductors to work together in parallel with the existing ones. This method can give large power loss reduction. However, it is not cost effective, as the cost of delivering conductors and their installation are usually in excess of the cost of the energy saved [27].

This technique is implemented when existing conductor on the feeder line is no more optimal because of rapid growth of load demand [28]. The technique is also good for the countries under developing stages where the annual energy demand growth rates are high and the conductors are selected to minimize power loss and voltage drop of the distribution network to decrease the initial capital investment. Moreover, feeder upgrading with larger conductor size can only be economically acceptable for aged distribution networks that are operating almost equal to their maximum capacity [22].

**Reactive Power Compensation:** Compensation of reactive power is defined as the controlling of reactive power to get better performance of AC power system. The benefits of compensation of reactive power in the distribution and transmission systems include voltage profile improvement, power loss reduction, by decreasing feeder impedance increases power flow capacity, and increases distribution network capacity using capacitors, and the distribution network capacity can also be improved by controlling reactive power flow [29].

Installations of capacitors are widely implemented in power distribution networks as one of the solutions to compensate reactive power, minimization of power loss and voltage regulation problems. The most frequent importance of reactive power compensations are simple in construction, reduction of line losses and improving of voltage profile, increasing of feeder capacity and lower implementation cost. However, during implementation of reactive power compensation, optimum size and placement of capacitors are important for its effectiveness [23, 30, 22].

Capacitors are installed in distribution network for reactive power compensation to carry out power and perform energy loss reduction. The size and optimal location for placement of capacitor are crucial factors in the application of capacitors for voltage profile improvement and power loss minimization. The appropriate size and optimal location for placement of capacitors is also important to make sure that the power losses and total capital investment costs for implanting the solution are minimal [30, 22].

**Network Reconfiguration:** One of the common approaches to the power loss minimization is reconfiguration of a distribution network. One should know that a power distribution network normally contains different types of loads such as industrial, commercial, and residential. On the other hand, the peak load occurs in different times of the days. Hence, by shifting the loads from overloaded feeders to slightly loaded feeders, it is possible to reduce the power losses in the acceptable amount and make the network more balanced [31, 32].

Network reconfiguration is the process of implementing load shifting to change the circuit topology so that operating costs are reduced while maintaining the identified constraints [28]. Reconfiguration of feeders is used for shifting of loads from heavily-loaded feeders to relatively lightly-loaded feeders and form higher-resistance feeders to lower resistance feeders to achieve the least loss, where resistance of feeder is the overall resistance from the source to end of load point. Such balancing of the loads is effective not only in terms of changing the level of loads on the feeder being switched to or from, and minimizing the losses, but also helps to improve voltage profile along the feeders lines and affecting reductions of power losses in the overall power system. However, for fare apart and feeders not automated, feeder reconfiguration may not be cost effective [27, 33].

An effective feeder reconfiguration approach takes advantages of the large level of load diversity that exist on some distribution networks. With the introduction of remotely control of switches for load shifting, online reconfiguration becomes an important part of the distribution network automation. As the operating condition change from time to time, the network can be reconfigured for two objectives: loss reduction and feeders balancing [22].

The advantages of network reconfiguration techniques include enhance the quality of power supply, significant reduction of line losses and subsequent saving of energy cost, and additional loads can be supplied without any additional investment on infrastructure. However, network reconfiguration has disadvantage as it involves approximation and exact amount of loads to be shifted is essential for its effectiveness [22].

**Distribution Transformer Locating and Sizing:** If the location distribution transformers in the network do not keep the load center with respect to consumers, the farthest consumers will obtain very low voltage level even though a reasonably acceptable voltage level is achieved at secondary side of transformer. This may bring significantly higher losses in distribution network. So, distribution transformers should be installed by keeping the load center as match as possible and replace the higher rating of the transformers by the transformers of small capacity so that it serves small amount of loads so that the acceptable voltage level is maintained for smooth operation [20].

To reduce losses, load management of distribution transformer involves balancing the power load between phases and resizing those over-and under-utilized transformers. Ideally, phase currents and all distribution transformers' voltage would need to be managed in order to practice load management of distribution transformers properly. However, for most power supply utilities, such measurements are only available at the substation level, and monitoring every pole and pad mounted transformer downstream from the substation would prove to be costly. At the very least, the load management of distribution transformers can be considered at the designing stages of a distribution network by determining the size of transformers for maximum efficiency [22].

Generally, to reduce the existing power loss and voltage drop problems of the distribution network of the study area, this study uses optimal capacitor placement (OCP), conductor upgrading (CU) and combination of both methods, and the results of these three cases are compared for the current scenario (existing condition) and the design scenario (after 10 years).

In this thesis, first, the load flow analysis is carried out using ETAP software to find the power losses and voltage drop on the distribution feeders. Next, for conductor upgrading techniques, appropriate size of conductor selection is done using ETAP software. For optimal capacitor placement, power loss based sensitivity index for candidate bus selection is calculated using MATLAB program. Then, using those selected candidate buses, the size and proper locations of the capacitor banks are identified by using ETAP. Finally, ETAP load flow analysis is carried out for the system after OCP, CU, and combination of OCP and CU.

## 2.4 Power Flow Analysis

The load flow study is an important for electrical distribution systems analysis and it is used in operational as well as for design stages. Many real time functions in electrical distribution automation system such as networks optimization, reactive power management, load shifting, state estimation and so etc. need the implementation of a robust and effective power flow analysis method. Such a power flow analysis method must support the model that contains the special features of distribution system analysis.

The power flow analysis is the basic for designing and study of power distribution network. It is the basic and necessary method for design, planning, operation, cost effective for scheduling and to exchange power between utilities. Implementing power flow analysis would time taking to get the calculated result; therefore, it prevents from getting more precise result for a power flow solution since there is a continuous change in demand and generation in the power system. The aim of power flow analysis is to determine voltages for the different type of buses, phase angles, the flow of active and reactive power through different branches, generators, transformers, settings conditions and status loads under the steady state, to help during operation and future expansion of the network [34, 35].

The implementation of power flow studies is very important to make ensure that the transfer of electrical power from generating units to end users through the grid system is stable, reliable and cost effective. The increasing presence of distributed alternative energy sources, often in geographically remote locations, complicates flow studies and has triggered a resurgence of interest in the research works in a three phase system because of the flow of active and reactive power from the generating unit to the end users through different networks buses and branches. Power flow or load flow means the flow of active and reactive power through busses and branches. Load flow studies provides a methodical mathematical approach to determine different type of bus voltage, there phase angle, active and reactive power flows through different branches, generators and also to determine loads for the system which is under steady state condition [34, 36].

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. In the past decades, various techniques of numerical analysis have been applied for solving problems of power flow analysis. The most usually used iterative numerical methods are the Gauss-Seidel (GS), Newton-Raphson (NR) and Fast Decoupled (FD) methods [34, 10].

An efficient and simple load flow method is proposed for analysis of the radial and weakly meshed network based on network topology and basic circuit laws (KCL and KVL).

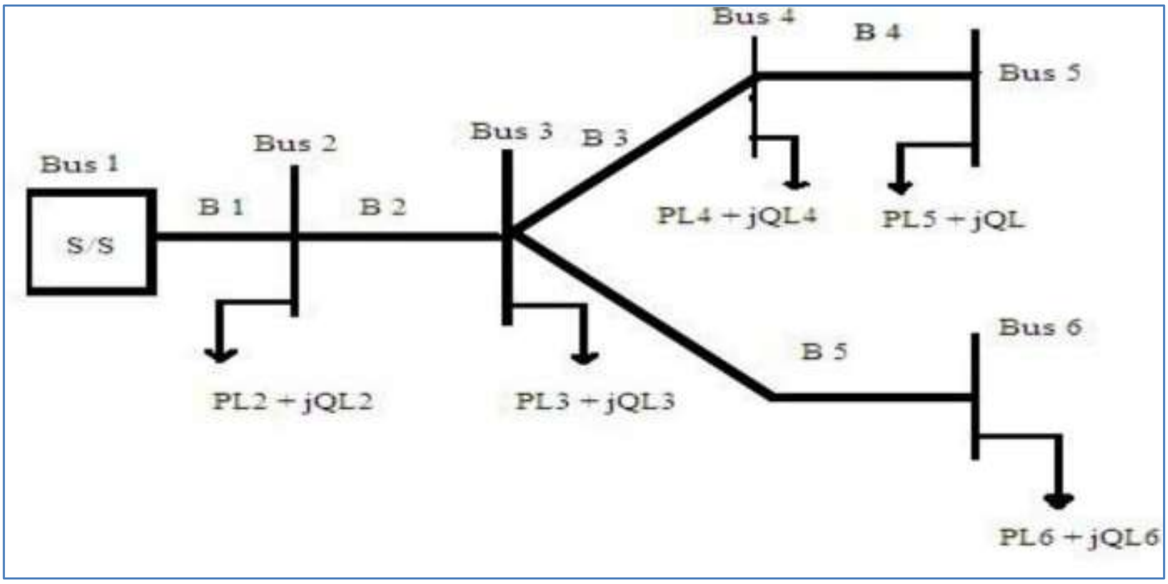

*Figure 2-2 Simple Radial Distribution System*

The effective powers at each node:

$P(1)+jQ(1)$, $P(2)+jQ(2)$, $P(3)+jQ(3)$, $P(4)+jQ(4)$, $P(5)+jQ(5)$, $P(6)+jQ(6)$

$$P(1)+jQ(1) = PL2 + jQL2 + PL3 + jQL3 + PL4 + jQL4 + PL5 + jQL5 + PL6 + jQL6 + Ploss(B1) + jQloss(B1) + Ploss(B2) + jQloss(B2) + Ploss(B3) + jQloss(B3) + Ploss(B4) + jQloss(B4) + Ploss(B5) + jQloss(B5) \quad \text{(Equation 2-4)}$$

$$P(2)+jQ(2) = PL2 + jQL2 + PL3 + jQL3 + PL4 + jQL4 + PL5 + jQL5 + PL6 + jQL6 + Ploss(B2) + jQloss(B2) + Ploss(B3) + jQloss(B3) + Ploss(B4) + jQloss(B4) + Ploss(B5) + jQloss(B5) \quad \text{(Equation 2-5)}$$

$$P(3) + jQ(3) = PL3 + jQL3 + PL4 + jQL4 + PL5 + jQL5 + PL6 + jQL6 + Ploss(B3) + jQloss(B3) + Ploss(B4) + jQloss(B4) + Ploss(B5) + jQloss(B5) \quad \text{(Equation 2-6)}$$

$$P(4)+jQ(4) = PL4 + jQL4 + PL5 + jQL5 + Ploss(B4) + jQloss(B4) \quad \text{(Equation 2-7)}$$

$$P(5)+jQ(5) = PL5 + jQL5 \quad \text{(Equation 2-8)}$$

$$P(6)+jQ(6) = PL6 + jQL6 \quad \text{(Equation 2-9)}$$

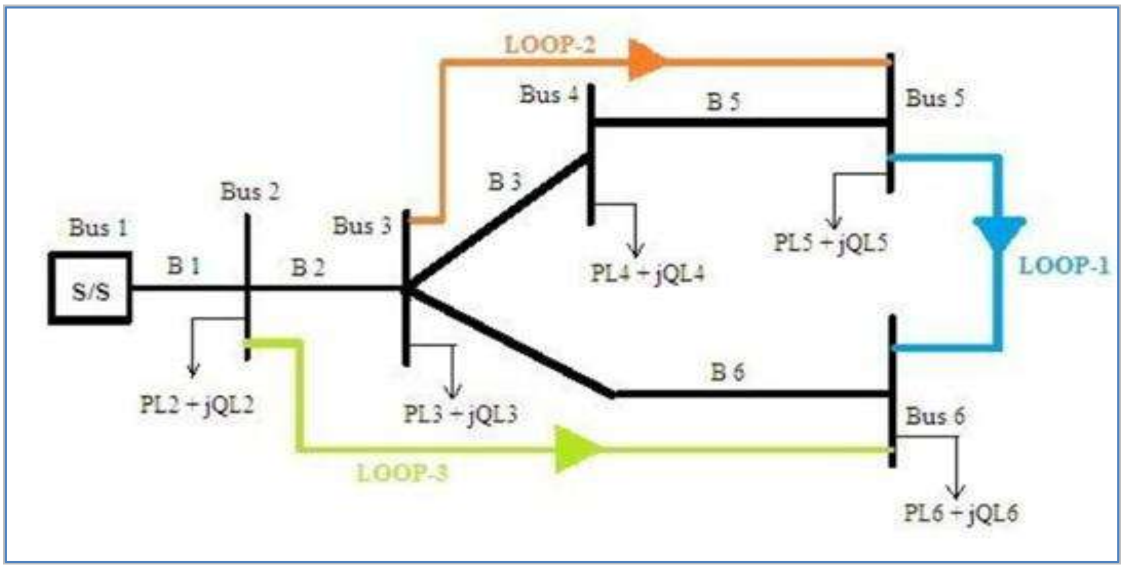

*Figure 2-3 Simple Meshed Distribution System*

Similarly, for mesh distribution system effective power at receiving end of each branch is recalculated as:

$P(1)' + jQ(1)' = P(1)+jQ(1)$ *(Equation 2-10)*

$P(2)' + jQ(2)' = P(2)+jQ(2)$ *(Equation 2-11)*

$P(3)' + jQ(3)' = P(3)+jQ(3) - \{ Iloop(3) * [V(3)]^*\}^*$ *(Equation 2-12)*

$P(4)' + jQ(4)' = P(4)+jQ(4) + \{Iloop(1) * [V(4)]^*\}^* - \{Iloop(2) * [V(4)]^*\}^*$ *(Equation 2-13)*

$P(5)' + jQ(5)' = P(5)+jQ(5) + \{ Iloop(1) * [V(5)]^*\}^* - \{Iloop(2)*[V(5)]^*\}^*$ *(Equation 2-14)*

$P(6)' + jQ(6)' = P(6)+jQ(6) - \{ Iloop(1) * [V(6)]^*\}^* - \{ Iloop(3) * [V(6)]^*\}^*$ *(Equation 2-15)*

Calculation of loop impedance matrix

KVL equations for simple meshed distribution system can be represented in matrix form as follow,

$$\begin{pmatrix} (Z34 + Z45 + Z36 + Z56) & -(Z34 + Z45) & Z36 \\ -(Z34 + Z45) & (Z34 + Z45 + Z35) & 0 \\ Z36 & 0 & (Z23 + Z36 + Z26) \end{pmatrix} \begin{pmatrix} Iloop(1) \\ Iloop(2) \\ Iloop(3) \end{pmatrix}$$

*(Equation 2-16)*

=

$(Z34 * \{[P(4) + jQ(4)/V(4)\}^* + Z45 * \{[P(5) + jQ(5)/V(5)\}^* + Z36 * \{[P(6) + jQ(6)/V(6)\}^* )$

$(- Z34 * \{[P(4) + jQ(4)/V(4)\}^* - Z45 * \{[P(5) + jQ(5)/V(5)\}^* )$

$(- Z23 * \{[P(3) + jQ(3)/V(3)\}^* - Z36 * \{[P(6) + jQ(6)/V(6)\}^*)$ *(Equation 2-17)*

Diagonal elements of loop impedance matrix,

$Zloop(i,i) = Zloop(i,i) + abs\,(C(j,i)) * Zpu(j)$ *(Equation 2-18)*

*For i = 1 : links, and for j = 1: elements*

Off diagonal elements of loop impedance matrix,

$Zloop(i,j) = Zloop(i,j) + C(k,i) * C(k,j) * Zpu(k)$ *(Equation 2-19)*

$Zloop(j,i) = Zloop(i,j)$ *(Equation 2-20)*

*For i = 1: links, j = i + 1: elements and for k = 1: branches*

Backward sweep to sum up the real and reactive power loads: starting from the last branch and moving towards the root node, the effective real and reactive power load demands are:

$PL(se(k)) = PL(re(k)) + PL(se(k))$

$QL(se(k)) = QL(re(k)) + QL(se(k))$ *(Equation 2-21)*

$P\,(re(k)) = PL(re(k))$

$Q\,(re(k)) = QL(re(k))$ *(Equation 2-22)*

*For k = 1, 2, 3, ….,nl*

$Pact = P$ and $Qact = Q$ *(Equation 2-23)*

Where Pact and Qact are the actual effective loads at each node (excluding losses)

Voltage drops in each loop containing radial branches

$VDloop(i) = VDloop(i) + C(j,i)* Zpu\,(j)* \{\,[\,P(\,re(j)\,) + Q(\,re(j)\,)\,]/\,V(\,re(j)\,)\,\}^*$ *(Equation 2-24)*

*For i = 1: links and for j = 1: branches*

Calculate the currents in each loop

$Iloop = (Zloop\ -1) * (- VDloop)$ *(Equation 2-25)*

Modify the effective real and reactive powers at receiving node of each branch

$P(re(i)) = P(re(i)) + real(\,C(i,j) * \{\,Iloop(j) * [\,V(re(i))\,]^*\,\}^*\,)$

$Q(re(i)) = P(re(i)) + imag(\,C(i,j) * \{\,Iloop(j) * [\,V(re(i))\,]^*\,\}^*\,)$ *(Equation 2-26)*

*For i = 1: branches and for j = 1: links*

Calculate the power losses in the tie lines using the loop currents

$Ploss\,(j + b) = [abs\,(Iloop\,(j))]^2 * Rpu\text{-}tie\,(j)$

$$Qloss\,(j + b) = [abs\,(\,Iloop\,(j)\,)\,]2 * Xpu\text{-}tie\,(j) \qquad \text{(Equation 2-27)}$$

The yearly energy consumption for the last twelve months is known for every consumer. Based on that, the power is estimated as follows:

$$P_{ave} = \frac{E\left(^{kWh}/_{year}\right)}{T\left(^{h}/_{year}\right)} \qquad \text{(Equation 2-28)}$$

where:

E= is the total energy which was used in the last twelve months,

T= is Time of use

In this thesis, a load flow analysis, which uses Newton-Raphson (NR) method, was deployed using ETAP software. The active and reactive power values based on NR method are estimated as follows [35, 16]:

$$P_k = \sum_{l=1}^{n} |V_k||V_l||Y_{kl}|\,cos(\theta_{kl} - \delta_k + \delta_l) \qquad \text{(Equation 2-29)}$$

$$Q_k = -\sum_{l=1}^{n} |V_k||V_l||Y_{kl}|\,sin(\theta_{kl} - \delta_k + \delta_l) \qquad \text{(Equation 2-30)}$$

A load flow report gives the data for active and reactive powers, voltage magnitude and voltage angle at each bus of the system. The total active and reactive power losses for the system were also extracted from the result of load flow analysis done by ETAP software.

**Power Flow Analysis using ETAP Software**: [37]In their work the load flow analysis was done to examine the performance of electrical system during normal and abnormal operating conditions, provided information needed to reduce KW and KVar losses; optimize circuit usage, develop practical voltage profiles to develop equipment specification requirement and identifies transformer tap settings. ETAP is computer based tools that can simulate the real time steady-state power system operations, computing voltages for different type of busses in the power system, determine real and reactive power flow and line losses through different branches in the network, etc.

ETAP offers the most accurate load flow analysis tools to create and evaluate electrical system designs effectively. ETAP calculate voltage drop and power losses in the system and efficiently build and evaluate system models using the advanced power flow analysis. ETAP system models efficiently and effectively function such as automatic device evaluation, alarms for critical and marginal units, a powerful results report comparison analyzer and intelligent, user friendly graphics make and it is the most consistent load flow analysis software. ETAP power flow software provides results, power factors for each branch, directional currents flows, and voltage drop calculations throughout each electrical system model. It allows multiple grid connections, detailed generator modeling, solar turbines, and induction generators for radial and mesh networks. ETAP interactively utilizes multiple calculation methods in order to calculate the best possible results [36].

ETP software is applied for the analysis and simulation of load flow, and voltage drop and mismatches in active and reactive power are determined in order to identify the buses or feeder line that are critically overloaded. The application of the ETAP software requested the argumentation of capacitor size to the distribution network that will help to improve the power network quality (performance) and investigate the activity of the network for future planning and expansion [38].

## 2.5 GIS for Power Distribution Utility

The complexity of the power distribution network and the importance of accurate and up-to-date information about the new network assets require software that is capable to store, analyze and plan existing and future networks. Hence, GIS comes as perfect software that helps utilities to reduce the cost of manual maintenance and enables the simultaneous assessment of financial, technical, and environmental factors [39].

According to [7], GIS can effectively used to manage the information about the distribution of electricity to the customers and information that can describe about the attribute data such as location and demand of electricity of each customer. It has already been found that the use of GIS is very crucial for electric companies in the effective management of distribution networks. The electric service provider has realized that GIS is an effective tool not only for visualizing the facilities on the digital map but to provide required information to enhance decision making and for better monitoring and controlling of infrastructure. Although the needs and uses of GIS are somehow different in the power utilities than other industries, GIS can provide a valuable information technology in the electric utility industry. In the presence of automated mapping, GIS can help the utilities to tastily create the digital maps of their networks using the digitization features of the software. These digitized maps of the infrastructure contain the detailed information about the land occupied by the utility, and the accurate location and engineering information of the distribution network equipment of the utility that are installed in the remote area. In facilities management, the files of the digitized map that are created with all the required information built into them can now be used to satisfy the needs of the facilities management. So, GIS in the electric power sector is used for the study and analysis for electrical distribution system, analysis and design and planning, different applications are also being developed for identifying problems of designing and planning of the electrical supply system or new expansion development, for process of automation in order to provide the end users with high quality attendance, to rebuild the design and planning of work procedures in electric utilities [7].

GIS can be called as a hub of data for electrical power engineers. It enables storing data in databases available constantly for analysis and performance monitoring, integration of real-time data, planning, design, etc. It allows a variety of devices to connect onto one database, share data and perform analysis in the same software. This makes the job of engineers' easier, sharing data between sectors more reliable. Geographical Information System (GIS) is a set of technological procedures intended to collect, store, and compute, analyze, manage, present and disseminate spatial or geographic data for public or decision-makers. Each component of the distribution network can be mapped spatially by using GIS. Moreover, the conceptual model of GIS is used to provide a useful way of visualize the facilities as a set of map layers (themes), all overlaid together to a common geographic area [7, 4].

The paper by [4] presented the importance of spatial elements (or GIS) in the power distribution network. This development brought a new aspect in power distribution management, starting from storing of digital data, sharing of digital data, and analysis of digital data. This digital map allows the data to be stored and processed by the experts in professional manners and also minimizes the risk of losing the data compare to the conventional method. Web based GIS application provides a new data-sharing method and platform for the user that can help improve efficiency in decision making and operation. In the meantime, more data is being collected to complete the whole Power Distribution Network System so that the analysis that can be carried out from the data can be more accurate and reliable [4].

Using GIS, the entire electrical networks can be overlaid on the geo referenced base map or a vector base map with the feature of zooming, adjust the size and scrolling. To begin the development of a GIS mapping for power distribution network, collection of GPS data becomes necessary for geo-referencing and mapping of the electrical distribution components on the digital base map. In some GIS applications, it is also possible to map the consumers to the corresponding electricity network components. The purpose of these applications is to index all the customers and categorize the complete customers' database with respect to their unique electrical address.

Integration of GIS with different utility applications includes customer information system (CIS), assets data management (ADM), outage management (OM) and utility billing system (UBS), and provides interfacing for cross-application data portability is the characteristics of seamlessly successful implementation of GIS.

**Digitization Process of Electric Distribution Networks**: The digitization process of electrical distribution network components, customers indexing and mapping of the network requires intensive steps:

- GPS survey of electrical power consumers and network assets: This involves the identification of all consumers and their service connections, followed by the preparation of GIS base map of the area.
- Digitization of electrical distribution network components (substations, feeders, transformers, poles and other equipments): differential GPS shall be obtained to collect the geo-coordinates with acceptable accuracy. Once the geospatial data is obtained, the electrical connectivity points with reference to pole, transformer, feeder, substation and other equipments is plotted on the base map.
- GIS mapping, indexing and codification of electrical power utilities customers and network assets data base with defined electrical relationships: This process requires collecting and updating of data of consumers of the utilities along with their electrical connection attributes.
- Exchange of data with other utilities application: The following important utility applications are needed to be integrated with the GIS application: Customer Information System (CIS), Asset Management System (AMS), Trouble Call Management System (TCM), Utility Billing and Energy Accounting System, Load Flow and Load Growth studies.

Availability of more precise GIS-based digital distribution network map showing the geo-coordinates and network configuration is an inessential precondition for analysis, planning, design, optimization of the load flow studies. The accurate GPS data and developing of an accurate digital base map for the distribution network is important for a successful implementation of GIS application. The collection of more accurate geo referenced data requires a GPS base station at a pre-determined location, supported by adequate number of GPS Rovers/ Receivers. Data collectors walk along the medium and low voltage feeders and capture the geo referenced data of the pole, transformer, feeder, substations and other equipments. Other required information (attribute data) of the distribution network shall also be collected in the process. Then differential correction of GPS data and verification shall be performed on the spatial data thus collected.

On the digital base map the important landmarks like roads, rivers etc. must be shown on the map which are important for easier identification of distribution network assets and plan new distribution network. In order to visualize geographically, the vector map of the distribution network shall be overlaid on the digital base map or on a satellite raster image.

Use of GIS application can assist real time query with a display of network section with location information of the particular network elements and their attributes data. The GIS applications have the ability to stitch together contiguous maps sections on the same scale into a continuous mosaic. Integrating with GIS application, the Customer Information System (CIS) can provide the complete information of the consumers and map of the network leading to the source from where the consumer is getting electricity. This information can be used for adding purpose like energy auditing, demand side management, network planning, designing and analysis.

Extensive and regular GIS updating of electrical network integrated with consumer and billing information can support utility managers with an important operational and decision making tools. Before forwarding any kind of decision, utility managers must use the GIS database to do important geospatial information like identifying the most suitable areas to place a new distribution lines, or finding the particular areas with most power outages and the parts of the networks system which are overloaded.

## 2.6 Literature Review

In recent years, several researchers have proposed different approaches and techniques for the analysis, simulation and modeling of power distribution networks. The paper by [40] proposed a novel method to deal with the energy minimization. The study by [2] demonstrated that GIS application helps in fast, precise and consistent data management provides timely, accurate and easy way of getting information and can be used as a decision making tool to improve the performance of electricity distribution network.

The paper by [4] presented the importance of GIS (spatial elements) in the power distribution network analysis, and it allows the data to be stored and processed with more professional manners. The author stated that the Web-GIS application provides a new data-sharing platform for the user that can help and improve efficiency in operation and decision making. In the meantime, more data is being collected and updated to complete the whole distribution network system so that the analysis that can be carried out from the data can be more accurate and reliable.

[21] Analyzed the power losses of the utility, Ekpoma distribution network using the mathematical and graphical analyses, and revealed that the occurring of losses on each of the three studied 11kV feeders increase yearly. They found that the average power losses on the three feeders for the years 2008 to 2012 were 0.35, 0.37, 0.41, 0.43, and 0.52MW respectively. The reasons of power losses in the studied parts of 11kV feeders were because of illegal connection resulting to overloading, route length of the feeders, transformer location that was too far from load centers, poor maintenance, wrong sized conductors and loads with poor power factor.

Power flow analysis or load flow analysis is one of the most useful parts to conduct study and to analyze power system operation effectively. Load flows are required to analyze the steady state performance of the power system during planning, design and operation of electrical power systems. These load flow studies can be done using specifically designed computer programs. According to [41] model and simulation are methods used to overcome the computational problems of power flow solution using numerical power flow iterative techniques such as Fast Decoupled, Newton-Raphson and Gauss-Seidel.

The power flow problem equations are non-linear and thus, it requires iterative techniques such as Gauss-Seidel, Newton-Raphson, and Fast Decoupled in solving it. According to [42]and [43], the development of these techniques mainly led to the basic requirements of power flow calculation, namely memory requirement, convergence properties, efficiency of computing, ease and flexibility of the execution. The study by [44] proposed a Fast

Decoupled load flow calculation method for distribution systems with high R/X ratio. For better convergence, a coordinate transformation in Y-matrix of the Fast Decoupled method was implemented.

In the study by [45], the analysis and comparison between Gauss-Seidel, Newton-Raphson, and Fast Decoupled were done successfully using MATLAB program. In Gauss-Seidel method, it was found that its rate of convergence was slow and the iterations number increases directly with the number of buses in the system. Whereas in the Newton-Raphson method, the rate of convergence was very fast and the number of iterations is independent of the size of the system. It was practical that only the Fast Decoupled and Newton-Raphson load flow methods were selected as the most popular and widely used techniques in power flow analysis. Moreover, due to its speed and storage capability, the Fast Decoupled load flow method is definitely superior to the Newton-Raphson method.

The authors [30] conducted study on optimal allocation of capacitor bank for power loss minimization and voltage profile improvement using analytical method. Instead of the conventional load flow algorithm such as Newton-Raphson and Fast Decoupled load flow methods they used a backward/forward sweep algorithm to carry out load flow analysis of the distribution system. After they performed the load flow using sweep algorithm, different size of capacitors were initialized and placed in each possible candidate bus and again load flow was carried out for the system. The objective function of the cost including cost of capacitor and cost of lost energy was formulated constrained with the limit of voltage. The capacitor with the cost effective was selected as the optimized solution and the proposed technique was applied to 12-bus radial distribution systems. The power loss and voltage drops before and after capacitor placement were compared and they showed better voltage profiles and improved power losses of the distribution system by implementation of the proposed solution.

The study [36] proposed load flow analysis using ETAP software to investigate the performance of electrical system during normal and abnormal operating conditions, provided information needed to minimize MW and MVar losses, optimize circuit usage, develop practical voltage profiles, and identifies transformer tap settings. They revealed that ETAP performed the computation of system bus voltage profiles, real and reactive power flow and line losses effectively.

The authors [5] assessed the performance of dropped voltage on electrical distribution network by using the electrical transient analyzer program (ETAP) simulation. They found that the highest drop voltage was in the furthest bus from the main station, and the furthest load experiences the highest losses.

In the paper [10], a comprehensive study for load flow analysis in distributed power system was presented. In this study, comparison of Newton-Raphson, Fast Decoupled, and accelerated Gauss-Seidel methods was presented and compared. The modeling and simulation of the power distribution network were done using the Electrical Transient Analyzer Program (ETAP) software. The results of load flow assessment such as total generation, loading, demand, and power losses were obtained and analyzed. Furthermore, simulation using ETAP were developed to find out the optimum location of distribution network unit for minimizing power losses and load profile improvement. The study stated that using ETAP software is very practical and helpful to improve performance and computational accuracy in distribution network analysis, and it also offers a better view of the distribution network.

Many researchers on distribution network have been performed and used computer based tools. Electrical simulator applications such as the electrical transient analyzer program (ETAP) is useful as its calculation is precise enough and trusted to be used as guidance to ensure proper network operation [10, 12, 11, 13].

For better management power industry as a result has to keep follow up of numbers poles, conductors/cables, feeder lines, transformers and other equipments. Information about location of network components, voltage, and distribution of electricity of these facilities seem to be very overpowering. However, with the application of GIS software, information can be organized in a computer system by connecting with the database of the digital map. In addition GIS can make the data easily updatable and precise and hence can simplify the needs of maintaining large and complex power system infrastructure [7].

Improving the of distribution systems performance in order to meet the planned/required target is a matter of choosing and implementing the most cost effective and suitable technology which can simplify operating practices. Carrying out of analysis to know how a particular portion of the network needed to be modified in order to improve its current performance is not sufficient, rather it is important to determine and implement the optimal solution based on future energy demand or load forecasting. Since the distribution network components have a geographical reference, it is important to build the network on digital GIS map and regularly update as per field collected parameters. With periodic updating and monitoring and managing, mapping of the electrical distribution network and customers database helps to enhance capacity of the utility to plan, design, and effective load management. It is also important for loss reduction; improve revenue protection, asset management that required for standard distribution network and possibly for better consumer relationship [2].

Implementation of GIS application enables precise and reliable data management, accurate and easier way of gathering information, which is very important in taking of on time and required decisions that necessary for smooth operation electricity distribution network. The GIS main task is to create geo referencing model to perform spatial analyses and ensure high precision of optimization procedure. This is important to carry out different studies like, load analysis, location analysis, and problem identification analysis, also to determine the average distributed power and utilized power. With the implementation this, the increasing of demand for electricity with increasing rates and high densification can be satisfied in an optimum ways. This study has explained that the result of GIS application analysis can be used as a decision making tool to improve electricity distribution in Nigeria [2].

# CHAPTER THREE

# 3 MODELING AND PERFORMANCE ANALYSIS OF ADAMA TOWN 15 KV DISTRIBUTION NETWORKS

## 3.1 Introduction

The performance of distribution network can be seen from the power losses and voltage drop along the network. If the power losses are low and voltage profile is undistorted, then it can be said that the performance network is good. The voltage profile and power loss are significant in the distribution network. A very long and loaded distribution lines will cause a voltage drop and power loss. This condition is very undesirable, so efforts must be made to improve the distribution network power loss and voltage profile.

Geospatial modeling is one of the most recent technologies which consider growth opportunities for fault analysis, optimization of networks, load forecasting, cost estimation and selection of suitable areas. Database which is the most important asset of an organization plays a central role in the operation of planning, can be divided into two main various data types: spatial data that describe the location and the shape of geographic features and spatial relationship of map features. Attribute data known as descriptive information of the map features. The two most frequently used GIS models of spatial data are raster and vector. Vector data are based on co-coordinating the system where geographic object is represented by points, lines and polygon. Vector data are more suitable for features that have discrete boundaries such as roads. Raster data consists of a regular grid of cells or pixels where each cell has an individual value that in the coordinate system the cell size indicates distance and geographical position of objects. Each set of cells constitute a layer which called coverage and several thematic layers can logically constitute a complete database .The raster data model is the most suitable format for arithmetic operations among cells.

Using GIS based modeling of the 15kV distribution networks was done. With the aid of GIS, variety of information was organized and linked the database to an output distribution networks map.

Using ETAP modeling of Adama town 15 kV distribution network was done to make ready for load flow analysis. Load flow was done for the existing 15 kV distribution network of Adama town considering current load scenario and forecasted load for the coming 10 years and then the results for both scenarios were analyzed.

Adama town 15kV distribution network and its components are discussed in Section 3.2. In Section 3.3 GIS based modeling of Adama town 15kV distribution network is carried out. In order to make ready for load flow studies ETAP modeling of Adama town 15kV distribution network is done in Section 3.4. Section 3.5 presents load description of Adama town 15kV distribution network. Load flow studies of Adama town 15kV distribution network performed in Section 3.6. Lastly, the load flow result is analyzed in Section 3.7.

## 3.2 Adama Town 15kV Distribution Networks

**Basic Information**: Adama is a town located in central of Oromia Region, Ethiopia. Adama town formed a special zone and that is surrounded by East Shewa Zone. The geographical location of the center Adama town is 8.54°N 39.27°E. And the elevation of the town is 1712 meters above the sea level. The distance of the town is 99 km southeast of Addis Ababa. The town found between the base of an escarpment to the west, and the Great Rift Valley to the east.

*Figure 3-1 Google Map of Adama City*

It is one of the larger towns of Ethiopia in a strategic location on the cross roads towards of the South East. The town has an estimated population about 414,240 (2020 ESA projection). The households are estimated about 83,000. The town's total number of customers is about 65, 5010 (as per 2020 EEU's Customer data).

**Melkassa Substation**: Melkasa substation is about 13km south (due East) of Adama centre supplied by Awash hydro power station. Two 20MVA transformers dedicated to the power station. A separate 25MVA transformer 132/15kV is also connected to the 132kV system with five 15kV feeders in total. The 15kV boards provide local supplies to Melkasa area and with two feeders supplies load to the border of south east of Adama town and the factories around. It is believed that at least the express Adama feeder may have been established during the time when there were capacity problems with the old Adama substation and was necessary to bring in additional power from Melkasa. The distance of 13km however is rather long for substantial power transfer to the town.

**Adama 2 Substation:** Adama substation is in the South-West outskirts of the town on the way of 'Wenji Mazoria'. The substation has been built (switchgear dated 2005). It is a 132/15kV substation with two transformers 2x25MVA. The 15kV switchboard has two incoming circuits and 7 outgoing feeders with no bus sectionaliser. Adama 132kV substation receives power supplies from the 132 kV Koka substation through a single 132 kV Koka - Adama line. Further, the nearby wind farm is also connected to the 132kV substation. The substation is build next to the old substation, which is now unused with some of the old equipment still in the yard.

**Adama Mobile Substation:** For temporally to overcome the overloading of Adama 2 (existing) substation, a 132/15kV mobile substation with one transformers 50 MVA was built, in 2017, inside the same premises of the existing substation. Adama mobile substation receives power supplies from the 132 kV Koka substations through a single 132 kV Koka-Adama line. Most of the loads have been transferred to the mobile substation to relief the overloading of the existing substation.

**Distribution Lines:** From Adama 2 (existing) substation, there are seven (7) outgoing 15k feeders (Line 1- Line 7) from the 15kV switchboard cabled to a gantry. Currently, the outgoing breaker of Line 2 and Line 6 feeders are free as the loads are completely transferred to mobile substation. And Line 5 is dedicated line for supplying electricity to the factory. The remaining outgoing feeders (Line 1, 3, 4 and 7) are supplying power to Adama town by reducing the existing loads; transferred to feeders of mobile substation.

From Adama mobile substation, there are six (6) outgoing 15kV feeders (M1- M6) from the 15kV switchboard cabled to a gantry. All the ten (10) 15kV feeders from both Adama 2 and mobile substations are supplying power to entire of Adama town.

*Figure 3-2 Existing Adama 2 and Mobile Substation*

**Switching Stations**: Switching station is termed the extensible ring main units (ERMU) which comprise of a six bay switchboard (two incoming and four outgoings) mounted on the ground at some selected locations in the town. Totally eight (8) switching stations are under operation in Adama town.

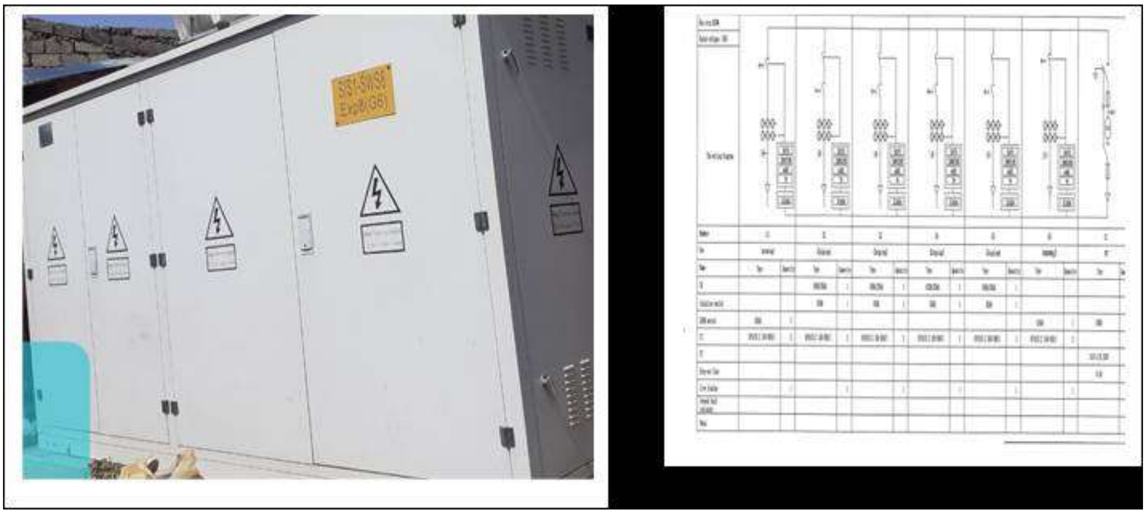

*Figure 3-3 Switching Station and its Layout*

**Distribution Transformers:** As of 2020 Adama town electric distribution network system has about 704 distribution transformers, with voltage level of 15/0.4kV, rating from 25-2500 KVA installed in the network and by now on service.

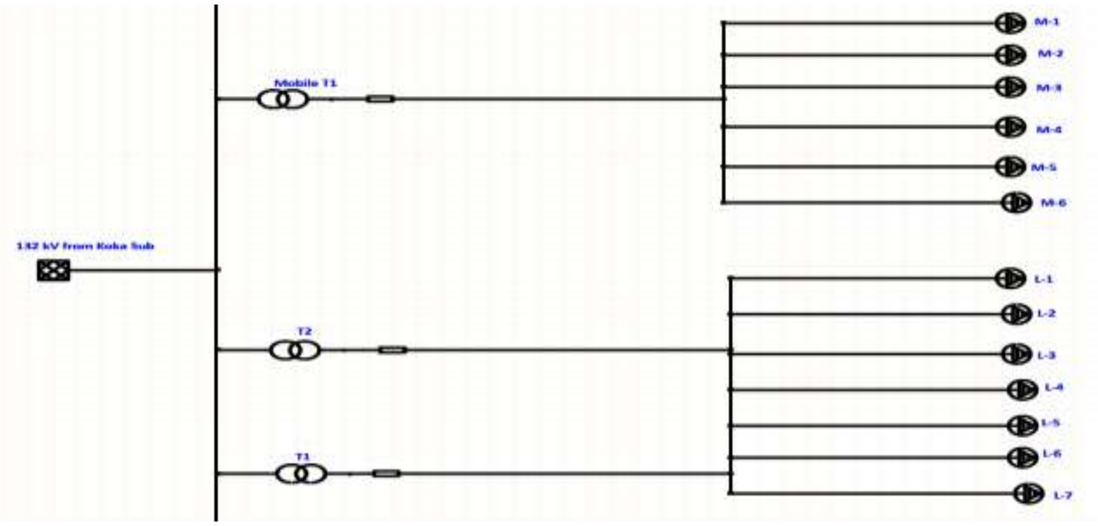

*Figure 3-4 Existing Adama 2 and Mobile Substations simplified layout*

## 3.3 GIS Based Modeling of Adama Town 15kV Distribution Network

The implementation of GIS application in distribution networks has improved greatly the efficiency in energy sector. Distribution system is an essential part of electrical utility, which attempt to improve the reliability of general power system. Analysis such as selection of suitable areas for the expansion, selection of optimum route for the lines, planning and design of wires and poles, and estimation of cost can be done using the application of GIS.

Electric utilities are realizing the importance of GIS technology for the purpose of management of facilities, construction, operations, and maintenance and services. Problems of planning in electrical distribution system can be solved by using new methods and specific techniques. Due to the complexity of electrical distribution networks and the need of accurate up to date information about the network is a reasonable intention for implementing new method of information technology.

This study is focused on ten (10) 15kV distribution networks from both Adama 2 existing and mobile substations, switching stations and distribution transformers are taken in to account. Most importantly, it is expected to maintain data of feeder lines and transformers involved in the study. With the aid of GIS, variety of information can be better organized on a computer system linking the database to an output map.

**Data Acquisition**: The first data was collected from Ethiopian Electric Utility from Fixed Assets Inventory and Revaluation (FAIR)) Project. The first step of this work was the verification of the obtained data with the study area.

The data was collected using ODK. ODK is a set of open source applications which allow one to create a questionnaire form in the X form format, fill it out on a mobile phone or tablet running the Android operating system, store and view the aggregated data on a central server of EEU, and retrieving the required aggregated data to one's computer for further analysis.

There were two types of data obtained which included: spatial and non-spatial data.

**Spatial Data**: The spatial data used for the study include the following;

- **Base Map**: The base map consists of roads, buildings and facilities digitized from a high-resolution image data. It is mainly two types; open street map and satellite image.
- **GPS Data**: GPS data for the required points on the available facilities (along the feeder angle points, T-points, transformers, etc) are acquired from the field. The length feeder segments is calculated using the taken end points

**Non-spatial data**: The non-spatial data includes the following information which was acquired from the Ethiopian Electric Utility Operation Office, Adama district office and from the site as well;

- **15kV Lines Details:** 15kV line conductor type and size, switching stations, poles and other information
- **Transformer Details:** Capacity/rating/, and other related information

**Shape Files:** The shape file is a data set format contains geospatial vector data format for geographic information system (GIS) software. The shape file format can spatially describe vector features: points, lines, representing, transformers point, switching stations and feeder lines. Data for feeder lines, transformers and other required equipments are organized in shape file and then added as layers that overlaid on the base map.

Shape file is created in Geographical Information System (GIS) by defining the types of features it will contain, whether those features will represent routes (m-values), and whether those features will be three-dimensional (z-values). These properties can't be modified after the shape file has been created. The coordinate system of the shape file shall also be defined. The process of defining the new shape file's attributes data is separate from creating the shape file itself. After creating the item, its attributes is defined. For shape files, an integer column named Id is added as an attribute and the appropriate attributes can be added to the shape file. After the new attributes have been added as part of the shape file, the default column can be deleted if decided not to use it.

Single line diagrams of the entire 15 kV networks were mapped on GIS according to its respective feeder network configuration. Finally, all the background data of network configuration used for mapping single line diagram was compiled in Postgre SQL data for further data analysis.

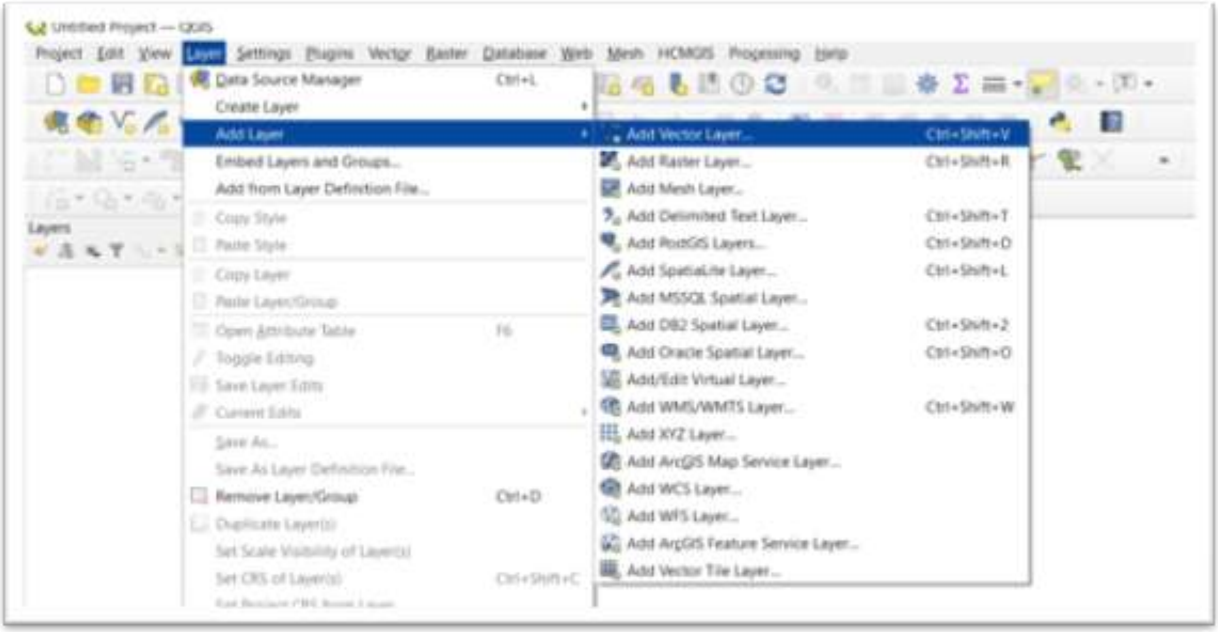

*Figure 3-5 Process of Adding Vector Layer*

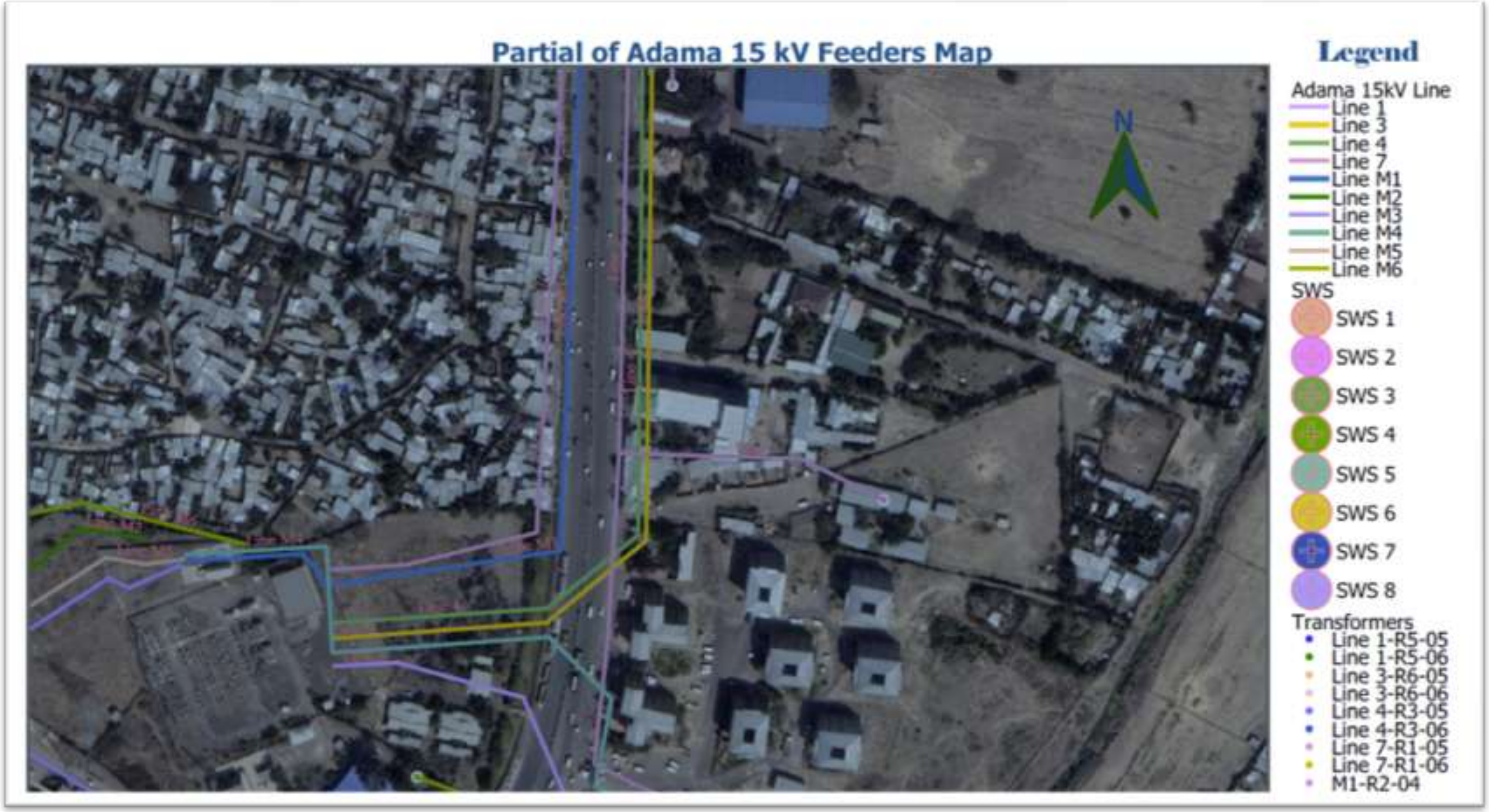

*Figure 3-6 Partial of Adama 15 kV Networks map (a)*

*Figure 3-7 Partial of Adama 15 kV Networks map (b)*

## 3.4 Adama Town 15kV Distribution Network Modeling using ETAP

This study presents generally the load flow analysis result that was carried out on 15 kV network of Adama town. The load flow analysis was carried out on ten (10) outgoing 15 kV lines that emerge from Adama 2 (existing) substation and Adama mobile substation up to the last transformer point.

There are eight (8) express feeders directly supplies power to the switching stations and then supply distribution transformers through outgoing feeders from the switching station and two lines are direct supplying distribution transformers.

The load flow analysis is done with the application of Electrical Transient Analyzer Program (ETAP 19.0.1) with current load scenario of the existing 15 kV distribution network and with considering forecasted load for the coming 10 years as well. ETAP represents substations, feeders, transformers, buses, loads, breakers, transformers etc. as a unique element in the model.

**System Data and input Parameters**: For existing system, the conductor and cable parameter were used from EEU's existing technical data. Based on these parameters a separate library was developed for the conductors. And for the cables and transformers typical equivalent values were customized from ETAP library.

*Table 3-1 Overhead conductors' data*

| Conductor Type | Site (Area mm2) | Ampacity (A) | OD | GMR | R at 20 $^0$c (ohm/km) | R at 75 $^0$c (ohm/km) | Rdc |
|---|---|---|---|---|---|---|---|
| ACSR_19mm2 | 25 | 98 | 0.636 | 0.00125 | 1.779 | 2.173315 | 1.779 |
| ACSR_30mm2 | 30 | 145 | 0.81 | 0.0013 | 1.128 | 1.378021 | 1.128 |
| AAC_25mm2 | 25 | 145 | 0.59 | 0.00127 | 1.179 | 1.440325 | 1.179 |
| AAC_50mm2 | 50 | 225 | 0.9 | 0.00327 | 0.578 | 0.706114 | 0.578 |
| AAC_95mm2 | 95 | 340 | 1.25 | 0.00466 | 0.307 | 0.375047 | 0.307 |
| AAAC_XLPE_150mm2 | 150 | 385 | 1.43 | 0.00608 | 0.239 | 0.292000 | 0.239 |
| AAAC_XLPE_200mm2 | 200 | 450 | 2.09 | 0.00768 | 0.1385 | 0.169200 | 0.1385 |

*Table 3-2 Distribution transformer input parameters*

| Transformer rating (KVA) | Transformer Impedance (% Z) | X/R Ratio |
|---|---|---|
| 25-630 | 4 | 1.5 |
| 800-1250 | 5 | 3.5 |
| 1500 | 6 | 6.25 |

In Adama town, there are eight (8) 15kV express feeders directly connected to switching stations and one or more outgoing feeders from each switching station to distribution transformers.

*Table 3-3 15kV express feeders' data*

| Substation | Feeder Name | Switching Station | Conductor Type | Length (Km) | Peak Current on the Feeder (A) | Conductor Derated Ampacity (A) |
|---|---|---|---|---|---|---|
| Adama 2 | Line 1 | SWS-5 | CU-XLPE-300 mm2 | 0.4514 | 266.70 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 6.0639 | | 342.1 |
| | | | AAAC_XLPE_150mm2 | 3.8440 | | 224.8 |
| Adama 2 | Line 3 | SWS-6 | CU-XLPE-300 mm2 | 0.1101 | 254.30 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 7.8149 | | 342.1 |
| Adama 2 | Line 4 | SWS-3 | CU-XLPE-300 mm2 | 0.1063 | 243.50 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 7.3874 | | 342.1 |
| Adama 2 | Line 7 | SWS-1 | CU-XLPE-300 mm2 | 2.4834 | 214.00 | 450.7 |
| Mobile Sub. | Line M1 | SWS-2 | CU-XLPE-300 mm2 | 0.1915 | 297.00 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 3.5197 | | 342.1 |
| Mobile Sub. | Line M4 | SWS-7 | CU-XLPE-300 mm2 | 0.3213 | 278.20 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 5.6219 | | 342.1 |
| Mobile Sub. | Line M5 | SWS-8 | CU-XLPE-240 mm2 | 0.0361 | 157.90 | 414.7 |
| | | | CU-XLPE-300 mm2 | 0.1307 | | 450.7 |
| | | | AAC-95mm2 | 5.5534 | | 188.3 |
| Mobile Sub. | Line M6 | SWS-4 | CU-XLPE-300 mm2 | 0.0811 | 116.90 | 450.7 |
| | | | AAAC_XLPE_200mm2 | 3.0075 | | 342.1 |

*Table 3-4 Switching stations and load lines' data*

| **Express Lines/Outgoing Feeder** | **Switching stations** | **Outgoing Load feeders** | **Length (km)** | **Transformers Under Connected to feeder Lines** | | | | | | | | | | | | | | **Total Connected KVA** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | **25** | **50** | **100** | **200** | **300** | **315** | **400** | **500** | **630** | **800** | **1250** | **1500** | **2000** | 2500 | |
| Line 1 | SWS-5 | Line 1-R5-05 | 7.761 | 4 | | 1 | 7 | 3 | 18 | | | 3 | 2 | | | | | 11,660 |
| | | Line 1-R5-06 | 11.540 | 4 | 1 | 11 | 8 | 1 | 14 | | | | | | | | | 7,560 |
| Line 3 | SWS-6 | Line 3-R6-05 | 9.160 | 5 | 1 | 4 | 8 | | 15 | | 1 | 1 | | | | | | 8,030 |
| | | Line 3-R6-06 | 6.502 | 1 | 2 | 6 | 4 | | 4 | | | 6 | 2 | | | | | 8,165 |
| Line 4 | SWS-3 | Line 4-R3-05 | 15.324 | 4 | 2 | 3 | 13 | | 9 | | | 1 | 1 | | | | | 7,365 |
| | | Line 4-R3-06 | 6.610 | 3 | 2 | 2 | 5 | | 14 | | | 3 | | | | | | 7,675 |
| Line 7 | SWS-1 | Line 7-R1-05 | 7.813 | 1 | 3 | 5 | | | 16 | | | 1 | 1 | | | | | 7,145 |
| | | Line 7-R1-06 | 7.452 | 1 | 3 | 9 | 3 | | 14 | | | 4 | 1 | 1 | | | | 10,655 |
| Line M1 | SWS-2 | Line M1-R2-04 | 20.796 | 8 | 5 | 22 | 19 | | 30 | | | 5 | 2 | 2 | | | | 23,150 |
| | | Line M1-R2-05 | 5.714 | 3 | 2 | 1 | 3 | | 13 | | 1 | | | | | | | 5,470 |
| | | Line M1-R2-05 | 1.454 | | | 1 | 1 | | 3 | | | 2 | 1 | 3 | | | | 7,055 |
| Line M2 | ---- | M2- Feeder | 22.408 | 3 | 3 | 7 | 8 | | 18 | | 1 | 10 | 1 | 8 | 1 | 1 | | 29,295 |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Line M3 | ----- | M3- Feeder | 11.034 | 4 | 1 | 11 | 4 | | 14 | | | 3 | | 1 | | 1 | | 11,600 |
| Line M4 | SWS-7 | Line M4-R7-05 | 3.630 | 4 | | 2 | 7 | | 7 | | | 1 | | | | | | 4,535 |
| | | Line M4-R7-06 | 9.634 | 2 | 2 | 2 | 7 | | 19 | | 1 | 1 | 8 | 5 | | 1 | 1 | 26,015 |
| Line M5 | SWS-8 | Line M5-R8-04 | 92.399 | 1 | 22 | 25 | 11 | | 7 | | | | | | | 3 | | 14,305 |
| Line M6 | SWS-4 | Line M6-R4-03 | 3.152 | | 1 | 3 | | | 3 | | | | 1 | | | | | 2,095 |
| | | Line M6-R4-04 | 43.768 | 4 | 3 | 2 | 6 | | 4 | | | 2 | | | 1 | | 1 | 12,500 |
| | | Line M6-R4-05 | 43.862 | 5 | 5 | 11 | 6 | | 3 | | | 2 | | 2 | | | | 7,380 |

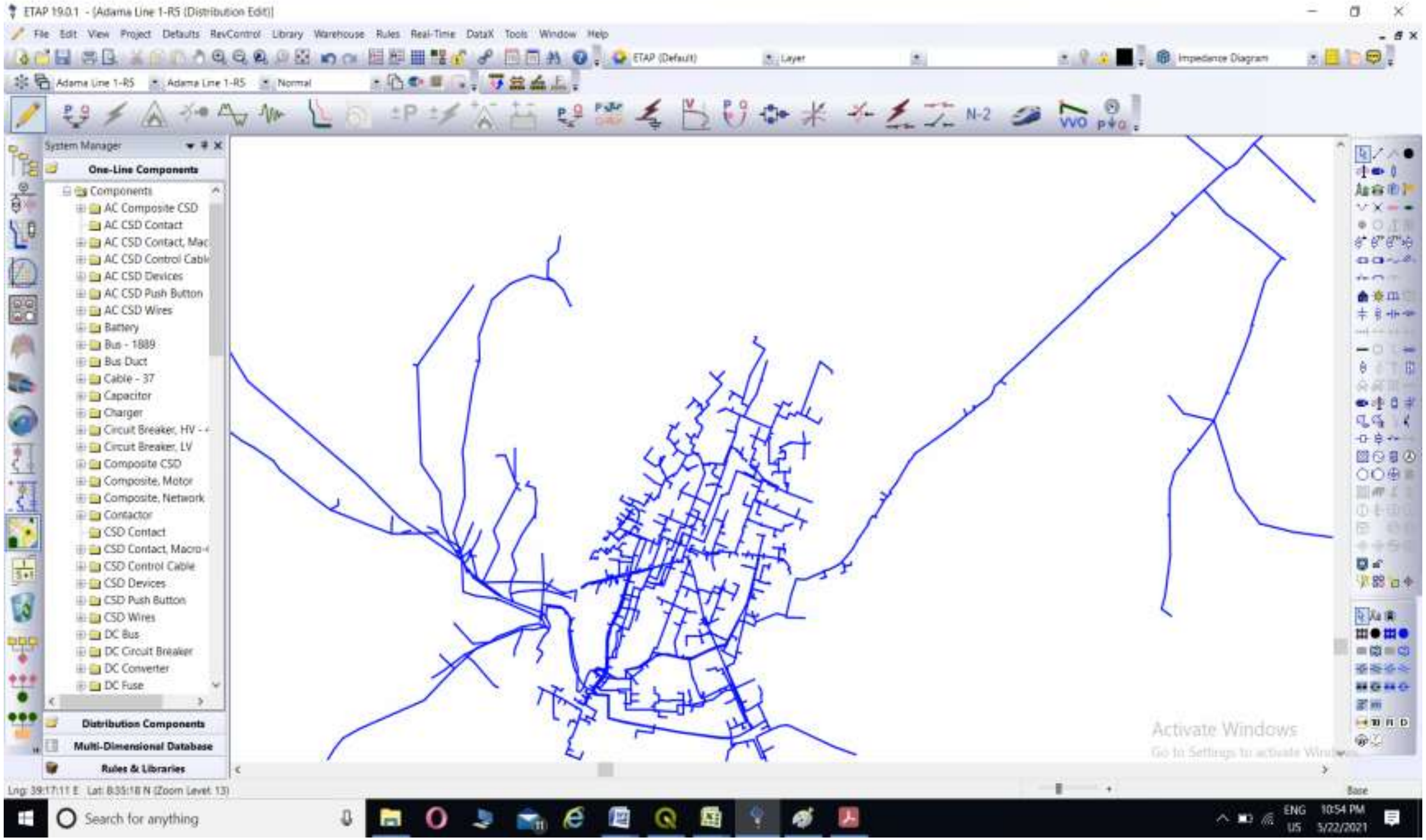

*Figure 3-8 ETAP GIS exported distribution model of Adama 15kV networks*

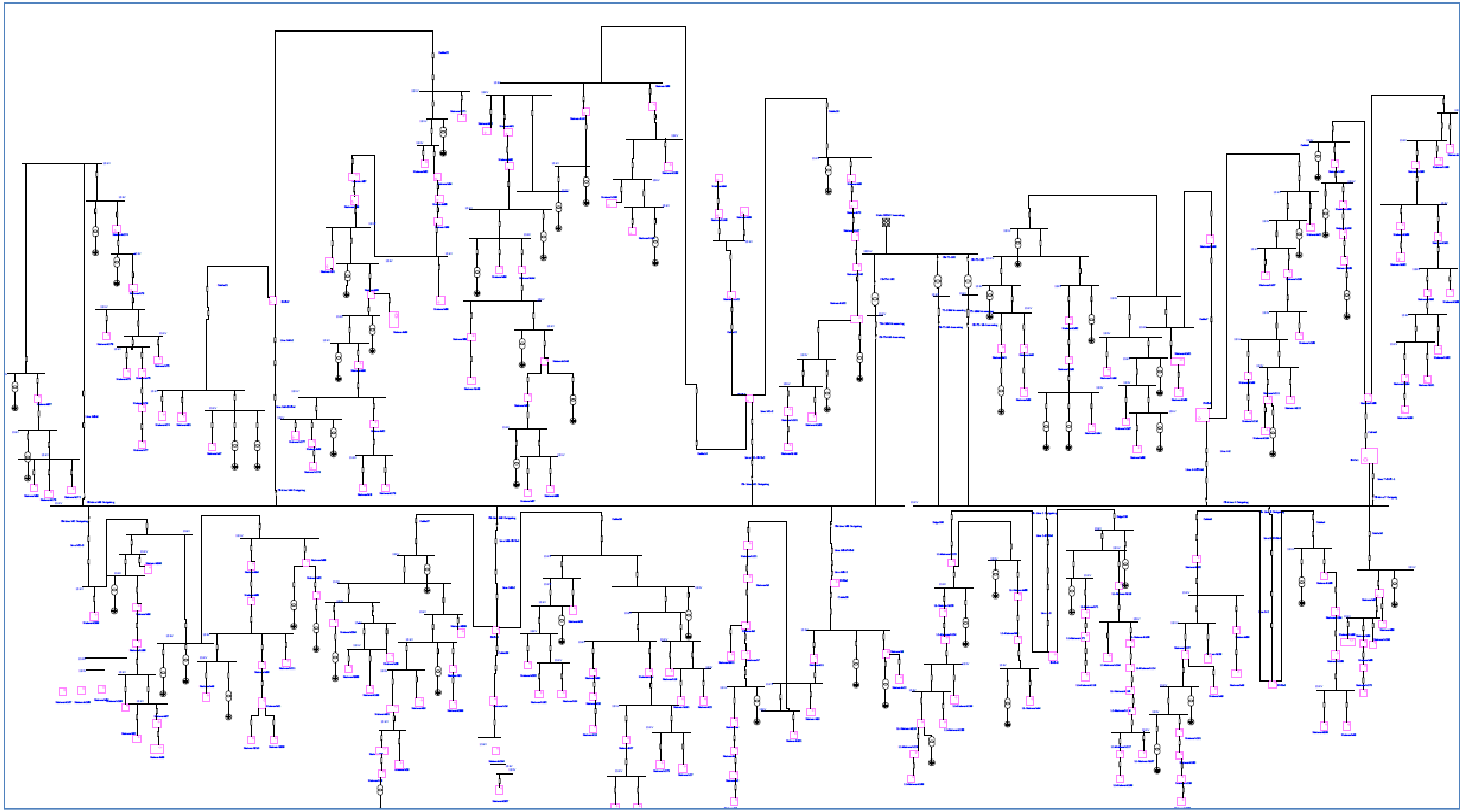

*Figure 3-9 ETAP single line diagram of Adama 15kV networks*

## 3.5 Load Description for Adama Town 15kV Distribution Networks

There are different load allocation approach for distribution system transformers and load points. But in this case the load allocation of top down approach was used which means allocating each distribution transformers by the ratio of their peak feeder reading from the substation.

Hence two type of load was allocated for each transformer

1. ***Normal load***: currently operating load
2. **Load growth after 10 years**: load forecast for the coming 10 years

**Normal Load (Case 1)**: Assuming the current operation as the normal operation of the system, all the transformers under the feeder line is loaded by the factor of peak feeder reading to total connected transformers rating under the feeder. For this case normal transformer loading factor of the lines are indicated in Table 3.5:

**Load growth after 10 years (Case 2):** Assuming that, the distribution line usually designed for 10 years and annual load growth rate of 5%, the following simple formula was used to calculate the load growth.

$Pd = Po \times e$, $Pd$ is Power demand at t year

$Po$ is current Load

$$e = (1 + r/100)^{t}$$

Where: r = annual load growth in percent

t = time of the load growth (10 years)

Accordingly, assuming 5% annual Load growth, e = 1.63.

This means Power demand growth by 63% after 10 years. And this loading factor is used for load growth analysis.

For all lines, the transformers loading as follow:

*Table 3-5 Transformers loading*

| Name of Substation | Name of Feeder | Switching Station | Average (from 5 months peak) | | Connected KVA | Current Transformers Loading | Transformers Loading After 10 year |
|---|---|---|---|---|---|---|---|
| | | | Amp (A) | Peak Feeder KVA | | | |
| Adama 2 Substation | Line 1-R5 | SWS-5 | 317 | 6523.86 | 19220 | 33.94% | 55.33% |
| | Line 3-R6 | SWS-6 | 357 | 7347.06 | 16195 | 45.37% | 73.95% |
| | Line 4- R3 | SWS-3 | 308 | 6338.64 | 15040 | 42.15% | 68.70% |
| | Line 7-R1 | SWS-7 | 275.4 | 5667.73 | 17800 | 31.84% | 51.90% |
| Adama Mobile Substation | Line M1-R2 | SWS-2 | 389 | 8005.62 | 35675 | 22.44% | 36.58% |
| | Line M2 | - | 176 | 3622.08 | 29295 | 12.36% | 20.15% |
| | Line M3 | - | 370 | 7614.60 | 11600 | 65.64% | 107.00% |
| | Line M4-R7 | SWS-7 | 354.2 | 7289.44 | 30550 | 23.86% | 38.89% |
| | Line M5-R8 | SWS-8 | 216.8 | 4461.74 | 14305 | 31.19% | 50.84% |
| | Line M6-R4 | SWS-4 | 149.8 | 3082.88 | 22290 | 13.83% | 22.54% |

## 3.6 Load flow Studies of Adama Town Distribution Network

The single line diagram (SLD) of the network is simulated in ETAP based upon the data input. Load flow analysis was done for the two cases. Case 1 and 2: Current peak loading scenario (existing load) and load after 10 years scenario, respectively.

The following detail load flow report is annexed to this report as Appendix A: Load Flow Results

- A1: Operating Voltage all 15 kV Lines
- A1.1: Alert report of 15kV Lines for Existing Condition
- A1.2: Alert report of 15kV Lines after 10 Years

The summary of load flow result is shown in Table 3-1

*Table 3-6 Load flow result of the network*

| **Scenarios** | **Source from Substation** | | **Load** | | **Loss** | |
|---|---|---|---|---|---|---|
| | **MW** | **Mvar** | **MW** | **Mvar** | **MW** | **Mvar** |
| Existing condition | 59.097 | 37.366 | 54.55 | 26.451 | 4.548 | 10.915 |
| After 10 Year | 93.903 | 69.944 | 81.766 | 39.646 | 12.137 | 30.298 |

## 3.7 Analysis of Load Flow Result

**Normal Load (Case 1)**: Different standards indicated voltage variations up to 33kV feeders should not be exceeded the limits of (-) 9.0% to (+) 6.0% at the farthest end point under peak load conditions and normal system operation.

From the load flow summary report the 15kV distribution system encountered total of 4.548 MW (7.70%) active power losses.

From the alert summary report the 15kV distribution network of Adama town, there is about 1183 15kV buses (load buses) among which 255 buses are operating with voltages below the acceptable range (under voltage condition). And about 35 line segments are overloaded [Appendix A1, A1.1].

**Load after 10 Years (Case 2):** If system will be continued in operation without improving the network, the amount of active power loss will be 12.137 MW (12.137%).

From the alert summary report, among 1183 15kV buses (load buses), 678 buses will be operating with voltages below the acceptable range (under voltage condition) and about 121 line segments will be overloaded [Appendix A1, A1.2].

**Significant Power Loss and Voltage Drop:** Among the ten (10) distribution lines included under the study, Line 1 experiences significant amount of power loss and Voltage drop, and hence, proposed solutions are simulated using Line 1 single line diagram.

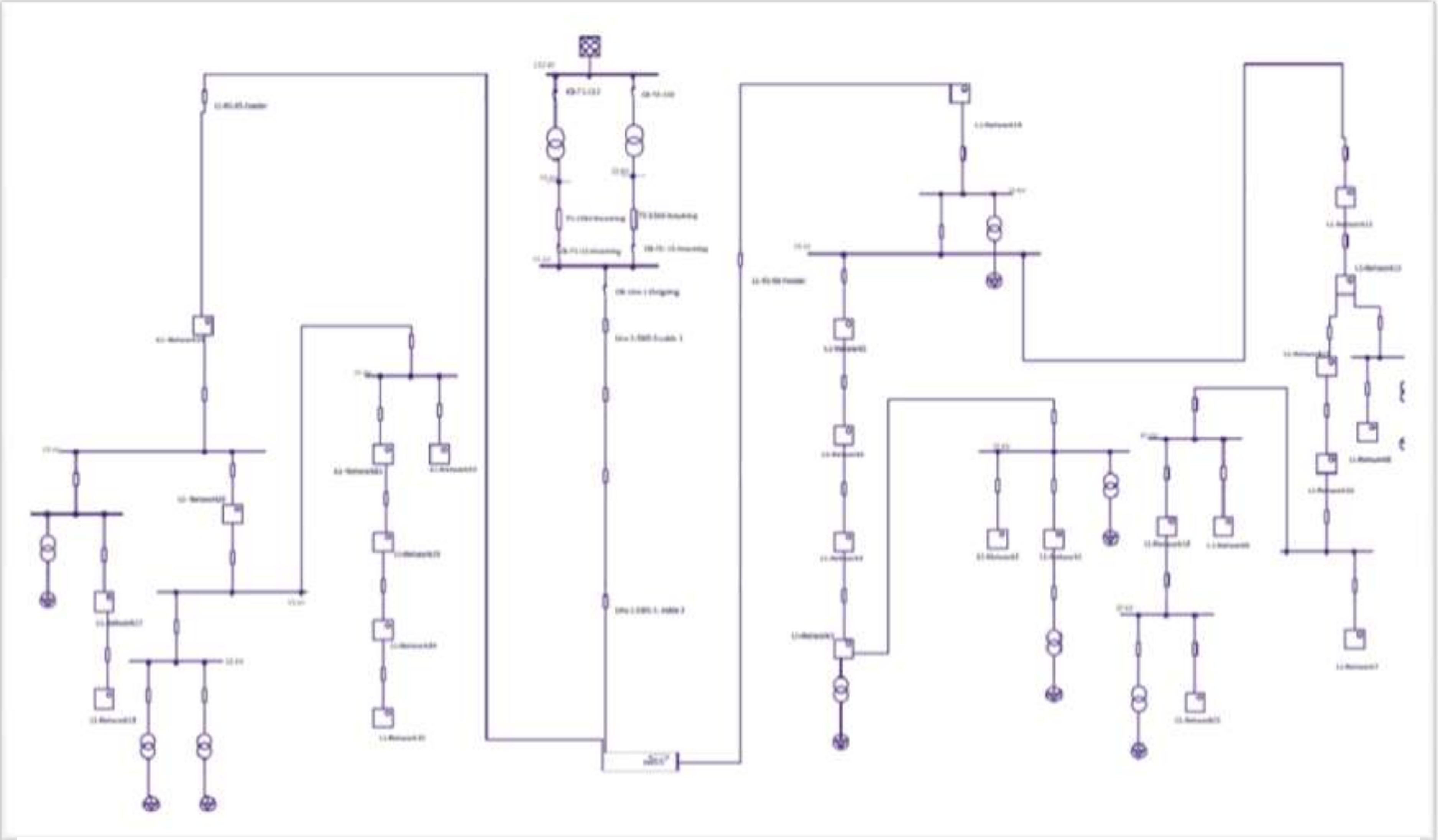

*Figure 3-10 ETAP single line diagram of Adama Line 1 15kV feeder*

**Load Flow Result of Line 1**: Load flow analysis was done for Line 1 separately using the two cases; i.e. Case 1: current peak loading scenario (existing load) and Case2: after 10 years scenario, using load forecast for the next ten (10) years.

*Table 3-7 Load Flow Result of Adama Line 1*

| **Scenarios** | **Source from Substation** | | **Load** | | **Loss** | |
|---|---|---|---|---|---|---|
| | **MW** | **Mvar** | **MW** | **Mvar** | **MW** | **Mvar** |
| Existing condition | 6.038 | 3.521 | 5.458 | 2.643 | 0.58 | 0.877 |
| After 10 Year | 10.406 | 6.981 | 8.566 | 4.149 | 1.84 | 2.832 |

**Normal Load of Line 1**: From the load flow report, Line 1 feeder encountered total of 0.58 MW (9.61%) active power losses.

From the alert summary report of Line 1 feeder, among 134 15kV buses (load buses) 129 buses are operating with voltages below the acceptable range (under voltage condition). And about 2 line segments are overloaded [Appendix A2, A2.1].

**Load of Line 1 after 10 Years**: From the load flow result, if this line will be continued in operation without improving the network, the amount of active power loss will be 1.84 MW (17.68%).

From the alert summary report of Line 1 (Appendix A1-1), among 134 15kV 130 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition). And about 7 line segments will be overloaded.

# CHAPTER FOUR

# 4 PERFORMANCE IMPROVEMENT OF ADAMA TOWN 15KV DISTRIBUTION NETWORKS

## 4.1 Introduction

The distribution system plays an important role in any electric power system and requires a detail analysis of various types of losses occurring in a distribution system and methods are required to be developed for reducing the same. A significant voltage drop power loss can harm the lifespan and the operational efficiency of electrical circuits and equipment. Therefore an effort must be made to improve voltage profile and reduce power loss. There are many ways to minimize power loss and improve voltage drops.

From the result of load flow analysis voltage drop and power loss are the major identified problems and hence the proposed methods are focused on minimizing of loss and improvement of voltage profile to the acceptable ranges.

Proposed methods for power loss minimization and voltage profile improvement are discussed in Section 4.2. Section 4.3 presents load flow of Adama town 15 kV distribution networks with the implementation of proposed methods. Simulation results after the implementation of proposed methods are studied in Section 4.4. Section 4.5 analyzes the cost benefit of proposed methods. Lastly, discussion and summary is presented in Section 4.6.

## 4.2 Proposed Methods for Power Loss Minimization and Voltage Profile Improvement

In order to minimize power loss and improve voltage profile of 15kV distribution network of Adama town, optimal capacitor replacement (OCP), conductor upgrading (CU), and combination of both techniques were applied and the results were compared.

### 4.2.1 Optimal Capacitors Placement (OCP)

To minimize the impact of the inductive load, optimal capacitor placement (OCP) can be used with the objective function of cost minimization for voltage profile improvement, power factor compensation and power losses minimization. Since implementation of OCP is a non-linear equation with equality and inequality limitations, the stated solution depends on the optimal placement and sizes of the capacitor banks [46]. In this thesis, Electrical Transient Analyzer Program (ETAP) software is used for the evaluation and modeling of the power systems. Capacitor bank size, locations, and cost consideration are vital issues that needed to be optimized.

MATLAB Program is used to determine candidate buses based on power loss and voltage drop sensitivity index.

**Candidate Buses identification for Capacitor placement**: In order to get the potential node, the capacitor placement was performed by making the reactive power zero at each node. After compensating reactive power at each bus, load flows have been run again. From this load flow, the new real power loss and voltage deviation will be evaluated.

Candidate buses are selected taking in to consideration the power loss reduction index and voltage profile improvement index calculated for each bus. According to [46], power loss reduction index ($PLI$) and voltage profile improvement index ($VII$) for each bus is calculated by using equations (4-2) and (4-3). By sorting these values, the candidate (potential) buses for capacitor placement will be identified.

Power Loss reduction Index ($PLI$) of the $i^{\text{th}}$ bus can be calculated as follows.

$$Loss\_Reduction\,(i) = P_{uncomp} - \,(i) \qquad \text{(Equation 4-1)}$$

$$PLI\,(i) = \frac{Loss\_Reduction\,(i) - Min\_Reduction}{Max\_Reduction - Min\_Reduction} \qquad \text{(Equation 4-2)}$$

where:

$P_{uncomp}$: is the uncompensated active power loss,

$(i)$**:** is the active power loss obtained by making the reactive power at bus $i$ zero,

$Loss\_Reduction\ (i)$: is the total power loss reduction resulting from compensated bus $i$,

$PLI\ (i)$**:** is normalized loss reduction weight due to compensation at bus $i$,

$Min\_Reduction$**:** is the minimum loss reduction of all individual bus compensation, and

$\boldsymbol{Max\_Reduction}$**:** is the maximum loss reduction of all individual bus compensation.

The voltage improvement index ($VII$) is also calculated in the same manner as:

$$VII = \frac{VoltageDropReduction\,(i) - MinVoltageDropReduction}{MaxVoltageDropReduction - MinVoltageDropReduction} \qquad \textit{(Equation 4-3)}$$

where:

$\boldsymbol{Voltage\ drop\ reduction\ (i)}$: is the total voltage drop reduction due to compensation at bus $i$

$\boldsymbol{MinVoltageDropReduction}$: is the minimum voltage drop reduction of all individual bus compensation.

$\boldsymbol{MaxVoltageDropReduction}$**:** is the maximum voltage drop reduction of all individual bus compensation.

$\boldsymbol{VII}$**:** is normalized voltage profile improvement weight measured due to compensation at bus $i$.

The algorithm for candidate bus (potential node) identification:

1) Read distribution network data
2) Run the load flow and calculate the uncompensated active power loss and voltage deviation.
3) By compensating the reactive power (QC) at each node and run the load flows, to calculate the active power loss and voltage deviation in each case.
4) Calculate the power loss reduction and voltage deviation reduction, power loss index (PLI) and voltage improvement index (VII).
5) Select the candidate node whose PLI and VII in the top.
6) Stop.

*Table 4-1 the first 16 Candidate buses*

| No. | Index | Bus ID | No. | Index | Bus ID |
|---|---|---|---|---|---|
| 1 | 1.000000 | Bus_J65 | 9 | 0.668458 | Bus_J123 |
| 2 | 0.747013 | Bus_J12 | 10 | 0.668289 | Bus_J126 |
| 3 | 0.730435 | Bus_J4 | 11 | 0.66813 | Bus_J96 |
| 4 | 0.709274 | Bus_J20 | 12 | 0.668107 | Bus_J106 |
| 5 | 0.670372 | Bus_J18 | 13 | 0.668094 | Bus_J23 |
| 6 | 0.668658 | Bus_J7 | 14 | 0.66809 | Bus_J97 |
| 7 | 0.668492 | Bus_J68 | 15 | 0.668089 | Bus_J103 |
| 8 | 0.668472 | Bus_J100 | 16 | 0.668089 | Bus_J84 |

From the result of MATLAB program, 16 buses are selected based on both $PLI$ $(i)$ (normalized loss reduction weight due to compensation at bus $i$ ) and $VII$ (normalized voltage profile improvement weight measured due to compensation at bus $i$) sensitivity index values and input to the ETAP modeling program to determine the size and locations of the capacitors.

*Table 4-2 ETAP result of OCP*

| Candidate Bus ID | Nominal kV | kvar/Bank | Rated kV | # of Banks | Total kvar |
|---|---|---|---|---|---|
| Bus_J4 | 15.00 | | | | |
| Bus_J7 | 15.00 | | | | |
| Bus_J12 | 15.00 | 300.00 | 15.00 | 1 | 300.00 |
| Bus_J18 | 15.00 | 300.00 | 15.00 | 2 | 600.00 |
| Bus_J20 | 15.00 | 300.00 | 15.00 | 1 | 300.00 |
| Bus_J23 | 15.00 | | | | |
| Bus_J65 | 15.00 | | | | |
| Bus_J68 | 15.00 | 300.00 | 15.00 | 2 | 600.00 |
| Bus_J84 | 15.00 | 300.00 | 15.00 | 2 | 600.00 |
| Bus_J96 | 15.00 | | | | |
| Bus_J97 | 15.00 | | | | |
| Bus_J100 | 15.00 | | | | |
| Bus_J103 | 15.00 | 300.00 | 15.00 | 2 | 600.00 |
| Bus_J106 | 15.00 | | | | |
| Bus_J123 | 15.00 | 300.00 | 15.00 | 2 | 600.00 |
| Bus_J126 | 15.00 | | | | |
| **Total** | | | | **12** | **3600.00** |

### 4.2.2 Conductor Upgrading (CU)

Conductor upgrading is the technique of replacing the existing conductor on the feeder by conductor of optimal size for optimal 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.

The overloaded line segments of Adama Line 1 were proposed to be replaced by optimal size of conductor.

*Table 4-3 Overloaded Line segments to be upgraded*

| Line Segment ID | Type | Length | Condition | Existing Conductor/ Cable size | Proposed Conductor Size |
|---|---|---|---|---|---|
| Edge47 | Line | 0.135 km | Overload | AAC 50mm2 | XLPE Covered AAAC 150mm2 |
| Edge48 | Line | 0.109 km | Overload | AAC 50mm2 | |
| Edge56 | Line | 0.153 km | Overload | AAC 50mm2 | |
| Line 1-SWS-5-OHL-2 | Line | 3.909 km | Overload | AAAC 150m2 | AAAC 2*150m2 |

### 4.2.3 Combination of OCP and CU

The two solutions, upgrading of overloaded conductor and optimal capacitor placement are applied and ETAP load flow was run using ETAP single line diagram.

## 4.3 Load flow Analysis of 15 kV Distribution Networks with Implementation of Proposed methods

The load flow is done for 15 kV Line 1 of Adama town, with the implementation of optimal capacitor replacement (OCP), conductor upgrading (CU), and combination of both techniques were for both scenarios (i.e. existing load condition and load after 10 years).

### 4.3.1 Load flow with Optimal Capacitor Placement

After connecting the identified capacitor sizes to the selected buses, ETAP load flow is run to see the effect.

*Table 4-4 Load flow Result of Adama Line 1 feeder after OCP*

| Scenarios | Source from Substation | | Load | | Loss | |
|---|---|---|---|---|---|---|
| | MW | Mvar | MW | Mvar | MW | Mvar |
| Existing condition | 5.641 | -0.43 | 5.251 | -1.011 | 0.389 | 0.581 |
| After 10 Year | 10.15 | 3.832 | 8.72 | 1.647 | 1.43 | 2.186 |

### 4.3.2 Load flow with Conductor Upgrading

After replacing the overloaded line segments with appropriate conductor size, ETAP load flow is run to see the effect.

*Table 4-5 Load flow Result of Adama Line 1 feeder after conductor/cable upgrading*

| Scenarios | Source from Substation | | Load | | Loss | |
|---|---|---|---|---|---|---|
| | MW | Mvar | MW | Mvar | MW | Mvar |
| Existing condition | 5.851 | 3.521 | 5.52 | 2.674 | 0.331 | 0.848 |
| After 10 Year | 9.73 | 6.812 | 8.74 | 4.233 | 0.989 | 2.579 |

### 4.3.3 Load flow with OCP and CU

After connecting the identified capacitor sizes to the selected buses and after replacing the overloaded line segments with appropriate conductor size, ETAP load flow is run to see the effect.

*Table 4-6 Load flow Result of Adama Line 1 feeder after CU and OCP*

| Scenarios | Source from Substation | | Load | | Loss | |
|---|---|---|---|---|---|---|
| | MW | Mvar | MW | Mvar | MW | Mvar |
| Existing condition | 5.71 | -0.617 | 5.463 | -1.224 | 0.246 | 0.606 |
| After 10 Year | 9.694 | 3.34 | 8.915 | 1.36 | 0.778 | 1.98 |

## 4.4 Analysis of Simulation Results

The load flow result was analyzed after the implementation of proposed methods of power loss minimization and voltage profile improvement.

**Load Flow Result Analysis after OCP**

**Normal Load Scenario**: From the load flow summary report, active power loss of Line 1 Feeder reduced to 0.389 MW (reduced by 32.93%).

From the alert summary report of Line 1 feeder, all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages (≥ 94%) [Appendix A3].

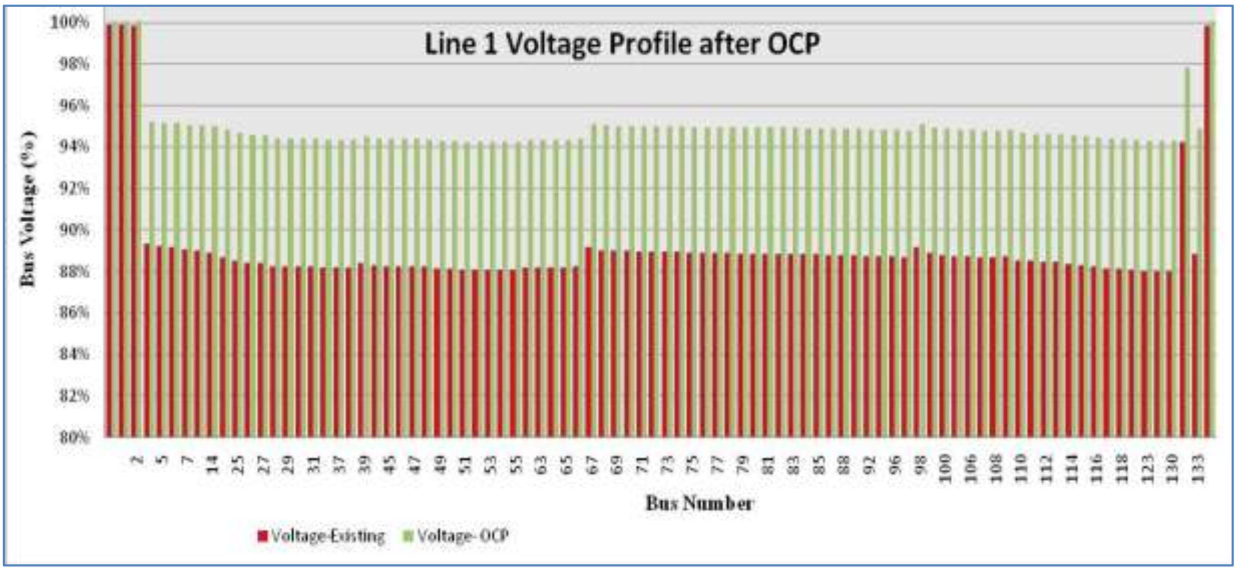

*Figure 4-1 Line 1 Feeder Voltage Profile for Existing condition and after OCP*

**Load after 10 Years**: If this line will be continued in operation by placing the selected capacitors at optimal place, the amount of active power loss will be reduced to 1.43 MW (reduced by 22.28%), after 10 years.

From the alert summary report, even though, the voltage drop is improved, among 134 15kV buses, 129 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition), and 7 line segments will be overloaded, after 10 years [Appendix A3.1].

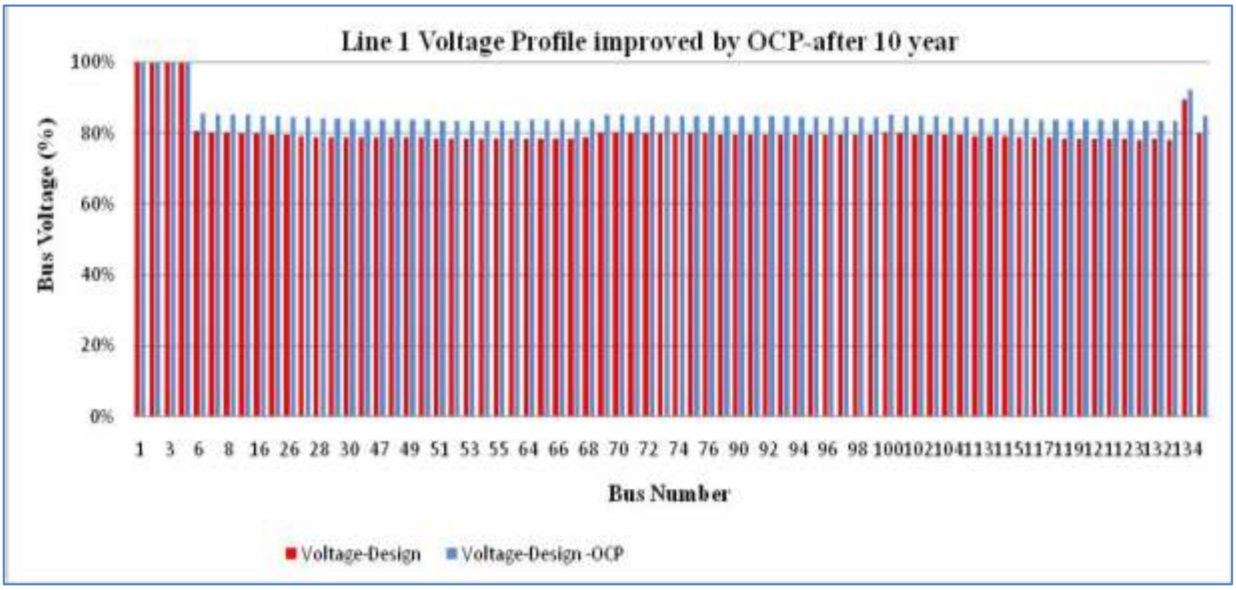

*Figure 4-2 Line 1 feeder voltage profile after 10 year for existing condition and after OCP*

## Load Flow Result Analysis after CU

**Normal Load Scenario**: From the load flow summary report, active power loss of Line 1 feeder reduced to 0.331 MW (reduced by 42.93%) active power losses. From the alert summary report of Line 1 feeder, all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages (>90%) [Appendix A4].

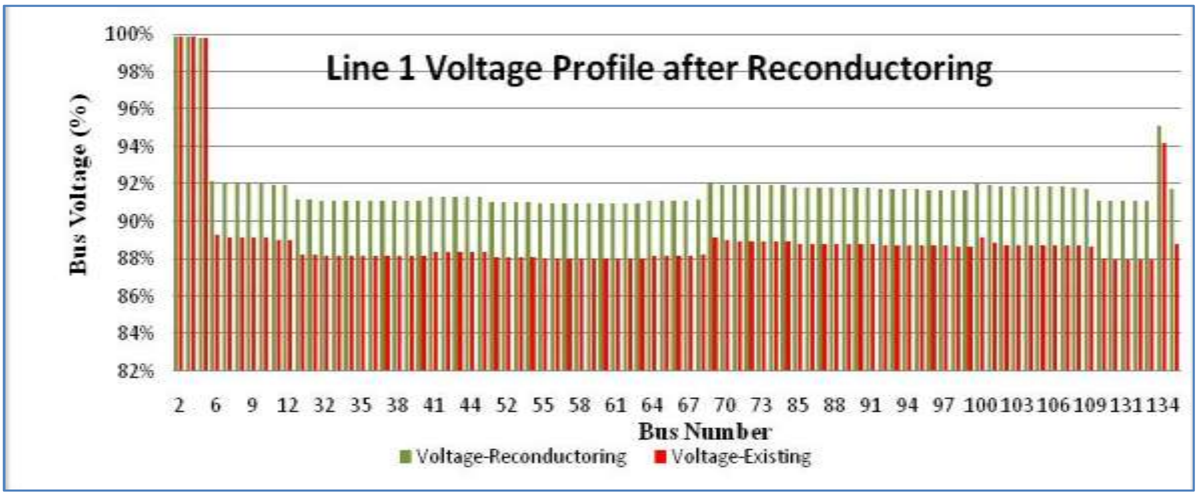

*Figure 4-3 Line 1 feeder voltage profile for existing condition and after CU*

**Load after 10 Years:** If this line will be continued in operation by replacing the overloaded line segments with appropriate conductor size, the amount of active power loss will be reduced 0.989 MW (reduced by 46.25%), after 10 years. From the alert summary report, even though, the voltage drop is improved, among 134 15kV buses, 129 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition) and none of the line segments is overloaded, after 10 years [Appendix A4.1].

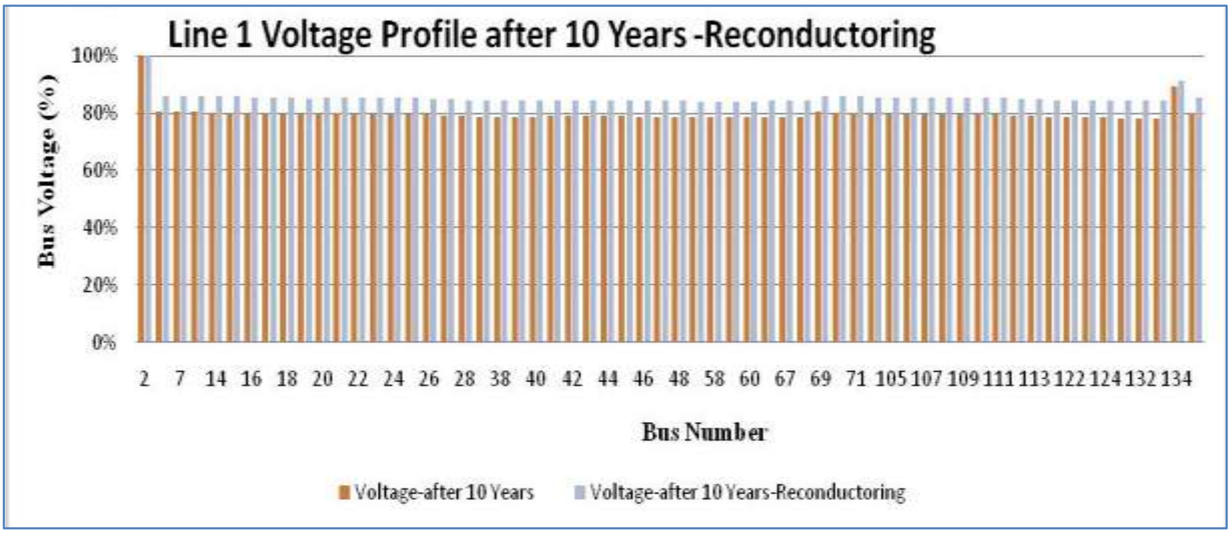

*Figure 4-4 Line 1 feeder voltage profile after 10 year for existing condition and after CU*

### Load Flow Result Analysis after OCP and CU

**Normal Load Scenario:** From the load flow summary report, active power loss of Line 1 feeder reduced to 0.246 MW (reduced by 57.58%) active power losses. From the alert summary report of Line 1 feeder, all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages (>98%) and none of the line segments is overloaded [Appendix A5].

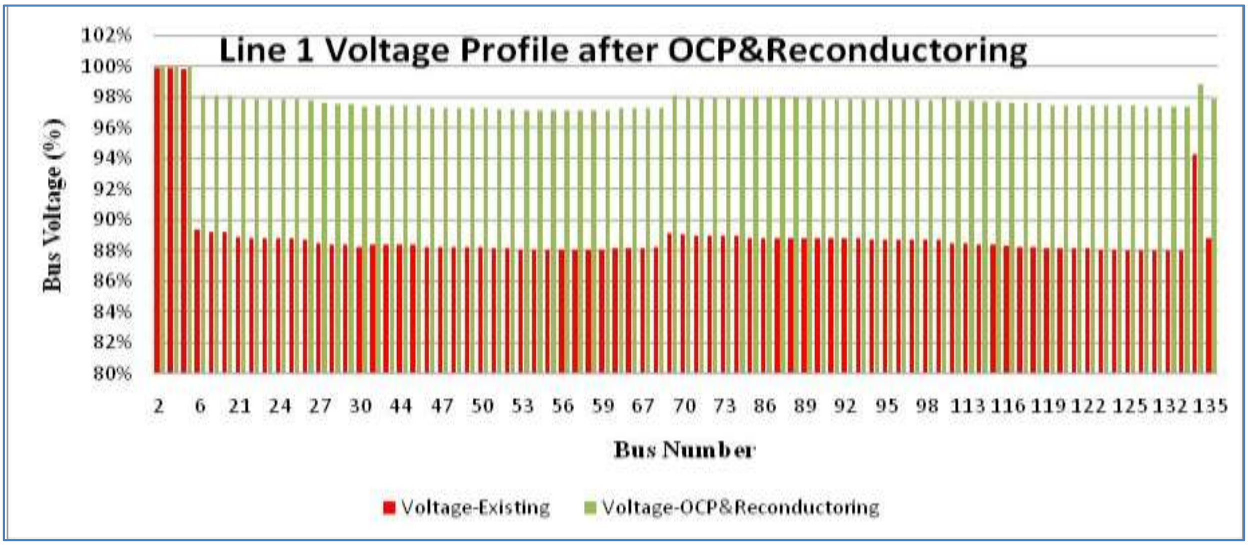

*Figure 4-5 Line 1 feeder voltage profile for existing condition and after OCP & CU*

**Load after 10 Years:** If this line will be continued in operation by replacing the overloaded line segments with appropriate conductor size and optimal placement of capacitor, the amount of active power loss will be reduced to 0.778 MW (reduced by 57.71%), after 10 years. From the alert summary report of Line 1 feeder, among 134 15kV buses, only 11 buses will be operating with voltages below the acceptable range (<90%) and none of the line segments is overloaded, after 10 years [Appendix A5.1].

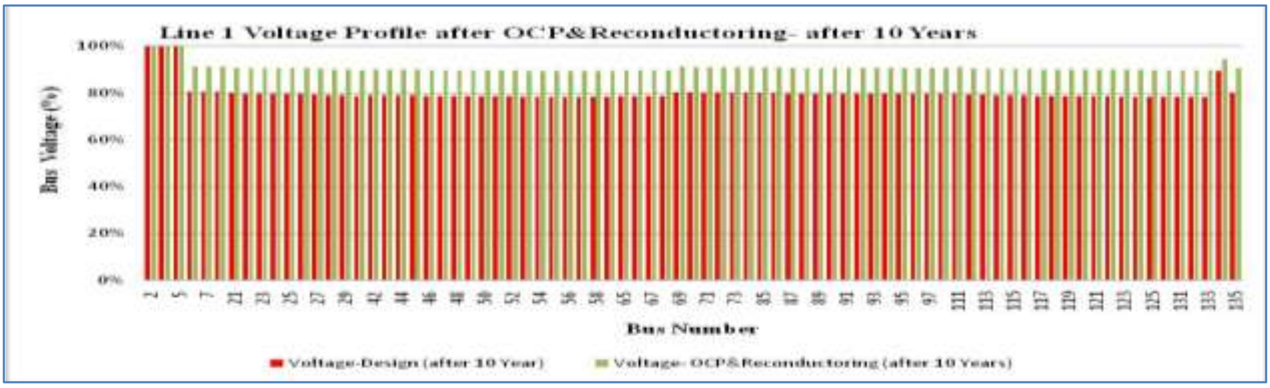

*Figure 4-6 Line 1 feeder voltage profile after 10 years for existing condition and after OCP & CU*

**Load Shifting among Feeders**: Using the GIS map of the distribution lines it was tried to shift the loads from over loaded feeders to relatively light loaded feeders to minimize the power loss and voltage drop. However, the over loaded feeders and those lightly loaded are physically far apart each other and load shifting among them is not practical. For those feeders nearby each other, no significance load amount can be shifted and hence loss minimization and voltage profile improvement couldn't be achieved.

## 4.5 Cost Benefit Analysis

### 4.5.1 Cost Analysis for Capacitor Placement:

After placement and sizing of capacitor has been accomplished, cost analysis of the selected size of capacitors for peak load has been done. From Table 6.2 and Appendix C, the cost of the selected size of capacitor is calculated as follows:

*Table 4-7: Costs of capacitors*

| **Bus ID** | **Nominal kV** | **kvar/ Bank** | **Rated kV** | **# of Banks** | **Total kvar** | **Cost of Capacitor** [45] |
|---|---|---|---|---|---|---|
| Bus_J12 | 15 | 300 | 15 | 1 | 300 | 6,300.00 |
| Bus_J18 | 15 | 300 | 15 | 2 | 600 | 9,450.00 |
| Bus_J20 | 15 | 300 | 15 | 1 | 300 | 6,300.00 |
| Bus_J68 | 15 | 300 | 15 | 2 | 600 | 9,450.00 |
| Bus_J84 | 15 | 300 | 15 | 2 | 600 | 9,450.00 |
| Bus_J103 | 15 | 300 | 15 | 2 | 600 | 9,450.00 |
| Bus_J123 | 15 | 300 | 15 | 2 | 600 | 9,450.00 |
| Sub total cost in USD | | | | | | 59,850.00 |
| Installation cost (10%) | | | | | | 5,985.00 |
| Annual maintenance cost (2%) | | | | | | 1,197.00 |
| Total cost in USD | | | | | | 67,032.00 |
| Total cost in Birr (*45.43) | | | | | | **Birr 3,045,263.76** |

The revised Energy tariff of Ethiopian Electric Utility is used to calculate the cost of loss reduction. From the revised tariff, average of the general tariff is used, which is 2.124 Birr/KWh. Power losses before capacitor placement was 0.58 MW and after capacitor placement is reduced to 0.389 MW.

Therefore, power loss reduction due to capacitor placement is:

$0.58\ MW - 0.389\ MW = 0.191\ MW.$

After capacitor placement total energy saved for one year is:

$0.191\ MW * 24 * 365 = 1{,}673.16\ M\text{Wh}.$

Saving in terms of Ethiopian Birr is:

$1{,}673.16\ M\text{Wh} * 1000\ (K/M) * 2.124\ (Birr/K\text{Wh})$ = **3,553,791.84 $Birr$/Year.**

The return of investment for capacitor placement (payback period) is calculated as the initial cost divided by the saving amount in one year. Thus, return of investment is calculated as follows:

$ROI$= Total Cost of Capacitors Placement/ saving amount per Year; $where\ \boldsymbol{ROI}: return\ of\ investiment$

$ROI$= 3,045,263.76/3,553,791.84 = 0.86 $year$.

Hence, for the current scenario, the cost analysis indicates that optimal capacitor placement needs initial capital investment cost of Birr **3,045,263.76** with return of investment of **0.86** year.

### 4.5.2 Cost Analysis for Conductor Upgrading:

Conductor upgrading/ re-conductor currently exercises by EEU under distribution network rehabilitation and upgrading projects. The average cost for materials supply and installation have been taken and applied for this cost analysis. The cost for required materials and for installation activities is calculated as follows;

*Table 4-8 Bill of quantities and prices for supply and installation of CU*

| No. | Description | Unit | Qty | Unit Price USD | Total Price USD | Unit Price ETB | Total Price, ETB |
|---|---|---|---|---|---|---|---|
| **Part I -Materials Supply** | | | | | | | |
| 1 | AAA Covered Conductor 1*150mm2 (3 phase) | km | 4.306 | 5,415.08 | 23,317.35 | | 0.00 |
| 2 | Column insulator (post ) | No | 310 | 15.46 | 4,786.27 | 2.34 | 724.13 |
| 3 | Suspension insulators | set | 297 | 46.39 | 13,764.42 | 7.02 | 2,081.88 |
| 4 | Hardware fittings | Set | 90 | 109.79 | 10,759.13 | 16.60 | 1,626.98 |
| 5 | Concrete Pole, SP (6 KN) | No | 51 | | | 10,195.96 | 519,993.96 |
| 6 | Concrete Pole, L.A (6 KN) | No | 13 | | | 10,195.96 | 132,547.48 |
| 7 | Concrete Pole, H.A (2x6 KN) | No | 26 | | | 10,195.96 | 265,094.96 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 8 | Concrete Pole, T-OFF (10KN) | No | 4 | | | 10,195.96 | 40,783.84 |
| 9 | Concrete Pole, DE (10KN) | No | 4 | | | 10,195.96 | 40,783.84 |
| **Part II - Installation Works** | | | | | | | |
| 1 | Pole planting including Pole Dressing | No | 98 | 271.24 | 26,581.40 | 948.85 | 92,986.92 |
| 2 | Pole concreting for SP & LA Pole | cu.m | 56.00 | 244.92 | 13,715.24 | 960.14 | 53,767.88 |
| 3 | 15kV Line stringing including transport of conductors | km | 4.31 | 966.73 | 4,162.75 | 3,637.24 | 15,661.95 |
| 4 | 15kV Line Testing and commissioning | km | 4.31 | 144.06 | 620.32 | 564.79 | 2,431.97 |
| **Total Cost** | | | | | **97,706.89** | | **1,168,485.80** |
| **Total Cost in ETB** | | | | | | | **5,607,309.85** |

The value of power losses before overloaded Conductor replacement was 0.58 MW and after replacing with proper size of Conductor, power loss is reduced to 0.331 M.

Therefore, power loss reduction due to Conductor replacement is:

$$0.58\ MW - 0.331\ MW = 0.249\ MW.$$

After Conductor replacement total energy saved for one year is:

$$0.249\ MW * 24 * 365 = 2{,}181.24\ M\text{Wh}.$$

Saving amount in terms of Ethiopian Birr is:

$$2{,}181.24\ M\text{Wh} * 1000\ (K/M) * 2.124\ (Birr/K\text{Wh}) = \mathbf{4{,}632{,}953.76}\ \boldsymbol{Birr}/\mathbf{Year.}$$

The return of investment for Conductor upgrading (payback period) is calculated as the initial cost divided by the saving amount in one year. Thus, return of investment is calculated as follows:

$ROI$= Total Cost of Conductor upgrading/ saving amount per Year;

$where\ \boldsymbol{ROI}: return\ of\ investiment$

$$ROI = 5{,}607{,}309.85 / 4{,}632{,}953.76 = 1.21\ year$$

Hence, for the current scenario, the cost analysis indicates that replacement of overloaded conductor with optimal conductor size needs initial capital investment cost of Birr **5,607,309.85** with return of investment of **1.21** year.

### 4.5.3 Cost Analysis for combination of OCP and Conductor Upgrading

It is needed to the cost effectiveness of the combined solution of Optimal Capacitor Placement and upgrading of overloaded conductors with optimal size of new conductors. The total cost for the combined solution is:

Total cost= 3,045,263.76+ 5,607,309.85= 8,652,573.61 Birr.

Power losses for the existing of Line 1 feeder is 0.58 MW and after optimal capacitor placement and replacing of overloaded conductor with proper size of conductor power is reduced to 0.246 M.

Therefore, power loss reduction due to both optimal capacitor placement and Conductor replacement is:

$0.58\ MW - 0.246\ MW = 0.334\ MW.$

The total energy saved for one year is:

$0.334\ MW * 24 * 365 = 2{,}925.84\ M\text{Wh}.$

Saving amount in terms of Ethiopian Birr is:

$2{,}925.84\ M\text{W}h * 1000\ (K/M) * 2.124\ (Birr/K\text{Wh})$ = **6,214,484.16 $Birr$/Year.**

The return of investment for both OCP and conductor upgrading (payback period) is calculated as the initial cost divided by the saving amount in one year. Thus, return of investment is calculated as follows:

R$eturn\ of\ investiment\ (ROI)$ = Total Cost of OCP and conductor upgrading/ saving amount per Year;

$ROI$= 8,652,573.61 /6,214,484.16 = 1.40 $yea$r.

For the current scenario, the cost analysis indicates that the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size needs initial capital investment cost of Birr **8,652,573.61** with return of investment of **1.40** years.

## 4.6 Summary and Discussion

Ten (10) 15 kV feeder lines have been included in the study in Adama town. In order to map the distribution lines on GIS, the shape file (spatially describe vector features: lines, transformers points, switching stations and feeder lines) was organized and then added as layers that overlaid on the base map of Adama town.

Single line diagrams of the entire 15 kV networks were mapped on GIS and all the background data of network configuration used for mapping were compiled in Postgre SQL data for further data analysis. The single line diagram of the network was simulated in Electrical Transient Analyzer Program (ETAP 19.0.1) using actual data collected and data imported from GIS map.

First, the load flow analysis was carried out on ten (10) outgoing 15 kV lines that emerge from Adama 2 (existing) and Adama mobile substations up to the last transformer point under each feeder.

The load flow analysis was done by using ETAP with current load scenario of the existing 15 kV distribution network and with load forecasting for the coming 10 years as well. ETAP single line represented substation, feeder lines, transformers, buses, breakers and Loads as a unique element in the model. The report presents a general description of 15 kV network of each feeder, followed by results of the load flow analysis in tabular form. From the load flow analysis result, overloaded conductors and load busses with excessive voltage drop (voltage below the acceptable range) were identified.

Among the ten (10) distribution lines included under the study, Line 1 experiences significant amount of power loss and voltage drop and hence, proposed solutions were simulated using single line diagram of Line 1 feeder.

From the load flow summary report, Line 1 feeder encountered total of **0.58 MW (9.61%)** active power losses. And among 134 15kV buses (load buses) 129 buses are operating with voltages below the acceptable range (under voltage condition) **(≤ 89.03%)**, and about 2 line segments are overloaded. If this line will be continued in operation without improving the network for the coming 10 years, the amount of active power loss will be increased to **1.84 MW (17.68**%), and among 134 15kV load busses, 130 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition) **(≤ 80.6%),** and about 7 line segments will be overloaded.

In order to overcome the identified power loss and under voltage problems at the study area, optimal capacitor placement, conductor upgrading, and the combined solution of both methods were proposed.

**Optimal Capacitor Placement (OCP)**:

It is proposed a function with cost minimization for voltage profile improvement, power factor improvement and power losses minimization. As OCP is a non-linear equation with the involvement of equality and inequality limitations, the stated solution depends on the optimal placement and sizes of the capacitor banks. ETAP software was used for the evaluation and modeling the power systems. Capacitor bank size, locations, and cost consideration are vital issues that needed to be optimized. MATLAB program was used to determine candidate buses based on power loss and voltage drop. In order to get the potential buses/nodes, the capacitor placement was performed by making the reactive power zero at each node. After compensating reactive power at each bus, load flows have been run again. From this load flow, the new real power loss and voltage deviation were evaluated. Candidate buses were selected considering power loss reduction index and improvement of voltage profile index calculated for each bus. By sorting these values, the candidate (potential) buses for capacitor placement were identified.

Accordingly, after OCP, the load flow result showed that active power loss of Line 1 feeder was reduced to **0.389 MW** (reduced by **32.93%)** and all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages (≥ 94%). If this line will be continued in operation by placing the capacitors at optimal place, the amount of active power loss will be reduced to 1.43 MW (reduced by 22.28%), and even though, the voltage drop is improved, among 134 15kV buses, 129 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition) (≤ 85.5%), and 7 line segments will be overloaded, after 10 years.

For the current scenario, the cost analysis indicates that optimal capacitor placement needs initial capital investment cost of Birr 3,045,263.76 with return of investment of 0.86 year.

**Upgrading of Overloaded Conductor:**

It is the technique of replacing the existing conductor on the feeder by conductor of optimal size for optimal 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. Thus, the overloaded line segments of Adama Line 1 were proposed to be replaced by optimal size of conductor.

Accordingly, after replacing of overloaded conductors, active power loss of Line 1 feeder was reduced to **0.331 MW** (reduced by **42.93%),** and all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages **(≥ 90%).** If this line will be continued in operation by replacing the overloaded line segments with appropriate conductor size, the amount of active power loss will be reduced **0.989 MW** (reduced by **46.25%),** and even though, the voltage drop is improved, among 134 15kV buses, 129 buses (load buses) will be operating with voltages below the acceptable range (under voltage condition) (**≤ 86%)** and none of the line segments is overloaded, after 10 years.

For the current scenario, the cost analysis indicates that replacement of overloaded conductor with optimal conductor size needs initial capital investment cost of Birr **5,607,309.85** with return of investment of **1.21 year**.

**Combination of Optimal Capacitor Placement and Conductor upgrading:**

The two solutions, optimal capacitor placement (OCP) and upgrading of overloaded conductor (CU) were applied and load flow was run using ETAP single line diagram. The load flow report shows that active power loss of Line 1 feeder reduced to **0.246 MW** (reduced by **57.58%), a**nd all 15kV buses (load buses) are operating with voltages above the minimum acceptable range of voltages (≥ 98%) and none of the line segments is overloaded. If this line will be continued in operation by replacing the overloaded line segments with optimal placement of capacitor and appropriate conductor size, the amount of active power loss will be reduced to **0.778 MW** (reduced by **57.71%),** and among 134 15kV buses, only 11 buses will be operating with voltages below the acceptable range (< 90%) and none of the line segments is overloaded, after 10 years.

For the current scenario, the cost analysis indicates that the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size needs initial capital investment cost of Birr **8,652,573.61** with return of investment of **1.40** years.

**Comparison of Loss, Voltage drop and Cost reduction for the three cases:**

Here, results of power loss reduction, voltage improvement, and cost analyses after OCP, CU and combination of OCP and CU were compared.

*Table 4-9 Comparison for the result of loss reduction and voltage improvement*

| **Main items** | **Current Scenario (One year)** | | | | **Design Scenario (10 years)** | | | |
|---|---|---|---|---|---|---|---|---|
| | **Existing Condition** | **OCP** | **CU** | **OCP+CU** | **Existing Condition** | **OCP** | **CU** | **OCP+CU** |
| Active power loss (MW) | 0.58 | 0.389 | 0.331 | 0.246 | 1.84 | 1.43 | 0.989 | 0.778 |
| Active power loss reduction (%) | - | 32.90 | 42.90 | 57.60 | - | 22.30 | 46.30 | 57.70 |
| Minimum bus voltage (pu) | 0.88 | 0.942 | 0.91 | 0.971 | 0.783 | 0.835 | 0.84 | 0.894 |

*Table 4-10 Comparison for the result of cost (return of investment)*

| | **OCP** | **CU** | **Combination of OCP and CU** |
|---|---|---|---|
| Total Costs (Birr) | 3,045,263.76 | 5,607,309.85 | 8,652,573.61 |
| Saving amount in a year (Birr) | 3,553,791.84 | 4,632,953.76 | 6,214,484.16 |
| Return of Investment (year) | 0.86 | 1.21 | 1.40 |

**Normal Load Scenario:**

The result for the current scenario shows that applying the combination of OCP and CU gives the highest active power loss reduction (57.6%), followed by CU (42.9%) and OCP (32.9%). It also shows the highest bus voltage profile (≥0.971pu), followed by OCP (≥0.942pu) and CU (≥0.91pu). However, the result of cost analysis indicates that the combination of OCP and CU needs higher initial capital investment cost of **Birr 8,652,573.61** with return of investment of 1.40 years. OCP needs initial capital investment cost of **Birr 3,045,263.76** with return of investment of 0.86 year whereas, CU needs initial capital investment cost of **Birr 5,607,309.85** with return of investment of 1.21 year.

Thus, among the three cases, OCP is selected for the current scenario due to its best power loss reduction and voltage improvement with best return of investment (cost saving amount). As we could observe from our result, if we make investments for addition of reactive power compensator using optimal placement of capacitors, reduced power losses cost will easily recover the investment cost.

For the current scenario, the result shows that in remaining two cases, even though the losses are reduced and bus voltage improved, the investment cost could be so high and economically are not effective to implement. Hence, for the current scenario, optimal capacitor placement can reduce losses and improve voltage profile with good investment saving.

**Load after 10 years:**

On the other hand, the result for the design scenario (10 years) shows that using the combination of OCP and CU gives the highest active power loss reduction (57.7%), followed by CU (46.3%) and OCP (22.3%). It also shows the minimum bus voltage profile of 0.894pu and among 134 15kV buses, only 11 buses will be operating with voltages below the acceptable range (< 90%) and none of the line segments is overloaded, after 10 years. However, the minimum bus voltage for CU and OCP are 0.840pu and 0.835pu, respectively, and indicating that even though the voltage drop is improved, among 134 15kV buses, majority of the load buses will be operating with voltages below the acceptable range in both cases, after 10 years.

Moreover, the result of cost analysis indicates that the combined solution of optimal capacitor placement and overloaded conductor replacement with optimal conductor size needs initial capital investment cost of Birr **8,652,573.61** with return of investment of **1.40** years. Hence, among the three cases, using combination of OCP and CU is selected for the design scenario (10 years) due to its best power loss reduction, voltage profile improvement and return of investment (cost saving amount).

In general, the results of this study revealed that for short term solution, optimal capacitor placement (OCP) method is proposed, whereas for long term solution, the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size is proposed to be implemented to smooth the operation for the next 10 years.

# CHAPTER FIVE

# 5 CONCLUSION, RECOMMENDATIONS AND FUTURE WORKS

## 5.1 Conclusion

In this thesis work, Geographic Information Systems (GIS) based modeling and performance improvement 15kV distribution network was done in terms of loss minimization and voltage profile improvement.

Ten (10) 15 kV distribution lines of Adama town were included in the study. In order to model the distribution lines using GIS, the shape file (spatially describe vector features: lines, transformers point, switching stations and etc.) was organized and then added as layers that overlaid on the base map of Adama town. The entire 15 kV distribution networks were mapped on GIS and all the background data of network configuration used for mapping were compiled in Postgre SQL data for further data analysis.

By integrating the GIS based database with the Electrical Transient Analyzer Program (ETAP 19.0.1), modeling the distribution network and power flow analysis were done using ETAP with current load scenario of the existing 15 kV distribution network and with load forecasting for the coming 10 years as well. From the ETAP load flow analysis result, overloaded conductors and load busses with excessive voltage drop (voltage below the acceptable range) were identified.

Among the ten (10) distribution lines included under the study, Line 1 experiences significant amount of power loss and voltage drop and hence, proposed solutions are simulated using Line 1 feeder single line diagram. Line 1 feeder encountered total of **0.58 MW (9.61%)** active power losses. And among 134 15kV buses, 129 of them are operating with voltages below the acceptable range **(≤ 89.3%)** and about 2 line segments are overloaded. Furthermore, if this line will be continued in operation without improving the network, the amount of active power loss will be increased to **1.84 MW (17.68**%), and among 134 15kV load busses, most (130) of them will be operating with voltages below the acceptable range, after 10 years.

In order to overcome the identified power loss and under voltage problems at the study area, optimal capacitor placement (OCP), conductor upgrading (CU), and the combined solution of both methods were proposed.

For the current scenario, the combined solution of OCP and CU shows the highest and significant active power loss reduction (57.6%), followed by CU (42.9%) and OCP (32.9%). It also shows bus voltage profile ≥0.971pu, followed by OCP ≥0.942pu and CU ≥0.91pu. However, using the combination of OCP and CU needs higher initial capital investment cost with larger payback period (return of investment), whereas using OCP needs lower initial capital investment cost with lower return of investment of 0.86 year. Hence, among the three cases, OCP is selected for the current scenario due to its best power loss reduction and voltage improvement with lower return of investment. The result revealed that if we make investments for addition of reactive power using optimal placement of capacitors, cost of reduced power losses will easily recover the investment cost than that of the remaining two cases.

Regarding the design scenario (10 years forecast), the combined solution of OCP and CU shows the highest and significant active power loss reduction (57.7%), followed by CU (46.3%) and OCP (22.3%). It also shows the highest bus voltage profile and among 134 15kV load buses, only 11 of them will be operating with voltages below the acceptable range (≤0.894pu) and none of the line segments is overloaded. However, even though the voltage drop is improved, among 134 15kV buses, majority of the load buses will be operating with voltages below the acceptable range in the remaining two cases, after 10 years. Hence, among the three cases, using the combined solution of optimal capacitor placement and overloaded conductor replacement with optimal conductor size is proposed for the design scenario (10 years forecast) due to its best power loss reduction and voltage profile improvement with return of investment of **1.40** years.

In general, the results of this study revealed that for short term solution, optimal capacitor placement (OCP) method is proposed, whereas for long term solution, the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size is proposed to be implemented to smooth the operation for the next 10 years.

## 5.2 Recommendations

Based on the above stated conclusions, the following proposed recommendations are made:

- For considering the short term solution, planning and operations engineers need to consider optimal capacitor placement techniques for power loss reduction and voltage profile improvement in the power distribution network. On the other hand, for long term solution, the combined solution of optimal capacitor placement and replacement of overloaded conductor with optimal conductor size should be considered for power loss reduction and voltage profile improvement in the power distribution network.
- The optimal capacitor placement methodology and replacement methods of overloaded conductor with optimal conductor size need to be reviewed by the Utility and to be use it in the planning and operational stages.

## 5.3 Suggested Future Works

In this thesis, performance improvement of distribution network in terms of loss reduction and voltage profile improvement using optimal capacitor placement, conductor upgrading and the combination of both methods has been done. There are other methods used to improve the performance of distribution networks in terms of loss minimization and voltage profile improvement.

Therefore, the following methods are suggested for future work to improve the performance of distribution networks in terms of loss minimization and voltage profile improvement.

1. Selection of optimal location of distribution transformers in distribution networks to minimize power losses.
2. Load balancing methods in distribution networks to minimize power losses.
3. Optimized loading of distribution transformers to minimize power loss in distribution network.

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# Appendix A: Load Flow Results

## A1: Operating Voltage all 15 kV Line

| Bus ID | Nominal kV | Type of Bus | Existing Voltage (%) | Existing Condition | Voltage after 10 Years (%) | Condition after 10 Year |
|---|---|---|---|---|---|---|
| Bus1 | 15 | Load | 100.06 | | 99.82 | |
| Bus3 | 15 | Load | 99.71 | | 100.14 | |
| Bus4 | 15 | Load | 92.17 | | 87.22 | Under Voltage |
| Bus5 | 15 | Load | 92.17 | | 87.22 | Under Voltage |
| Bus6 | 15 | Load | 91.56 | | 86.27 | Under Voltage |
| Bus7 | 15 | Load | 91.56 | | 86.26 | Under Voltage |
| Bus8 | 15 | Load | 91.21 | | 85.72 | Under Voltage |
| Bus9 | 15 | Load | 91.16 | | 85.64 | Under Voltage |
| Bus10 | 15 | Load | 91.15 | | 85.63 | Under Voltage |
| Bus11 | 15 | Load | 90.88 | | 85.2 | Under Voltage |
| Bus12 | 15 | Load | 90.88 | | 85.2 | Under Voltage |
| Bus13 | 15 | Load | 90.51 | | 84.61 | Under Voltage |
| Bus14 | 15 | Load | 90.49 | | 84.59 | Under Voltage |
| Bus15 | 15 | Load | 90.32 | | 84.32 | Under Voltage |
| Bus16 | 15 | Load | 90.26 | | 84.22 | Under Voltage |
| Bus17 | 15 | Load | 90.14 | | 84.04 | Under Voltage |
| Bus18 | 15 | Load | 90.11 | | 83.99 | Under Voltage |
| Bus19 | 15 | Load | 90.1 | | 83.97 | Under Voltage |
| Bus20 | 15 | Load | 90.08 | | 83.94 | Under Voltage |
| Bus21 | 15 | Load | 90.04 | | 83.89 | Under Voltage |
| Bus22 | 15 | Load | 89.95 | Under Voltage | 83.74 | Under Voltage |
| Bus23 | 15 | Load | 89.87 | Under Voltage | 83.61 | Under Voltage |
| Bus24 | 15 | Load | 89.82 | Under Voltage | 83.54 | Under Voltage |
| Bus25 | 15 | Load | 89.82 | Under Voltage | 83.53 | Under Voltage |
| Bus26 | 15 | Load | 89.8 | Under Voltage | 83.5 | Under Voltage |
| Bus27 | 15 | Load | 89.74 | Under Voltage | 83.41 | Under Voltage |
| Bus28 | 15 | Load | 89.74 | Under Voltage | 83.41 | Under Voltage |
| Bus29 | 15 | Load | 89.74 | Under Voltage | 83.41 | Under Voltage |
| Bus30 | 15 | Load | 89.74 | Under Voltage | 83.41 | Under Voltage |
| Bus31 | 15 | Load | 89.71 | Under Voltage | 83.36 | Under Voltage |
| Bus32 | 15 | Load | 89.7 | Under Voltage | 83.35 | Under Voltage |
| Bus33 | 15 | Load | 89.69 | Under Voltage | 83.33 | Under Voltage |
| Bus34 | 15 | Load | 89.69 | Under Voltage | 83.33 | Under Voltage |
| Bus35 | 15 | Load | 89.69 | Under Voltage | 83.33 | Under Voltage |
| Bus36 | 15 | Load | 89.71 | Under Voltage | 83.35 | Under Voltage |
| Bus37 | 15 | Load | 90.07 | | 83.93 | Under Voltage |
| Bus38 | 15 | Load | 90.07 | | 83.93 | Under Voltage |
| Bus39 | 15 | Load | 92.14 | | 87.17 | Under Voltage |
| Bus40 | 15 | Load | 92.13 | | 87.16 | Under Voltage |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bus41 | 15 | Load | 92.07 | | 87.07 | Under Voltage |
| Bus42 | 15 | Load | 92.07 | | 87.06 | Under Voltage |
| Bus43 | 15 | Load | 92.03 | | 87.01 | Under Voltage |
| Bus44 | 15 | Load | 91.75 | | 86.57 | Under Voltage |
| Bus45 | 15 | Load | 91.73 | | 86.52 | Under Voltage |
| Bus46 | 15 | Load | 91.73 | | 86.52 | Under Voltage |
| Bus47 | 15 | Load | 91.67 | | 86.44 | Under Voltage |
| Bus48 | 15 | Load | 91.67 | | 86.43 | Under Voltage |
| Bus49 | 15 | Load | 91.66 | | 86.43 | Under Voltage |
| Bus50 | 15 | Load | 91.67 | | 86.43 | Under Voltage |
| Bus51 | 15 | Load | 91.63 | | 86.37 | Under Voltage |
| Bus52 | 15 | Load | 91.62 | | 86.35 | Under Voltage |
| Bus53 | 15 | Load | 91.65 | | 86.4 | Under Voltage |
| Bus54 | 15 | Load | 91.57 | | 86.28 | Under Voltage |
| Bus55 | 15 | Load | 91.57 | | 86.28 | Under Voltage |
| Bus56 | 15 | Load | 91.53 | | 86.22 | Under Voltage |
| Bus57 | 15 | Load | 91.53 | | 86.22 | Under Voltage |
| Bus58 | 15 | Load | 91.46 | | 86.11 | Under Voltage |
| Bus59 | 15 | Load | 91.46 | | 86.11 | Under Voltage |
| Bus60 | 15 | Load | 91.46 | | 86.11 | Under Voltage |
| Bus61 | 15 | Load | 91.45 | | 86.09 | Under Voltage |
| Bus62 | 15 | Load | 91.45 | | 86.09 | Under Voltage |
| Bus63 | 15 | Load | 91.45 | | 86.09 | Under Voltage |
| Bus64 | 15 | Load | 91.45 | | 86.09 | Under Voltage |
| Bus65 | 15 | Load | 91.59 | | 86.32 | Under Voltage |
| Bus66 | 15 | Load | 91.58 | | 86.29 | Under Voltage |
| Bus67 | 15 | Load | 91.58 | | 86.29 | Under Voltage |
| Bus68 | 15 | Load | 91.57 | | 86.27 | Under Voltage |
| Bus69 | 15 | Load | 91.4 | | 86 | Under Voltage |
| Bus70 | 15 | Load | 91.38 | | 85.98 | Under Voltage |
| Bus71 | 15 | Load | 91.38 | | 85.98 | Under Voltage |
| Bus72 | 15 | Load | 91.3 | | 85.85 | Under Voltage |
| Bus73 | 15 | Load | 91.3 | | 85.85 | Under Voltage |
| Bus74 | 15 | Load | 91.3 | | 85.85 | Under Voltage |
| Bus75 | 15 | Load | 91.3 | | 85.85 | Under Voltage |
| Bus76 | 15 | Load | 91.25 | | 85.77 | Under Voltage |
| Bus77 | 15 | Load | 91.23 | | 85.75 | Under Voltage |
| Bus78 | 15 | Load | 91.24 | | 85.75 | Under Voltage |
| Bus79 | 15 | Load | 91.23 | | 85.74 | Under Voltage |
| Bus80 | 15 | Load | 91.23 | | 85.74 | Under Voltage |
| Bus81 | 15 | Load | 91.23 | | 85.74 | Under Voltage |
| Bus82 | 15 | Load | 91.23 | | 85.74 | Under Voltage |
| Bus83 | 15 | Load | 91.33 | | 85.9 | Under Voltage |
| Bus84 | 15 | Load | 91.33 | | 85.9 | Under Voltage |
| Bus85 | 15 | Load | 91.26 | | 85.79 | Under Voltage |
| Bus86 | 15 | Load | 91.21 | | 85.71 | Under Voltage |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bus87 | 15 | Load | 91.21 | | 85.71 | Under Voltage |
| Bus88 | 15 | Load | 91.12 | | 85.58 | Under Voltage |
| Bus89 | 15 | Load | 91.12 | | 85.56 | Under Voltage |
| Bus90 | 15 | Load | 91.1 | | 85.54 | Under Voltage |
| Bus91 | 15 | Load | 91.1 | | 85.53 | Under Voltage |
| Bus92 | 15 | Load | 91.06 | | 85.47 | Under Voltage |
| Bus93 | 15 | Load | 91.06 | | 85.47 | Under Voltage |
| Bus94 | 15 | Load | 91.04 | | 85.45 | Under Voltage |
| Bus95 | 15 | Load | 91.04 | | 85.44 | Under Voltage |
| Bus96 | 15 | Load | 91.02 | | 85.41 | Under Voltage |
| Bus97 | 15 | Load | 91.02 | | 85.41 | Under Voltage |
| Bus98 | 15 | Load | 91.02 | | 85.41 | Under Voltage |
| Bus99 | 15 | Load | 91.02 | | 85.41 | Under Voltage |
| Bus100 | 15 | Load | 91.02 | | 85.41 | Under Voltage |
| Bus101 | 15 | Load | 91 | | 85.38 | Under Voltage |
| Bus102 | 15 | Load | 91 | | 85.38 | Under Voltage |
| Bus103 | 15 | Load | 90.33 | | 84.33 | Under Voltage |
| Bus104 | 15 | Load | 92.27 | | 87.38 | Under Voltage |
| Bus105 | 15 | Load | 92.26 | | 87.37 | Under Voltage |
| Bus114 | 15 | Load | 99.43 | | 99.69 | |
| Bus116 | 15 | Load | 100.19 | | 100.04 | |
| Bus117 | 15 | Load | 100.19 | | 100.04 | |
| Bus167 | 15 | Load | 90.93 | | 85.45 | Under Voltage |
| Bus168 | 15 | Load | 90.92 | | 85.44 | Under Voltage |
| Bus169 | 15 | Load | 90.91 | | 85.43 | Under Voltage |
| Bus170 | 15 | Load | 92.73 | | 88.26 | Under Voltage |
| Bus171 | 15 | Load | 100.06 | | 99.82 | |
| Bus172 | 15 | Load | 92.73 | | 88.25 | Under Voltage |
| Bus173 | 15 | Load | 92.73 | | 88.26 | Under Voltage |
| Bus174 | 15 | Load | 92.73 | | 88.26 | Under Voltage |
| Bus175 | 15 | Load | 92.73 | | 88.25 | Under Voltage |
| Bus176 | 15 | Load | 92.6 | | 88.06 | Under Voltage |
| Bus177 | 15 | Load | 92.6 | | 88.06 | Under Voltage |
| Bus178 | 15 | Load | 92.34 | | 87.65 | Under Voltage |
| Bus179 | 15 | Load | 92.33 | | 87.63 | Under Voltage |
| Bus180 | 15 | Load | 91.74 | | 86.71 | Under Voltage |
| Bus181 | 15 | Load | 91.64 | | 86.55 | Under Voltage |
| Bus182 | 15 | Load | 91.71 | | 86.66 | Under Voltage |
| Bus183 | 15 | Load | 91.7 | | 86.66 | Under Voltage |
| Bus184 | 15 | Load | 91.69 | | 86.63 | Under Voltage |
| Bus185 | 15 | Load | 91.55 | | 86.42 | Under Voltage |
| Bus186 | 15 | Load | 91.52 | | 86.37 | Under Voltage |
| Bus187 | 15 | Load | 91.46 | | 86.28 | Under Voltage |
| Bus188 | 15 | Load | 91.44 | | 86.25 | Under Voltage |
| Bus189 | 15 | Load | 91.43 | | 86.23 | Under Voltage |
| Bus190 | 15 | Load | 91.32 | | 86.06 | Under Voltage |

| | | | | | | |
|---|---|---|---|---|---|---|
| Bus191 | 15 | Load | 91.51 | | 86.35 | Under Voltage |
| Bus192 | 15 | Load | 91.51 | | 86.35 | Under Voltage |
| Bus193 | 15 | Load | 91.35 | | 86.11 | Under Voltage |
| Bus194 | 15 | Load | 91.01 | | 85.58 | Under Voltage |
| Bus195 | 15 | Load | 90.94 | | 85.46 | Under Voltage |
| Bus196 | 15 | Load | 90.93 | | 85.45 | Under Voltage |
| Bus197 | 15 | Load | 90.95 | | 85.48 | Under Voltage |
| Bus198 | 15 | Load | 90.83 | | 85.3 | Under Voltage |
| Bus199 | 15 | Load | 90.71 | | 85.11 | Under Voltage |
| Bus200 | 15 | Load | 90.69 | | 85.08 | Under Voltage |
| Bus201 | 15 | Load | 90.69 | | 85.08 | Under Voltage |
| Bus202 | 15 | Load | 90.51 | | 84.79 | Under Voltage |
| Bus203 | 15 | Load | 90.5 | | 84.79 | Under Voltage |
| Bus204 | 15 | Load | 90.41 | | 84.65 | Under Voltage |
| Bus205 | 15 | Load | 90.39 | | 84.62 | Under Voltage |
| Bus206 | 15 | Load | 90.41 | | 84.65 | Under Voltage |
| Bus207 | 15 | Load | 90.38 | | 84.59 | Under Voltage |
| Bus208 | 15 | Load | 90.36 | | 84.56 | Under Voltage |
| Bus209 | 15 | Load | 90.88 | | 85.37 | Under Voltage |
| Bus210 | 15 | Load | 90.92 | | 85.43 | Under Voltage |
| Bus211 | 15 | Load | 90.91 | | 85.42 | Under Voltage |
| Bus212 | 15 | Load | 90.92 | | 85.43 | Under Voltage |
| Bus213 | 15 | Load | 90.85 | | 85.33 | Under Voltage |
| Bus214 | 15 | Load | 90.84 | | 85.31 | Under Voltage |
| Bus215 | 15 | Load | 90.83 | | 85.3 | Under Voltage |
| Bus216 | 15 | Load | 90.83 | | 85.3 | Under Voltage |
| Bus217 | 15 | Load | 92.7 | | 88.21 | Under Voltage |
| Bus218 | 15 | Load | 92.69 | | 88.19 | Under Voltage |
| Bus219 | 15 | Load | 92.68 | | 88.18 | Under Voltage |
| Bus220 | 15 | Load | 92.67 | | 88.17 | Under Voltage |
| Bus221 | 15 | Load | 91.75 | | 86.73 | Under Voltage |
| Bus222 | 15 | Load | 91.74 | | 86.71 | Under Voltage |
| Bus223 | 15 | Load | 91.73 | | 86.7 | Under Voltage |
| Bus224 | 15 | Load | 91.71 | | 86.67 | Under Voltage |
| Bus225 | 15 | Load | 91.7 | | 86.65 | Under Voltage |
| Bus226 | 15 | Load | 91.62 | | 86.53 | Under Voltage |
| Bus227 | 15 | Load | 91.6 | | 86.5 | Under Voltage |
| Bus228 | 15 | Load | 91.6 | | 86.49 | Under Voltage |
| Bus229 | 15 | Load | 91.61 | | 86.51 | Under Voltage |
| Bus230 | 15 | Load | 91.61 | | 86.51 | Under Voltage |
| Bus231 | 15 | Load | 91.6 | | 86.5 | Under Voltage |
| Bus232 | 15 | Load | 91.43 | | 86.23 | Under Voltage |
| Bus233 | 15 | Load | 91.43 | | 86.23 | Under Voltage |
| Bus234 | 15 | Load | 91.28 | | 86 | Under Voltage |
| Bus235 | 15 | Load | 91.22 | | 85.91 | Under Voltage |
| Bus236 | 15 | Load | 91.22 | | 85.9 | Under Voltage |

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| Bus237 | 15 | Load | 91.18 | | 85.84 | Under Voltage |
| Bus238 | 15 | Load | 91.15 | | 85.8 | Under Voltage |
| Bus239 | 15 | Load | 91.14 | | 85.78 | Under Voltage |
| Bus240 | 15 | Load | 91.13 | | 85.77 | Under Voltage |
| Bus241 | 15 | Load | 90.98 | | 85.53 | Under Voltage |
| Bus242 | 15 | Load | 90.9 | | 85.4 | Under Voltage |
| Bus243 | 15 | Load | 90.89 | | 85.39 | Under Voltage |
| Bus244 | 15 | Load | 92.29 | | 87.58 | Under Voltage |
| Bus245 | 15 | Load | 90.94 | | 85.46 | Under Voltage |
| Bus247 | 15 | Load | 90.83 | | 85.3 | Under Voltage |
| Bus253 | 15 | Load | 91.31 | | 86.04 | Under Voltage |
| Bus257 | 15 | Load | 91.48 | | 86.31 | Under Voltage |
| Bus260 | 15 | Load | 91.44 | | 86.25 | Under Voltage |
| Bus262 | 15 | Load | 91.42 | | 86.22 | Under Voltage |
| Bus264 | 15 | Load | 91.42 | | 86.21 | Under Voltage |
| Bus266 | 15 | Load | 91.39 | | 86.17 | Under Voltage |
| Bus272 | 15 | Load | 90.84 | | 85.32 | Under Voltage |
| Bus276 | 15 | Load | 90.7 | | 85.1 | Under Voltage |
| Bus281 | 15 | Load | 90.39 | | 84.61 | Under Voltage |
| Bus283 | 15 | Load | 90.37 | | 84.58 | Under Voltage |
| Bus286 | 15 | Load | 91.73 | | 86.69 | Under Voltage |
| Bus291 | 15 | Load | 90.9 | | 85.41 | Under Voltage |
| Bus294 | 15 | Load | 92.67 | | 88.17 | Under Voltage |
| Bus298 | 15 | Load | 91.22 | | 85.9 | Under Voltage |
| Bus300 | 15 | Load | 90.91 | | 85.42 | Under Voltage |
| Bus312 | 15 | Load | 91.28 | | 86 | Under Voltage |
| Bus316 | 15 | Load | 90.91 | | 85.42 | Under Voltage |
| Bus319 | 15 | Load | 90.92 | | 85.44 | Under Voltage |
| Bus321 | 15 | Load | 90.91 | | 85.42 | Under Voltage |
| Bus323 | 15 | Load | 91.13 | | 85.76 | Under Voltage |
| Bus326 | 15 | Load | 90.95 | | 85.48 | Under Voltage |
| Bus328 | 15 | Load | 92.7 | | 88.21 | Under Voltage |
| Bus333 | 15 | Load | 99.14 | | 98.34 | |
| Bus334 | 15 | Load | 99.13 | | 98.34 | |
| Bus335 | 15 | Load | 99.03 | | 98.17 | |
| Bus336 | 15 | Load | 99 | | 98.13 | |
| Bus337 | 15 | Load | 99 | | 98.13 | |
| Bus338 | 15 | Load | 98.98 | | 98.09 | |
| Bus339 | 15 | Load | 98.98 | | 98.09 | |
| Bus340 | 15 | Load | 98.92 | | 98 | |
| Bus341 | 15 | Load | 98.92 | | 98 | |
| Bus342 | 15 | Load | 98.88 | | 97.93 | |
| Bus343 | 15 | Load | 98.84 | | 97.86 | |
| Bus344 | 15 | Load | 98.84 | | 97.86 | |
| Bus345 | 15 | Load | 98.75 | | 97.72 | |
| Bus346 | 15 | Load | 98.74 | | 97.71 | |

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| Bus347 | 15 | Load | 98.73 | | 97.7 | |
| Bus348 | 15 | Load | 98.73 | | 97.7 | |
| Bus349 | 15 | Load | 98.72 | | 97.68 | |
| Bus350 | 15 | Load | 99.24 | | 98.51 | |
| Bus351 | 15 | Load | 99.24 | | 98.51 | |
| Bus352 | 15 | Load | 99.2 | | 98.45 | |
| Bus353 | 15 | Load | 98.83 | | 97.85 | |
| Bus354 | 15 | Load | 98.82 | | 97.84 | |
| Bus355 | 15 | Load | 98.82 | | 97.84 | |
| Bus356 | 15 | Load | 98.81 | | 97.82 | |
| Bus357 | 15 | Load | 98.8 | | 97.81 | |
| Bus358 | 15 | Load | 98.8 | | 97.81 | |
| Bus359 | 15 | Load | 98.8 | | 97.81 | |
| Bus360 | 15 | Load | 98.8 | | 97.81 | |
| Bus361 | 15 | Load | 98.69 | | 97.63 | |
| Bus362 | 15 | Load | 98.69 | | 97.63 | |
| Bus363 | 15 | Load | 98.69 | | 97.62 | |
| Bus364 | 15 | Load | 98.55 | | 97.41 | |
| Bus365 | 15 | Load | 98.55 | | 97.41 | |
| Bus366 | 15 | Load | 98.48 | | 97.3 | |
| Bus367 | 15 | Load | 98.48 | | 97.3 | |
| Bus368 | 15 | Load | 98.42 | | 97.2 | |
| Bus369 | 15 | Load | 98.42 | | 97.2 | |
| Bus370 | 15 | Load | 98.35 | | 97.08 | |
| Bus371 | 15 | Load | 98.34 | | 97.08 | |
| Bus372 | 15 | Load | 98.34 | | 97.07 | |
| Bus373 | 15 | Load | 98.34 | | 97.07 | |
| Bus374 | 15 | Load | 98.04 | | 96.6 | |
| Bus375 | 15 | Load | 97.16 | | 95.19 | |
| Bus376 | 15 | Load | 97.15 | | 95.19 | |
| Bus377 | 15 | Load | 97.15 | | 95.18 | |
| Bus378 | 15 | Load | 97.15 | | 95.18 | |
| Bus379 | 15 | Load | 97.04 | | 95 | |
| Bus380 | 15 | Load | 97.04 | | 95 | |
| Bus381 | 15 | Load | 96.9 | | 94.78 | |
| Bus382 | 15 | Load | 96.9 | | 94.78 | |
| Bus383 | 15 | Load | 96.88 | | 94.74 | |
| Bus384 | 15 | Load | 96.86 | | 94.72 | |
| Bus385 | 15 | Load | 96.86 | | 94.71 | |
| Bus386 | 15 | Load | 96.85 | | 94.71 | |
| Bus387 | 15 | Load | 96.6 | | 94.31 | |
| Bus388 | 15 | Load | 96.6 | | 94.31 | |
| Bus389 | 15 | Load | 96.6 | | 94.31 | |
| Bus390 | 15 | Load | 96.35 | | 93.91 | |
| Bus391 | 15 | Load | 96.35 | | 93.91 | |
| Bus392 | 15 | Load | 96.29 | | 93.81 | |

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| Bus393 | 15 | Load | 96.29 | | 93.81 | |
| Bus394 | 15 | Load | 96.24 | | 93.74 | |
| Bus395 | 15 | Load | 96.24 | | 93.74 | |
| Bus396 | 15 | Load | 96.18 | | 93.64 | |
| Bus397 | 15 | Load | 96.17 | | 93.62 | |
| Bus398 | 15 | Load | 96.17 | | 93.62 | |
| Bus399 | 15 | Load | 96.15 | | 93.59 | |
| Bus400 | 15 | Load | 96.15 | | 93.59 | |
| Bus401 | 15 | Load | 96.12 | | 93.54 | |
| Bus402 | 15 | Load | 96.12 | | 93.54 | |
| Bus403 | 15 | Load | 96.1 | | 93.5 | |
| Bus404 | 15 | Load | 96.1 | | 93.5 | |
| Bus405 | 15 | Load | 96.09 | | 93.49 | |
| Bus406 | 15 | Load | 96.08 | | 93.48 | |
| Bus407 | 15 | Load | 96.08 | | 93.48 | |
| Bus408 | 15 | Load | 96.08 | | 93.47 | |
| Bus409 | 15 | Load | 96.05 | | 93.43 | |
| Bus410 | 15 | Load | 96.05 | | 93.43 | |
| Bus411 | 15 | Load | 96.05 | | 93.43 | |
| Bus412 | 15 | Load | 96.05 | | 93.43 | |
| Bus413 | 15 | Load | 96.05 | | 93.43 | |
| Bus414 | 15 | Load | 99.24 | | 98.51 | |
| Bus415 | 15 | Load | 99.22 | | 98.48 | |
| Bus416 | 15 | Load | 99.14 | | 98.35 | |
| Bus417 | 15 | Load | 99.14 | | 98.34 | |
| Bus418 | 15 | Load | 98.97 | | 98.07 | |
| Bus419 | 15 | Load | 98.95 | | 98.05 | |
| Bus420 | 15 | Load | 98.92 | | 98 | |
| Bus421 | 15 | Load | 98.92 | | 97.99 | |
| Bus422 | 15 | Load | 98.83 | | 97.85 | |
| Bus423 | 15 | Load | 98.82 | | 97.84 | |
| Bus424 | 15 | Load | 98.82 | | 97.84 | |
| Bus425 | 15 | Load | 98.82 | | 97.83 | |
| Bus426 | 15 | Load | 98.74 | | 97.71 | |
| Bus427 | 15 | Load | 98.73 | | 97.7 | |
| Bus428 | 15 | Load | 98.69 | | 97.63 | |
| Bus429 | 15 | Load | 98.69 | | 97.62 | |
| Bus430 | 15 | Load | 98.67 | | 97.6 | |
| Bus431 | 15 | Load | 98.65 | | 97.57 | |
| Bus432 | 15 | Load | 98.65 | | 97.57 | |
| Bus433 | 15 | Load | 98.65 | | 97.56 | |
| Bus434 | 15 | Load | 98.6 | | 97.48 | |
| Bus435 | 15 | Load | 98.6 | | 97.48 | |
| Bus436 | 15 | Load | 98.46 | | 97.26 | |
| Bus437 | 15 | Load | 98.46 | | 97.26 | |
| Bus438 | 15 | Load | 98.46 | | 97.26 | |

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| Bus439 | 15 | Load | 98.46 | | 97.26 | |
| Bus440 | 15 | Load | 98.44 | | 97.23 | |
| Bus441 | 15 | Load | 98.44 | | 97.23 | |
| Bus442 | 15 | Load | 98.41 | | 97.17 | |
| Bus443 | 15 | Load | 98.4 | | 97.17 | |
| Bus444 | 15 | Load | 98.39 | | 97.14 | |
| Bus510 | 15 | Load | 95.01 | | 92.79 | |
| Bus511 | 15 | Load | 94.84 | | 92.56 | |
| Bus512 | 15 | Load | 94.84 | | 92.56 | |
| Bus513 | 15 | Load | 94.81 | | 92.52 | |
| Bus514 | 15 | Load | 94.79 | | 92.48 | |
| Bus515 | 15 | Load | 94.78 | | 92.47 | |
| Bus516 | 15 | Load | 94.77 | | 92.45 | |
| Bus517 | 15 | Load | 94.77 | | 92.44 | |
| Bus518 | 15 | Load | 94.76 | | 92.44 | |
| Bus519 | 15 | Load | 94.76 | | 92.43 | |
| Bus520 | 15 | Load | 94.76 | | 92.43 | |
| Bus521 | 15 | Load | 94.75 | | 92.42 | |
| Bus522 | 15 | Load | 94.74 | | 92.42 | |
| Bus523 | 15 | Load | 94.73 | | 92.42 | |
| Bus524 | 15 | Load | 94.73 | | 92.41 | |
| Bus525 | 15 | Load | 94.72 | | 92.4 | |
| Bus526 | 15 | Load | 94.72 | | 92.4 | |
| Bus527 | 15 | Load | 94.72 | | 92.4 | |
| Bus528 | 15 | Load | 94.72 | | 92.4 | |
| Bus529 | 15 | Load | 95.02 | | 92.8 | |
| Bus530 | 15 | Load | 94.89 | | 92.61 | |
| Bus531 | 15 | Load | 94.89 | | 92.61 | |
| Bus532 | 15 | Load | 94.89 | | 92.6 | |
| Bus533 | 15 | Load | 94.75 | | 92.38 | |
| Bus534 | 15 | Load | 94.75 | | 92.38 | |
| Bus535 | 15 | Load | 94.68 | | 92.27 | |
| Bus536 | 15 | Load | 94.68 | | 92.27 | |
| Bus537 | 15 | Load | 94.66 | | 92.23 | |
| Bus538 | 15 | Load | 94.66 | | 92.23 | |
| Bus539 | 15 | Load | 94.63 | | 92.18 | |
| Bus540 | 15 | Load | 94.62 | | 92.17 | |
| Bus541 | 15 | Load | 94.62 | | 92.17 | |
| Bus542 | 15 | Load | 94.58 | | 92.12 | |
| Bus543 | 15 | Load | 94.58 | | 92.11 | |
| Bus544 | 15 | Load | 94.55 | | 92.06 | |
| Bus545 | 15 | Load | 94.55 | | 92.06 | |
| Bus546 | 15 | Load | 94.53 | | 92.03 | |
| Bus547 | 15 | Load | 94.52 | | 92.02 | |
| Bus548 | 15 | Load | 94.46 | | 91.91 | |
| Bus549 | 15 | Load | 94.46 | | 91.91 | |

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| Bus550 | 15 | Load | 94.35 | | 91.74 | |
| Bus551 | 15 | Load | 94.34 | | 91.72 | |
| Bus552 | 15 | Load | 94.34 | | 91.72 | |
| Bus553 | 15 | Load | 94.28 | | 91.63 | |
| Bus554 | 15 | Load | 94.2 | | 91.51 | |
| Bus555 | 15 | Load | 94.19 | | 91.5 | |
| Bus556 | 15 | Load | 94.2 | | 91.5 | |
| Bus557 | 15 | Load | 94.2 | | 91.5 | |
| Bus558 | 15 | Load | 94.18 | | 91.47 | |
| Bus559 | 15 | Load | 94.18 | | 91.47 | |
| Bus560 | 15 | Load | 94.16 | | 91.44 | |
| Bus561 | 15 | Load | 94.15 | | 91.43 | |
| Bus562 | 15 | Load | 94.16 | | 91.44 | |
| Bus563 | 15 | Load | 94.16 | | 91.44 | |
| Bus564 | 15 | Load | 94.12 | | 91.38 | |
| Bus565 | 15 | Load | 94.11 | | 91.37 | |
| Bus566 | 15 | Load | 99.32 | | 99.53 | |
| Bus567 | 15 | Load | 95.04 | | 92.84 | |
| Bus568 | 15 | Load | 95.04 | | 92.84 | |
| Bus569 | 15 | Load | 95.04 | | 92.84 | |
| Bus570 | 15 | Load | 95.04 | | 92.84 | |
| Bus571 | 15 | Load | 95.03 | | 92.83 | |
| Bus572 | 15 | Load | 95 | | 92.78 | |
| Bus573 | 15 | Load | 94.92 | | 92.65 | |
| Bus574 | 15 | Load | 94.92 | | 92.65 | |
| Bus575 | 15 | Load | 94.99 | | 92.76 | |
| Bus576 | 15 | Load | 94.99 | | 92.76 | |
| Bus577 | 15 | Load | 94.95 | | 92.7 | |
| Bus578 | 15 | Load | 94.95 | | 92.7 | |
| Bus579 | 15 | Load | 94.92 | | 92.64 | |
| Bus580 | 15 | Load | 94.92 | | 92.64 | |
| Bus581 | 15 | Load | 94.9 | | 92.62 | |
| Bus582 | 15 | Load | 94.9 | | 92.62 | |
| Bus583 | 15 | Load | 94.88 | | 92.59 | |
| Bus584 | 15 | Load | 94.62 | | 92.17 | |
| Bus585 | 15 | Load | 94.55 | | 92.06 | |
| Bus586 | 15 | Load | 94.36 | | 91.76 | |
| Bus587 | 15 | Load | 94.35 | | 91.75 | |
| Bus588 | 15 | Load | 94.35 | | 91.75 | |
| Bus589 | 15 | Load | 94.34 | | 91.73 | |
| Bus590 | 15 | Load | 94.33 | | 91.72 | |
| Bus591 | 15 | Load | 94.24 | | 91.57 | |
| Bus592 | 15 | Load | 94.23 | | 91.56 | |
| Bus593 | 15 | Load | 94.23 | | 91.56 | |
| Bus594 | 15 | Load | 94.23 | | 91.55 | |
| Bus595 | 15 | Load | 94.23 | | 91.55 | |

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| Bus596 | 15 | Load | 94.22 | | 91.55 | |
| Bus597 | 15 | Load | 94.12 | | 91.38 | |
| Bus598 | 15 | Load | 94.11 | | 91.37 | |
| Bus599 | 15 | Load | 94.11 | | 91.37 | |
| Bus600 | 15 | Load | 94.11 | | 91.37 | |
| Bus601 | 15 | Load | 94.11 | | 91.37 | |
| Bus602 | 15 | Load | 94.1 | | 91.34 | |
| Bus603 | 15 | Load | 94.09 | | 91.34 | |
| Bus604 | 15 | Load | 93.88 | | 91.01 | |
| Bus605 | 15 | Load | 93.88 | | 91.01 | |
| Bus606 | 15 | Load | 93.82 | | 90.92 | |
| Bus607 | 15 | Load | 93.8 | | 90.87 | |
| Bus608 | 15 | Load | 93.8 | | 90.87 | |
| Bus609 | 15 | Load | 93.74 | | 90.79 | |
| Bus610 | 15 | Load | 93.74 | | 90.79 | |
| Bus611 | 15 | Load | 93.7 | | 90.72 | |
| Bus612 | 15 | Load | 93.7 | | 90.72 | |
| Bus613 | 15 | Load | 93.57 | | 90.52 | |
| Bus614 | 15 | Load | 93.54 | | 90.47 | |
| Bus615 | 15 | Load | 93.54 | | 90.47 | |
| Bus616 | 15 | Load | 93.57 | | 90.51 | |
| Bus617 | 15 | Load | 93.57 | | 90.51 | |
| Bus618 | 15 | Load | 93.57 | | 90.51 | |
| Bus619 | 15 | Load | 93.87 | | 90.99 | |
| Bus620 | 15 | Load | 93.86 | | 90.98 | |
| Bus621 | 15 | Load | 93.86 | | 90.98 | |
| Bus622 | 15 | Load | 93.85 | | 90.97 | |
| Bus623 | 15 | Load | 93.85 | | 90.96 | |
| Bus624 | 15 | Load | 93.85 | | 90.96 | |
| Bus625 | 15 | Load | 93.85 | | 90.95 | |
| Bus626 | 15 | Load | 93.84 | | 90.95 | |
| Bus627 | 15 | Load | 93.84 | | 90.95 | |
| Bus628 | 15 | Load | 93.84 | | 90.95 | |
| Bus629 | 15 | Load | 93.84 | | 90.95 | |
| Bus630 | 15 | Load | 93.84 | | 90.94 | |
| Bus631 | 15 | Load | 93.85 | | 90.95 | |
| Bus632 | 15 | Load | 93.24 | | 89.99 | Under Voltage |
| Bus633 | 15 | Load | 93.23 | | 89.99 | Under Voltage |
| Bus634 | 15 | Load | 93.07 | | 89.73 | Under Voltage |
| Bus635 | 15 | Load | 93.06 | | 89.72 | Under Voltage |
| Bus636 | 15 | Load | 93.06 | | 89.71 | Under Voltage |
| Bus637 | 15 | Load | 93.06 | | 89.71 | Under Voltage |
| Bus638 | 15 | Load | 93.06 | | 89.71 | Under Voltage |
| Bus639 | 15 | Load | 93.06 | | 89.72 | Under Voltage |
| Bus640 | 15 | Load | 93.07 | | 89.73 | Under Voltage |
| Bus641 | 15 | Load | 93.05 | | 89.7 | Under Voltage |

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| Bus642 | 15 | Load | 93.05 | | 89.7 | Under Voltage |
| Bus643 | 15 | Load | 93.05 | | 89.7 | Under Voltage |
| Bus644 | 15 | Load | 92.97 | | 89.57 | Under Voltage |
| Bus645 | 15 | Load | 92.97 | | 89.58 | Under Voltage |
| Bus646 | 15 | Load | 93.29 | | 90.07 | |
| Bus647 | 15 | Load | 93.28 | | 90.07 | |
| Bus648 | 15 | Load | 92.66 | | 89.08 | Under Voltage |
| Bus649 | 15 | Load | 92.66 | | 89.08 | Under Voltage |
| Bus650 | 15 | Load | 92.66 | | 89.08 | Under Voltage |
| Bus651 | 15 | Load | 92.58 | | 88.96 | Under Voltage |
| Bus652 | 15 | Load | 92.58 | | 88.95 | Under Voltage |
| Bus653 | 15 | Load | 92.58 | | 88.95 | Under Voltage |
| Bus654 | 15 | Load | 92.46 | | 88.77 | Under Voltage |
| Bus655 | 15 | Load | 92.58 | | 88.96 | Under Voltage |
| Bus656 | 15 | Load | 92.42 | | 88.71 | Under Voltage |
| Bus657 | 15 | Load | 92.42 | | 88.71 | Under Voltage |
| Bus658 | 15 | Load | 92.39 | | 88.66 | Under Voltage |
| Bus659 | 15 | Load | 92.25 | | 88.44 | Under Voltage |
| Bus660 | 15 | Load | 92.24 | | 88.42 | Under Voltage |
| Bus661 | 15 | Load | 92.13 | | 88.25 | Under Voltage |
| Bus662 | 15 | Load | 92.14 | | 88.26 | Under Voltage |
| Bus663 | 15 | Load | 92.06 | | 88.14 | Under Voltage |
| Bus664 | 15 | Load | 92.06 | | 88.13 | Under Voltage |
| Bus665 | 15 | Load | 92.04 | | 88.11 | Under Voltage |
| Bus666 | 15 | Load | 92.12 | | 88.23 | Under Voltage |
| Bus667 | 15 | Load | 92.12 | | 88.23 | Under Voltage |
| Bus668 | 15 | Load | 92.09 | | 88.19 | Under Voltage |
| Bus669 | 15 | Load | 92.08 | | 88.17 | Under Voltage |
| Bus670 | 15 | Load | 92.07 | | 88.16 | Under Voltage |
| Bus671 | 15 | Load | 92.04 | | 88.11 | Under Voltage |
| Bus672 | 15 | Load | 92.09 | | 88.19 | Under Voltage |
| Bus673 | 15 | Load | 92.08 | | 88.17 | Under Voltage |
| Bus674 | 15 | Load | 92.09 | | 88.18 | Under Voltage |
| Bus675 | 15 | Load | 92.09 | | 88.18 | Under Voltage |
| Bus676 | 15 | Load | 91.92 | | 87.92 | Under Voltage |
| Bus677 | 15 | Load | 91.91 | | 87.9 | Under Voltage |
| Bus678 | 15 | Load | 91.91 | | 87.9 | Under Voltage |
| Bus679 | 15 | Load | 91.91 | | 87.9 | Under Voltage |
| Bus680 | 15 | Load | 91.76 | | 87.66 | Under Voltage |
| Bus681 | 15 | Load | 91.77 | | 87.67 | Under Voltage |
| Bus682 | 15 | Load | 91.78 | | 87.7 | Under Voltage |
| Bus683 | 15 | Load | 91.78 | | 87.7 | Under Voltage |
| Bus684 | 15 | Load | 91.82 | | 87.76 | Under Voltage |
| Bus685 | 15 | Load | 91.83 | | 87.77 | Under Voltage |
| Bus686 | 15 | Load | 91.8 | | 87.73 | Under Voltage |
| Bus687 | 15 | Load | 91.8 | | 87.73 | Under Voltage |

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| Bus688 | 15 | Load | 91.79 | | 87.71 | Under Voltage |
| Bus689 | 15 | Load | 91.79 | | 87.71 | Under Voltage |
| Bus690 | 15 | Load | 91.79 | | 87.71 | Under Voltage |
| Bus691 | 15 | Load | 91.76 | | 87.67 | Under Voltage |
| Bus692 | 15 | Load | 91.76 | | 87.67 | Under Voltage |
| Bus693 | 15 | Load | 91.76 | | 87.66 | Under Voltage |
| Bus694 | 15 | Load | 91.72 | | 87.6 | Under Voltage |
| Bus695 | 15 | Load | 91.71 | | 87.59 | Under Voltage |
| Bus696 | 15 | Load | 91.71 | | 87.58 | Under Voltage |
| Bus697 | 15 | Load | 91.7 | | 87.56 | Under Voltage |
| Bus698 | 15 | Load | 91.69 | | 87.56 | Under Voltage |
| Bus699 | 15 | Load | 91.64 | | 87.47 | Under Voltage |
| Bus700 | 15 | Load | 91.59 | | 87.39 | Under Voltage |
| Bus701 | 15 | Load | 91.59 | | 87.39 | Under Voltage |
| Bus702 | 15 | Load | 91.58 | | 87.38 | Under Voltage |
| Bus703 | 15 | Load | 91.56 | | 87.36 | Under Voltage |
| Bus704 | 15 | Load | 91.56 | | 87.36 | Under Voltage |
| Bus705 | 15 | Load | 91.56 | | 87.36 | Under Voltage |
| Bus706 | 15 | Load | 91.56 | | 87.36 | Under Voltage |
| Bus707 | 15 | Load | 91.56 | | 87.35 | Under Voltage |
| Bus708 | 15 | Load | 91.56 | | 87.35 | Under Voltage |
| Bus709 | 15 | Load | 91.55 | | 87.34 | Under Voltage |
| Bus710 | 15 | Load | 91.56 | | 87.35 | Under Voltage |
| Bus711 | 15 | Load | 91.55 | | 87.34 | Under Voltage |
| Bus712 | 15 | Load | 91.55 | | 87.33 | Under Voltage |
| Bus713 | 15 | Load | 91.55 | | 87.33 | Under Voltage |
| Bus714 | 15 | Load | 94.39 | | 91.82 | |
| Bus715 | 15 | Load | 94.35 | | 91.75 | |
| Bus716 | 15 | Load | 94.34 | | 91.73 | |
| Bus717 | 15 | Load | 93.07 | | 89.73 | Under Voltage |
| Bus718 | 15 | Load | 93.05 | | 89.7 | Under Voltage |
| Bus719 | 15 | Load | 94.36 | | 91.76 | |
| Bus851 | 15 | Load | 97.22 | | 96.19 | |
| Bus852 | 15 | Load | 99.42 | | 99.68 | |
| Bus853 | 15 | Load | 99.19 | | 99.31 | |
| Bus854 | 15 | Load | 99.18 | | 99.31 | |
| Bus855 | 15 | Load | 98.26 | | 97.84 | |
| Bus856 | 15 | Load | 98.02 | | 97.46 | |
| Bus857 | 15 | Load | 97.94 | | 97.33 | |
| Bus858 | 15 | Load | 97.93 | | 97.32 | |
| Bus859 | 15 | Load | 97.93 | | 97.31 | |
| Bus860 | 15 | Load | 97.92 | | 97.31 | |
| Bus861 | 15 | Load | 97.92 | | 97.3 | |
| Bus862 | 15 | Load | 97.92 | | 97.3 | |
| Bus863 | 15 | Load | 97.91 | | 97.29 | |
| Bus864 | 15 | Load | 97.61 | | 96.82 | |

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| Bus865 | 15 | Load | 97.34 | | 96.39 | |
| Bus866 | 15 | Load | 97.22 | | 96.19 | |
| Bus867 | 15 | Load | 97.34 | | 96.38 | |
| Bus868 | 15 | Load | 97.12 | | 96.04 | |
| Bus869 | 15 | Load | 97.12 | | 96.04 | |
| Bus870 | 15 | Load | 97.13 | | 96.05 | |
| Bus871 | 15 | Load | 97 | | 95.84 | |
| Bus872 | 15 | Load | 96.96 | | 95.79 | |
| Bus873 | 15 | Load | 96.98 | | 95.81 | |
| Bus874 | 15 | Load | 96.97 | | 95.79 | |
| Bus875 | 15 | Load | 96.97 | | 95.79 | |
| Bus876 | 15 | Load | 96.96 | | 95.79 | |
| Bus877 | 15 | Load | 96.92 | | 95.72 | |
| Bus878 | 15 | Load | 96.92 | | 95.71 | |
| Bus879 | 15 | Load | 96.91 | | 95.7 | |
| Bus880 | 15 | Load | 96.91 | | 95.69 | |
| Bus881 | 15 | Load | 96.9 | | 95.68 | |
| Bus882 | 15 | Load | 96.79 | | 95.5 | |
| Bus883 | 15 | Load | 96.59 | | 95.2 | |
| Bus884 | 15 | Load | 96.51 | | 95.07 | |
| Bus885 | 15 | Load | 96.39 | | 94.88 | |
| Bus886 | 15 | Load | 96.35 | | 94.82 | |
| Bus887 | 15 | Load | 96.25 | | 94.66 | |
| Bus888 | 15 | Load | 96.38 | | 94.86 | |
| Bus889 | 15 | Load | 97.87 | | 97.22 | |
| Bus890 | 15 | Load | 97.87 | | 97.22 | |
| Bus891 | 15 | Load | 97.54 | | 96.69 | |
| Bus892 | 15 | Load | 97.53 | | 96.67 | |
| Bus893 | 15 | Load | 97.53 | | 96.67 | |
| Bus894 | 15 | Load | 97.53 | | 96.67 | |
| Bus895 | 15 | Load | 97.52 | | 96.66 | |
| Bus896 | 15 | Load | 97.51 | | 96.64 | |
| Bus897 | 15 | Load | 97.49 | | 96.61 | |
| Bus898 | 15 | Load | 97.51 | | 96.65 | |
| Bus899 | 15 | Load | 97.49 | | 96.61 | |
| Bus900 | 15 | Load | 97.48 | | 96.59 | |
| Bus901 | 15 | Load | 97.41 | | 96.49 | |
| Bus902 | 15 | Load | 97.41 | | 96.48 | |
| Bus903 | 15 | Load | 97.38 | | 96.44 | |
| Bus904 | 15 | Load | 97.37 | | 96.43 | |
| Bus905 | 15 | Load | 97.37 | | 96.42 | |
| Bus906 | 15 | Load | 97.37 | | 96.42 | |
| Bus907 | 15 | Load | 97.37 | | 96.42 | |
| Bus908 | 15 | Load | 97.36 | | 96.41 | |
| Bus909 | 15 | Load | 97.36 | | 96.4 | |
| Bus910 | 15 | Load | 97.37 | | 96.42 | |

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|---|---|---|---|---|---|---|
| Bus911 | 15 | Load | 97.37 | | 96.42 | |
| Bus912 | 15 | Load | 97.35 | | 96.4 | |
| Bus913 | 15 | Load | 97.35 | | 96.4 | |
| Bus914 | 15 | Load | 97.91 | | 97.28 | |
| Bus915 | 15 | Load | 97.86 | | 97.2 | |
| Bus916 | 15 | Load | 96.34 | | 94.8 | |
| Bus918 | 15 | Load | 99.19 | | 99.31 | |
| Bus921 | 15 | Load | 97.92 | | 97.3 | |
| Bus923 | 15 | Load | 97.34 | | 96.37 | |
| Bus925 | 15 | Load | 98.02 | | 97.46 | |
| Bus927 | 15 | Load | 96.46 | | 94.98 | |
| Bus933 | 15 | Load | 97.52 | | 96.66 | |
| Bus935 | 15 | Load | 97.52 | | 96.66 | |
| Bus938 | 15 | Load | 97.51 | | 96.64 | |
| Bus940 | 15 | Load | 97.51 | | 96.64 | |
| Bus942 | 15 | Load | 97.47 | | 96.59 | |
| Bus946 | 15 | Load | 97.4 | | 96.47 | |
| Bus954 | 15 | Load | 97.92 | | 97.3 | |
| Bus957 | 15 | Load | 97.92 | | 97.3 | |
| Bus961 | 15 | Load | 97.9 | | 97.27 | |
| Bus963 | 15 | Load | 97.91 | | 97.28 | |
| Bus965 | 15 | Load | 97.9 | | 97.28 | |
| Bus969 | 15 | Load | 97.34 | | 96.38 | |
| Bus979 | 15 | Load | 96.96 | | 95.78 | |
| Bus982 | 15 | Load | 96.98 | | 95.81 | |
| Bus984 | 15 | Load | 96.96 | | 95.79 | |
| Bus986 | 15 | Load | 96.78 | | 95.5 | |
| Bus988 | 15 | Load | 96.59 | | 95.19 | |
| Bus990 | 15 | Load | 96.51 | | 95.07 | |
| Bus992 | 15 | Load | 96.37 | | 94.84 | |
| Bus994 | 15 | Load | 96.36 | | 94.83 | |
| Bus996 | 15 | Load | 96.37 | | 94.84 | |
| Bus998 | 15 | Load | 96.38 | | 94.86 | |
| Bus1001 | 15 | Load | 96.34 | | 94.8 | |
| Bus1003 | 15 | Load | 96.25 | | 94.65 | |
| Bus1005 | 15 | Load | 96.24 | | 94.65 | |
| Bus1008 | 15 | Load | 99.41 | | 99.67 | |
| Bus1009 | 15 | Load | 95.44 | | 93.37 | |
| Bus1010 | 15 | Load | 95.09 | | 92.82 | |
| Bus1011 | 15 | Load | 94.75 | | 92.28 | |
| Bus1012 | 15 | Load | 95.09 | | 92.82 | |
| Bus1013 | 15 | Load | 95.38 | | 93.27 | |
| Bus1014 | 15 | Load | 95.17 | | 92.94 | |
| Bus1015 | 15 | Load | 95.13 | | 92.88 | |
| Bus1016 | 15 | Load | 95.13 | | 92.87 | |
| Bus1017 | 15 | Load | 95.11 | | 92.85 | |

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| Bus1018 | 15 | Load | 95.1 | | 92.83 | |
| Bus1019 | 15 | Load | 95.1 | | 92.83 | |
| Bus1020 | 15 | Load | 95.04 | | 92.73 | |
| Bus1021 | 15 | Load | 95.02 | | 92.71 | |
| Bus1022 | 15 | Load | 95.02 | | 92.71 | |
| Bus1023 | 15 | Load | 95.02 | | 92.7 | |
| Bus1024 | 15 | Load | 95.02 | | 92.7 | |
| Bus1025 | 15 | Load | 95.01 | | 92.69 | |
| Bus1026 | 15 | Load | 95.04 | | 92.73 | |
| Bus1027 | 15 | Load | 95.02 | | 92.7 | |
| Bus1028 | 15 | Load | 95.01 | | 92.69 | |
| Bus1029 | 15 | Load | 95.02 | | 92.7 | |
| Bus1030 | 15 | Load | 93.9 | | 90.93 | |
| Bus1031 | 15 | Load | 93.45 | | 90.23 | |
| Bus1032 | 15 | Load | 93.2 | | 89.83 | Under Voltage |
| Bus1033 | 15 | Load | 92.66 | | 88.97 | Under Voltage |
| Bus1034 | 15 | Load | 92.65 | | 88.97 | Under Voltage |
| Bus1035 | 15 | Load | 92.65 | | 88.96 | Under Voltage |
| Bus1036 | 15 | Load | 91.81 | | 87.64 | Under Voltage |
| Bus1037 | 15 | Load | 91.76 | | 87.55 | Under Voltage |
| Bus1038 | 15 | Load | 91.7 | | 87.46 | Under Voltage |
| Bus1039 | 15 | Load | 91.68 | | 87.43 | Under Voltage |
| Bus1040 | 15 | Load | 91.64 | | 87.36 | Under Voltage |
| Bus1041 | 15 | Load | 91.62 | | 87.33 | Under Voltage |
| Bus1042 | 15 | Load | 91.51 | | 87.17 | Under Voltage |
| Bus1043 | 15 | Load | 91.5 | | 87.14 | Under Voltage |
| Bus1044 | 15 | Load | 91.49 | | 87.13 | Under Voltage |
| Bus1045 | 15 | Load | 91.48 | | 87.11 | Under Voltage |
| Bus1046 | 15 | Load | 91.38 | | 86.95 | Under Voltage |
| Bus1047 | 15 | Load | 91.32 | | 86.86 | Under Voltage |
| Bus1048 | 15 | Load | 91.32 | | 86.85 | Under Voltage |
| Bus1049 | 15 | Load | 91.29 | | 86.8 | Under Voltage |
| Bus1050 | 15 | Load | 91.28 | | 86.8 | Under Voltage |
| Bus1051 | 15 | Load | 91.25 | | 86.75 | Under Voltage |
| Bus1052 | 15 | Load | 91.24 | | 86.73 | Under Voltage |
| Bus1053 | 15 | Load | 91.16 | | 86.6 | Under Voltage |
| Bus1054 | 15 | Load | 91.33 | | 86.87 | Under Voltage |
| Bus1055 | 15 | Load | 91.3 | | 86.83 | Under Voltage |
| Bus1056 | 15 | Load | 91.08 | | 86.45 | Under Voltage |
| Bus1057 | 15 | Load | 90.9 | | 86.16 | Under Voltage |
| Bus1058 | 15 | Load | 90.88 | | 86.13 | Under Voltage |
| Bus1059 | 15 | Load | 90.79 | | 85.98 | Under Voltage |
| Bus1060 | 15 | Load | 90.79 | | 85.97 | Under Voltage |
| Bus1061 | 15 | Load | 90.66 | | 85.76 | Under Voltage |
| Bus1062 | 15 | Load | 90.58 | | 85.63 | Under Voltage |
| Bus1063 | 15 | Load | 90.9 | | 86.16 | Under Voltage |

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| Bus1102 | 15 | Load | 93.57 | | 90.21 | |
| Bus1103 | 15 | Load | 99.34 | | 99.55 | |
| Bus1104 | 15 | Load | 93.61 | | 90.28 | |
| Bus1105 | 15 | Load | 93.57 | | 90.2 | |
| Bus1106 | 15 | Load | 93.55 | | 90.17 | |
| Bus1107 | 15 | Load | 93.51 | | 90.11 | |
| Bus1108 | 15 | Load | 93.51 | | 90.11 | |
| Bus1109 | 15 | Load | 93.51 | | 90.11 | |
| Bus1110 | 15 | Load | 93.4 | | 89.94 | Under Voltage |
| Bus1111 | 15 | Load | 93.39 | | 89.93 | Under Voltage |
| Bus1112 | 15 | Load | 93.39 | | 89.92 | Under Voltage |
| Bus1113 | 15 | Load | 93.38 | | 89.91 | Under Voltage |
| Bus1114 | 15 | Load | 93.38 | | 89.9 | Under Voltage |
| Bus1115 | 15 | Load | 93.37 | | 89.9 | Under Voltage |
| Bus1116 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1117 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1118 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1119 | 15 | Load | 93.35 | | 89.86 | Under Voltage |
| Bus1120 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1121 | 15 | Load | 93.35 | | 89.86 | Under Voltage |
| Bus1122 | 15 | Load | 93.35 | | 89.86 | Under Voltage |
| Bus1123 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1124 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1125 | 15 | Load | 93.34 | | 89.85 | Under Voltage |
| Bus1126 | 15 | Load | 93.53 | | 90.14 | |
| Bus1127 | 15 | Load | 93.52 | | 90.13 | |
| Bus1128 | 15 | Load | 93.52 | | 90.13 | |
| Bus1129 | 15 | Load | 93.52 | | 90.13 | |
| Bus1130 | 15 | Load | 93.53 | | 90.14 | |
| Bus1131 | 15 | Load | 93.53 | | 90.14 | |
| Bus1132 | 15 | Load | 93.52 | | 90.13 | |
| Bus1133 | 15 | Load | 93.51 | | 90.12 | |
| Bus1134 | 15 | Load | 93.52 | | 90.12 | |
| Bus1135 | 15 | Load | 93.51 | | 90.12 | |
| Bus1136 | 15 | Load | 93.51 | | 90.12 | |
| Bus1137 | 15 | Load | 93.35 | | 89.86 | Under Voltage |
| Bus1138 | 15 | Load | 93.35 | | 89.87 | Under Voltage |
| Bus1139 | 15 | Load | 93.56 | | 90.19 | |
| Bus1140 | 15 | Load | 93.26 | | 89.71 | Under Voltage |
| Bus1141 | 15 | Load | 93.22 | | 89.65 | Under Voltage |
| Bus1142 | 15 | Load | 93.25 | | 89.7 | Under Voltage |
| Bus1143 | 15 | Load | 93.25 | | 89.7 | Under Voltage |
| Bus1144 | 15 | Load | 92.97 | | 89.25 | Under Voltage |
| Bus1145 | 15 | Load | 92.79 | | 88.95 | Under Voltage |
| Bus1146 | 15 | Load | 92.79 | | 88.95 | Under Voltage |
| Bus1147 | 15 | Load | 92.68 | | 88.78 | Under Voltage |

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| Bus1148 | 15 | Load | 92.9 | | 89.14 | Under Voltage |
| Bus1149 | 15 | Load | 92.9 | | 89.14 | Under Voltage |
| Bus1150 | 15 | Load | 92.9 | | 89.13 | Under Voltage |
| Bus1151 | 15 | Load | 92.88 | | 89.1 | Under Voltage |
| Bus1152 | 15 | Load | 92.86 | | 89.07 | Under Voltage |
| Bus1153 | 15 | Load | 92.86 | | 89.07 | Under Voltage |
| Bus1154 | 15 | Load | 92.86 | | 89.06 | Under Voltage |
| Bus1155 | 15 | Load | 92.86 | | 89.06 | Under Voltage |
| Bus1156 | 15 | Load | 92.85 | | 89.06 | Under Voltage |
| Bus1157 | 15 | Load | 92.89 | | 89.12 | Under Voltage |
| Bus1158 | 15 | Load | 92.85 | | 89.05 | Under Voltage |
| Bus1159 | 15 | Load | 92.85 | | 89.05 | Under Voltage |
| Bus1160 | 15 | Load | 92.85 | | 89.05 | Under Voltage |
| Bus1161 | 15 | Load | 92.84 | | 89.05 | Under Voltage |
| Bus1162 | 15 | Load | 92.84 | | 89.05 | Under Voltage |
| Bus1163 | 15 | Load | 92.69 | | 88.79 | Under Voltage |
| Bus1164 | 15 | Load | 92.6 | | 88.65 | Under Voltage |
| Bus1165 | 15 | Load | 92.58 | | 88.61 | Under Voltage |
| Bus1166 | 15 | Load | 92.55 | | 88.56 | Under Voltage |
| Bus1167 | 15 | Load | 92.54 | | 88.56 | Under Voltage |
| Bus1168 | 15 | Load | 92.5 | | 88.5 | Under Voltage |
| Bus1169 | 15 | Load | 92.5 | | 88.49 | Under Voltage |
| Bus1170 | 15 | Load | 92.5 | | 88.5 | Under Voltage |
| Bus1171 | 15 | Load | 92.51 | | 88.5 | Under Voltage |
| Bus1172 | 15 | Load | 92.51 | | 88.5 | Under Voltage |
| Bus1173 | 15 | Load | 92.45 | | 88.41 | Under Voltage |
| Bus1174 | 15 | Load | 92.45 | | 88.41 | Under Voltage |
| Bus1175 | 15 | Load | 92.39 | | 88.32 | Under Voltage |
| Bus1176 | 15 | Load | 92.37 | | 88.29 | Under Voltage |
| Bus1177 | 15 | Load | 92.37 | | 88.28 | Under Voltage |
| Bus1178 | 15 | Load | 92.37 | | 88.27 | Under Voltage |
| Bus1179 | 15 | Load | 92.37 | | 88.27 | Under Voltage |
| Bus1180 | 15 | Load | 92.35 | | 88.25 | Under Voltage |
| Bus1181 | 15 | Load | 92.36 | | 88.27 | Under Voltage |
| Bus1182 | 15 | Load | 92.18 | | 87.98 | Under Voltage |
| Bus1183 | 15 | Load | 92.17 | | 87.97 | Under Voltage |
| Bus1184 | 15 | Load | 92.16 | | 87.96 | Under Voltage |
| Bus1185 | 15 | Load | 92.16 | | 87.96 | Under Voltage |
| Bus1186 | 15 | Load | 92.09 | | 87.84 | Under Voltage |
| Bus1187 | 15 | Load | 92.03 | | 87.75 | Under Voltage |
| Bus1188 | 15 | Load | 91.89 | | 87.54 | Under Voltage |
| Bus1189 | 15 | Load | 91.89 | | 87.53 | Under Voltage |
| Bus1190 | 15 | Load | 91.85 | | 87.47 | Under Voltage |
| Bus1191 | 15 | Load | 91.85 | | 87.47 | Under Voltage |
| Bus1192 | 15 | Load | 91.84 | | 87.45 | Under Voltage |
| Bus1193 | 15 | Load | 91.83 | | 87.44 | Under Voltage |

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| Bus1194 | 15 | Load | 91.83 | | 87.44 | Under Voltage |
| Bus1195 | 15 | Load | 91.83 | | 87.43 | Under Voltage |
| Bus1196 | 15 | Load | 91.82 | | 87.43 | Under Voltage |
| Bus1197 | 15 | Load | 91.8 | | 87.39 | Under Voltage |
| Bus1198 | 15 | Load | 91.82 | | 87.42 | Under Voltage |
| Bus1199 | 15 | Load | 91.75 | | 87.31 | Under Voltage |
| Bus1200 | 15 | Load | 91.74 | | 87.3 | Under Voltage |
| Bus1201 | 15 | Load | 91.73 | | 87.29 | Under Voltage |
| Bus1202 | 15 | Load | 91.73 | | 87.29 | Under Voltage |
| Bus1203 | 15 | Load | 91.71 | | 87.25 | Under Voltage |
| Bus1204 | 15 | Load | 91.71 | | 87.25 | Under Voltage |
| Bus1205 | 15 | Load | 91.69 | | 87.22 | Under Voltage |
| Bus1206 | 15 | Load | 91.69 | | 87.22 | Under Voltage |
| Bus1207 | 15 | Load | 91.69 | | 87.22 | Under Voltage |
| Bus1208 | 15 | Load | 91.71 | | 87.24 | Under Voltage |
| Bus1209 | 15 | Load | 91.78 | | 87.36 | Under Voltage |
| Bus1210 | 15 | Load | 91.78 | | 87.36 | Under Voltage |
| Bus1248 | 15 | Load | 91.69 | | 87.22 | Under Voltage |
| Bus1273 | 15 | Load | 82.87 | Under Voltage | 74.18 | Under Voltage |
| Bus1274 | 15 | Load | 74.54 | Under Voltage | 61.2 | Under Voltage |
| Bus1275 | 15 | Load | 74.54 | Under Voltage | 61.2 | Under Voltage |
| Bus1276 | 15 | Load | 82.66 | Under Voltage | 73.85 | Under Voltage |
| Bus1277 | 15 | Load | 74.19 | Under Voltage | 60.66 | Under Voltage |
| Bus1278 | 15 | Load | 84.4 | Under Voltage | 76.55 | Under Voltage |
| Bus1279 | 15 | Load | 73.91 | Under Voltage | 60.22 | Under Voltage |
| Bus1280 | 15 | Load | 76.01 | Under Voltage | 63.49 | Under Voltage |
| Bus1281 | 15 | Load | 74.46 | Under Voltage | 61.08 | Under Voltage |
| Bus1282 | 15 | Load | 73.15 | Under Voltage | 59.04 | Under Voltage |
| Bus1283 | 15 | Load | 73.32 | Under Voltage | 59.31 | Under Voltage |
| Bus1284 | 15 | Load | 92.28 | | 88.68 | Under Voltage |
| Bus1285 | 15 | Load | 92.26 | | 88.65 | Under Voltage |
| Bus1286 | 15 | Load | 92.18 | | 88.53 | Under Voltage |
| Bus1287 | 15 | Load | 92.18 | | 88.53 | Under Voltage |
| Bus1288 | 15 | Load | 91.92 | | 88.14 | Under Voltage |
| Bus1289 | 15 | Load | 92.23 | | 88.6 | Under Voltage |
| Bus1290 | 15 | Load | 86.31 | Under Voltage | 79.53 | Under Voltage |
| Bus1291 | 15 | Load | 86.92 | Under Voltage | 80.49 | Under Voltage |
| Bus1292 | 15 | Load | 86.3 | Under Voltage | 79.51 | Under Voltage |
| Bus1293 | 15 | Load | 84.76 | Under Voltage | 77.12 | Under Voltage |
| Bus1294 | 15 | Load | 84.77 | Under Voltage | 77.13 | Under Voltage |
| Bus1295 | 15 | Load | 84.4 | Under Voltage | 76.55 | Under Voltage |
| Bus1296 | 15 | Load | 83.35 | Under Voltage | 74.92 | Under Voltage |
| Bus1297 | 15 | Load | 73.32 | Under Voltage | 59.31 | Under Voltage |
| Bus1298 | 15 | Load | 99.42 | | 99.68 | |
| Bus1299 | 15 | Load | 74.56 | Under Voltage | 61.24 | Under Voltage |
| Bus1300 | 15 | Load | 75.58 | Under Voltage | 62.83 | Under Voltage |

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| Bus1301 | 15 | Load | 74.05 | Under Voltage | 60.44 | Under Voltage |
| Bus1302 | 15 | Load | 74.05 | Under Voltage | 60.44 | Under Voltage |
| Bus1303 | 15 | Load | 89.77 | Under Voltage | 84.84 | Under Voltage |
| Bus1304 | 15 | Load | 82.95 | Under Voltage | 74.3 | Under Voltage |
| Bus1305 | 15 | Load | 81 | Under Voltage | 71.26 | Under Voltage |
| Bus1306 | 15 | Load | 80.99 | Under Voltage | 71.25 | Under Voltage |
| Bus1307 | 15 | Load | 80.18 | Under Voltage | 69.99 | Under Voltage |
| Bus1308 | 15 | Load | 80.19 | Under Voltage | 70 | Under Voltage |
| Bus1309 | 15 | Load | 78.3 | Under Voltage | 67.06 | Under Voltage |
| Bus1310 | 15 | Load | 77.65 | Under Voltage | 66.05 | Under Voltage |
| Bus1311 | 15 | Load | 77.54 | Under Voltage | 65.88 | Under Voltage |
| Bus1312 | 15 | Load | 76.53 | Under Voltage | 64.31 | Under Voltage |
| Bus1313 | 15 | Load | 75.8 | Under Voltage | 63.17 | Under Voltage |
| Bus1314 | 15 | Load | 75.58 | Under Voltage | 62.82 | Under Voltage |
| Bus1315 | 15 | Load | 74.94 | Under Voltage | 61.83 | Under Voltage |
| Bus1316 | 15 | Load | 74.94 | Under Voltage | 61.83 | Under Voltage |
| Bus1317 | 15 | Load | 74.72 | Under Voltage | 61.49 | Under Voltage |
| Bus1318 | 15 | Load | 74.62 | Under Voltage | 61.34 | Under Voltage |
| Bus1319 | 15 | Load | 74.56 | Under Voltage | 61.24 | Under Voltage |
| Bus1320 | 15 | Load | 74.44 | Under Voltage | 61.05 | Under Voltage |
| Bus1321 | 15 | Load | 74.44 | Under Voltage | 61.05 | Under Voltage |
| Bus1322 | 15 | Load | 74.54 | Under Voltage | 61.2 | Under Voltage |
| Bus1323 | 15 | Load | 74.25 | Under Voltage | 60.76 | Under Voltage |
| Bus1324 | 15 | Load | 74.25 | Under Voltage | 60.76 | Under Voltage |
| Bus1325 | 15 | Load | 74.25 | Under Voltage | 60.76 | Under Voltage |
| Bus1326 | 15 | Load | 74.25 | Under Voltage | 60.76 | Under Voltage |
| Bus1327 | 15 | Load | 74.06 | Under Voltage | 60.46 | Under Voltage |
| Bus1328 | 15 | Load | 74.05 | Under Voltage | 60.45 | Under Voltage |
| Bus1329 | 15 | Load | 74.05 | Under Voltage | 60.45 | Under Voltage |
| Bus1330 | 15 | Load | 74.05 | Under Voltage | 60.44 | Under Voltage |
| Bus1331 | 15 | Load | 74.01 | Under Voltage | 60.38 | Under Voltage |
| Bus1332 | 15 | Load | 74.01 | Under Voltage | 60.38 | Under Voltage |
| Bus1333 | 15 | Load | 73.92 | Under Voltage | 60.25 | Under Voltage |
| Bus1334 | 15 | Load | 73.88 | Under Voltage | 60.18 | Under Voltage |
| Bus1335 | 15 | Load | 73.83 | Under Voltage | 60.1 | Under Voltage |
| Bus1336 | 15 | Load | 73.79 | Under Voltage | 60.04 | Under Voltage |
| Bus1337 | 15 | Load | 73.76 | Under Voltage | 59.99 | Under Voltage |
| Bus1338 | 15 | Load | 73.8 | Under Voltage | 60.05 | Under Voltage |
| Bus1339 | 15 | Load | 73.76 | Under Voltage | 59.99 | Under Voltage |
| Bus1340 | 15 | Load | 73.75 | Under Voltage | 59.97 | Under Voltage |
| Bus1341 | 15 | Load | 73.75 | Under Voltage | 59.97 | Under Voltage |
| Bus1342 | 15 | Load | 73.69 | Under Voltage | 59.88 | Under Voltage |
| Bus1343 | 15 | Load | 73.69 | Under Voltage | 59.88 | Under Voltage |
| Bus1344 | 15 | Load | 73.4 | Under Voltage | 59.44 | Under Voltage |
| Bus1345 | 15 | Load | 73.4 | Under Voltage | 59.44 | Under Voltage |
| Bus1346 | 15 | Load | 73.34 | Under Voltage | 59.33 | Under Voltage |

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| Bus 1347 | 15 | Load | 73.29 | Under Voltage | 59.26 | Under Voltage |
| Bus 1348 | 15 | Load | 73.16 | Under Voltage | 59.06 | Under Voltage |
| Bus 1349 | 15 | Load | 74.19 | Under Voltage | 60.66 | Under Voltage |
| Bus 1350 | 15 | Load | 74.45 | Under Voltage | 61.07 | Under Voltage |
| Bus 1351 | 15 | Load | 75.71 | Under Voltage | 63.03 | Under Voltage |
| Bus 1352 | 15 | Load | 92.1 | | 88.41 | Under Voltage |
| Bus 1353 | 15 | Load | 91.53 | | 87.54 | Under Voltage |
| Bus 1354 | 15 | Load | 90.52 | | 85.99 | Under Voltage |
| Bus 1355 | 15 | Load | 90.51 | | 85.98 | Under Voltage |
| Bus 1356 | 15 | Load | 91.52 | | 87.52 | Under Voltage |
| Bus 1357 | 15 | Load | 91.52 | | 87.52 | Under Voltage |
| Bus 1358 | 15 | Load | 87.13 | Under Voltage | 80.8 | Under Voltage |
| Bus 1359 | 15 | Load | 86.31 | Under Voltage | 79.53 | Under Voltage |
| Bus 1360 | 15 | Load | 82.95 | Under Voltage | 74.3 | Under Voltage |
| Bus 1361 | 15 | Load | 80.81 | Under Voltage | 70.97 | Under Voltage |
| Bus 1362 | 15 | Load | 80.81 | Under Voltage | 70.97 | Under Voltage |
| Bus 1363 | 15 | Load | 76.54 | Under Voltage | 64.31 | Under Voltage |
| Bus 1364 | 15 | Load | 74.95 | Under Voltage | 61.84 | Under Voltage |
| Bus 1365 | 15 | Load | 74.54 | Under Voltage | 61.2 | Under Voltage |
| Bus 1366 | 15 | Load | 92.27 | | 88.66 | Under Voltage |
| Bus 1367 | 15 | Load | 92.25 | | 88.64 | Under Voltage |
| Bus 1368 | 15 | Load | 92.28 | | 88.68 | Under Voltage |
| Bus 1369 | 15 | Load | 89.77 | Under Voltage | 84.84 | Under Voltage |
| Bus 1370 | 15 | Load | 89.41 | Under Voltage | 84.29 | Under Voltage |
| Bus 1371 | 15 | Load | 89.41 | Under Voltage | 84.29 | Under Voltage |
| Bus 1372 | 15 | Load | 89.31 | Under Voltage | 84.14 | Under Voltage |
| Bus 1373 | 15 | Load | 89.31 | Under Voltage | 84.13 | Under Voltage |
| Bus 1374 | 15 | Load | 84.4 | Under Voltage | 76.55 | Under Voltage |
| Bus 1375 | 15 | Load | 83.03 | Under Voltage | 74.42 | Under Voltage |
| Bus 1376 | 15 | Load | 83.03 | Under Voltage | 74.42 | Under Voltage |
| Bus 1377 | 15 | Load | 82.87 | Under Voltage | 74.18 | Under Voltage |
| Bus 1378 | 15 | Load | 75.44 | Under Voltage | 62.61 | Under Voltage |
| Bus 1379 | 15 | Load | 75.43 | Under Voltage | 62.59 | Under Voltage |
| Bus 1380 | 15 | Load | 74.63 | Under Voltage | 61.35 | Under Voltage |
| Bus 1381 | 15 | Load | 75.36 | Under Voltage | 62.48 | Under Voltage |
| Bus 1382 | 15 | Load | 74.42 | Under Voltage | 61.03 | Under Voltage |
| Bus 1383 | 15 | Load | 74.41 | Under Voltage | 61.02 | Under Voltage |
| Bus 1384 | 15 | Load | 74.42 | Under Voltage | 61.02 | Under Voltage |
| Bus 1385 | 15 | Load | 74.72 | Under Voltage | 61.49 | Under Voltage |
| Bus 1386 | 15 | Load | 75.38 | Under Voltage | 62.52 | Under Voltage |
| Bus 1387 | 15 | Load | 74.95 | Under Voltage | 61.84 | Under Voltage |
| Bus 1388 | 15 | Load | 73.12 | Under Voltage | 59 | Under Voltage |
| Bus 1389 | 15 | Load | 73.12 | Under Voltage | 59 | Under Voltage |
| Bus 1390 | 15 | Load | 73.17 | Under Voltage | 59.07 | Under Voltage |
| Bus 1391 | 15 | Load | 92.19 | | 88.54 | Under Voltage |
| Bus 1392 | 15 | Load | 74.35 | Under Voltage | 60.92 | Under Voltage |

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| Bus 1393 | 15 | Load | 93.06 | | 89.88 | Under Voltage |
| Bus 1394 | 15 | Load | 93.03 | | 89.83 | Under Voltage |
| Bus 1395 | 15 | Load | 92.98 | | 89.76 | Under Voltage |
| Bus 1406 | 15 | Load | 83.35 | Under Voltage | 74.92 | Under Voltage |
| Bus 1416 | 15 | Load | 83.91 | Under Voltage | 75.8 | Under Voltage |
| Bus 1445 | 15 | Load | 84.39 | Under Voltage | 76.55 | Under Voltage |
| Bus 1489 | 15 | Load | 98.07 | | 97.48 | |
| Bus 1490 | 15 | Load | 97.79 | | 97.01 | |
| Bus 1491 | 15 | Load | 97.78 | | 97.01 | |
| Bus 1492 | 15 | Load | 97.77 | | 96.99 | |
| Bus 1493 | 15 | Load | 97.77 | | 96.98 | |
| Bus 1494 | 15 | Load | 97.77 | | 96.98 | |
| Bus 1495 | 15 | Load | 97.76 | | 96.98 | |
| Bus 1496 | 15 | Load | 97.76 | | 96.97 | |
| Bus 1497 | 15 | Load | 97.74 | | 96.94 | |
| Bus 1498 | 15 | Load | 97.71 | | 96.9 | |
| Bus 1499 | 15 | Load | 97.7 | | 96.88 | |
| Bus 1500 | 15 | Load | 97.7 | | 96.88 | |
| Bus 1501 | 15 | Load | 97.69 | | 96.86 | |
| Bus 1502 | 15 | Load | 97.69 | | 96.87 | |
| Bus 1503 | 15 | Load | 97.69 | | 96.87 | |
| Bus 1504 | 15 | Load | 97.43 | | 96.43 | |
| Bus 1505 | 15 | Load | 97.35 | | 96.31 | |
| Bus 1506 | 15 | Load | 97.35 | | 96.31 | |
| Bus 1507 | 15 | Load | 97.35 | | 96.31 | |
| Bus 1508 | 15 | Load | 97.35 | | 96.31 | |
| Bus 1509 | 15 | Load | 97.33 | | 96.26 | |
| Bus 1510 | 15 | Load | 97.32 | | 96.26 | |
| Bus 1511 | 15 | Load | 97.42 | | 96.42 | |
| Bus 1512 | 15 | Load | 97.32 | | 96.25 | |
| Bus 1513 | 15 | Load | 97.24 | | 96.13 | |
| Bus 1514 | 15 | Load | 97.24 | | 96.12 | |
| Bus 1515 | 15 | Load | 97.22 | | 96.09 | |
| Bus 1516 | 15 | Load | 97.21 | | 96.07 | |
| Bus 1517 | 15 | Load | 97.2 | | 96.06 | |
| Bus 1518 | 15 | Load | 97.2 | | 96.06 | |
| Bus 1519 | 15 | Load | 97.22 | | 96.09 | |
| Bus 1520 | 15 | Load | 97.22 | | 96.09 | |
| Bus 1521 | 15 | Load | 97.17 | | 96 | |
| Bus 1522 | 15 | Load | 97.17 | | 96 | |
| Bus 1523 | 15 | Load | 97.14 | | 95.96 | |
| Bus 1524 | 15 | Load | 96.74 | | 95.3 | |
| Bus 1525 | 15 | Load | 96.74 | | 95.3 | |
| Bus 1526 | 15 | Load | 96.52 | | 94.94 | |
| Bus 1527 | 15 | Load | 96.52 | | 94.93 | |
| Bus 1528 | 15 | Load | 96.46 | | 94.84 | |

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| Bus1529 | 15 | Load | 96.46 | | 94.84 | |
| Bus1530 | 15 | Load | 96.08 | | 94.22 | |
| Bus1531 | 15 | Load | 96.07 | | 94.2 | |
| Bus1532 | 15 | Load | 95.33 | | 92.97 | |
| Bus1533 | 15 | Load | 95.24 | | 92.83 | |
| Bus1534 | 15 | Load | 95.24 | | 92.83 | |
| Bus1535 | 15 | Load | 95.08 | | 92.57 | |
| Bus1536 | 15 | Load | 95.08 | | 92.56 | |
| Bus1537 | 15 | Load | 94.76 | | 92.03 | |
| Bus1538 | 15 | Load | 94.76 | | 92.03 | |
| Bus1539 | 15 | Load | 97.41 | | 96.4 | |
| Bus1540 | 15 | Load | 97.4 | | 96.39 | |
| Bus1541 | 15 | Load | 97.4 | | 96.39 | |
| Bus1542 | 15 | Load | 97.41 | | 96.39 | |
| Bus1543 | 15 | Load | 97.14 | | 95.96 | |
| Bus1544 | 15 | Load | 97.14 | | 95.95 | |
| Bus1545 | 15 | Load | 94.41 | | 91.45 | |
| Bus1546 | 15 | Load | 97.78 | | 97.01 | |
| Bus1547 | 15 | Load | 97.61 | | 96.74 | |
| Bus1548 | 15 | Load | 97.54 | | 96.62 | |
| Bus1549 | 15 | Load | 97.52 | | 96.59 | |
| Bus1550 | 15 | Load | 97.52 | | 96.59 | |
| Bus1551 | 15 | Load | 97.49 | | 96.54 | |
| Bus1552 | 15 | Load | 97.45 | | 96.48 | |
| Bus1553 | 15 | Load | 97.53 | | 96.61 | |
| Bus1554 | 15 | Load | 97.53 | | 96.61 | |
| Bus1555 | 15 | Load | 97.53 | | 96.61 | |
| Bus1556 | 15 | Load | 97.53 | | 96.61 | |
| Bus1557 | 15 | Load | 98.07 | | 97.49 | |
| Bus1558 | 15 | Load | 98.07 | | 97.48 | |
| Bus1559 | 15 | Load | 97.99 | | 97.35 | |
| Bus1560 | 15 | Load | 97.89 | | 97.2 | |
| Bus1561 | 15 | Load | 97.89 | | 97.19 | |
| Bus1562 | 15 | Load | 97.81 | | 97.07 | |
| Bus1563 | 15 | Load | 97.8 | | 97.04 | |
| Bus1564 | 15 | Load | 97.75 | | 96.97 | |
| Bus1565 | 15 | Load | 97.74 | | 96.94 | |
| Bus1566 | 15 | Load | 97.73 | | 96.93 | |
| Bus1567 | 15 | Load | 97.72 | | 96.92 | |
| Bus1568 | 15 | Load | 97.55 | | 96.65 | |
| Bus1569 | 15 | Load | 97.36 | | 96.34 | |
| Bus1570 | 15 | Load | 97.76 | | 96.99 | |
| Bus1571 | 15 | Load | 97.35 | | 96.34 | |
| Bus1572 | 15 | Load | 97.89 | | 97.2 | |
| Bus1573 | 15 | Load | 99.41 | | 99.67 | |
| Bus1574 | 15 | Load | 98.07 | | 97.48 | |

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| Bus1575 | 15 | Load | 98.05 | | 97.44 | |
| Bus1576 | 15 | Load | 98.04 | | 97.43 | |
| Bus1577 | 15 | Load | 98.04 | | 97.42 | |
| Bus1578 | 15 | Load | 98.03 | | 97.41 | |
| Bus1579 | 15 | Load | 98.02 | | 97.4 | |
| Bus1580 | 15 | Load | 98.02 | | 97.4 | |
| Bus1581 | 15 | Load | 97.94 | | 97.27 | |
| Bus1582 | 15 | Load | 97.94 | | 97.27 | |
| Bus1583 | 15 | Load | 97.94 | | 97.27 | |
| Bus1584 | 15 | Load | 97.94 | | 97.27 | |
| Bus1585 | 15 | Load | 97.94 | | 97.27 | |
| Bus1586 | 15 | Load | 98.05 | | 97.45 | |
| Bus1587 | 15 | Load | 98.07 | | 97.49 | |
| Bus1621 | 15 | Load | 97.45 | | 96.48 | |
| Bus1623 | 15 | Load | 97.52 | | 96.59 | |
| Bus1625 | 15 | Load | 97.53 | | 96.61 | |
| Bus1629 | 15 | Load | 97.45 | | 96.47 | |
| Bus1631 | 15 | Load | 97.75 | | 96.97 | |
| Bus1634 | 15 | Load | 97.22 | | 96.11 | |
| Bus1636 | 15 | Load | 97.53 | | 96.61 | |
| Bus1638 | 15 | Load | 97.48 | | 96.53 | |
| Bus1640 | 15 | Load | 97.52 | | 96.59 | |
| Bus1642 | 15 | Load | 97.72 | | 96.92 | |
| Bus1646 | 15 | Load | 97.79 | | 97.03 | |
| Bus1648 | 15 | Load | 97.76 | | 96.99 | |
| Bus1650 | 15 | Load | 97.54 | | 96.62 | |
| Bus1652 | 15 | Load | 97.49 | | 96.54 | |
| Bus1670 | 15 | Load | 100.1 | | 99.89 | |
| Bus_J0 | 15 | Load | 92.26 | | 87.37 | Under Voltage |
| Bus_J1 | 15 | Load | 92.26 | | 87.37 | Under Voltage |
| Bus_J2 | 15 | Load | 87.29 | Under Voltage | 75.36 | Under Voltage |
| Bus_J3 | 15 | Load | 87.11 | Under Voltage | 75.01 | Under Voltage |
| Bus_J4 | 15 | Load | 87.1 | Under Voltage | 74.99 | Under Voltage |
| Bus_J5 | 15 | Load | 87.05 | Under Voltage | 74.9 | Under Voltage |
| Bus_J6 | 15 | Load | 87.05 | Under Voltage | 74.9 | Under Voltage |
| Bus_J7 | 15 | Load | 86.93 | Under Voltage | 74.68 | Under Voltage |
| Bus_J8 | 15 | Load | 86.93 | Under Voltage | 74.68 | Under Voltage |
| Bus_J9 | 15 | Load | 86.93 | Under Voltage | 74.67 | Under Voltage |
| Bus_J10 | 15 | Load | 86.93 | Under Voltage | 74.68 | Under Voltage |
| Bus_J11 | 15 | Load | 86.88 | Under Voltage | 74.58 | Under Voltage |
| Bus_J12 | 15 | Load | 86.76 | Under Voltage | 74.35 | Under Voltage |
| Bus_J13 | 15 | Load | 86.62 | Under Voltage | 74.09 | Under Voltage |
| Bus_J14 | 15 | Load | 86.61 | Under Voltage | 74.08 | Under Voltage |
| Bus_J15 | 15 | Load | 86.39 | Under Voltage | 73.66 | Under Voltage |
| Bus_J16 | 15 | Load | 86.73 | Under Voltage | 74.29 | Under Voltage |
| Bus_J17 | 15 | Load | 86.73 | Under Voltage | 74.29 | Under Voltage |

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| Bus_J18 | 15 | Load | 86.66 | Under Voltage | 74.17 | Under Voltage |
| Bus_J19 | 15 | Load | 86.66 | Under Voltage | 74.17 | Under Voltage |
| Bus_J20 | 15 | Load | 86.62 | Under Voltage | 74.1 | Under Voltage |
| Bus_J21 | 15 | Load | 86.62 | Under Voltage | 74.09 | Under Voltage |
| Bus_J22 | 15 | Load | 86.54 | Under Voltage | 73.94 | Under Voltage |
| Bus_J23 | 15 | Load | 86.36 | Under Voltage | 73.61 | Under Voltage |
| Bus_J24 | 15 | Load | 86.24 | Under Voltage | 73.38 | Under Voltage |
| Bus_J25 | 15 | Load | 86.24 | Under Voltage | 73.38 | Under Voltage |
| Bus_J26 | 15 | Load | 86.08 | Under Voltage | 73.07 | Under Voltage |
| Bus_J27 | 15 | Load | 86.07 | Under Voltage | 73.06 | Under Voltage |
| Bus_J28 | 15 | Load | 86.06 | Under Voltage | 73.04 | Under Voltage |
| Bus_J29 | 15 | Load | 86.06 | Under Voltage | 73.03 | Under Voltage |
| Bus_J30 | 15 | Load | 86.02 | Under Voltage | 72.97 | Under Voltage |
| Bus_J31 | 15 | Load | 86.01 | Under Voltage | 72.94 | Under Voltage |
| Bus_J32 | 15 | Load | 86 | Under Voltage | 72.93 | Under Voltage |
| Bus_J33 | 15 | Load | 86 | Under Voltage | 72.93 | Under Voltage |
| Bus_J34 | 15 | Load | 86.01 | Under Voltage | 72.95 | Under Voltage |
| Bus_J35 | 15 | Load | 86.01 | Under Voltage | 72.95 | Under Voltage |
| Bus_J36 | 15 | Load | 85.99 | Under Voltage | 72.91 | Under Voltage |
| Bus_J37 | 15 | Load | 86.21 | Under Voltage | 73.31 | Under Voltage |
| Bus_J38 | 15 | Load | 86.2 | Under Voltage | 73.31 | Under Voltage |
| Bus_J39 | 15 | Load | 86.2 | Under Voltage | 73.3 | Under Voltage |
| Bus_J40 | 15 | Load | 86.2 | Under Voltage | 73.3 | Under Voltage |
| Bus_J41 | 15 | Load | 86.2 | Under Voltage | 73.29 | Under Voltage |
| Bus_J42 | 15 | Load | 86.04 | Under Voltage | 73 | Under Voltage |
| Bus_J43 | 15 | Load | 86.03 | Under Voltage | 72.98 | Under Voltage |
| Bus_J44 | 15 | Load | 86.01 | Under Voltage | 72.94 | Under Voltage |
| Bus_J45 | 15 | Load | 86.01 | Under Voltage | 72.94 | Under Voltage |
| Bus_J46 | 15 | Load | 85.99 | Under Voltage | 72.9 | Under Voltage |
| Bus_J47 | 15 | Load | 85.88 | Under Voltage | 72.7 | Under Voltage |
| Bus_J48 | 15 | Load | 85.87 | Under Voltage | 72.68 | Under Voltage |
| Bus_J49 | 15 | Load | 85.83 | Under Voltage | 72.6 | Under Voltage |
| Bus_J50 | 15 | Load | 85.83 | Under Voltage | 72.59 | Under Voltage |
| Bus_J51 | 15 | Load | 85.8 | Under Voltage | 72.55 | Under Voltage |
| Bus_J52 | 15 | Load | 85.79 | Under Voltage | 72.54 | Under Voltage |
| Bus_J53 | 15 | Load | 85.78 | Under Voltage | 72.51 | Under Voltage |
| Bus_J54 | 15 | Load | 85.77 | Under Voltage | 72.5 | Under Voltage |
| Bus_J55 | 15 | Load | 85.77 | Under Voltage | 72.5 | Under Voltage |
| Bus_J56 | 15 | Load | 85.77 | Under Voltage | 72.49 | Under Voltage |
| Bus_J57 | 15 | Load | 85.77 | Under Voltage | 72.49 | Under Voltage |
| Bus_J58 | 15 | Load | 85.77 | Under Voltage | 72.49 | Under Voltage |
| Bus_J59 | 15 | Load | 85.77 | Under Voltage | 72.49 | Under Voltage |
| Bus_J60 | 15 | Load | 85.95 | Under Voltage | 72.83 | Under Voltage |
| Bus_J61 | 15 | Load | 85.95 | Under Voltage | 72.83 | Under Voltage |
| Bus_J62 | 15 | Load | 85.95 | Under Voltage | 72.83 | Under Voltage |
| Bus_J63 | 15 | Load | 85.94 | Under Voltage | 72.82 | Under Voltage |

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| Bus_J64 | 15 | Load | 86 | Under Voltage | 72.92 | Under Voltage |
| Bus_J65 | 15 | Load | 87.08 | Under Voltage | 74.96 | Under Voltage |
| Bus_J66 | 15 | Load | 86.89 | Under Voltage | 74.61 | Under Voltage |
| Bus_J67 | 15 | Load | 86.85 | Under Voltage | 74.52 | Under Voltage |
| Bus_J68 | 15 | Load | 86.85 | Under Voltage | 74.52 | Under Voltage |
| Bus_J69 | 15 | Load | 86.82 | Under Voltage | 74.47 | Under Voltage |
| Bus_J70 | 15 | Load | 86.82 | Under Voltage | 74.47 | Under Voltage |
| Bus_J71 | 15 | Load | 86.82 | Under Voltage | 74.47 | Under Voltage |
| Bus_J72 | 15 | Load | 86.81 | Under Voltage | 74.46 | Under Voltage |
| Bus_J73 | 15 | Load | 86.76 | Under Voltage | 74.35 | Under Voltage |
| Bus_J74 | 15 | Load | 86.76 | Under Voltage | 74.35 | Under Voltage |
| Bus_J75 | 15 | Load | 86.71 | Under Voltage | 74.27 | Under Voltage |
| Bus_J76 | 15 | Load | 86.7 | Under Voltage | 74.25 | Under Voltage |
| Bus_J77 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J78 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J79 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J80 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J81 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J82 | 15 | Load | 86.67 | Under Voltage | 74.18 | Under Voltage |
| Bus_J83 | 15 | Load | 86.63 | Under Voltage | 74.13 | Under Voltage |
| Bus_J84 | 15 | Load | 86.63 | Under Voltage | 74.11 | Under Voltage |
| Bus_J85 | 15 | Load | 86.62 | Under Voltage | 74.11 | Under Voltage |
| Bus_J86 | 15 | Load | 86.62 | Under Voltage | 74.1 | Under Voltage |
| Bus_J87 | 15 | Load | 86.62 | Under Voltage | 74.1 | Under Voltage |
| Bus_J88 | 15 | Load | 86.59 | Under Voltage | 74.04 | Under Voltage |
| Bus_J89 | 15 | Load | 86.59 | Under Voltage | 74.04 | Under Voltage |
| Bus_J90 | 15 | Load | 86.56 | Under Voltage | 73.99 | Under Voltage |
| Bus_J91 | 15 | Load | 86.57 | Under Voltage | 74 | Under Voltage |
| Bus_J92 | 15 | Load | 86.53 | Under Voltage | 73.93 | Under Voltage |
| Bus_J93 | 15 | Load | 86.53 | Under Voltage | 73.93 | Under Voltage |
| Bus_J94 | 15 | Load | 86.52 | Under Voltage | 73.9 | Under Voltage |
| Bus_J95 | 15 | Load | 86.49 | Under Voltage | 73.85 | Under Voltage |
| Bus_J96 | 15 | Load | 87.08 | Under Voltage | 74.96 | Under Voltage |
| Bus_J97 | 15 | Load | 86.75 | Under Voltage | 74.34 | Under Voltage |
| Bus_J98 | 15 | Load | 86.6 | Under Voltage | 74.05 | Under Voltage |
| Bus_J99 | 15 | Load | 86.59 | Under Voltage | 74.04 | Under Voltage |
| Bus_J100 | 15 | Load | 86.57 | Under Voltage | 74.01 | Under Voltage |
| Bus_J101 | 15 | Load | 86.57 | Under Voltage | 74 | Under Voltage |
| Bus_J102 | 15 | Load | 86.57 | Under Voltage | 73.99 | Under Voltage |
| Bus_J103 | 15 | Load | 86.57 | Under Voltage | 73.99 | Under Voltage |
| Bus_J104 | 15 | Load | 86.54 | Under Voltage | 73.95 | Under Voltage |
| Bus_J105 | 15 | Load | 86.47 | Under Voltage | 73.8 | Under Voltage |
| Bus_J106 | 15 | Load | 86.47 | Under Voltage | 73.8 | Under Voltage |
| Bus_J107 | 15 | Load | 86.54 | Under Voltage | 73.95 | Under Voltage |
| Bus_J108 | 15 | Load | 86.24 | Under Voltage | 73.38 | Under Voltage |
| Bus_J109 | 15 | Load | 86.23 | Under Voltage | 73.36 | Under Voltage |

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| Bus_J110 | 15 | Load | 86.18 | Under Voltage | 73.27 | Under Voltage |
| Bus_J111 | 15 | Load | 86.19 | Under Voltage | 73.28 | Under Voltage |
| Bus_J112 | 15 | Load | 86.09 | Under Voltage | 73.09 | Under Voltage |
| Bus_J113 | 15 | Load | 85.97 | Under Voltage | 72.86 | Under Voltage |
| Bus_J114 | 15 | Load | 85.95 | Under Voltage | 72.83 | Under Voltage |
| Bus_J115 | 15 | Load | 85.8 | Under Voltage | 72.55 | Under Voltage |
| Bus_J116 | 15 | Load | 85.8 | Under Voltage | 72.54 | Under Voltage |
| Bus_J117 | 15 | Load | 85.8 | Under Voltage | 72.54 | Under Voltage |
| Bus_J118 | 15 | Load | 85.79 | Under Voltage | 72.54 | Under Voltage |
| Bus_J119 | 15 | Load | 85.73 | Under Voltage | 72.42 | Under Voltage |
| Bus_J120 | 15 | Load | 85.73 | Under Voltage | 72.42 | Under Voltage |
| Bus_J121 | 15 | Load | 85.69 | Under Voltage | 72.33 | Under Voltage |
| Bus_J122 | 15 | Load | 85.67 | Under Voltage | 72.31 | Under Voltage |
| Bus_J123 | 15 | Load | 85.67 | Under Voltage | 72.31 | Under Voltage |
| Bus_J124 | 15 | Load | 85.67 | Under Voltage | 72.3 | Under Voltage |
| Bus_J125 | 15 | Load | 85.67 | Under Voltage | 72.31 | Under Voltage |
| Bus_J126 | 15 | Load | 85.64 | Under Voltage | 72.25 | Under Voltage |
| Bus_J127 | 15 | Load | 85.64 | Under Voltage | 72.25 | Under Voltage |
| Bus_J128 | 15 | Load | 85.66 | Under Voltage | 72.28 | Under Voltage |
| Bus_J129 | 15 | Load | 85.65 | Under Voltage | 72.26 | Under Voltage |
| Bus_J131 | 15 | Load | 93.25 | | 86.62 | Under Voltage |
| Bus_J132 | 15 | Load | 86.69 | Under Voltage | 74.23 | Under Voltage |
| Bus_J286 | 15 | Load | 90.91 | | 85.43 | Under Voltage |
| Bus_J289 | 15 | Load | 97.55 | | 96.64 | |
| Bus_J292 | 15 | Load | 91.81 | | 87.56 | Under Voltage |
| Bus_J317 | 15 | Load | 92.6 | | 88.65 | Under Voltage |
| Bus_J323 | 15 | Load | 78.3 | Under Voltage | 67.06 | Under Voltage |
| Bus_J329 | 15 | Load | 86.92 | Under Voltage | 80.5 | Under Voltage |
| Bus_J335 | 15 | Load | 92.25 | | 88.63 | Under Voltage |
| Bus_J338 | 15 | Load | 92.22 | | 88.58 | Under Voltage |
| Bus_J350 | 15 | Load | 85.01 | Under Voltage | 77.51 | Under Voltage |
| Bus_J362 | 15 | Load | 92.19 | | 88.54 | Under Voltage |
| Bus_J365 | 15 | Load | 92.17 | | 88.51 | Under Voltage |
| Bus_J380 | 15 | Load | 84.77 | Under Voltage | 77.13 | Under Voltage |
| Bus_J383 | 15 | Load | 84.76 | Under Voltage | 77.12 | Under Voltage |
| Bus_J386 | 15 | Load | 92.17 | | 88.51 | Under Voltage |
| Bus_J401 | 15 | Load | 91.9 | | 87.89 | Under Voltage |
| Bus_J458 | 15 | Load | 93.86 | | 90.98 | |
| Bus_J461 | 15 | Load | 93.86 | | 90.98 | |
| Bus_Junction1 | 15 | Load | 100.08 | | 99.86 | |

### A1.1: Alert Summary report of 15kV Lines at Existing Condition

| Line ID | Type | Condition | Rating (A) | Operating Current (A) | % of Loading | Phase |
|---|---|---|---|---|---|---|
| Edge125 | Line | Overload | 224.800 | 324.345 | 144.3 | 3-Phase |
| Edge48 | Line | Overload | 120.826 | 188.698 | 156.2 | 3-Phase |
| Line135 | Line | Overload | 120.826 | 149.965 | 124.1 | 3-Phase |
| Line347 | Line | Overload | 120.826 | 170.791 | 141.4 | 3-Phase |
| Line358 | Line | Overload | 120.826 | 169.832 | 140.6 | 3-Phase |
| Line361 | Line | Overload | 120.826 | 178.286 | 147.6 | 3-Phase |
| Line459 | Line | Overload | 120.826 | 199.734 | 165.3 | 3-Phase |
| Line582 | Line | Overload | 120.826 | 155.123 | 128.4 | 3-Phase |
| Line621 | Line | Overload | 120.826 | 223.727 | 185.2 | 3-Phase |
| Line622 | Line | Overload | 120.826 | 220.242 | 182.3 | 3-Phase |
| Line623 | Line | Overload | 120.826 | 211.917 | 175.4 | 3-Phase |
| Line627 | Line | Overload | 83.042 | 151.356 | 182.3 | 3-Phase |
| Line633 | Line | Overload | 83.042 | 102.633 | 123.6 | 3-Phase |
| Line644 | Line | Overload | 188.254 | 269.369 | 143.1 | 3-Phase |
| Line653 | Line | Overload | 120.826 | 223.030 | 184.6 | 3-Phase |
| Line654 | Line | Overload | 120.826 | 214.687 | 177.7 | 3-Phase |
| Line655 | Line | Overload | 120.826 | 206.384 | 170.8 | 3-Phase |
| Line657 | Line | Overload | 120.826 | 202.943 | 168.0 | 3-Phase |
| Line710 | Line | Overload | 120.826 | 147.648 | 122.2 | 3-Phase |
| Line749 | Line | Overload | 120.826 | 150.878 | 124.9 | 3-Phase |
| Line754 | Line | Overload | 120.826 | 193.808 | 160.4 | 3-Phase |
| Line768 | Line | Overload | 120.826 | 193.552 | 160.2 | 3-Phase |
| Line776 | Line | Overload | 120.826 | 200.770 | 166.2 | 3-Phase |
| Line81 | Line | Overload | 120.826 | 146.639 | 121.4 | 3-Phase |
| Line842 | Line | Overload | 120.826 | 186.880 | 154.7 | 3-Phase |
| Line846 | Line | Overload | 120.826 | 187.535 | 155.2 | 3-Phase |
| Line847 | Line | Overload | 120.826 | 184.260 | 152.5 | 3-Phase |
| Line852 | Line | Overload | 120.826 | 181.002 | 149.8 | 3-Phase |
| Line855 | Line | Overload | 111.917 | 169.403 | 151.4 | 3-Phase |
| Mobile Sub. Incoming | Cable | Overload | 829.306 | 1422.957 | 171.6 | 3-Phase |
| Cable15 | Cable | Overload | 450.710 | 357.510 | 79.3 | 3-Phase |
| Line M1-SWS 2 | Cable | Overload | 450.710 | 357.457 | 79.3 | 3-Phase |
| Line136 | Line | Overload | 120.826 | 144.382 | 119.5 | 3-Phase |
| Line286 | Line | Overload | 120.826 | 142.016 | 117.5 | 3-Phase |

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|---|---|---|---|---|---|---|
| Line82 | Line | Overload | 120.826 | 144.754 | 119.8 | 3-Phase |

### *A1.2: Alert Summary report of 15kV Lines after 10 Years*

| **Line ID** | **Type** | **Condition** | **Rating (A)** | **Operating Current (A)** | **% of Loading** | **Phase** |
|---|---|---|---|---|---|---|
| Cable14 | Cable | Overload | 450.710 | 360.075 | 79.9 | 3-Phase |
| Cable15 | Cable | Overload | 450.710 | 553.282 | 122.8 | 3-Phase |
| Cable2 | Cable | Overload | 450.710 | 455.123 | 101.0 | 3-Phase |
| Cable20 | Cable | Overload | 450.710 | 476.889 | 105.8 | 3-Phase |
| Cable22 | Cable | Overload | 450.710 | 398.098 | 88.3 | 3-Phase |
| Cable6 | Cable | Overload | 450.710 | 448.942 | 99.6 | 3-Phase |
| Edge125 | Line | Overload | 224.800 | 607.330 | 270.2 | 3-Phase |
| Edge126 | Line | Overload | 342.147 | 607.282 | 177.5 | 3-Phase |
| Edge128 | Cable | Overload | 450.710 | 607.330 | 134.7 | 3-Phase |
| Edge129 | Cable | Overload | 450.710 | 363.296 | 80.6 | 3-Phase |
| Edge24 | Line | Overload | 120.826 | 160.003 | 132.4 | 3-Phase |
| Edge25 | Line | Overload | 120.826 | 159.188 | 131.7 | 3-Phase |
| Edge27 | Line | Overload | 120.826 | 148.867 | 123.2 | 3-Phase |
| Edge47 | Line | Overload | 120.826 | 217.996 | 180.4 | 3-Phase |
| Edge48 | Line | Overload | 120.826 | 353.300 | 292.4 | 3-Phase |
| Edge56 | Line | Overload | 120.826 | 207.736 | 171.9 | 3-Phase |
| Edge58 | Line | Overload | 120.826 | 170.305 | 141.0 | 3-Phase |
| Line 1-SWS 5 | Cable | Overload | 450.710 | 607.179 | 134.7 | 3-Phase |
| Line 3-SWS 6 | Cable | Overload | 450.710 | 455.000 | 101.0 | 3-Phase |
| Line 4-SWS 3 | Cable | Overload | 450.710 | 448.827 | 99.6 | 3-Phase |
| Line 7-SWS 1 | Cable | Overload | 450.710 | 403.675 | 89.6 | 3-Phase |
| Line M1-SWS 2 | Cable | Overload | 450.710 | 553.228 | 122.7 | 3-Phase |
| Line M3- SWS 0 | Cable | Overload | 414.653 | 425.817 | 102.7 | 3-Phase |
| Line M4-SWS 7 | Cable | Overload | 450.710 | 476.802 | 105.8 | 3-Phase |
| Line101 | Line | Overload | 342.100 | 455.123 | 133.0 | 3-Phase |
| Line103 | Line | Overload | 120.826 | 198.519 | 164.3 | 3-Phase |
| Line135 | Line | Overload | 120.826 | 233.241 | 193.0 | 3-Phase |
| Line136 | Line | Overload | 120.826 | 224.546 | 185.8 | 3-Phase |
| Line14 | Line | Overload | 120.826 | 218.845 | 181.1 | 3-Phase |
| Line156 | Line | Overload | 120.826 | 160.179 | 132.6 | 3-Phase |
| Line158 | Line | Overload | 120.826 | 150.773 | 124.8 | 3-Phase |
| Line16 | Line | Overload | 120.826 | 212.879 | 176.2 | 3-Phase |
| Line17 | Line | Overload | 120.826 | 206.916 | 171.3 | 3-Phase |

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|---|---|---|---|---|---|---|
| Line176 | Line | Overload | 120.826 | 185.936 | 153.9 | 3-Phase |
| Line189 | Line | Overload | 120.826 | 194.629 | 161.1 | 3-Phase |
| Line200 | Line | Overload | 342.100 | 448.942 | 131.2 | 3-Phase |
| Line255 | Line | Overload | 120.826 | 183.172 | 151.6 | 3-Phase |
| Line257 | Line | Overload | 120.826 | 157.999 | 130.8 | 3-Phase |
| Line258 | Line | Overload | 120.826 | 160.211 | 132.6 | 3-Phase |
| Line270 | Line | Overload | 120.826 | 184.292 | 152.5 | 3-Phase |
| Line271 | Line | Overload | 120.826 | 186.537 | 154.4 | 3-Phase |
| Line278 | Line | Overload | 120.826 | 187.658 | 155.3 | 3-Phase |
| Line279 | Line | Overload | 120.826 | 196.989 | 163.0 | 3-Phase |
| Line286 | Line | Overload | 120.826 | 226.485 | 187.4 | 3-Phase |
| Line297 | Line | Overload | 120.826 | 171.633 | 142.0 | 3-Phase |
| Line298 | Line | Overload | 120.826 | 169.408 | 140.2 | 3-Phase |
| Line310 | Line | Overload | 224.769 | 360.075 | 160.2 | 3-Phase |
| Line347 | Line | Overload | 120.826 | 269.643 | 223.2 | 3-Phase |
| Line358 | Line | Overload | 120.826 | 268.122 | 221.9 | 3-Phase |
| Line361 | Line | Overload | 120.826 | 281.521 | 233.0 | 3-Phase |
| Line364 | Line | Overload | 224.769 | 344.144 | 153.1 | 3-Phase |
| Line365 | Line | Overload | 224.769 | 339.329 | 151.0 | 3-Phase |
| Line366 | Line | Overload | 120.826 | 183.258 | 151.7 | 3-Phase |
| Line376 | Line | Overload | 120.826 | 202.251 | 167.4 | 3-Phase |
| Line377 | Line | Overload | 120.826 | 175.440 | 145.2 | 3-Phase |
| Line378 | Line | Overload | 120.826 | 163.021 | 134.9 | 3-Phase |
| Line380 | Line | Overload | 120.826 | 172.407 | 142.7 | 3-Phase |
| Line383 | Line | Overload | 120.826 | 158.485 | 131.2 | 3-Phase |
| Line386 | Line | Overload | 224.769 | 348.964 | 155.3 | 3-Phase |
| Line407 | Line | Overload | 120.826 | 180.221 | 149.2 | 3-Phase |
| Line424 | Line | Overload | 120.826 | 159.994 | 132.4 | 3-Phase |
| Line426 | Line | Overload | 120.826 | 153.727 | 127.2 | 3-Phase |
| Line458 | Line | Overload | 224.769 | 350.494 | 155.9 | 3-Phase |
| Line459 | Line | Overload | 120.826 | 315.527 | 261.1 | 3-Phase |
| Line461 | Line | Overload | 342.147 | 553.282 | 161.7 | 3-Phase |
| Line554 | Line | Overload | 120.826 | 211.516 | 175.1 | 3-Phase |
| Line581 | Line | Overload | 188.254 | 260.549 | 138.4 | 3-Phase |
| Line582 | Line | Overload | 120.826 | 246.225 | 203.8 | 3-Phase |
| Line583 | Line | Overload | 120.835 | 158.929 | 131.5 | 3-Phase |
| Line584 | Line | Overload | 120.826 | 147.658 | 122.2 | 3-Phase |

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|---|---|---|---|---|---|---|
| Line611 | Line | Overload | 120.826 | 214.367 | 177.4 | 3-Phase |
| Line621 | Line | Overload | 120.826 | 353.527 | 292.6 | 3-Phase |
| Line622 | Line | Overload | 120.826 | 348.011 | 288.0 | 3-Phase |
| Line623 | Line | Overload | 120.826 | 334.884 | 277.2 | 3-Phase |
| Line627 | Line | Overload | 83.042 | 239.944 | 288.9 | 3-Phase |
| Line633 | Line | Overload | 83.042 | 163.589 | 197.0 | 3-Phase |
| Line635 | Line | Overload | 83.042 | 136.605 | 164.5 | 3-Phase |
| Line637 | Line | Overload | 83.042 | 109.616 | 132.0 | 3-Phase |
| Line644 | Line | Overload | 188.254 | 425.852 | 226.2 | 3-Phase |
| Line65 | Line | Overload | 120.826 | 164.260 | 135.9 | 3-Phase |
| Line653 | Line | Overload | 120.826 | 352.422 | 291.7 | 3-Phase |
| Line654 | Line | Overload | 120.826 | 339.248 | 280.8 | 3-Phase |
| Line655 | Line | Overload | 120.826 | 326.176 | 270.0 | 3-Phase |
| Line657 | Line | Overload | 120.826 | 320.765 | 265.5 | 3-Phase |
| Line68 | Line | Overload | 120.826 | 182.761 | 151.3 | 3-Phase |
| Line688 | Line | Overload | 120.826 | 160.139 | 132.5 | 3-Phase |
| Line709 | Line | Overload | 120.826 | 165.223 | 136.7 | 3-Phase |
| Line710 | Line | Overload | 120.826 | 236.431 | 195.7 | 3-Phase |
| Line73 | Line | Overload | 120.826 | 217.985 | 180.4 | 3-Phase |
| Line749 | Line | Overload | 120.826 | 241.489 | 199.9 | 3-Phase |
| Line75 | Line | Overload | 120.826 | 192.014 | 158.9 | 3-Phase |
| Line751 | Line | Overload | 224.769 | 392.614 | 174.7 | 3-Phase |
| Line753 | Line | Overload | 224.769 | 387.530 | 172.4 | 3-Phase |
| Line754 | Line | Overload | 120.826 | 312.855 | 258.9 | 3-Phase |
| Line756 | Line | Overload | 224.769 | 398.101 | 177.1 | 3-Phase |
| Line768 | Line | Overload | 120.826 | 312.454 | 258.6 | 3-Phase |
| Line774 | Line | Overload | 342.100 | 476.889 | 139.4 | 3-Phase |
| Line775 | Line | Overload | 188.254 | 307.884 | 163.5 | 3-Phase |
| Line776 | Line | Overload | 120.826 | 307.889 | 254.8 | 3-Phase |
| Line789 | Line | Overload | 224.769 | 269.780 | 120.0 | 3-Phase |
| Line81 | Line | Overload | 120.826 | 230.319 | 190.6 | 3-Phase |
| Line82 | Line | Overload | 120.826 | 227.338 | 188.2 | 3-Phase |
| Line842 | Line | Overload | 120.826 | 285.667 | 236.4 | 3-Phase |
| Line846 | Line | Overload | 120.826 | 286.714 | 237.3 | 3-Phase |
| Line847 | Line | Overload | 120.826 | 281.483 | 233.0 | 3-Phase |
| Line852 | Line | Overload | 120.826 | 276.281 | 228.7 | 3-Phase |
| Line855 | Line | Overload | 111.917 | 258.722 | 231.2 | 3-Phase |

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|---|---|---|---|---|---|---|
| Line856 | Line | Overload | 111.917 | 138.483 | 123.7 | 3-Phase |
| Line86 | Line | Overload | 120.826 | 202.752 | 167.8 | 3-Phase |
| Line87 | Line | Overload | 120.826 | 201.280 | 166.6 | 3-Phase |
| Mobile Sub. Incoming | Cable | Overload | 829.306 | 2238.829 | 270.0 | 3-Phase |
| Sub T1-Incoming | Cable | Overload | 829.306 | 956.285 | 115.3 | 3-Phase |
| Sub. T2- Incoming | Cable | Overload | 829.306 | 956.285 | 115.3 | 3-Phase |
| Line108 | Line | Overload | 120.826 | 141.725 | 117.3 | 3-Phase |
| Line160 | Line | Overload | 120.826 | 142.059 | 117.6 | 3-Phase |
| Line281 | Line | Overload | 120.826 | 144.063 | 119.2 | 3-Phase |
| Line534 | Line | Overload | 120.826 | 143.927 | 119.1 | 3-Phase |
| Line537 | Line | Overload | 120.826 | 142.131 | 117.6 | 3-Phase |
| Line639 | Line | Overload | 83.042 | 96.127 | 115.8 | 3-Phase |
| Line790 | Line | Overload | 224.769 | 262.802 | 116.9 | 3-Phase |
| Line854 | Line | Overload | 224.769 | 263.313 | 117.1 | 3-Phase |

### *A2: Operating Voltage of Line 1*

| **Bus ID** | **Nominal kV** | **Type of Bus** | **Existing Voltage (%)** | **Voltage After 10 Years (%)** |
|---|---|---|---|---|
| Bus115 | 132 | SWNG | 100 | 100 |
| Bus116 | 15 | Load | 99.86 | 99.75 |
| Bus117 | 15 | Load | 99.86 | 99.75 |
| Bus1670 | 15 | Load | 99.84 | 99.72 |
| Bus_J2 | 15 | Load | 89.33 | 80.67 |
| Bus_J3 | 15 | Load | 89.18 | 80.4 |
| Bus_J4 | 15 | Load | 89.17 | 80.38 |
| Bus_J5 | 15 | Load | 89.13 | 80.31 |
| Bus_J6 | 15 | Load | 89.13 | 80.31 |
| Bus_J7 | 15 | Load | 89.03 | 80.13 |
| Bus_J8 | 15 | Load | 89.03 | 80.13 |
| Bus_J9 | 15 | Load | 89.03 | 80.13 |
| Bus_J10 | 15 | Load | 89.03 | 80.13 |
| Bus_J11 | 15 | Load | 88.99 | 80.05 |
| Bus_J12 | 15 | Load | 88.88 | 79.86 |
| Bus_J13 | 15 | Load | 88.76 | 79.64 |
| Bus_J14 | 15 | Load | 88.75 | 79.63 |
| Bus_J15 | 15 | Load | 88.56 | 79.28 |
| Bus_J16 | 15 | Load | 88.85 | 79.81 |
| Bus_J17 | 15 | Load | 88.85 | 79.81 |
| Bus_J18 | 15 | Load | 88.79 | 79.71 |
| Bus_J19 | 15 | Load | 88.79 | 79.71 |
| Bus_J20 | 15 | Load | 88.76 | 79.64 |
| Bus_J21 | 15 | Load | 88.76 | 79.64 |

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|---|---|---|---|---|
| Bus_J22 | 15 | Load | 88.68 | 79.5 |
| Bus_J23 | 15 | Load | 88.51 | 79.2 |
| Bus_J24 | 15 | Load | 88.39 | 78.98 |
| Bus_J25 | 15 | Load | 88.39 | 78.98 |
| Bus_J26 | 15 | Load | 88.23 | 78.69 |
| Bus_J27 | 15 | Load | 88.22 | 78.68 |
| Bus_J28 | 15 | Load | 88.21 | 78.66 |
| Bus_J29 | 15 | Load | 88.21 | 78.65 |
| Bus_J30 | 15 | Load | 88.18 | 78.6 |
| Bus_J31 | 15 | Load | 88.16 | 78.58 |
| Bus_J32 | 15 | Load | 88.16 | 78.57 |
| Bus_J33 | 15 | Load | 88.16 | 78.57 |
| Bus_J34 | 15 | Load | 88.17 | 78.59 |
| Bus_J35 | 15 | Load | 88.17 | 78.59 |
| Bus_J36 | 15 | Load | 88.15 | 78.56 |
| Bus_J37 | 15 | Load | 88.39 | 78.99 |
| Bus_J38 | 15 | Load | 88.39 | 78.99 |
| Bus_J39 | 15 | Load | 88.39 | 78.98 |
| Bus_J40 | 15 | Load | 88.39 | 78.98 |
| Bus_J41 | 15 | Load | 88.38 | 78.97 |
| Bus_J42 | 15 | Load | 88.25 | 78.74 |
| Bus_J43 | 15 | Load | 88.24 | 78.72 |
| Bus_J44 | 15 | Load | 88.23 | 78.69 |
| Bus_J45 | 15 | Load | 88.23 | 78.69 |
| Bus_J46 | 15 | Load | 88.21 | 78.66 |
| Bus_J47 | 15 | Load | 88.12 | 78.5 |
| Bus_J48 | 15 | Load | 88.11 | 78.49 |
| Bus_J49 | 15 | Load | 88.08 | 78.43 |
| Bus_J50 | 15 | Load | 88.08 | 78.43 |
| Bus_J51 | 15 | Load | 88.06 | 78.39 |
| Bus_J52 | 15 | Load | 88.05 | 78.38 |
| Bus_J53 | 15 | Load | 88.04 | 78.36 |
| Bus_J54 | 15 | Load | 88.04 | 78.35 |
| Bus_J55 | 15 | Load | 88.04 | 78.35 |
| Bus_J56 | 15 | Load | 88.03 | 78.35 |
| Bus_J57 | 15 | Load | 88.03 | 78.34 |
| Bus_J58 | 15 | Load | 88.03 | 78.35 |
| Bus_J59 | 15 | Load | 88.03 | 78.35 |
| Bus_J60 | 15 | Load | 88.18 | 78.6 |
| Bus_J61 | 15 | Load | 88.17 | 78.59 |
| Bus_J62 | 15 | Load | 88.18 | 78.6 |
| Bus_J63 | 15 | Load | 88.17 | 78.59 |
| Bus_J64 | 15 | Load | 88.22 | 78.68 |
| Bus_J65 | 15 | Load | 89.16 | 80.36 |
| Bus_J66 | 15 | Load | 89.01 | 80.09 |
| Bus_J67 | 15 | Load | 88.97 | 80.02 |

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|---|---|---|---|---|
| Bus_J68 | 15 | Load | 88.97 | 80.02 |
| Bus_J69 | 15 | Load | 88.95 | 79.98 |
| Bus_J70 | 15 | Load | 88.94 | 79.98 |
| Bus_J71 | 15 | Load | 88.94 | 79.98 |
| Bus_J72 | 15 | Load | 88.94 | 79.97 |
| Bus_J73 | 15 | Load | 88.9 | 79.89 |
| Bus_J74 | 15 | Load | 88.89 | 79.89 |
| Bus_J75 | 15 | Load | 88.86 | 79.82 |
| Bus_J76 | 15 | Load | 88.85 | 79.81 |
| Bus_J77 | 15 | Load | 88.84 | 79.79 |
| Bus_J78 | 15 | Load | 88.84 | 79.79 |
| Bus_J79 | 15 | Load | 88.84 | 79.79 |
| Bus_J80 | 15 | Load | 88.84 | 79.79 |
| Bus_J81 | 15 | Load | 88.84 | 79.79 |
| Bus_J82 | 15 | Load | 88.82 | 79.76 |
| Bus_J83 | 15 | Load | 88.8 | 79.71 |
| Bus_J84 | 15 | Load | 88.79 | 79.7 |
| Bus_J85 | 15 | Load | 88.79 | 79.7 |
| Bus_J86 | 15 | Load | 88.78 | 79.69 |
| Bus_J87 | 15 | Load | 88.78 | 79.69 |
| Bus_J88 | 15 | Load | 88.76 | 79.65 |
| Bus_J89 | 15 | Load | 88.76 | 79.65 |
| Bus_J90 | 15 | Load | 88.74 | 79.61 |
| Bus_J91 | 15 | Load | 88.74 | 79.61 |
| Bus_J92 | 15 | Load | 88.71 | 79.56 |
| Bus_J93 | 15 | Load | 88.71 | 79.56 |
| Bus_J94 | 15 | Load | 88.7 | 79.54 |
| Bus_J95 | 15 | Load | 88.68 | 79.5 |
| Bus_J96 | 15 | Load | 89.16 | 80.36 |
| Bus_J97 | 15 | Load | 88.89 | 79.88 |
| Bus_J98 | 15 | Load | 88.76 | 79.66 |
| Bus_J99 | 15 | Load | 88.76 | 79.65 |
| Bus_J100 | 15 | Load | 88.75 | 79.62 |
| Bus_J101 | 15 | Load | 88.74 | 79.62 |
| Bus_J102 | 15 | Load | 88.74 | 79.61 |
| Bus_J103 | 15 | Load | 88.74 | 79.61 |
| Bus_J104 | 15 | Load | 88.72 | 79.58 |
| Bus_J105 | 15 | Load | 88.66 | 79.47 |
| Bus_J106 | 15 | Load | 88.66 | 79.47 |
| Bus_J107 | 15 | Load | 88.72 | 79.58 |
| Bus_J108 | 15 | Load | 88.47 | 79.14 |
| Bus_J109 | 15 | Load | 88.47 | 79.13 |
| Bus_J110 | 15 | Load | 88.43 | 79.06 |
| Bus_J111 | 15 | Load | 88.43 | 79.06 |
| Bus_J112 | 15 | Load | 88.35 | 78.92 |
| Bus_J113 | 15 | Load | 88.25 | 78.74 |

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|---|---|---|---|---|
| Bus_J114 | 15 | Load | 88.24 | 78.72 |
| Bus_J115 | 15 | Load | 88.12 | 78.5 |
| Bus_J116 | 15 | Load | 88.11 | 78.49 |
| Bus_J117 | 15 | Load | 88.11 | 78.49 |
| Bus_J118 | 15 | Load | 88.11 | 78.49 |
| Bus_J119 | 15 | Load | 88.06 | 78.4 |
| Bus_J120 | 15 | Load | 88.06 | 78.4 |
| Bus_J121 | 15 | Load | 88.02 | 78.33 |
| Bus_J122 | 15 | Load | 88.02 | 78.32 |
| Bus_J123 | 15 | Load | 88.01 | 78.32 |
| Bus_J124 | 15 | Load | 88.01 | 78.31 |
| Bus_J125 | 15 | Load | 88.01 | 78.31 |
| Bus_J126 | 15 | Load | 87.99 | 78.27 |
| Bus_J127 | 15 | Load | 87.99 | 78.27 |
| Bus_J128 | 15 | Load | 88 | 78.29 |
| Bus_J129 | 15 | Load | 88 | 78.28 |
| Bus_J131 | 15 | Load | 94.23 | 89.46 |
| Bus_J132 | 15 | Load | 88.82 | 79.76 |
| Bus_Junction1 | 15 | Load | 99.83 | 99.7 |

### *A2.1: Alert Report of Line 1 at Existing Condition*

| Device ID | Type | Condition | Rating (kV) | Unit | Operating Voltage (kV) | % of Operating Voltage | Phase |
|---|---|---|---|---|---|---|---|
| Bus_J10 | Bus | Under Voltage | 15.000 | kV | 13.355 | 89.0 | 3-Phase |
| Bus_J100 | Bus | Under Voltage | 15.000 | kV | 13.312 | 88.7 | 3-Phase |
| Bus_J101 | Bus | Under Voltage | 15.000 | kV | 13.312 | 88.7 | 3-Phase |
| Bus_J102 | Bus | Under Voltage | 15.000 | kV | 13.311 | 88.7 | 3-Phase |
| Bus_J103 | Bus | Under Voltage | 15.000 | kV | 13.311 | 88.7 | 3-Phase |
| Bus_J104 | Bus | Under Voltage | 15.000 | kV | 13.308 | 88.7 | 3-Phase |
| Bus_J105 | Bus | Under Voltage | 15.000 | kV | 13.299 | 88.7 | 3-Phase |
| Bus_J106 | Bus | Under Voltage | 15.000 | kV | 13.299 | 88.7 | 3-Phase |
| Bus_J107 | Bus | Under Voltage | 15.000 | kV | 13.308 | 88.7 | 3-Phase |
| Bus_J108 | Bus | Under Voltage | 15.000 | kV | 13.271 | 88.5 | 3-Phase |
| Bus_J109 | Bus | Under Voltage | 15.000 | kV | 13.270 | 88.5 | 3-Phase |
| Bus_J11 | Bus | Under Voltage | 15.000 | kV | 13.348 | 89.0 | 3-Phase |
| Bus_J110 | Bus | Under Voltage | 15.000 | kV | 13.264 | 88.4 | 3-Phase |
| Bus_J111 | Bus | Under Voltage | 15.000 | kV | 13.265 | 88.4 | 3-Phase |
| Bus_J112 | Bus | Under Voltage | 15.000 | kV | 13.253 | 88.4 | 3-Phase |
| Bus_J113 | Bus | Under Voltage | 15.000 | kV | 13.238 | 88.3 | 3-Phase |
| Bus_J114 | Bus | Under Voltage | 15.000 | kV | 13.236 | 88.2 | 3-Phase |
| Bus_J115 | Bus | Under Voltage | 15.000 | kV | 13.218 | 88.1 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J116 | Bus | Under Voltage | 15.000 | kV | 13.217 | 88.1 | 3-Phase |
| Bus_J117 | Bus | Under Voltage | 15.000 | kV | 13.217 | 88.1 | 3-Phase |
| Bus_J118 | Bus | Under Voltage | 15.000 | kV | 13.217 | 88.1 | 3-Phase |
| Bus_J119 | Bus | Under Voltage | 15.000 | kV | 13.209 | 88.1 | 3-Phase |
| Bus_J12 | Bus | Under Voltage | 15.000 | kV | 13.332 | 88.9 | 3-Phase |
| Bus_J120 | Bus | Under Voltage | 15.000 | kV | 13.209 | 88.1 | 3-Phase |
| Bus_J121 | Bus | Under Voltage | 15.000 | kV | 13.204 | 88.0 | 3-Phase |
| Bus_J122 | Bus | Under Voltage | 15.000 | kV | 13.202 | 88.0 | 3-Phase |
| Bus_J123 | Bus | Under Voltage | 15.000 | kV | 13.202 | 88.0 | 3-Phase |
| Bus_J124 | Bus | Under Voltage | 15.000 | kV | 13.202 | 88.0 | 3-Phase |
| Bus_J125 | Bus | Under Voltage | 15.000 | kV | 13.202 | 88.0 | 3-Phase |
| Bus_J126 | Bus | Under Voltage | 15.000 | kV | 13.199 | 88.0 | 3-Phase |
| Bus_J127 | Bus | Under Voltage | 15.000 | kV | 13.198 | 88.0 | 3-Phase |
| Bus_J128 | Bus | Under Voltage | 15.000 | kV | 13.200 | 88.0 | 3-Phase |
| Bus_J129 | Bus | Under Voltage | 15.000 | kV | 13.199 | 88.0 | 3-Phase |
| Bus_J13 | Bus | Under Voltage | 15.000 | kV | 13.314 | 88.8 | 3-Phase |
| Bus_J132 | Bus | Under Voltage | 15.000 | kV | 13.323 | 88.8 | 3-Phase |
| Bus_J14 | Bus | Under Voltage | 15.000 | kV | 13.313 | 88.8 | 3-Phase |
| Bus_J15 | Bus | Under Voltage | 15.000 | kV | 13.283 | 88.6 | 3-Phase |
| Bus_J16 | Bus | Under Voltage | 15.000 | kV | 13.328 | 88.9 | 3-Phase |
| Bus_J17 | Bus | Under Voltage | 15.000 | kV | 13.328 | 88.9 | 3-Phase |
| Bus_J18 | Bus | Under Voltage | 15.000 | kV | 13.319 | 88.8 | 3-Phase |
| Bus_J19 | Bus | Under Voltage | 15.000 | kV | 13.319 | 88.8 | 3-Phase |
| Bus_J2 | Bus | Under Voltage | 15.000 | kV | 13.400 | 89.3 | 3-Phase |
| Bus_J20 | Bus | Under Voltage | 15.000 | kV | 13.314 | 88.8 | 3-Phase |
| Bus_J21 | Bus | Under Voltage | 15.000 | kV | 13.313 | 88.8 | 3-Phase |
| Bus_J22 | Bus | Under Voltage | 15.000 | kV | 13.302 | 88.7 | 3-Phase |
| Bus_J23 | Bus | Under Voltage | 15.000 | kV | 13.276 | 88.5 | 3-Phase |
| Bus_J24 | Bus | Under Voltage | 15.000 | kV | 13.258 | 88.4 | 3-Phase |
| Bus_J25 | Bus | Under Voltage | 15.000 | kV | 13.258 | 88.4 | 3-Phase |
| Bus_J26 | Bus | Under Voltage | 15.000 | kV | 13.234 | 88.2 | 3-Phase |
| Bus_J27 | Bus | Under Voltage | 15.000 | kV | 13.233 | 88.2 | 3-Phase |
| Bus_J28 | Bus | Under Voltage | 15.000 | kV | 13.232 | 88.2 | 3-Phase |
| Bus_J29 | Bus | Under Voltage | 15.000 | kV | 13.231 | 88.2 | 3-Phase |
| Bus_J3 | Bus | Under Voltage | 15.000 | kV | 13.377 | 89.2 | 3-Phase |
| Bus_J30 | Bus | Under Voltage | 15.000 | kV | 13.227 | 88.2 | 3-Phase |
| Bus_J31 | Bus | Under Voltage | 15.000 | kV | 13.225 | 88.2 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J32 | Bus | Under Voltage | 15.000 | kV | 13.224 | 88.2 | 3-Phase |
| Bus_J33 | Bus | Under Voltage | 15.000 | kV | 13.224 | 88.2 | 3-Phase |
| Bus_J34 | Bus | Under Voltage | 15.000 | kV | 13.225 | 88.2 | 3-Phase |
| Bus_J35 | Bus | Under Voltage | 15.000 | kV | 13.225 | 88.2 | 3-Phase |
| Bus_J36 | Bus | Under Voltage | 15.000 | kV | 13.223 | 88.2 | 3-Phase |
| Bus_J37 | Bus | Under Voltage | 15.000 | kV | 13.259 | 88.4 | 3-Phase |
| Bus_J38 | Bus | Under Voltage | 15.000 | kV | 13.259 | 88.4 | 3-Phase |
| Bus_J39 | Bus | Under Voltage | 15.000 | kV | 13.258 | 88.4 | 3-Phase |
| Bus_J4 | Bus | Under Voltage | 15.000 | kV | 13.376 | 89.2 | 3-Phase |
| Bus_J40 | Bus | Under Voltage | 15.000 | kV | 13.258 | 88.4 | 3-Phase |
| Bus_J41 | Bus | Under Voltage | 15.000 | kV | 13.258 | 88.4 | 3-Phase |
| Bus_J42 | Bus | Under Voltage | 15.000 | kV | 13.238 | 88.3 | 3-Phase |
| Bus_J43 | Bus | Under Voltage | 15.000 | kV | 13.237 | 88.2 | 3-Phase |
| Bus_J44 | Bus | Under Voltage | 15.000 | kV | 13.234 | 88.2 | 3-Phase |
| Bus_J45 | Bus | Under Voltage | 15.000 | kV | 13.234 | 88.2 | 3-Phase |
| Bus_J46 | Bus | Under Voltage | 15.000 | kV | 13.231 | 88.2 | 3-Phase |
| Bus_J47 | Bus | Under Voltage | 15.000 | kV | 13.218 | 88.1 | 3-Phase |
| Bus_J48 | Bus | Under Voltage | 15.000 | kV | 13.217 | 88.1 | 3-Phase |
| Bus_J49 | Bus | Under Voltage | 15.000 | kV | 13.212 | 88.1 | 3-Phase |
| Bus_J5 | Bus | Under Voltage | 15.000 | kV | 13.370 | 89.1 | 3-Phase |
| Bus_J50 | Bus | Under Voltage | 15.000 | kV | 13.212 | 88.1 | 3-Phase |
| Bus_J51 | Bus | Under Voltage | 15.000 | kV | 13.209 | 88.1 | 3-Phase |
| Bus_J52 | Bus | Under Voltage | 15.000 | kV | 13.208 | 88.1 | 3-Phase |
| Bus_J53 | Bus | Under Voltage | 15.000 | kV | 13.206 | 88.0 | 3-Phase |
| Bus_J54 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J55 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J56 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J57 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J58 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J59 | Bus | Under Voltage | 15.000 | kV | 13.205 | 88.0 | 3-Phase |
| Bus_J6 | Bus | Under Voltage | 15.000 | kV | 13.370 | 89.1 | 3-Phase |
| Bus_J60 | Bus | Under Voltage | 15.000 | kV | 13.226 | 88.2 | 3-Phase |
| Bus_J61 | Bus | Under Voltage | 15.000 | kV | 13.226 | 88.2 | 3-Phase |
| Bus_J62 | Bus | Under Voltage | 15.000 | kV | 13.226 | 88.2 | 3-Phase |
| Bus_J63 | Bus | Under Voltage | 15.000 | kV | 13.226 | 88.2 | 3-Phase |
| Bus_J64 | Bus | Under Voltage | 15.000 | kV | 13.233 | 88.2 | 3-Phase |
| Bus_J65 | Bus | Under Voltage | 15.000 | kV | 13.374 | 89.2 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J66 | Bus | Under Voltage | 15.000 | kV | 13.351 | 89.0 | 3-Phase |
| Bus_J67 | Bus | Under Voltage | 15.000 | kV | 13.345 | 89.0 | 3-Phase |
| Bus_J68 | Bus | Under Voltage | 15.000 | kV | 13.345 | 89.0 | 3-Phase |
| Bus_J69 | Bus | Under Voltage | 15.000 | kV | 13.342 | 88.9 | 3-Phase |
| Bus_J7 | Bus | Under Voltage | 15.000 | kV | 13.355 | 89.0 | 3-Phase |
| Bus_J70 | Bus | Under Voltage | 15.000 | kV | 13.342 | 88.9 | 3-Phase |
| Bus_J71 | Bus | Under Voltage | 15.000 | kV | 13.342 | 88.9 | 3-Phase |
| Bus_J72 | Bus | Under Voltage | 15.000 | kV | 13.341 | 88.9 | 3-Phase |
| Bus_J73 | Bus | Under Voltage | 15.000 | kV | 13.334 | 88.9 | 3-Phase |
| Bus_J74 | Bus | Under Voltage | 15.000 | kV | 13.334 | 88.9 | 3-Phase |
| Bus_J75 | Bus | Under Voltage | 15.000 | kV | 13.329 | 88.9 | 3-Phase |
| Bus_J76 | Bus | Under Voltage | 15.000 | kV | 13.328 | 88.9 | 3-Phase |
| Bus_J77 | Bus | Under Voltage | 15.000 | kV | 13.326 | 88.8 | 3-Phase |
| Bus_J78 | Bus | Under Voltage | 15.000 | kV | 13.326 | 88.8 | 3-Phase |
| Bus_J79 | Bus | Under Voltage | 15.000 | kV | 13.326 | 88.8 | 3-Phase |
| Bus_J8 | Bus | Under Voltage | 15.000 | kV | 13.355 | 89.0 | 3-Phase |
| Bus_J80 | Bus | Under Voltage | 15.000 | kV | 13.326 | 88.8 | 3-Phase |
| Bus_J81 | Bus | Under Voltage | 15.000 | kV | 13.326 | 88.8 | 3-Phase |
| Bus_J82 | Bus | Under Voltage | 15.000 | kV | 13.323 | 88.8 | 3-Phase |
| Bus_J83 | Bus | Under Voltage | 15.000 | kV | 13.319 | 88.8 | 3-Phase |
| Bus_J84 | Bus | Under Voltage | 15.000 | kV | 13.318 | 88.8 | 3-Phase |
| Bus_J85 | Bus | Under Voltage | 15.000 | kV | 13.318 | 88.8 | 3-Phase |
| Bus_J86 | Bus | Under Voltage | 15.000 | kV | 13.317 | 88.8 | 3-Phase |
| Bus_J87 | Bus | Under Voltage | 15.000 | kV | 13.318 | 88.8 | 3-Phase |
| Bus_J88 | Bus | Under Voltage | 15.000 | kV | 13.314 | 88.8 | 3-Phase |
| Bus_J89 | Bus | Under Voltage | 15.000 | kV | 13.314 | 88.8 | 3-Phase |
| Bus_J9 | Bus | Under Voltage | 15.000 | kV | 13.354 | 89.0 | 3-Phase |
| Bus_J90 | Bus | Under Voltage | 15.000 | kV | 13.310 | 88.7 | 3-Phase |
| Bus_J91 | Bus | Under Voltage | 15.000 | kV | 13.311 | 88.7 | 3-Phase |
| Bus_J92 | Bus | Under Voltage | 15.000 | kV | 13.306 | 88.7 | 3-Phase |
| Bus_J93 | Bus | Under Voltage | 15.000 | kV | 13.306 | 88.7 | 3-Phase |
| Bus_J94 | Bus | Under Voltage | 15.000 | kV | 13.305 | 88.7 | 3-Phase |
| Bus_J95 | Bus | Under Voltage | 15.000 | kV | 13.302 | 88.7 | 3-Phase |
| Bus_J96 | Bus | Under Voltage | 15.000 | kV | 13.374 | 89.2 | 3-Phase |
| Bus_J97 | Bus | Under Voltage | 15.000 | kV | 13.333 | 88.9 | 3-Phase |
| Bus_J98 | Bus | Under Voltage | 15.000 | kV | 13.315 | 88.8 | 3-Phase |
| Bus_J99 | Bus | Under Voltage | 15.000 | kV | 13.314 | 88.8 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Edge 48 | Line | Overload | 120.82 | Amp | 153.335 | 126.9 | 3-Phase |
| Line 1-SWS-5-OHL-2 | Line | Overload | 224.76 | Amp | 267.490 | 119.0 | 3-Phase |

## *A3: Operating Voltage of Line 1 after OCP*

| Bus ID | Nominal kV | Bus Type | Voltage Improved- OCP (%) | Voltage Improved- OCP- after 10 Years (%) |
|---|---|---|---|---|
| Bus116 | 15 | Load | 100.04 | 99.77 |
| Bus117 | 15 | Load | 100.04 | 99.77 |
| Bus1670 | 15 | Load | 100.03 | 99.74 |
| Bus_J2 | 15 | Load | 95.19 | 85.51 |
| Bus_J3 | 15 | Load | 95.12 | 85.31 |
| Bus_J4 | 15 | Load | 95.12 | 85.3 |
| Bus_J5 | 15 | Load | 95.09 | 85.24 |
| Bus_J6 | 15 | Load | 95.09 | 85.24 |
| Bus_J7 | 15 | Load | 95.03 | 85.1 |
| Bus_J8 | 15 | Load | 95.03 | 85.1 |
| Bus_J9 | 15 | Load | 95.03 | 85.1 |
| Bus_J10 | 15 | Load | 95.03 | 85.1 |
| Bus_J11 | 15 | Load | 95.01 | 85.04 |
| Bus_J12 | 15 | Load | 94.95 | 84.89 |
| Bus_J13 | 15 | Load | 94.84 | 84.68 |
| Bus_J14 | 15 | Load | 94.83 | 84.67 |
| Bus_J15 | 15 | Load | 94.65 | 84.34 |
| Bus_J16 | 15 | Load | 94.94 | 84.86 |
| Bus_J17 | 15 | Load | 94.94 | 84.86 |
| Bus_J18 | 15 | Load | 94.93 | 84.8 |
| Bus_J19 | 15 | Load | 94.93 | 84.8 |
| Bus_J20 | 15 | Load | 94.91 | 84.75 |
| Bus_J21 | 15 | Load | 94.9 | 84.75 |
| Bus_J22 | 15 | Load | 94.83 | 84.62 |
| Bus_J23 | 15 | Load | 94.68 | 84.33 |
| Bus_J24 | 15 | Load | 94.57 | 84.12 |
| Bus_J25 | 15 | Load | 94.57 | 84.12 |
| Bus_J26 | 15 | Load | 94.42 | 83.84 |
| Bus_J27 | 15 | Load | 94.42 | 83.84 |
| Bus_J28 | 15 | Load | 94.41 | 83.82 |
| Bus_J29 | 15 | Load | 94.4 | 83.81 |
| Bus_J30 | 15 | Load | 94.38 | 83.76 |
| Bus_J31 | 15 | Load | 94.37 | 83.74 |
| Bus_J32 | 15 | Load | 94.36 | 83.73 |
| Bus_J33 | 15 | Load | 94.36 | 83.73 |
| Bus_J34 | 15 | Load | 94.37 | 83.75 |
| Bus_J35 | 15 | Load | 94.37 | 83.74 |
| Bus_J36 | 15 | Load | 94.35 | 83.72 |
| Bus_J37 | 15 | Load | 94.51 | 84.06 |
| Bus_J38 | 15 | Load | 94.5 | 84.06 |
| Bus_J39 | 15 | Load | 94.5 | 84.05 |
| Bus_J40 | 15 | Load | 94.5 | 84.05 |

| | | | | |
|---|---|---|---|---|
| Bus_J41 | 15 | Load | 94.5 | 84.05 |
| Bus_J42 | 15 | Load | 94.38 | 83.82 |
| Bus_J43 | 15 | Load | 94.37 | 83.81 |
| Bus_J44 | 15 | Load | 94.35 | 83.78 |
| Bus_J45 | 15 | Load | 94.35 | 83.78 |
| Bus_J46 | 15 | Load | 94.34 | 83.75 |
| Bus_J47 | 15 | Load | 94.26 | 83.6 |
| Bus_J48 | 15 | Load | 94.25 | 83.59 |
| Bus_J49 | 15 | Load | 94.22 | 83.53 |
| Bus_J50 | 15 | Load | 94.22 | 83.52 |
| Bus_J51 | 15 | Load | 94.2 | 83.49 |
| Bus_J52 | 15 | Load | 94.2 | 83.48 |
| Bus_J53 | 15 | Load | 94.19 | 83.46 |
| Bus_J54 | 15 | Load | 94.18 | 83.45 |
| Bus_J55 | 15 | Load | 94.18 | 83.45 |
| Bus_J56 | 15 | Load | 94.18 | 83.45 |
| Bus_J57 | 15 | Load | 94.18 | 83.45 |
| Bus_J58 | 15 | Load | 94.18 | 83.45 |
| Bus_J59 | 15 | Load | 94.18 | 83.45 |
| Bus_J60 | 15 | Load | 94.31 | 83.69 |
| Bus_J61 | 15 | Load | 94.3 | 83.68 |
| Bus_J62 | 15 | Load | 94.31 | 83.69 |
| Bus_J63 | 15 | Load | 94.3 | 83.68 |
| Bus_J64 | 15 | Load | 94.35 | 83.76 |
| Bus_J65 | 15 | Load | 95.11 | 85.29 |
| Bus_J66 | 15 | Load | 95.01 | 85.06 |
| Bus_J67 | 15 | Load | 94.99 | 85.01 |
| Bus_J68 | 15 | Load | 94.99 | 85.01 |
| Bus_J69 | 15 | Load | 94.97 | 84.98 |
| Bus_J70 | 15 | Load | 94.97 | 84.97 |
| Bus_J71 | 15 | Load | 94.97 | 84.97 |
| Bus_J72 | 15 | Load | 94.97 | 84.97 |
| Bus_J73 | 15 | Load | 94.94 | 84.9 |
| Bus_J74 | 15 | Load | 94.94 | 84.9 |
| Bus_J75 | 15 | Load | 94.91 | 84.84 |
| Bus_J76 | 15 | Load | 94.91 | 84.84 |
| Bus_J77 | 15 | Load | 94.9 | 84.82 |
| Bus_J78 | 15 | Load | 94.9 | 84.82 |
| Bus_J79 | 15 | Load | 94.9 | 84.82 |
| Bus_J80 | 15 | Load | 94.9 | 84.82 |
| Bus_J81 | 15 | Load | 94.9 | 84.82 |
| Bus_J82 | 15 | Load | 94.89 | 84.8 |
| Bus_J83 | 15 | Load | 94.88 | 84.76 |
| Bus_J84 | 15 | Load | 94.88 | 84.76 |
| Bus_J85 | 15 | Load | 94.88 | 84.76 |
| Bus_J86 | 15 | Load | 94.87 | 84.74 |
| Bus_J87 | 15 | Load | 94.87 | 84.74 |
| Bus_J88 | 15 | Load | 94.85 | 84.7 |
| Bus_J89 | 15 | Load | 94.85 | 84.7 |
| Bus_J90 | 15 | Load | 94.83 | 84.66 |

| | | | | |
|---|---|---|---|---|
| Bus_J91 | 15 | Load | 94.83 | 84.67 |
| Bus_J92 | 15 | Load | 94.8 | 84.62 |
| Bus_J93 | 15 | Load | 94.8 | 84.62 |
| Bus_J94 | 15 | Load | 94.79 | 84.6 |
| Bus_J95 | 15 | Load | 94.77 | 84.56 |
| Bus_J96 | 15 | Load | 95.11 | 85.29 |
| Bus_J97 | 15 | Load | 94.93 | 84.89 |
| Bus_J98 | 15 | Load | 94.84 | 84.7 |
| Bus_J99 | 15 | Load | 94.84 | 84.69 |
| Bus_J100 | 15 | Load | 94.83 | 84.67 |
| Bus_J101 | 15 | Load | 94.82 | 84.66 |
| Bus_J102 | 15 | Load | 94.83 | 84.66 |
| Bus_J103 | 15 | Load | 94.83 | 84.66 |
| Bus_J104 | 15 | Load | 94.81 | 84.64 |
| Bus_J105 | 15 | Load | 94.76 | 84.54 |
| Bus_J106 | 15 | Load | 94.76 | 84.53 |
| Bus_J107 | 15 | Load | 94.81 | 84.64 |
| Bus_J108 | 15 | Load | 94.63 | 84.25 |
| Bus_J109 | 15 | Load | 94.62 | 84.24 |
| Bus_J110 | 15 | Load | 94.59 | 84.17 |
| Bus_J111 | 15 | Load | 94.59 | 84.18 |
| Bus_J112 | 15 | Load | 94.54 | 84.06 |
| Bus_J113 | 15 | Load | 94.46 | 83.9 |
| Bus_J114 | 15 | Load | 94.45 | 83.88 |
| Bus_J115 | 15 | Load | 94.37 | 83.7 |
| Bus_J116 | 15 | Load | 94.36 | 83.69 |
| Bus_J117 | 15 | Load | 94.36 | 83.69 |
| Bus_J118 | 15 | Load | 94.36 | 83.69 |
| Bus_J119 | 15 | Load | 94.33 | 83.61 |
| Bus_J120 | 15 | Load | 94.33 | 83.61 |
| Bus_J121 | 15 | Load | 94.3 | 83.56 |
| Bus_J122 | 15 | Load | 94.3 | 83.55 |
| Bus_J123 | 15 | Load | 94.3 | 83.55 |
| Bus_J124 | 15 | Load | 94.3 | 83.54 |
| Bus_J125 | 15 | Load | 94.29 | 83.54 |
| Bus_J126 | 15 | Load | 94.27 | 83.5 |
| Bus_J127 | 15 | Load | 94.27 | 83.5 |
| Bus_J128 | 15 | Load | 94.28 | 83.52 |
| Bus_J129 | 15 | Load | 94.27 | 83.51 |
| Bus_J131 | 15 | Load | 97.8 | 92.27 |
| Bus_J132 | 15 | Load | 94.89 | 84.79 |
| Bus_Junction1 | 15 | Load | 100.02 | 99.73 |

### *A3.1: Alert Report of Line 1 after OCP after 10 Years*

| Device ID | Type | Condition | Rating (kV) | Unit | Operating Voltage | % of Operating Voltage | Phase |
|---|---|---|---|---|---|---|---|
| Bus_J10 | Bus | Under Voltage | 15.00 | kV | 12.765 | 85.1 | 3-Phase |
| Bus_J100 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J101 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J102 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J103 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J104 | Bus | Under Voltage | 15.00 | kV | 12.695 | 84.6 | 3-Phase |
| Bus_J105 | Bus | Under Voltage | 15.00 | kV | 12.680 | 84.5 | 3-Phase |
| Bus_J106 | Bus | Under Voltage | 15.00 | kV | 12.680 | 84.5 | 3-Phase |
| Bus_J107 | Bus | Under Voltage | 15.00 | kV | 12.695 | 84.6 | 3-Phase |
| Bus_J108 | Bus | Under Voltage | 15.00 | kV | 12.637 | 84.2 | 3-Phase |
| Bus_J109 | Bus | Under Voltage | 15.00 | kV | 12.636 | 84.2 | 3-Phase |
| Bus_J11 | Bus | Under Voltage | 15.00 | kV | 12.756 | 85.0 | 3-Phase |
| Bus_J110 | Bus | Under Voltage | 15.00 | kV | 12.626 | 84.2 | 3-Phase |
| Bus_J111 | Bus | Under Voltage | 15.00 | kV | 12.627 | 84.2 | 3-Phase |
| Bus_J112 | Bus | Under Voltage | 15.00 | kV | 12.609 | 84.1 | 3-Phase |
| Bus_J113 | Bus | Under Voltage | 15.00 | kV | 12.586 | 83.9 | 3-Phase |
| Bus_J114 | Bus | Under Voltage | 15.00 | kV | 12.582 | 83.9 | 3-Phase |
| Bus_J115 | Bus | Under Voltage | 15.00 | kV | 12.555 | 83.7 | 3-Phase |
| Bus_J116 | Bus | Under Voltage | 15.00 | kV | 12.554 | 83.7 | 3-Phase |
| Bus_J117 | Bus | Under Voltage | 15.00 | kV | 12.554 | 83.7 | 3-Phase |
| Bus_J118 | Bus | Under Voltage | 15.00 | kV | 12.554 | 83.7 | 3-Phase |
| Bus_J119 | Bus | Under Voltage | 15.00 | kV | 12.542 | 83.6 | 3-Phase |
| Bus_J12 | Bus | Under Voltage | 15.00 | kV | 12.734 | 84.9 | 3-Phase |
| Bus_J120 | Bus | Under Voltage | 15.00 | kV | 12.542 | 83.6 | 3-Phase |
| Bus_J121 | Bus | Under Voltage | 15.00 | kV | 12.534 | 83.6 | 3-Phase |
| Bus_J122 | Bus | Under Voltage | 15.00 | kV | 12.532 | 83.5 | 3-Phase |
| Bus_J123 | Bus | Under Voltage | 15.00 | kV | 12.532 | 83.5 | 3-Phase |
| Bus_J124 | Bus | Under Voltage | 15.00 | kV | 12.531 | 83.5 | 3-Phase |
| Bus_J125 | Bus | Under Voltage | 15.00 | kV | 12.531 | 83.5 | 3-Phase |
| Bus_J126 | Bus | Under Voltage | 15.00 | kV | 12.525 | 83.5 | 3-Phase |
| Bus_J127 | Bus | Under Voltage | 15.00 | kV | 12.524 | 83.5 | 3-Phase |
| Bus_J128 | Bus | Under Voltage | 15.00 | kV | 12.528 | 83.5 | 3-Phase |
| Bus_J129 | Bus | Under Voltage | 15.00 | kV | 12.526 | 83.5 | 3-Phase |
| Bus_J13 | Bus | Under Voltage | 15.00 | kV | 12.703 | 84.7 | 3-Phase |

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|---|---|---|---|---|---|---|---|
| Bus_J132 | Bus | Under Voltage | 15.00 | kV | 12.719 | 84.8 | 3-Phase |
| Bus_J14 | Bus | Under Voltage | 15.00 | kV | 12.701 | 84.7 | 3-Phase |
| Bus_J15 | Bus | Under Voltage | 15.00 | kV | 12.651 | 84.3 | 3-Phase |
| Bus_J16 | Bus | Under Voltage | 15.00 | kV | 12.730 | 84.9 | 3-Phase |
| Bus_J17 | Bus | Under Voltage | 15.00 | kV | 12.730 | 84.9 | 3-Phase |
| Bus_J18 | Bus | Under Voltage | 15.00 | kV | 12.720 | 84.8 | 3-Phase |
| Bus_J19 | Bus | Under Voltage | 15.00 | kV | 12.720 | 84.8 | 3-Phase |
| Bus_J2 | Bus | Under Voltage | 15.00 | kV | 12.827 | 85.5 | 3-Phase |
| Bus_J20 | Bus | Under Voltage | 15.00 | kV | 12.712 | 84.7 | 3-Phase |
| Bus_J21 | Bus | Under Voltage | 15.00 | kV | 12.712 | 84.7 | 3-Phase |
| Bus_J22 | Bus | Under Voltage | 15.00 | kV | 12.692 | 84.6 | 3-Phase |
| Bus_J23 | Bus | Under Voltage | 15.00 | kV | 12.649 | 84.3 | 3-Phase |
| Bus_J24 | Bus | Under Voltage | 15.00 | kV | 12.618 | 84.1 | 3-Phase |
| Bus_J25 | Bus | Under Voltage | 15.00 | kV | 12.618 | 84.1 | 3-Phase |
| Bus_J26 | Bus | Under Voltage | 15.00 | kV | 12.576 | 83.8 | 3-Phase |
| Bus_J27 | Bus | Under Voltage | 15.00 | kV | 12.576 | 83.8 | 3-Phase |
| Bus_J28 | Bus | Under Voltage | 15.00 | kV | 12.573 | 83.8 | 3-Phase |
| Bus_J29 | Bus | Under Voltage | 15.00 | kV | 12.571 | 83.8 | 3-Phase |
| Bus_J3 | Bus | Under Voltage | 15.00 | kV | 12.797 | 85.3 | 3-Phase |
| Bus_J30 | Bus | Under Voltage | 15.00 | kV | 12.564 | 83.8 | 3-Phase |
| Bus_J31 | Bus | Under Voltage | 15.00 | kV | 12.561 | 83.7 | 3-Phase |
| Bus_J32 | Bus | Under Voltage | 15.00 | kV | 12.559 | 83.7 | 3-Phase |
| Bus_J33 | Bus | Under Voltage | 15.00 | kV | 12.560 | 83.7 | 3-Phase |
| Bus_J34 | Bus | Under Voltage | 15.00 | kV | 12.562 | 83.7 | 3-Phase |
| Bus_J35 | Bus | Under Voltage | 15.00 | kV | 12.562 | 83.7 | 3-Phase |
| Bus_J36 | Bus | Under Voltage | 15.00 | kV | 12.557 | 83.7 | 3-Phase |
| Bus_J37 | Bus | Under Voltage | 15.00 | kV | 12.610 | 84.1 | 3-Phase |
| Bus_J38 | Bus | Under Voltage | 15.00 | kV | 12.609 | 84.1 | 3-Phase |
| Bus_J39 | Bus | Under Voltage | 15.00 | kV | 12.608 | 84.1 | 3-Phase |
| Bus_J4 | Bus | Under Voltage | 15.00 | kV | 12.795 | 85.3 | 3-Phase |
| Bus_J40 | Bus | Under Voltage | 15.00 | kV | 12.608 | 84.1 | 3-Phase |
| Bus_J41 | Bus | Under Voltage | 15.00 | kV | 12.607 | 84.0 | 3-Phase |
| Bus_J42 | Bus | Under Voltage | 15.00 | kV | 12.574 | 83.8 | 3-Phase |
| Bus_J43 | Bus | Under Voltage | 15.00 | kV | 12.571 | 83.8 | 3-Phase |
| Bus_J44 | Bus | Under Voltage | 15.00 | kV | 12.567 | 83.8 | 3-Phase |
| Bus_J45 | Bus | Under Voltage | 15.00 | kV | 12.567 | 83.8 | 3-Phase |
| Bus_J46 | Bus | Under Voltage | 15.00 | kV | 12.562 | 83.7 | 3-Phase |

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|---|---|---|---|---|---|---|---|
| Bus_J47 | Bus | Under Voltage | 15.00 | kV | 12.540 | 83.6 | 3-Phase |
| Bus_J48 | Bus | Under Voltage | 15.00 | kV | 12.538 | 83.6 | 3-Phase |
| Bus_J49 | Bus | Under Voltage | 15.00 | kV | 12.529 | 83.5 | 3-Phase |
| Bus_J5 | Bus | Under Voltage | 15.00 | kV | 12.787 | 85.2 | 3-Phase |
| Bus_J50 | Bus | Under Voltage | 15.00 | kV | 12.529 | 83.5 | 3-Phase |
| Bus_J51 | Bus | Under Voltage | 15.00 | kV | 12.524 | 83.5 | 3-Phase |
| Bus_J52 | Bus | Under Voltage | 15.00 | kV | 12.522 | 83.5 | 3-Phase |
| Bus_J53 | Bus | Under Voltage | 15.00 | kV | 12.519 | 83.5 | 3-Phase |
| Bus_J54 | Bus | Under Voltage | 15.00 | kV | 12.518 | 83.5 | 3-Phase |
| Bus_J55 | Bus | Under Voltage | 15.00 | kV | 12.518 | 83.5 | 3-Phase |
| Bus_J56 | Bus | Under Voltage | 15.00 | kV | 12.518 | 83.5 | 3-Phase |
| Bus_J57 | Bus | Under Voltage | 15.00 | kV | 12.517 | 83.4 | 3-Phase |
| Bus_J58 | Bus | Under Voltage | 15.00 | kV | 12.518 | 83.5 | 3-Phase |
| Bus_J59 | Bus | Under Voltage | 15.00 | kV | 12.518 | 83.5 | 3-Phase |
| Bus_J6 | Bus | Under Voltage | 15.00 | kV | 12.787 | 85.2 | 3-Phase |
| Bus_J60 | Bus | Under Voltage | 15.00 | kV | 12.554 | 83.7 | 3-Phase |
| Bus_J61 | Bus | Under Voltage | 15.00 | kV | 12.553 | 83.7 | 3-Phase |
| Bus_J62 | Bus | Under Voltage | 15.00 | kV | 12.554 | 83.7 | 3-Phase |
| Bus_J63 | Bus | Under Voltage | 15.00 | kV | 12.552 | 83.7 | 3-Phase |
| Bus_J64 | Bus | Under Voltage | 15.00 | kV | 12.564 | 83.8 | 3-Phase |
| Bus_J65 | Bus | Under Voltage | 15.00 | kV | 12.793 | 85.3 | 3-Phase |
| Bus_J66 | Bus | Under Voltage | 15.00 | kV | 12.759 | 85.1 | 3-Phase |
| Bus_J67 | Bus | Under Voltage | 15.00 | kV | 12.752 | 85.0 | 3-Phase |
| Bus_J68 | Bus | Under Voltage | 15.00 | kV | 12.751 | 85.0 | 3-Phase |
| Bus_J69 | Bus | Under Voltage | 15.00 | kV | 12.747 | 85.0 | 3-Phase |
| Bus_J7 | Bus | Under Voltage | 15.00 | kV | 12.766 | 85.1 | 3-Phase |
| Bus_J70 | Bus | Under Voltage | 15.00 | kV | 12.746 | 85.0 | 3-Phase |
| Bus_J71 | Bus | Under Voltage | 15.00 | kV | 12.746 | 85.0 | 3-Phase |
| Bus_J72 | Bus | Under Voltage | 15.00 | kV | 12.745 | 85.0 | 3-Phase |
| Bus_J73 | Bus | Under Voltage | 15.00 | kV | 12.735 | 84.9 | 3-Phase |
| Bus_J74 | Bus | Under Voltage | 15.00 | kV | 12.735 | 84.9 | 3-Phase |
| Bus_J75 | Bus | Under Voltage | 15.00 | kV | 12.727 | 84.8 | 3-Phase |
| Bus_J76 | Bus | Under Voltage | 15.00 | kV | 12.725 | 84.8 | 3-Phase |
| Bus_J77 | Bus | Under Voltage | 15.00 | kV | 12.723 | 84.8 | 3-Phase |
| Bus_J78 | Bus | Under Voltage | 15.00 | kV | 12.723 | 84.8 | 3-Phase |
| Bus_J79 | Bus | Under Voltage | 15.00 | kV | 12.722 | 84.8 | 3-Phase |
| Bus_J8 | Bus | Under Voltage | 15.00 | kV | 12.765 | 85.1 | 3-Phase |

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|---|---|---|---|---|---|---|---|
| Bus_J80 | Bus | Under Voltage | 15.00 | kV | 12.723 | 84.8 | 3-Phase |
| Bus_J81 | Bus | Under Voltage | 15.00 | kV | 12.723 | 84.8 | 3-Phase |
| Bus_J82 | Bus | Under Voltage | 15.00 | kV | 12.720 | 84.8 | 3-Phase |
| Bus_J83 | Bus | Under Voltage | 15.00 | kV | 12.715 | 84.8 | 3-Phase |
| Bus_J84 | Bus | Under Voltage | 15.00 | kV | 12.714 | 84.8 | 3-Phase |
| Bus_J85 | Bus | Under Voltage | 15.00 | kV | 12.714 | 84.8 | 3-Phase |
| Bus_J86 | Bus | Under Voltage | 15.00 | kV | 12.712 | 84.7 | 3-Phase |
| Bus_J87 | Bus | Under Voltage | 15.00 | kV | 12.712 | 84.7 | 3-Phase |
| Bus_J88 | Bus | Under Voltage | 15.00 | kV | 12.706 | 84.7 | 3-Phase |
| Bus_J89 | Bus | Under Voltage | 15.00 | kV | 12.705 | 84.7 | 3-Phase |
| Bus_J9 | Bus | Under Voltage | 15.00 | kV | 12.765 | 85.1 | 3-Phase |
| Bus_J90 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J91 | Bus | Under Voltage | 15.00 | kV | 12.700 | 84.7 | 3-Phase |
| Bus_J92 | Bus | Under Voltage | 15.00 | kV | 12.693 | 84.6 | 3-Phase |
| Bus_J93 | Bus | Under Voltage | 15.00 | kV | 12.693 | 84.6 | 3-Phase |
| Bus_J94 | Bus | Under Voltage | 15.00 | kV | 12.690 | 84.6 | 3-Phase |
| Bus_J95 | Bus | Under Voltage | 15.00 | kV | 12.685 | 84.6 | 3-Phase |
| Bus_J96 | Bus | Under Voltage | 15.00 | kV | 12.793 | 85.3 | 3-Phase |
| Bus_J97 | Bus | Under Voltage | 15.00 | kV | 12.733 | 84.9 | 3-Phase |
| Bus_J98 | Bus | Under Voltage | 15.00 | kV | 12.705 | 84.7 | 3-Phase |
| Bus_J99 | Bus | Under Voltage | 15.00 | kV | 12.704 | 84.7 | 3-Phase |
| Edge47 | Line | Overload | 120.82 | Amp | 146.821 | 121.5 | 3-Phase |
| Edge48 | Line | Overload | 120.82 | Amp | 235.694 | 195.1 | 3-Phase |
| Line 1-SWS-5-OHL-2 | Line | Overload | 224.76 | Amp | 415.070 | 184.7 | 3-Phase |
| Edge56 | Line | Overload | 120.82 | Amp | 139.444 | 115.4 | 3-Phase |

### *A4: Operating Voltage of Line 1 after Conductor Upgrading*

| **Bus ID** | **Nominal kV** | **Bus Type** | **Operating Voltage-after 10 Years (%)** | **Operating Voltage (%)** |
|---|---|---|---|---|
| Bus115 | 132 | SWNG | 100 | 100 |
| Bus116 | 15 | Load | 99.79 | 99.86 |
| Bus117 | 15 | Load | 99.79 | 99.86 |
| Bus1670 | 15 | Load | 99.76 | 99.84 |
| Bus_J2 | 15 | Load | 86.07 | 92.18 |
| Bus_J3 | 15 | Load | 85.94 | 92.1 |
| Bus_J4 | 15 | Load | 85.92 | 92.09 |
| Bus_J5 | 15 | Load | 85.86 | 92.05 |
| Bus_J6 | 15 | Load | 85.85 | 92.05 |
| Bus_J7 | 15 | Load | 85.69 | 91.96 |
| Bus_J8 | 15 | Load | 85.68 | 91.95 |
| Bus_J9 | 15 | Load | 85.68 | 91.95 |

| | | | | |
|---|---|---|---|---|
| Bus_J10 | 15 | Load | 85.68 | 91.95 |
| Bus_J11 | 15 | Load | 85.61 | 91.91 |
| Bus_J12 | 15 | Load | 85.43 | 91.81 |
| Bus_J13 | 15 | Load | 85.22 | 91.69 |
| Bus_J14 | 15 | Load | 85.21 | 91.68 |
| Bus_J15 | 15 | Load | 84.88 | 91.49 |
| Bus_J16 | 15 | Load | 85.38 | 91.78 |
| Bus_J17 | 15 | Load | 85.38 | 91.78 |
| Bus_J18 | 15 | Load | 85.28 | 91.72 |
| Bus_J19 | 15 | Load | 85.28 | 91.72 |
| Bus_J20 | 15 | Load | 85.22 | 91.69 |
| Bus_J21 | 15 | Load | 85.22 | 91.69 |
| Bus_J22 | 15 | Load | 85.09 | 91.61 |
| Bus_J23 | 15 | Load | 84.8 | 91.44 |
| Bus_J24 | 15 | Load | 84.6 | 91.33 |
| Bus_J25 | 15 | Load | 84.59 | 91.33 |
| Bus_J26 | 15 | Load | 84.32 | 91.17 |
| Bus_J27 | 15 | Load | 84.31 | 91.16 |
| Bus_J28 | 15 | Load | 84.29 | 91.15 |
| Bus_J29 | 15 | Load | 84.29 | 91.15 |
| Bus_J30 | 15 | Load | 84.24 | 91.12 |
| Bus_J31 | 15 | Load | 84.22 | 91.11 |
| Bus_J32 | 15 | Load | 84.21 | 91.1 |
| Bus_J33 | 15 | Load | 84.21 | 91.1 |
| Bus_J34 | 15 | Load | 84.23 | 91.11 |
| Bus_J35 | 15 | Load | 84.22 | 91.11 |
| Bus_J36 | 15 | Load | 84.19 | 91.09 |
| Bus_J37 | 15 | Load | 84.61 | 91.33 |
| Bus_J38 | 15 | Load | 84.6 | 91.33 |
| Bus_J39 | 15 | Load | 84.59 | 91.33 |
| Bus_J40 | 15 | Load | 84.59 | 91.33 |
| Bus_J41 | 15 | Load | 84.59 | 91.32 |
| Bus_J42 | 15 | Load | 84.37 | 91.19 |
| Bus_J43 | 15 | Load | 84.35 | 91.19 |
| Bus_J44 | 15 | Load | 84.32 | 91.17 |
| Bus_J45 | 15 | Load | 84.32 | 91.17 |
| Bus_J46 | 15 | Load | 84.29 | 91.15 |
| Bus_J47 | 15 | Load | 84.14 | 91.07 |
| Bus_J48 | 15 | Load | 84.13 | 91.06 |
| Bus_J49 | 15 | Load | 84.07 | 91.02 |
| Bus_J50 | 15 | Load | 84.07 | 91.02 |
| Bus_J51 | 15 | Load | 84.04 | 91 |
| Bus_J52 | 15 | Load | 84.03 | 91 |
| Bus_J53 | 15 | Load | 84.01 | 90.99 |
| Bus_J54 | 15 | Load | 84 | 90.98 |
| Bus_J55 | 15 | Load | 84 | 90.98 |
| Bus_J56 | 15 | Load | 84 | 90.98 |
| Bus_J57 | 15 | Load | 83.99 | 90.98 |
| Bus_J58 | 15 | Load | 83.99 | 90.98 |
| Bus_J59 | 15 | Load | 84 | 90.98 |

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|---|---|---|---|---|
| Bus_J60 | 15 | Load | 84.24 | 91.12 |
| Bus_J61 | 15 | Load | 84.23 | 91.11 |
| Bus_J62 | 15 | Load | 84.23 | 91.12 |
| Bus_J63 | 15 | Load | 84.23 | 91.11 |
| Bus_J64 | 15 | Load | 84.31 | 91.16 |
| Bus_J65 | 15 | Load | 85.9 | 92.08 |
| Bus_J66 | 15 | Load | 85.77 | 92 |
| Bus_J67 | 15 | Load | 85.71 | 91.97 |
| Bus_J68 | 15 | Load | 85.7 | 91.97 |
| Bus_J69 | 15 | Load | 85.67 | 91.95 |
| Bus_J70 | 15 | Load | 85.67 | 91.94 |
| Bus_J71 | 15 | Load | 85.67 | 91.94 |
| Bus_J72 | 15 | Load | 85.66 | 91.94 |
| Bus_J73 | 15 | Load | 85.58 | 91.9 |
| Bus_J74 | 15 | Load | 85.58 | 91.89 |
| Bus_J75 | 15 | Load | 85.52 | 91.86 |
| Bus_J76 | 15 | Load | 85.51 | 91.85 |
| Bus_J77 | 15 | Load | 85.49 | 91.84 |
| Bus_J78 | 15 | Load | 85.49 | 91.84 |
| Bus_J79 | 15 | Load | 85.49 | 91.84 |
| Bus_J80 | 15 | Load | 85.49 | 91.84 |
| Bus_J81 | 15 | Load | 85.49 | 91.84 |
| Bus_J82 | 15 | Load | 85.46 | 91.82 |
| Bus_J83 | 15 | Load | 85.42 | 91.8 |
| Bus_J84 | 15 | Load | 85.41 | 91.79 |
| Bus_J85 | 15 | Load | 85.4 | 91.79 |
| Bus_J86 | 15 | Load | 85.4 | 91.79 |
| Bus_J87 | 15 | Load | 85.4 | 91.79 |
| Bus_J88 | 15 | Load | 85.36 | 91.76 |
| Bus_J89 | 15 | Load | 85.35 | 91.76 |
| Bus_J90 | 15 | Load | 85.32 | 91.74 |
| Bus_J91 | 15 | Load | 85.32 | 91.74 |
| Bus_J92 | 15 | Load | 85.27 | 91.71 |
| Bus_J93 | 15 | Load | 85.27 | 91.71 |
| Bus_J94 | 15 | Load | 85.25 | 91.7 |
| Bus_J95 | 15 | Load | 85.22 | 91.68 |
| Bus_J96 | 15 | Load | 85.9 | 92.08 |
| Bus_J97 | 15 | Load | 85.67 | 91.95 |
| Bus_J98 | 15 | Load | 85.56 | 91.88 |
| Bus_J99 | 15 | Load | 85.56 | 91.88 |
| Bus_J100 | 15 | Load | 85.53 | 91.87 |
| Bus_J101 | 15 | Load | 85.53 | 91.86 |
| Bus_J102 | 15 | Load | 85.52 | 91.86 |
| Bus_J103 | 15 | Load | 85.52 | 91.86 |
| Bus_J104 | 15 | Load | 85.49 | 91.84 |
| Bus_J105 | 15 | Load | 85.38 | 91.78 |
| Bus_J106 | 15 | Load | 85.38 | 91.78 |
| Bus_J107 | 15 | Load | 85.49 | 91.84 |
| Bus_J108 | 15 | Load | 85.07 | 91.6 |
| Bus_J109 | 15 | Load | 85.06 | 91.6 |

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|---|---|---|---|---|
| Bus_J110 | 15 | Load | 84.99 | 91.56 |
| Bus_J111 | 15 | Load | 85 | 91.56 |
| Bus_J112 | 15 | Load | 84.87 | 91.48 |
| Bus_J113 | 15 | Load | 84.7 | 91.38 |
| Bus_J114 | 15 | Load | 84.68 | 91.37 |
| Bus_J115 | 15 | Load | 84.47 | 91.25 |
| Bus_J116 | 15 | Load | 84.46 | 91.25 |
| Bus_J117 | 15 | Load | 84.46 | 91.25 |
| Bus_J118 | 15 | Load | 84.46 | 91.25 |
| Bus_J119 | 15 | Load | 84.38 | 91.2 |
| Bus_J120 | 15 | Load | 84.38 | 91.2 |
| Bus_J121 | 15 | Load | 84.31 | 91.16 |
| Bus_J122 | 15 | Load | 84.3 | 91.15 |
| Bus_J123 | 15 | Load | 84.29 | 91.15 |
| Bus_J124 | 15 | Load | 84.29 | 91.15 |
| Bus_J125 | 15 | Load | 84.29 | 91.15 |
| Bus_J126 | 15 | Load | 84.25 | 91.13 |
| Bus_J127 | 15 | Load | 84.25 | 91.13 |
| Bus_J128 | 15 | Load | 84.27 | 91.14 |
| Bus_J129 | 15 | Load | 84.26 | 91.13 |
| Bus_J131 | 15 | Load | 91.22 | 95.1 |
| Bus_J132 | 15 | Load | 85.33 | 91.75 |
| Bus_Junction1 | 15 | Load | 99.75 | 99.84 |

### *A4.1: Alert Report of Line 1 after Conductor Replacement: after 10 Years*

| Line ID | Type | Condition | Rating | Unit | Operating Voltage (kV) | % of Operating Voltage | Phase |
|---|---|---|---|---|---|---|---|
| Bus_J10 | Bus | Under Voltage | 15.00 | kV | 12.853 | 85.7 | 3-Phase |
| Bus_J100 | Bus | Under Voltage | 15.00 | kV | 12.830 | 85.5 | 3-Phase |
| Bus_J101 | Bus | Under Voltage | 15.00 | kV | 12.829 | 85.5 | 3-Phase |
| Bus_J102 | Bus | Under Voltage | 15.00 | kV | 12.828 | 85.5 | 3-Phase |
| Bus_J103 | Bus | Under Voltage | 15.00 | kV | 12.828 | 85.5 | 3-Phase |
| Bus_J104 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J105 | Bus | Under Voltage | 15.00 | kV | 12.808 | 85.4 | 3-Phase |
| Bus_J106 | Bus | Under Voltage | 15.00 | kV | 12.807 | 85.4 | 3-Phase |
| Bus_J107 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J108 | Bus | Under Voltage | 15.00 | kV | 12.761 | 85.1 | 3-Phase |
| Bus_J109 | Bus | Under Voltage | 15.00 | kV | 12.760 | 85.1 | 3-Phase |
| Bus_J11 | Bus | Under Voltage | 15.00 | kV | 12.842 | 85.6 | 3-Phase |
| Bus_J110 | Bus | Under Voltage | 15.00 | kV | 12.749 | 85.0 | 3-Phase |
| Bus_J111 | Bus | Under Voltage | 15.00 | kV | 12.750 | 85.0 | 3-Phase |
| Bus_J112 | Bus | Under Voltage | 15.00 | kV | 12.730 | 84.9 | 3-Phase |
| Bus_J113 | Bus | Under Voltage | 15.00 | kV | 12.705 | 84.7 | 3-Phase |
| Bus_J114 | Bus | Under Voltage | 15.00 | kV | 12.702 | 84.7 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J115 | Bus | Under Voltage | 15.00 | kV | 12.670 | 84.5 | 3-Phase |
| Bus_J116 | Bus | Under Voltage | 15.00 | kV | 12.670 | 84.5 | 3-Phase |
| Bus_J117 | Bus | Under Voltage | 15.00 | kV | 12.670 | 84.5 | 3-Phase |
| Bus_J118 | Bus | Under Voltage | 15.00 | kV | 12.669 | 84.5 | 3-Phase |
| Bus_J119 | Bus | Under Voltage | 15.00 | kV | 12.657 | 84.4 | 3-Phase |
| Bus_J12 | Bus | Under Voltage | 15.00 | kV | 12.815 | 85.4 | 3-Phase |
| Bus_J120 | Bus | Under Voltage | 15.00 | kV | 12.656 | 84.4 | 3-Phase |
| Bus_J121 | Bus | Under Voltage | 15.00 | kV | 12.647 | 84.3 | 3-Phase |
| Bus_J122 | Bus | Under Voltage | 15.00 | kV | 12.645 | 84.3 | 3-Phase |
| Bus_J123 | Bus | Under Voltage | 15.00 | kV | 12.644 | 84.3 | 3-Phase |
| Bus_J124 | Bus | Under Voltage | 15.00 | kV | 12.644 | 84.3 | 3-Phase |
| Bus_J125 | Bus | Under Voltage | 15.00 | kV | 12.644 | 84.3 | 3-Phase |
| Bus_J126 | Bus | Under Voltage | 15.00 | kV | 12.638 | 84.3 | 3-Phase |
| Bus_J127 | Bus | Under Voltage | 15.00 | kV | 12.638 | 84.3 | 3-Phase |
| Bus_J128 | Bus | Under Voltage | 15.00 | kV | 12.641 | 84.3 | 3-Phase |
| Bus_J129 | Bus | Under Voltage | 15.00 | kV | 12.639 | 84.3 | 3-Phase |
| Bus_J13 | Bus | Under Voltage | 15.00 | kV | 12.784 | 85.2 | 3-Phase |
| Bus_J132 | Bus | Under Voltage | 15.00 | kV | 12.799 | 85.3 | 3-Phase |
| Bus_J14 | Bus | Under Voltage | 15.00 | kV | 12.782 | 85.2 | 3-Phase |
| Bus_J15 | Bus | Under Voltage | 15.00 | kV | 12.732 | 84.9 | 3-Phase |
| Bus_J16 | Bus | Under Voltage | 15.00 | kV | 12.807 | 85.4 | 3-Phase |
| Bus_J17 | Bus | Under Voltage | 15.00 | kV | 12.807 | 85.4 | 3-Phase |
| Bus_J18 | Bus | Under Voltage | 15.00 | kV | 12.792 | 85.3 | 3-Phase |
| Bus_J19 | Bus | Under Voltage | 15.00 | kV | 12.792 | 85.3 | 3-Phase |
| Bus_J2 | Bus | Under Voltage | 15.00 | kV | 12.910 | 86.1 | 3-Phase |
| Bus_J20 | Bus | Under Voltage | 15.00 | kV | 12.783 | 85.2 | 3-Phase |
| Bus_J21 | Bus | Under Voltage | 15.00 | kV | 12.783 | 85.2 | 3-Phase |
| Bus_J22 | Bus | Under Voltage | 15.00 | kV | 12.763 | 85.1 | 3-Phase |
| Bus_J23 | Bus | Under Voltage | 15.00 | kV | 12.720 | 84.8 | 3-Phase |
| Bus_J24 | Bus | Under Voltage | 15.00 | kV | 12.690 | 84.6 | 3-Phase |
| Bus_J25 | Bus | Under Voltage | 15.00 | kV | 12.689 | 84.6 | 3-Phase |
| Bus_J26 | Bus | Under Voltage | 15.00 | kV | 12.648 | 84.3 | 3-Phase |
| Bus_J27 | Bus | Under Voltage | 15.00 | kV | 12.647 | 84.3 | 3-Phase |
| Bus_J28 | Bus | Under Voltage | 15.00 | kV | 12.644 | 84.3 | 3-Phase |
| Bus_J29 | Bus | Under Voltage | 15.00 | kV | 12.643 | 84.3 | 3-Phase |
| Bus_J3 | Bus | Under Voltage | 15.00 | kV | 12.891 | 85.9 | 3-Phase |
| Bus_J30 | Bus | Under Voltage | 15.00 | kV | 12.636 | 84.2 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J31 | Bus | Under Voltage | 15.00 | kV | 12.632 | 84.2 | 3-Phase |
| Bus_J32 | Bus | Under Voltage | 15.00 | kV | 12.631 | 84.2 | 3-Phase |
| Bus_J33 | Bus | Under Voltage | 15.00 | kV | 12.631 | 84.2 | 3-Phase |
| Bus_J34 | Bus | Under Voltage | 15.00 | kV | 12.634 | 84.2 | 3-Phase |
| Bus_J35 | Bus | Under Voltage | 15.00 | kV | 12.633 | 84.2 | 3-Phase |
| Bus_J36 | Bus | Under Voltage | 15.00 | kV | 12.629 | 84.2 | 3-Phase |
| Bus_J37 | Bus | Under Voltage | 15.00 | kV | 12.691 | 84.6 | 3-Phase |
| Bus_J38 | Bus | Under Voltage | 15.00 | kV | 12.690 | 84.6 | 3-Phase |
| Bus_J39 | Bus | Under Voltage | 15.00 | kV | 12.689 | 84.6 | 3-Phase |
| Bus_J4 | Bus | Under Voltage | 15.00 | kV | 12.889 | 85.9 | 3-Phase |
| Bus_J40 | Bus | Under Voltage | 15.00 | kV | 12.689 | 84.6 | 3-Phase |
| Bus_J41 | Bus | Under Voltage | 15.00 | kV | 12.688 | 84.6 | 3-Phase |
| Bus_J42 | Bus | Under Voltage | 15.00 | kV | 12.655 | 84.4 | 3-Phase |
| Bus_J43 | Bus | Under Voltage | 15.00 | kV | 12.653 | 84.4 | 3-Phase |
| Bus_J44 | Bus | Under Voltage | 15.00 | kV | 12.648 | 84.3 | 3-Phase |
| Bus_J45 | Bus | Under Voltage | 15.00 | kV | 12.648 | 84.3 | 3-Phase |
| Bus_J46 | Bus | Under Voltage | 15.00 | kV | 12.644 | 84.3 | 3-Phase |
| Bus_J47 | Bus | Under Voltage | 15.00 | kV | 12.621 | 84.1 | 3-Phase |
| Bus_J48 | Bus | Under Voltage | 15.00 | kV | 12.620 | 84.1 | 3-Phase |
| Bus_J49 | Bus | Under Voltage | 15.00 | kV | 12.611 | 84.1 | 3-Phase |
| Bus_J5 | Bus | Under Voltage | 15.00 | kV | 12.878 | 85.9 | 3-Phase |
| Bus_J50 | Bus | Under Voltage | 15.00 | kV | 12.610 | 84.1 | 3-Phase |
| Bus_J51 | Bus | Under Voltage | 15.00 | kV | 12.605 | 84.0 | 3-Phase |
| Bus_J52 | Bus | Under Voltage | 15.00 | kV | 12.604 | 84.0 | 3-Phase |
| Bus_J53 | Bus | Under Voltage | 15.00 | kV | 12.601 | 84.0 | 3-Phase |
| Bus_J54 | Bus | Under Voltage | 15.00 | kV | 12.600 | 84.0 | 3-Phase |
| Bus_J55 | Bus | Under Voltage | 15.00 | kV | 12.600 | 84.0 | 3-Phase |
| Bus_J56 | Bus | Under Voltage | 15.00 | kV | 12.599 | 84.0 | 3-Phase |
| Bus_J57 | Bus | Under Voltage | 15.00 | kV | 12.599 | 84.0 | 3-Phase |
| Bus_J58 | Bus | Under Voltage | 15.00 | kV | 12.599 | 84.0 | 3-Phase |
| Bus_J59 | Bus | Under Voltage | 15.00 | kV | 12.599 | 84.0 | 3-Phase |
| Bus_J6 | Bus | Under Voltage | 15.00 | kV | 12.878 | 85.9 | 3-Phase |
| Bus_J60 | Bus | Under Voltage | 15.00 | kV | 12.636 | 84.2 | 3-Phase |
| Bus_J61 | Bus | Under Voltage | 15.00 | kV | 12.634 | 84.2 | 3-Phase |
| Bus_J62 | Bus | Under Voltage | 15.00 | kV | 12.635 | 84.2 | 3-Phase |
| Bus_J63 | Bus | Under Voltage | 15.00 | kV | 12.634 | 84.2 | 3-Phase |
| Bus_J64 | Bus | Under Voltage | 15.00 | kV | 12.646 | 84.3 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J65 | Bus | Under Voltage | 15.00 | kV | 12.885 | 85.9 | 3-Phase |
| Bus_J66 | Bus | Under Voltage | 15.00 | kV | 12.866 | 85.8 | 3-Phase |
| Bus_J67 | Bus | Under Voltage | 15.00 | kV | 12.856 | 85.7 | 3-Phase |
| Bus_J68 | Bus | Under Voltage | 15.00 | kV | 12.856 | 85.7 | 3-Phase |
| Bus_J69 | Bus | Under Voltage | 15.00 | kV | 12.851 | 85.7 | 3-Phase |
| Bus_J7 | Bus | Under Voltage | 15.00 | kV | 12.853 | 85.7 | 3-Phase |
| Bus_J70 | Bus | Under Voltage | 15.00 | kV | 12.850 | 85.7 | 3-Phase |
| Bus_J71 | Bus | Under Voltage | 15.00 | kV | 12.850 | 85.7 | 3-Phase |
| Bus_J72 | Bus | Under Voltage | 15.00 | kV | 12.849 | 85.7 | 3-Phase |
| Bus_J73 | Bus | Under Voltage | 15.00 | kV | 12.838 | 85.6 | 3-Phase |
| Bus_J74 | Bus | Under Voltage | 15.00 | kV | 12.837 | 85.6 | 3-Phase |
| Bus_J75 | Bus | Under Voltage | 15.00 | kV | 12.828 | 85.5 | 3-Phase |
| Bus_J76 | Bus | Under Voltage | 15.00 | kV | 12.826 | 85.5 | 3-Phase |
| Bus_J77 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J78 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J79 | Bus | Under Voltage | 15.00 | kV | 12.823 | 85.5 | 3-Phase |
| Bus_J8 | Bus | Under Voltage | 15.00 | kV | 12.853 | 85.7 | 3-Phase |
| Bus_J80 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J81 | Bus | Under Voltage | 15.00 | kV | 12.824 | 85.5 | 3-Phase |
| Bus_J82 | Bus | Under Voltage | 15.00 | kV | 12.819 | 85.5 | 3-Phase |
| Bus_J83 | Bus | Under Voltage | 15.00 | kV | 12.812 | 85.4 | 3-Phase |
| Bus_J84 | Bus | Under Voltage | 15.00 | kV | 12.811 | 85.4 | 3-Phase |
| Bus_J85 | Bus | Under Voltage | 15.00 | kV | 12.810 | 85.4 | 3-Phase |
| Bus_J86 | Bus | Under Voltage | 15.00 | kV | 12.809 | 85.4 | 3-Phase |
| Bus_J87 | Bus | Under Voltage | 15.00 | kV | 12.809 | 85.4 | 3-Phase |
| Bus_J88 | Bus | Under Voltage | 15.00 | kV | 12.803 | 85.4 | 3-Phase |
| Bus_J89 | Bus | Under Voltage | 15.00 | kV | 12.803 | 85.4 | 3-Phase |
| Bus_J9 | Bus | Under Voltage | 15.00 | kV | 12.852 | 85.7 | 3-Phase |
| Bus_J90 | Bus | Under Voltage | 15.00 | kV | 12.797 | 85.3 | 3-Phase |
| Bus_J91 | Bus | Under Voltage | 15.00 | kV | 12.798 | 85.3 | 3-Phase |
| Bus_J92 | Bus | Under Voltage | 15.00 | kV | 12.791 | 85.3 | 3-Phase |
| Bus_J93 | Bus | Under Voltage | 15.00 | kV | 12.791 | 85.3 | 3-Phase |
| Bus_J94 | Bus | Under Voltage | 15.00 | kV | 12.788 | 85.3 | 3-Phase |
| Bus_J95 | Bus | Under Voltage | 15.00 | kV | 12.783 | 85.2 | 3-Phase |
| Bus_J96 | Bus | Under Voltage | 15.00 | kV | 12.885 | 85.9 | 3-Phase |
| Bus_J97 | Bus | Under Voltage | 15.00 | kV | 12.851 | 85.7 | 3-Phase |
| Bus_J98 | Bus | Under Voltage | 15.00 | kV | 12.834 | 85.6 | 3-Phase |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bus_J99 | Bus | Under Voltage | 15.00 | kV | 12.834 | 85.6 | 3-Phase |

### *A5: Operating Voltage of Line 1 after OCP and Conductor Upgrading*

| Bus ID | Nominal kV | Bus Type | Operating Voltage After 10 Years (%) | Operating Voltage (%) |
|---|---|---|---|---|
| Bus115 | 132 | SWNG | 100 | 100 |
| Bus116 | 15 | Load | 99.87 | 100.07 |
| Bus117 | 15 | Load | 99.87 | 100.07 |
| Bus1670 | 15 | Load | 99.85 | 100.06 |
| Bus_J2 | 15 | Load | 91.25 | 98.09 |
| Bus_J3 | 15 | Load | 91.16 | 98.06 |
| Bus_J4 | 15 | Load | 91.15 | 98.05 |
| Bus_J5 | 15 | Load | 91.1 | 98.03 |
| Bus_J6 | 15 | Load | 91.1 | 98.03 |
| Bus_J7 | 15 | Load | 90.97 | 97.97 |
| Bus_J8 | 15 | Load | 90.96 | 97.97 |
| Bus_J9 | 15 | Load | 90.96 | 97.97 |
| Bus_J10 | 15 | Load | 90.97 | 97.97 |
| Bus_J11 | 15 | Load | 90.91 | 97.94 |
| Bus_J12 | 15 | Load | 90.77 | 97.89 |
| Bus_J13 | 15 | Load | 90.57 | 97.77 |
| Bus_J14 | 15 | Load | 90.56 | 97.77 |
| Bus_J15 | 15 | Load | 90.25 | 97.59 |
| Bus_J16 | 15 | Load | 90.75 | 97.88 |
| Bus_J17 | 15 | Load | 90.75 | 97.88 |
| Bus_J18 | 15 | Load | 90.67 | 97.84 |
| Bus_J19 | 15 | Load | 90.66 | 97.84 |
| Bus_J20 | 15 | Load | 90.62 | 97.82 |
| Bus_J21 | 15 | Load | 90.61 | 97.82 |
| Bus_J22 | 15 | Load | 90.49 | 97.75 |
| Bus_J23 | 15 | Load | 90.21 | 97.59 |
| Bus_J24 | 15 | Load | 90.02 | 97.48 |
| Bus_J25 | 15 | Load | 90.02 | 97.48 |
| Bus_J26 | 15 | Load | 89.75 | 97.33 |
| Bus_J27 | 15 | Load | 89.75 | 97.33 |
| Bus_J28 | 15 | Load | 89.73 | 97.32 |
| Bus_J29 | 15 | Load | 89.72 | 97.31 |
| Bus_J30 | 15 | Load | 89.68 | 97.29 |
| Bus_J31 | 15 | Load | 89.65 | 97.27 |
| Bus_J32 | 15 | Load | 89.65 | 97.27 |
| Bus_J33 | 15 | Load | 89.65 | 97.27 |
| Bus_J34 | 15 | Load | 89.66 | 97.28 |
| Bus_J35 | 15 | Load | 89.66 | 97.28 |
| Bus_J36 | 15 | Load | 89.63 | 97.26 |
| Bus_J37 | 15 | Load | 89.98 | 97.44 |
| Bus_J38 | 15 | Load | 89.98 | 97.44 |
| Bus_J39 | 15 | Load | 89.97 | 97.43 |

| | | | | |
|---|---|---|---|---|
| Bus_J40 | 15 | Load | 89.97 | 97.43 |
| Bus_J41 | 15 | Load | 89.97 | 97.43 |
| Bus_J42 | 15 | Load | 89.76 | 97.31 |
| Bus_J43 | 15 | Load | 89.74 | 97.3 |
| Bus_J44 | 15 | Load | 89.71 | 97.29 |
| Bus_J45 | 15 | Load | 89.71 | 97.29 |
| Bus_J46 | 15 | Load | 89.68 | 97.27 |
| Bus_J47 | 15 | Load | 89.54 | 97.19 |
| Bus_J48 | 15 | Load | 89.53 | 97.19 |
| Bus_J49 | 15 | Load | 89.47 | 97.15 |
| Bus_J50 | 15 | Load | 89.47 | 97.15 |
| Bus_J51 | 15 | Load | 89.44 | 97.14 |
| Bus_J52 | 15 | Load | 89.43 | 97.13 |
| Bus_J53 | 15 | Load | 89.41 | 97.12 |
| Bus_J54 | 15 | Load | 89.4 | 97.12 |
| Bus_J55 | 15 | Load | 89.4 | 97.11 |
| Bus_J56 | 15 | Load | 89.4 | 97.11 |
| Bus_J57 | 15 | Load | 89.4 | 97.11 |
| Bus_J58 | 15 | Load | 89.4 | 97.11 |
| Bus_J59 | 15 | Load | 89.4 | 97.11 |
| Bus_J60 | 15 | Load | 89.63 | 97.24 |
| Bus_J61 | 15 | Load | 89.62 | 97.24 |
| Bus_J62 | 15 | Load | 89.63 | 97.24 |
| Bus_J63 | 15 | Load | 89.62 | 97.24 |
| Bus_J64 | 15 | Load | 89.7 | 97.28 |
| Bus_J65 | 15 | Load | 91.14 | 98.05 |
| Bus_J66 | 15 | Load | 91.05 | 98.01 |
| Bus_J67 | 15 | Load | 91 | 97.99 |
| Bus_J68 | 15 | Load | 91 | 97.99 |
| Bus_J69 | 15 | Load | 90.97 | 97.98 |
| Bus_J70 | 15 | Load | 90.96 | 97.97 |
| Bus_J71 | 15 | Load | 90.96 | 97.97 |
| Bus_J72 | 15 | Load | 90.96 | 97.97 |
| Bus_J73 | 15 | Load | 90.9 | 97.94 |
| Bus_J74 | 15 | Load | 90.89 | 97.94 |
| Bus_J75 | 15 | Load | 90.84 | 97.92 |
| Bus_J76 | 15 | Load | 90.83 | 97.91 |
| Bus_J77 | 15 | Load | 90.82 | 97.9 |
| Bus_J78 | 15 | Load | 90.82 | 97.9 |
| Bus_J79 | 15 | Load | 90.82 | 97.9 |
| Bus_J80 | 15 | Load | 90.82 | 97.91 |
| Bus_J81 | 15 | Load | 90.82 | 97.91 |
| Bus_J82 | 15 | Load | 90.8 | 97.9 |
| Bus_J83 | 15 | Load | 90.77 | 97.89 |
| Bus_J84 | 15 | Load | 90.77 | 97.89 |
| Bus_J85 | 15 | Load | 90.76 | 97.89 |
| Bus_J86 | 15 | Load | 90.75 | 97.87 |
| Bus_J87 | 15 | Load | 90.75 | 97.87 |

| | | | | |
|---|---|---|---|---|
| Bus_J88 | 15 | Load | 90.71 | 97.85 |
| Bus_J89 | 15 | Load | 90.71 | 97.85 |
| Bus_J90 | 15 | Load | 90.67 | 97.83 |
| Bus_J91 | 15 | Load | 90.68 | 97.83 |
| Bus_J92 | 15 | Load | 90.63 | 97.81 |
| Bus_J93 | 15 | Load | 90.63 | 97.81 |
| Bus_J94 | 15 | Load | 90.61 | 97.8 |
| Bus_J95 | 15 | Load | 90.58 | 97.78 |
| Bus_J96 | 15 | Load | 91.14 | 98.05 |
| Bus_J97 | 15 | Load | 90.97 | 97.98 |
| Bus_J98 | 15 | Load | 90.89 | 97.95 |
| Bus_J99 | 15 | Load | 90.89 | 97.95 |
| Bus_J100 | 15 | Load | 90.86 | 97.93 |
| Bus_J101 | 15 | Load | 90.86 | 97.93 |
| Bus_J102 | 15 | Load | 90.86 | 97.93 |
| Bus_J103 | 15 | Load | 90.86 | 97.93 |
| Bus_J104 | 15 | Load | 90.83 | 97.92 |
| Bus_J105 | 15 | Load | 90.74 | 97.87 |
| Bus_J106 | 15 | Load | 90.74 | 97.87 |
| Bus_J107 | 15 | Load | 90.83 | 97.92 |
| Bus_J108 | 15 | Load | 90.47 | 97.73 |
| Bus_J109 | 15 | Load | 90.46 | 97.73 |
| Bus_J110 | 15 | Load | 90.4 | 97.7 |
| Bus_J111 | 15 | Load | 90.4 | 97.7 |
| Bus_J112 | 15 | Load | 90.29 | 97.64 |
| Bus_J113 | 15 | Load | 90.15 | 97.57 |
| Bus_J114 | 15 | Load | 90.13 | 97.56 |
| Bus_J115 | 15 | Load | 89.95 | 97.47 |
| Bus_J116 | 15 | Load | 89.95 | 97.47 |
| Bus_J117 | 15 | Load | 89.95 | 97.47 |
| Bus_J118 | 15 | Load | 89.95 | 97.47 |
| Bus_J119 | 15 | Load | 89.88 | 97.43 |
| Bus_J120 | 15 | Load | 89.88 | 97.43 |
| Bus_J121 | 15 | Load | 89.82 | 97.41 |
| Bus_J122 | 15 | Load | 89.81 | 97.4 |
| Bus_J123 | 15 | Load | 89.81 | 97.4 |
| Bus_J124 | 15 | Load | 89.81 | 97.4 |
| Bus_J125 | 15 | Load | 89.81 | 97.4 |
| Bus_J126 | 15 | Load | 89.77 | 97.38 |
| Bus_J127 | 15 | Load | 89.76 | 97.37 |
| Bus_J128 | 15 | Load | 89.78 | 97.38 |
| Bus_J129 | 15 | Load | 89.78 | 97.38 |
| Bus_J131 | 15 | Load | 94.38 | 98.86 |
| Bus_J132 | 15 | Load | 90.68 | 97.83 |
| Bus_Junction1 | 15 | Load | 99.84 | 100.06 |

## *A5.1: Alert Report of Line 1 after OCP and Conductor Replacement after 10 Years*

| Buss ID | Type | Condition | Rating | Unit | Operating Voltage (kV) | % of Operating Voltage | Phase |
|---|---|---|---|---|---|---|---|
| Bus_J49 | Bus | Under Voltage | 15.00 | kV | 13.421 | 89 | 3-Phase |
| Bus_J50 | Bus | Under Voltage | 15.00 | kV | 13.421 | 89 | 3-Phase |
| Bus_J51 | Bus | Under Voltage | 15.00 | kV | 13.416 | 89 | 3-Phase |
| Bus_J52 | Bus | Under Voltage | 15.00 | kV | 13.415 | 89 | 3-Phase |
| Bus_J53 | Bus | Under Voltage | 15.00 | kV | 13.412 | 89 | 3-Phase |
| Bus_J54 | Bus | Under Voltage | 15.00 | kV | 13.411 | 89 | 3-Phase |
| Bus_J55 | Bus | Under Voltage | 15.00 | kV | 13.410 | 89 | 3-Phase |
| Bus_J56 | Bus | Under Voltage | 15.00 | kV | 13.410 | 89 | 3-Phase |
| Bus_J57 | Bus | Under Voltage | 15.00 | kV | 13.409 | 89 | 3-Phase |
| Bus_J58 | Bus | Under Voltage | 15.00 | kV | 13.410 | 89 | 3-Phase |
| Bus_J59 | Bus | Under Voltage | 15.00 | kV | 13.410 | 89 | 3-Phase |

# Appendix B: MATLAB code for Candidate Bus selection

```
% Program for Admittance and Impedance Bus Formation

function Y = ybusppg(num) % Returns Y matrix

    linedata=      xlsread('BLinedata.xls','Linedata1','E3:J133');
%Reading Line data from Excel
    [r,d] = size(linedata);
    num = r;
    fb = linedata(:,1);
    tb = linedata(:,2);
    r = linedata(:,3);
    x = linedata(:,4);
    b = linedata(:,5);
    a = linedata(:,6);
    z = r + 1i*x;
    y= 1./z;
    b = 1i*b;
    nb = max(max(fb), max(tb));
    nl = length(fb);
    Y = zeros(nb,nb);
    % Formation of the Off Diagonal Elements
    for k= 1:nl
        Y(fb(k), tb(k))= Y(fb(k), tb(k)) - y(k)/a(k);
        Y(tb(k), fb(k))= Y(fb(k), tb(k));
    end
    % Formation of Diagonal Elements
    for m= 1:nb
        for n= 1:nl
            if fb(n) == m
                Y(m,m) = Y(m,m) + y(n)/(a(n)^2) + b(n);
            elseif tb(n) == m
                Y(m,m) = Y(m,m) + y(n) + b(n);
            end
        end
    end


end

% Program for Candidate Bus Selection
busdatas=xlsread('Busdatas.xls','Busdata1','C3:L133');  %Read  Bus
Data from Excel

[n,d]= size(busdatas);
nbus=n;
```

```
P_loss = zeros(nbus,1);
Q_loss = zeros(nbus,1);
v_dev = zeros(nbus,1);

for count=1:nbus+1
    tempBus = busdatas;
    if count~=nbus+1
        diff = tempBus(count,8)-tempBus(count,6);
        if diff>0
            tempBus(count,6) = + diff;
        end
    end
    Y = ybusppg; % Calling ybusppg.m to get Y-Bus Matrix..
    busd = tempBus;             % Calling busdatas..
    BMva = 100;                 % Base MVA..
    bus = busd(:,1);            % Bus Number..
    type = busd(:,2);             % Type of Bus 1-Slack, 2-PV, 3-
PQ..
    V = busd(:,3);              % Specified Voltage..
    del = busd(:,4);            % Voltage Angle..
    Pg = busd(:,5)/BMva;        % PGi..
    Qg = busd(:,6)/BMva;        % QGi. .
    Pl = busd(:,7)/BMva;        % PLi..
    Ql = busd(:,8)/BMva;        % QLi..
    Qmin = busd(:,9)/BMva;      % Minimum Reactive Power Limit..
    Qmax = busd(:,10)/BMva;     % Maximum Reactive Power Limit..
    P = Pg - Pl;                % Pi = PGi - PLi..
    Q = Qg - Ql;                % Qi = QGi - QLi..
    Psp = P;                    % P Specified..
    Qsp = Q;                    % Q Specified..
    G = real(Y);                % Conductance matrix..
    B = imag(Y);                % Susceptance matrix..
    pv = find(type == 2 | type == 1);   % PV Buses..
    pq = find(type == 3);               % PQ Buses..
    npv = length(pv);                   % No. of PV buses..
    npq = length(pq);                   % No. of PQ buses..
    Tol = 1;
    Iter = 1;
    while (Tol > 1e-3)                  % Iteration starting..
        P = zeros(nbus,1);
        Q = zeros(nbus,1);
        % Calculate P and Q
        for i = 1:nbus
            for k = 1:nbus
                P(i)   =   P(i)   +   V(i)*   V(k)*(G(i,k)*cos(del(i)-
del(k)) + B(i,k)*sin(del(i)-del(k)));
                Q(i)   =   Q(i)   +   V(i)*   V(k)*(G(i,k)*sin(del(i)-
del(k)) - B(i,k)*cos(del(i)-del(k)));
            end
```

```
        end
        % Checking Q-limit violations..
        if  Iter  <=  7  &&  Iter  >  2  %  Only  checked  up  to  7th
iterations..
            for n = 2:nbus
                if type(n) == 2
                    QG = Q(n)+ Ql(n);
                    if QG < Qmin(n)
                        V(n) = V(n) + 0.01;
                    elseif QG > Qmax(n)
                        V(n) = V(n) - 0.01;
                    end
                end
            end
        end

        % Calculate change from specified value
        dPa = Psp-P;
        dQa = Qsp-Q;
        k = 1;
        dQ = zeros(npq,1);
        for i = 1:nbus
            if type(i) == 3
                dQ(k,1) = dQa(i);
                k = k+1;
            end
        end
        dP = dPa(2:nbus);
        M = [dP; dQ]; % Mismatch Vector
        % Jacobian
        % J1 - Derivative of Real Power Injections with Angles..
        J1 = zeros(nbus-1,nbus-1);
        for i = 1:(nbus-1)
            m = i+1;
            for k = 1:(nbus-1)
                n = k+1;
                if n == m
                    for n = 1:nbus
                        J1(i,k)   =   J1(i,k)   +   V(m)*   V(n)*(-
G(m,n)*sin(del(m)-del(n)) + B(m,n)*cos(del(m)-del(n)));
                    end
                    J1(i,k) = J1(i,k) - V(m)^2*B(m,m);
                else
                    J1(i,k)   =   V(m)*   V(n)*(G(m,n)*sin(del(m)-
del(n)) - B(m,n)*cos(del(m)-del(n)));
                end
            end
        end
```

```
        % J2 - Derivative of Real Power Injections with V..
        J2 = zeros(nbus-1,npq);
        for i = 1:(nbus-1)
            m = i+1;
            for k = 1:npq
                n = pq(k);
                if n == m
                    for n = 1:nbus
                        J2(i,k) = J2(i,k) +
V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
                    end
                    J2(i,k) = J2(i,k) + V(m)*G(m,m);
                else
                    J2(i,k) = V(m)*(G(m,n)*cos(del(m)-del(n)) +
B(m,n)*sin(del(m)-del(n)));
                end
            end
        end
        % J3 - Derivative of Reactive Power Injections with
Angles..
        J3 = zeros(npq,nbus-1);
        for i = 1:npq
            m = pq(i);
            for k = 1:(nbus-1)
                n = k+1;
                if n == m
                    for n = 1:nbus
                        J3(i,k) = J3(i,k) + V(m)*
V(n)*(G(m,n)*cos(del(m)-del(n)) + B(m,n)*sin(del(m)-del(n)));
                    end
                    J3(i,k) = J3(i,k) - V(m)^2*G(m,m);
                else
                     J3(i,k) = V(m)* V(n)*(-G(m,n)*cos(del(m)-
del(n)) - B(m,n)*sin(del(m)-del(n)));
                end
            end
        end
        % J4 - Derivative of Reactive Power Injections with V..
        J4 = zeros(npq,npq);
        for i = 1:npq
            m = pq(i);
            for k = 1:npq
                n = pq(k);
                if n == m
                    for n = 1:nbus
                        J4(i,k) = J4(i,k) +
V(n)*(G(m,n)*sin(del(m)-del(n)) - B(m,n)*cos(del(m)-del(n)));
                    end
                    J4(i,k) = J4(i,k) - V(m)*B(m,m);
```

```
                    J4(i,k) = V(m)*(G(m,n)*sin(del(m)-del(n)) -
B(m,n)*cos(del(m)-del(n)));
                end
            end
        end
        J = [J1 J2; J3 J4]; % Jacobian Matrix..
        X = J\M; % Correction Vector
        dTh = X(1:nbus-1); % Change in Voltage Angle..
        dV = X(nbus:end); % Change in Voltage Magnitude..
        % Updating State Vectors..
        del(2:nbus) = dTh + del(2:nbus); % Voltage Angle..
        k = 1;
        for i = 1:nbus
            if type(i) == 3
                V(i) = dV(k) + V(i); % Voltage Magnitude..
                k = k+1;
            end
        end
        Iter = Iter + 1;
        Tol = max(abs(M)); % Tolerance..
    end

    % Calling loadflow2.m..
        if count ~= nbus + 1
            P_loss = Psp - P;
            Q_loss = Qsp - Q;
            v_dev = 1-min(V);
        elseif count == nbus + 1
            PlossN= Psp - P;
            QlossN= Qsp - Q;
            v_devN = 1-min(V);
        end
end

P_reduct = PlossN - P_loss;
Q_reduct = QlossN - Q_loss;
V_imprv = v_devN - v_dev;

minP_loss = min(P_reduct);
maxP_loss = max(P_reduct);
minV_imprv = min(V_imprv);
maxV_imprv = max(V_imprv);

loss_diff = maxP_loss - minP_loss;
imprv_diff = maxV_imprv - minV_imprv;

PLI = (P_reduct - minP_loss)/loss_diff;
VLI = (V_imprv - minV_imprv)/imprv_diff;
```

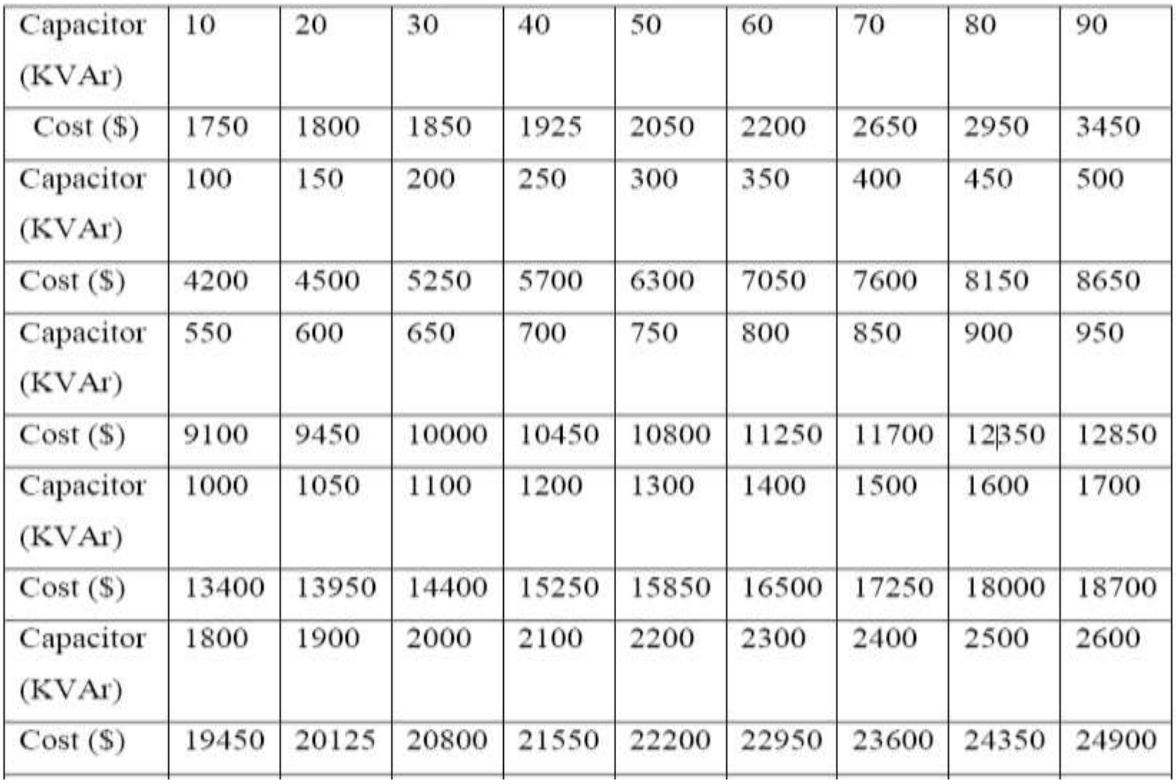
```
LI = PLI + VLI;

[sortedPLI, I] = sort(PLI,'descend');
candidateBuses = I(1:10);
[sortedVLI, J] = sort(VLI,'descend');
[sortedLI, K] = sort(LI,'descend');

SenssitivityIndex= [I, PLI(I)];
SenssitivityIndex2= [J, VLI(J)];
SenssitivityIndex3= [K, LI(K)];
disp(SenssitivityIndex);
```

# Appendix C: Capacitors' Size and cost

The size and cost of capacitors [45] are as follows.



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Capacitor (KVAr) | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
| Cost ($) | 1750 | 1800 | 1850 | 1925 | 2050 | 2200 | 2650 | 2950 | 3450 |
| Capacitor (KVAr) | 100 | 150 | 200 | 250 | 300 | 350 | 400 | 450 | 500 |
| Cost ($) | 4200 | 4500 | 5250 | 5700 | 6300 | 7050 | 7600 | 8150 | 8650 |
| Capacitor (KVAr) | 550 | 600 | 650 | 700 | 750 | 800 | 850 | 900 | 950 |
| Cost ($) | 9100 | 9450 | 10000 | 10450 | 10800 | 11250 | 11700 | 12350 | 12850 |
| Capacitor (KVAr) | 1000 | 1050 | 1100 | 1200 | 1300 | 1400 | 1500 | 1600 | 1700 |
| Cost ($) | 13400 | 13950 | 14400 | 15250 | 15850 | 16500 | 17250 | 18000 | 18700 |
| Capacitor (KVAr) | 1800 | 1900 | 2000 | 2100 | 2200 | 2300 | 2400 | 2500 | 2600 |
| Cost ($) | 19450 | 20125 | 20800 | 21550 | 22200 | 22950 | 23600 | 24350 | 24900 |