Power Reliability Assessment of Adama Power Distribution System

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APPROVAL Of BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by **Adane Getachew** have read and evaluated his thesis entitled "POWER RELIABILITY ASSESSMENT OF ADAMA POWER DISTRIBUTION SYSTEM" and examine the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Electrical Power and Control Engineering Program (Specialization in Electrical Power Engineering).

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DECLARATION

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

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This MSc Thesis has been submitted for examination with my approval as thesis advisor.

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Date of submission: ____/_____/_______

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ACRONYM

A	ampere
AC	alternating current
ANSI	American national standard institute
ASAI	Average Service availability Index
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
CADI	Customer Average Interruption Index
CC	covered conductor
Ckt	circuit
DC	direct current
DG	Distributed Generation
ECOST	expected interruption cost
EENS	expected energy not supply
EEP	Ethiopian electric power
EEU	Ethiopian Electric utility
EF	earth fault
ETAP	electrical transient and analysis program
F_{1-7}	feeders of old system
Fig.	Figure
Fr	frequency

GC	Gregorian Calendar
GJ	Giga Joule
HDPE	High Density Polyethylene
Hr	hour
HV	High Voltage
I>>	over current
IEAR	interrupted energy assessment rate
IEC	international electrotechnical commission
IEEE	International Electrical and Electronic Engineering
ISO	international standard organization
kA	kilo ampere
kV	kilo Volt
kWh	kilo Watt hour
L_{1-7}	lines of old distribution system
LV	Low Voltage
M_{1-5}	feeders of mobile substation
mm^2	milli meter
MJ	Mega Joule
MTBF	Mean Time between Failures
MTTR	Mean Time to Repair
MV	Medium Voltage

MVA	Mega volt ampere
MW	Mega Watt
O&M	operation and maintenance
OC	over current
OP	operational
PE	polyethylene
P.f	power factor
PPM	Preventive and Predictive Maintenance
PSS	proposed switching station
PVC	polyvinyl chloride)
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SS_{1-8}	switching stations of rehabilitant system
UPS	uninterrupted power supply
V	voltage
XLPE	cross -linked polyethylene
yr	year
Z	impedance

Abstract

The objectives of this thesis work are assessing reliability of Adama distribution systems and proposed potential solution to enhance reliability of the system. This thesis starts with collecting important data for reliability assessment in Adama distribution system. Based on this data, reliability indices of the distribution system have been calculated and evaluated. This thesis work compares the three-distribution system of Adama city, namely the old distribution system, upgraded distribution system and rehabilitant distribution system. Based on this analysis, gaps have been identified and major improvement options have been developed. The two well-known customer oriented average system reliability indices have been evaluated for the year 2015 to 2017of old distribution system. The average annual SAIFI and SAIDI values of this system are 314.43 fr/customer/year and 325.24 hr/customer/year respectively. As a result of this long-time outage the power utility has lost on the average 8.075 Billion birrs/year. The upgraded Adama distribution system with the rating of 100MVA has been evaluated for its reliability for six months starting from January to June 2018. SAIFI and SAIDI of this system are 117.63 Intr./customer/year and 183.83 hr/customer/yea, respectively. Even though, improvements are being observed reliability indices are beyond EEA's standard., The revenue lost by the power utility is around 4.579. Billion birrs in half of year approximately 9 billion birrs per year. The reliability of rehabilitated and upgraded distribution of Adama city has been computed using ETAP software which results in SAIF value of 139.49 Intr./customer /year and SAIDI value of 148.26 hr/ customer /yr to verify the result. To improve the reliability of the distribution system, this thesis proposed one additional distribution substation. This results in significant improvement distribution system based on rehabilitant distribution system. this results SAIFI and SAIDI, 62.194 fr/customer /yr and 66.4688.75 hr/customer/yr respectively, which is most reliable distribution system for Adama city.

***Key word**: power reliability assessment, power reliability, power distribution system*

CHAPTER ONE

1. INTRODUCTION

1.1 Background Information

Adama is the second largest city in Ethiopia and is found at 8.54°N 39.27°E at 1712 meters elevation and 99 km southeast of Addis Ababa [1]. Adama has been supplied from the national grid. With the growth of the city and the high demand of electricity, providing a reliable power supply becomes a formidable task to the power utility. Frequent power interruptions have posed serious problems to the city and mitigating the problem is very critical to improve the livelihood of the population.

The power system has three components with generation, transmission and distribution components. Among these the distribution system is the most complex and delivers power to end user customers at their living place. The power system should supply reliable power to its customer without any interruption.

The old Adama power distribution system has a substation with capacity of 50 MVA, two 25MVA power transformer and 7 radialy connected feeders. This system has experienced frequent interruptions of long durations.

Ethiopian electric utility has the rehabilitation and upgrading of the distribution network of 8 cities in Ethiopian to enhance power reliability. Adama is one of included in the rehabilitation program. This new distribution system comprises 8 switching stations with 15 kV voltage rating near to load centers of the city forming loop configuration. These switching stations act as small substations that are distributed in different parts of city. These stations get their power from Adama substation by seven express feeders without feeding loads on the way. So as to form loop distribution configuration, at least one switching station is tied to another switching stations by intermediate feeders. and also, cable express feeders.

Electricity is a basic need for human being life. But, in some nations, not all people have access to electricity from the grid. based on the International Energy Agency (IEA), around 1.2 billion people which is 16% of the global population were still without access to electricity in 2015 [2]

Because of numerous economic, technical, and political problems, a low quality of electricity provided by the grid can be expected in some developing countries [3]. This issue can be categorized by the intermittent and unreliable supply of electricity to the customers usually through regular grid outages, either planned or unplanned.

Everywhere in the world, reliable electric power is crucial to economic development countries, education sector, and medical care. Electric power for developing countries is vital for many critical services, including those that increase income and benefit rural areas. Lowe reliability correlated with the development and economic states of a country. A low gross domestic product (GDP) consequences from a low power grid in a country or vice versa. The decrease in the quantity of interruptions from 100 days/yr to 10 days / yr corresponds to more than a two-fold growth in GDP per person [4].

The reliability of electricity services of distribution system is computed with two well-known customer-oriented reliability indices such as the System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) [5], which are normally calculated data that documented by utility companies.

Customer outages are caused by different types of phenomena comprises equipment failure, lightning, animals, trees, severe weather, and human error. These rea root causes of distribution reliability, and knowing them permits abstract topics like reliability modeling and computer optimization to be observed from a practical perspective. In addition, the most cost-effective way to address reliability problems by finding and addressing physical root causes [6].

So, this thesis evaluated how much the new power distribution system addresses the power reliability problem of Adama city by comparing the power reliability indices of three power distribution systems as stated above and also proposed new distribution configuration for better reliability.

1.2 Statement of The Problem

Adama city, mostly suffer with power reliability problem which mean many times the utility interrupts power to the customers suddenly without any notification. This affects customer's daily activities which impacts the economic development of the city, health sector, communication network like telecom, banks etc. The EEU is working to solve this problem by rehabilitation of the existing network. So, this thesis tries to evaluate the impact of the new power distribution network in comparison of the old system

1.3 Objective

1.3.1 Main Objective

The main objective of this thesis assesses power reliability and proposes reliability improvement options for Adama distribution system.

1.3.2 The Specific Objectives

- ✓ Evaluate the distribution reliability of the old and upgraded substation
- ✓ Identify the causes of power reliability problems in existing distribution network.
- ✓ Evaluate power reliability of the rehabilitated power distribution system
- ✓ Model and simulate the reliability improvement of the substation to verify the results.
- ✓ Make recommendations for improvement of the power reliability based on the gaps identified.

1.4 Scope

This thesis evaluates the power reliability of existing and upgraded power distribution system of Adama city but does not include secondary distribution system.

The switching device coordination is not done like coordination of circuit breakers, and also the cost analysis of proposed substation, outgoing feeders, automatic recloser and switching station of proposed distribution system is not worked in this thesis work.

1.5 Significant of the study

One significant of this thesis try to indicate reliability problem, operational and maintenance practice gaps of Adama distribution system relative to theoretical knowledge of electrical distribution system. And also, this thesis benefit by improving reliability of distribution system through proposing new substation design and distribution configuration.

1.6 Thesis outline

This thesis study has five chapters. The first chapter presents introduction about the thesis which contains background of study, statement of problem, limitation, significant of study and thesis outline. The second chapter discuss about literature background of reliability and review of related journal with a title of thesis. The third chapter computes reliability indexes of old and upgraded system manually by using data collected in Adama distribution system, identifies type of faults and causes of outages in both systems, and finally designed proposed substation capacity. The fourth chapter presented about modeling of rehabilitant and proposed system by ETAP software. according to the modeling system reliability indexes of rehabilitant and proposed systems are assessed. And finally, in chapter five discussed on conclusion and recommendations of the thesis.

CHAPTER TWO

2. Review of the Literature

2.1 Reliability Terms and Definitions

Reliability is capacity of power system to supply continuity of service to the utility's customers. A reliable power system delivers power without interruption.

To study about reliability of system there are terms must be known are defines as follow [7, pp. 104-106]:

Availability: the portion of the time that service is accessible. The possibility that power will be available.

Clear: to remove a fault or other disturbance-causing condition from the power supply source or from the electrical route between it and the customer.

Cut set: a set of elements which when removed from service causes a interruption of power flow.

Dependability: means reliability of performance over the short-range, or with respect to only a certain plan.

Durability: the ability to preserve high levels of reliability while in service over long periods of time. Two units of apparatus can be equally reliable, when firstly installed, but the more tough will be in much better shape after ten years, etc.

Duration: the total passed time of an interruption.

EEAR (Expected Energy at Risk): it forecasts the percent of annual energy at risk of not being distributed for a scheduled system and load.

Event: a specific change in electrical equipment condition.

Extent: the amount of the system, may be the number of customers, become out of service by failure.

Failure: a change in status of a system from carrying out its function as predictable to cessation its function completely.

Failure rate: the average number of failures of a equipment of the system in a given time.

Frequency: how often interruptions or outages happened in a system.

Interruption: a termination of facility to customers.

- **Instantaneous interruption**: an interruption lasting only as long as it takes for totally automatic switch to clear the disturbance. Often fewer than one second.
- **Momentary interruption**: an interruption lasting only as long as it takes automatic but manually controlled switch to be started to restore service, usually only a few minutes, occasionally less than fifteen seconds.
- **Planned interruption**: an interruption of power because of a scheduled outage, of which clienteles were informed rationally far in advance.
- **Temporary interruption**: an interruption manually reinstated, waits as long as it takes.

Interruption duration: the time from cessation of service till service is returned.

Interruption frequency: the average number of interruptions of service during some period (usually a year,).

Mean time between failures (MTBF): the average time length of device in service between failures.

Mean time to repair (MTTR): the average time to repair an outaged equipment of the system once failed.

Minimal cut set: a cut set that does not comprise any other cut set as a subsection.

Mis-operation: improper operation of the power system due to different condition.

Outage: the failure of part of the power supply system it includes failure of transformer or line.

Expected Outage- an equipment outage that was predicted in some sense. generally, this means something more definite than Well, it would fail eventually. Often, this is applied to equipment failures that were predicted and for which preparation shad been made: Diagnostics showed that cable failure was occur but not which section would fail.

Forced Outage-an equipment outage that was not planned in an advance, even if started by the utility. The equipment may not be damaged but usually something improper function:

The unit was detected to be smoking slightly so it was reserved from service. It happens just to be a slight oil leak and the unit was repaired and returned to service the next day.

Scheduled Outage-an equipment outage that was scheduled in advance and initiated by the utility's actions, as for example when work technicians get rid of electric equipment from service for maintenance, etc.

Unexpected Outage-an equipment outage that was not expected. Usually, a non-expected outage is because of equipment failure, an accident, or damage of some type.

Reliability: the ability of the power delivery system to make continuously available sufficient voltage, of satisfactory quality, to meet the consumers' needs.

Repair time: the time required to coming back unit of the system to normal service. Associated in a cause and effect way, but not certainly the same as, interruption duration.

Reporting period: the period of time over which reliability, interruption, and outage statistics have been collected or analyzed.

Restoration: return of electric facility after an interruption, due to repair of the outage causing the interruption or due to re-switching of delivery source.

Restoration time: the time needed to return service to portion of the system. Also, in T&D operations, the time required to restore device to service in a temporary configuration as for example an overhead feeder replace in to service with stubbed pole sand slack span stem polarity in place. It has been restored to service, but not repaired.

Service: delivery of electric power in adequate amount and quality to satisfy end user customer demand.

Storm: a weather conditional series of events producing outages who consequences fulfill specific criteria for storm, usually measured by number of customers out of service, amount of restore work needed, (customer-hours of interruption), and reported as a distinct category of interruptions.

Switching time: the time required to operate equipment to switch on or off the source of power flow to a circuit, usually to restore service where interrupted due to an equipment outage.

Trouble: anything that causes an unanticipated outage (interruption) including devices failures, vandalism, earth quakes, storms, automobile wrecks, operator error, or unknown causes.

2.2 Reliability Indices

2.2.1 Customer-Based Indices

Utilities most frequently use two indices, SAIFI and SAIDI, to standard reliability. These illustrate the frequency and duration of interruptions during the reporting period (usually years) [8, pp. 436-437].

SAIFI, System average interruption frequency index

$$\text{SAIFI} = \frac{\textit{Total number of customer interruption}}{\textit{Total number of customers served}} = \text{------------ (2. 1)}$$

Naturally, a utility's customers average between one and two continued interruptions per year. SAIFI is also the average failure rate of unit of system. Another valuable measure is the mean time between failure (MTBF), which is the reverse of the failure rate: MTBF in years.

SAIDI, System average interruption duration frequency index

$$\text{SAIDI} = \frac{\textit{Sum of all customer interruption durations}}{\textit{Total number of customers served}} \text{ ----------------- (2. 2)}$$

SAIDI measures the average total duration of interruptions. SAIDI is measured in units of hours or minutes per year. SAIFI and SAIDI are the well- known pair out of many reliability indices. Another related index is CAIDI:

CAIDI, Customer average interruption duration frequency index

$$\text{CAIDI} = \frac{\textit{SAIDI}}{\textit{SAIFI}} = \frac{\textit{Sum of all custtomer interuuption durations}}{\textit{Total number of customer interruption}} = \text{------------------- (2. 3)}$$

CAIDI is the repair time from the customers' perspective. It is generally much shorter than the real repair time due to utilities usually sectionalize circuits to reactivate as many customers as possible before technicians fix the real damage.

Also used in many other industries, the availability is quantified as, ASAI, Average service availability index

$$\text{ASAI} = \frac{\textit{Customer hours service availability}}{\textit{Customers hours service demand}} \text{ ---------------------------- (2. 4)}$$

2.2.2 Load-Based Indices

Residential customers lead SAIFI and SAIDI since these indices measures each customer the same. To more equally weight larger customers, load-based indices are existing; the equivalent of SAIFI and SAIDI, but scaled by load, are ASIFI and ASIDI [8, p. 440]:

ASIFI, Average system interruption frequency index

$$\text{ASIFI} = \frac{\textit{Connected kVA interrupted}}{\textit{Total connected kVA served}} \text{ (Average number of interruptions) --------- (2. 5)}$$

ASIDI, Average system interruption frequency index

$$\text{ASIDI} = \frac{\textit{Connected kVA interrupted durations}}{\textit{Total connected kVA served}} \text{ ------------------------------------ (2. 6)}$$

Few of utilities know ASIFI and ASIDI, mainly since they are hard to knowing load interrupted is harder than knowing number of customers interrupted. Utilities also feel that commercial and industrial customers have enough clout that their problems are given due attention.

2.3 Distribution System Reliability Assessment

The application of reliability perceptions to distribution systems varies from generation and transmission applications in that it is more customer load point focused on instead of being system oriented, and the local distribution system is considered rather than the entire integrated system involving the generation and transmission facilities. Generation and transmission reliability as well emphasize capacity and loss of load probability, with some care paid to components, whereas distribution reliability considers all facets of engineering: design, planning, and operations. Since the distribution system is fewer complex than the combined generation and transmission system, the probability mathematics used is much simpler than that required for generation and transmission reliability assessments [9].

It is important to note that the distribution system is a vital connection between the bulk power system and its customers. In many cases, these links are radial in nature that makes them susceptible to customer interruptions due to a single outage event. A radial distribution circuit generally practices main feeders and lateral distributors to deliver customer energy requirements. Formerly, the distribution part of a power system received considerably less attention in terms of reliability planning compared to generation and transmission segments.

The basic reason behind this is the fact that generation and transmission parts are too capital intensive, and outages in these segments can cause widespread disastrous economic consequences for customers [7, pp. 85-86].

There are four important characteristics to this definition that planners need to keep in mind when laying out and optimizing their system.

Customer focused: The focus of a planner's reliability assessment should be on the service customers receive. In the end, this is all that matters. Analysis of and focus on reliability measured regarding the utility's system and equipment is not sufficient. The utility must check itself that consumers perceive good reliability from their point of view when looking back into the system, irrespective of equipment issues.

Continuous availability: Possibly the most important feature of reliability is that power most be uninterruptedly available. Fundamentally, the utility must sustain an always continuous chain of power flow from a source of power to each end-user consumer.

Sufficient power: This chain of power flow must be capable to provide enough power that it does not pressure the consumer's ability to have as much as he needs whenever he needs it.

Satisfactory quality: Voltage, frequency, and other characteristics of the power made available must be appropriate to meet the consumer's needs.

There are multiple reasons for making reliability analysis, these are [9, p. 115]:

- Illustrate reliability measurements to a single customer (to the whole system) satisfactorily
- Characterize reliability by means of reliability indices
- Computing cost of reliability or performance at a given cost
- Showing the worth of reliability and its effect on cost versus improvements to the system

Reliability analysis lets to power distribution to determine indices for supplying power to specific customers or to entire systems. These indices allow for contrast between customers in terms of system capability and enhancements to be made. Therefore, reliability analysis used to [9, pp. 115-116]:

1. Forecast changes in reliability that will consequence from changes to the design, operation, and maintenance of a distribution system. it will identify weaknesses in the design, operation, or maintenance; identify the main causes of unreliability; or establish whether major improvements such as tree trimming or replacement of failed insulators and absent grounds are desired or justified based on cost.
2. Analyze outage designs by using reliability indices to predict the reliability of system configurations with or without several maintenance activities or options and their related costs
3. propose improvements to show utility and customer interruption costs according to cost-benefit analyses

Other relevant reasons for reliability assessment are to:

- Offer a reliability history of each circuits for discussion with prospective customers.
- Fulfill regulatory reporting requirements.
- Furnish management with performance data with respect to the quality of customer service for each operating area.

2.4 An Inputs Required for Historical Assessment

Utilities use outage management system (OMS) software to calculate reliability indices. Such systems typically record interruptions in terms of location, date/time, failed components, frequency of occurrence, number of customers.

Distribution System Reliability affected by maintenance activities like load interrupted, time to restore service, time to repair or replace failed components, cause of interruptions or anomalies, etc. Reliability indices are assessed based on historical events classified in the following outage categories [9, p. 117]:

1. Maintenance: outages produced by vegetation, animals, or human error; such outages show the need for corrective action or maintenance improvements to the system.
2. Component failure: outages influenced by the reliability of individual components such as fuses, auto-reclosers, switch gears, contactors, transformers, etc. Failure can be categorized based on the components that fail and cause an outage.
3. Weather: outages affected by weather conditions prevalent in the system. The use of a reliability index can provision in minimizing damage to the system. Duration of

outage: reliability indices along with outage duration are supportive in defining the impact on reliability of improvement with component switches by installing reclosers, automated switches, changes in network reconfiguration, restoration that will enhance the system's reliability at optimal cost.

4. Location of outage: reliability indices based on regional service areas and districts (e.g., urban, rural areas) are used to find where forthcoming improvements could be applied.

2.5 Paper Review

This world is enlightened by Electric power which determines every activity of individual humans, companies and national economy the countries. So electric power is a vital element in any modernized human life. The availability of a reliable power supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution system have to be upgraded, operated and maintained accordingly. To fulfill and meet customer demands currently the following researches are going on, on electric power distribution system:

In this paper [10], proposes inter-loop configuration to optimize the radial power distribution for better reliability and to minimize energy not supplied. The author explained how inter loop system improves power reliability and its cost benefit from normal radial power distribution system. This paper uses Genetic algorism to solve optimization problems. The strength of this paper is improved the reliability of radial distribution network but interlopes increases fault currents in a system

Another paper evaluates power reliability indexes of Debre Markos substation 230/15 KV 23MVa transformer with two outgoing feeders. Authors analyses reliability indices using DIGSILENT software which results two major system indices; SAIDI is 597.476 hr/customer and SAIFI is 608.168 inter./customer. This justifies that Debre Markos substation is no reliable [11]. But it did not provide any improvement options as to enhance reliability of the system and also it difficult to conclude distribution system as unreliable by assessing reliability of two feeders only.

Another paper [12] present assessment of power reliability and improving power reliability using smart reclosers of Adama power distribution system which is one large city of Ethiopia. Authors show the reliability of Adama city can improve up to 75% by connecting two nearly feeder through smart reclosers. The paper uses WindMil software to verify the application in the distribution system. The author tried to show reliability problem of Adama city was due to radial configuration, but in distribution system, low reliability will result due to various factor. So, this paper did not present those causes of unreliability and proposed potential solutions.

Another paper [13] explains how can improve reliability of radial distribution system by adding distributed generation (DG) to the substation of power distribution system. Also, author compares the reliability indices when distribution system without lateral protection, both with lateral protection and with lateral protection and DG. It verifies reliability indices of system without lateral protection is much greater than with lateral protection and both with lateral protection and DG, and system with lateral protection has greater system index with that of system having both lateral protection and with lateral protection and DG. This paper uses analytical method to analysis the reliability indices of the network. This paper improves reliability of radial distribution system by adding DG at substation, but radial system by its nature unreliable system. Even though lateral protection system is used, end users must wait until system is repair if fault happened in radial system because due to a single feeding of radial system.

In another paper [14] presented that insulated conductors have higher advantage over bare conductor by minimizing the reliability and increasing availability of LV, MV and HV overhead distribution system. And also, he analyzed the advantage and limitation of insulated Piercing Connector (IPC). This paper verified that covered conductor more reliable than bar conductor of power system, but it did not show effect of cover insulator failure due numerous factors in reliability of system.

In this thesis [15], presented, the power availability improvement and power loss reduction in Adama distribution system, by designing distributed generation (DG) to outgoing feeders. This thesis evaluated the effect of DG on reliabilities of the system using GIGSILENT software. This thesis improved reliability of Adama distribution system by sizing and placing DG along radial feeder. However, one major that affects reliability of a distribution system is configuration. The author had weak that he did not consider distribution configuration.

Another thesis [16] worked on Adama town by Modeling of grid connected distributed generations and design the control system between the DGs and the grid system to improve reliability and uninterruptable system in both standalone and grid connected distributed generation (DG) power systems. This thesis simulated the feasibility study by HOMER simulator software and controlling of the DG did by Mathlab. The author din not assess reliability of the distribution system before DG applied and also it did not show what reliability problem of power distribution network of Adama town.

Generally, various reliability assessment studies did on Adama power distribution system. those studies varied that Adama power distribution system is unreliable. But these did not show what are cause of power reliability and gaps of Adama distribution system for this insufficient reliability of the city. And also, still did not do any study on reliability analysis on upgraded and rehabilitated system of Adama distribution. So that, this thesis study presents reliability assessment of old upgraded, and rehabilitant system, causes of power interruption and gaps of distribution system for low reliability, and proposes new distribution system with new additional substation to enhance power reliability of Adama city.

CHAPTER THREE

3. Reliability Analysis of Adama Distribution System

3.1 Data Collected from Adama substation

Data has been collected for Adama distribution system. These are 2 years recorded data that incorporates type of fault, duration and frequency of interruption and peak load of 15 kV outgoing feeders of the distribution system**.**

Adama substation had the capacity of 50 MVA up to October 2017 with 132 kV input high voltage. After October 2017, its capacity was upgraded to 100 MVA by adding mobile substation. Adama substation has 3 incoming feeders. These are Adama wind farm, Koka and Awash. But currently, Adama substation is feed only from Adama wind farm and Koka hydropower generation. When load capacity of Adama distribution system is above generation capacity of Adama wind and Koka hydropower, Adama substation gets its power from awash hydropower as well. After October 2017, the substation feeds Adama city with 11 medium voltage outgoing feeder from which six feeders are from old 50MVA substation and the remaining five feeders are from mobile substation.

Data collected in Adama substation includes 28 months which are arranged in to two parts. These are:

a. Data of Adama substation before upgrading
b. Data of Adama substation after upgrading

3.1.1 Data of Adama substation before the upgrade

This power interruption data covers from October 2015 up to September 2017 GC for the 50MVA and seven 15 kV outgoing feeders.

a) Frequency and duration of interruption

Duration and frequency of interruption are evaluated for each outgoing feeder. Figure 3.1 shows interruption frequency of feeder from October 2015 to September 2016 along each month. As observed in Fig. 3.1, higher fault frequency is recorded from October to January 2015 GC. In this particular year, feeders L1, L2, L3, L4 and L7 experienced higher interruption frequency. Totally, in this particular year, 2201 faults occurred in the power distribution system as shown Fig. 3.2

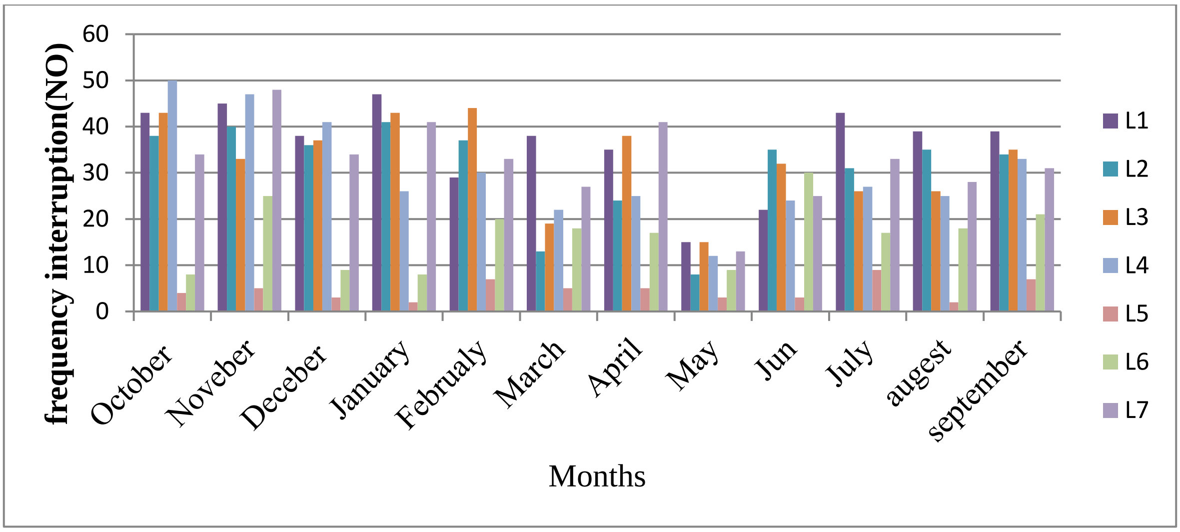

Figure 3.1 Monthly interruption frequency from October 2015 to September 2016

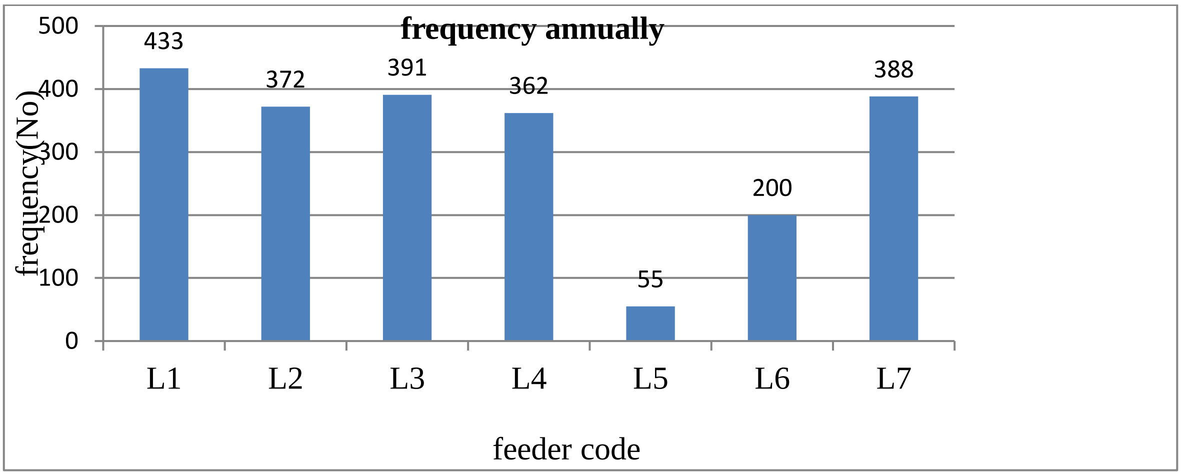

Figure 3.2 Annually interruption frequency of feeder from October 2015 to September 2016 GC

In same year, Adama city had not got power for 2276.68 hours which is 26% of the total time in a year. As shown in Fig. 3.5, monthly power interruption duration of January is the highest. Feeder 7 and 5 have the highest and lowest fault duration in Adama distribution as shown in Fig. 3.6, respectively.

The Second Data is collected from October 2016 to 2017 GC. Monthly occurrence of interruptions is given in figure 3.3. Annual frequency of faults of this year is shown in figure 3.4. Feeder 3 has the highest frequency of interruption (533) and line 5 has the lowest frequency interruption (115).

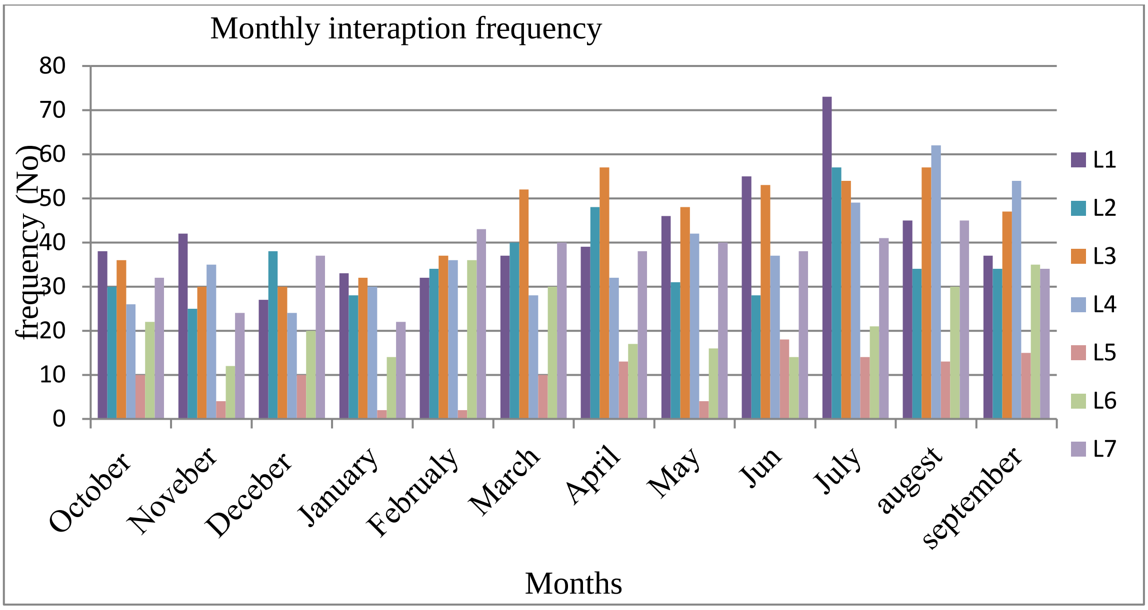

Figure 3.3 Monthly interruption frequency from October 2016 to September 2017 GC

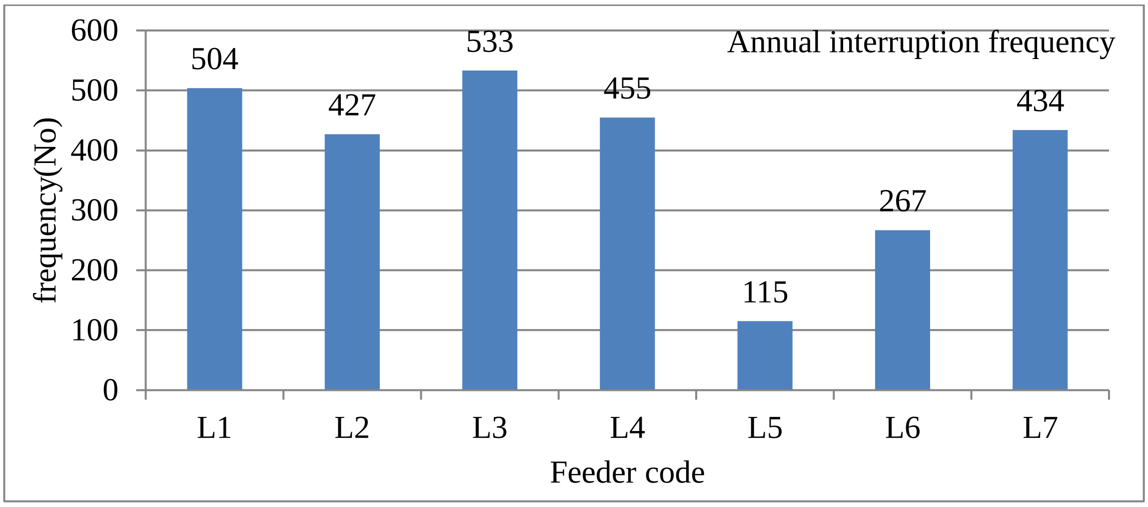

Figure 3.4 Annually interruption frequency of feeder from October 2016 to September 2017 GC

For this particular year, the monthly duration is depicted in Fig.3.7 and 3.8 respectively. May and July have longer duration of interruption. And annually fault duration of feeders shown Fig.3.8, so feeder 3 has the highest length of time of fault in Adama distribution system.

Monthly average interruption frequency of two years, from October 2015 to September 2017 GC are shown Fig. 3.9 and annually average interruption frequency 3.10 and also monthly average fault duration and annually are shown figure 3.11 and 3.12.

Generally, in these two years the interruption frequency ranges from 85 to 468.5 f/yr and the interruption duration ranges from 63.87 to 452.72 Hr/yr. The feeders L1, L2 and L3 having higher number of interruption of faults and L1, L2 and L7 have higher interruption durations.

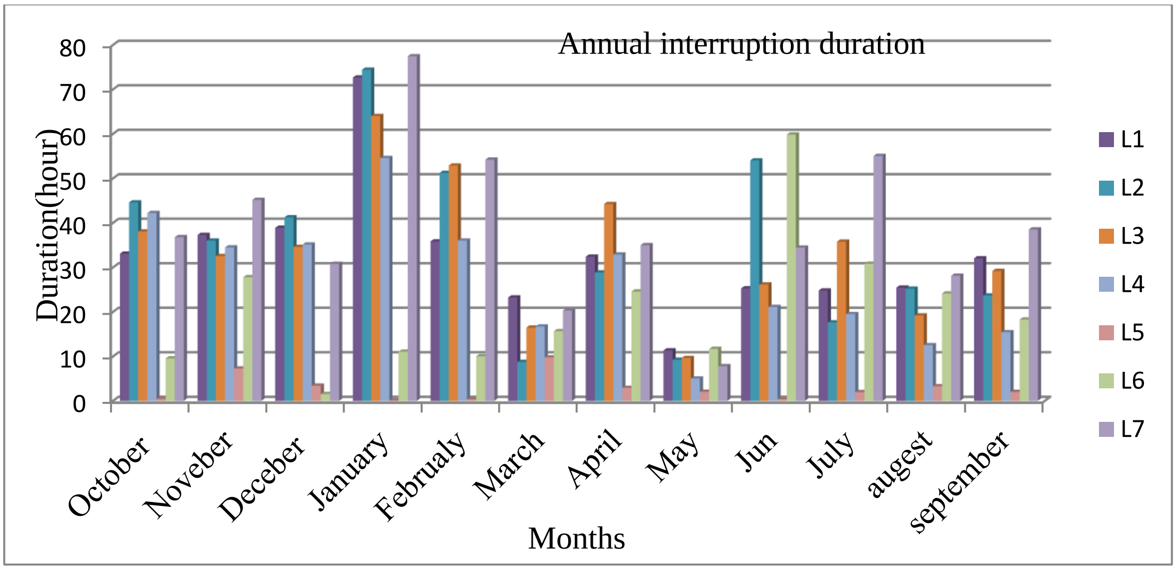

Figure 3.5 Monthly interruption duration from October 2015 to September 2016

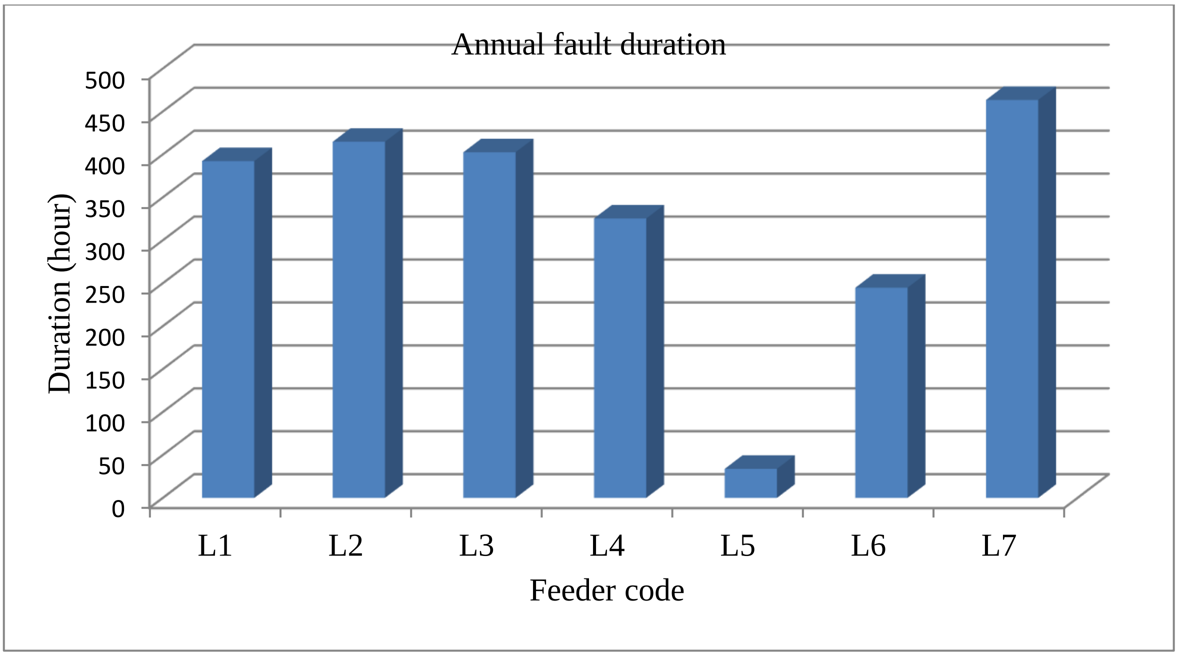

Figure 3.6 Annual interruption duration of feeder from October 2015 to September 2016 GC

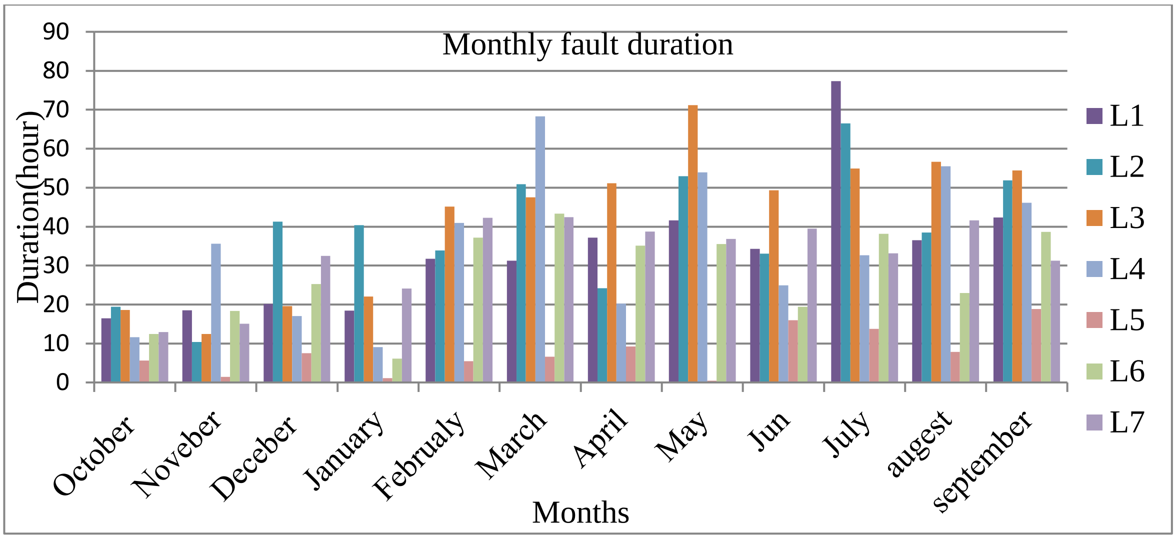

Figure 3.7 Monthly interruption duration from October 2016 to September 2017 GC

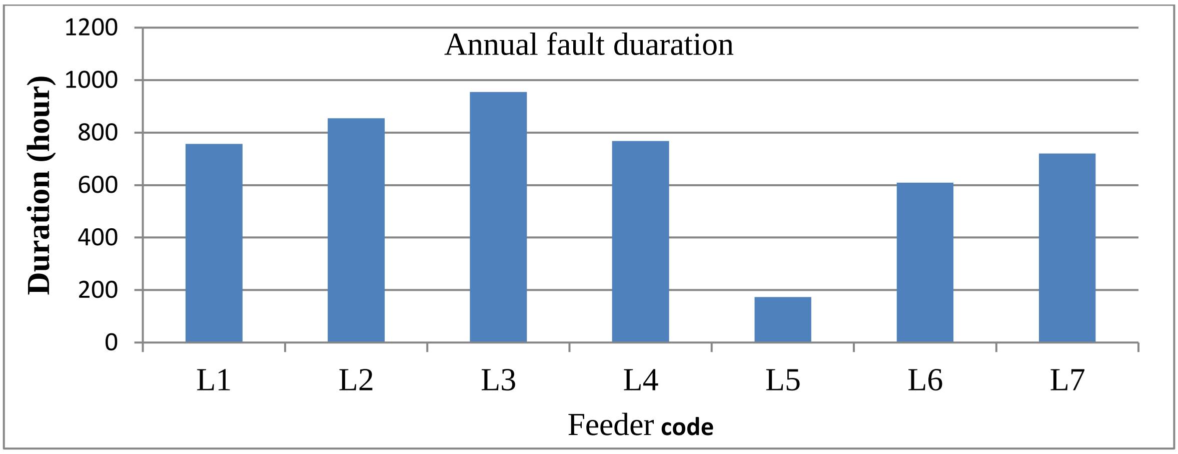

Figure 3.8 Annual interruption duration of feeder from October 2016 to September 2017 GC

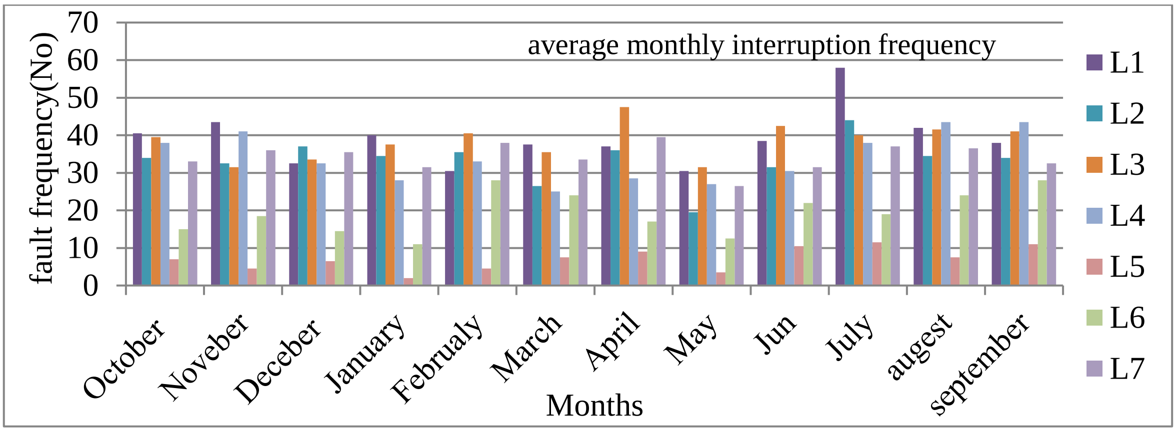

Figure 3.9 Average monthly fault frequency of feeders October 2015 to 2017 GC

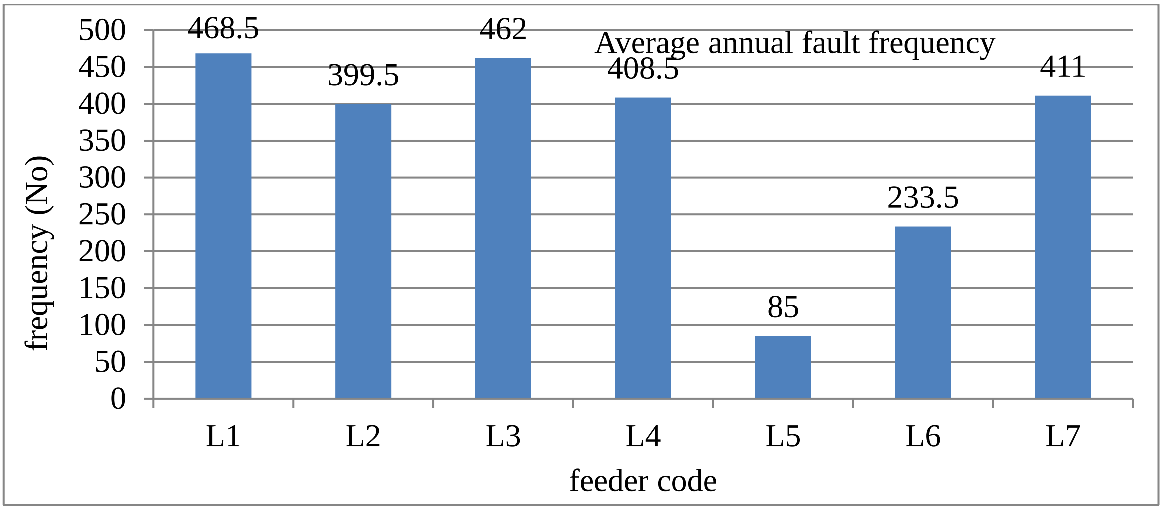

Figure 3.10 Two years average annual fault frequency of feeders October 2015 to 2017 GC

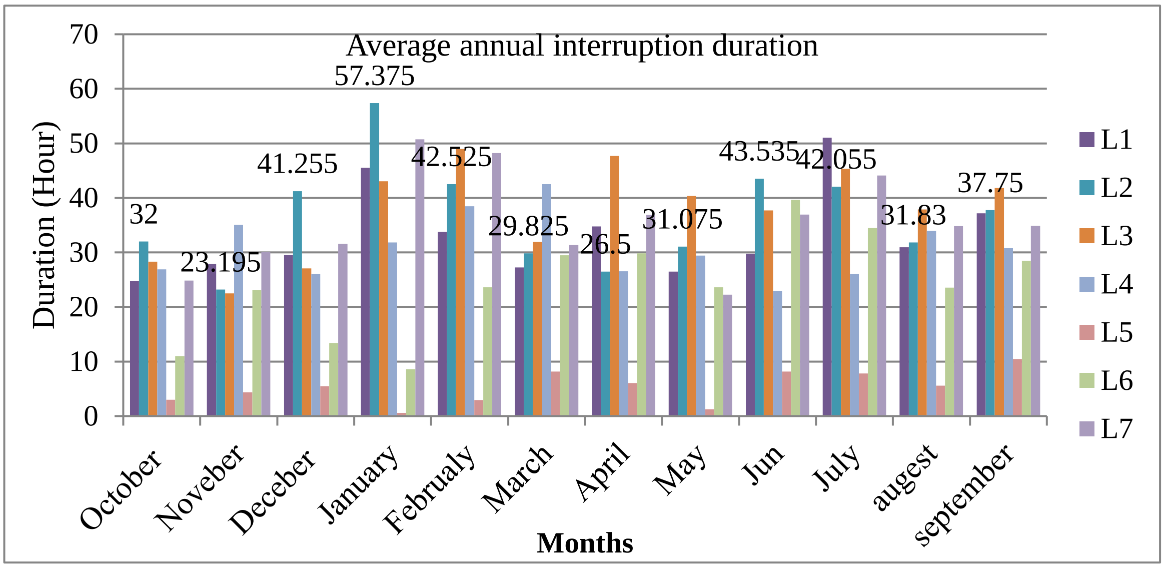

Figure 3.11 Average monthly fault duration of feeders

b) Reliability analysis before upgraded system

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

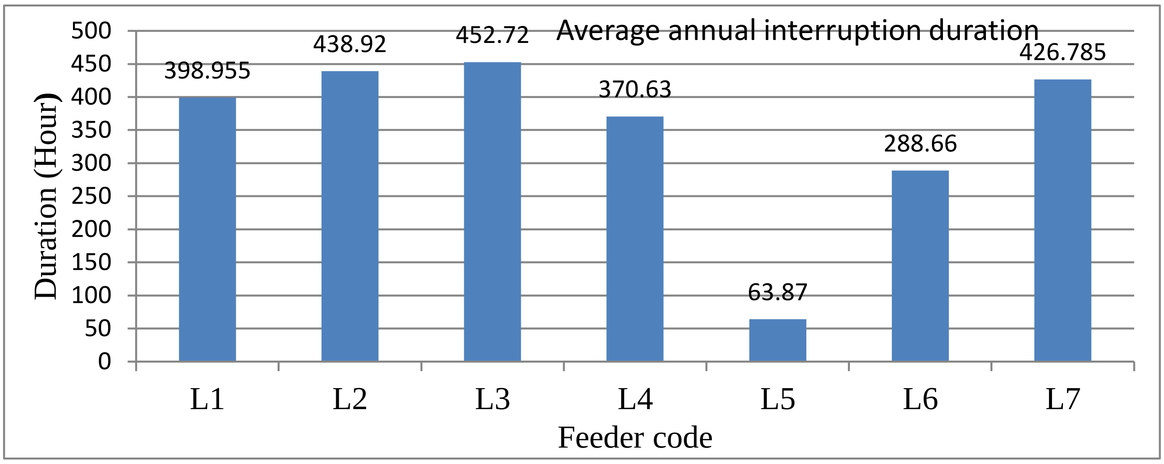

Figure 3.12 Two years average annual fault duration of feeders

As shown chapter two reliability indexes has two types. these are customer oriented and load based reliability indexes. In this thesis work it enough to show system reliability of Adama power distribution system by evaluating customer-oriented system reliability because these well-known reliability indexes enough to show reliability or unreliability of the given power distribution network. Using equations shown from (2.1) - (2.5) customer-based system reliability index are tabulated as depicted in Tables 3.1-3.3. To know SAIFI and SAIDI of a given system, total number customers must be known, but in Adama distributing system all customers connected to a given feeder is interrupted simultaneously during a single fault happened because all feeders have radial configuration, so total customer in a feeder considered as a single customer. And also, to calculate ASAI and ASUI of system, service demand hours must be known, so that service demand time for old system is one year which is about 8760 Hr. Table 3.1 shows system reliability index assessment result of each feeder. From these except L_5 and L_6 all other feeders have SAIFI and SAIDI above 350/year and 390 Hr/year respectively from October 2015 to September 2016 GC. In the same year, feeder L_1 has highest SAIFI, L_7 has highest SAIDI but feeder L5 has lowest in both.

In Adama distribution system, average customer-based reliability indexes of SAIFI, SAIDI, CAIDI, ASAI and ASUI, 314.43 fr/yr,325.24 Hr/yr, 0.997 Hr/interruption, 96.29% and 3.71% respectively in the same year. This show that 314.43 interruptions with duration of 325.24 Hr happened in this year. Every interruption takes almost 1Hr (0.997) to back to normal condition and power is available 96.29% of a year but 3.71% of this year power is unavailable.

In the same fashion, customer-oriented reliability indexes of a year from October 2016 to September 2017 GC as depicted in Table 3.2. relatively, this year have higher indexes with respect to previous year. SAIFI of feeders except L_5 and L_6 have between 427 fr/year and 533 fr/yr, and the minimum is line 5 with SAIFI 115 fr/year. It indicates that Adama city faced higher interruption problem in this year. But relatively to SAIFI, there is less SAIDI in every feeder. The maximum SAIDI occur in feeder 3 (L_3) with 502.94 Hr/yr which is most faulty in distribution system and minimum one is feeder 5 has 93.97 Hr/yr. Adama distribution system supplied power 95.75% of this year and did not 4.25% of it. Adama city waits 0.96 Hr for every fault until the restore to its normal condition almost it is an hour. average of SAIFI and SAIDI of the distribution system are 390.71 fr/yr and 372.05 Hr/yr respectively in this year.

Generally, in two years, line 1and 3 have highest SAIFI, line 2,3 and 7 have highest SAIDI and in terms of CAIDI line 2, 6 and 7 have highest which above an hour. Average system reliability indexes of Adama distribution system in this two-year as shown table 3.3. these are SAIFI has 342.83.71 fr/yr, SAIDI has 335.17 Hr/yr, CAIDU has 0.97 Hr/interruption, ASAI has 96.17% and ASUI has 3.83%. unfortunately, Adama power distribution system unreliable power distribution system.

c) Type of faults in Adama distribution system before upgrading

As clearly seen in the above analysis, the interruption frequencies and durations are excessive in Adama power distribution system. These interruptions can be divided to two type based on their controllability. These are:

- **Planed interruptions**: these are controlled interruptions caused by operators' action to do maintenance or installation work on the distribution system. These include deliberately turning off the substation circuit breaker manly for maintenances of different component of distribution system or expansion of the power network to other areas.

  In Adama distribution system, 40.9% of interruption frequency and 41.33% of interruption duration are due to planned interruptions as shown Table 3.4.

Table 3.1 System reliability index of Adama distribution system from October 2015 to September 2016 GC

No	Feeder	frequency and duration		Customer-Oriented System Reliability Indexes				
		fr	D(Hr)	SAIFI	SAIDI	CAIDI	ASAI	ASUI
1	L1	433	392.14	433	392.14	0.906	95.524	4.4765
2	L2	372	414.7	372	414.7	1.115	95.266	4.734
3	L3	391	402.5	391	402.5	1.029	95.405	4.595
4	L4	362	325.37	362	325.37	0.899	96.286	3.714
5	L5	55	33.77	55	33.77	0.614	99.615	0.385
6	L6	200	244.78	200	244.78	1.224	97.206	2.794
7	L7	388	463.42	388	463.42	1.1944	94.709	5.290
TOTAL		314.43	325.24	314.43	325.24	0.997	96.28	3.71

Table 3.2 System reliability index of Adama distribution system from October 2016 to September 2017 GC

No	Feeder code	frequency and duration		Customer-Oriented System Reliability Indexes				
		fr	(Hr)	SAIFI	SAIDI	CAIDI	ASAI	ASUI
1	L1	504	405.77	504	405.77	0.806	95.36	4.632
2	L2	427	463.14	427	463.14	1.085	94.713	5.2869
3	L3	533	502.94	533	502.94	0.9442	94.258	5.741
4	L4	455	415.89	455	415.89	0.914	95.253	4.747
5	L5	115	93.97	115	93.97	0.817	98.927	1.072
6	L6	267	332.54	267	332.54	1.245	96.204	3.796
7	L7	434	390.15	434	390.15	0.898	95.546	4.454
Average		390.71	372.06	390.71	372.06	0.96	95.75	4.25

- **Unplanned interruptions**: these are power system interruptions due to faults happened in power distribution system. These faults account 59.1% and 58.67% of interruption frequency and duration, respectively as shown in Table 3.4, from which earthing fault (single line ground fault) is 29.42% and 24.48%, short circuit fault is 19.99% and 22.4%, under frequency is 0.42% and 0.19%, over loading is 9.26% and 11.59% in terms of interruption frequency and duration respectively.

Table 3.3 Average system reliability index of Adama distribution system from October 2015 to September 2017 GC

No	Feeder	frequency and duration		Customer-Oriented System Reliability Indexes				
		fr	(Hr)	SAIFI	SAIDI	CAIDI	ASAI	ASUI
1	L1	468.5	398.955	468.5	398.955	0.852	95.445	4.554
2	L2	399.5	438.92	399.5	438.92	1.098	94.989	5.011
3	L3	462	452.72	462	452.72	0.979	94.832	5.168
4	L4	408.5	370.63	408.5	370.63	0.907	95.7691	4.231
5	L5	85	63.87	85	63.87	0.751	99.271	0.729
6	L6	233.5	288.66	233.5	288.66	1.236	96.705	3.295
7	L7	411	426.785	411	426.785	1.038	95.128	4.872
Average		342.83	335.63	342.83	335.63	0.97	96.17	3.83

a) **Loss of Revenue due to Power Interruption in old Distribution system**

A common approach used in quantifying the worth or benefit of electric service reliability is to guess the customer costs associated with power interruptions. The customer interruption cost when an electric provide failure occurs depends on many factors. The lack of many of the data sets required in a detailed evaluation of the customer outage costs makes it difficult to estimate precise individual customer outage costs due to a specific failure event. This part of the thesis work estimates only cost lost by the utility in Adama substation due to interruptions. The electric tariff category for EEU and EEP is shown in Table 3.5.

The cost of energy not supplied due to interruption for Adama Substation is calculated by using equation (3.1).

Cost of energy = $power * interruption\ time * trarff\ for\ electric$power -------- (3. 1)

Table 3.4 Two years Average frequency and duration of fault type from October 2015 to 2017 GC

Feeder code	Frequency & Duration of faults of type									
	Operation		Earthing		Short ckt		Under frequency		Over Load	
	Fr	Hr	Fr	Hr	Fr	Hr	Fr	Hr	fr	Hr
L1	192.5	169.68	120.5	89.56	70	68.02	5.5	2.28	80	69.41
L2	161	192.37	109.5	99.91	84	81.57	0	0	45	65.06
L3	218.5	215.06	116	111.3	82	78.13	0	0	45.5	48.23
L4	168	169.65	137	81.74	76.5	88.35	5	2.3	22	28.58
L5	18	10.31	48	34.63	16	12.3	0	0	3	6.635
L6	92.5	79.42	66.5	75.09	67	120.06	0	0	7.5	14.09
L7	159	172.24	128.5	105.25	98	98.35	0	0	25.5	50.94
TOTAL	1009.5	1008.7	726	597.48	493.5	546.78	10.5	4.585	228.5	282.9
Percentage	40.9	41.33	29.42	24.48	19.99	22.40	0.43	0.19	9.26	11.59

By considering an average price of 0.6 Birr/kWh for electricity in EEU as given in Table 3.6, the average energy not supplied and average cost of energy lost due to power interruption for two years from 2015 -2017 at Adama substation outgoing feeders are calculated and tabulated in Table 3.6 and 3.7.

As shown in Table 3.6, from October 2015 to 2016 GC, 12.74GJ energy is lost due to power interruption which accounts 7.645 Billion Birr. And also, from October 2016 to September 2017 GC, as shown Table 3.4, 14.067 GJ of energy is not supplied to the load end points which has a cost of 8.5 Billion Birr. Within two years, a total energy of 26.909 GJ is not supplied with a cost of 16.145 Billion Birr as shown Table 3.6 and 3.7. Generally, yearly average power not supplied of 35.98MW/yr and energy not sold of 13.454 GJ/yr, its cost is 8.0725 Billion Birr/yr.

3.1.2 Data of Adama substation after upgrading

As previously mentioned, due to the high power need the substation of Adama is upgraded in 2017 twice of its capacity by installing 50MVA mobile substation with 6 lines having 15 kV voltage level but one line is not functional until now. Consequently, since January 2017

GC, Adama substation has 11 outgoing feeders with voltage level of 15kV five feeders from mobile substation and six lines from old substation. Over-loaded feeder of old substation is transferred to mobile substation to minimize over loadings in Adama

Table 3.5 Electricity tariff Ethiopian electric utility (EEU) since July 8, 2007 *[17]*

No	Tariff Category & Block Identification	Monthly Consumption(kWh)	Birr/kWh)	
1	Domestic			
	1st block	0-50	0.273	
	2nd block	51-100	0.3564	
	3rd block	101-200	0.4993	
	4th Block	201-300	0.55	
	5th block	301-400	0.5666	
	6th block	401-500	0.588	
	7th block	above 500	0.6943	
2	General			
	1st block	0-50	0.6088	
	2nd block	above 500	0.6943	
3	low voltage time of day industry			
	Peak		0.7426	
	off-Peak		0.5453	
4	High Voltage Time of Day Industry @ 15KV			
	Peak		0.4736	
	off-Peak		0.3664	
5	High Voltage Industry @ 132KV			
	Peak		0.4736	
	off-Peak		0.3664	
6	Street Lighting Tariff		0.4843	

distribution system and L_2 line load of old substation is totally supplied by M_1 line of mobile substation.

The Mobile substation was first time energized in October 2017 GC with only two feeders M_3 and M_4. But in this study, data were collected after five feeders of Mobile substation were started supplying power to Adama city in January 2018 GC. So, data were collected for only six months, from January to June 2018 GC. Thus, Data is computed and analyzed for six-month duration only for this case.

Table 3.6 Average loading and energy lost during fault from October 2015-september 2016 GC

Feeder name	Average load (MW)	Duration (Hr)	Energy not used (MJ)	Lost Revenue (Birr in Billions)
L1	6.955	392.14	2727.138	1.636
L2	6.348	414.7	2632.758	1.579
L3	6.395	402.5	2573.853	1.544
L4	5.540	325.37	1802.604	1.082
L5	3.533	33.77	119.299	0.072
L6	1.994	244.78	488.1525	0.293
L7	5.175	463.42	2398.005	1.439
Total	35.939	2276.68	12741.81	7.645

Table 3.7 Power and energy lost in Adama distribution system October 2016 to September 2017 GC

Feeder name	Average load (MW)	Duration (Hr)	Energy not used (MWh)	Lost revenue (Birr in Billions)
L1	6.533	405.77	2650.693	1.590
L2	5.815	463.14	2693.159	1.6159
L3	6.25	502.94	3143.375	1.886
L4	6.013	415.89	2500.885	1.501
L5	3.902	93.97	366.718	0.220
L6	2.035	332.54	676.719	0.406
L7	5.475	390.15	2136.071	1.282
Total	36.023	2604.4	14167.62	8.501

a. Frequency and duration of faults of upgraded distribution system

Fig. 3.13 shows monthly interruption frequencies occurred in the six months for the upgraded Adama distribution system. From all 11 feeders, L_3 and L_7 are feeders with higher interruption frequency in this system. Relative to previous interruption frequency history, most of the months have less interruption frequencies after upgrading the distribution system as shown in Fig. 3.15.

The analysis clearly indicates that the new upgraded system has less interruption frequency compared to old distribution system. The maximum interruption frequency is 170 for line L_3. Average interruption frequency of old distribution system for L_1 was 468.5 per year as shown in Fig. 3.10 and for half year interruption it is 234.25. So, one can conclude that the upgraded distribution system has better performance in terms of fault frequency than old system.

As shown Fig. 3.14, the interruption duration is higher than the old system with the maximum monthly interruption duration of 64.13 Hr/month at April on feeder L_6 compared to the old system which is 57.375 Hr/month. In the upgraded system, the monthly interruption duration of four feeders are above maximum monthly interruption duration of old system. As shown figure 3.15, the six-month minimum interruption of the feeders is above 150 Hr and maximum interruption duration is 303.7 Hr. Minimum and maximum duration required to restore system to normal condition is 1 Hr and 2.28 Hr respectively.

b. Type of fault in upgraded system

Type of faults found in upgraded system is almost similar to the old system. In similar way type faults in this system are operational and non-operational faults. The operational faults have interruption frequency of 48.29% and 34.22% of interruption duration in this distribution system. And also 51.71% and 65.78% of interrupting frequency and durations are due non-operational faults respectively. From these non-operational faults earthing fault type contributes in both frequency and duration 27.97% and 30.92% respectively and short circuit fault type has interruption duration of 34.54% and 23.34% of interruption frequency. Feeders L_1 and L_3 are lines that operational faults happened higher fault frequency with longer duration for each fault as shown Table 3.9.

The main deference between old and upgraded distribution system in type fault happened in distribution system is due overloading. That is, the overloading of the upgraded substation is lower than the old substation as shown in Table 3.4 and 3.9.

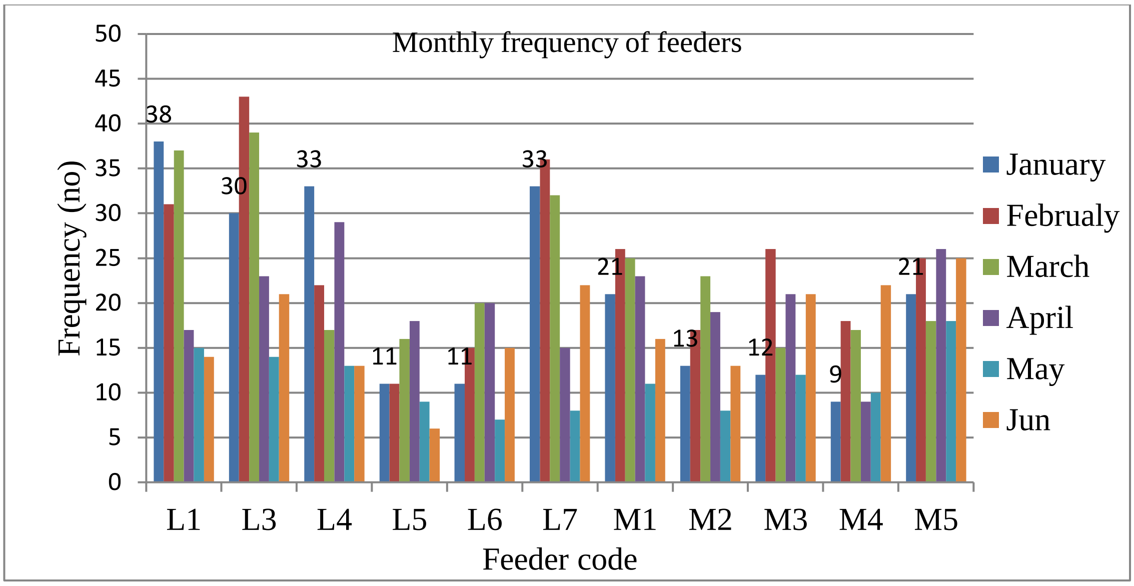

Figure 3.13 Monthly interruption frequency of upgraded Adama distribution system from January to June 2018 GC

c. Loss of Revenue upgraded Distribution system

Loss of revenue due to power interruption in upgraded distribution system is calculated using equation (3.1) and the results are tabulated as shown Table 3.8. For this half year period feeder L_3 lost highest amount of energy accountings 1182.94 MJ with cost of 709.76 Million Birrs. Totally, in upgraded system utility lost 4.579 Billion Birrs/ half yr, as shown Table 3.8. It Approximately 9 Billion Birr per year. As it compares with respect to old system annually it rises by one billion birrs. So, the upgraded system has not any improvement in terms of revenue lost in Adama distribution system due to high interruption duration relative to old system.

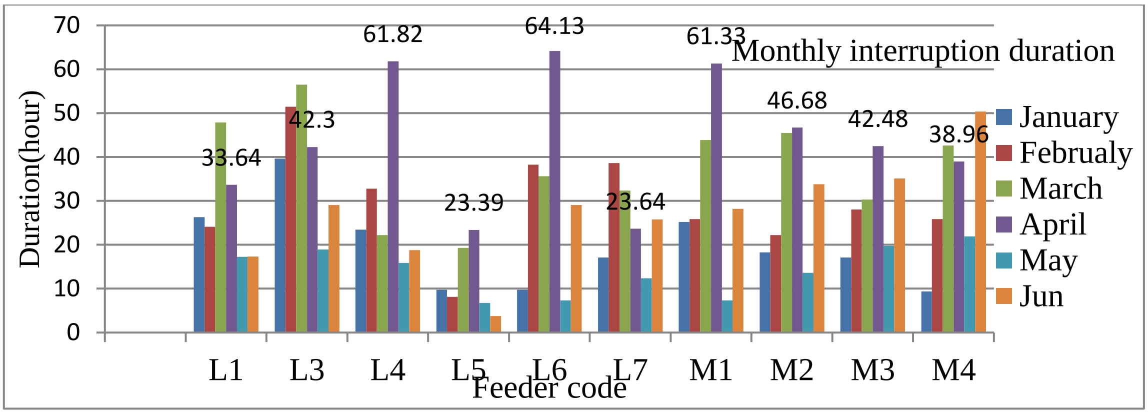

Figure 3.14 Monthly interruption duration of upgraded Adama distribution system from January to June 2018 GC

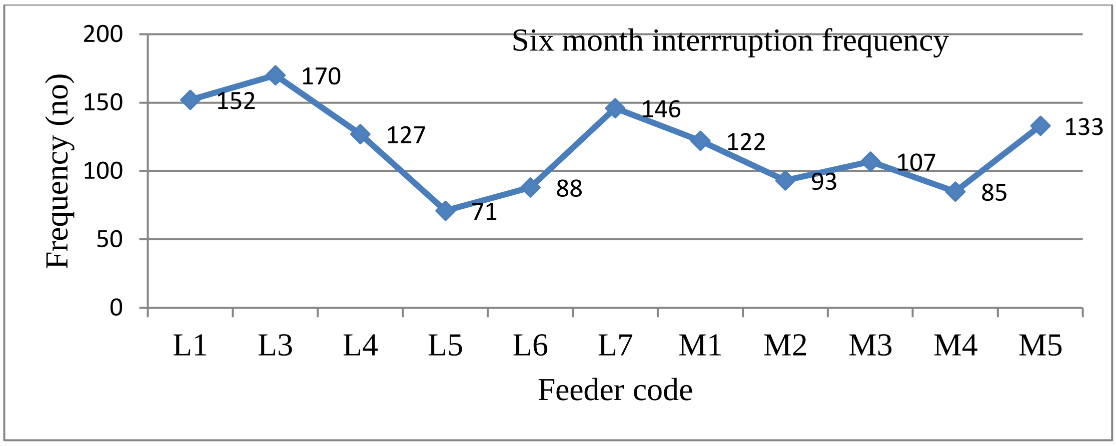

Figure 3.15 Total six-month fault frequency of upgraded Adama distribution system feeders from January to June 2018 GC

a. Reliability analysis of upgraded system

To show the reliability or unreliability of given power distribution system, it is enough calculating two well-known customer-based system reliability indexes. These system reliability indexes can be calculated using formulas given in (2.1) - (2.5), feeders of upgraded system also radial so total customers considered as a single customer and for this system data collected for half year so that service demand hour is half year that is 4380 Hr then results are tabulated in Table 3.10. For feeder L_1, L_3 and L_7 with SAIFI value of 152 fault/customer, 170 fault/customer and 146 fault/customer respectively for the six months. And also, lines L_3 and M_5 have higher SAIDI with 237.88 Hr/half yr and 303.7 Hr/half year respectively. The upgraded substation system's average interruption frequency index is 117.64 fault/customer in half year, for a year it is calculated to be approximately 235.28 faults/customer/yr. This value is less than the SAIFI (342.83) of old distribution system as given Table 3.3 This indicates that number of customers affected by a fault is decrease by increasing number of feeders in a given power distribution system. And also, SAIDU of this system higher than old distribution. It has SAIDI of 183.92 Hr/half year and in a year 367.84 Hr/yr but SAIDI of old system is 235.63 Hr/yr. The CAIDI of all feeders of this system are above 1 Hr/fault and the average CAIDI of feeders is 1.6 Hr/fault which long hour compared with CAIDI of before upgrade average 0.97 Hr/fault. The upgraded system has higher SAIDI than old system because it took long duration for rehabilitation work of distribution system.

Table 3.8 Average power loading and lost revenue of feeders during fault for six months of upgraded system

Feeder code	Average loading (MW)	Duration (Hr)	Energy not used (MJ)	Lost revenue (Birr in Millions)
L1	3.7623	166.53	626.537	375.922
L3	4.973	237.88	1182.938	709.763
L4	3.560	174.86	622.577	373.546
L5	4.981	71.13	354.275	212.565
L6	1.859	184.11	342.261	205.356
L7	3.439	149.93	515.584	309.351
M1	5.205	191.88	998.735	599.241
M2	2.826	180.033	508.773	305.264
M3	4.983	172.86	861.333	516.799
M4	4.532	189.14	857.151	514.291
M5	2.508	303.7	761.578	456.947
Total	42.63	2022.053	7631.741	4579.045

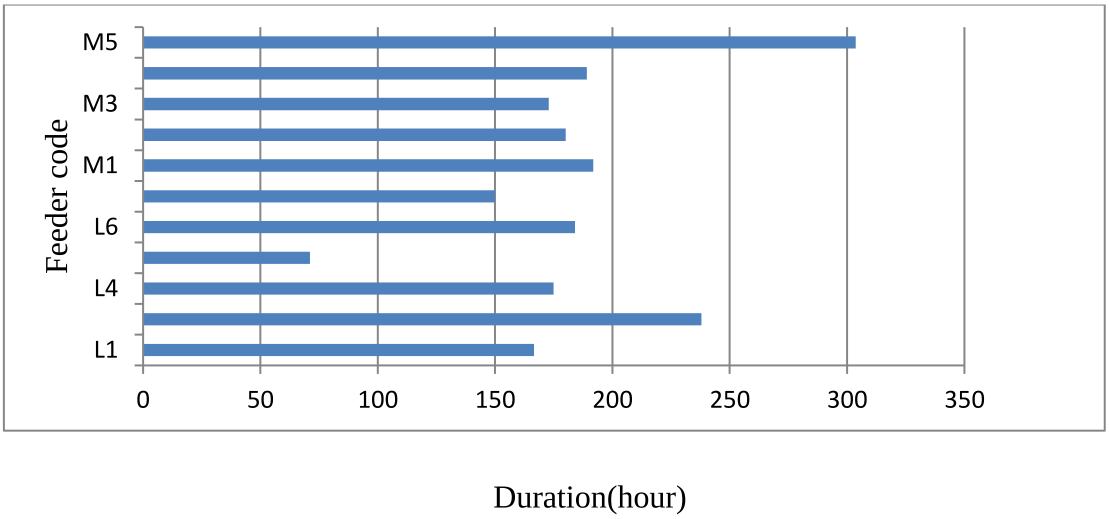

Figure 3.16 Six-month interruption duration of upgraded Adama distribution system of feeders from January to June 2018 GC

3.2 Comparison of power reliability indices of Adama power distribution system with benchmarks

The reliability assessment result of this thesis shows that both old and upgraded power distribution of Adama city have poor reliability. The reliability indices are not within EEA's and international standard values as shown Fig. 3.17 and 3.18. Generally, Adama power distribution system needs urgent rehabilitation in order to improve the reliability problem of Adama city.

3.3 Causes of interruption in Adama distribution system

Even though there are deferent cause of power interruption in Adama distribution system, based on data collected for two-month cause of power outage in it are summarized as the following:

3.3.1 Equipment failures

Each piece of apparatus on a distribution system has a probability of failing. When first installed, a piece of equipment can fail due to poor manufacturing, damage during shipping, or improper installation. Healthy equipment can fail due to excessive currents, excessive voltages, mischievous animals, severe weather, and many other causes. Sometimes equipment will stop working spontaneously for reasons such as chronological age, thermal age, state of chemical decomposition, state of contamination, and state of mechanical wear.

The most common modes of failure for equipment in Adama power distribution system are shown in Table 3. 11.. Data collected during two-month shows that equipment have failed in old system, 181 times on the distribution system and the repair time them was 209.93 Hr. So, individual faults consume above an hour to restore system in to normal condition. This higher failure rate of equipment is due to failure of tap connection, lines, transformer, load switch, gantry and pole in the distribution system. From this failures load switch has the highest percentage of 14.1% and15.74%, in terms of interruption frequency and duration respectively. In system, 36.64% of short circuit faults are happened due to failure of section switch and maintenance of them has taken 34.43% time of the short circuit faults. Feeder L_5 is mostly affected by line, tape and section switch failure and also took the longest time to restore the line. Lines 1 and line 3 are among lines that have frequent equipment failures in system.

Table 3.9 Type of fault in upgrading Adama distribution feeders

Feeder	Frequency & Duration of interruption									
	Operation		Earthing		Short circuit		Over Load		under frequency	
	fr	Hr	Fr	Hr	fr	Hr	fr	Hr	Fr	Hr
L1	105	88.97	27	46.65	18	28.28	0	0	2	2.63
L3	104	112.4	33	51.84	33	73.64	0	0	0	0
L4	52	64.19	45	70.11	28	38.01	0	0	2	2.55
L5	35	40.08	29	21.72	6	8.13	1	1.2	0	0
L6	41	50.33	25	55.29	22	78.49	0	0	0	0
L7	84	77.28	26	27.33	36	45.32	0	0	0	0
M1	42	52.07	40	49.45	40	90.36	0	0	0	0
M2	38	49.4	29	48.7	26	81.93	0	0	0	0
M3	39	39.57	37	48.96	31	84.33	0	0	0	0
M4	33	49.4	29	75.16	23	64.58	0	0	0	0
M5	52	68.35	42	129.9	39	105.4	0	0	0	0
Total	625	692.1	362	625.2	302	698.4	1	1.2	4	5.18
Percentage	48.29 %	34.22 %	27.97 %	30.92 %	23.34 %	34.54 %	0.05 %	0.06 %	0.31 %	0.26 %

Table 3.10 Customer based reliability indexes of upgraded Adama distribution system from January to June 2018 GC

Feeder code	frequency and duration		System Reliability Indeces				
	Fr	(Hr)	SAIFI (fr)	SAIDI (Hr)	CAIDI (Hr./fault)	ASAI (%)	ASUI (%)
L1	152	166.53	152	166.53	1.09	96.19	3.8
L3	170	237.88	170	237.88	1.39	94.57	5.43
L4	127	174.86	127	174.86	1.38	96.01	3.99
L5	71	71.13	71	71.13	1.0	98.	1.62
L6	88	184.11	88	184.11	2.09	95.79	4.20
L7	146	149.93	146	149.93	1.03	96.58	3.42
M1	122	191.88	122	191.88	1.57	95.62	4.38
M2	93	180.03	93	180.03	1.94	95.89	4.11
M3	107	172.86	107	172.86	1.62	96.05	3.95
M4	85	189.14	85	189.14	2.23	95.68	4.32
M5	133	303.7	133	303.7	2.28	93.07	6.93
Average			117.66	183.82	1.6	95.8	4.19

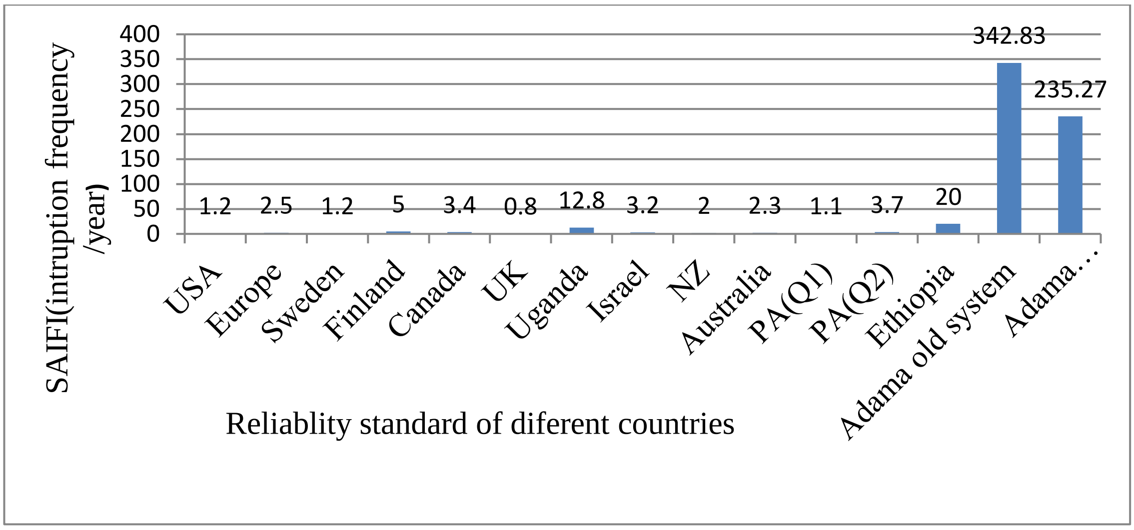

Figure 3.17 SAIDI of Adama power distribution system with respect to countries reliability benchmark

This thesis also studied what type of equipment failed after Adama distribution substation is upgraded from 50MVA to 100MVA and distribution network from 7 outgoing feeder to 11 for two months. In the upgraded system, 41.95% of interruption frequency and 43.15% of interruption duration were due to equipment failure as shown in Table 3.13 and 3.14. In the two-months of data collection, the upgraded distribution system has 227 equipment failures registered and associated 378.95 Hr of repair time. From these equipment failures, switch failure is a major problem which has an interruption frequency of 23.66% and interruption duration of 25.41%, so that if Adama utility solves this problem 56.39% of frequency and 58.88% of duration of equipment failure problem is answered. For the upgraded system, feeders L_7 and M_5 have the highest equipment failure frequency happened in this period of time with frequency of 36 and 31 respectively, and also line M_5 took also the highest time for restoring it to normal operation condition.

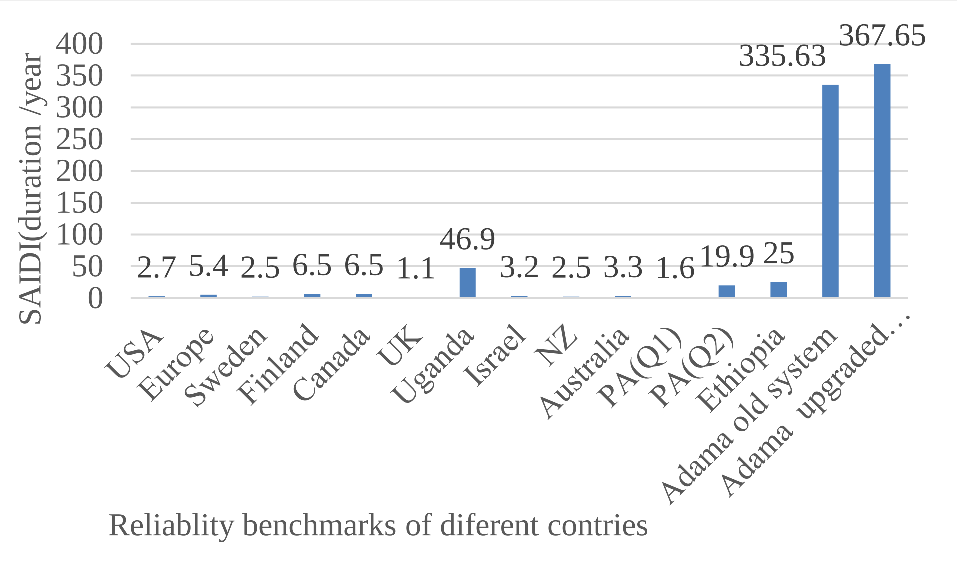

Figure 3.18 SAIFI of Adama power distribution system with respect to countries reliability benchmark

Within two-month, the upgraded system has lower numbers of average interruption frequency that 36 interruptions per feeder than before substation upgraded that is 37 interruptions per feeder. This shows one important of upgraded system is number of customers affected by a single fault is reduced. But number of equipment failure in upgraded system (227) is higher than old system (181) as shown Table 3.12 and 3.13. Interruption duration of upgraded system per feeder is 34.45 hr and old system is 29.99 hr, So, the upgraded system consumes more amount of time to recover failed equipment to normal operation.

3.3.2 Operational faults

It is sometimes necessary to break off customer service when performing work on radial distribution systems. Since this work is planned in advance, customers can be notified as to the time and expected duration of the interruption. Advance knowledge greatly reduces the economic impact and negative perception that interruptions have on end user.

Table 3.11 Duration of equipment failure in Adama distribution system before upgrading

Feeder code	Tap failure	Line failure	Failure around distributions Transformer	Section switch failure	Gantry failure	Pole failure	Total
	Hr	Hr	Hr	Hr	Hr	Hr	Hr
L1	0.33	5.33	3.99	5.68	0	0	15.33
L2	0	2.08	11.08	11.52	0	0.83	25.51
L3	5.13	3.21	2.17	20.86	0	0	31.37
L4	2	0.55	3.25	10.49	0	2.17	18.46
L5	0	2	0	1.75	1	1.17	5.92
L6	32.41	23.09	18.42	19.34	0	0	93.26
L7	0	2.84	5.45	9.96	1	0.83	20.08
Total	39.87	39.1	44.36	79.6	2	5	209.93
Percentage	7.88	7.73	8.77	15.74	0.39	0.99	41.51

Table 3.12 Frequency of equipment failure in Adama distribution system before upgrading

Feeder code	Tap failure	Line failure	Failure around distributions Transformer	Section switch failure	Gantry failure	Pole failure	Total
	Fr	Fr	Fr	Fr	Fr	Fr	Fr
L1	2	9	15	10	0	0	36
L2	0	4	9	10	0	1	24
L3	8	4	9	16	0	0	37
L4	4	3	11	11	0	1	30
L5	0	2	0	2	1	1	6
L6	12	4	2	7	0	0	25
L7	0	3	7	9	1	3	23
Total	26	29	53	65	2	6	181
Percentage	5.64	6.29	11.49	14.1	0.43	1.30	39.26

Table 3.13 Frequency of equipment failure in Adama distribution system after upgrading

Feeder code	Tap failure	Line failure	Transformer failure	Section switch failure	Gantry failure	Pole failure	Total
	Fr	Fr	Fr	Fr	Fr	Fr	Fr
L1	2	1	10	9	1	0	23
L3	0	4	3	13	1	0	21
L4	0	1	7	15	1	1	25
L5	0	0	0	3	1	0	4
L6	2	0	0	5	4	1	12
L7	2	5	7	19	2	1	36
M1	0	3	5	13	3	0	24
M2	0	0	5	15	0	0	20
M3	3	0	4	7	1	1	16
M4	0	2	3	9	1	0	15
M5	3	1	6	20	0	1	31
Total	12	17	50	128	15	5	227
Percentage	2.22	3.14	9.24	23.66	2.77	0.92	41.95

Certain types of distribution maintenance require equipment to be de-energized and grounded. During maintenance, all customers downstream of the maintenance location will experience interruptions unless they can be fed from an alternate path. Even if the system can be reconfigured to restore certain customers, short interruptions may be necessary since many switches can only be switched while de-energized. Even if all switches are capable of making and breaking load, operating the system as a temporary network may be unacceptable and customer interruptions may be required.

The situation is similar for feeder cutovers. Before load can be transferred from an original feeder to an existing or new adjacent feeder, it may need to be de-energized. If load break switches are not available, both feeders need to be interrupted at the feeder breaker until the cutover is complete.

Table 3.14 Duration of equipment failure in Adama distribution system after upgrading

Feeder code	Tap failure	Line failure	Transformer failure	Section switch failure	Gantry failure	Pole failure	Total
	Hr	Hr	Hr	Hr	Hr	Hr	Hr
L1	0.33	0.33	30.03	9.28	2.5	0	42.47
L3	0	12.34	1.08	27.16	0.83	0	41.41
L4	0	1.7	11.04	12.22	1.33	1	27.29
L5	0	0	0	4.25	2.33	0	6.58
L6	2	0	0	23.43	9.26	2.33	37.02
L7	0.58	3.33	7.8	11.89	2.83	1	27.43
M1	0	14.67	4.2	22.32	3.34	0	44.53
M2	0	0	2.26	42.33	0	0	44.59
M3	2.52	0	2.83	8	0.42	1	14.77
M4	0	17.08	1.62	12.08	0.58	0	31.36
M5	1.16	3.83	2.34	50.17	0	4	61.5
Total	6.59	53.28	63.2	223.13	23.42	9.33	378.95
Percentage	0.75	6.07	7.19	25.41	2.67	1.06	43.15

Feeder expansions also require scheduled interruptions. Since the expansion location must be de-energized before a feeder extension can be connected, all customers downstream of this point (on the original feeder) may need to be interrupted. The use of live-line construction techniques can avoid these types of interruptions.

Scheduled power interruption in distribution system is common causes of interruption which can be reduced but can’t prevent it especially radial distribution system like Adama city. This cause of interruption in Adama city includes switched off main feeder breaker for maintenance, for rehabilitant work of china project, for load sharing and for finding fault location when fault occur in MV feeder line.

Operational interruption is main cause of power interruption in Adama distribution system. As shown Table 3.15, in the old system frequency and duration of operational interruptions are 35.79% and 39.92% of total faults which happened in Adama distribution system respectively. In this system, the maintenance took on average 1 hour and 13 minutes to restore the system to normal operating condition for each scheduled interruption.

And also, after distribution system upgrade, the frequency and duration of operational interruptions are 25.88% and 32.19% respectively as shown in Table 3.16. This system has 2-hour of restoration time.

Generally, scheduled interruption is main reliability problem in Adama power distribution network. In every two days, the feeder lines switched off for operational faults in Adama distribution system. So, the utility should consider how to schedule the maintenance and operational practices of the system.

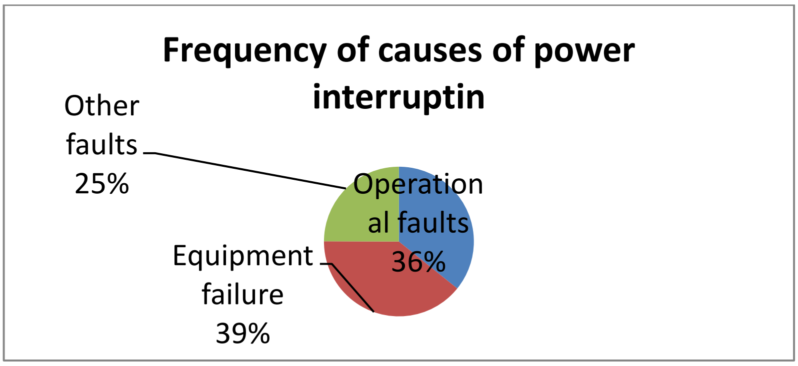

Figure 3.19 Interruption frequency of cause of faults in Adama old distribution system

Table 3.15 Frequency and duration of operational and others faults of old Adama power distribution system

Feeder code	operational faults		other faults	
	Fr	Hr	Fr	Hr
L1	32	28.41	21	9.26
L2	18	24.58	22	14.24
L3	43	41.24	25	33.93
L4	31	45.58	17	12.58
L5	1	0.25	6	3.98
L6	13	17.76	6	3.19
L7	27	44.69	18	16.71
Total	165	202.51	115	93.89
Percentage	35.79176	39.91682	24.94577	18.50669

3.3.3 Other fault causes

Other fault includes fault due to transient, clearance, birds, animals and unknow fault cause happened in Adama distribution system. In Adama distribution system, other interruption causes have 24.95% of fault frequency and 18.51% duration interruptions old distribution system as shown Table 3.15 and for upgraded frequency of other fault causes have 32.16% and fault duration 24.74% as shown Table 3.16.

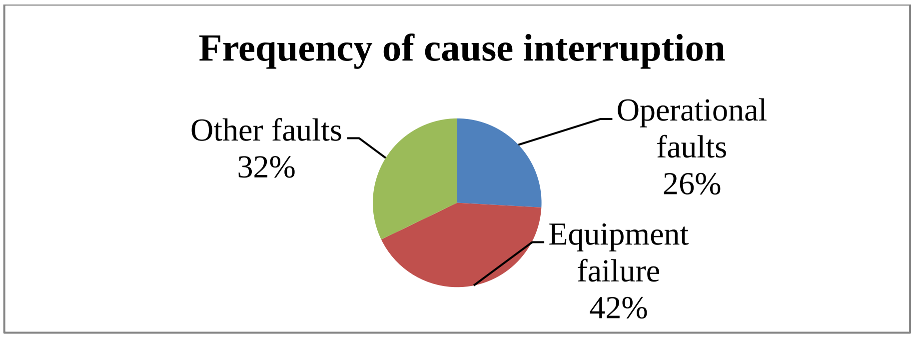

Figure 3.20 Percentage of interruption frequency of cause of interruption of Adama upgraded power distribution system

Table 3.16 Frequency and duration of operational and others faults of Adama upgraded power distribution system

Feeder code	operational faults		other faults	
	Fr	Hr	Fr	Hr
L1	12	13.78	9	9.4
L3	20	40.43	22	14.55
L4	12	23.34	17	11.7
L5	5	5.33	6	3.72
L6	9	54.51	5	10.01
L7	12	23.2	20	16.51
M1	17	25.08	21	25.76
M2	8	13.66	27	61.11
M3	15	19.24	13	10.47
M4	13	18.03	13	19.46
M5	17	46.59	21	35
Total	140	283.19	174	217.69
Percentage	25.878	32.1869	32.16266	24.74228

3.4 Gaps and improving reliability problem of Adama distribution network

Traditionally, efforts to improve the reliability of electrical service within an industrial plant or other facility with critical power requirements have focused on increasing the reliability of the electric utility supply. Facility operators may not be in a position to improve the reliability of their utility supply, as such improvements may be very costly, and they have no impact on outages resulting from internal failures. Facility operators, as a result, focus their attention on critical areas within their own system. A logical approach to the analysis of options available in the electrical system will lead to the greatest reliability improvement for the least cost [18, p. 89].

As explained in the above section, the two-distribution system of Adama city are not reliable. So, this thesis made an attempt to identify the gaps in the distribution system and proposes improvement methods as follows:

3.4.1 Utility supply

The 1974 survey of electrical equipment reliability in industrial plants and subsequent investigations showed the utility supply to be the largest single component affecting the reliability of distribution system [18, p. 90]. Most customers simply hook up to the utility system and do not fully recognize that their reliability requirements can have an impact on how the utility supplies them. A utility is somewhat bound by the system available at the customer site and the investment that can be made per revenue dollar. However, most utilities are willing to discuss the various supply systems that are available to their customers. Many times, an option is available (sometimes with financial sharing between the user and the utility) that will meet the exact reliability needs of a specific facility. It is well known that there is financial shortage at EEU. So, utility managements should mobilize the customers to share cost for improvement to reduce its financial crisis.

3.4.2 Configuration

One major factor that influences the reliability of a power distribution system is the configuration of the system. It includes configuration of substation topology and distribution network. The system configuration, as determined from the one-line diagram, determines the inherent reliability that can be obtained from the system without adding or rearranging components. This should be the first level of analysis, in which vulnerabilities due to single paths, common-mode failure points, capacity shortfalls, etc., can be identified.

One-line diagram

The blueprint for electrical analysis is the *one-line diagram*. The existence of an up-to date one-line diagram is important for any plant electrical engineer. It is the road map of the electric system [18, p. 94].

The one-line diagram should start at the incoming power supply. Standard IEEE symbols must be used in representing electrical components. It is usually impractical to show all circuits in a plant on a single schematic, so the initial one-line diagram should show only major components, circuits, and panels. More detailed analysis may be required in critical areas, and additional one-line diagrams should be ready for these areas as required.

In Adama distribution system getting an updated one-line diagram is somewhat hard, as there is no responsible office or body for this. So, absence of one-line diagram ~~is~~ makes difficult to know and improve reliability problem of the given system. Since an analysis is being made from the one-line diagram, the type, size, and rating of each device as well as its availability should be shown on the diagram.

The one-line diagram might show planned, as well as real, feeder circuit breaker and substation loads based on actual measurements. In most facilities, load is added or deleted in small additions, and the net effect is not always seen until some part of the system becomes overloaded or underloaded. This is one of the serious problems of Adama distribution system.

Most of the secondary outing feeders of distribution transformers are having no fuse, making the distribution transformer without any protection means. Many times, circuits are added without appropriate modification of the existing settings on the associated upstream circuit breakers. In addition, original designs may not have included special attention to the critical areas of production. With these thoughts in mind, the following information should be added to the one-line diagram [18, p. 95]:

- The original system should be identified. The exact nature of the new loads and their approximate locations should be noted.
- Critical areas of the system should be highlighted.

- The component reliability data key should be inserted so that the reliability performance of the revised system can be analyzed on an “if new” basis.

For complex systems, it is beneficial to generate an overall one-line diagram at a reduced level of detail that permits viewing the whole system topology on a single sheet. It is advantageous to contain the incoming supply, switchgear, main feeders, substations, secondary tie circuits, and major equipment such as large motors or other concentrated loads on the overall diagram. This can be supplemented by drawings comprising full detail of relaying, metering, and substation loads at larger scale spread over several sheets. After completion of the one-line diagrams, a comprehensive analysis can begin. However, the general inspection can, and should, be done concurrently with the preparation of the one-line diagram(s).

Distribution configuration

The main gap that affects the reliability of Adama distribution system is choosing the right distribution configuration. The Adama distribution system uses radial configuration which is a major cause of low power reliability.

In power system, the following different distribution configuration may be used for the connection of an electrical installation to a MV utility distribution network:

a) **Radial configuration (Single-line service):** Radial feed systems (Figure 3.21) are well defined as having a single source and single load with no interconnections to other sources [19]. The substation is fed by a tee-off from the MV radial network, also known as a spur network. This method offers only one supply for loads. It is widely applied for installations including a single MV/LV transformer with LV metering. It can also be used without any limitation for installations with MV metering including either several MV/LV transformers or even an internal MV distribution network. The connection is done by means of a single load break switch associated to an earthing switch dedicated to overhead line or underground cable grounding. This principle can be the first step of the two other methods of connection (ring main and dual parallel feeders), the upgrading of the substation being generally attained during an extension of the installation or required by the adjunction of loads asking a higher level of supply continuity. Generally, the pole-mounted transformers in rural areas are connected to the overhead lines along with this principle without load break switch nor fuses. Protection of the line and associated switching devices are located in the remote substations delivering the overhead distribution network [20].

are the least expensive to build and limit losses

Limitations: Radial feed systems have the highest interruption impact

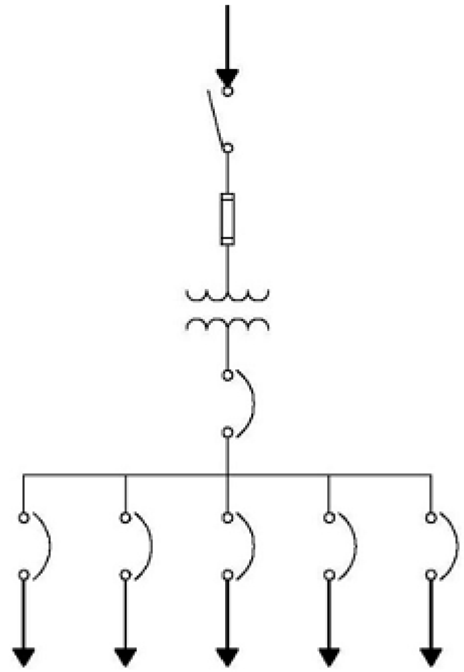

Figure 3.21 Radial configuration *[19]*

Benefits: Radial feed systems because of being unable to feed load from other sources of power. Overhead systems typically employ fuse saving methods using reclosers and sectionalizers to diminish the impacts of the majority of faults that are self-clearing.

b) **Loop configuration (Ring-main service**): Loop systems (Figure 3.22) loop through the service area and then back to the source. Alternate paths for the service feeder may be installed. The substation is connected to a loop of the medium voltage distribution system. The line current passes through the substation which provides the possibility to feed the substation by two different ways. With this arrangement, the user gets a reliable power supply based on two redundant MV feeders. The connection is done by means of two independent load break switches, individually associated to an earthing switch for underground cables earthing. This method is mostly applied for the underground MV distribution networks found in urban areas.

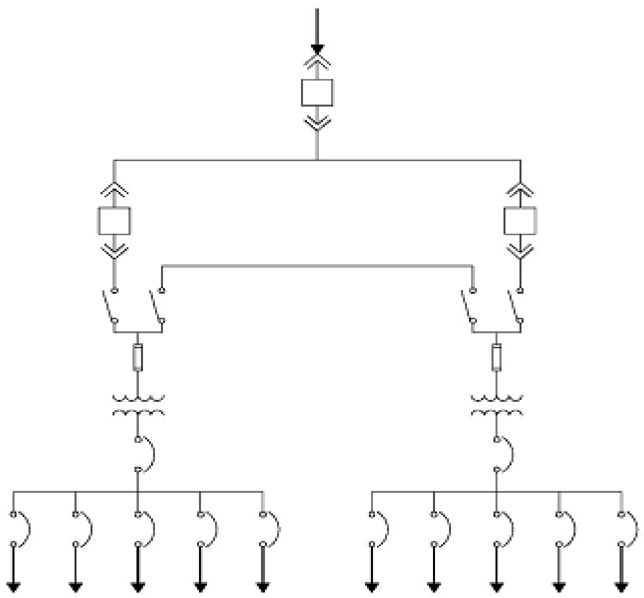

Figure 3.22 Loop configuration *[19]*

Benefits: This is the subsequent lowest cost system. The ring system gives another backup for the primary power feed. If a failure of the system is noted, power can be redirected through a re-configuration of the loop automatically, or manually as the system is set up. If system operate a loop-feed closed, it can decrease the events that the entire system sees when the downstream protective devices are properly coordinated. But more fault current is available due to the paralleling effect, which is not desirable.

Limitations: By working it open-looped, you are eliminating some of the benefits of building the loop. However, in the event of a typical interruption caused by a blown splice on a feeder cable, the outage will take down the whole loop. Additionally, troubleshooting may be more difficult, based how the loop is installed.

Adama distribution system has a radial feeding system which has lowest expenses over other distribution configuration but results in higher reliability problem. So that, to mitigate this reliability problem, this thesis proposes the utility to change distribution configuration of Adama city from radial to loop-feed configuration.

Substation Configurations

Substation configuration is affects reliability of substation and distribution system. selection of substation configuration one method that enhance reliability of given distribution network. There are different substation configurations in power system, some of them are listed and explained as following:

- **Double Feed (Double Bus)**: In a double bus system (Figure 3.23), two identical busses are   in such a way that any outgoing or incoming feeder can be taken from any of the bus. Every feeder is connected to both of the buses in parallel through individual feeds. With double feeds, only the loads are individual. The system is able to have a failure of any individual feed and have a spare component substituted into its place.

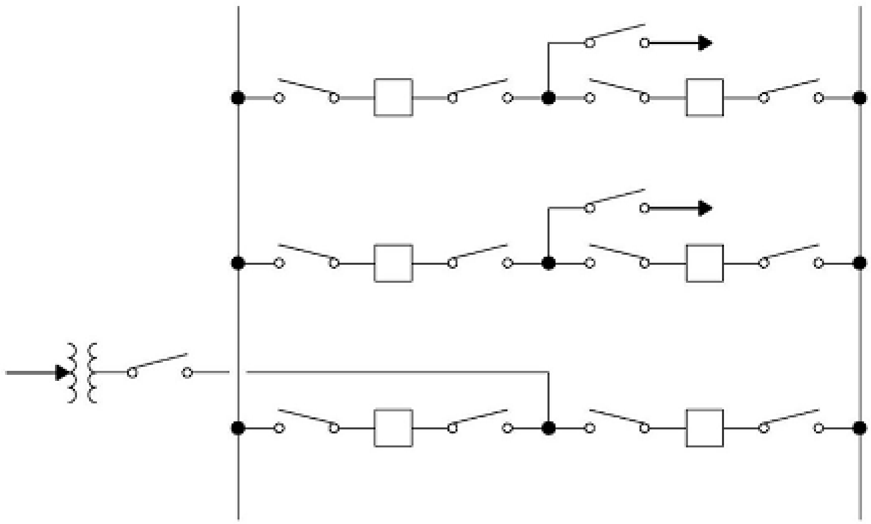

Figure 3.23 Double busbar configuration *[19]*

Benefit: Double bus configuration increases flexibility for maintaining service through outages and performing maintenance in substations.

Limitations: Any large fault on the system will affect both buses. This is also the most expensive system, and has a lower reliability than a ring bus due to the fact that the radial feeds are not able to be maintained or replaced without taking the end load down.

- **Straight Bus (single bus)**: A straight bus (Figure 3.24) is one where there is one source, and individual feeds to the loads. This is the same as the radial feed described above for connectivity purposes.

Benefit: Straight bus/radial feed systems are the least expensive to build and radial feeds limit losses when there is a problem as only the loads on that system are affected.

Limitation: Straight bus/radial feed systems have the highest outages and highest mean time to repair due to the entire load being unable to be fed from other sources of power.

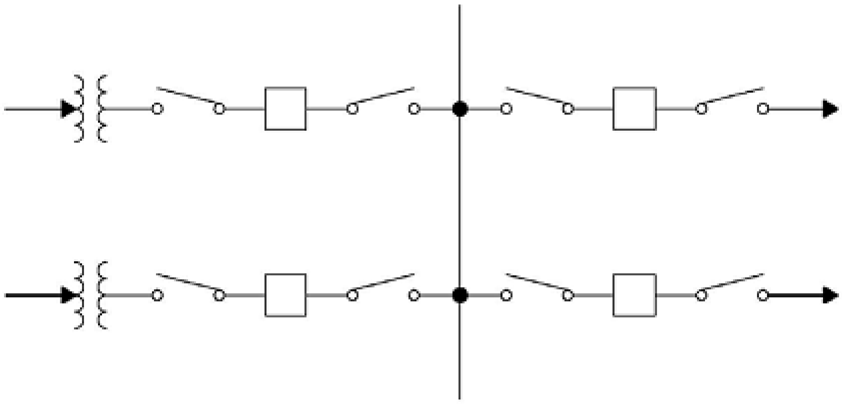

Figure 3.24 Single bus configuration *[19]*

- **Ring Bus.**: A ring bus (Figure 3.25) is identical to a loop feed on the distribution side. This allows switching components to feed any load based upon faults anywhere on the bus structure. Loop systems must be carefully applied, as tying the two systems together, or completing the loop, will result in a future fault taking down both sides of the loop, rather than just one side. A loop system is fault tolerant to the extent that the faulted portion of the loop can usually be isolated and the entire ring placed back into service while the damaged portion is repaired.

Benefits: A loop system loops through the service area and then returns to the source. Sometimes there are alternate sources for the power, sometimes just alternate paths.

Fault Tolerance: This system is more expensive that a single bus, however reliability is increased based upon the ability to move feeds to loads from any direction on the bus.

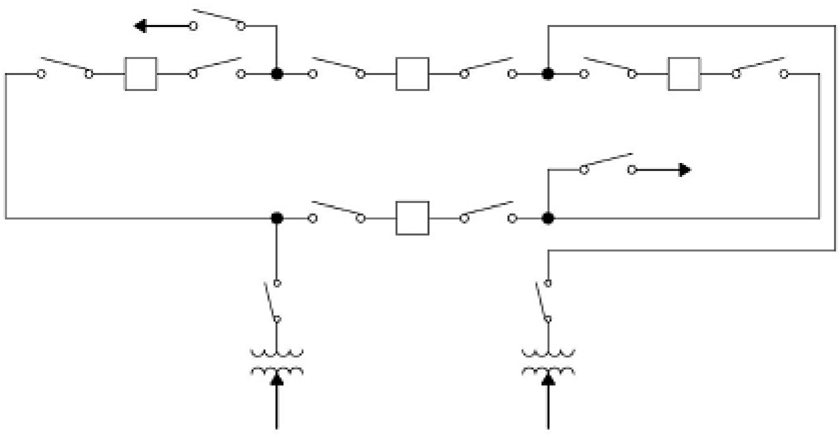

Figure 3.25 Ring bus configuration *[19]*

- **Breaker-and-a-Half:** The breaker and a half system (Figure 3.26) is an advance on the double breaker scheme as costs are lowered by reducing the number of required circuit breakers. For every two circuits, only one spare breaker is provided. The protection is however complexed since it must associate the central breaker with the feeder whose own breaker is taken out for maintenance. Because of the high costs of equipment, even this scheme is not very familiar. As shown in the figure that it is a simple plan, two feeders are fed from two different buses through their associated breakers and these two feeders are tied by a third breaker which is called tie breaker. Normally all the three breakers are closed and power is supplied to both the circuits from two buses which are operated in parallel. The tie breaker acts as coupler for the two feeder circuits.

Benefits: During any fault on any one of the buses, that faulty bus will be cleared instantly without interrupting any feeders in the system since all feeders will continue to feed from other healthy bus; however, it is cheaper than the double breaker configuration.

Limitation: This scheme is very expensive due to investment for third breaker.

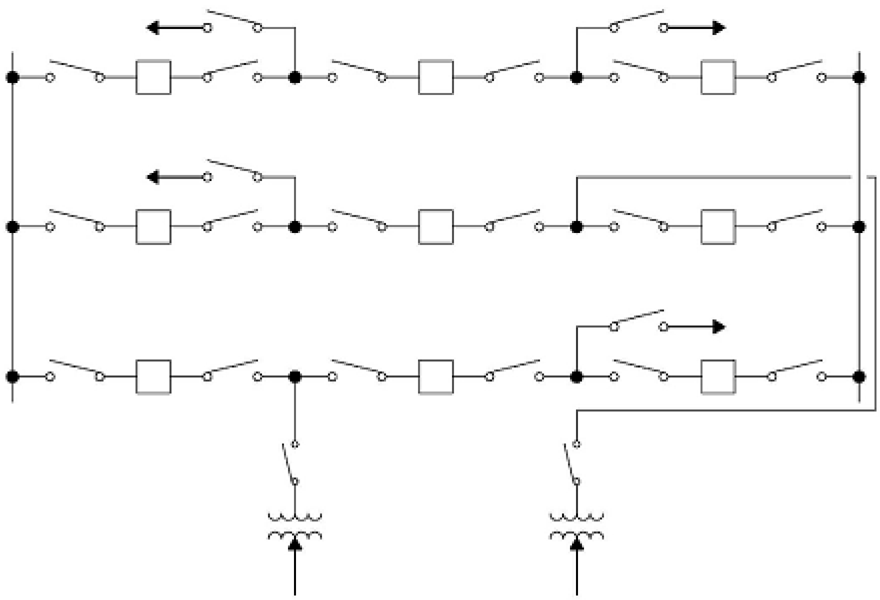

Figure 3.26 Breaker and half configuration *[19]*

- **Network Model:** A Network model (example provided in Figure 3.27) is a configuration using several of the above mentioned configurations. This allows many options and many configurations. However, this flexibility, because of complexity, requires a cybersecurity certified SCADA (Supervisory Control and Data

Acquisition) system and highly trained operators to control feeders, monitor status, control breakers, and report maintenance issues.

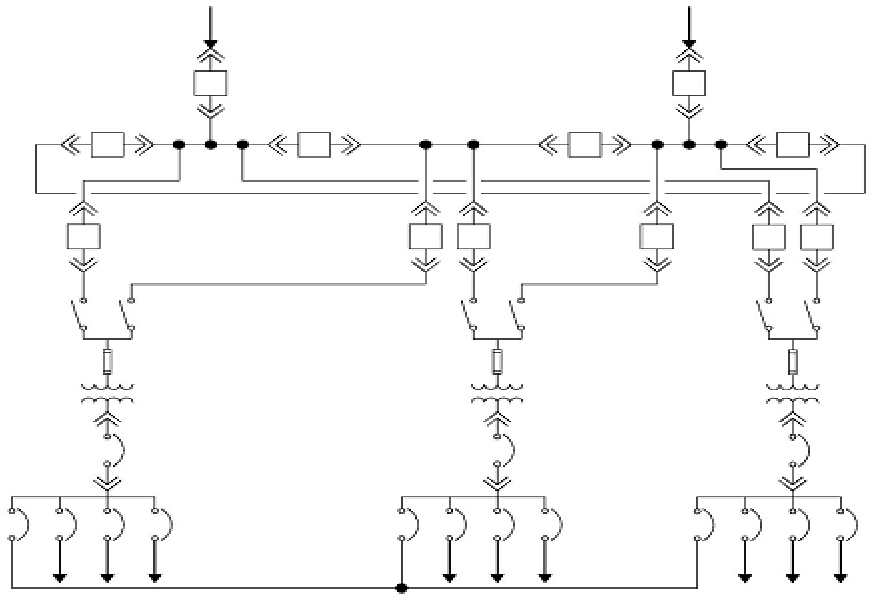

Figure 3.27 Network model configuration *[19]*

In Ethiopia most substations configuration is single bus, but this configuration has difficult during maintenance period, as the whole load connected to this substation should be de-energized. There is no choice to transfer loads to another bus during fault or during maintenance time, so that this became one cause for total block out for distribution system. For example, in Adama distribution system from to June January 2018 in six-month duration 3 total block out occurred in Adama city, this is due to single bus bar configuration of Adama substation. So, to improve this problem, it is better to use double bus bar configuration system for Adama substation. It has relatively lower expenses to build it relative to other substation configurations and has better reliability with respect to straight bus.

3.4.3 Control and protection

One level below the configuration is the control and protection system. Even if the system configuration is suitable to deliver the required level of reliability, its performance can be compromised by failure of the control and protection system. Controls such as automatic bus transfer schemes and standby generator starting systems must function properly to make alternate paths or sources of power available to the load on failure of the primary source. Protective devices must be selectively coordinated to isolate the load from faulted portions of the system and prevent faults on one path or in one portion of the system from causing interruption of multiple paths or sources.

The one-line diagram developed should provide the basic information required to begin an assessment of whether the control and protection system design will support the reliability level that the system configuration is intended to provide. Protective relays should be identified by ANSI device type number; instrument transformer ratios and connections should be shown and tripping logic indicated either by dashed lines between devices or by a tripping schedule. For complicated systems, separate instrumentation and relaying one-line diagrams may be required to supplement the overall one-line diagrams.

Perform a protective device coordination analysis. Protection for critical systems should be designed to meet three objectives:

- ✓ Sensitive and high-speed clearing to minimize the depth and duration of voltage dips associated with faults.
- ✓ Selective coordination to limit the outage to the affected portion of the system.
- ✓ Security against nuisance tripping due to load characteristics and system transients.

In Adama distribution system it is very difficult to answer the above questions, so protection and coordination system of this distribution system should be reconfiguring.

Table 3.17 Interruption frequency of transient fault and switching operation fault before upgrading

Feeder code	Transient fault	opening and closing of section switch	Total
	F	F	F
L1	18	22	40
L2	14	13	27
L3	16	36	52
L4	15	25	40
L5	3	0	3
L6	4	8	12
L7	14	20	34
Total	84	124	208
Percentage	18.22	26.89	45.11

Overhead distribution system has faced with two types of faults: these are transient fault and permanent faults [21]. usually, transient faults occur when the phase conductor electrically contact with other phase conductor or ground momentary due to trees, birds, or other animals, lightening, high winds, flashover, etc. transient faults are cleared by a service interruption of sufficient length of time to extinguish power arc. The fault duration is minimized and unnecessary fuse blowing is prevented by circuit breaker or automatic tripping and automatic reclosing of a circuit recloser. The breaker speed, the relay setting, and recloser characteristic are chosen in a manner to interrupt fault current before a series fuse is blown, which could cause transient fault to happen to a permanent fault. Permanent faults are those faults which require repairs.

Here, the number of customers affected by a fault is minimized by properly selecting and locating protective apparatus on the feeder main, at tap point of branches, and at critical location on branches. Permanent faults on overhead distribution systems are usually sectionalized by using fuse as shown figure 3.21. Permanent faults occurred on sub main and lateral branches cleared by fuse cutout installed on them

Table 3.18 Interruption duration of transient fault and switching operation fault before upgrading

Feeder code	Transient fault	opening and closing of section switch	Total
	Hr	Hr	Hr
L1	7.16	24.2	31.36
L2	4.3	22.99	27.29
L3	24.78	35.87	60.65
L4	9.31	32.64	41.95
L5	1.28	0	1.28
L6	2.77	15.09	17.86
L7	6.04	42.81	48.85
Total	55.64	173.6	229.24
Percentage	11.00	34.32	45.32

Protection system of Adama distribution is very poor, all very long MV distribution feeder are protected by a single circuit breaker that is found inside substations. There is no sub main or lateral which has fuse cutout. But there are some fuse-cutouts at connection point of distribution transformers, also most of these are shorted due to poor maintenance. So that every fault that happens on the long outgoing main feeder, sub main, lateral, and sub laterals is cleared by substation circuit breaker, it may be transient fault or permanent fault. Every fault occurring in every point of feeder affects all customers connected to it, because all faults are removed by substation circuit breaker. General, protection system of Adama power distribution system is weak; this is the major reason why Adama distribution network is unreliable.

As shown in Table 3.17 and 3.18, first column shows registered transient faults in nature but transferred to permanent faults due the absence of transient fault clearing device like auto recloser or automatic reclosing apparatus in Adama power distribution system.

Table 3.19 Interruption frequency of transient fault and switching operation fault after upgrading

Feeder code	transient fault	opening and closing of section switch	Total
	Fr	Fr	Fr
L1	7	5	12
L3	13	11	24
L4	16	6	22
L5	4	3	7
L6	2	6	8
L7	12	6	18
M1	15	9	24
M2	13	1	14
M3	11	4	15
M4	8	5	13
M5	13	9	22
Total	114	65	179
Percentage	21.07	12.02	33.09

Adama distribution system has no sub main, sub lateral, or lateral protection devices for sectionalization of customers during fault; for finding possible location faults like fuse cutout and auto recloser, only there is load switch deferent part of medium voltage line. When fault happened in system, the crews finds fault by opening and closing a load switch and substation circuit breaker opens. This practice of fault-finding methods is one cause unreliability of Adama distribution system. As a result, old system 26.89% of interruption frequency and 34.32% of interruption duration, and after upgraded 12.02% of interruption frequency and 17.19% of interruption duration are due fault-finding practice of crews as tabulated Tables 3.17 to 3.20. In both system times to find faults and to maintain them, average time it took almost two hour per fault.

In distribution system, protection system is very important for reducing duration of faults especial transient faults and for limiting number of customers affected by fault. In Adama power distribution, cause of power interruption frequency is different but cause of long power interruption is shortage of protection device in it. To minimize time duration of fault and limit number of customers affected by faults is done by installing appropriate protection devices with appropriate location and coordination.

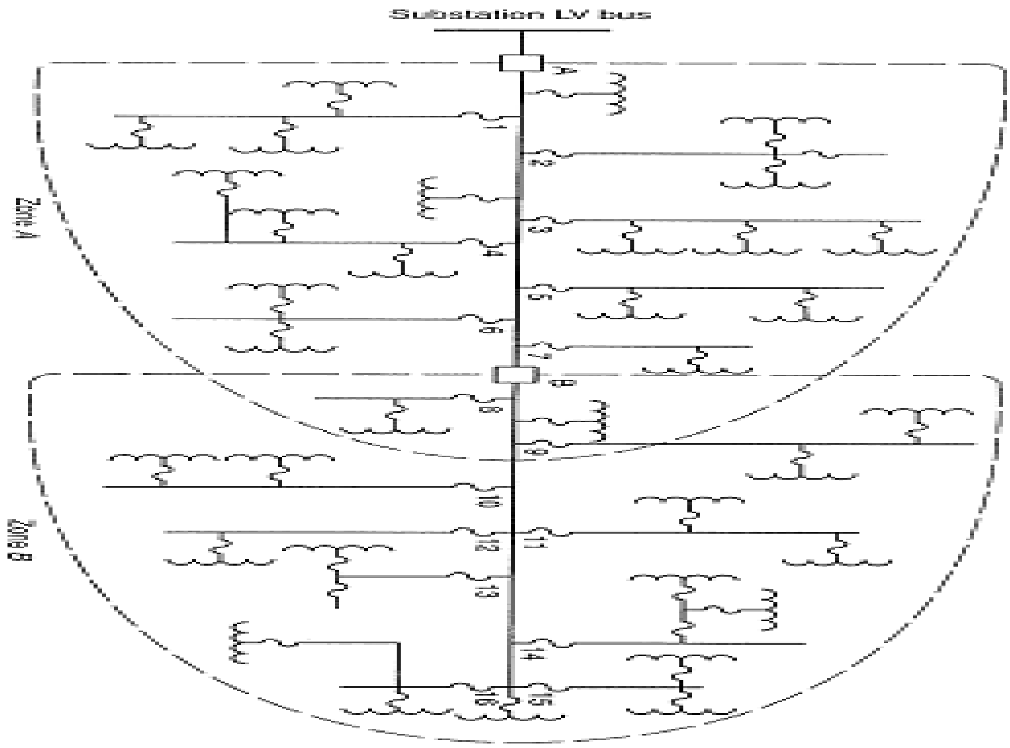

Figure 3.28 Distribution protection scheme*[21]*.

3.4.4 Physical installation

The physical configuration and location of electrical equipment is also another important factor for reliability of the system and hence should be reviewed. Is the equipment adequately protected from physical damage and environmental hazards? Are redundant paths provided with physical segregation so that a major failure of one piece of equipment cannot readily propagate to redundant circuits or equipment?

A thorough inspection of the physical condition of a plant's distribution system can be utilized, hopefully on a continual basis, to improve reliability. All systems serving critical loads or processes should be part of a comprehensive preventive and predictive maintenance (PPM) program, which combines periodic visual inspections of equipment with mechanical and electrical testing to identify and correct deteriorating conditions before they result in unscheduled outages. If such a program has not been in place for the system being assessed,

Table 3.20 Interruption duration of transient fault and switching operation fault after upgrading

Feeder code	Permanent fault	opening and closing of section switch	Total
	Hr	Hr	Hr
L1	5.98	7	12.98
L3	4.9	26.59	31.49
L4	9.82	16.5	26.32
L5	0.5	4.16	4.66
L6	0.34	43.01	43.35
L7	5.24	9.54	14.78
M1	16.9	4.94	21.84
M2	14	0.83	14.83
M3	7.09	5.5	12.59
M4	12.84	1.75	14.59
M5	28.42	31.18	59.6
Total	106.03	151	257.03
Percentage	12.08	17.19	29.27

a thorough initial round of inspection and testing is recommended as providing the following benefits:

1) Immediate identification of conditions that may cause failures in the short term.
2) An indication of the general conditions of maintenance of the system that can be used in reliability calculations to select failure rate multipliers as discussed.
3) Establishing baseline testing values that can be used to start trend monitoring as part of a PPM program. Guidelines for inspection and testing of electrical equipment can be found in the relevant IEEE and ANSI standards documents It is recommended that these sources be consulted and written checklists and procedures appropriate to the specific types of equipment and the system being assessed be prepared prior to undertaking the initial inspection and testing.

In addition to the inspection of the equipment itself, other physical conditions that can impact reliability should be considered. Physical construction of switchgear may compromise the independence of components that appear to be completely redundant to each other on the one-line diagram. A significant fraction of electrical equipment failures stem from nonelectrical causes such as human activity, physical contamination, and failure of environmental systems, with contamination from leakage of steam, water, or other process fluids leading the list.

Physical installation of Adama distribution system as installations, pole type, erections, protection and clearance of lines etc., have also serious impacts on the distribution system reliability.

3.4.5 Conductor type

Cables are used for the transmission and distribution of electrical energy in public and industrial power systems. The permissible loading of the cables is determined by different parameters such as environmental conditions, type of laying (in ground or in air), cable design and type of insulation, operating conditions and so on. Conductors are made of aluminum or copper. The insulation is of various materials: PVC (polyvinyl chloride) and PE (polyethylene) are used as standard used in LV and MV cables; oil-insulation and gas - pressure cables can still be found in HV systems (Un > 110 kV), whereas XLPE (cross -linked polyethylene) -insulated cables are today standard in power systems with nominal voltages of 110 kV and above. Mass - impregnated paper-insulated cables are still in use in the medium-voltage range, but are found only on older cable routes; this type will no longer be installed [22].

Nowadays, there are two types of conductor used in electrical power overhead distribution systems [23]:

- Bare conductor/wire
- Covered Conductor (CC)

And also, there are three basic types of CC overhead line systems in use at distribution voltages:

- XLPE/HDPE Covered Conductors (single or multiple sheathed)
- Aerial cable systems
- Spacer Cable concept

XLPE (Cross-Linked Polyethylene) and HDPE (High Density Polyethylene) are the most common sheath materials.

The conductor material can be a high conductivity copper or aluminum or a conductor designed to give a balance between strength and conductivity (steel cord aluminum types such as ACSR).

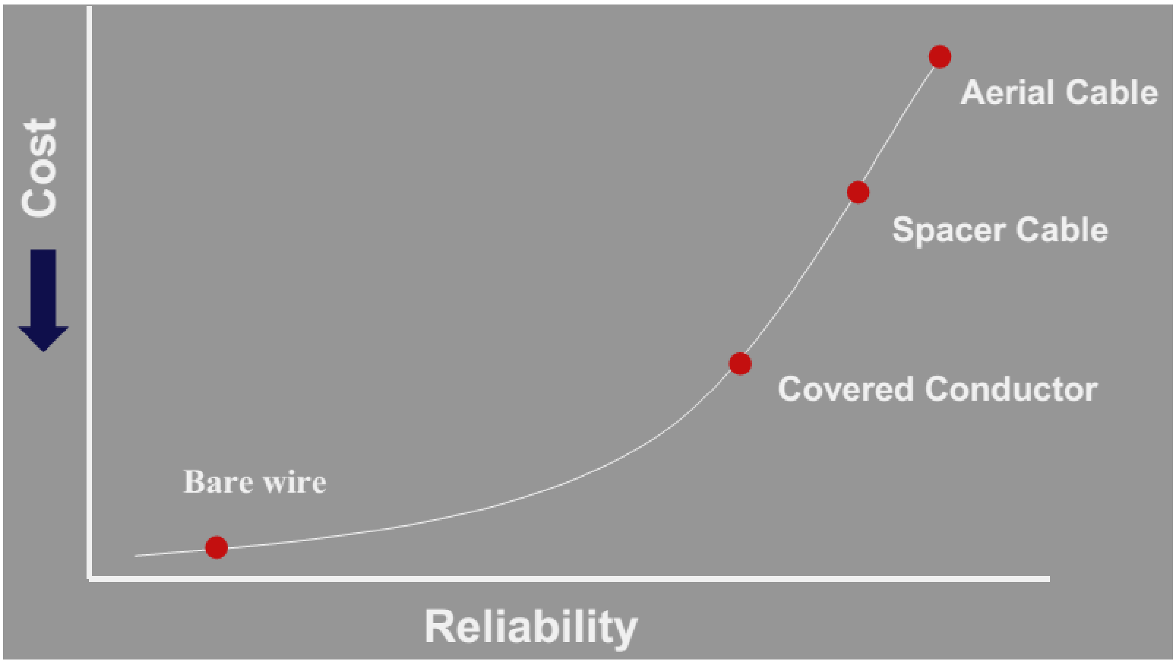

Figure 3.29 Schematic reliability of various distribution systems *[23]*

Bare wire is normally the cheapest and easiest system to build but covered conductors have a higher reliability because clashing and accidental contact is not a problem. Spacer cable is essentially the three CC phases held in a cradle and supported by a steel or alumoweld cable. The fact that the conductors are not self-supporting means that vibration risks are reduced and reliability increased. Aerial cable is essentially a fully insulated 3-core cable with an earth screen used for overhead applications. Its low susceptibility to lightning and the inherent reliability of the cable design means, this system is the most expensive, but also the most reliable. In very general terms, the reliability of bare wire distribution systems and the three basic types of CC described here is shown schematically in Figure 3.29.

In Ethiopia, almost transmission and distribution cables are bare conductors except in some urban areas and industries. These conductors have low cost, but lowest reliability as shown Figure 3.29. In Adama distribution system, transient faults and clearance problem are major problems and can be mitigated using insulated.

3.4.6 Operations and maintenance

Finally, operations and maintenance (O&M) practices are critical to achieving the designed-in reliability of the system. Effective commissioning helps assure that control and protection systems function per design. Preventive maintenance can reduce failure rates and an adequate level of spare parts stocking can reduce repair times when failures do occur. There is no effective policies, procedures, documentation, and training of O&M personnel reduce outages in Adama distribution due to human activity and improves operator response time when failures occur. As stated above 48 % of interruption faults are du e to operational and maintenance activities in this distribution system.

Table 3.21 Interruption frequency due to permanent fault and clearance for before upgraded system

Feeder code	Permanent fault	Clearance	Total
	F	F	F
L1	18	0	18
L2	14	4	18
L3	16	2	18
L4	15	1	16
L5	3	3	6
L6	4	0	4
L7	14	1	15
Total	84	11	95
Percentage	18.22	2.39	20.61

Table 3.22 Interruption duration due to permanent fault and clearance for before upgraded system

Feeder code	transient fault	Clearance	Total
	Hr	Hr	Hr
L1	7.16	0	7.16
L2	4.3	2.73	7.03
L3	24.78	4.17	28.95
L4	9.31	2.45	11.76
L5	1.28	2.7	3.98
L6	2.77	0	2.77
L7	6.04	0.42	6.46
Total	55.64	12.47	68.11
Percentage	11.00	2.47	13.47

Table 3.23 Interruption frequency due to transient fault and clearance for after upgraded system

Feeder code	Transient fault	Clearance	Total
	Fr	Fr	Fr
L1	7	0	7
L3	13	5	18
L4	16	1	17
L5	4	0	4
L6	2	1	3
L7	12	2	14
M1	15	2	17
M2	13	7	20
M3	11	0	11
M4	8	4	12
M5	13	1	14
Total	114	23	137
Percentage	21.07	4.25	25.32

The final area to be considered in the evaluation is O&M practices. As mentioned earlier that an effective PPM program is important to achieving the designed-in reliability of Adama distribution systems, but this is only one of many aspects of O&M that can impact reliability. Other considerations include commissioning, training, documentation, and spare parts stocking. If an assessment of current O&M practices finds gaps in any of these areas, the impact on reliability should be considered and improvements made. The greatest challenge in this area in most facilities is maintaining a long-term commitment to effective O&M practice in the face of short-term production schedules, cost control measures, and other management pressures.

a) **Commissioning:** Effective commissioning of power distribution systems and equipment is critical to achieving reliable performance. Commissioning provides an organized and documented process to verify proper installation, electrical integrity, and functional performance in accordance with the manufacturer’s specifications and the design intent. This includes basic equipment acceptance tests such as relay testing, insulation resistance measurement, over-potential withstands, and contact resistance measurement, but should extend to step by-step verification of control system operation, and system-level functional testing. It is also important that a similar process be in place for commissioning additions and modifications to the system, and recommissioning any control or protection systems that may be affected by the change.

Table 3.24 Interruption duration due to permanent fault and clearance for before upgraded system

Feeder code	Transient	Clearance	Total
	Hr	Hr	Hr
L1	5.98	0	5.98
L3	4.9	6.57	11.47
L4	9.82	1.08	10.9
L5	0.5	0	0.5
L6	0.34	2.25	2.59
L7	5.24	4.53	9.77
M1	16.9	3.33	20.23
M2	14	20.91	34.91
M3	7.09	0	7.09
M4	12.84	4.75	17.59
M5	28.42	4.33	32.75
Total	106.03	47.75	153.78
Percentage	12.07	5.44	17.51

b) **Training:** The level of training and degree of knowledge of the system on the part of the personnel who are called on to operate and maintain it should be reviewed. Human activity is often claimed to be a factor in more than half of all failures of critical power systems and training may the most effective tool available to reduce outages. When new systems and equipment are installed, operators should be provided with training, not only from the manufacturer on the equipment itself, but from the designer or the plant engineer on the overall operation of the system and how the individual pieces of equipment function within it. Written system descriptions and operating procedures should be developed and used as the basis for both initial training and periodic retraining. While it is common to provide some operator training in the form of a “walk-through” and demonstration conducted by the installing contractor, a comprehensive program that includes both classroom and field training components is recommended. It is increasingly common to video tape or otherwise record initial training sessions to assist in training new employees and retraining existing staff.

c) **System documentation**: Accurate and up-to-date system documentation is another aspect of O&M practice that can significantly impact system reliability. The development of an up-to-date one-line diagram was discussed previously, but maintaining other items of system documentation are also important.

Accurate one-line diagrams and relay schedules are necessary to assess the extent of the system affected by an outage and to select appropriate switching procedures for restoration of service.

Preparing commonly used switching procedures in advance, such as a clearance procedure for each feeder in the system, can speed operator response and reduce outage durations. Schematic and wiring diagrams and manufacturer's instruction manuals for all equipment should also be kept up-to-date and maintained either at the equipment location, or in a readily accessible and effectively indexed central filing system. This will reduce repair times and decrease the probability of increasing the extent of an outage through inadvertent action by maintenance staff.

The most useful documentation is accurate, concise, and located where it is needed during switching procedures or response to unplanned outages. Some measures that can be taken to reduce outages associated with human activity include the following:

- ❖ Post one-line diagrams and operating procedures at the locations of switchgear and control panels.
- ❖ Make sure that labels on equipment correspond to designations on the drawings.
- ❖ Provide clear warning labels on control devices whose operation affects critical loads.
- ❖ Post names and contact numbers for supervisors, engineering staff, utility dispatchers and emergency services in all electrical rooms and provide telephones, radios, or other means for rapid communication.
- ❖ Use colors on drawings, mimic buses, and labels to distinguish between different systems and circuits.

d) **Spare parts levels:** A review of spare parts stocking levels for critical equipment can help assure higher reliability levels associated with short duration "replace with spare" outage times, in lieu of much longer "repair in place" outages.

Most plants have a population of motors large enough to expect several failures per year. The large variety usually precludes the maintenance of a spare motor stock, although availability should be checked with local distributors. Highly critical nonstandard equipment may require spares. However, each component of the electric system should be viewed in its relationship to the critical process and downtime. The value of carrying spare parts should be carefully weighed when long process interruptions could result from a single component failure. The cost of carrying spares for critical long repair time items, may be prohibitive; in such cases careful advance planning for repairs including assembling equipment data, planning rigging arrangements, etc., may significantly shorten repair times.

Maintenance is an activity involved in maintaining a system or equipment to be in a good working order, to improve the reliability and sustainability of the system or equipment and to extent its life expectancy.

Maintenance activities in most instances are not carried out as planned due to unplanned and unforeseen circumstances within the electricity distribution industry; and we then embarked on corrective maintenance only, and that resulted to not meeting the scheduled activities of preventive maintenance.

The eventual ageing of the electrical network, the extent damage experienced, conduction of repeatable repairs in the same areas and lack of maintenance leads to deterioration of the electricity distribution network.

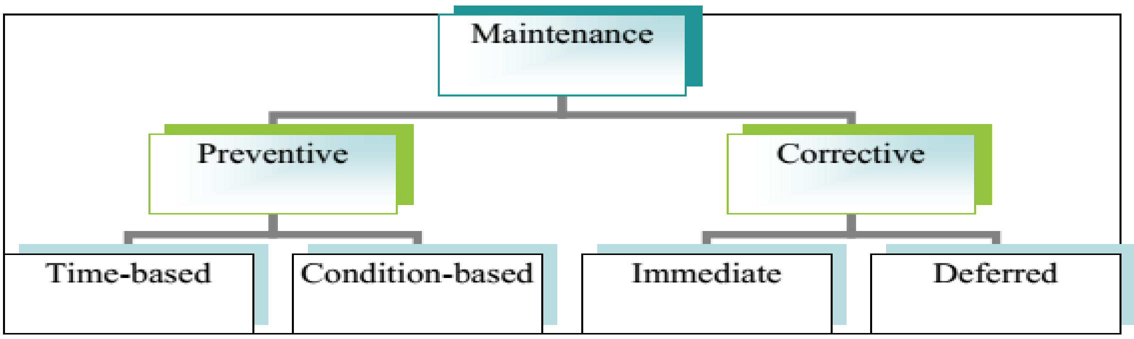

Figure 3.30 indicates the commonly most effective maintenance types that incorporate all maintenance activities in order to keep the equipment or system in a good working order being reliable and sustainable.

Preventive maintenance: is the maintenance that is performed before a failure occurs to preserve a system in satisfactory condition; it involves performing routine inspections and servicing. It is categorized by time-base (regular) and conditional -based (predictive). Time based maintenance is performed at regular time intervals (e.g. number of tripping); and condition-based maintenance is based on the knowledge of the condition of the equipment from routine or continuous monitoring (systematic inspections, measurements).

Preventative maintenance is an overhaul or inspection activity before a piece of equipment fails. The major goal of preventative maintenance is to reduce deterioration and prolong the lifetime of equipment, and it addresses both repairable and end of-life failures. The usable or economic value of equipment is reduced as its ages, and preventative maintenance activities delay the aging process. The relationship between the value, time, and preventative maintenance is shown in Figure 3.31. It can be seen from the figure that maintenance can recover part of the lost value caused by deterioration in the aging process. However, although maintenance can slow aging, it cannot fully stop it.

Of the many factors involved in availability, preventive maintenance often receives meager emphasis in the design phase and operation of distribution systems when it can be a key factor in high availability. Large expenditures for systems are made to provide the desired reliability; however, failure to provide timely, high-quality preventive maintenance leads to system or component malfunction or failure and prevents obtaining the intended design goal.

Experience indicates that equipment lasts longer and performs better when covered under a preventive maintenance program. An effective preventive maintenance program can reduce accidents and operator error, and minimize costly breakdowns and unscheduled outages by identifying and solving problems early, before they become major problems.

Reliability centered maintenance (RCM) is a powerful approach in predictive maintenance activities. It has a wide range of interpretations and may be defined differently in various publications. In our opinion, RCM should include at the minimum the following components [24]:

- collecting statistical data such as operation history, failure records, aging status tests or assessments
- estimating failure probabilities due to repairable and end-of-life failures of equipment
- evaluating impacts of individual equipment failures on the system

- quantifying the effects of maintenance activities on improving equipment failure frequencies/repair times and whole system reliability
- applying economic or reliability criteria to determine the best maintenance scheme, which may be an optimal maintenance alternative (range and sequence in maintenance) or lowest-risk maintenance scheduling timing) or most cost-efficient workforce planning.

In Adama distribution system, there is no any preventive maintenance done, as this is one reason for the low unreliability of power in Adama city. 42% of equipment fail in distribution system due to the absence of preventive maintenance. In this distribution system there is no time-based preventive maintenance that regularly maintains equipment or conditional based preventive maintenance that is based on conditions of equipment and environmental conditions. For example, in Adama distribution system, there is the highest number of outages around June indicating that the system needs conditional preventive maintenance.

So, the utility should allocate budget and human resource for both time - based and condition - based preventive maintenance in order to reduce frequent failure of equipment and to minimize transient faults.

Corrective maintenance: is the maintenance performed after a failure occurs, and it is also categorized by immediate and deferred maintenance. Immediate maintenance is performed immediately as it is being regarded as an emergency; and the deferred maintenance might be scheduled for another period based on the priority of activities.

It is tremendously important to integrate preventive and corrective maintenance activities during the assembling of the maintenance plan. Compliance to planned maintenance activities should be treated as a trend towards maintaining the network in good working order and best practices.

Maintenance budget should be given priority during the budget provision process in order to ensure conduction of effective maintenance activities as per maintenance plan. Comprehensive tactical plans to limit negative contributing factors towards maintenance activities should be articulated and be implemented; as this will serve as an absolute investment towards the industry and will worth the price during the course of time.

3.4.7 Aging of electrical equipment

Equipment aging is a fact of life in power systems although there may be different causes of aging for different types of equipment. Aging can be produced by insulation deterioration of electrical components (such as transformers and reactors), fatigue damage of mechanical parts (such as generators and motors), or erosion of metal structures (such as underground cable sheathing). Similar human beings, any equipment will experience its infancy, normal operation, and wear-out stages. As a piece of equipment ages, it fails more frequently, needs longer times to repair, and eventually reaches its end of life. The direct consequence of equipment aging is higher system risk due to higher failure probability and possible system damage following the end-of-life failure. Utilities normally carry out preventative overhauls and regular inspections. Maintenance activities can, to some extent, extend the life of equipment but could be very costly for equipment at their end-of-life stage. A compromise between maintenance and replacement must be carefully considered [24]. The probability of end-of-life failure increases with equipment aging (Fig 3.32). On the other hand, the aging process can be slowed through maintenance activities (Fig. 3.31).

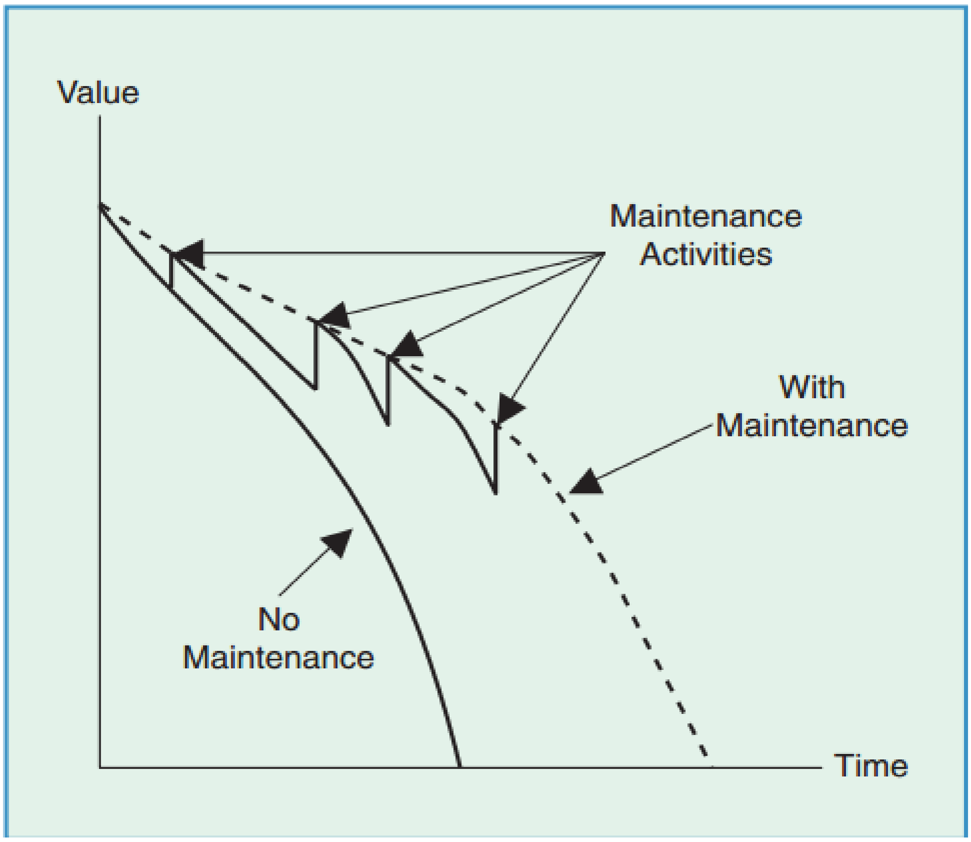

Figure 3.31 Relationship between the value, time, and preventative maintenance for aged equipment*[24]*.

The Failure rate of electrical distribution equipment increase as aging of it. This results reliability of the distributions becomes at risk. In Adama distribution system outage due to equipment failure rate of old system is 42% and upgraded system is49%. This large outage frequency is mainly due aging of electrical apparatuses in distribution system. Because age most of equipment's in distribution are so long as distribution is installed especially distribution transformers and medium voltage cable without preventive maintenance practice. In order to increase aging of equipment, the maintenance practice of distribution system should provide preventive maintenance.

In Adama distribution system there is no way of retiring aged equipment. Mostly, the aged equipment retired from a system after they fall. As a result, this harms reliability of distribution system. so that the utility should have documented data about life time and maintenance frequency of electrical equipment to retire them at their proper aged time without affecting reliability of the system.

If the age of equipment is too long, system should remove this oldest equipment to protect distribution system from risk. Retirement of old equipment is eventually unavoidable. It is just a matter of retiring earlier or later. Never-ending maintenance activities on a piece of aged equipment will produce the following problems or concerns [24]:

- The maintenance cost will increase as equipment ages.
- Repeated maintenance activities over a very long time cannot assure the original performance of equipment, resulting in increasing operational cost.
- The failure probability or unavailability due to the end of-life failure will still continuously increase with the age although maintenance can slow deterioration. This leads to increasing system risk.
- Economically, the total cost of ownership consisting of investment, maintenance, operation, and system risk costs may be lower if the equipment is replaced.
- Financially, a very low book value of aged equipment may have negative effects on the design of electricity rates, which are associated with asset values and investment return requirements.
- In a wider sense, an over-maintenance strategy will impede progress of new technology

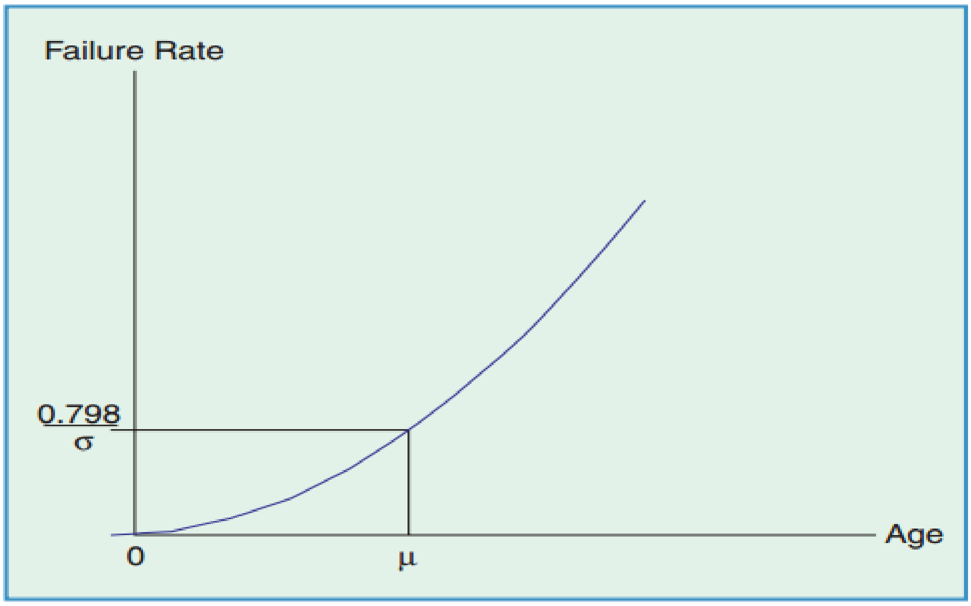

Figure 3.32 Relationship between failure rate and age for a normal probability distribution *[24]*.

3.4.8 Overloading of Adama substation

One reliability problem for Adama power distribution network is overloading of the substation and outgoing feeders. In old distribution system 9.26% of interruption frequencies are due to overloading of distribution system and also after system is upgraded still overloading is continued with 0.31%, of interruption frequencies as shown in chapter three. The peak load of Adama city is almost approaches (83.5 MW with 0.9 P. F 93 MVA) to peak maximum (100 MVA) capacity of the substation as shown in Table 3.25 in 2018 GC. So, to solve this problem of distribution additional new substation should be design and installed. This done as the following:

Load demand forecasting of Adama distribution system: in distribution system to design new substation capacity first load demand estimation for some length of time must be done. to do this peak demand growth rate of Adama city should be known. This growth rate is 12.3 % which studied by EEP for 25 years for the time horizon from 2013 – 2037 GC. The methodologies that this study have employed are founded on well-established principles of economic/econometric modeling of key economic drivers to produce a demand forecast for the period 2013-2037. This study verified that the total peak demand forecast grows from 1,186 MW in 2012 to 21,731 MW by 2037 with an average compound growth rate of 12.3% [25]. Based on this average growth rate, this thesis anticipated peak load demand of Adama distribution system for next 10 years. Peak load of Adama substation is 83.5 MW in 2018.

The power growth after 10-year period will be 268.75 MW peak real power (Table 3.26) and 298.3 MVA (almost 300MVA) apparent power with power factor of 0.9. So that, rating of the new substation for Adama distribution system will be 200 MVA.

Table 3.25 Peak loading of Adama distribution feeders after upgrading

Feeder	Peak load (MW)
L1	6.5
L3	8
L4	7.8
L5	8.2
L6	7
L7	8.2
M1	9
M2	7
M3	8.4
M4	8.4
M5	5
Total	83.5

Table 3.26 10 years peak demand farecasting of Adama distribution system

Year	MW
2018	83.5
2019	93.854
2020	105.4919
2021	118.5729
2022	133.2759
2023	149.8021
2024	168.3776
2025	189.2564
2026	212.7242
2027	239.102
2028	268.7507

New substation design: this new substation capacity is 200 MVA based on load demand forecasting for 10 years. So, the design of the power distribution system shall be done with the best standard and shall comply with the relevant legislation and Ethiopian Standards, or if such do not exist, with the relevant IEC or International Standard Organization (ISO) Standards.

Selection of Transformers: Transformer size/s should be selected based on the peak expected load and possibility of future expansions. The size of transformer is selected from power ratings given by manufactures list to supply present and anticipated future loads. To accommodate load demand of preset and 10-year period four power transformers with 132/15kV and 50MVA is enough.

Selection of Transformer feeders: To choose primary and secondary feeders of transformer, the following criteria mist be fulfilled:

- Size and type of load to be supplied
- Permissible voltage drops
- Prospective fault current
- Circuit protection
- environmental conditions of installation

Calculation of Current: In order to select the appropriate cable size, it is necessary to know the voltage and load current in Amperes or as MW or MVA.

The rated current of the primary cable is calculated by equation (3.2) as follow [26]

$$I_{\text{rated}} = \frac{\text{MVA}}{\sqrt{3} * \text{V}} = \frac{50 * 10^{6}\text{MA}}{\sqrt{3} * 132 * 10^{3}\text{V}} = 218.95\text{A} \text{ ------------------- } (3.2)$$

By considering a De-rating factor of 0.85, the standard current that flows through the primary cable is given by [26]

$$\text{I}_{\text{standard}} = \frac{\text{Irated}}{de\text{−}rating\ factor} = \frac{218.95}{0.85} A = 257.59A \text{ -------------------- } (3.3)$$

Table 3.27 shows that a 70 mm^2 15 kV armoured XLPE insulated single corer conductor cable would be capable of carrying a load of 285 A.

The rated current of the secondary cable is calculated by equation (3.2) as follow [26]

$$I_{rated} = \frac{\mathrm{MVA}}{\sqrt{3} * \mathrm{V}} = \frac{50 * 10^6 \mathrm{MA}}{\sqrt{3} * 15 * 10^3 \mathrm{V}} = 1924.5\mathrm{A}$$

By considering a De-rating factor of 0.85, the standard current that flows through the secondary cable is given by

$$\mathrm{I}_{\mathrm{standard}} = \frac{\mathrm{Irated}}{de\text{-}rating\ factor} = \frac{1924.5}{0.85} A = 2.26KA$$

Table 3.27 shows that a 2x800 mm^2 15 KV armoured XLPE insulated single core copper conductors' cable would be capable of carrying a load of 1280A.

Table 3.27 Current ratings for armoured XLPE cable *[27]*

Conductor size(mm^2)	3.8/6.6(7.2) KV to 8.7/15 / (17.5)				12.7/22(24) KV to19/33(34)			
	Conductor installation							
	In air		In ground		In air		In ground	
	(A)	(A)	(A)	(A)	(A)	(A)	(A)	(A)
Copper conductor								
50	235	220	220	210	245	225	220	210
70	285	270	270	255	300	275	270	255
95	360	330	320	300	360	330	320	295
120	415	375	360	340	425	380	360	335
150	470	430	410	380	485	430	410	375
185	540	490	460	430	550	490	460	420
240	640	570	530	490	650	570	530	480
300	740	650	600	540	740	650	600	530
400	840	740	680	600	850	740	690	590
500	900	-	750	-	380	-	760	
630	1110	-	830	-	1130	-	850	-
800	1270	-	920	-	1280	-	930	-

Fault Current Calculation

For a power transformer with 132/15 kV with 50MVA rating, the short-circuit capacity is 1000MVA [IEC 60076-5]. The earth fault level is 100MVA, and it may be assumed that the fault should be cleared within 0.3 second

The supply impedance seen from the primary side is given by equation (3.4) [26]

$$Z_{sys}=\frac{(V_p)2}{S_{sc}} \quad \text{--} \ (3.4)$$

$$Z_{sys}=\frac{(132)2}{1000}=17.424\Omega$$

The short circuit current that can exist on the primary feeder is calculated by equation (3.5)

$$I_{sc}=\frac{V_p}{\sqrt{3}*Z_{sys}}=\frac{132V}{\sqrt{3}*17.424\Omega}=4.37KA \ \text{-----------------------} \ (3.5)$$

The short circuit current withstand capacity of the cable is calculated by equation 3.6 [26]

$$\mathrm{I_{sc}}=\frac{\mathrm{K*A}}{\sqrt{\mathrm{t}}} \ \text{---} \ (3.6)$$

Where: Isc = Short circuit rating of cable (kA)

A = Cross-section of conductor (mm^2)

t = time to trip (0.3 second)

K = A constant that depends on conductor material and temperature

= 115 A/mm^2 for PVC, Copper conductor

= 76 A/mm^2 for PVC, Aluminum conductor

= 115 A/mm^2 for Paper, Copper conductor

= 76 A/mm^2 for Paper, Copper conductor

= 143 A/mm^2 for XLPE, Copper conductor

= 92 A/mm^2 for XLPE, Aluminum conductor

$$\mathrm{I_{sc}}=\frac{143*70}{\sqrt{0.3}}=18.275 \text{ KA}$$

Therefore, the cable can withstand the prospective short circuit current.

The cable earth fault current that can exist in the primary feeder is calculated by equation (3.7) [26]

$$I_{EF} = \frac{\text{Earth fault MVA}}{\sqrt{3} * \text{voltage rating}} \text{--} (3.7)$$

$$= \frac{100 * 10^6 \text{VA}}{\sqrt{3} * 132 * 10^3 \text{V}} = 437.39\text{A}$$

The cable earth fault current withstand capacity is calculated by equation 3.8

$$I_{EF} = \frac{K * A}{\sqrt{t}} \text{--} (3.8)$$

Where: IEF = Earth fault current (kA)

A = Cross-sectional area of earth path (mm^2)

t = Fault duration in seconds (0.3 second)

K = A constant that depends on earth path material

= 42 A/mm^2 for steel wire armour

= 24 A/mm^2 for lead sheath

= 143 A/mm^2 for Copper tape

= 76 A/mm^2 for Aluminum wire armour

$$I_{EF} = \frac{143 * 70}{\sqrt{0.3}} = 18.275 \text{ kA}$$

Therefore, the cable can withstand the prospective earth fault current.

In many cases, the cable conductor size is larger than dictated by the full load current, and is chosen in order to withstand the prospective short-circuit current. The use of large conductors can be avoided by improving the speed of protection and in the case of earth fault current, by the use of sensitive earth fault protection.

The supply impedance transferred to the secondary side is given by equation (3.9)

$$Z_L = Z_{sys} * \left(\frac{V_s}{V_p}\right)^2 \text{ -- (3.9)}$$

$$= 17.424 * \left(\frac{15}{132}\right)^2 = 0.225\Omega$$

The short circuit current that can exist on the secondary feeder is calculated by equation (3.10)

$$I_{sc} = \frac{V_s}{\sqrt{3} * Z_L} \text{ -- (3.10)}$$

$$= \frac{15}{\sqrt{3} * 0.225} = 38.49 \text{ KA}$$

The short circuit current withstand capacity of the cable is calculated by equation (3.11)

$$I_{sc} = \frac{K * A}{\sqrt{t}} \text{ -- (3.11)}$$

Where: Isc = Short circuit rating of cable (kA)

A = Cross-section of conductor (mm^2)

t = time to trip (0.3 seconds)

K = A constant that depends on conductor material and temperature

= 115 A/mm2 for PVC, Copper conductor

= 76 A/mm2 for PVC, Aluminum conductor

= 115 A/mm2 for Paper, Copper conductor

= 76 A/mm2 for Paper, Copper conductor

= 143 A/mm2 for XLPE, Copper conductor

= 92 A/mm2 for XLPE, Aluminum conductortor

$$I_{sc} = \frac{143 * 800}{\sqrt{0.3}} = 208.864 \text{ kA}$$

Therefore, the cable can withstand the prospective short circuit current.

The cable earth fault current that can exist in the secondary feeder is calculated by equation (3.12)

$$\mathrm{I_{EF}} = \frac{\text{Earth fault MVA}}{\sqrt{3} * \text{voltage rating}} \text{ ------------------------------------- (3.12)}$$

$$= \frac{100 * 10^6\mathrm{VA}}{\sqrt{3} * 15 * 10^3\mathrm{V}} = 3.849\mathrm{KA}$$

The cable earth fault current withstand capacity is calculated by equation (3.13)

$$I_{EF} = \frac{K*A}{\sqrt{t}} \text{-- (3.13)}$$

$$= \frac{143 * 800}{\sqrt{0.3}}$$

$$= 208.864\ kA$$

Therefore, the cable can resist the prospective earth fault current.

In many cases, the cable conductor size is larger than command by the full load current, and is chosen in order to withstand the prospective short-circuit current. The use of large conductors can be avoided by improving the speed of protection and in the case of earth fault current, by the use of sensitive earth fault protection.

Selection of Circuit Breakers: Circuit breakers are a piece of electrical device that:

- Make or break a circuit either manually or by remote control under normal conditions.
- Break a circuit automatically under fault conditions.
- Make a circuit either manually or by remote control under fault condition

Rated voltage, rated current and rated short-circuits breaking (interrupting) capacity of circuit breaker must be determined. Short circuit capacity of the circuit breaker must be above the maximum short circuit current exists in the location. Short circuit that occur in primary and secondary of power transformer is 4.37 kA and 38.49 kA respectively.

The ratings of 132 and 15 kV circuit breakers are indicated in Tables 3.28 and 3.29 respectively.

Table 3.28 Ratings of 132 kV Circuit Breaker *[28]*

Description	Minimum requirement
Type of circuit breaker	Outdoor type
Rated service voltage	132 kV
Rated maximum voltage	145 kV
Type of quenching medium	SF_6
Rated current	400 A
Rated short circuit current	31.5
Number of poles	3
Rated frequency	50 Hz
Rated short circuit making current	63 kA
Short circuit current withstand duration	0.3 sec
Insulation level • Power frequency withstand voltage (KV RMS for 1min) • Impulse withstand voltage (1.2/50 μsec) KV peak	 170 kV 650 kV

Design of Bus Bars: Bus bars are Cu/Al rods of thin walled tubes and operate at constant voltage. The bus-bars are designed to carry normal current continuously. The cross section of conductors is designed on the basis of rated normal current and the following factors:

- system voltage
- Position of sub-station
- Flexibility
- Reliability of supply and cost

Table 3.29 Ratings of 15 kV circuit breaker [28]

Description	Minimum requirement
Type of circuit breaker	Outdoor type
Rated service voltage	15 kV
Rated maximum voltage	24 kV
Type of quenching medium	SF_6
Rated current	2000 A
Rated short circuit current	31.5 kA
Number of poles	3
Rated frequency	50 Hz
Rated short circuit making current	100 kA
Short circuit current withstand duration	0.3 sec
Insulation level • Power frequency withstand voltage (KV RMS for 1min) • Impulse withstand voltage (1.2/50 µsec) KV peak	 38 kV 95 kV

Bus bar design must ensure easy and uninterrupted maintenance, avoiding any danger to the operating of operating personnel. It must be simple in design and must possess provision for future extension. Any fluctuation of load must not hinder its mechanical characters. The buses should be coupled using a bus-coupler which facilitates load transfer while maintenance and fault conditions.

Consider the following data to determine the size of a bus-bar for new substation

Rated Load Capacity = 200MVA

Voltage = 132kV

The rated current (I_{rated}) of the bus-bar is calculated by equation (3.15)

$$I_{rated} = \frac{S}{\sqrt{3}*V} = \frac{200}{\sqrt{3}*132} = 874.77 \text{ A} \quad \text{------------------------------------} \quad (3.15)$$

So, a bus-bar with a current rating of 1 kA is selected for the 132-kV side.

Rated Load Capacity = 200MVA

Voltage = 15 kV

The rated current (I_{rated}) of the bus-bar is calculated by equation 3.15

$$I_{rated} = \frac{S}{\sqrt{3}*V} = \frac{200}{\sqrt{3}*15} = 7.69 \text{ kA}$$

So, a bus-bar with a current rating of 8 kA is selected for the 15kV side. The ratings of 132 and 15kV bus-bars are indicated in Tables 3.30 and 3.31 respectively.

Table 3.30 Ratings of 132kv bus-bar *[29]*

Description	Minimum requirement
Type of busbar	aluminum
Rated current	1.2 kA
Rated insulation voltage	1000 V
Rated short time withstand current	55 kA
Conductor • Bar dimension • Cross section area	 6 mm^2x 110 mm^2 660 mm^2
Resistance at an ambient air temperature of 35 °	(0.057 mΩ/m)
Reactance	(0.034mΩ/m
Rated Power Loss at 35 °C	268.6 W

Table 3.31 Ratings of 15 kV bus-bar *[29]*

Description	Minimum requirement
Type of busbar	Copper
Rated current	2(4 kA)
Rated insulation voltage	1000 V
Rated short time withstand current	120 kA
Conductor • Bar dimension • Cross section area	 2*250 mm^2 * 6 mm^2 3000 mm^2
Resistance at an ambient air temperature of 35 °	(0.013 mΩ/m)
Reactance	(0.010 mΩ/m
Rated Power Loss at 35 °C	604.8 W

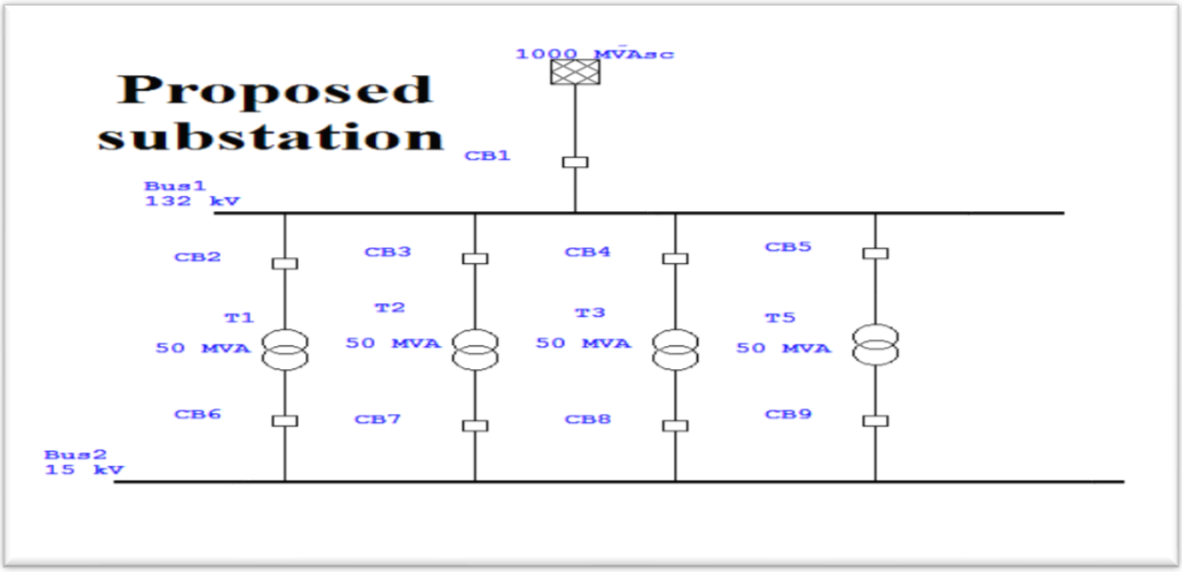

Figure 3.33 Single line diagram modeling of proposed substation

CHAPTER FOUR

4. RESULT AND DISCUSSION

In this chapter, the modeling and simulation of the existing and rehabilitated power distribution network of Adama city using ETAP 12.6 software are discussed, in order to get system reliability indexes. And improvement method for enhancing the power reliably of the distribution system have been evaluated.

4.1 Simulating and modeling Adama power distribution using ETAP

4.1.1 Old distribution system

The old Adama power distribution system has radial configuration with seven 15 kV outgoing feeders and the substation capacity was 50MVA.

The reliability indexes of this system have been calculated in chapter four, so this simulation shows how much ETAP reliability index result matches to calculated value. To analyze the reliability of the power system by ETAP, appropriate inputs must be provided. The input for the old Adama power distribution system is given as Tables 4.1 and 4.2.

Table 4.1 Input data for ETAP of old distribution system

Name feeder	Length (km)	Interruption frequency(f/yr)	Interruption duration (Hr)	Active failure rate μ_A(fr/km.yr)	Mean time to repair (MTTR) (Hr)
L1	19.65	468.5	398.955	19.96	0.852
L2	39.23	399.5	438.92	10.18	1.0987
L3	23.52	462	452.72	19.64	0.979
L4	34.75	408.5	370.63	11.75	0.907
L5	5.6	85	63.87	15.18	0.751
L6	25	233.5	288.66	9.34	1.236
L7	11.8	411	426.785	34.83	1.038

Fig.4.1 shows single line diagram of old Adama power distribution system that is modeled using ETAP software. The result of the simulation is shown in Table 4.3 with SAIFI value of 352.44 fr/customer/yr and SAIDI value of 349.75 Hr/customer/yr. This simulation reliability index values are almost similar with real calculated value, with SAIFI and SAIDI real values of 342.83 fr/customer/yr and 335.63 Hr/customer/yr, respectively. And also, annual interruption frequency and duration of load points are simulated and shown in Table 4.4 with similar calculated values, as shown in Table 3.3. This helps to verify that the modeling of the power system with ETAP software can give reliable results.

Table 4.2 Default input data for ETAP of designed electrical equipment

[18]

Name equipment	Active Failure Rate (fr/km.yr.)	Passive Failure Rate (fr/km.yr.)	MTTR (Hr)	Switch Time (Hr)	Replace time (Hr)
Transformer	0.0130	0.0130	367.00	367.00	71.50
Circuit breaker	0.0052	0.0078	31.70	31.7	4.50
Cable	0.0462	0.0462	26.8	26.8	60.4
Power grid	0.643	0.643	200	200	200
Busbar	0.001	0.0	2	1	1
Reclosure	0.003	0.003	200	200	10
Load	0.02	-	50	50	10

4.1.2 Rehabilitant Adama Distribution system

This new distribution system of Adama is still under construction. Most field works are finished, but setting up SCADA automation system is not yet completed.

The rehabilitant distribution network of Adama city has 7 outgoing 15 kV feeders and 8 switching stations installed in different parts of city near to customers. Seven feeders supply seven switching stations except station 5. Switching station 5 get its power from proposed new substation by loop configuration from switching station 1, 7, and 8. All switching stations are connected in loop configuration in order to increase reliability of the distribution system. Every switching station has two 15 kV outgoing feeder to supply the load around it. This system also feeds switching stations 3, 5, 6, 7 and 8 from proposed new substation. At switching station, every incoming and outgoing feeder has automatic circuit breaker as shown Figure 4.2.

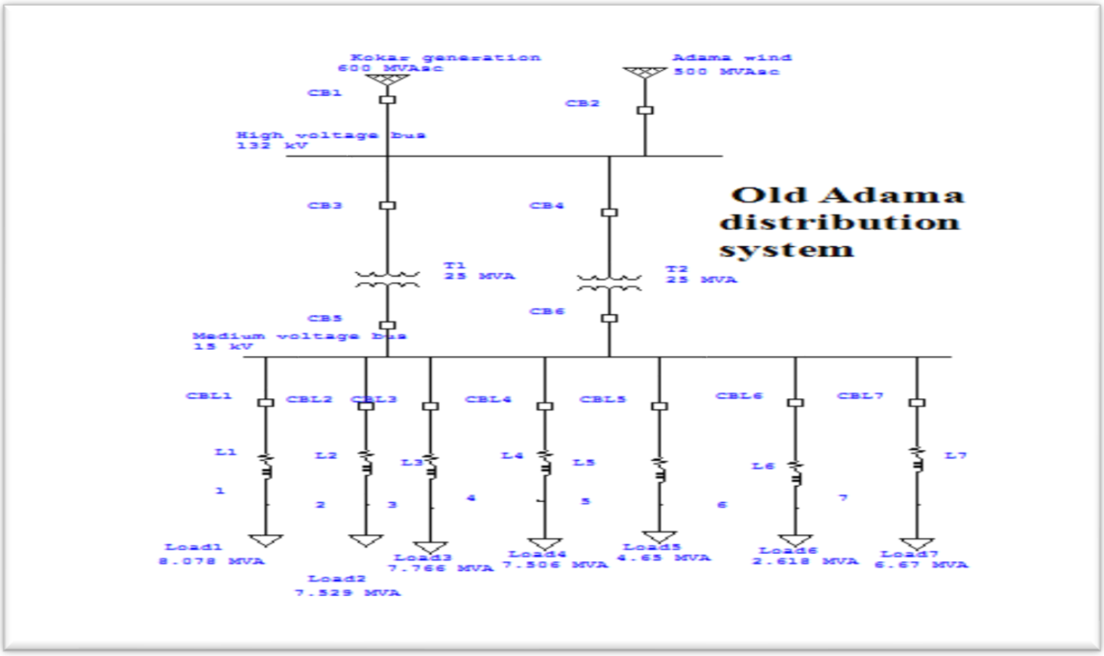

Figure 4.1 Single line diagram of old Adama power distribution system

Table 4.3 System reliability index output of old system by ETAP software

Project:
Location:
Contract:
Engineer: Adama
Filename: gech

ETAP
12.6.0H
Study Case: RA

Page: 12
Date: 11-25-2018
SN:
Revision: Base
Config.: Normal

SUMMARY

System Indexes

SAIFI	352.4413	f / customer.yr
SAIDI	349.7679	hr / customer.yr
CAIDI	0.992	hr / customer interruption
ASAI	0.9601	pu
ASUI	0.03993	pu
EENS	13484.480	MW hr / yr
ECOST	7,327,137.00	$ / yr
AENS	1926.3540	MW hr / customer.yr
IEAR	0.543	$ / kW hr

Where:
SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied
ECOST Expected Interruption Cost
AENS Average Energy Not Supplied
IEAR Interruption Energy Assessment Rate

Current and voltage rating of individual switching stations are 630A and 15 kV respectively with power rating of 16 MVA load. So, the total capacity of this distribution system is 128 MVA. This result shows that the existing capacity of Adama substation cannot supply it. In order to meet the full load demand rehabilitation of the whole substation is essential.

Table 4.4 Load points output reports of old system by ETAP

Project: | ETAP | Page: 9
Location: | 12.6.0H | Date: 11-25-2018
Contract: | | SN:
Engineer: Adane | Study Case: RA | Revision: Base
Filename: gech | | Config.: Normal

Load Point Output Report

Bus ID	Load Sector	Connected Bus ID	Average Interrupting Rate f / yr	Average Outage Duration hour	Annual Outage Duration hr / yr	EENS MW hr / yr	ECOST $ / yr	IEAR $ / kW hr
1	N/A		468.5224	0.85	398.5791	2686.2150	4516.39	0.002
2	N/A		399.4278	1.10	439.6891	2673.4940	4074.73	0.002
3	N/A		461.0584	0.98	452.1637	2857.6630	4235.26	0.001
4	N/A		408.3789	0.92	376.0390	2169.9780	3867.11	0.002
5	N/A		85.0745	0.75	64.1477	241.1945	2331990.00	9.669
6	N/A		233.5666	1.24	289.9315	579.9072	4974889.00	8.579
7	N/A		411.0604	1.04	427.8253	2276.0280	3565.14	0.002
High voltage bus	N/A		0.0130	4.37	0.0568	0.0000	0.00	0.000
Medium voltage bus	N/A		0.0410	4.20	0.1721	0.0000	0.00	0.000
Load1	Residential	1	468.5224	0.85	398.5791	2686.2150	4516.39	0.002
Load2	Residential	2	399.4278	1.10	439.6891	2673.4940	4074.73	0.002
Load3	Residential	3	461.0584	0.98	452.1637	2857.6630	4235.26	0.001
Load4	Residential	4	408.3789	0.92	376.0390	2169.9780	3867.11	0.002
Load5	Industrial	5	85.0745	0.75	64.1477	241.1945	2331990.00	9.669
Load6	Industrial	6	233.5666	1.24	289.9315	579.9072	4974888.00	8.579
Load7	Residential	7	411.0604	1.04	427.8253	2276.0280	3565.14	0.002

Automation system is designed for the new Adama distribution system, which contains master station side and remote field station side. Master station side is found at the substation that comprises software, servers, disk arrays, UPS, communication and network units, data acquisition device and air conditioning. Remote field side is found at different location of distribution network which contains measurement and control devices and terminals, satellite synchronized clocks, communication and network units.

This new distribution system upgrades the old system from manual to automation, from bare conductor to single covered conductor (XLPE), from radial configuration to loop configuration, from single manual circuit breaker at substation to three automatic circuit breakers. These are done at substation, at switching station levels, and at secondary side of the distribution transformer.

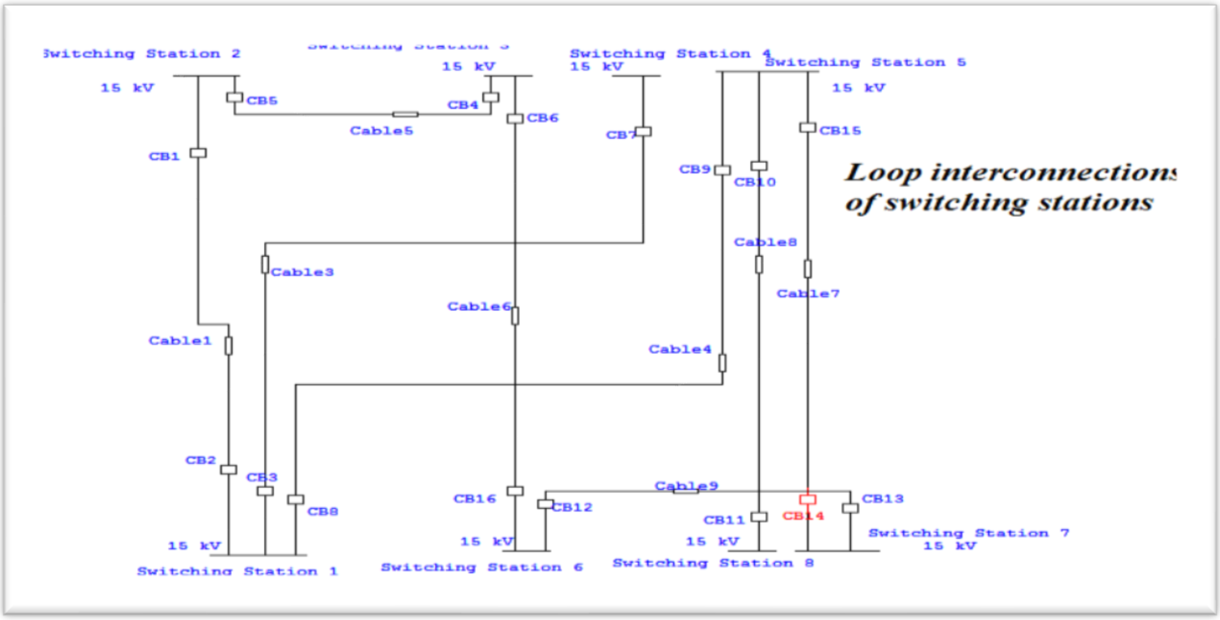

Figure 4.2 Single line diagram of loop interconnection of the switching stations

Table 4.5 Input data for outgoing feeder from substation to switching stations

Name of feeder	Length (km)	Interruption frequency, fr/yr	Interruption duration (Hr)	Active failure rate μ_A(fr/km.yr)	Mean time to repair (MTTR) (Hr)
Feeder 01(F01)	6.015	468.5	398.955	77.88	0.852
Feeder 02(F02)	5.625	399.5	438.92	71.02	1.099
Feeder 03(F03)	2.313	462	452.72	199.74	0.979
Feeder 04(F04)	7.797	408.5	370.63	52.39	0.907
Feeder 05(F05)	7.955	85	63.87	10.68	0.751
Feeder 06(F06)	8.579	233.5	288.66	27.22	1.236
Feeder 07(F07)	3.23	411	426.785	127.45	1.038

It is difficult to get data for reliability analysis like failure rate of equipment and mean time to repair (MTTR). To compare system reliability of this new system with the old distribution network of Adama city, the reliability data of the old system as tabulated in Table 4.5 and 4.6 are used.

The old distribution system load transferred to switching station's feeders based on length of load from switching stations. So that line 1 loads transferred to two feeders of switching station 5(SS-5) and second feeder of switching station 7(SS-7). The interruption duration and fault frequency of these three lines of new system are one third of line 1. And also, the line 2 loads loaded to second feeder of SS-1, second feeder of SS-2 and first feeder of SS-4 then interruption duration and fault frequency of these feeder is one third of line 2. In the same way, two feeders of SS-6 and first feeder of SS-7 got load from line 3. Line 4 load reconnected to two feeders of SS-3 and first feeders of SS-1. Line 5 load to first feeder of SS-2, line 6 loads to second feeders of SS-4 as tabulated in Table 4.6. This load reconfiguration is done based of AutoCAD drawings of rehabilitant distribution system.

Table 4.6 Input dates of outgoing feeder of switching stations

Name of switching station	Outgoing feeders from switching station	Length (Km)	Interruption frequency, fr/yr	Interruption duration (Hr)	Active failure rate μ_A(fr/km.yr)	Mean time to repair (MTTR) hr	Loading
SS- 1	$F_{1(\text{from L-4})}$	4.651	136.17	123.54	29.27	1.1	1.847
	$F_{2(\text{from L-2})}$	3.29	133.17	146.31	40.47	0.91	2.116
SS- 2	$F_{1(\text{from L-5})}$	0.758	85	63.87	112.14	1.33	3.533
	$F_{2(\text{from L-2})}$	3.75	133.17	146.31	35.51	0.91	2.116
SS- 3	$F_{1(\text{from L-4})}$	2.658	136.17	123.54	51.23	1.1	1.847
	$F_{2(\text{from L-4})}$	4.562	136.17	123.54	29.85	1.1	1.847

SS- 4	$F_{1(\text{from L-2})}$	17.13	133.17	146.31	7.77	0.91	2.116
	$F_{2(\text{from L-7 and 6})}$	2.823	411	426.785	145.59	0.96	5.175
SS- 5	$F_{1(\text{from L-1})}$	3.403	156.17	132.98	45.89	1.17	2.318
	$F_{2(\text{from L-1})}$	4.385	156.17	132.98	35.61	1.17	2.318
SS- 6	$F_{1(\text{from L-3})}$	3.809	154	150.9	40.43	1.02	3.197
	$F_{2(\text{from L-3})}$	2.905	154	150.9	53.01	1.02	3.197
SS- 7	$F_{1(\text{from L-3})}$	1.243	154	150.9	123.89	1.02	3.197
	$F_{2(\text{from L-1})}$	1.286	156.17	132.98	121.44	1.17	2.318

The single line diagram shown in Fig. 4.3 is done on ETAP design of rehabilitant system. The input reliability data for ETAP software for simulating the system reliability indices shown in Table 4.2, 4.5 and 4.6 with design data given in chapter 3 part 3.4.6.1.

The load forecast of Adama city for 10 year is discussed in chapter three. According to this estimate, the load demand will reach to 300 MVA with 200 MVA new substation capacity and 100 MVA old substation capacity. The rehabilitation program proposes five feeders. So, capacity of these feeders must be known to simulate ETAP software. Accordingly, the rating of these feeder can be calculated:

$$\text{MVA rating of each feeder} = \frac{Total\ capacity\ of\ substation}{number\ of\ feeders} \text{ --------------------------------- (4.1)}$$

$$= \frac{200\text{MVA}}{5} = 40 \text{ MVA}$$

$$\text{Current rating of each feeder} = \frac{\text{MVA capacity of feeder}}{\sqrt{3}\text{ voltage rating}} \text{ ------------------------------------ (4.2)}$$

$$= \frac{40\ MVA}{\sqrt{3}*15\ kV} = 1.539\ k\text{A}$$

$$\text{Derating factor} = \frac{1.539}{0.85} = 1.8\ kA \text{ -- (4.3)}$$

Table 3. 27 shows that a 2x500 mm^2 15 kV armoured XLPE single core copper conductors-cable would be capable of carrying a load of 1.8 kA.

The system reliability indexes simulated for the rehabilitated Adama distribution system are shown in table 4.7. From these well- known system reliability indexes SAIFI and SAIDI are calculated with values of 139.49 fr/customer.yr and 148.26 Hr/customer.yr respectively. The SAIFI of this distribution system is decreased by 60.42 % with respect to old Adama distribution system and 40.71 % relative to upgraded Adama distribution system. In the same way, the SAIDI of rehabilitated Adama distribution system is reduced by 57.61% and 59.63 % with respect to old and upgraded distribution system respectively.

Generally, the rehabilitated Adama distribution system is more reliable compared with respect to old and upgraded Adama distribution system in terms of all system reliability indexes value. But the distribution system is unreliable relative to international and national standards.

The new distribution system is a better distribution configuration to mitigate the reliability problems of old and upgraded distribution system. the following gaps exist in the system.

a) The system is not sufficiently reliable due to long radial medium voltage feeders after switching stations.
b) Maximum capacity of switching stations is 128 MVA, so this system will be overloaded after 2022 as per the forecasted result done in chapter three.

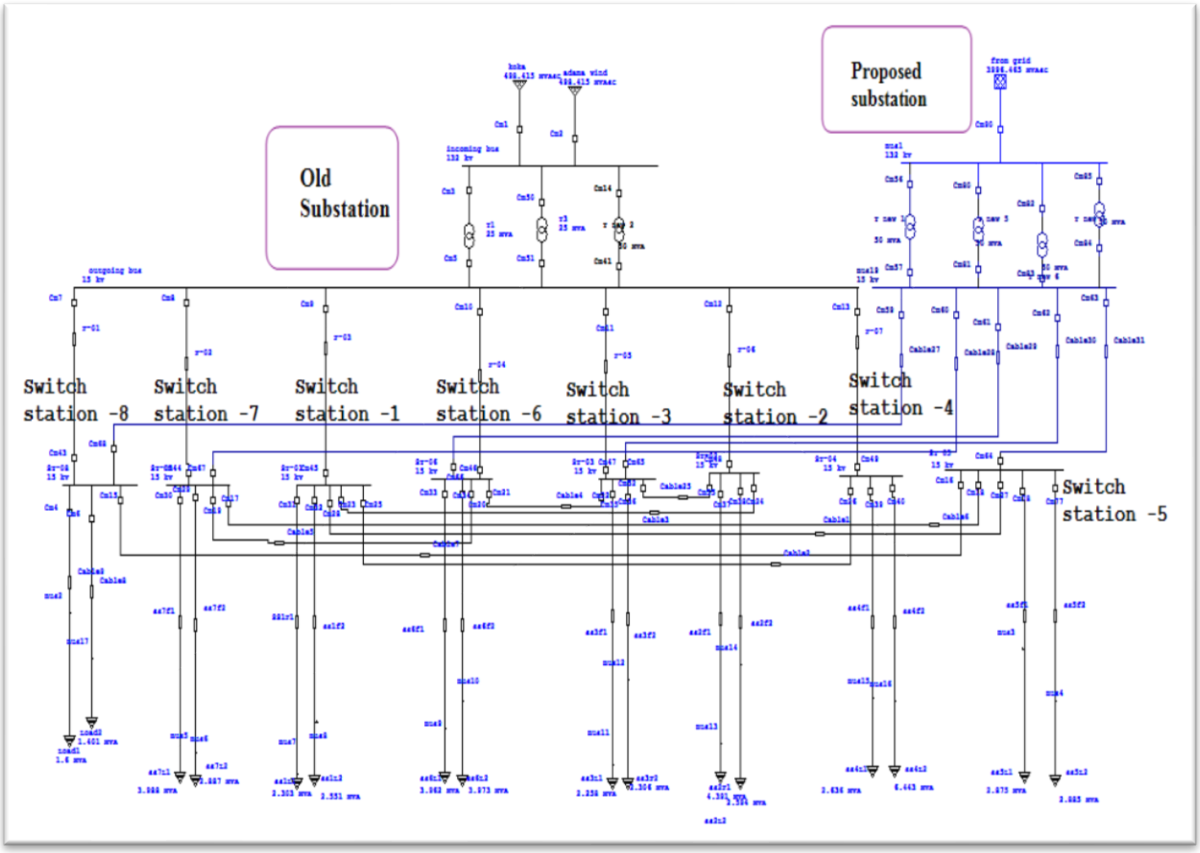

Figure 4.3 Single line diagram modeling of rehabilitant and upgrade Adama distribution system by ETAP

4.1.3 Proposed Adama Distribution system

The above analysis shows that the old, upgraded and rehabilitated distribution systems are not at a level to provide reliable power to the customers by meeting the national standard.

In the rehabilitant distribution system, the main important of proposed substation is only to meet load demand of the city rather has no a contribution to improve the reliability of it. In this proposed system, the proposed substation improves reliability of Adama city additional to supplying overloaded load by giving redundant path.

The feeder between substation and switching station of rehabilitant Adama distribution system is reliable because it is looping configuration and the feeder cable is covered conductor. So that the problem is onwards switching station because, the feeders are radial configuration and bare conductor. This is one gaps of rehabilitant distribution system; this thesis tries to address this problem by linking two or three near feeders of switching stations by automatic recloser as depicted figure 4.4.

Table 4.7 System reliability index output of ETAP software for rehabilitant Adama distribution system

Project:	rehabilitant and upgrade system	ETAP		Page:	1
Location:	Adama, Ethiopia	12.6.0H		Date:	05-26-2019
Contract:	0921263988				
Engineer:	Adane	Study Case:	RA	Revision:	Base
Filename:	new network adama			Config.:	Normal

SUMMARY

System Indexes

SAIFI	139.4894 f / customer.yr
SAIDI	148.2569 hr / customer.yr
CAIDI	1.063 hr / customer interruption
ASAI	0.9831 pu
ASUI	0.01692 pu
EENS	6896.442 MW hr / yr
ECOST	195,677.10 $ / yr
AENS	431.0276 MW hr / customer.yr
IEAR	0.028 $ / kW hr

Where: SAIFI System Average Interruption Frequency Index
SAIDI System Average Interruption Duration Index
CAIDI Customer Average Interruption Duration Index
ASAI Average service Availability Index
ASUI Average Service Unavailability Index
EENS Expected Energy Not Supplied
ECOSTExpected Interruption Cost
AENS Average Energy Not Supplied
IEAR Interruption Energy Assessment Rate

Since 2022 load demand prediction of Adama city will became above 130 MVA according to the forecasted result done in chapter three. As a result, the rehabilitated system will be overload after four years. This problem of this system solved by designing and installing new 8 switching station which feed by new proposed substation. So, total reactive power capacity of these switching station should the same maximum capacity of proposed substation that is 200 MVA. Each of the switching stations capacity calculated by:

$$\text{Individual Switching station capacity} = \frac{\textit{Total capacity of proposed substation}}{\textit{total number os switching stations}} \text{ -------------- (4.4)}$$

$$= \frac{200\ MVA}{8}$$

$$= 25\ MVA$$

Caple ampacity of outgoing feeder from proposed substation to new switch station should be feed its load plus half of load of another switching station if it fails:

$$\text{Each Feeder capacity} = \frac{\text{Total capacity of switching station}*\frac{2}{3}}{\text{voltage rating}*\sqrt{3}} \text{ ---------------- (4.5)}$$

$$= \frac{37.5\ MVA}{15\ kV*\sqrt{3}}$$

$$= 1.44 \text{ kA}$$

Table 3. 27 shows that a 2*300 mm^2 15 kV armoured XLPE single core copper conductors would be capable of carrying a load of 740 A.

The rating of circuit breaker for outgoing feeder should accommodate a current flow through it, so its rating is 1.6 KA which is above 1.44 kA.

As same as rehabilitant system switching stations of proposed also has two outgoing from each of switching stations. So that total load of the switching station supplied by these two feeders. As a result, power of each of the outgoing feeder from switching stations is 12.5 MVA (the half of power rating of switching station). To supply half load of another tied feeder during fault condition, Current capacity of each feeders should be third twos (3/2) of its load as calculated in equation (4.6):

$$\text{Current ampacity} = \frac{\text{MVA capacity of feeder}*\frac{3}{2}}{\text{voltage rating}*\sqrt{3}} \text{ --------------------------- (4.6)}$$

$$= \frac{18.75\ MVA}{15\ kV*\sqrt{3}}$$

$$= 722 \text{ A}$$

Table 3. 27 shows that a 300 mm^2 15 kV armoured XLPE single core copper conductors would be capable of carrying a load of 740 A.

The individual busbar of switching station also can handle its load and half loads of another switching station busbar's load during fault condition. Busbar current capacity of each switching station is calculated by:

$$\text{Current ampacity} = \frac{\text{MVA capacity of switching station}*\frac{3}{2}}{\text{voltage rating}*\sqrt{3}} \text{ ------------- (4.7)}$$

$$= \frac{37.5 \text{ MVA}}{15 \text{ kV}*\sqrt{3}} = 1.44 \text{ kA}$$

So, rating of individual switching stations of proposed substation is 1.6 kA.

The rating of automatic recloser that connects two feeders must be handle current flowing across it.as stated above power cross automatic recloser is half of loading of outgoing feeder during fault time that 6.25 MVA. Rating of recloser can be give:

$$\text{Current ampacity of recloser} = \frac{Total\ power\ pass\ thorough\ recloser}{15\ kV*\sqrt{3}} \quad \text{--------------------} \quad (4.8)$$

$$= \frac{6.25\ MVA}{15\ kV*\sqrt{3}}$$

$$= 241\ \text{A}$$

So, the rating of automatic recloser is 280 A

As stated above, switching station rating is designed during fault time to handle its load plus half of another switching station's load. So that power rating of interloping feeder is half of load of the switching station that is 12.5 MVA. So current ampacity of interloping feeder can be calculated:

$$\text{Cable ampacity} = \frac{MVA\ of\ interlooping}{15\ kV*\sqrt{3}} \quad \text{------------------------------------} \quad (4.9)$$

$$= \frac{12.5\ MVA}{15\ kV*\sqrt{3}} = 481\ \text{A}$$

Table 3. 27 shows that a 185 mm^2 15 kV armoured XLPE single core copper conductors would be capable of carrying a load of 540 A.

The rating of circuit breaker for interloping feeder should accommodate a current flow through it, so its rating is 630 A which is above 481 A.

The proposed power distribution for Adama city is shown in Fig. 4.4. The proposed substation will have 200MVA rating, with four 50MVA power transformers and eight switching station and two outgoing feeds like the rehabilitated system. As indicated above, reliability gap is found after switching station because the feeders are of radial configuration. So, switching stations with redundant source are recommend to improve the reliability of the city.

Based on ETAP reliability assessment of the proposed distribution system. the reliability of the system is improved with SAIFI value of 62.19 f/customer, indicating a decrease by 52.55% and SAIDI value of 66.47 Hr/customer indicating a decrease by 55.17% in comparison with the rehabilitated Adama distribution system. The average service availability index (ASAI) of proposed system is 99.24% as shown in Table 4.8, but rehabilitated Adama distribution system has 98.07% ASAI value. Thus, the proposed system has higher power availability than the rehabilitated Adama distribution system. Also, expected energy not supplied (EENS) of this system is decreased by more than 50 % of the rehabilitated system.

Generally, the new proposed system shows better reliability indices due to more switching stations in loop configuration. And also, the system has redundant path by tying two outgoing feeders of different switching stations through automatic recloser in order to improve reliability problems.

Table 4.8 Reliability assessment simulation results of ETAP of proposed distribution system

Project: power reliability proposed system
Location: Adama, Ethiopia
Contract: +251921263988
Engineer: Adane Getachew
Filename: proposed system

ETAP
12.6.0H
Study Case: RA

Page: 1
Date: 30-05-2019
SN:
Revision: Base
Config.: Normal

SUMMARY

System Indexes

SAIFI	62.1940 f / customer.yr
SAIDI	66.4688 hr / customer.yr
CAIDI	1.069 hr / customer interruption
ASAI	0.9924 pu
ASUI	0.00759 pu
EENS	3017.123 MW hr / yr
ECOST	180,265.40 $ / yr
AENS	97.3266 MW hr / customer.yr
IEAR	0.060 $ / kW hr

Where:

SAIFI	System Average Interruption Frequency Index
SAIDI	System Average Interruption Duration Index
CAIDI	Customer Average Interruption Duration Index
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
EENS	Expected Energy Not Supplied
ECOST	Expected Interruption Cost
AENS	Average Energy Not Supplied
IEAR	Interruption Energy Assessment Rate

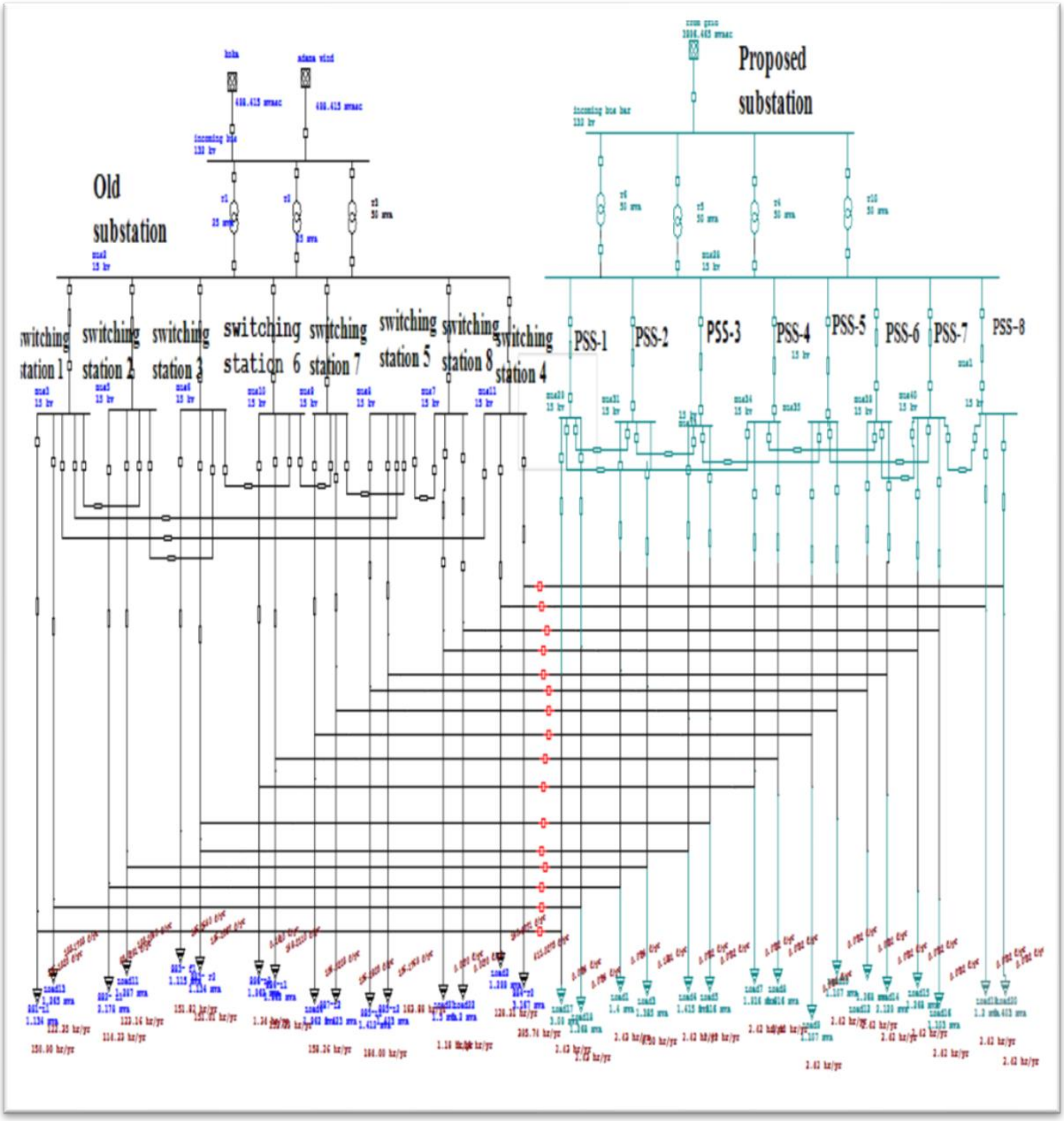

Figure 4.4 Single line diagram modeling of proposed Adama distribution system

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This thesis work presented an in-depth analysis of the reliability problems and improvements options, type of faults, cause of faults and gaps in the old and new power distribution system of Adama city.

In Adama power distribution system, all feeders have unacceptable level of interruption frequency and duration of faults as shown in Fig. 3.10 and 3.12, respectively. The analysis clearly shows that the old and upgraded distribution systems are not sufficiently reliable.

This thesis work got different types of faults in Adama distribution system old distribution system as tabulated Table 3.4. The operational faults have outage frequency and duration of 40.9% and 41.33%respectively. From non-operational faults the earthing fault with outage frequency and duration 29.42% and 24.48%, the short circuit fault with outage frequency and duration 19.99% and 22.4%, under frequency with outage frequency and duration 0.43% and 0.19% and over loading with outage frequency and duration 9.26% and 11.59%, respectively.

Type faults occurred After Adama distribution system upgraded was similar old system as shown Table 3.9. The major difference and input of upgrading reduced outage frequency and duration due to overloading. The fault frequency of overloading of old system was 9.26%, but the upgraded system was 0.31%. And also, the interruption duration of old system was 11.59% but upgraded was 0.26%.

Two well-known customer-oriented reliability indexes SAIFI and SAIDI of old distribution system has314.43 fr/costomer/yr and 325.24 Hr/customer/yr respectively. And also, SAIFI with 235.27 fr/costomer/yr and SAIDI with 367.65 Hr/customer/yr of upgraded system. The rehabilitant system has 139.48 fr/costomer/yr and 148.26 Hr/customer/yr interms of SAIFI and SAIDI respectively. The proposed system has 62.19 fr/costomer/yr and 66.47 Hr/customer/yr of SAIFI and SAIDI respectively, as summarized in Table 5.1. From these system, proposed distribution system is more reliable than old, upgraded and rehabilitated system for Adama distribution system. So, all of four distribution system described in above are not within Ethiopian Electric Agency (EEA) but proposed system is more near it.

Table 5.1 SAIFI and SAIDI reliability result summery of Adama city distribution systems

Reliability index	Before upgrading	After upgrading	Rehabilitant	Proposed system
SAIFI (fr/customer/yr)	352.44	235.27	139.48	62.19
SAIDI (hr/customer/yr)	349.77	367.65	148.26	66.47

Due to unreliability of old and upgraded Adama distribution system, Ethiopian electric utility Adam lost 8.075 Billion birrs/ year and 4.579 Billion Birrs in half of year approximately 9 billion birrs per year respectively.

As this thesis studied power reliability problem on old and upgraded power distribution system includes electric utility management, substation and distribution configuration of the city, control and protection system problem, physical installation of distribution system, operation and maintenance practice of utility, aging of electrical equipment and substation and distribution system overloading.

5.2 Recommendations

This thesis work recommends the following points for Adama distribution system:

- Changing cables of distribution system from bare conductor to covered conductor
- Rehabilitating all primary lines of distribution system
- New substation must be design and build
- As much as possible distribution configuration from radial feed to loop feed
- Substation configuration to have double bus configuration.

Future works for Adama distribution system can be:

- Studying voltage drop in distribution system
- Studying secondary line configuration to improve reliability of system
- Thorough demand load forecasting for Adama city

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Appendix i

Table 1 July substation fault report of old distribution system

No	Feeder / Bay	Date (E.C)	Type of fault / Relay acted	Cause of fault	Interruption Time (Hrs)	Reconnection Time (Hrs)	Difference (Hrs)	Line load (Kw)
1	7	17/10/2009	OC	e.f	8:25	8:31	0:06	5600
2	4	>>	OC	Over Load	9:00	11:12	2:12	5800
3	2	>>	OC	e.f	11:09	13:35	2:26	6000
4	1	>>	OC	e.f	14:35	15:39	0:04	7200
5	3	>>	OC	e.f	14:36	14:41	0:05	7400
6	2	>>	OC	e.f	14:33	15:37	1:04	7200
7	5	>>	OC	e.f	15:01	5:55	0:54	3200
8	1	>>	OC	Over Load	17:37	19:08	1:31	8400
9	1	>>	OC	Over Load	19:48	20:10	0:22	8400
10	6	18/10/2009	OC	I>>	10:12	11:30	1:18	1000
11	3	>>	OC	e.f	12:20	12:21	0:01	7000
12	3	>>	OP	request	14:20	14:40	0:20	2800
13	3	19/10/2009	OC	e.f	6:50	8:20	1:30	4000
14	2	>>	OC	e.f	8:05	8:25	0:20	4000
15	7	>>	OC	e.f	8:08	8:25	0:17	2800
16	1	>>	OC	e.f	11:18	12:30	1:12	7800
17	4	>>	OC	Over Load	14:35	14:45	0:10	2800
18	3	>>	OC	e.f	15:20	16:20	1:00	3200
19	6	>>	OC	I>>	15:20	16:20	1:00	1000
20	7	>>	OC	e.f	15:21	16:20	0:59	2600
21	2	>>	OC	I>>	15:30	16:25	0:55	2200
22	5	>>	OC	e.f	17:16	18:55	1:39	1400
23	4	>>	OC	e.f	21:07	23:55	2:48	3000
24	4	20/10/2009	OC	e.f	6:33	7:27	0:54	6000
25	1	>>	OC	e.f	6:48	7:02	0:14	6000
26	3	>>	OC	I>>	8:07	9:23	1:16	7000

27	7	>>	OC	Over Load	13:21	16:21	3:00	7000
28	1	>>	OC	Over Load	16:24	18:05	1:41	7000
29	1	>>	OC	Over Load	18:54	19:48	0:54	8000
30	3	21/10/2009	OP	request	6:14	7:40	1:26	6800
31	7	>>	OP	request	7:40	7:44	0:04	5800
32	6	>>	OP	request	7:44	8:20	0:36	2000
33	3	>>	OC	e.f	9:43	10:42	0:59	6600
34	1	>>	OC	e.f	10:31	10:43	0:12	7200
35	1	>>	OC	Over Load	10:54	11:35	0:41	7600
36	1	>>	OC	e.f	13:00	13:31	0:31	7600
37	7	>>	OC	e.f	13:46	14:40	0:54	6200
38	5	>>	OC	e.f	18:30	19:36	0:36	4000
39	4	22/10/2009	OP	request	6:20	7:00	0:40	5000
40	2	>>	OC	e.f	6:30	8:20	1:50	6000
41	3	>>	OP	request	14:34	14:39	0:05	6000
42	2	>>	OC	e.f	2:12	3:10	0:48	4000
43	1	>>	OC	e.f	2:18	3:10	0:52	3000
44	6	>>	OC	I>>	2:20	6:45	4:25	2000
45	7	>>	OC	e.f	2:25	3:10	0:45	3000
46	3	>>	OC	I>>	2:26	5:10	2:44	5000
47	2	>>	OC	e.f	3:12	3:40	0:28	3000
48	2	>>	OC	e.f	4:15	4:17	0:02	3000
49	2	>>	OC	e.f	4:40	5:10	0:30	2000
50	6	23/10/2009	OC	e.f	6:16	9:55	3:39	500
51	2	>>	OC	e.f	7:35	11:55	4:20	3000
52	2	>>	OC	e.f	11:19	11:23	0:04	400
53	1	>>	OC	Over Load	11:42	13:50	1:08	8000
54	6	>>	OP	request	12:05	12:15	0:10	800
55	6	>>	OC	I>>	13:25	13:55	0:30	800
56	2	>>	OP	request	17:05	17:25	0:20	3200
57	2	>>	OC	e.f	19:22	19:35	0:13	3200
58	4	>>	OP	request	19:30	19:40	0:10	3300
59	6	>>	OC	e.f	20:18	10:08	13:50	1800
60	2	>>	OC	e.f	20:48	21:10	0:22	3200
61	2	>>	OC	e.f	21:17	22:45	1:28	3200
62	1	24/10/2009	OC	I>>	10:31	11:32	1:01	7000
63	6	>>	OP	request	11:54	12:31	0:37	1500

64	7	>>	*OC*	*e.f*	*11:12*	*13:00*	*1:48*	*6000*
65	4	>>	*OP*	*request*	*12:31*	*13:00*	*0:29*	*6000*
66	1	>>	*OC*	*e.f*	*12:11*	*12:54*	*1:43*	*7000*
67	3	>>	*OC*	*I>>*	*13:55*	*15:19*	*1:24*	*7000*
68	1	>>	*OP*	*request*	*15:03*	*15:09*	*0:06*	*7000*
69	2	>>	*OC*	*I>>*	*17:20*	*18:30*	*1:10*	*7000*
70	7	>>	*OC*	*e.f*	*17:19*	*19:10*	*1:51*	*7000*
71	3	>>	*OC*	*I>>*	*19:25*	*20:22*	*0:57*	*7000*
72	7	>>	*OC*	*e.f*	*20:30*	*20:53*	*0:23*	*5000*
73	2	>>	*OC*	*e.f*	*21:26*	*22:35*	*1:09*	*7000*
74	7	25/10/2009	*OC*	*e.f*	*8:25*	*9:25*	*1:00*	*4000*
75	3	>>	*OC*	*I>>*	*12:25*	*12:40*	*0:15*	*6000*
76	4	>>	*OP*	*request*	*15:50*	*15:55*	*0:05*	*6000*
77	1	>>	*OP*	*request*	*16:50*	*16:55*	*0:05*	*6000*
78	7	>>	*OC*	*I>>*	*17:19*	*17:21*	*0:02*	*5000*
79	1	>>	*OC*	*e.f*	*5:41*	*5:42*	*0:01*	*4000*
80	4	>>	*OC*	*I>>*	*5:50*	*5:55*	*0:05*	*0:00*
81	1	26/10/2009	*OC*	*Over Load*	*11:32*	*11:35*	*1:03*	*8000*
82	4	>>	*OC*	*I>>*	*12:10*	*12:58*	*0:48*	*7000*
83	4	>>	*OC*	*I>>*	*13:30*	*13:35*	*0:05*	*7000*
84	1	>>	*OC*	*e.f*	*20:34*	*20:45*	*0:11*	*6200*
85	4	>>	*OP*	*request*	*22:40*	*22:45*	*0:05*	*2500*
86	2	27/10/2009	*OC*	*e.f*	*6:41*	*7:35*	*0:54*	*7000*
87	1	>>	*OC*	*e.f*	*7:21*	*7:36*	*0:15*	*7000*
88	7	>>	*OC*	*Over Load*	*8:27*	*9:14*	*0:47*	*7000*
89	1	>>	*OP*	*request*	*9:14*	*13:41*	*5:27*	*8000*
90	7	>>	*OP*	*request*	*10:40*	*11:04*	*0:24*	*6000*
91	3	>>	*OP*	*request*	*11:34*	*12:50*	*1:16*	*7600*
92	1	>>	*OC*	*e.f*	*15:06*	*15:48*	*0:42*	*8000*
93	2	>>	*OC*	*e.f*	*4:02*	*4:40*	*0:38*	*5000*
94	4	28/10/2009	*OP*	*request*	*8:00*	*8:09*	*0:09*	*5600*
95	4	>>	*OC*	*Over Load*	*8:47*	*10:25*	*1:48*	*6800*
96	5	>>	*OC*	*Over Load*	*10:25*	*13:00*	*2:35*	*5200*
97	2	>>	*OC*	*e.f*	*11:34*	*13:00*	*1:26*	*6000*
98	1	>>	*OC*	*e.f*	*12:22*	*13:01*	*0:39*	*8000*
99	4	>>	*OC*	*e.f*	*12:31*	*12:45*	*0:14*	*5400*
100	4	>>	*OP*	*request*	*15:50*	*15:53*	*0:03*	*5000*
101	1	>>	*OC*	*e.f*	*13:50*	*16:02*	*2:12*	*6200*

102	1	>>	*OC*	*Over Load*	*19:24*	*21:30*	*2:06*	*6600*
103	2	29/10/2009	*OC*	*e.f*	*2:13*	*2:21*	*0:08*	*3800*
104	2	>>	*OC*	*e.f*	*3:52*	*6:17*	*2:25*	*3800*
105	2	>>	*OC*	*e.f*	*6:51*	*7:40*	*0:49*	*7000*
106	3	>>	*OC*	*e.f*	*7:03*	*7:26*	*0:23*	*7000*
107	3	>>	*OP*	*request*	*9:26*	*9:34*	*0:08*	*7000*
108	1	>>	*OC*	*Over Load*	*10:58*	*11:30*	*0:32*	*8400*
109	3	>>	*OC*	*I>>*	*11:40*	*13:04*	*1:24*	*7000*
110	2	>>	*OC*	*I>>*	*12:50*	*13:29*	*0:39*	*7000*
111	5	>>	*OC*	*e.f*	*16:12*	*16:40*	*0:28*	*4000*
112	7	>>	*OC*	*e.f*	*17:17*	*17:47*	*0:30*	*7000*
123	5	>>	*OC*	*e.f*	*17:17*	*17:48*	*0:31*	*5000*
114	2	>>	*OC*	*I>>*	*18:54*	*20:09*	*1:15*	*7000*
115	7	>>	*OC*	*e.f*	*23:20*	*0:15*	*0:55*	*5000*
116	1	>>	*OC*	*e.f*	*23:48*	*0:15*	*0:27*	*6000*
117	2	>>	*OC*	*e.f*	*0:14*	*6:50*	*6:34*	*4000*
118	1	30/10/2009	*OC*	*e.f*	*2:54*	*6:55*	*4:01*	*5000*
119	3	>>	*OC*	*I>>*	*2:54*	*8:00*	*5:06*	*5000*
120	7	>>	*OC*	*I>>*	*3:46*	*9:06*	*5:20*	*4000*
121	6	>>	*OC*	*I>>*	*3:52*	*7:00*	*3:18*	*2000*
122	1	>>	*OC*	*e.f*	*7:57*	*8:20*	*0:23*	*4000*
123	5	>>	*OC*	*e.f*	*8:00*	*8:10*	*0:10*	*4000*
124	3	>>	*OC*	*e.f*	*8:15*	*8:35*	*0:20*	*2600*
125	4	>>	*OC*	*Over Load*	*23:15*	*23:20*	*0:05*	*2800*
126	2	>>	*OC*	*e.f*	*22:55*	*23:00*	*0:05*	*2600*
127	2	1/11/2009	*OC*	*e.f*	*1:01*	*1:23*	*0:22*	*2600*
128	2	>>	*OC*	*e.f*	*9:22*	*9:23*	*0:01*	*6000*
129	3	>>	*OC*	*e.f*	*10:15*	*10:16*	*0:01*	*8000*
130	4	>>	*OC*	*Over Load*	*13:20*	*14:20*	*1:00*	*8000*
131	7	>>	*OP*	*request*	*16:20*	*16:30*	*0:10*	*6000*
132	3	>>	*OP*	*request*	*17:12*	*17:40*	*0:28*	*7000*
133	2	>>	*OC*	*e.f*	*23:03*	*5:20*	*6:17*	*4000*
134	1	>>	*OC*	*I>>*	*23:46*	*13:35*	*13:49*	*5000*
135	7	2/11/2009	*OC*	*Over Load*	*7:10*	*7:50*	*0:40*	*4200*
136	7	>>	*OC*	*I>>*	*8:19*	*9:50*	*1:31*	*3200*
137	3	>>	*OC*	*e.f*	*8:45*	*10:40*	*1:45*	*4200*
138	7	>>	*OC*	*I>>*	*9:56*	*11:25*	*1:29*	*2100*
139	2	>>	*OC*	*I>>*	*10:10*	*13:28*	*3:18*	*1400*

140	3	>>	*OP*	*request*	*12:29*	*13:28*	*0:59*	*5000*
141	2	>>	*OC*	*I>>*	*13:30*	*14:50*	*1:20*	*4000*
142	3	>>	*OC*	*e.f*	*13:31*	*14:01*	*0:30*	*3000*
143	5	>>	*OP*	*request*	*13:53*	*14:00*	*0:07*	*2000*
144	3	>>	*OC*	*e.f*	*15:35*	*16:16*	*0:41*	*3000*
145	2	>>	*OC*	*e.f*	*15:01*	*15:52*	*0:51*	*5600*
146	2	3/11/2009	*OC*	*I>>*	*5:55*	*7:35*	*1:40*	*5000*
147	1	>>	*OC*	*e.f*	*7:35*	*7:36*	*0:01*	*6000*
148	1	>>	*OC*	*Over Load*	*8:41*	*9:41*	*1:00*	*8400*
149	6	>>	*OC*	*Over Load*	*10:35*	*13:00*	*2:25*	*4000*
150	4	>>	*OP*	*request*	*12:50*	*14:55*	*1:55*	*8000*
151	4	>>	*OC*	*I>>*	*15:30*	*15:32*	*0:02*	*7000*
152	1	>>	*OC*	*e.f*	*16:38*	*16:45*	*0:07*	*7000*
153	2	>>	*OP*	*request*	*17:14*	*17:30*	*0:16*	*5000*
154	4	>>	*OC*	*e.f*	*18:55*	*18:57*	*0:02*	*7000*
155	4	>>	*OC*	*e.f*	*19:00*	*19:10*	*0:10*	*7000*
156	2	4/11/2009	*OC*	*I>>*	*6:47*	*7:00*	*0:13*	*3000*
157	4	>>	*OC*	*Over Load*	*6:57*	*8:45*	*1:48*	*3000*
158	1	>>	*OC*	*Over Load*	*6:59*	*7:35*	*0:36*	*4000*
159	3	>>	*OC*	*e.f*	*7:45*	*8:50*	*1:05*	*5000*
160	6	>>	*OC*	*I>>*	*8:25*	*8:50*	*0:25*	*1200*
161	1	>>	*OC*	*e.f*	*9:16*	*10:55*	*1:39*	*3500*
162	3	>>	*OC*	*e.f*	*9:16*	*11:05*	*1:49*	*5000*
163	4	>>	*OC*	*e.f*	*9:17*	*9:45*	*0:28*	*3000*
164	7	>>	*OC*	*e.f*	*9:16*	*10:20*	*1:04*	*3400*
165	3	>>	*OP*	*request*	*11:45*	*13:50*	*2:05*	*5000*
166	7	>>	*OC*	*I>>*	*13:30*	*14:20*	*0:50*	*2800*
167	5	>>	*OC*	*e.f*	*16:15*	*0:15*	*8:00*	*2200*
168	7	>>	*OC*	*I>>*	*17:11*	*17:20*	*0:09*	*2100*
169	3	>>	*OC*	*e.f*	*17:30*	*18:20*	*0:50*	*3600*
170	1	>>	*OC*	*e.f*	*18:10*	*20:30*	*2:20*	*3600*
171	4	>>	*OC*	*e.f*	*18:43*	*20:20*	*1:35*	*0:00*
172	3	5/11/2009	*OC*	*I>>*	*6:32*	*6:54*	*0:22*	*7000*
173	5	>>	*OP*	*request*	*10:31*	*10:50*	*0:19*	*1000*
174	4	>>	*OC*	*e.f*	*11:22*	*11:35*	*0:13*	*6000*
175	4	>>	*OC*	*e.f*	*11:55*	*12:35*	*0:40*	*6000*
176	6	>>	*OP*	*request*	*12:10*	*12:19*	*0:09*	*1000*
177	7	>>	*OP*	*request*	*15:29*	*16:00*	*0:31*	*6000*
178	2	>>	*OC*	*e.f*	*18:05*	*18:31*	*0:26*	*6000*

179	7	>>	OC	I>>	18:35	18:41	0:06	7000
180	1	>>	OC	Over Load	19:12	19:24	0:12	8400
181	3	6/11/2009	OC	e.f	1:47	2:00	0:13	5000
182	1	>>	OC	I>>	5:12	6:12	1:00	4000
183	3	>>	OP	request	6:38	7:40	1:02	7600
184	2	>>	OP	request	7:08	7:42	0:34	6800
185	2	>>	OC	Over Load	8:29	10:07	1:38	7600
186	3	>>	OP	request	9:45	10:07	0:22	8000
187	4	>>	OC	Over Load	10:40	12:47	2:07	8400
188	6	>>	OC	I>>	8:33	10:45	2:12	400
189	4	>>	OC	Over Load	13:10	14:20	1:10	8400
190	2	>>	op	request	14:44	14:47	0:03	4600
191	4	>>	op	request	15:00	15:25	0:25	6500
192	3	>>	op	request	15:00	15:22	0:22	6200
193	3	>>	OP	request	18:45	19:00	0:15	7200
194	1	7/11/2009	OC	e.f	6:56	9:55	2:59	6000
195	2	>>	OC	e.f	6:56	7:56	1:00	4000
196	2	>>	OC	e.f	8:20	8:40	0:20	4000
197	7	>>	OC	Over Load	12:30	12:36	0:06	7000
198	3	>>	OC	Over Load	12:30	15:30	3:00	8000
199	7	>>	op	request	13:50	13:55	0:05	7000
200	6	>>	OC	e.f	16:55	16:58	0:03	500
201	5	8/11/2009	OC	e.f	6:19	6:25	0:06	4000
202	3	>>	op	request	6:28	6:55	0:27	6000
203	3	>>	OC	I>>	7:53	9:10	1:17	8000
204	7	>>	op	request	14:04	14:06	0:02	6000
205	6	>>	OC	I>>	17:25	18:06	0:51	1000
206	2	>>	OC	e.f	18:49	19:49	1:00	6000
207	4	9/11/2009	op	request	1:16	1:22	0:06	4000
208	1	>>	OC	I>>	5:03	6:20	1:17	4000
209	7	>>	OC	Over Load	6:30	6:55	0:25	3000
210	4	>>	OC	e.f	7:43	8:39	0:56	5000
211	3	>>	OC	e.f	8:05	9:30	1:25	4400
212	4	>>	OC	e.f	9:18	9:45	0:27	5000
213	3	>>	OC	e.f	10:25	10:30	0:05	5000
214	4	>>	OP	request	12:20	12:35	0:15	1500

215	1	>>	OP	request	23:50	0:00	0:10	2700
216	1	10/11/2009	OP	request	7:54	8:09	0:15	8600
217	3	>>	OP	request	8:42	8:45	0:03	7800
218	2	>>	OC	e.f	10:35	10:42	0:07	6600
219	1	>>	OC	Over Load	13:00	13:48	0:18	8400
220	7	>>	OP	request	13:38	13:40	0:02	6800
221	4	>>	OC	I>>	14:36	15:14	0:38	6800
222	1	>>	OC	e.f	14:41	14:53	0:12	8400
223	1	>>	OP	request	18:10	18:21	0:11	7600
224	4	>>	OP	request	23:26	23:33	0:07	5200
225	4	11/11/2009	OC	I>>	4:49	5:29	0:40	3200
226	5	>>	OC	e.f	7:00	7:05	0:05	4200
227	1	>>	OC	Over Load	7:20	10:20	3:00	8400
228	3	>>	OC	I>>	8:48	9:05	0:17	8000
229	2	>>	OC	e.f	9:50	9:54	0:04	7400
230	1	>>	OC	e.f	10:30	10:56	0:26	7200
231	4	>>	OC	e.f	12:23	12:40	0:17	7600
232	3	>>	OC	I>>	14:30	15:00	0:30	7600
233	2	>>	OC	Over Load	15:54	16:10	0:16	6000
234	7	>>	OC	Over Load	19:12	21:00	1:48	7200
235	1	>>	OC	Over Load	19:25	19:56	0:31	8400
236	1	>>	OC	I>>	22:24	23:00	0:36	4600
237	1	12/11/2009	OC	e.f	1:40	2:40	1:00	4000
238	4	>>	OC	I>>	7:04	7:40	0:36	3000
239	4	>>	OC	I>>	8:13	8:25	0:12	3600
240	4	>>	OC	I>>	11:10	11:20	0:10	8000
241	1	>>	OC	Over Load	12:06	12:25	0:19	8000
242	1	>>	OC	e.f	13:25	13:55	0:30	8000
243	1	>>	OC	e.f	22:34	22:55	0:21	1800
244	3	>>	OC	Over Load	23:15	23:30	0:15	2800
245	1	>>	OC	e.f	23:55	0:04	0:09	1800
246	3	>>	OP	request	23:57	0:00	0:03	2800
247	1	13/11/2009	OC	e.f	1:05	2:05	1:00	1800
248	2	>>	OC	e.f	1:29	6:55	5:26	2200

249	4	>>	OC	e.f	1:29	3:05	1:36	2000
250	1	>>	OC	e.f	3:26	6:27	3:01	800
251	3	>>	OP	request	8:35	8:44	0:09	7000
252	1	>>	OC	e.f	8:40	10:09	1:29	7000
253	2	>>	OC	e.f	8:57	10:54	1:57	6000
254	1	>>	OC	e.f	10:53	13:48	2:55	7000
255	2	>>	OC	e.f	14:50	15:05	0:15	7000
256	6	>>	OC	I>>	15:11	16:50	1:39	4000
257	1	>>	OP	request	16:24	16:31	0:07	8000
258	5	>>	OC	e.f	16:33	16:40	0:07	4000
259	1	>>	OC	Over Load	19:06	19:16	0:10	8000
260	3	14/11/2009	OC	I>>	3:21	3:38	0:17	5000
261	1	>>	OC	e.f	10:50	11:24	0:34	8400
262	7	>>	OC	Over Load	11:24	12:42	1:18	7000
263	4	>>	OP	request	16:28	17:00	0:59	5800
264	2	>>	OP	request	18:28	18:46	0:18	6200
265	2	>>	OC	Over Load	19:08	20:26	1:18	6800
266	1	15/11/2009	OC	Over Load	8:30	9:30	1:00	8500
267	4	>>	OC	Over Load	12:05	14:56	2:51	4500
268	3	>>	OC	Over Load	19:15	21:15	2:00	6500
269	7	>>	OC	I>>	19:25	20:18	0:53	7400
270	2	16/11/2009	OC	I>>	6:40	7:20	0:40	3200
271	7	>>	OC	I>>	7:11	8:15	1:04	3000
272	3	>>	OP	request	8:55	10:10	1:15	2900
273	6	>>	OP	request	10:30	10:40	0:10	100
274	1	>>	OC	Over Load	12:00	12:30	0:30	7600
275	3	>>	OP	request	13:50	13:55	0:05	1700
276	3	17/11/2009	OC	I>>	9:14	9:24	0:10	7000
277	7	>>	OP	request	10:09	10:10	0:01	7000
278	3	>>	OC	I>>	11:15	11:46	0:31	7000
279	4	>>	OC	e.f	11:31	11:47	0:16	6000
280	1	>>	OC	Over Load	12:05	12:19	0:14	8600
281	2	>>	OC	e.f	14:41	14:57	0:16	6000
282	1	>>	OC	Over Load	19:15	19:42	0:27	8600

283	3	>>	OC	Over Load	20:10	20:22	0:12	8500
284	7	>>	OC	I>>	23:06	2400	0:54	5000
285	3	18/11/2009	OC	I>>	2:30	2:46	0:16	4000
286	1	>>	OC	Over Load	11:59	13:16	1:17	8600
287	2	>>	OP	request	14:33	14:47	0:14	6800
288	3	>>	OC	e.f	14:13	14:34	0:21	7800
289	3	>>	OP	request	16:00	16:20	0:20	6200
290	2	>>	OC	Over Load	18:00	21:00	3:00	6400
291	1	>>	OP	request	4:14	4:25	0:11	4400
292	7	>>	OC	e.f	4:40	7:10	2:30	3200
293	5	19//11/2009	OC	e.f	7:10	7:52	0:42	7000
294	7	>>	OP	request	9:52	10:12	0:20	6000
295	4	>>	OC	e.f	10:07	10:26	0:19	6000
296	1	>>	OC	Over Load	11:32	11:47	0:15	8600
297	7	>>	OC	I>>	15:25	15:43	0:18	7000
298	7	>>	OC	I>>	16:57	17:16	0:19	7000
299	6	>>	OC	I>>	17:09	17:22	0:13	3000
300	6	>>	OP	request	22:40	22:55	0:15	2000
301	2	20/11/2009	OC	I>>	6:24	6:55	0:31	300
302	1	>>	OP	request	7:05	7:15	0:10	4400
303	2	>>	OC	Over Load	8:52	9:48	0:56	7000
304	4	>>	OP	request	9:54	12:15	2:19	6500
305	4	>>	OP	request	10:25	10:35	0:10	1200
306	4	>>	OC	e.f	12:35	12:45	0:10	3500
307	1	>>	OP	request	15:20	15:55	0:35	3200
308	6	>>	OC	I>>	20:17	20:40	0:23	300
309	1	>>	OP	request	23:00	23:08	0:08	3500

Table 2 Interruption report data of upgraded system for January 2016

Ro.No	Date (E.C)	feeder name	Interruption time	Reconnect time	Duration in H:Min	Reason of interruption		Remark
						For Operation	By fault &it's types	
1	01/05/10	L-3	7:15	7:25	0:10		Earthing	

2		L-3	7:40	9:14	1:34		Earthing	Open sec.& reconnect
3		L-3	10:15	12:00	1:45		Unbalance	
4		L-1	11:30	12:00	0:30		Earthing	Open sec.& reconnect
5		M-2	14:50	15:20	0:30	√		Around Adama Steel
6		L-1	15:00	16:44	1:44		Earthing	Open sec.& reconnect
7		L-1	16:50	19:40	2:50		Earthing	Open sec.& reconnect
8		L-6	18:50	19:30	0:40		Earthing	Sub. Section problem
9	02/05/10	M-5	7:10	11:00	3:50		Short ckt	Around Erdata
10		M-3	7:35	8:50	1:15	√		for pole insert
11		M-2	7:30	11:00	3:30		Over current	Temporary fault
12		M-1	5:55	9:15	3:20	√		for 8 town project work
13		M-4	10:35	10:40	0:05	√		Open sec.& reconnect
14		L-1	10:40	11:00	0:20	√		Open sec.& reconnect
15		L-3	11:30	11:50	0:20		Earthing	Reconnection
16		L-1	13:05	13:20	0:15		Under fre:uency	Reconnection
17		L-4	13:05	13:20	0:15		Under fre:uency	Reconnection
18		M-2	14:50	15:18	0:28	√		
19	03/05/10	L-7	9:10	9:25	0:15	√		
20		L-4	9:28	9:30	0:02		short ckt	Temporary fault
21		L-4	9:40	10:35	0:55		Short ckt	
22		L-7	11:05	11:25	0:20	√		By Alemu (tap & reconne.)
23		L-4	14:35	14:50	0:15		Short ckt	√en sec.& reconnect
24		L-4	17:10	18:15	1:05		Short ckt	MV pole tilt
25		L-7	17:10	18:15	1:05		Short ckt	MV pole tilt
26	04/05/10	M-5	7:15	7:35	0:20		Short ckt	Temporary fault
27		L-1	10:55	11:05	0:10	√		By Adama csc 3 (trafo main)

28		L-1	11:30	12:45	1:15		Short ckt(Φ to Φ)	105 area
29		L-7	13:05	13:10	0:05		Earthing	Temporary fault
30	05/05/10	M-3	6:45	7:30	0:45	√		By Hassen(GL Conn.ke.03 cond)
31		M-4	6:45	7:30	0:45	√		By Hassen(GL Conn.ke.03 cond)
32		L-4	8:35	10:03	1:28	√		8 town project make chain
33		L-1	10:10	11:02	0:52	√		By Alemu (105 tap conn.)
34		M-5	11:45	12:00	0:15	√		By Adama csc 3
35		M-1	11:55	12:00	0:05		Earthing	Temporary fault
36		M-1	13:40	14:30	0:50		Earthing	Temporary fault
37		L-4	13:45	14:00	0:15		Earthing	√en sec.& reconnect
38	06/05/10	L-4	5:20	5:25	0:05		Short ckt	Temporary fault
39		L-1	5:35	5:44	0:09		Earthing	Temporary fault
40		M-1	7:20	7:30	0:10		Earthing	Temporary fault
41		L-3	7:30	9:20	1:50	√		√en sec.& reconnect
42		L-1	7:40	8:10	0:30	√		By Samson trafo main
43		L-1	8:30	8:55	0:25	√		By Samson trafo main
44		L-1	9:25	9:45	0:20	√		By Samson trafo main
45		L-3	12:10	12:15	0:05	√		By Alemu (sec. close)
46		M-2	13:25	15:50	2:25		Short ckt(Φ to Φ)	Around new kera
47		M-4	16:40	16:52	0:12	√		By Adama csc 3(Osman)
48	07/05/10	M-5	8:00	8:30	0:30	√		
49		M-3	8:55	9:45	0:50	√		for 8 town project work
50		L-4	10:25	10:30	0:05	√		Tsehay
51		M-3	12:00	12:25	0:25	√		for 8 town project work
52		L-7	13:20	13:30	0:10		Earthing	

53		L-3	15:00	15:05	0:05		Earthing	
54		L-1	22:00	22:08	0:08	√		By Adama csc 2
55		L-3	0:35	9:50	9:15		Short ckt	
56		M-1	0:40	1:45	1:05		Earthing	
57		M-1	2:00	9:55	7:55		Earthing	
58	08/05/10	M-4	8:10	10:45	2:35	√		for 8 town project work
59		M-3	10:05	10:45	0:40	√		for 8 town project work
60		M-5	11:30	11:45	0:15	√		By Adama csc 3
61		M-1	12:25	13:20	0:55		Earthing	
62		M-3	12:35	13:35	1:00		Short ckt	
63		M-2	13:00	15:30	2:30		Short ckt	
64		M-5	14:20	15:30	1:10	√		Alemu
65		M-3	16:05	16:10	0:05	√		By Adama csc 3
66		M-1	16:35	17:00	0:25		Earthing	
67		M-1	17:20	19:05	1:45		Short ckt	
68		L-4	18:55	19:00	0:05		Earthing	
69	09/05/10	L-5	8:10	8:20	0:10		Earthing	
70		L-5	10:15	10:20	0:05		Short ckt	
71		M-5	10:15	10:20	0:05		Short ckt	
72		L-4	11:45	12:50	1:05		Short ckt	
73		L-3	11:45	12:50	1:05		Earthing	
74		L-4	13:28	14:45	1:17		Earthing	
75		L-7	13:30	14:45	1:15	√		
76		L-1	14:15	14:25	0:10	√		By Adama csc 1
77		M-5	15:10	15:15	0:05	√		By Wolencity
78		M-1	15:45	16:40	0:55		Earthing	
79		L-4	15:50	17:05	1:15		Earthing	
80		M-2	17:00	17:50	0:50		Earthing	
81		L-5	17:40	17:45	0:05		Earthing	

82		M-2	19:15	20:50	1:35		Earthing	
83	10/05/10	M-3	6:50	7:00	0:10		Earthing	
84		M-1	7:00	8:25	1:25	√		Alemu
85		L-4	7:10	7:40	0:30	√		Samson
86		M-3	8:50	9:15	0:25	√		Alemu
87		M-4	8:50	9:15	0:25	√		Alemu
88		L-6	14:45	14:55	0:10	√		Alemu
89		L-3	15:35	15:55	0:20	√		
90		M-1	17:25	17:29	0:04		Earthing	
91		L-3	23:30	23:40	0:10	√		6 Emergency
92	11/05/10	L-7	8:20	8:28	0:08		Earthing	
93		L-3	9:05	10:28	1:23	√		Alemu
94		L-7	3:00	3:11	0:11		Earthing	
95		M-2	6:50	11:10	4:20		Short ckt	
96		M-5	6:50	11:10	4:20		Short ckt	
97	12/05/10	L-7	9:35	9:50	0:15	√		Alemu
98		L-6	10:45	11:00	0:15	√		Alemu
99		M-2	15:20	15:30	0:10		Earthing	
100	13-05-10	M-1	9:00	9:15	0:15		Over current	
101		L-4	12:05	12:25	0:20	√		By Adama csc 1
102		L-7	16:40	16:50	0:10		Short ckt	
103		L-1	19:45	20:20	0:35		Under fre:uency	
104	14/05/10	M-1	6:50	7:30	0:40		Over current	
105		M-5	12:10	12:50	0:40	√		Wolenchity
106		M-2	14:45	15:00	0:15	√		Tsehay
107		M-5	15:00	15:15	0:15	√		Tsehay
108		L-1	12:20	12:50	0:30	√		for 8 town project work

109		L-1	8:05	12:05	4:00		Earthing	
110		L-1	12:20	12:50	0:30	√		
111		L-4	17:40	17:55	0:15		Earthing	
112		L-4	18:45	20:00	1:15		Short ckt	
113		L-6	7:00	9:20	2:20	√		
114	15/05/10	M-2	7:05	9:10	2:05	√		
115		M-5	7:00	10:40	3:40		Short ckt	
116		M-5	16:25	17:40	1:15	√		
117		M-1	15:10	15:30	0:20		Over current	
118	16/05/10	M-5	6:35	7:55	1:20		Short ckt	
119		M-3	9:05	9:33	0:28	√		
120		M-5	12:25	13:05	0:40	√		
121		M-2	12:25	13:05	0:40	√		
122	17/05/10	M-1	13:05	13:15	0:10		Unbalance	
123		M-1	20:45	21:15	0:30	√		
124		M-1	8:30	8:35	0:05	√		
125		M-1	14:45	15:25	0:40	√		
126	18/05/10	M-4	8:20	8:45	0:25	√		
127		M-5	8:50	11:25	2:35		Short ckt	
128		M-1	10:40	10:45	0:05		Unbalance	
129		M-2	10:45	11:25	0:40	√		
130		M-1	14:00	14:25	0:25		Unbalance	
131		M-2	10:45	11:25	0:40	√		
132		M-1	14:00	14:25	0:25		Unbalance	
133	19/05/10	M-5	8:40	8:50	0:10		Earthing	

134		M-2	9:25	9:30	0:05		Earthing	
135		M-4	12:25	13:15	0:50		Earthing	
136		L-7	16:20	16:33	0:13		Earthing	
137	20/05/10	M-1	6:20	8:35	2:15		Earthing	
138		M-5	7:55	8:15	0:20		Short ckt	
139		L-4	6:35	8:35	2:00	√		
140		L-5	6:35	8:55	2:20	√		
141		L-6	6:35	8:15	1:40	√		
142		L-1	6:35	8:35	2:00	√		
143		L-6	6:35	8:55	2:20	√		
144		L-7	10:35	10:50	0:15	√		
145		L-3	13:15	13:25	0:10		Short ckt	
146	21/05/10	M-5	7:15	8:40	1:25		Short ckt	Temporary fault
147		L-3	7:35	7:50	0:15		Earthing	"
148		M-5	8:40	10:15	1:35		Short ckt	"
149		L-7	10:45	11:00	0:15	√		Maintainance
150		M-3	15:45	16:35	0:50	√		Maintainance
151		M-4	19:35	19:45	0:10	√		Maintainance
152	22/05/10	M-3	6:20	6:50	0:30	√		New connection
153		M-5	6:20	10:20	4:00		Short ckt	Around A
154		M-2	7:10	10:20	3:10		Short ckt	
155		L-1	7:45	12:10	4:25	√		Maintenance (pole damage)
156		L-1	16:15	18:15	2:00		Short ckt	
157		M-4	16:20	16:50	0:30		Short ckt	
158		M-4	17:15	18:15	1:00	√		
159		M-3	17:50	20:23	2:33		Earthing	
160		M-5	3:00	6:00	3:00		Earthing	
161	23/05/10	M-5	6:15	8:50	2:35		Earthing	

162		M-1	8:10	8:20	0:10	√		
163		M-1	9:45	9:55	0:10	√		
164		M-5	11:09	12:30	1:21		Short ckt	
165		M-2	11:12	11:15	0:03		Earthing	
166		L-3	13:45	14:10	0:25	√		
167		M-3	13:55	14:02	0:07		Earthing	
168		M-5	15:45	16:45	1:00		Short ckt	
169		M-4	17:00	17:46	0:46		Short ckt	
170		M-4	17:55	18:35	0:40		Short ckt	
171	24/05/10	M-4	0:05	0:30	0:25		Earthing	
172		L-4	7:18	8:40	1:22	√		
173		L-6	8:20	8:30	0:10		Earthing	
174		M-2	8:40	8:50	0:10		Earthing	
175		M-1	8:50	10:30	1:40	√		
176	25/05/10	M-5	6:30	9:30	3:00		Earthing	
177		M-3	7:25	10:55	3:30	√		
178		L-5	9:10	9:15	0:05	√		
179		M-2	9:30	10:30	1:00		Earthing	
180		L-7	22:55	23:30	0:35	√		
181	26/05/10	L-3	22:55	23:30	0:35	√		
182		M-1	7:20	9:05	1:45		Short ckt	
183		M-5	9:15	9:30	0:15		Earthing	
184		L-7	14:00	14:05	0:05		Earthing	
185		L-4	23:05	1:15	1:10		Earthing	
186		L-3	23:05	4:45	5:40		Short ckt	
187		L-6	23:05	20:00	21:55		Short ckt	
188		L-7	23:05	1:15	2:10		Earthing	

189		M-1	23:05	6:30	7:25		Earthing	
190		M-4	23:05	6:30	7:25		Earthing	
191		M-5	23:05	17:00	17:55		Earthing	
192	27/05/10	L-1	4:30	4:35	0:05		Earthing	
193	"	L-7	7:30	8:55	1:25	√		
194		M-1	8:55	10:05	1:10	√		
195		L-4	8:55	9:15	0:20		Short ckt	
196		L-1	8:55	9:55	1:00		Short ckt	
197		L-5	12:00	16:00	4:00		Short ckt	
198		M-1	12:50	13:35	0:45	√		
199		L-1	12:50	14:45	1:55	√		
200		L-3	12:50	14:45	1:55	√		
201		L-4	12:50	14:45	1:55	√		
202		L-5	12:50	16:00	3:10	√		
203		L-6	12:50	20:00	7:10	√		
204		L-7	12:50	14:45	1:55	√		
205		L-3	17:55	18:45	0:50	√		
206	**5/28/2010**	**M1**	**6:40**	**10:05**	**3:25**		**Short ckt**	
207		L1	11:15	11:40	**0:25**	√		
208		M2	12:45	15:25	2:40		Short ckt	
209		M1	16:45	18:20	1:35		Earthing	
210		M2	16:20	11:30	19:10		Short ckt	
211		L7	6:55	9:15	2:20	√		
212		L1	8:15	10:30	2:15	√		
213	5/29/2010	M1	11:00	11:10	0:10	√		
214		M2	12:20	13:20	1:00		Short ckt	
215		L7	14:40	16:25	1:45		Short ckt	
216		M3	17:25	17:40	0:15		Earthing	
217		M4	18:40	19:15	0:35		Gantree	
218		M3	19:20	19:45	0:25	√		
219		M5	4:00	6:55	2:55		Over current	
220		L7	7:30	7:35	0:05		Earthing	

221	5/30/2010	L3	8:25	9:45	1:20	√		
222		L7	10:40	11:05	0:25	√		
223		M5	11:15	11:20	0:05	√		
224		M5	13:00	13:10	0:10	√		
225		M3	13:10	13:30	0:20		Earthing	
226		M3	19:30	21:00	1:30		Earthing	
227		L1	19:30	21:00	1:30		Earthing	