



RELIABILITY ASSESSMENT AND ENHANCEMENT OF DISTRIBUTION
SYSTEM BY INCORPORATING RENEWABLE DISTRIBUTED
GENERATION

(CASE STUDY: 33KV DISTRIBUTION FEEDER LINE 10 FROM HAWASSA
SUBSTATION)

MSc. THESIS

BY

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JUNE, 2016

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A THESIS SUBMITTED TO THE
SCHOOL OF ELECTRICAL AND COMPUTER ENGINEERING,
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DECLARATION

I, the undersigned, declare that this thesis is my own original work, and it has not been presented for in this or other university, and all sources of material used for thesis have been fully acknowledged.

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

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ABSTRACT

Electricity is produced and delivered to customers through generation, transmission and distribution systems. A stable and reliable electric power supply system serve customer loads without interruptions. Distribution systems deliver power from bulk power systems to customers. Distribution reliability primarily relates to equipment outages and customer interruptions.

This thesis work attempts to thoroughly identify causes for power interruptions and customer dissatisfaction and discusses the design, reliability and operation and maintenance of Hawassa feeder 10 distribution networks.

With recent advances in technology, utilities expect to see increasing amounts of distributed generation (DG) on the distribution systems. Reliability worth is very important in power system planning and operation. Having a DG ensures reliability improvement and may be used to increase the reliability worth.

This research presents the study of a radial distribution system and the impact of placing renewable energy DG (PV, Wind) and battery energy storage in order to increase the reliability worth. The reliability improvement is measured by different reliability indices that include SAIDI, CAIDI, EENS and ASAI. The analyzed and calculated distribution reliability indices values have been compared with standard benchmark values and comparison clearly indicates that Hawassa feeder 10 distribution systems is extremely unreliable.

The values for SAIDI, SAIFI, CAIDI and ASAI are 240 minutes/year, 1.5 interruptions/customer, 123 minutes/year and 99.91% respectively in a USA standard, whereas the corresponding values for the existing distribution system of Hawassa feeder 10 are 5129.002 minutes/year, 47.5205 interruptions/customer, 107.94 minutes/year and 99.02% respectively. also unavailability of energy per year is 93.706mwh.

The thesis also evaluates reliability of distribution networks, including islanded micro grid cases, is presented. The network includes two types of distributed energy resources solar photovoltaic (PV), wind turbine (WT) and energy storage as back up. These distributed generators contribute to supply part of the load during grid-connected mode, but supply the high densely loaded area Arbegona load during islanded micro grid operation. The studies performed are supported with the Power Management System Software ETAP and MATLAB CODED for power output of renewable energy source.

LIST OF ABBREVIATIONS

AC	Alternating Current
AENS	Average Energy Not Supplied Index
ANSI	American National Standards Institute
ASAI	Average Service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CT	Current transformer
DC	Direct current
EEU	Ethiopian Electric Utility
ENS	Energy not supplied
HRC	High Rupturing Capacity
IEC	International Electro technical Commission
IEEE	Institute of Electrical and Electronics Engineers
KVAR	Kilovolt Ampere Reactive
KVA	Kilovolt Ampere
MW	Mega watt
MVA	Mega volt ampere
P	Active power
PF	Power factor
PT	Potential transformer
Q	Reactive power
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SOL	System over load

TABLE OF CONTENTS

ACKNOWLEDGEMENT	v
ABSTRACT.....	vi
LIST OF ABBREVIATIONS	vii
LIST OF FIGURES	x
LIST OF TABLES	xi
CHAPTER ONE	1
INTRODUCTION	1
1.1 Introduction	1
1.2 Background.....	1
1.3 Distributed energy resources and generation	2
1.4 Power system reliability analysis.....	2
1.5 Micro grids	3
1.6 Problem statements and motivation.....	4
1.7 Objectives	6
1.8 Description of the study area	7
CHAPTER TWO	8
DISTRIBUTED GENERATION MODEL	8
2.1 Introduction	8
2.2 Modeling of PV power output	9
2.3 Wind output power model	11
2.4 Energy storage system model	13
2.5 Load model.....	14
2.6 Reliability model for the combined DGs and storage energy system	14
2.7 Case study.....	15
2.7.1 Meteorological data.....	15
2.7.2 Component selection	16
2.8 Micro grid structure	21
CHAPTER THREE	22
THEORETICAL BACKGROUND AND LITERATURE REVIEW	22
3.1 Introduction	22
3.2 Electric Power Distribution System Design	22
3.3 Voltage Drop in an Electric Power Distribution System	23
3.4 Power Loss in an Electric Power Distribution System	25
3.5 Reliability Analysis of an Electric Power Distribution System	26
3.6 Literature Review	31
CHAPTER FOUR.....	33
RELIABILITY ANALYSIS OF THE EXISTING HAWASSA DISTRIBUTION FEEDER	33

4.1 Power Distribution System Standards and Design Guidelines	33
4.2 Existing Structure of Hawassa Distribution System Feeder 10	34
4.3 Data Collected from Hawassa substation 33kv feeder lines	35
4.4 Hawassa substation power transformer, feeders and load data.....	37
4.5 Major Causes of Interruption in the Existing Distribution System.....	39
4.6 Types of fault in Hawassa 33kv distribution feeders	40
4.7 Reliability Indices Evaluation of Hawassa 33kv (feeder 10) Distribution System	43
4.8 Base case reliability analysis	48
4.9 Comparison of Reliability Indices with Benchmarks	49
4.10 Loss of Revenue due to Power Interruption (shading) in Hawassa feeder 10 line.....	50
CHAPTER FIVE	52
SOLUTIONS FOR IMPROVING THE RELIABILITY OF DISTRIBUTION FEEDER	52
5.1 Design solution to Hawassa feeder 10 distribution line.....	53
5.1.1 Selection of distribution transformer capacity	53
5.1.2 Selection of distribution cable.....	54
5.1.3 Permissible Voltage Drop Calculation and power loss calculation.....	55
5.1.4 Fault Current Calculation	56
5.1.5 Selection of Circuit Breakers	58
5.1.6 Selection of Surge Arrestors	59
5.1.7 Selection of Isolators.....	60
5.1.8 Selection of CT and PT	61
5.1.9 Selection of insulator.....	62
5.2 Reliability Improvement Strategies to Hawassa feeder 10 Distribution System based on protection device and preventive maintenance system	63
5.2.1 Sensitivity study based on protection device and preventive maintenance system.....	63
5.3 Reliability Improvement Strategies to Hawassa feeder 10 Distribution System based on adequacy issue	66
5.4 Cost benefit effect	69
CHAPTER SIX.....	69
RESULT AND DISCUSSION	71
CHAPTER SEVEN	75
CONCLUSION, RECOMMENDATIONS AND FUTURE SCOPE.....	75
7.1 Conclusion	75
7.2 Recommendation	75
7.3 Future work.....	76
REFERENCE.....	77
APPENDIX.....	80

LIST OF FIGURES

Figure 1.1: Distribution network containing micro grids	4
Figure 1.2: Block Diagram of Energy Management System	4
Figure 1.3: Block Diagram of towns supplied from Hawassa feeder 1.....	7
Figure 2.1 Equivalent circuit of a PV cell	9
Figure 2.2: PV efficiency versus Sunlight intensity	11
Figure 2.3: output characteristics curve of wind turbine	12
Figure 2.4 For 400kw PV Hourly Charge and Discharge Profile of the Storage (P>0 Charging and P<0 Discharging)	14
Figure 2.5: System configuration with charge controller and the inverter as one unit	16
Figure 2.6: Single line diagram of Hawassa feeder 10 modified Radial distribution network with RDG.....	21
Figure 4.1: Single line diagram of Existing structure of Hawassa substation 33kv feeder 10 line.....	34
Figure 4.2: Single line diagram of Hawassa substation 33kv feeder 10 distribution system	45
Figure 5.1: Single line diagram of modified Hawassa sub. Feeder 10 distribution system	64
Figure 5.2: Single line diagram of modified micro grid containing Hawassa 33kv feeder 10 distribution line.....	67

LIST OF TABLES

Table: 2.1 Analysis of state of micro grid in islanded mode	15
Table 2.2: sunshine hour duration	15
Table 2.3: calculated and measured values of basic parameters for Hawassa city	15
Table 2.4: wind speed at different height above the earth	16
Table 2.5: Typical Electric Characteristics of Generic poly 250w Module	17
Table 2.6: Electrical characteristics of IG PLUS 150 V-3 inverter	17
Table 2.7: PV generator characteristics	19
Table 2.8: Storage battery basic parameters data	20
Table 2.9: Wind turbine generator wind characteristics data.....	20
Table 2.10: Micro grid structure and supplying RDG	21
Table 4.1: Hawassa substation of 33kv lines data	35
Table 4.2 Frequency of Interruption for Hawassa 33kv (feeder 10) Distribution System	35
Table 4.3 Duration of Interruption for Hawassa 33kv (feeder 10) Distribution System	36
Table 4.4: Hawassa substation 33kv power transformer technical details	37
Table 4.5: Hawassa substation 33kv feeder 10 data	38
Table 4.6: Showing study area load point and customer data	38
Table 4.7: Hawassa substation 33KV distribution feeder's interruption data in 2015G.C	40
Table 4.8: Hawassa substation 33kv feeder interruption data in 2015G.C caused by line fault 2015 G.C	41
Table 4.9: Hawassa substation 33kv feeder interruption due to line and transformer overload..	41
Table 4.10: Hawassa substation 33kv feeder interruption due generation inadequacy/shading in 2015 G.C.....	42
Table 4.11: Summarizing the interruption data on 33kv feeder 10 line	42
Table 4.12: Distribution line fault interruption reliability indices	46

Table 4.13: Distribution line and power transformer overload interruption reliability indices.....	46
Table 4.14: Generation failure and system overload load point interruption reliability indices..	47
Table 4.15: Component reliability data	48
Table 4.16: Load point output report for base case Hawassa substation feeder 10 line	48
Table 4.17: system indices of 33kv feeder 10 line	49
Table 4.18: Benchmarks for Reliability Indices	50
Table 4.19: Electricity tariff Ethiopian Electric Power Corporation (EEPCO) Since July 8, 2006	53
Table 5.1: AAC Overhead cables data.....	54
Table 5.2: Ratings of 33 kV Circuit Breaker	58
Table 5.3: Ratings of 33 kV Surge Arrester.....	59
Table 5.4: Ratings of 33 kV Isolator.....	60
Table 5.5: Ratings of 33kV Current Transformer.....	61
Table 5.6: Ratings of 33kV Voltage Transformer	61
Table 5.7: Ratings of 33kV suspension Insulator.....	62
Table 5.8: Load point output report for automated Hawassa substation feeder 10 line	65
Table 5.9: system indices of automated 33kv feeder 10 line	65
Table 5.10: Reliability input data of distributed generation components	67
Table 5.11: Load point output report for automated and micro grid containing Hawassa 33kv feeder 10 distribution line	68
Table 5.12: system indices of automated and micro grid containing 33kv feeder 10 line	68
Table 5.13: Showing component price of 400kw PV power generation.....	69
Table 5.14: Showing component price of 100kw wind power generation.....	69
Table 5.15: Showing component price of Battery system.....	70

CHAPTER ONE

INTRODUCTION

1.1 Introduction

In recent years, researchers in the field of power systems engineering have become interested in the implementation of renewable energy resources in power networks. This interest is motivated by environmental issues and rising fossil fuel prices. Since greenhouse gas emissions are the main cause of global warming, using technologies that do not produce Carbon Dioxide emissions would naturally eliminate their effects. Rising fossil fuel prices have made renewable resources more competitive in the market and could encourage more technologies to compete in the power market. For example, plug-in hybrid electric vehicles that are predicted to reshape the transportation future could interact with power grids as a means of energy storage. Alternative energy can be used to supply these vehicles, and this would reduce the dependency on fossil fuels. Distributed energy resources take different forms such as wind, solar, geothermal etc.

1.2 Background

The power distribution system is made up of sub-transmission lines, power transformers, 33kV lines, 15kV lines, distribution transformers, LV Lines, etc. Distribution substations monitor and adjust circuits within the system. Currently Ethiopian Electric Power Corporation power system have 400kV, 230kV, 132 kV primary transmission systems and 66kV, 45kV as sub transmission system and 33kV and 15kV as distribution system. At all the 66 or 45kV substations power transformers of various ratings like 25 /12 /6.3/3MVA are installed for step down of voltage to 15kV for feeding to Distribution Transformers. The outgoing feeders are connected in radial fashion. Mostly 33kV and 15kV overhead conductors are used for feeding 60 to 70 distribution transformers on each 33kV and 15kV feeder. The voltage is then further reduced by distribution transformers to the utilization voltages of 380 volts three-phase or 220 volts single-phase supply required by most users.

Electric distribution system power quality is a growing concern. Customers require higher quality service due to more sensitive electrical and electronic equipment. The effectiveness of a power distribution system is measured in terms of efficiency, service continuity or reliability, service quality in terms of voltage profile and stability and power distribution system performance.

In the context of Ethiopia, electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems. The drop of the voltage, especially at the residential loads, is causing early failure of equipment, blackening of light bulbs, and decreased efficiency and performance of high-power appliances. Damage of electronic devices and burning of light bulbs have also occurred due to over voltages.

1.3 Distributed energy resources and generation

In typical power networks, the electricity is generated by large-scale power plants and transported via the transmission and distribution networks to end users. This concept is called centralized generation. Distributed generation or decentralized generation is an approach that implements small-scale generators installed on the low-voltage networks by the customers or the utility companies. The advantages of employing this technology in power systems include:

- ✓ Reduction in power losses caused by the power traveling through long transmission lines and high voltage transformers.
- ✓ Relieving the congested transmission networks and reducing the need to expand transmission networks.
- ✓ Enabling consumers to select the source of energy based on the cost and awareness of the environmental issues.
- ✓ Improving the reliability of the power service by providing an alternative source during power disturbance events.
- ✓ It can reduce the cost of electricity, and lower emissions of air pollutants.

1.4 Power system reliability analysis

Power system reliability assessment is primarily focused on an analysis of the healthy and failure states of a power system. Power system reliability can be subdivided in to two classes.

Adequacy assessment takes into account the determination of sufficient facilities within the systems satisfy the customer load and with static conditions in the power system.

Power system security has the goal to respond to disturbance arising within the system and therefore deals with the dynamic conditions in the system.

A power system is a complex network, highly integrated and very large. The reliability evaluation of the entire configuration at a time is complex if it is considered the power systems

as an entire entity. Despite the evaluation complexity, the need for reliability assessment is ever increasing and more utilities are investing time in reliability analysis. Thus, to reduce the complexity of an overall power system, there are methodology that consider on divide it in different parts that is into three functional zones. These are generation facilities and their ability to satisfy the system demand, the second one is composite generation and transmission systems and the ability to deliver energy to the bulk power points, Finally the third refers to the complete system including the distribution at the satisfaction of the demand of individual costumers.

1.5 Micro grids

In the traditional centralized generation version of power networks, the distribution networks are radial that allow the power to flow in one direction. However, high penetration of distributed generation could change this practice, and more new technologies must be adopted on the distribution networks to prepare power grids to accept high levels of distributed generations. The micro grids concept is associated with the distribution networks that contain one or more micro generators. The implementation of micro grids would reshape distribution engineering on different aspects such as protection, control and communication systems. Also, micro grids can be operated in an interconnected mode where the distributed generation contributes with power grid to supply the load or, in an islanded mode where the loads are supplied by the distributed generation only. The integration of micro grids in power systems would pave the way for high penetration of intermittent resources such as wind and solar energy.

Figure 1 shows an example of a micro grid in a distribution network. Since the breaker is open, micro grid 1 is isolated from the system and operated in island mode. Micro grid 2 is interconnected with the grid where the loads are supplied by the distributed generation and the main grid.

In a conventional distribution network, the power flow is radial which needs simple protection devices such as fuses, unidirectional over current relays and reclosers. These devices don't fulfill the micro grid protection and does not offer the desired flexibility. Different configurations of distribution networks result in changing the short circuit levels which are caused by changing system impedance. In addition, bidirectional power flow is expected in operating distribution networks containing micro grids. For these reasons, protection systems must be reengineered to handle different operating modes. One of the promising features of micro grids is the capability to perform auto configuration of distribution networks without the interaction of networks operators. This feature makes micro grids self-healing from network components failure or power disturbances, and this will result in fewer interruptions leading to

higher reliability. The use of power electronic-based or static switches would provide the protection and control systems of micro grids with faster response compared to convention mechanical circuit breakers.

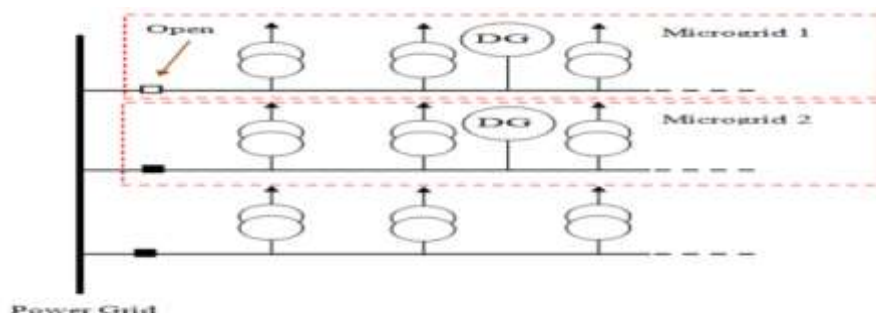


Fig1.1: Distribution network containing micro grids

Since the load and distributed generation from renewable resources variable in nature, energy management systems could be useful tools to allocate energy resources and control power production. Live data needs to be collected and exchanged between within the system. These include, weather, load demand, power production and power outages. Therefore, two lines of communication should be installed in the distribution networks. The energy management system’s function is to process the data and achieve an efficient operation of the network with consideration of economic dispatch and system reliability. Figure below shows an example of a simplified block diagram of energy management system in a distribution network.

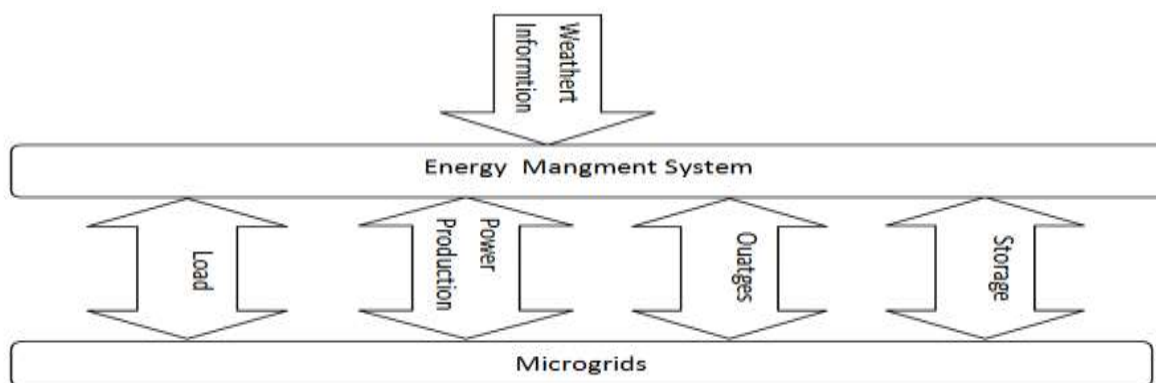


Figure1.2: Block Diagram of Energy Management System

1.6 Problem statements and motivation

The reliability benefits are appreciated from a costumer point of view, where a properly located, installed and operated DG can improve reliability of energy supply, and essential to somewhere interruption of service is unacceptable economically or where health and safety is impacted. Each customer can decide his own reliability.

A. Industry or factory level and commercial level

Power outage and fluctuations are factors for weak performance. The Ministry of Industry, which targeted over billion dollars revenue, has reported that this year's overall performance was much lower than what was originally planned. According to the minister, in February a total of 204 cases of power outages were registered among eight textile factories and as a result an estimated 106 working hours were wasted.” “Apart from wastage of production time, devastating impacts on electronic equipment that disrupt production and productivity occurred. He added that four leather factories around Mojo suffered similar problems related to power outages.”[6]. Also some commercial and service giving utilities like banks, ethio telecom ,water supply and many governmental and nongovernmental office and company are complaining of the interruption in order to give their service with any power supply problems.

B. On an individual and community level,

- ✓ Economic, health and security hazards. Rendering electrical equipment useless,
- ✓ Considerably diminish the working hours of small businesses and individuals eroding their sustainability.
- ✓ With a considerable number of power cuts, small businesses find it hard to pay rent, salary of employees and expand their businesses.
- ✓ Individuals and families, on the other hand, would be subjected to additional energy and other costs as a result of power cuts. Power cuts also infringe on quality of life.

Health facilities:

- ✓ The use of electronic health machines is hampered by power cuts and fluctuations, making it harder for medical personnel to save lives.
- ✓ At individual level, alternative energy sources such as biomass or charcoal for cooking purposes could prove to be bad for health besides the environmental negative impact, these promote minor to fatal health hazards

Additionally power cuts also pose security threats on both businesses and households as those with criminal intent find it easy to manipulate the situation. Besides using the dark, criminals find it easy to maneuver security breaches as electronic security materials would be out of use during power outages.

Due to future load growth, distribution systems may not be able to supply required load and hence additional energy is required. To avoid expansion of substation, DG installed close to them. Distributed generation could serve as a substitute for investments in transmission and distribution capacity or as a bypass for transmission and distribution costs (demand for

distributed generation from electricity customers). Of course, this is possible only to the extent that alternative primary fuels or renewable energy are locally available.

Apart from main reliability problems, which involve high voltage drops, one can also have smaller voltage destination. These are aspects of power quality: it refers to the degree to which power aligns with the sinusoidal deal voltage and current wave form. Thus, power quality encompasses reliability and the insufficiency power quality may be caused by reliability issue as failure and switching operations. With a better reliability it is also assure a better power quality.

This investigation addresses some of the reliability issues encountered with the number, sizes and placement of DG sources connected to a radial system. However, there are more technical issues as power control (system voltage and frequency) and connection issues (change in power flow, protection, reactive power).

1.7 Objectives

General Objective: The main objective of this thesis work is to conduct a study and evaluation of the reliability and design of Hawassa feeder 10 line and examine impact of grid connected solar, wind power generation (DG) and Battery storage system as backup on existing distribution network reliability enhancement for customers power delivery.

Specific objectives: The specific objectives are;

- ✓ To investigate and identify the possible power distribution problems that affects the performance of the network
- ✓ To make a detailed analysis on the design and operation practice of the existing power distribution system.
- ✓ To propose an improved power distribution design that helps to mitigate the identified power reliability problems.
- ✓ To make a detailed reliability analysis of the existing distribution system
- ✓ To evaluate the available solar and wind energy resource near to Hawassa, Ethiopia.
- ✓ To explore the implications of installing solar, wind and BES system on reliability of distribution network operation.
- ✓ To make relevant conclusions and recommendations that can be of use for the performance improvement of the Hawassa feeder 10 distribution network.

1.8 Description of the study area

Hawassa distribution substation is fed by a 132 KV overhead transmission line coming from Halaba synchronizing station. The substation has a maximum capacity of 66 MVA and supplied by three power transformers of the following rating:

Two winding transformer: 132/15 KV, 25 MVA and 25 MVA

Three winding transformer: 132/33/15 KV, 16/8/8 MVA

The substation has eight (13) outgoing feeders: ten on 15 KV level and three on 33 KV level. The ten 15 KV outgoing feeders supply various loads in main town and nearby towns, Textile factory, ceramic factory and Rural areas. Three 33 KV outgoing feeders supply to loads of BGI brewery, Hawassa, university, industry park and rural areas like Arbegona , kokosa, Boro connected to Hawassa feeder 10 where the study is based on while the remaining one feeder is left idle as a standby.

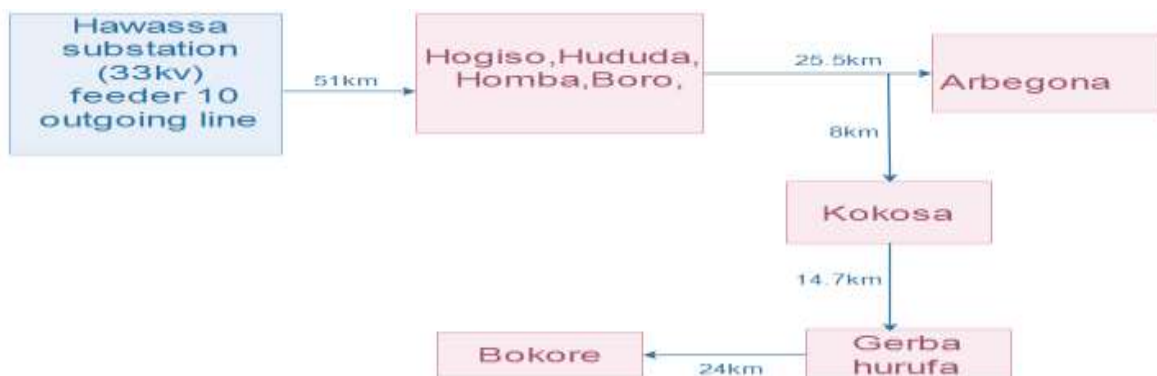


Figure 1.3: Block Diagram of towns supplied from Hawassa feeder 1

CHAPTER TWO

DISTRIBUTED GENERATION MODEL

2.1 Introduction

In this study, the reliability of distribution system containing renewable resources such as wind and solar energy was assessed. It is well known that due to the fact that solar insolation and wind speeds are both intermittent, the output powers of PV and WT systems are not deterministic. That brings up the need for a stochastic model to simulate PV and WT outputs. The stochastic model is a simulation-based technique to describe a non-deterministic behavior and the randomness of the system. The probability distribution, therefore, can be used to predict the output power of PV and WT. In order to find statistical data of the wind speed and solar insolation, meteorological data of a variety of weather conditions at one location must be measured. In this study, the distribution system contains distributed gas turbines (DGT's). The output power of the DGT's is modeled. The storage systems is needed to decrease the peak load since the peak of the output power of the PV's and the peak load do not occur at the same time in most load profiles.

Estimation of irradiation(Insolation)

According to world metrological organization (WMO) the sunshine duration is defined as the period during which the direct solar irradiance exceed a threshold value of 120 W/m²-day. Solar radiation of a certain period is proportional to sunshine duration. Akinoçglu and Ecevit model is used for this study purpose.

$$\frac{H}{H_0} = 0.145 + 0.845 \frac{S}{S_0} - 0.28 \left(\frac{S}{S_0}\right)^2$$

$$H_0 = \frac{24}{\pi} G_{sc} * \left(1 + \cos \frac{360n}{365}\right) \left(\cos \varphi \cos \delta \sin \omega_s + \frac{\pi \omega_s}{180} \sin \varphi \sin \delta\right)$$

$$\delta = 23.45 \sin\left(360 \frac{284 + n}{365}\right)$$

$$\cos \omega_s = -\tan \varphi \tan \delta$$

$$S_0 = \frac{2}{15} \omega_s$$

Where H= monthly average daily global irradiation (Wh/m²/day),

H₀ =monthly average daily extraterrestrial irradiation at specific location.

S= monthly average daily maximum bright sunshine duration in hours.

S_0 = monthly average day length

G_{sc} = global solar constant = 1.367 Kw/m^2

n = the day of a year (a number between 1 to 365, starting from first January.

φ = the latitude in degree.

δ = the solar declination in degree.

ω_s = the sunset hour angle in degree

It should be noted that this equation has been obtained solely by using the Angstrom coefficients a and b of 100 locations over the Earth's surface located at different climates and latitudes.

2.2 Modeling of PV power output

To understand the electronic behavior of a solar cell, it is useful to create a model which is electrically equivalent, and is based on discrete ideal electrical components whose behavior is well defined.

The building block of PV arrays is the solar cell, which is basically a p-n junction that directly converts light energy into electricity: it has a equivalent circuit as shown below

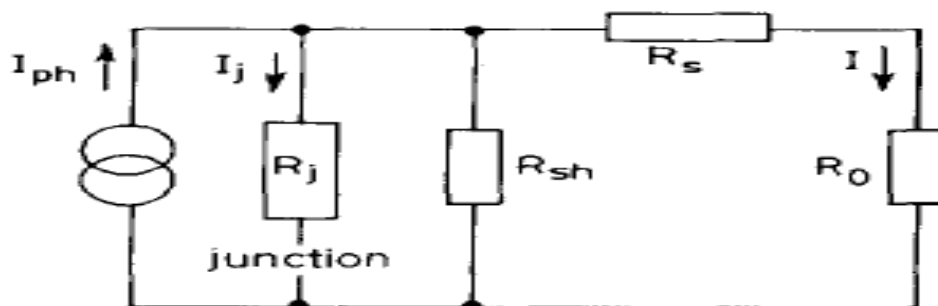


Figure 2.1 Equivalent circuit of a PV cell

The current source I_{ph} represents the cell photo current; R_j is used to represent the non-linear impedance of the p-n junction; R_{sh} and R_s are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis also I_{rs} is the cell reverse saturation current is assumed zero. PV cells are grouped in larger units called PV modules which are further interconnected in series-parallel configuration to form PV arrays or PV generators [3].The PV mathematical model used to simplify our PV array is represented by the equation:

(Assuming $R_s=0$, $R_{sh}=\infty$ and $I_{rs}=0$, for simplifying the study) and applying Kirchhoff law we get: The electrical powers generated by a PV array consist of N modules can be computed using equations below

$$T_c = T_A + \frac{(N_{oct}-20)S}{80}$$

$$I = I_{ph} = [I_{sc} + K_i(T_c - 25)] \frac{S}{100}$$

$$V = V_{oc} - K_v T_c$$

$$FF = \frac{V_{mpp} * I_{mpp}}{V_{oc} I_{sc}}$$

$$P_{out} = N * FF * VI = n_s * n_p * FF * VI$$

Where, I is the PV array output current

V is the PV array output voltage;

n_s , n_p is the number of cells in series and in parallel;

N is number of module

T_c , T_A is the cell effective and ambient temperature($^{\circ}C$);

I_{sc} is the cell short-circuit current

V_{oc} is the open circuit voltage

I_{mpp} , V_{mpp} is the current and voltage at maximum power point

K_i is the short circuit current temperature coefficient

K_v is the open circuit voltage temperature coefficient

S is the solar radiation in mW/cm^2 .

FF is the fill factor

Define the fundamental intensity H(t) to be the average value of sunlight at time t in a statistical time range (usually a year). Neglecting the influence of seasons change on the sunrise and sunset time, H(t) can be considered to be a quadratic function, which is represented by, for a typical sunny day, the hourly solar insolation H(t) can be expressed by the following equation [11]:

$$H(t) = \begin{cases} I_{max} \left(-\frac{1}{32} t^2 + \frac{2}{3} t - 3 \right) & 0 \leq t < 18 \\ 0 & 0 \leq t < 6, 18 \leq t < 24 \end{cases}$$

Where t is time in a day, whose unit is hour; I_{\max} is the maximum sunlight intensity in a day, which is at the time 12 in the midday, that is $I_{\max}=H(12)$. The solar insolation can be affected by several factors such as clouds, temperature, and relative humidity. To make the PV model more realistic, a prediction tool should be implemented. Studies have proven that the variation of PV output power ΔP_{out} follows a normal distribution [23]. Therefore, ΔP_{out} can be expressed by the following equation [23]:

$$f(\Delta P_{\text{out}}) = \frac{1}{\sqrt{2\pi}} * \exp. \left(-\frac{\Delta P_{\text{out}}^2}{2 * \sigma_{\text{pv}}^2} \right)$$

Where σ_{pv}^2 is the variance of PV output power + $(f(t) * I(MF)/24)$

The predicted PV output power includes, P_{out} , on a sunny day plus ΔP_{out} . Thus, the PV output can be calculated by the following equation [23]:

$$P_{\text{pv}} = P_{\text{out}} + \Delta P_{\text{out}}$$

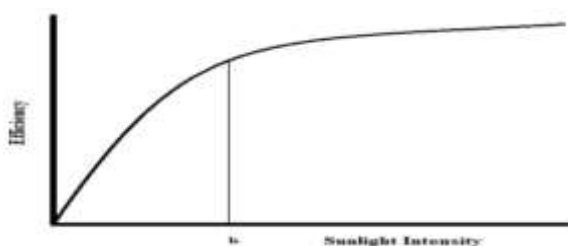


Fig.2.2 PV efficiency versus Sunlight intensity

Number of modules used in PV generation is found by

2.3 Wind output power model

The output power of a wind turbine depends on wind velocity. If the wind velocity is below the cut-in speed, there is no enough power to generate power, and the wind turbine would be turned off. If the wind velocity is between the cut-in and rated speed, the output power would be variable. If the wind velocity is between the rated and cut-on speed, the output power would be constant. In the case of the wind speed goes above cut-on speed, the wind turbine would be turned off because it exceeds the mechanical safety limit. The relationship between the output power and wind velocity is shown in Figure 2.3, and to model the wind system performance, its power curve must be also formulated in the form of polynomials as below [8].

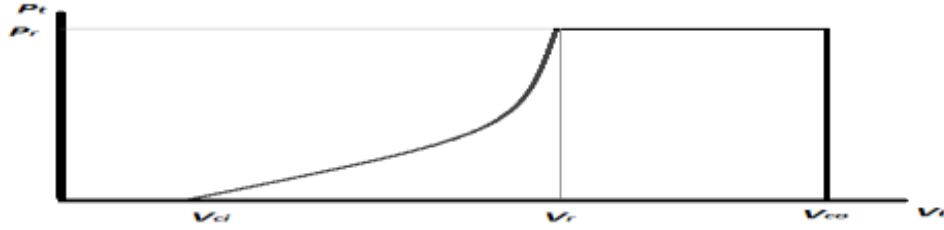


Fig.2.3: output characteristics curve of wind turbine

$$P_{WTG} = \begin{cases} 0 & 0 \leq V_t \leq V_{ci} \\ A + BV_t^3 & V_{ci} \leq V_t \leq V_r \\ P_r & V_r < V_t \leq V_{co} \\ 0 & V_t > V_{co} \end{cases}$$

where P_{WTG} and V_t represents the output of wind turbine and actual wind velocity, respectively, at the time of t ; V_{ci} , V_r and V_{co} represent the cut-in wind velocity, rated wind velocity and cut-off wind velocity respectively; P_r represents the rated power of the wind turbine. A and B are parameters, which can be calculated by the following equations:

$$A = \frac{P_r \cdot V_{ci}^3}{V_{co}^3 - V_r^3}$$

$$B = \frac{P_r}{V_r^3 - V_{co}^3}$$

Although wind is random and intermittent, distribution of wind velocity in most districts still follows some rules, and certain distributions can be adopted to represent the probability distribution of wind velocity. Consequently, a probabilistic method should be implemented to simulate the uncertainty of the wind speed. Statistical data has shown that probability distribution of wind speed follows a Weibull distribution. Weibull distribution is considered to be a simple function suitable to describe the wind [23]. It's a single-peak and two-parameter function, whose distribution function and probability density function can be expressed as below: The probability density function of a two parameter Weibull distribution is given as [25]:

$$f(V_t) = \frac{k}{c} \left(\frac{V_t}{c}\right)^{k-1} \exp. \left[-\left(\frac{V_t}{c}\right)^k\right]$$

Where

V_t wind speed

c Scale parameter

k Shape parameter

Both of them can be calculated from the average wind velocity (μ) and the standard deviation (σ)

$$k = \left(\frac{\sigma}{\mu}\right)^{-1.086} \text{ and}$$

$$c = \frac{\mu}{\Gamma\left(1 + \frac{1}{k}\right)}$$

Since the Weibull probability function of the wind speed is very sensitive to any change in c and k , statistical data of the wind speed at the desired location should be collected for several years.

2.4 Energy storage system model

Storage device is usually configured with intermittent generations like wind power and photovoltaic in order to smooth the fluctuation of these DGs' output so that power quality and power supply reliability in micro grid can be improved. In islanded mode, when DGs' output is greater than load, residual energy is stored in storage device; when DGs' output is less than load, the stored energy is released to supply customers. Assume that the combined DGs and storage energy system is autonomous and controllable, neglecting the influence of the time constant of power regulation, it can be considered that output of the combined DGs and storage energy system and load can reach equilibrium all the time. When DGs' output is insufficient, which is caused by the insufficiency of wind or sunlight, or is zero, which may be caused by DG outage, or no sunlight in the night, or no wind, the released energy by storage device is greater than the stored energy, then the operation time of storage system in micro grid islanded mode is constrained by its storage capacity.

In addition, battery storage can associate with the distributed energy resources to supply the load when the main source is not available. In this thesis, a generic battery storage system developed, which serves the main purpose of this study.

The total system energy interrupted capacity and the converter capacity are 2400kwh and 400kw respectively in 24 hours. Figure 2.4 shows the hourly charge and discharge profile of the battery. From 1:00 am to 6:00 am, the storage draws 400kw continuously to charge the batteries because this time is considered to be off- peak (based on the load profile). From 4:00 pm to 9:00 pm, the storage system is discharged to supply the load during the peak.

Because there is no output power of the PV during the night, the storage battery is charged by the main grid. During interruptions in the power network, the load can draw up to 2400 KWh of energy in 6 hours if the battery is fully charged.

Batteries used in all solar systems are sized in Ampere hours under standard test conditions (Temp: 25⁰ C).

$$C_x = \frac{E_{tot}}{V_{dc}} * \frac{G_{ft}}{DOD_{max}}$$

Where C_x = battery capacity, for a specified discharge rate in ampere hours.

E_{tot} = total energy in watt hours to be supplied by battery bank during grid failure

G_{ft} = the number of days the battery bank needs supply during grid failure.

It is important to remember that in hours this will be divided by 24.

DOD_{max} = design maximum depth of discharge

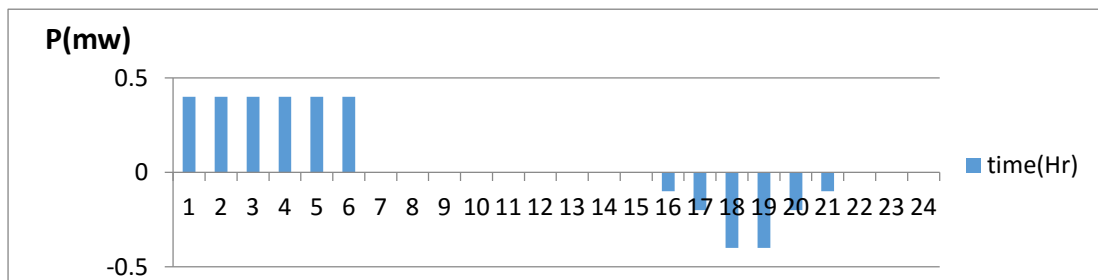


Fig.2.4 for 400kw PV Hourly Charge and Discharge Profile of the Storage (P>0 Charging and P<0 Discharging)

2.5 Load model

Weather conditions and seasonal events affect the load. Fortunately, most of these events take place at the same time annually. Therefore, the behavior of power system loads is a frequent pattern during normal conditions.

2.6 Reliability model for the combined DGs and storage energy system

In interconnection model, whether DGs generate power does not influence the power supply to customers because of the support from the distribution grid. While in islanded mode, the states of DGs and storage devices will directly influence the power supply for customers within micro grid. According to analytic requirements in this paper, DG states are divided into failure state and non-failure state, and the storage states are divided into failure state, non-failure but exhausted state and non-failure with residual energy state.

The states of micro grid can be determined by analyzing the states of DGs and storage, and the energy stored in storage device. Analysis results are shown in Table below.

Table: 2.1 Analysis of state of micro grid in islanded mode

State of DG and storage device	Energy in storage	State of micro grid
Storage non failure, DG non-failure	Energy not exhausted	Supply power
	Energy exhausted	Load shed or outage
Storage failure, DG non-failure		Shed load or outage
Storage non-failure, DG failure	Energy not exhausted	Supply power
	Energy exhausted	Shed load or outage
Storage failure, DG failure		Shed load or outage

2.7 Case study

2.7.1 Meteorological data

Table 2.2: sunshine hour duration

Hawassa/2015 G.C		Daily Sunshine Duration per Hour																															average
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31		
Jan	11.0	10.8	10.6	10.5	10.0	9.8	10.5	10.5	10.4	10.0	10.4	9.6	8.0	9.2	10.0	10.6	10.4	10.3	8.3	9.9	9.8	9.7	9.0	10.4	10.5	10.8	10.8	11.0	10.8	10.5	10.8	10.8	10.15
Feb	10.3	10.5	11.0	11.0	10.8	10.4	10.4	10.3	10.4	10.7	10.0	10.6	10.5	9.4	7.6	9.1	9.9	9.5	8.4	10.0	10.5	10.9	9.9	9.7	8.3	6.7	8.2	10.2	10.8	10.5	10.8	9.76	
Mar	10.3	9.5	10.3	10.4	10.8	10.6	10.6	9.7	10.4	10.4	10.5	8.2	8.1	9.5	10.7	10.5	8.6	9.7	10.4	7.6	7.8	6.4	8.0	2.0	7.4	6.8	10.3	8.6	9.6	8.5	7.7	8.05	
Apr	9.5	10.4	6.4	6.0	9.4	7.6	6.5	9.4	8.3	9.3	10.0	8.0	6.1	5.4	5.2	6.5	6.3	10.5	9.5	8.1	10.5	8.5	10.3	8.0	9.1	4.5	7.5	7.0	10.8	7.9	6.63		
May	8.5	9.6	5.7	5.7	4.7	4.2	3.2	3.4	3.2	7.8	7.7	8.3	3.8	9.3	8.0	7.7	6.9	8.2	9.8	8.5	10.5	8.3	8.5	8.2	2.8	8.8	7.2	7.0	2.1	6.3	8.2	6.63	
Jun	5.0	1.7	7.4	9.5	8.2	10.9	7.8	7.2	8.0	7.5	2.0	7.6	8.1	7.5	6.7	6.5	8.0	6.6	5.8	6.6	9.9	7.4	3.5	4.0	4.7	4.6	9.0	1.0	2.2	6.0	6.22		
Jul	6.0	4.0	7.3	8.1	8.2	9.2	10.0	8.0	7.8	6.4	9.6	8.3	4.4	3.2	7.0	8.5	6.7	3.3	6.5	9.2	5.5	3.8	3.8	8.6	9.8	6.6	3.2	6.3	5.5	6.7	1.7	6.58	
Aug	7.0	8.8	8.0	6.6	5.8	8.3	2.8	6.8	8.8	6.8	7.2	8.1	7.8	8.3	10.7	9.0	6.5	8.8	7.9	8.0	6.6	8.7	9.0	9.4	4.2	7.0	10.9	7.6	4.9	6.4	4.0	7.18	
Sep	8.8	8.8	8.2	7.3	8.0	7.1	8.3	4.6	5.5	8.0	8.3	9.2	3.9	8.2	8.8	9.0	5.8	5.3	4.7	5.8	1.2	9.6	7.1	8.0	7.7	8.5	8.6	7.1	6.1	5.3	7.11		
Oct	9.2	7.4	9.7	6.0	7.4	8.0	6.8	8.8	10.8	5.5	6.2	4.5	6.7	9.7	5.7	10.4	9.3	4.0	8.0	3.2	5.0	1.5	7.4	8.3	8.3	8.3	7.7	8.7	8.8	9.0	8.0	7.29	
Nov	8.2	9.3	10.0	7.0	6.0	8.8	4.0	6.5	10.5	8.0	9.8	8.3	4.8	8.6	10.3	10.1	10.2	9.9	8.0	8.6	10.8	10.3	10.3	10.8	10.4	9.6	6.5	6.2	10.3	6.7	8.65		
Dec	7.5	10.5	10.8	9.6	8.6	9.8	10.3	10.3	10.0	6.4	7.5	8.6	4.1	8.0	10.3	9.7	9.8	10.2	9.8	10.4	18.7	10.5	9.5	7.4	5.0	7.5	10.8	10.5	10.3	10.3	10.1	8.65	
																																	7.95

Table 2.3: calculated and measured values of basic parameters for Hawassa city

Mon.	Ho Aver	Declination angle (δ)	Sunset hour angle(ω_s)	monthly average daily maximum bright sunshine (S)	Average Monthly day length (S_o)	Estimated monthly average irradiation (H_{est})	Measured monthly average irradiation, $H_{meas.}(NASA)$
Jan.	9.87	-17.78	87.73	10.15	11.698	6.59	6.02
Feb.	9.72	-8.67	88.92	9.76	11.856	6.33	6.41
Mar.	9.52	3.62	90.45	9.11	12.0596	5.93	6.35
Apr.	9.26	14.59	91.84	8.05	12.2452	5.36	6.04
May.	8.96	21.90	92.84	6.63	12.379	4.64	5.95
June.	8.94	23.19	93.03	6.22	12.404	4.45	5.42
July.	8.99	18.17	93.03	6.58	12.404	4.62	4.83
Aug.	8.92	8.11	91	7.18	12.13	4.98	5.01
Sep.	9.12	-3.82	89.53	7.11	11.94	5.00	5.64
Oct.	9.16	-15.06	88.09	7.29	11.747	5.15	6.04
Nov.	9.48	-21.97	87.15	8.65	11.6198	5.87	6.25
Dec.	9.48	-23.09	86.99	8.65	11.5983	5.88	6.10
Aver.				7.95		5.4	5.84

Graph 2.1: Monthly average daily global irradiation of Hawassa city

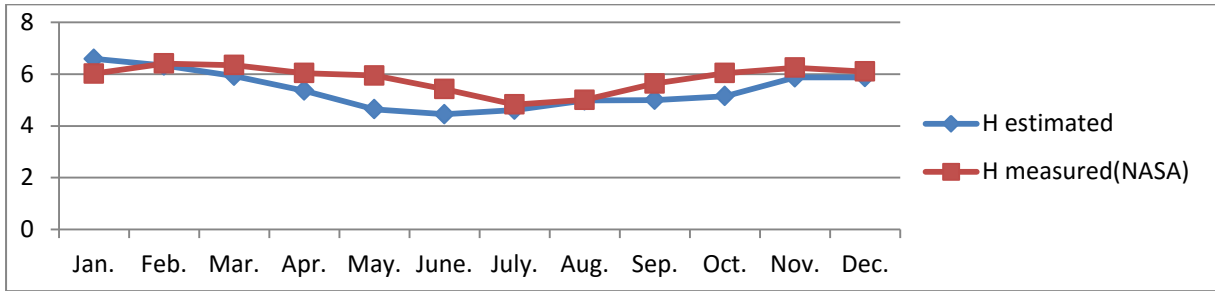


Table 2.4: wind speed at different height above the earth

Monthly averaged wind speed at 50,100,150 and 300m above the surface of the Earth(m/s)													
Vegetation type "Airport"; flat rough grass													
Lat. 7.03 Lon.38.29	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Annual average
50m	4.49	4.05	3.84	3.93	3.72	3.67	3.19	2.96	3.05	3.66	4.20	4.47	3.76
100m	4.98	4.50	4.26	4.36	4.12	4.07	3.53	3.28	3.38	4.06	4.66	4.95	4.18
150m	5.29	4.78	4.52	4.63	4.38	4.32	3.76	3.49	3.59	4.31	4.95	5.27	4.44
300m	5.87	5.31	5.02	5.14	4.86	4.80	4.17	3.87	3.99	4.78	5.49	5.84	4.93

2.7.2 Component selection

All solar systems are designed to solve a particular power problem; the grid connected system with a battery back up to be designed has two main functions;

- ✓ To supply power to all the loads when the grid has failed for a specified period
- ✓ To supply A.C power to the national grid when there is excess power.

The selected configurations for grid connected PV systems with battery back up the charge controller and the inverter are one unit; Figure below shows the block diagram of such a system.

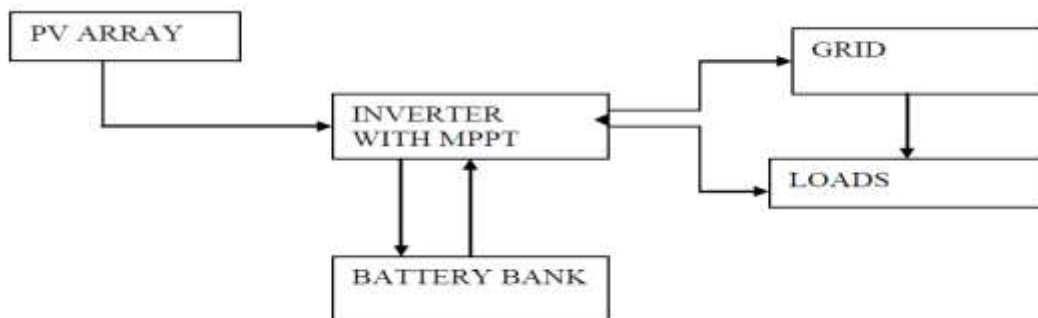


Fig 2.5: System configuration with charge controller and the inverter as one unit

Block diagram shows a design configuration that can both supply and store energy. When the demand is high then the system will deliver energy from inverter current will be supplied to the bus bar then to the load. But when the demand is low or in off day the battery can store energy by solar panel through charge controller. This stored energy can be used as backup for gloomy day or at night [34].

Module Selection

PV module selection criteria:

- ❖ The performance warranty in case of any problems
- ❖ Module replacement ease
- ❖ Compliance with natural electrical and building codes
- ❖ Manual should be available to see the quality and characteristics of module

Table 2.5: Typical Electric Characteristics of Generic poly 250w Module

Type	Polycrystalline
Power (max)	250 W
Voltage @ Max. power point	30 V
Current @ MPP	8.33 A
V _{oc} (open circuit voltage)	36.4 V
I _{sc} (Short circuit current)	8.63 A
Conversion Efficiency(per module area)	17 %
Area (dimension)	1.627 m ²
Nominal voltage	24 V
Max. system voltage	600V DC
Max. series fuse rating	750V DC
Temperature derating factor	0.06%/°C

Inverter Selection

Table 2.6: Electrical characteristics of IG PLUS 150 V-3 inverter

Continuous output power	400KW
Weighted Efficiency(CEC)	95.5 %
Maximum DC input voltage	800 V
DC peak power tracking range (V _{mpp} min —V _{mpp} max)	500-750 V
DC max. current (A)	700A
AC nominal voltage (V)	400 V
AC frequency (Hz)	50 Hz

Sizing the array

In this proposal we will design a medium scale PV system which has a size of 400kw

$$N = \frac{P_{\text{rated}}}{P_{\text{max}}} = \frac{400000}{250} = 1600 \text{ modules}$$

$$\text{Max. Number of modules in string series} = \frac{V_{\text{dc bus bar}}}{V_{\text{mpp}}} = \frac{600V}{30} = 20 \text{ Modules}$$

$$\text{Therefore the number in parallel will be} = \frac{1600}{20} = 80$$

Given

$$T_A = 30^\circ\text{C}, K_i = 0.005, K_v = 0.118, N_{\text{oct}} = 50^\circ\text{C}, S = 70\text{mW/cm}^2$$

$$V_{\text{oc}} = 37.4\text{V}, I_{\text{sc}} = 8.63\text{A}, V_{\text{mpp}} = 30\text{V}, I_{\text{mpp}} = 8.33\text{A}, P_{\text{it}} = 250\text{w}$$

Solution

(To get actual output power of PV)

$$T_c = T_A + \frac{(N_{\text{oct}} - 20)S}{80}$$

$$T_c = 30 + \frac{(50 - 20)70}{80} = 56.24^\circ\text{C}$$

$$I = I_{\text{ph}} = [I_{\text{sc}} + K_i(T_c - 25)] \frac{S}{100}$$

$$I = I_{\text{ph}} = [8.63 + 0.005(56.24 - 25)] \frac{70}{100} = 6.15\text{A}$$

$$I_{\text{array}} = 80 * 6.15 = 492\text{A}$$

$$I_{\text{max array}} = 80 * 8.63 = 690.4\text{A}$$

$$V = V_{\text{oc}} - K_v T_c$$

$$V = 37.4 - 0.129 * 56.3 = 30\text{V}$$

$$V_{\text{array}} = 20 * 30 = 600\text{V}$$

$$V_{\text{max array}} = 20 * 37.4 = 748\text{V}$$

$$FF = \frac{V_{\text{mpp}} * I_{\text{mpp}}}{V_{\text{oc}} * I_{\text{sc}}}$$

$$FF = \frac{30 * 8.33}{37.4 * 8.63} = 0.774$$

$$P_{out} = FF * V_{array} * I_{array}$$

$$P_{out} = 0.774 * 600 * 492 = 228.5 \text{ KW}$$

Inverter sizing

- ✓ **Check inverter input voltage rating:** Inverter's MPPT voltage range = module's open circuit voltage * number of module in series, If this is within the inverter's MPPT voltage range. We didn't put more modules due to safety.
- ✓ **Check inverter input current rating:** Inverter's maximum current rating range = module's short circuit * number of module in parallel.

Solution

$$V_{DC \text{ inverter max.range}} = 37.4 * 20 = 748 \text{ V}$$

$$I_{DC \text{ inverter max range}} = 8.63 * 80 = 690.4 \text{ A}$$

Battery storage design

- ✓ 400kw rated power is assumed
- ✓ The battery supplies the grid during failure for 6 hours.

So that $E_{tot} = 400 * 6 = 2400 \text{ kWh}$, $DOD_{max} = 0.7$, $G_{ft} = \frac{6}{24} \text{ day}$.

$$C_x = \frac{E_{tot}}{V_{dc}} * \frac{G_{ft}}{DOD_{max}}$$

Since x is the typical average discharge hours which was selected as 6 hours earlier.

$$\text{It is taken as, } C_6 = \frac{2400 \text{ kWh}}{600 \text{ v}} * \frac{6}{0.7} = 480 * 0.357143 = 1428.6 \text{ Ah}$$

Since the system voltage is 600VDC, the number of 2 volts batteries required in series is

$$\text{Number in series} = \frac{600}{2} = 300$$

Table 2.7: PV generator characteristics

S.no	Name Of RDG	P _{rated} [kw]	Number of module	Inverter V _{mpp} max	Array M _{pp} DC voltag	Array mpp DC current	Number of module in series	Number o module in parallel	Actual power output , P _{out} [kw]
1	PV	400	1600	600	600	492	20	80	228.5

Table 2.8: Storage battery basic parameters data

s.no	Model of Battery	Total number of cells connected	Total energy supplied to the grid	Battery capacity
1	JC DYNASTY	300	400*6 kwh = 2400kwh	1428.6Ah

Table 2.9: Wind turbine generator wind characteristics data

S.no	Name of RDG	P _{rated} [kw]	Average Wind speed at 100m	V _{ci} [m/s]	V _r [m/s]	V _{co} [m/s]	Out put Power
1	WGT1	100	4.18	2 m/s	11m/s	50m/s	65.53

To get out put power of wind

$$P_{WTG} = \begin{cases} 0 & 0 \leq V_t \leq V_{ci} \\ A + BV_t^3 & V_{ci} \leq V_t \leq V_r \\ P_r & V_r < V_t \leq V_{co} \\ 0 & V_t > V_{co} \end{cases}$$

$$A = \frac{P_r \cdot V_{ci}^3}{V_{co}^3 - V_r^3} = \frac{100000 \cdot 8}{125,000 - 1,331} = \frac{800,000}{123,669} = 6.469$$

$$B = \frac{P_r}{V_{co}^3 - V_r^3} = \frac{100,000}{123,669} = 0.80861$$

Since average wind speed is $V_t = 4.18 \text{ m/s}$, $V_{ci} = 2 \text{ m/s}$, $V_r = 11 \text{ m/s}$, $P_r = 100 \text{ kw}$.

$$P_{WTG} = 6.469 + 0.80861 \cdot 4.18^3 = 65.53 \text{ kw}$$

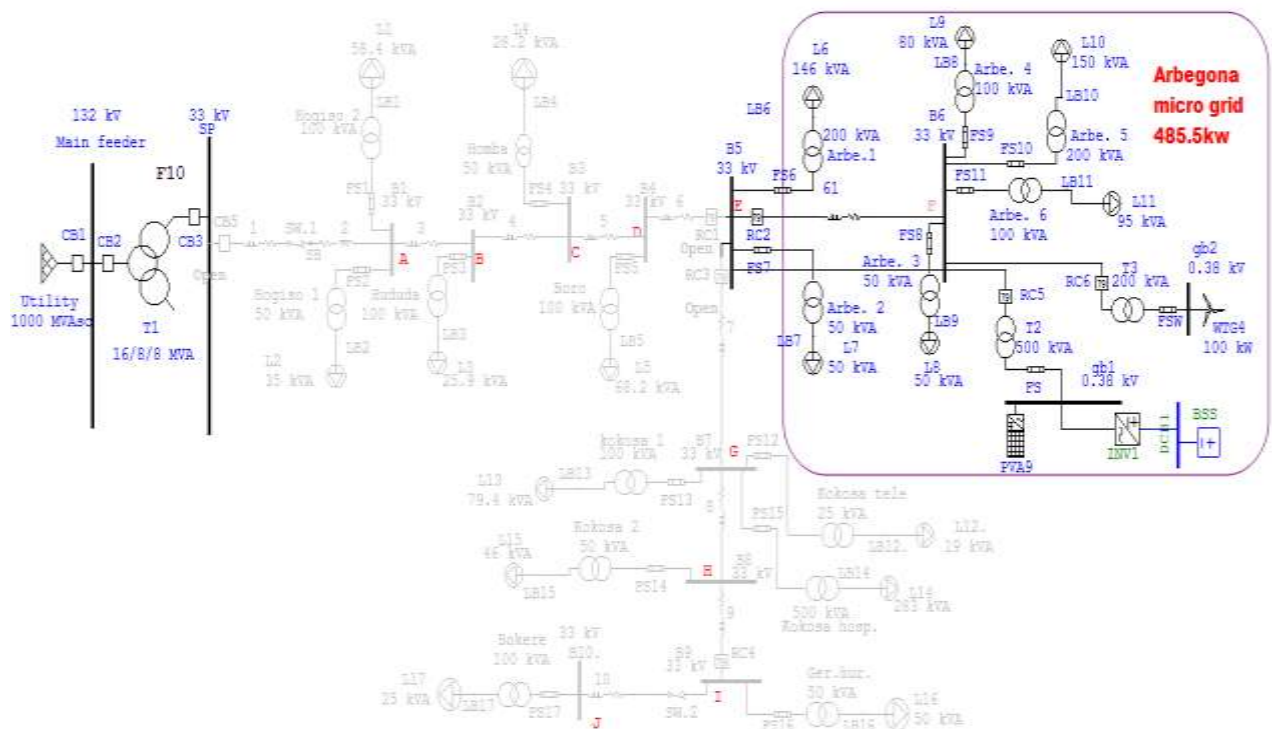
2.8 Micro grid structure

In this study, structures of micro grid including WTG, PV, as listed in Table below is used to show the effectiveness of each energy supply in total reliability of the system. The area actual power output is given in this Table to be compared with the capacity of the RDG plant.

Table 2.10: Micro grid structure and supplying RDG

S.no.	Microgrid structure name	Peak load capacity	RDG CAPACITY				Total plan capacity	Total Actual out put
			PV	Actual output	WTG	Actual output		
1	Arbegona Micro grid	485.5kw	400kw	228.5kw	100kw	65.53kw	500kw	294.03kw

Single line diagram of the study area is identified in the figure below; as it is shown the radial distribution line contains one micro grids having wind and solar micro sources.



Single line diagram of modified micro grid containing Hawassa 33kv feeder 10 distribution line

Fig.2.6: Single line diagram of Hawassa feeder 10 modified Radial distribution network with RDG

CHAPTER THREE

THEORETICAL BACKGROUND AND LITERATURE REVIEW

3.1 Introduction

To obtain a full understanding of the performance of electric power distribution system and the problems associated with the reliability of the distribution system a literature review has been performed on the following areas:

- ❖ Electric power distribution system design
- ❖ Power quality analysis in an electric power distribution system
- ❖ Voltage drop in an electric power distribution systems
- ❖ Power loss in an electric power distribution system
- ❖ Reliability analysis of an electric power distribution system
- ❖ Current research progress on the power reliability problem
- ❖ Reliability improvement technique using distribution generation is seen

Literature reviewing was the first step in order to better understand the present problem, a review on comprehensive issues regarding classification of distribution faults, existing fault minimizing techniques and RDG grid integration design had been given a wide coverage.

The study in this report is concentrated on using renewable energy, in particular solar PV, wind, to supply the energy needs of study area customers in case of adequacy problem.

3.2 Electric Power Distribution System Design

In order to design the best electric power distribution system, information concerning the load profile and knowledge of the various types of electric power distribution systems that are applicable to the design of the electric power distribution system is a necessity. To this end, different electrical power distribution system designs have been researched.

The basic principles or factors requiring consideration during design of the power distribution systems include [22]:

- ❖ Electric power distribution system standards
- ❖ Functions of electric power distribution system structure
- ❖ Life and flexibility of structure
- ❖ Locations of service entrance and distribution equipment, locations and characteristics of loads, locations of unit substations

- ❖ Density of customers (demand) and diversity factors of loads
- ❖ Sources of power; including normal, standby and emergency
- ❖ Continuity and quality of power available and required
- ❖ Energy efficiency and management
- ❖ Distribution and utilization voltages
- ❖ Bus and/or cable feeders
- ❖ Distribution equipment and control system
- ❖ Power monitoring systems
- ❖ Electric utility requirements

In the design of distribution system there are two standards applied in the world [22]:

- ❖ North American standards governed by ANSI and the IEEE
 - ✓ The standard secondary voltage level is 208/120 Volts and 190/110 Volts
- ❖ European standards governed by IEC
 - ✓ The standard secondary voltage level is 380/220 Volts and 400/230 Volts
- ❖ EEPCO is using standards set by IEC

3.3 Voltage Drop in an Electric Power Distribution System

The equipment connected to a utility system is designed to operate at a specific voltage level. It is difficult to supply power to each customer at a voltage exactly equal to what is written on the customer equipment nameplates. The main cause of this difficulty is that there is a voltage drop in each element of the power system [23]:

- ❖ Generation
- ❖ Transmission
- ❖ Distribution

One of the most important constraints on distribution system design is the voltage level of the customer intake point. In distribution system, the voltage drop is proportional to the magnitude of demand current and the entire impedance between the source and the customer. Voltage drop in electric power distribution system can occur because of various factors. Few of them are mentioned as below [25].

1. Nature and type of load,
2. Design of electrical installations/equipment,
3. Layout of installations,
4. Poor maintenance of the system,
5. Undersize and lengthy service lines.

The voltage drop along a distribution feeder can be calculated in two methods [24]:

Approximate Method

$$V_{\text{drop}} = |V_s - V_r| = I \cdot R \cos\theta + I \cdot X \sin\theta$$

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

V_r = Receiving end voltage, V

V_s = Source voltage, line-to-neutral, V

I = Line (Load) current, A

R = Circuit (branch, feeder) resistance, Ω

X = Circuit (branch, feeder) reactance, Ω

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

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

θ = angle between the voltage and the current

Exact Method 1

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

$$V_{\text{drop}} = |V_s| + I \cdot R \cos\theta + I \cdot X \sin\theta - \sqrt{V_s^2 - (I \cdot X \cos\theta - I \cdot R \sin\theta)^2}$$

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

V_s = Source voltage, line-to-neutral, V

I = Line (Load) current, A

R = Circuit (branch, feeder) resistance, Ω

X = Circuit (branch, feeder) reactance, Ω

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

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

θ = angle between the voltage and the current

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

$$V_{\text{drop}} = \sqrt{(V_r \cos\theta + I_R)^2 + (V_r \sin\theta + I_X)^2}$$

Exact Method 2

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

$$V_s^2 = V_r^2 + \frac{Z \cdot (MVA_r)^2}{V_r^2} + 2Z \cdot MVA_r \cdot \cos(\gamma - \theta_r)$$

$$V_r^2 = V_s^2 + \frac{Z \cdot (MVA_s)^2}{V_s^2} + 2Z \cdot MVA_s \cdot \cos(\gamma - \theta_s)$$

Where, V_r = Receiving line-line voltage in kV

V_s = Sending line-line voltage in kV

MVA_r = Receiving three-phase, MVA

MVA_s = Sending three-phase, MVA

Z = Impedance between sending and receiving ends

γ = the angle of impedance Z

θ_r = Receiving end PF

θ_s = Sending end PF, positive when lagging

In electric power distribution system, voltage drop depends upon numerous factors. The type and nature of conductor, the size of conductor and the length of circuit are the few out of many. The supply conductor, if not of reasonable size, will cause excessive voltage drop in an electrical circuit. The voltage drop is in direct proportion to the circuit length. Proper starting and running of motors, lighting equipment, and other loads having inrush currents should be considered. The NEC recommends that the steady-state voltage drop in power, heating, or lighting feeder be no more than 3%, and the total drop including feeders and branch circuits be no more than 5% overall [24].

Poor performance of equipment's, overheating; nuisance tripping of over current protective devices and excessive burnouts are the sign of unsatisfactory voltage at customer's terminals.

When the voltage at the terminals of utilizing equipment deviates from the value of name plate of electrical appliances, the performance and the operating life of the equipment is affected. The effect may be minor or prominent depending on the characteristics of the equipment and amount of the voltage drop deviation from the nameplate rating. Generally performance conforms to the utilization voltage limits specified in American National Standard Institute (ANSI) but it may vary for specific items of voltage sensitive equipment [25].

3.4 Power Loss in an Electric Power Distribution System

Distribution power loss refers to the difference between amount of energy delivered to the distribution system and the amount of energy consumed. The level of losses will be influenced by a number of factors, technical and operational, such as network configuration, load characteristics, substations in service, and power quality required. It is important to manage these factors by appropriate incentives and thus optimize the level of losses [25].

Power losses in distribution lines (feeders) can be divided into two categories

❖ Real power loss

$$P_{\text{loss}} = \sum_{i=1}^n I_i^2 * R_i$$

- ❖ Reactive power loss

$$Q_{loss} = \sum_{i=1}^n I_i^2 * X_i$$

Losses in distribution networks are divided into technical and non-technical losses [24].

Technical Losses

Technical losses comprise of variable losses and fixed losses [24].

Variable losses (load losses) are proportional to the square of the current depending on the power distributed across the network. They are often referred to as copper losses that occur mainly in lines, cables, and copper parts of transformers. Variable losses can be reduced by [10]:

- ❖ Increasing the cross - sectional area of lines and cables for a given load;
- ❖ Reconfiguring the network, for example, by providing more direct and/or shorter lines to where demand is situated;
- ❖ Managing the demand to reduce the peaks on the distribution network;
- ❖ Balancing the loads on three - phase networks;
- ❖ Encouraging the customers to improve their power factors; and
- ❖ Locating the embedded generating units as close as possible to demand side.

Fixed losses (no-load losses) occur mainly in the transformer cores and take the form of heat and noise as long as the transformer is energized. These losses do not vary with the power transmitted through the transformer and can be reduced by using high - quality raw material in the core (e.g., special steel or amorphous iron cores incur lower losses). Another way to reduce fixed losses is to switch off transformers operating at low demand. Of course, this depends on the network configuration that enables the operator to switch some loads to other sources in the distribution network [23]

Nontechnical Losses

Nontechnical losses (commercial losses) comprise of units that are delivered and consumed, but for some reason are not recorded as sales. They are attributed to metering errors, incorrect meter installation, billing errors, illegal abstraction of electricity, and unread meters. Use of electronic meters will help reduce those losses since the accuracy is high. Also, incentives and obligation on participants should be as correct as possible to reduce the illegal abstraction of electricity.

3.5 Reliability Analysis of an Electric Power Distribution System

Reliability evaluation of a distribution system is associated with the continuity of supply of energy from the supply points to the individual customer load points. The basic parameters used to evaluate the reliability of a distribution system can be categorized as load point indices and system indices. The load point failure rate, the average outage time and the average annual

outage time are the basic load point indices. The system indices can be obtained from these three load point indices and information on the number of customers and load connected at each load point in the system. The set of system reliability indices can be further classified into customer-oriented indices and load-oriented indices. Customer-oriented indices include the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Index of Reliability (IOR), Customers Experiencing Multiple Interruptions (CEMI), and Customers Experiencing Longest Interruption Duration (CELID). Load-oriented indices include Average System Interruption Frequency Index (ASIFI) and Average System Interruption Duration Index (ASIDI)[26].

Most of the power interruptions of Hawassa sub 33kv distribution system are due to the result of failures in the secondary distribution system. A highly reliable generation and transmission system may still result in poor energy supply to the customers if the distribution system is unreliable. Therefore, distribution system reliability evaluation is important to ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks.

Analysis of past performance and prediction of future performance are two crucial factors of distribution system reliability evaluation. Most distribution systems are radial in nature because of their low cost and simple design. Most low voltage distribution systems are operated radially. A radial system consists of a series of components between the substation and the load points. Failure of any of these components may result in outage at the load point(s). The duration of the outage depends on the protection and sectionalizing schemes used in the distribution system. The research work presented in this thesis is focused on analyzing a radial distribution system.

Reliability Evaluation

Reliability in power system can be divided in two basic aspects; system adequacy and system security. Adequacy relates to the capacity of the system in relation to energy demand and security relates to the dynamic response of the system to disturbances (such as faults). In case of load shedding system adequacy will be concern and distribution systems are seldom loaded near their limits reliability emphasis in on system security [26].

The two main approaches applied to reliability evaluation of distribution systems are [26]:

- ❖ Simulation methods based on drawings from statistical distributions (Monte Carlo)
- ❖ Analytical methods based on solution of mathematical models.

The Monte Carlo techniques are normally very “time” consuming due to large number of drawings necessary in order to obtain accurate results. The fault contribution from each component is given by a statistical distribution of failure rates and outage times.

Reliability Indices

The reliability of a distribution system can be described using two sets of reliability parameters. These are the load point reliability indices and the system reliability indices.

Load Point Indices

A distribution system provides power supply from a substation to individual customer load points. Three basic reliability indices can be used to describe the degree of service continuity. These are the load point average failure rate (λ), average outage time (r) and the average annual unavailability or average annual outage time (U). The average failure frequency is approximately equal to the average failure rate and indicates the number of failures a load point will experience during a given period of time. The average outage time is the average duration of failure at the load point. The average annual outage time is the average total duration of outage in a year experienced at the load point. It is the product of the average frequency of failure and the average outage time. These reliability indices are expected values and represent the long-run average values [26].

$$f_s = \sum_{i=1}^{12} \lambda_i (\text{Interruptions/year})$$

$$U_s = f_s r_i = \sum_{i=1}^{12} \lambda_i r_i (\text{Hours/year})$$

$$r_s = \frac{U_s}{f_s} = \frac{\sum_{i=1}^{12} \lambda_i r_i}{\sum_{i=1}^{12} \lambda_i} (\text{Hours})$$

Where, f_s = Interruption frequency [interruptions/year]
 λ_i = Failure rate
 r_i = interruption duration [hours/year]
 r_s = average outage time
 U_s = Annual downtime

System Reliability Indices

Systems reliability indices indicate the annual average performance of the network in terms of interruption frequency and duration. They are weighted by the number of customers or energy supplied

Quantitative reliability evaluation of a distribution system can be divided into two basic segments; measuring of the past performance and predicting the future performance. Some of the basic indices that have been used to assess the past performance are [16]:

1. System Average Interruption Frequency Index (SAIFI)

SAIFI indicates how often an average customer is subjected to sustained interruption over a predefine time interval. This index is average number of interruptions per customer served per year. It is determined by dividing the accumulated number of customer interruptions in a year by the number of customers served. A customer interruption is considered to be one interruption to one customer.

$$SAIFI = \frac{\text{Total number of customers interruptions}}{\text{Total number of customer served}} = \frac{\sum \lambda_i N_i}{\sum N_t}$$

Where, N_i is Total number of customers interrupted,

N_t is Total number of customers served,

λ_i is no. of interruption

2. System Average Interruption Duration Index, SAIDI (hr/cust.yr)

SAIDI indicates the total duration of interruption an average customer is subjected for a pre-defined time interval. This index is the average interruption duration for customers served during a year. It is determined by dividing the sum of all customer interruption duration during a year by the number of customers served during the year.

$$SAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer served}} = \frac{\sum r_i N_i}{\sum N_t}$$

Where: r_i is Restoration time, minutes

3. Customer Average Interruption Duration Index, CAIDI (hr/customer interruption)

$$CAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer interruption}} = \frac{\sum U_i N_i}{\sum N_i \lambda_i}$$

CAIDI indicates the average time required to restore the service. This index is the average interruption duration for customers interrupted during year. It is determined by dividing the sum of all customer sustained interruption duration by the number of sustained customer interruptions over a one year period.

$$CAIDI = \frac{\text{Sum of customer interruption duration}}{\text{Total number of customer interruption}} = \frac{\sum U_i N_i}{\sum N_i \lambda_i} = \frac{SAIDI}{SAIFI}$$

4. The Average Service Availability (Unavailability) Index (ASAI)

ASAI specifies the fraction of time that a customer has received the power during the predefine interval of time and is vice versa for ASUI. This is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes known as the “Service Reliability Index”. ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. The ASAI is found as,

$$ASAI = \frac{\text{Customer Hour of Available Service}}{\text{Customers Hour Demanded}}$$

$$ASAI = \frac{\text{Customer hour of available service}}{\text{customer hour demanded}} = \frac{\sum N_i * 8760 - \sum U_i N_i}{\sum N_i * 8760}$$

$$ASUI = 1 - ASAI = \frac{\text{Customer hour of unavailable service}}{\text{customer hour demanded}} = \frac{\sum U_i N_i}{\sum N_i * 8760}$$

Where 8760(365*24) is the number of hours in a calendar year, both indices ASAI and AUI are measured per unit.

ASAI is the customer weighted availability of the system and provides the same information as SAIDI. Higher ASAI values mean higher levels of system reliability, with most US utilities having ASAI greater than 0.999

5. Expected Energy Not Supplied Index at Load Point, EENS_i (Mwh/yr)

$$EENS = \sum EENS_i = \sum L_a U_i$$

L_a is the average load connected to load point i.

6. Average Energy Not Supplied Index, AENS (Mwh/cust..yr) or average system curtailment

$$AENS = \frac{\text{Total energy not supplied by the system}}{\text{Total number of customer served}} = \frac{\sum EENS_i}{\sum N_i} = \frac{\sum L_a U_i}{\sum N_i}$$

Past performance statistics provide valuable reliability profile of the existing system. However, distribution planning involves the analysis of future systems and evaluation of system reliability when there are changes in configuration, operation conditions or in protection schemes. This estimates the future performance of the system based on system topology and failure data of the components. Due to stochastic nature of failure occurrence and outage duration, it is general based on probabilistic models. The basic indices associated with system load points are: failure rate, average outage duration and annual unavailability [16].

3.6 Literature Review

Electric power is a vital element in any modern economy. 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 [28]. To fulfill and meet customer demands currently the following researches are going on, on electric power distribution system:

Energy losses in distribution systems are generally estimated rather than measured, because of inadequate metering in these systems and also due to the high cost of data collection. These estimations are generally based on some rules of thumb. This paper presents the results of a joint investigation undertaken in collaboration with a local utility to study this issue. Based on data collected from feeders, true losses in some primary and secondary feeders are obtained. These losses are compared with the estimated losses obtained by the methods presently in use. In view of the large discrepancies observed between measured and estimated values, two new schemes for estimating losses in primary and secondary distribution networks have been developed. The measured values are used to highlight the reliability of the new estimation methods [20].

The distribution system is part of the electric power system that links the bulk transmission system and the individual customers. The aim of a power system is to supply electricity to its customers in an economical and reliable manner. In distribution system reliability is one of the major issues for the consumers. Reliability means the probability that a system or components perform their assigned task for a given period of time under the operating conditions stumbled upon during its anticipated lifetime. Most of developing African country including Ethiopia distributed system has received less attention devoted to the reliability modeling and evaluation of the generation systems. A distribution system is cheap and the outages have a much localized effect. However, statistics show that failures in distribution systems contribute as much as high (85%) towards the unavailability of supply to a load as compared with other parts of electric power systems [1]. It is therefore important to understand the impact of the outages on the customer outage costs and the system reliability

In [25] evaluates various analytical and simulation techniques which incorporate varying degrees of complexity and data to evaluate the expected customer costs at the system and load level of a radial distribution system. A computer program based on time sequential Monte Carlo simulation has been developed. The results show that certain analytical techniques provide as accurate results as using a Monte Carlo simulation technique.

In [28] authors provide a framework for a predictive, condition-based, and cost effective maintenance optimization program for transmission and distribution systems. As system equipment continue to age and gradually deteriorate the probability of service interruption due to component failure increases. An effective maintenance strategy is essential in delivering safe and reliable electric power to customers economically.

In [29], the results of a power quality survey in a distribution system are presented and discussed and the power quality indices are extracted based on IEEE and IEC Standards. In publications [10] – [13], a power quality analysis, mitigation design and simulation of power quality problem of a factory, an active filters for power quality improvement, a quality comparisons of an electric power distribution systems and a power quality problems, issues, related international standard, effect of power quality problem in different apparatuses and methods for its correction, are discussed.

In [30], the application of the method of experimental design to the analysis of electrical power distribution systems is discussed. The theory of experimental design allows us to construct and experimentally verify the qualitative model of a power distribution system in order to analyze significance of each component in distribution system modeling.

Abdul-Aziz Abdullaha, 2012[35] Reliability evaluation of distribution systems containing renewable distributed generations. Presented wind, PV, BESS, and load stochastic models, then assessed the distribution reliability by using Monte Carlo simulation method.

Samuel Tesfaye, 2015[36] studied reliability assessment using grid connected PV system in Arbaminch town. The study covers power generation using PV technology and has used the generation for assessing distribution system reliability after connecting with it. It shows reliability indexes change with generation connected with it and optimal placing.

CHAPTER FOUR

RELIABILITY ANALYSIS OF THE EXISTING HAWASSA DISTRIBUTION FEEDER

4.1 Power Distribution System Standards and Design Guidelines

Power distribution system standards and design guidelines are the minimums acceptable criteria's for the design of efficient, economical, durable, maintainable, and reliable electrical power supply and distribution systems. Clarifications of baseline design criteria, standards, policy, and guidelines are provided by Institute of Electrical and Electronics Engineers (IEEE), International Electro-technical Commission (IEC), National Electrical Code (NEC), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), or International (ISO).

The most suitable solution for any single design of power distribution system will depend on the particular requirements of the facility. In addition to the standards and guide lines designers would use their judgment, experience, knowledge and local conditions as a guide during design to suit the particular installation requirements. When designing and developing the distribution system for a particular area the following main points should be considered:

1) Service conditions

- ✓ Type of loads to be served
- ✓ Density of customers
- ✓ Length of lines
- ✓ Points of supply

2) Electrical Design

- ✓ Voltage of supply
- ✓ Voltage regulation at the customers
- ✓ Transformers and accessories
- ✓ Protection of electrical systems
- ✓ Operation of the system

3) Mechanical design

- ✓ Poles and spans
- ✓ Wires and clearances
- ✓ Installation of transformers and substations
- ✓ Supports and guying

- 4) The economics of the design
- 5) The availability of proven technology
- 6) The integration and compatibility with existing equipment, and
- 7) Equipment and installation compliance.

The main objectives of the distribution planning & design are:

- ✓ To enable the planning, design and construction of the Distribution System for a safe, reliable and economical operation conforming to the statutory acts, standards, regulations and codes.
- ✓ To facilitate the use of the distribution system by any user connected to or seeking connection with it.
- ✓ To specify technical conditions to be followed by the respective distribution standards for an efficient operation.
- ✓ To provide the required information to the users for connection, planning and development of their own systems and to make them compatible with the distribution system.

4.2 Existing Structure of Hawassa Distribution System Feeder 10

The area chosen for this study is Hawassa substation distribution system feeder 10 line. The power distribution has only one substation, with primary distribution (medium voltage) having 132kv/33kv voltage level.

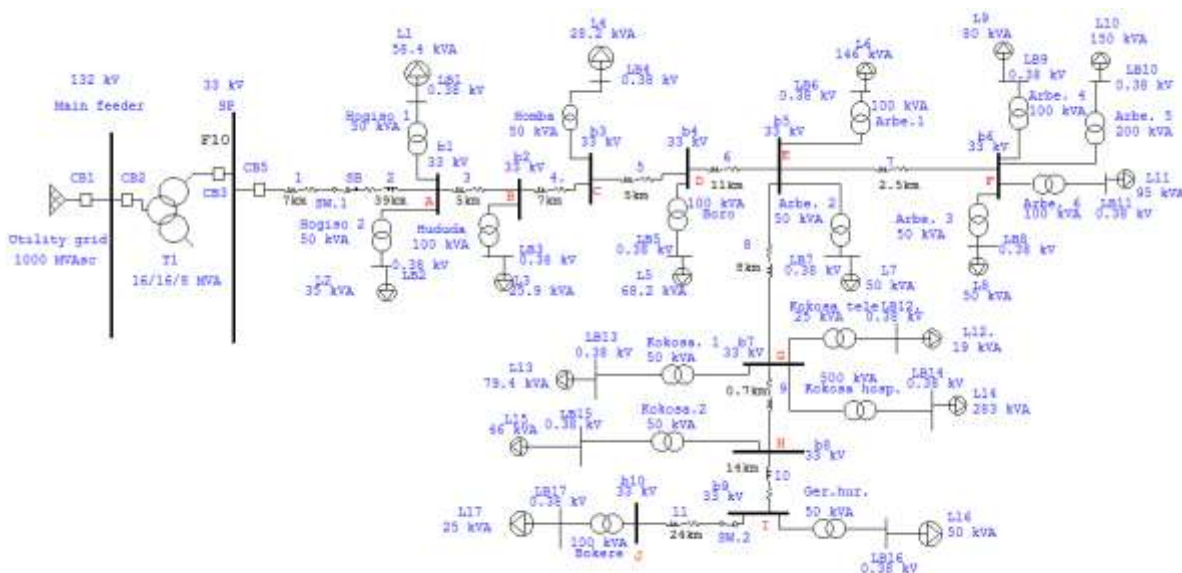


Fig 4.1: Single line diagram of Existing structure of Hawassa substation 33kv feeder 10 line

4.3 Data Collected from Hawassa substation 33kv feeder lines

Data for Hawassa 33kv distribution system (refer Appendix A) has been collected. The collected data are a recorded data that includes peak load, type of faults, frequency and duration of interruption of all medium voltage (33kV) outgoing feeders of the distribution system. Hawassa town has only one substation, 13 outgoing feeders out of which 3 are 33kv, around 50MWpeak load, around 29,906 customers (i.e. industrial, commercial and residential). There is only one feeder dedicated for textile factory separately. The collected data for 33kv feeder line of Hawassa Substation are shown in Table 4.1. The frequency of interruption and duration of interruption for Hawassa 33kv distribution system for 11 Months are analyzed and interpreted as shown in Tables 4.2 and 4.3 and Figures 4.1 and 4.2 respectively, collected data is a recorded data for eleven months.

Table 4.1: Hawassa substation of 33kv lines data

Substation name/ Feeder name	33kv Power transformer capacity	Line	Transformer Qty.(kva)	Location/name
		MV(33kv)		
Hawassa/F9	16/8/8MVA	2	2*1250	Hawassa BGI
Hawassa/F10		120.7	1*25,8*50,6*100, 1*200,1*500	Arbegona,kokosa,boro, Hududa,Bokore so on
Hawassa/F11		7	5*630,1*500	Hawassa university

Table 4.2 Frequency of Interruption for Hawassa 33kv(feeder 10) Distribution System

month	Frequency of interruption
Jan./2015	12
Feb./2015	29
Mar./2015	34
Apr./2015	20
May./2015	30
June./2015	14
July./2015	26
Aug./2015	54

Sep./2015	89
Oct./2015	55
Nov./2015	57
Total	420

Graph 4.1: Frequency of Interruption for Hawassa sub. 33kv feeder 10 line

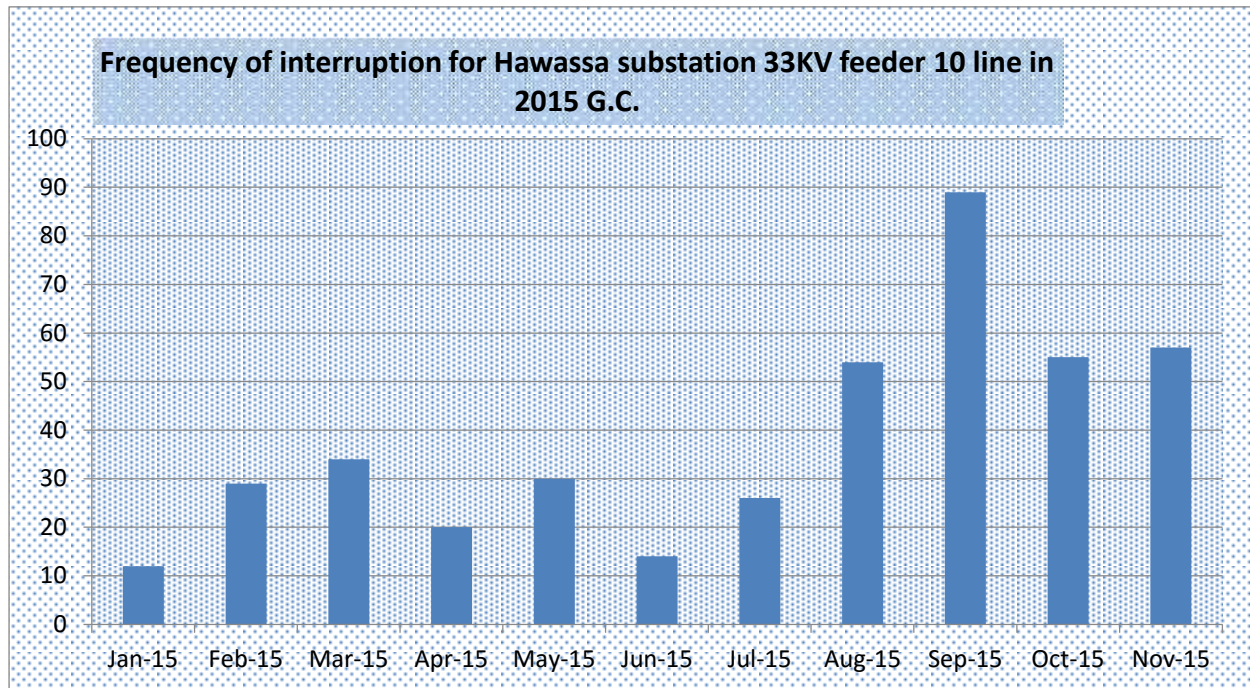
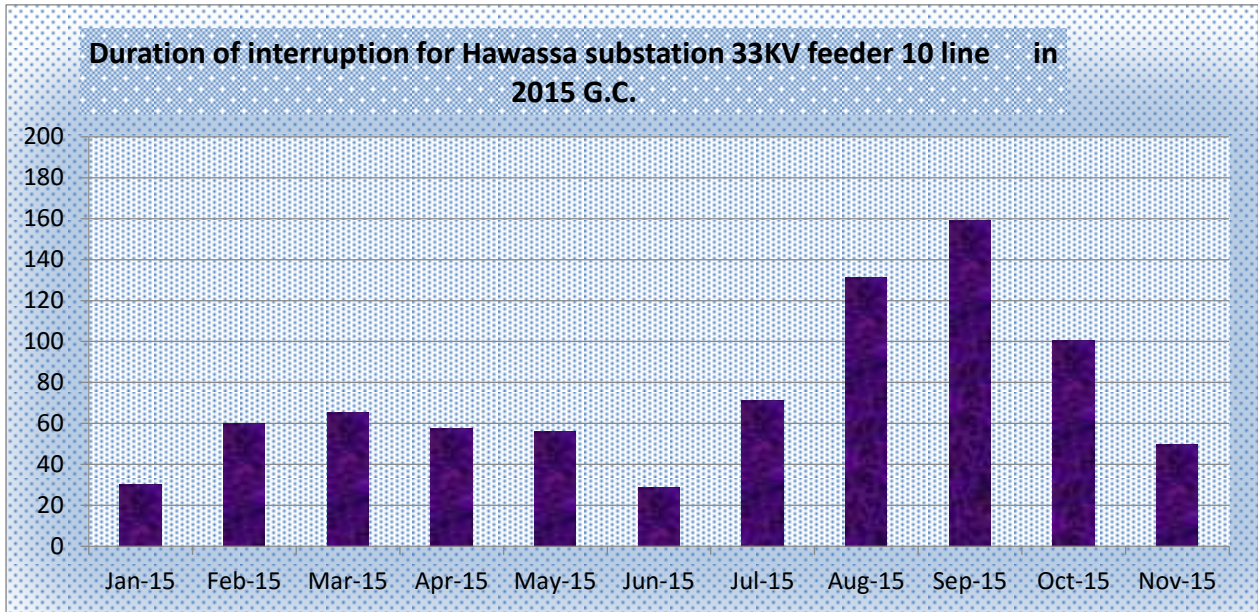


Table 4.3 duration of Interruption for Hawassa 33kv (feeder 10) Distribution System

month	Duration of interruption
Jan./2015	30.149
Feb./2015	60.05
Mar./2015	65.16
Apr./2015	57.29
May./2015	55.94
June./2015	28.75
July./2015	71.16
Aug./2015	131.2

Sep./2015	159.25
Oct./2015	100.63
Nov./2015	49.66
Total.	809.24

Graph 4.2:Duration of Interruption for Hawassa sub. 33kv feeder 10 line



4.4 Hawassa substation power transformer, feeders and load data

There are 3 feeders coming out of Hawassa substation having 33kv voltage level, Data collected for this substation, typical for feeder 10 and load data are shown in Table below respectively

Table 4.4: Hawassa substation 33kv power transformer technical details

Rating	16MVA
Primary voltage	132KV
Secondary voltage	33KV
Short circuit impedance	0.63+j8.9 per unit
Zero sequence impedance	j8 per unit

Table 4.5: Hawassa substation 33kv feeder 10 data

No	Feeder parameters	unit	detail
1	Voltage level	KV	33/0.4
2	Feeder load	A	24
3	Feeder load	MW	1.145
4	Feeder load	MVAR	0.743
5	Feeder load	MVA	1.365
6	No. of customers	NO.	1,583
7	total no. of distribution transformers	NO.	17
8	Total length of feeder line	Km	120.7

Load and customer data:

Distribution system has 17 distribution transformer and 17 load point(LP) that supplies power to different types of costumers loads : Residential, Industrial, Commercial and Government and institutional (G&I), the costumer data is shown as shown below.

Table 4.6: Showing study area load point and customer data

Load point name	Place name	Distribution transformer capacity (kva)	Load in KVA	Average load connected (kw)	Customer type	Customer number
L1	Hogiso 1	50	58.4	49.6	residential	121
L2	Hogiso 2	50	35	29.75	residential	80
L3	Hunduda	100	25.9	22	residential	11
L4	Homba	50	28.2	24	residential	16
L5	Boro	100	68.2	58	residential	58
L6	Arbegona 1	100	146	124	residential	275
L7	Arbegona 2	50	50	42.5	residential	105
L8	Arbegona 3	50	50	42.5	commercial	9
L9	Arbegona 4	100	80	68	commercial	27
L10	Arbegona 5	200	150	128	industrial	3

L11	Arbegona 6	100	95	80.75	residential	300
L12	Kokosa tele	25	19	16.15	Government and institutional (G&I)	1
L13	Kokosa 1	50	79.4	67.5	residential	285
L14	Kokosa Hospital	500	283	240.2	Government and institutional (G&I)	1
L15	Kokosa 2	50	46	39.1	commercial	167
L16	Gerba huru.	50	50	42.5	residential	104
L17	Bokore	100	25	21.25	residential	20
Sum total				1095.8 kw		

4.5 Major Causes of Interruption in the Existing Distribution System

According to medium voltage feeders interruption report on area covered by radial distribution network in Ethiopia monthly average number of frequency and duration of interruption is 3,238 and 5, 648, 05 respectively. The main Cause of this much interruption is DPEF, DPSC, DTEF, DTSC, TLP, SOL, GUP, DLO, PTOL, OP, S. Since power interruption and fluctuations are still a primary part of life in Ethiopia, businesses and individuals have been complaining about the situation.

According to IEEE100-1992, an interruption to service is the isolation of an electrical load from the system supplying that load, resulting from an abnormality in that system. The abnormality in the system can either be a malfunction of a system component, a fault or a system operation due to maintenance or repair. Interruptions, independent from the cause, are generally undesired, as they leave energy not served and customers without service. Most of the time, interruptions occur because the system is reacting to a fault. A fault or short-circuit is defined by IEEE100-1992 as an abnormal connection of relatively low impedance, whether made accidentally or intentionally, between two points of different potential [31], [32].

Over-loading, earth fault and short circuits are the major cause of interruptions in Hawassa 33kv distribution system. These major faults are classified in to two main categories: temporary and permanent faults.

Temporary faults account for the majority of faults in distribution systems. Temporary faults can occur for many reasons, but may include tree or animal contact and weather as the main contributors. Temporary faults can be easily solved, with little or no intervention from the system

itself. Many are self-clearing, such as a branch or animal contact which burn and fall off, conductors slapping together in severe wind or insulation flashover due to contamination. Lightning is also a temporary fault. Lightning arrester failure, on the other hand, can become a permanent fault. Other temporary faults are simply cleared once a trip from the substation is issued. Instantaneous reclosing de-energizes the line for a short duration of time, which allows the arc or contact path to disappear, which in turn eliminates the fault path. Once the circuit is re-energized, the system resumes normal operation.

Permanent faults, on the other hand, are those that cannot be solved with reclosing action and will not self-clear. Equipment malfunction, cable failure, downed lines or persistent tree contact can all produce permanent faults. It is important to point out, that some tree contact can cause permanent faults, such as a tree falling on a line [31] [32].

4.6 Types of fault in Hawassa 33kv distribution feeders

A sample average evaluation for frequency and duration of interruption for the months from January 2015 to December 2015 has been considered based on the number of interruptions caused by the stat of cause of is tabulated in table below.

Table 4.7 Hawassa substation 33KV distribution feeder’s interruption data in 2015G.C

Item No.	Substation Name	Feeder Name	site name	Frequency and Duration of Interruption																		Frequency of Interruption (No.)	Duration of Interruption (Hr.)		
				DPEF		DPSC		DTEF		DTSC		TLP		SQL		GUP		DLDL		PTOL				OP	
				F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D			F	D
1	Hawassa	9 (33 kv)	BGI	1	0.73	3	2.45	0	0	17	4.2467	67	137.46	67	123.33	0	0	4	40.38	2	11.8	21	68.09	182	388.5
2	Hawassa	10 (33 kv)	Arbegona	10	45.866	132	465	11	0.322	116	3.8638	45	61.657	52	104.01	0	0	2	19.82	12	33.321	40	75.382	420	809.2
3	Hawassa	11 (33 kv)	HU	1	0.73	6	10.2	0	0	20	0.59	20	3.7167	38	31.8	0	0	0	0	1	0.866	16	15.516	102	63.4
Sum																								704	1261.1

N.B.: DPEF- Distribution Permanent Earth Fault
 DPSC- Distribution Permanent Short Circuit
 DTEF- Distribution Temporary Earth Fault
 DTSC- Distribution Temporary Short Circuit
 TLP- Transmission Line Problem (Failure on 45 KV,66KV,132Kv ,230Kv and 400KV)
 SQL- System Over Load (When Generated power is below the total Demand)
 GUP- Generating Unit Problem (Generation Unit Failure)
 DLDL- Distribution Line Overload (When Medium Voltage Feeders are loaded beyond their capacity or CT ratio)
 PTOL- Power transformer Overload (When the load is beyond the capacity of Substation transformer)
 OP- Operational (When Medium Voltage feeders are interrupted Volentarily for maintenance ,Load transfer , new transformer erection . . . ecc.)

Where F = Frequency of Interruption (No)

D = Duration of Interruption (Hours)

A. Distribution line fault or problem

Is caused by faults such as open circuit, earth fault, temporary and permanent short circuit can cause the interruption of the end users.

Table 4.8: Hawassa substation 33kv feeder interruption data in 2015G.C caused by line fault

Item No.	Substation Name	Feeder Name	site name	Frequency and Duration of Interruption								Frequency of Interruption (No.)	Duration of Interruption
				DPEF		DPSC		DTEF		DTSC			
				F	D	F	D	F	D	F	D		
1	Hawassa	9 (33 kv)	BGI	1	0.7	3	2.5	0	0.0	17	4.2	21.00	7.43
2	Hawassa	10 (33 kv)	Arbegona	10	45.9	132	465.0	11	0.3	116	3.9	269.00	515.05
3	Hawassa	11 (33 kv)	HU	1	0.7	6	10.2	0	0.0	20	0.6	27.00	11.52
Sum												317.00	533.99
N.B.:													
DPEF- Distribution Permanent Earth Fault													
DPSC- Distribution Permanent Short Circuit													
DTEF- Distribution Temporary Earth Fault													
DTSC- Distribution Temporary Short Circuit													

As we can see in the table the study area feeder 10 frequency of interruption 269 and duration of interruption is 515.05 hours in the given year.

B. Distribution line and transformer overload

Table 4.9: Hawassa substation 33kv feeder interruption due to line and transformer overloaded in 2015 G.C.

Item No.	Substation Name	Feeder Name	site name	Overload				Frequency of Interruption (No.)	Duration of Interruption (Hr.)
				DLOL		PTOL			
				F	D	F	D		
1	Hawassa	9 (33 kv)	BGI	4	40.38	2	11.8	6	52.2
2	Hawassa	10 (33 kv)	Arbegona	2	19.82	12	33.321	14	53.1
3	Hawassa	11 (33 kv)	HU	0	0	1	0.866	1	0.9
Sum								21	106.187
NB.									
DLOL- Distribution Line Overload (When									
PTOL- Power transformer Overload									

C. Generation failure or system overload(Shading)

This is caused mainly due to power demand and generation mismatch or due to technical failure, which has unwanted consequence of power outage to the customer

Table 4.10: Hawassa substation 33kv feeder interruption due generation inadequacy/shading in 2015 G.C

Item No.	Substation Name	Feeder Name	site name	SOL		GUP		Frequency of Interruption (No.)	Duration of Interruption (Hr.)
				F	D	F	D		
				1	Hawassa	9 (33 kv)	BGI		
2	Hawassa	10 (33 kv)	Arbegona	52	104.007	0	0	52	104.0
3	Hawassa	11 (33 kv)	HU	38	31.8	0	0	38	31.8
Sum								157	259.14

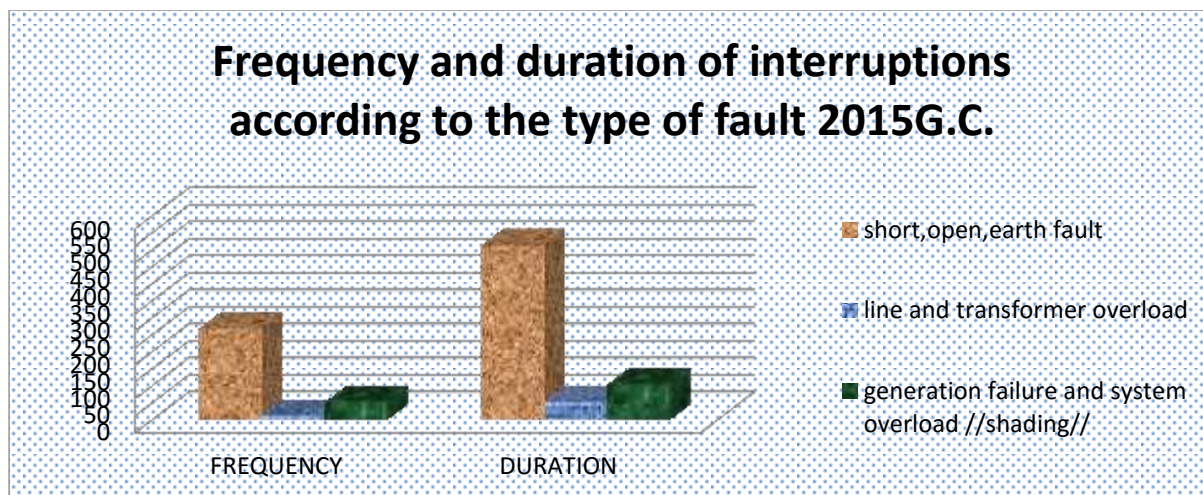
NB

- SOL-** System Over Load (When Generated power is below the total Demand)
- GUP-** Generating Unit Problem (Generation Unit)

Table 4.11: Summarizing the interruption data on 33kv feeder 10 line

No.	Type of the fault	Frequency	Duration	Percentage of fault (%)
1	Distribution fault(open, short, earth)	269	515.05	80.30
2	Line and transformer Overload fault	14	53.14	4.18
3	Generation failure or system overload (Shading)	52	104.01	15.52

Graph 4.3: Frequency and Duration of Interruption for Hawassa sub. 33kv feeder 10 line based on the type of fault



From the analysis, it is observed that majority (80.30%) of the faults in Hawassa substation feeder 10 distribution network are due to short circuit, open circuit and earth fault. The remaining faults are due to black out, operation and system over load (when generated power is below the total demand other than black out).

4.7 Reliability Indices Evaluation of Hawassa 33kv (feeder 10) Distribution System

As one object of this thesis work 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 Hawassa 33kv feeder 10. The availability of power for customers from this substation is performed on the medium voltage side of the customer transformers (33kV). The reliability is highly affected by outages occurred on the customer side secondary distribution lines which unable to collect data for analysis due to lack of resource, lack of organized data and advanced technology at the substation to view the performance of the customer side secondary distribution network. The causes occurred on the secondary sides of customer transformers that may affect the service reliability of the feeders:

- a. HRC fuses on the transformer usually get blown for different reasons mentioned
- b. Distribution lines on the low voltage side may fail for different reasons such as lack of clearance from trees, use of lines below the rated limit etc.
- c. Damage of transformers due to different reasons.

The customer-oriented indices (SAIFI, SAIDI, CAIDI, ASAI, ASUI) for Hawassa substation feeder 10 is calculated using ETAP (Electrical Transient Analyzer Program):

❖ ETAP software (Electrical Transient Analyzer Program (ETAP) PowerStation 4.0.0.)

ETAP PowerStation provides a fully graphical editor to construct a one-line diagram of a system. From the one-line diagram Edit Toolbar it is possible to add, delete, move, connect, zoom in or out, change element size, orientation, symbol (IEC or ANSI), enter properties, set operating status, etc. Calculation results can be displayed on the one-line diagram for convenience.

With PowerStation it is possible to build one-line diagrams graphically and perform load flow, short-circuit, motor starting, transient stability, protective coordination and cable derating studies of a given electrical network. Among PowerStation's most powerful features are the capability to be fed nameplate data of many electrical components which reduces the time required for data analysis; and its ability to provide a feature of nesting composite networks. Composite networks

allow to graphically nest network elements in a block which provides construction of complex electrical networks while maintaining a clean and uncluttered diagrams that display what you want to emphasize. Data editors can speed up the data entry process by requiring the minimum data for the particular study [24].

Also by ETAP we can calculate the reliability of the given network Software capabilities are listed below

1. Model reliability characteristics of each component
2. Implement user-defined parameters & settings
3. Calculate bus and load point reliability indices
4. Calculate system reliability indices
5. Calculate reliability energy (cost) indices
6. Rank element contributions to energy (cost) indices

The load bus and system indices evaluated by ETAP software are abbreviated as follows

- ✓ Customer Oriented Indices System Average Interruption Frequency Index [SAIFI]
- ✓ System Average Interruption Duration Index [SAIDI]
- ✓ Customer Average Interruption Duration Index [CAIDI]
- ✓ Average Service Availability Index [ASAI]
- ✓ Average Service Unavailability Index [ASUI]

Energy (Cost) Indices

- ✓ Expected Energy Not Supplied [EENS] sensitivity analysis

Model assumptions and limitations

- ✓ All switching devices operate successfully when required
- ✓ Switching devices can be opened whenever possible to isolate a fault.
- ✓ Power supply can be restored to provide power to as many load points as possible using the appropriate switching action and alternative supplies
- ✓ All failures are statistically independent
- ✓ Second order faults (double contingency) is considered

❖ Single line diagram

The starting point of any power-flow problem is the development of a single-line diagram of the power system, from which computer solutions can be obtained. The one line diagram of the case study network, 33kv Hawassa substation feeder 10 lines, was thus drawn on the ETAP Power Station platform for this study. All the organized data were then fed to the one-line diagram. Partial view of the one-line diagram is given below in both edit and run modes of ETAP.

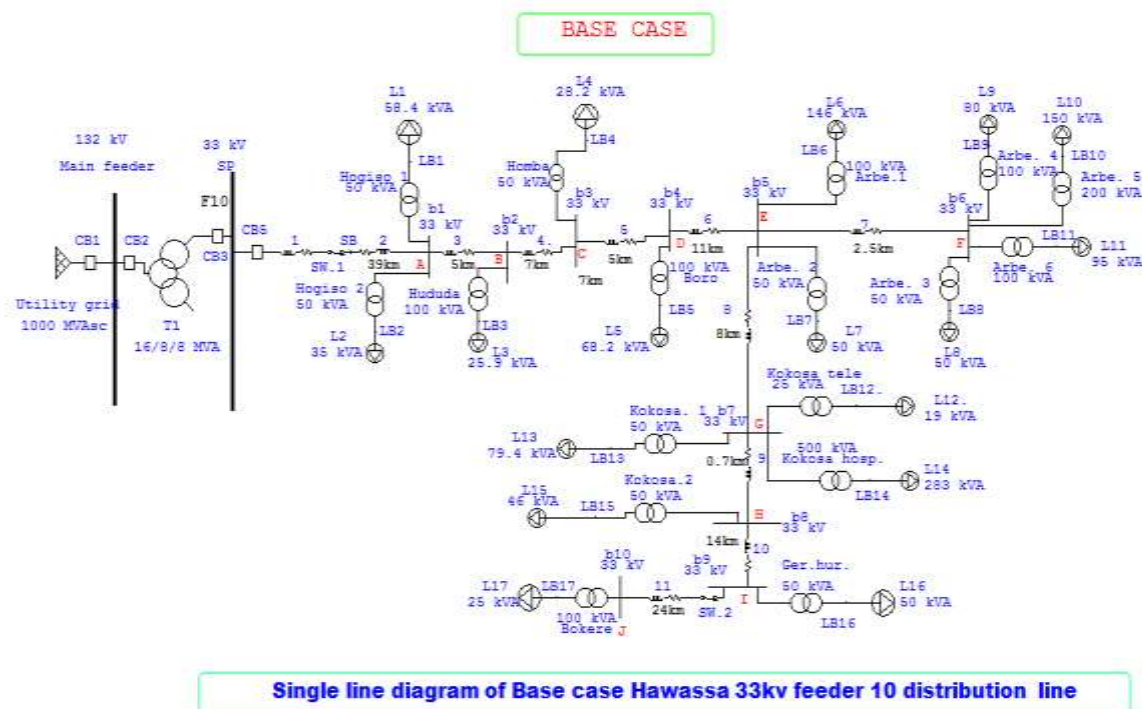


Fig 4.2: Single line diagram of Hawassa substation 33kv feeder 10 distribution system

❖ ETAP software input feeder data per feeder distance and assumptions taken

Assumptions

- ✓ All the components along the radial feeder line will have the same frequency and duration regardless of the its placement because of difficulty in source data for individual components but their rate depend on the distance from supply source.
- ✓ Assessment of reliability in the given calendar year is done based on the type of fault that resulted in for the outage of the feeder so that improvement is compared easily
- ✓ Only case 3 power interruption because of supply inadequacy is considered in ETAP software so that it is easy to recommend some capacity distribution generation for the solution to the problem. Leaving the security case for other type of solution instead of distributed generation in the next chapter.

❖ **Inputs data based on the type of fault that resulted interruption**

1. Distribution line fault(open ckt, short ckt, earth fault)

Table 4.12: distribution line fault interruption reliability indices

No.	Location Name /Node points/	Distance from Source point	Freq uency	Annual outage Duration(hr/yr) U_s	Average outage rate (f/yr/km) f_s	Average outage duration (hr/yr/km)	Mean time to repair (hr), r_s
1	A/Hogiso 1,2/	46km	269	515.05	0.85	11.2	1.91
2	B/Hududa/	51km	269	515.05	0.94	10.1	1.91
3	C/Homba/	58km	269	515.05	1.07	8.88	1.91
4	D/Boro/	63km	269	515.05	1.16	8.18	1.91
5	E/Arbegona 1, 2/	74km	269	515.05	1.37	6.96	1.91
6	F/Arbegona 3,4,5,6/	76.5km	269	515.05	1.41	6.73	1.91
7	G/Kokosa 1, Kokosa tele, Kokosa hospi. /	82km	269	515.05	1.51	6.28	1.91
8	H/Kokosa 2/	82.7km	269	515.05	1.53	6.23	1.91
9	I/ Gerba hurufa/	96.7	269	515.05	1.79	5.33	1.91
10	H/Bokore/	120.7	269	515.05	2.23	4.27	1.91

2. Distribution line and power transformer overload

Table 4.13: distribution line and power transformer overload interruption reliability indices

No.	Location Name/ Node points/	Distance from Source point	Freq uency	Annual outage Duration(hr/yr) U_s	Average outage rate (f/yr/km) f_s	Average outage duration (hr/yr/km)	Mean time to repair (hr) r_s
1	A/Hogiso 1,2/	46km	14	53.14	0.044	1.16	3.8
2	B/Hududa/	51km	14	53.14	0.049	1.04	3.8
3	C/Homba/	58km	14	53.14	0.056	0.92	3.8
4	D/Boro/	63km	14	53.14	0.06	0.84	3.8
5	E/Arbegona 1, 2/	74km	14	53.14	0.071	0.72	3.8
6	F/Arbegona 3,4,5,6/	76.5km	14	53.14	0.073	0.69	3.8

7	G/Kokosa 1, Kokosa tele, Kokosa hospi. /	82km	14	53.14	0.078	0.65	3.8
8	H/Kokosa 2/	82.7km	14	53.14	0.08	0.64	3.8
9	I/ Gerba hurufa/	96.7	14	53.14	0.09	0.55	3.8
10	H/Bokore/	120.7	14	53.14	0.12	0.44	3.8

3. Generation failure or system overload (Shading)

Table 4.14: Generation failure and system overload load point interruption reliability indices

No	Location Name/ Node points/	Distance from Source Point	Freq uency	Annual outage Duration(hr/yr) U_s	Average outage rate (f/yr/km) f_s	Average outage duration (hr/yr/km)	Mean time to repair (hr) , r_s
1	A/Hogiso 1,2/	46km	52	104.01	0.15	2.26	2.0
2	B/Hududa/	51km	52	104.01	0.17	2.04	2.0
3	C/Homba/	58km	52	104.01	0.19	1.79	2.0
4	D/Boro/	63km	52	104.01	0.21	1.65	2.0
5	E/Arbegona 1, 2/	74km	52	104.01	0.25	1.41	2.0
6	F/Arbegona 3,4,5,6/	76.5km	52	104.01	0.26	1.36	2.0
7	G/Kokosa 1, Kokosa tele, Kokosa hospi. /	82km	52	104.01	0.28	1.27	2.0
8	H/Kokosa 2/	82.7km	52	104.01	0.29	1.26	2.0
9	I/ Gerba hurufa/	96.7	52	104.01	0.34	1.08	2.0
10	J/Bokore/	120.7	52	104.01	0.43	0.86	2.0

- ❖ The failure rates and repair duration of the different components such as power transformers, feeder, breakers, and bus bars are presented in table below. The feeder rates are in f/yr.km. 132/33 Kv transformers are considered 16MVA.

Table 4.15: Component reliability data

Component type	Average outage rate (f/yr/km), f_s	Mean time to repair (hr), r_s	Switching time (hr)
Power transformer	0.075	10	1
Circuit breaker	0.04	4	1
Main bus bars	0.02	4	1
Utility grid	0.02	24	1
Feeder	0.3	6	1

4.8 Base case reliability analysis

The base case test systems used for the reliability analyses discussed in this section is shown in Figure 4.1. The data used will be reliability problem caused by generation outage (inadequacy) for the reason assumed before. The ETAP program computes several reliability indices explained in section 4.7 these have been recommended in various publications [23, 24].

The calculated individual load point system reliability indices are shown in table below, as a radial system with no meshed connections the average outage rate [λ] increases as the LP are further from the supply point (SP); however the average duration time tends to be smaller. The mean time to repair has assumed constant value. [r_s] and the annual outage duration has also constant value.

Table 4.16: Load point output report for base case Hawassa substation feeder 10 line

Load Point Output Report						
ID	Bus Load Sector	Connected Bus ID	Average Interrupting Rate f / yr	Average Outage Duration hour	Annual Outage Duration hr / yr	EENS MW hr / yr
L1	Residential	LB1	47.5205	1.80	85.3316	4.2324
L2	Residential	LB2	47.5205	1.80	85.3316	2.5386
L3	Residential	LB3	47.5205	1.80	85.3316	1.8773
L4	Residential	LB4	47.5205	1.80	85.3316	2.0480
L5	Residential	LB5	47.5205	1.80	85.3316	4.9492
L6	Residential	LB6	47.5205	1.80	85.3316	10.5679
L7	Residential	LB7	47.5205	1.80	85.3316	3.6266
L8	Commercial	LB8	47.5205	1.80	85.3316	3.6266
L9	Commercial	LB9	47.5205	1.80	85.3316	5.8025
L10	Industrial	LB10	47.5205	1.80	85.3316	10.8798
L11	Residential	LB11	47.5205	1.80	85.3316	6.8905
L12	Govt. & Inst.	LB12	47.5205	1.80	85.3316	1.3781
L13	Residential	LB13	47.5205	1.80	85.3316	5.7599
L14	Govt. & Inst.	LB14	47.5205	1.80	85.3316	20.4965
L15	Commercial	LB15	47.5205	1.80	85.3316	3.3365
L16	Residential	LB16	47.5205	1.80	85.3316	3.6266
L17	Residential	LB17	47.5205	2.05	97.3716	2.0691
						93.7062

Table 4.17: system indices of 33kv feeder 10 line

System indices	
SAIFI System Average Interruption Frequency Index	47.5205 f / cust.yr
SAIDI System Average Interruption Duration Index	85.4837 hr / cust.yr
CAIDI Customer Average Interruption Duration Index	1.799 hr / cust. inter.
ASAI Average service Availability Index	0.9902pu
ASUI Average Service Unavailability Index	0.00976pu
EENS Expected Energy Not Supplied	93.706 MW hr / yr
AENS Average Energy Not Supplied	0.592 MW hr / customer.yr

4.9 Comparison of Reliability Indices with Benchmarks

Reliability benchmarks are the standards against which analyzed or measured reliability is judged. The purposes of reliability benchmarks are to define minimum average reliability performance, by feeder type, for a distribution network and provide a basis against which a distribution network service provider's reliability performance can be assessed. The benchmarks were calculated using the IEEE Guide for electric power distribution reliability indices – IEEE Standard 1366-2003.

Reliability analysis and calculations for the Addis Ababa distribution system had not been done for the indices (such as SAIFI, SAIDI, CAIDI, and ASAI).

A benchmark of SAIDI, CAIDI, SAIFI and ASAI for nine countries is shown in Table below. From the calculation and analysis considered in reliability evaluation of Hawassa substation 33kv feeder 10 distribution system has an average value of SAIDI=85.4837 hr/cust.(5105 min.), SAIFI =47.5205 interruptions/customer, CAIDI=1.799hr /cust. (107.4 minutes) and ASAI=99.02 %.and ASUI = 0.976%

A higher SAIDI, SAIFI and CAIDI index number indicates worse performance. Lower number for SAIDI, SAIFI and CAIDI index indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration.

Comparing the average SAIDI, SAIFI, CAIDI and ASAI value of feeder 10 of Hawassa distribution with the benchmarks shows that has the worst performance

Table 4.18: Benchmarks for Reliability Indices [34]

No	Country	SAIDI (Minutes/year)	SAIFI (Interruptions/Customer)	CAIDI (Minutes/outage)	ASAI (%)
1	United States	240	1.5	123	99.91
2	Austria	72	0.9	112	99.97
3	Denmark	24	0.5	70	99.981
4	France	62	1	58	99.97
5	Germany	23	0.5	50	99.9999
6	Italy	58	2.2	106	99.9991
7	Netherlands	33	0.3	75	99.97
8	Spain	104	2.2	114	99.968
9	UK	90	0.8	100	99.964
10	(Addis Ababa) Ethiopia	252/min	3.65	2280	99.425

4.10 Loss of Revenue due to Power Interruption (shading) in Hawassa feeder 10 line

A common approach used in quantifying the worth or benefit of electric service reliability is to estimate the customer costs associated with power interruptions. The customer interruption cost when an electric supply failure occurs depends on many factors. The absence 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 Hawassa feeder 10 due to interruptions.

Table 4.19: Electricity tariff Ethiopian Electric Power Corporation (EEU) Since July 8,2006[34]

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		
	1stBlock	0 – 50	0.6088
	2nd Block	Above 50	0.6943
3	Low Voltage Time of Day Industry		
	Peak		0.5085
	Off – Peak		0.3933

The cost of energy not supplied due to interruption for Hawassa Substation is calculated by using equation below

Cost of Energy = Power *time *tariff for electric

By considering an average price of 0.6 Birr/kWh for electricity in EEU, the average energy not supplied and average cost of energy not supplied due to power interruption for Hawassa substation feeder 10 in 2015G.C as shown in table from load point output report above is 93.706Mwh/yr.

Cost of Energy =0.6*1000*93.706 =56,223.06 birr

Poor voltage profile (under voltage) of branching points that is except the first branching node point all other are under voltage (in the red color) and total voltage drop of the distribution line violate $\pm 5\%$ of nominal voltage value 33KV line so that needs re-conductoring with better cable capacity and the distribution transformer at node point A,E and G are overloaded since it has red color so that needs upgrading.

5.1 Design solution to Hawassa feeder 10 distribution line

In the design of power distribution system all materials and workmanship shall be of 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.

- ❖ The Hawassa substation distribution system is mainly made up of radial network which is making things worse in case of line tripping. So it is better to convert radial networks to ring network for better reliability. There is severe under voltage from branch point B up to G.
- ❖ Distribution transformers are without surge arrestors and drop out fuses at the majority of locations. So, it is better the distribution transformer with their accessories are equipped with surge arresters and drop out fuse.
- ❖ Various kva ratings for distribution ranging from 50,100, 200, 315, 500 etc. exists in Hawassa feeder 10 distribution line. Ratings of distribution transformers need to be standardized to avoid spare inventory and overloaded.
- ❖ For better distribution reliability, Loads or customers should be separated by specifying industrial, commercial and residential consumers.

5.1.1 Selection of distribution transformer capacity

Electric power utilities are frequently faced with a common challenge of efficiently determining the transformer size to provide service for their customers. Inaccurate estimation of transformer size ultimately leads to problems related to reliability issues and excessive costs [11]. Supplying a transformer much larger than necessary to a customer results in excessive capital costs and future costs of transformer losses resulting from large no-load losses. On the other hand, under sizing a transformer for a particular application leads to reliability problems and reduced transformer service life. Therefore proper selection of transformer size is important from financial saving and energy loss reduction perspectives. There are varying practices around the world towards selecting the size and number of distribution transformers; each one trying to match the desired operational conditions with the technical characteristics of the system. In some countries, distribution transformers are installed very close to the loads that they are supposed to serve. So in our case distribution transformers at node point A,E and G have to be upgraded as expressed below.

- ✓ At node point A since the load is 58.4kva the capacity of the transformer upgrade to 100kva
- ✓ At node point E since the load is 146kva the capacity of the transformer upgrade to 200kva
- ✓ At node point G since the load is 79.4kva the capacity of the transformer upgrade 100kva

5.1.2 Selection of distribution cable

In order to select an appropriate cable for the secondary side of power transformers, it is necessary to know the following:

SECONDARY (33KV) SIDE

33kv Feeder's maximum rating is 8MVA so that

$$I_{\text{rated}} = \frac{\text{MVA}}{\sqrt{3} * V} = \frac{8 * 10^6 \text{VA}}{\sqrt{3} * 33 * 10^3 * V} = 139.96 \text{A}$$

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

$$I_{\text{standard}} = \frac{I_{\text{rated}}}{\text{Derating factor}} = \frac{139.96}{0.85} = 164.66 \text{A}$$

From the table data below shows that a 3x95mm² AAC Overhead cables would be capable of carrying a load of 204.5A.

Table 5.1: AAC Overhead cables data

Nominal Area	Approximate over all diameter	Approximate weight	Nominal resistance	Nominal reactar	Current rating
(mm ²)	Mm	Kg/km	Ohm/km	Ohm/km	A
35	6.9	1780	1.11	0.164	120.6
50	8.1	1970	0.822	0.156	157.3
70	9.7	2260	0.568	0.145	178.3
95	11.4	2600	0.411	0.137	204.5
120	12.8	2880	0.325	0.136	262.2
150	14.2	3280	0.265	0.131	319.9
185	15.7	3640	0.211	0.127	361.8

Note: The values of current rating mentioned in above Table are based on wind velocity of 0.6 meter/second, solar heat radiation of 1200 watt/metre², ambient temperature of 50° C & conductor temperature of 80° C.

5.1.3 Permissible Voltage Drop Calculation and power loss calculation

Permissible voltage drop is computed by calculating the highest current drawn by the load multiplied by an appropriate factor. The maximum voltage drop allowed by SANS 10142-1 during full load running condition is 5% [46].

The voltage drop may be calculated in two different ways:

- ❖ Multiplying the current by the impedance of the length of the cable. Calculate the percentage voltage drop by reference to the phase to earth voltage.
- ❖ Multiply the current by the length of cable, and then multiply the result by the volt dropper amp per meter

The voltage drop is calculated by equation

$$V_{3\phi \text{ drop}} = \sqrt{3} * \left(\frac{R \cos \phi + X \sin \phi}{\text{km}} \right) * I_{\text{load cur.}} * D$$

Where, D is distance in km

From Table above for 50 mm² the impedance per kilometer is 0.84343Ω/km and considering the average distance from Hawassa substation to study area is 91.7km, the voltage drop in the secondary feeder is calculated as follows

- ❖ Power losses/variable or load loss or copper loss/ in distribution lines (feeders) can be calculated by taking longest distance of the feeder line equal to 120.7km.

Real power loss

$$P_{\text{loss}} = \sum_{i=1}^n I_i^2 * R_i = 24.6^2 * 0.822 * 120.7 = 60.04 \text{kw}$$

Reactive power loss

$$Q_{\text{loss}} = \sum_{i=1}^n I_i^2 * X_i = 24.6^2 * 0.156 * 120.7 = 11.39 \text{kvar}$$

Solution for the problem

Re-conductoring of feeder line by higher size conductor

- ❖ From the table data above shows that a 3x95 mm² AAC Overhead cables would be capable of carrying a load of 325.9A. has $Z=0.411+ j0.137\Omega/\text{km}$ ohmic resistance value so that calculating the voltage drop for the above case again.

$$I_{\text{load current}} = 23.2\text{A and } Z=0.411+ j0.137\Omega/\text{km}$$

$$V_{\text{drop}} = \sqrt{3} * \left(\frac{0.411\Omega * 0.85 + 0.137 * 0.53}{\text{km}} \right) * 24.6\text{A} * 91.7\text{km} = \sqrt{3} * \frac{0.42196}{\text{km}} * 24.6 * 91.7\text{km} = 1,648.7\text{V}$$

$$\text{Percentage voltage drop} = \frac{1648.7}{33000} * 100 = 4.99 \% \text{ is acceptable}$$

- ❖ Power losses/variable or load loss or copper loss/ in distribution lines (feeders) can be calculated by taking the longest distance equal to 120.7km.

Real power loss

$$P_{\text{loss}} = \sum_{i=1}^n I_i^2 * R_i = 24.6^2 * 0.411 * 120.7 = 30.02\text{kw}$$

Reactive power loss

$$Q_{\text{loss}} = \sum_{i=1}^n I_i^2 * X_i = 24.6^2 * 0.137 * 120.7 = 10\text{kvar}$$

NB: The above loss calculation only covers losses in cable line; it doesn't cover no-load loss of any type and load loss of distribution transformer.

5.1.4 Fault Current Calculation

Electric cables are designed to operate below a certain maximum temperature, this being dependent on the conductor material and the type and the thickness of the insulation. Cable selection for a particular installation must therefore be made on the basis of not exceeding these temperature limits. For a power transformer with 132/33 kV with 32MVA rating, the short-circuit capacity is 800MVA [IEC 60076-5]. The earth fault level is 100MVA, and it may be assumed that the fault should be cleared within a half second

SECONDARY (33KV) SIDE

The supply impedance seen from the primary side is given by equation

$$Z_{\text{sys}} = \frac{V_p^2}{S_{sc}} = \frac{132^2}{800} = 21.78\Omega$$

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

$$Z_L = Z_{SYS} * \left(\frac{V_S}{V_P}\right)^2$$

$$Z_L = 21.78 * \left(\frac{33}{132}\right)^2 = 1.36\Omega$$

❖ The short circuit current that can exist on the secondary feeder is calculated by equation

$$I_{SC} = \frac{V_S}{\sqrt{3} * Z_L} = \frac{33000}{\sqrt{3} * 1.36} = 14.009KA$$

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

Where:

I_{sc} = Short circuit rating of cable (kA)

A = Cross-section of conductor (mm²)

t = time to trip (in 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, Aluminum conductor

= 143 A/mm² for XLPE, Copper conductor

= 105 A/mm² for XLPE, Aluminum conductor

$$I_{sc} = \frac{K * A}{\sqrt{t}} = \frac{105 * 50}{\sqrt{0.5}} = 7.42KA$$

Therefore the cable cannot withstand the prospective short circuit current, if the cable is aluminum conductor and 50mm² area.

Taking cable size of 95mm² XLPE, Aluminum conductor the short circuit capacity will be

$$I_{sc} = \frac{K * A}{\sqrt{t}} = \frac{105 * 95}{\sqrt{0.5}} = 14.106KA$$

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

$$I_{EF} = \frac{\text{Earth fault MVA}}{\sqrt{3} * \text{VOLTAGE RATING}}$$

$$I_{EF} = \frac{100 * 10^6}{\sqrt{3} * 33 * 10^3} = 1.75KA$$

The cable earth fault current withstand capacity is calculated by equation

$$I_{EF} = \frac{K * A}{\sqrt{t}}$$

Where:

I_{EF} = Earth fault current (kA)

A = Cross-sectional area of earth path (mm²)

t = Fault duration in seconds (0.5 second)

K = A constant that depends on earth path material

= 42 A/mm² for steel wire armour

= 24 A/mm² for lead sheath

= 143 A/mm² for Copper tape

= 76 A/mm² for Aluminum wire armour

$$I_{EF} = \frac{K \cdot A}{\sqrt{t}} = \frac{76 \cdot 50}{\sqrt{0.5}} = 5.37 \text{ KA}$$

Therefore the cable can withstand the prospective earth fault current.

In many cases, the cable conductor size is smaller than dictated by the full load current, and is not chosen in order to withstand the prospective short-circuit current. The use of large conductor 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.

5.1.5 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 conditions

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.

Table 5.2: Ratings of 33 kV Circuit Breaker

Description	Minimum Requirements
Type of Circuit Breaker	Outdoor Type
Rated Service Voltage	33 kV
Rated Maximum Voltage	36 kV
Type of Quenching Medium	SF ₆
Rated Current	1250A
Rated Short Circuit Current	25 kA

Number of Poles	3
Rated Frequency	50 Hz
Rated Short Circuit Making Current	100 kA
Short Circuit withstand current duration	0.5 Sec
Insulation level	
a) Power Frequency Withstand (kV RMS 1 min)	70kv
b) Impulse Withstand (1.2/50 μ sec) kV Peak	170kv

5.1.6 Selection of Surge Arrestors

The lightning arrester mainly differs in their constructional features. However they work with the same operating principle, i.e. providing low resistance path for the surges. They are mainly classified as:

- 1) Rod gap arrester
- 2) Metal Oxide without gap arrester
- 3) Horn gap arrester
- 4) Multi-gap arrester
- 5) Expulsion type lightning arrester

Selection of the proper ratings of a metal oxide arrester without gap is considered in this design; this is because currently EEPCO is using metal oxide without gap arresters.

Table 5.3: Ratings of 33 kV Surge Arrester

Description	Minimum Requirements
Type of Surge Arresters	Outdoor
Rated Service Voltage	33 kV
Rated Operating Voltage (U_r)	30 kV
Rated Continuous Operating Voltage (U_c)	21 kV
Nominal Discharge Current	10 kA
Rated Frequency	50 Hz
Maximum Short Circuit Rating	25 kA
Insulation level	

a) Power Frequency Withstand Voltage (kV RMS for 1 min)	70kv
b) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	170kv
Residual voltage for	
a) Lightning current 8/20 impulse	
b) Step current 1/20 impulse of 10 kA	
c) Switching Current 30/60 Impulse of 500 A/1000 A	
High current 4/10 impulse withstand value	100 kA
Low current, long duration current impulse withstand (upper value)	1000

5.1.7 Selection of Isolators

Isolator shall be designed such that in fully open position, it shall provide adequate electrical isolation between the contacts on all the three switches. Isolator shall be horizontal side opening, double side break rotating post type for use on a 33kV, 50 Hz, 3 - phase system

Table 5.4: Ratings of 33 kV Isolator

Description	Minimum Requirements
Rated Service Voltage	33 kV
Rated Maximum Voltage	36 kV
Rated Current	1250A
Rated Short-time Current	31.5 kA
Number of Poles	3
Rated Frequency	50 Hz
Rated Maximum Withstand current	100 kA
Closing or Opening Time	≤ 30 Sec
Insulation level	70kv
a) Power Frequency Withstand Voltage (kV RMS for 1 min) 70KV	170kv
b) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	

5.1.8 Selection of CT and PT

A CT is essentially a step up transformer which steps down a current to known ratio. The primary of this transformer consists of one or more turns of thick wire connected in series with the line. The secondary consists of a large no. of turns of a fine wire and provides for the measuring instruments and relays a current which is a constant fraction of current in the line.

PT is essentially a step down transformer and steps down the voltage to a known ratio. The primary of PT consists of a large number of turns of fine wire connected across the line.

Table 5.5: Ratings of 33kV Current Transformer

Description	Minimum Requirements
Rated Service Voltage	33 kV
Rated Maximum Voltage	36 kV
Rated Primary Current	
a) for line feeder	400-200-100
b) for transformer feeder	800-400-200
Rated secondary currents	5-5-5
Short-time Current Ratings	31.5 kA
Rated Short Circuit Maximum Current	60 kA
Rated Frequency	50 Hz
Insulation level	
a) Power Frequency Withstand Voltage (kV RMS for 1 min)	70kv
b) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	170kv

Table 5.6: Ratings of 33kV Voltage Transformer

Description	Minimum Requirements
Rated Maximum Voltage	36 kV
Rated Primary Voltage	$\frac{33kv}{\sqrt{3}}$
Rated Secondary Voltage (second winding)	$\frac{0.1kv}{\sqrt{3}}$

Rated Frequency	50 Hz
Insulation level	
a) Power Frequency Withstand Voltage (kV RMS for 1 min)	70kv
b) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	170kv
Power frequency withstand voltage secondary winding (kV RMS for 1 min)	2kv

5.1.9 Selection of insulator

The insulators serve two purposes. They support the conductors (or bus-bars) and confine the current to the conductors. The most commonly used material for the manufacture of insulator is porcelain. There are several types of insulators, and their use in the sub-station will depend upon the service requirement. The main four types of insulators are as follows

- ❖ Pin Type Insulators
- ❖ Suspension Type Insulators
- ❖ Strain Insulators
- ❖ Shackle Insulators

As there are two types of insulators in EEPCO's power substation (Post-Type and Suspension) Insulators.

Table 5.7: Ratings of 33kV suspension Insulator

Description	Minimum Requirements
Type of Insulators	Porcelain
Installation	Outdoor
Rated Service Voltage	33 kV
Rated Maximum Voltage	45kv
Rated Frequency	50 Hz
Insulation level	
a) Power Frequency Withstand Voltage (kV RMS for 1 min) 170 kV	132kv
b) Impulse Withstand Voltage (1.2/50 μ sec) kV Peak	130kv

5.2 Reliability Improvement Strategies to Hawassa feeder 10 Distribution

System based on protection device and preventive maintenance system

Due to increase in dependence on electricity and the growth of sensitive loads in all customer sectors (residential, commercial and industrial), the utilities must strive to maximize reliability to ensure that customer requirements are satisfied while incurring the lowest possible cost. By knowing the root causes of faults, it is possible to take actions that will prevent faults from occurring.

5.2.1 Sensitivity study based on protection device and preventive maintenance system

Security actions such as performing tree trimming and installing animal guards and surge arresters, dropout fuse and disconnecting switches. Improving component performances by replacing existing components with comparable components that are less prone to failure, employing network structures that are less sensitive to component outages, e.g., meshed networks. Introducing permanent network solutions incorporating such options as automatic reclosing, manual and automatic feeder sectionalizing, automatic feeder fault locating, remote monitoring and control capabilities and emergency supplies from adjacent feeders. Generally there are two possible strategies for reducing frequency and duration of interruptions:

1. Reduction of the number of faults

The reduction of the interruption frequency is possible by decreasing failure rates of the network component. For example, the reduction of the number of faults in an overhead line can be reached by a tree trimming program, which ensures the clearance distance. This will reduce the failure rate, and increase the system reliability and reduce interruption. A reduction of the number of interruptions leads to lower interruption indices. In summary, the reduction of the number of faults causes a decrease of the frequency of interruptions and unavailability. In the following list, we can find the most important measures for reducing failure rates.

- ❖ Preventive maintenance
- ❖ Monitoring critical components
- ❖ Preventive replacement of components which have reached the end of their useful life
- ❖ isolated or tree wires in overhead lines to prevent tree contact with the conductor
- ❖ Tree trimming and periodical trimming of the adjacent vegetation to prevent contact with the conductors
- ❖ Protection against animals contact with conductors

Table 5.8: Load point output report for automated Hawassa substation feeder 10 line

Load Point Output Report

LOAD BUS			Average Interrupting Rate	Average Outage Duration	Annual Outage Duration	EENS
ID	Load Sector	Connected Bus ID	f / yr	hour	hr / yr	MW hr / yr
L1	Reside	LB1	16.1995	2.14	34.73	1.7225
L2	Reside	LB2	16.1995	2.14	34.73	1.0332
L3	Reside	LB3	16.2595	2.14	34.85	0.7667
L4	Reside	LB4	16.3195	2.14	34.97	0.8392
L5	Reside	LB5	16.3795	2.14	35.09	2.0351
L6	Reside	LB6	17.7795	2.13	37.89	4.6922
L7	Reside	LB7	17.7795	2.13	37.89	1.6102
L8	Com	LB9	19.5025	2.12	41.42	1.7603
L9	Com	LB8	19.50451	2.13	41.48	2.8205
L10	Indust	LB10	19.5025	2.12	41.42	5.2808
L11	Reside	LB11	19.5025	2.12	41.42	3.3445
L12.	Govt.	LB12.	27.11251	2.09	56.55	0.9133
L13	Reside	LB13	27.11251	2.09	56.55	3.8174
L14	Govt.	LB14	27.11451	2.09	56.56	13.6050
L15	Com	LB15	27.14251	2.09	56.61	2.2136
L16	Reside	LB16	39.4955	1.80	71.00	3.0175
L17	Reside	LB17	39.7655	2.06	81.86	1.7395
						51.21

Table 5.9: system indices of automated 33kv feeder 10 line

System indices	
SAIFI System Average Interruption Frequency Index	22.1833 f / customer.yr
SAIDI System Average Interruption Duration Index	46.0464hr / customer.yr
CAIDI Customer Average Interruption Duration Index	2.076hr / customer interruption
ASAI Average service Availability Index	0.9947pu
ASUI Average Service Unavailability Index	0.00526pu
EENS Expected Energy Not Supplied	51.212 MW hr / yr
AENS Average Energy Not Supplied	0.0318 MW hr / customer.yr

- ✓ From the figure above the pink color shows the voltage drop at branch point A-J is in acceptable range. Also the transformers at A, E and G shows pink color b/c it is upgraded so that not overloaded.
- ✓ Comparing with bench mark

SAIDI =46.0464, CAIDI=2.076, SAIFI =22.1833, and ASAI=99.47% shows it is still not good but improved by SAIDI = 46.13%, SAIFI=53.32% and EENS=45.35% from base case.

✓ Loss of Revenue due to Power Interruption(shading)

Cost of Energy = Power *time *tariff for electric

Cost of Energy = 0.6*1000*51.212 = 30,727.2 birr better than first case

5.3 Reliability Improvement Strategies to Hawassa feeder 10 Distribution System based on adequacy issue

As it is seen in interruption table in the given calendar year due to high capacity load demand than the actual generation there comes load shading or interruption of supply.

The main reasons for generating stations are individually very capital intensive and that generation inadequacy can have widespread catastrophic consequences for both society and its environment. Consequently great emphasis has been placed on ensuring the adequacy and meeting the needs of this part of a power system [1].

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment's (except standby) are energized and all customers are energized. Scheduled and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions.

In planning distribution systems, the present trend is installation of distributed (or local) generators other than central generating stations closer to consumer premises preferably at high load density locations. Distributed Generators (DGs) are small modular resources such as photo voltaic cells, fuel cells, wind generators, solar cells. Distributed generation (DG) is expected to play an increasing role in emerging power systems [4]. The reliability of a distribution system may be increased by modifying failure rate and repair time of each section of the network. Such modifications may require additional investments which in the presence of DG may be mitigated. This will result in annual savings. The time necessary to start up the DG should be taken in to account for the reliability evaluation of distribution system. If this time is sufficiently short the customers suffer a momentary interruption, while, if not, they suffer a sustained interruption.

Studies have predicted that DG will be a significant percentage of all new generation going online. Different resources can be used in DG. Its impact on distribution systems may be either positive or

negative depending on the system's operating condition [4-5], DGs characteristics and location [4-5]. Potential positive impacts include

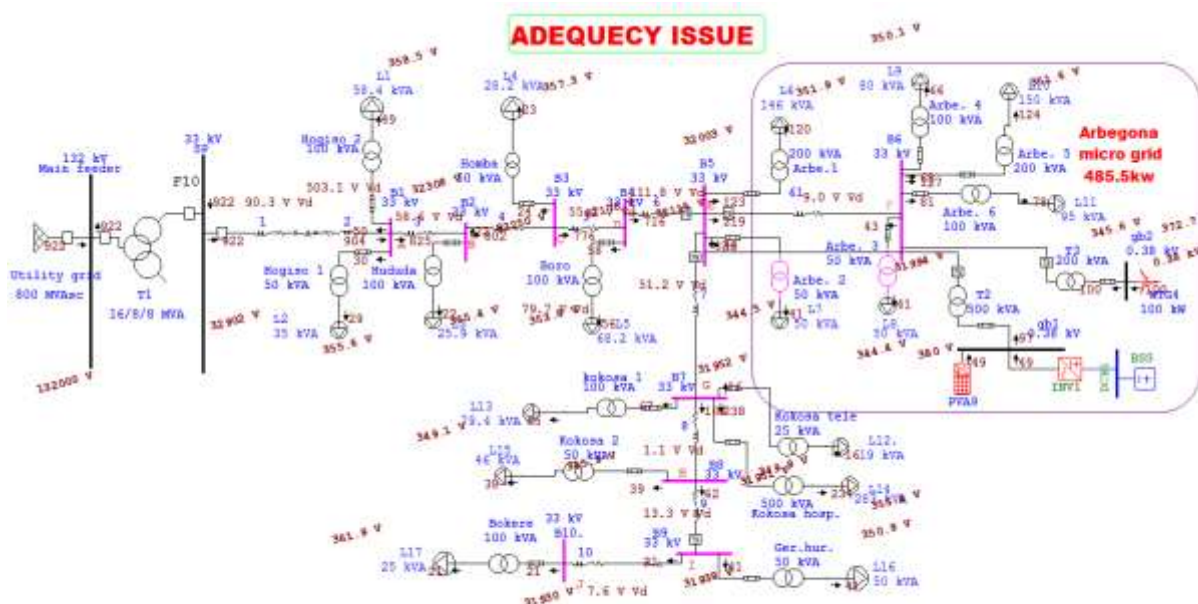
- ✓ improved system reliability;
- ✓ Loss reduction;
- ✓ Improved power quality.

This project covers several implications of RDG installation on a residential, commercial and governmental offices distribution system for the purpose of continuing electric supply based on high load density locations here in our case as we have seen Arbegona area has huge energy demand so that we concentrate our distributed generation in that area .

Let us take 400kw PV generator, 100kw wind generator and 1465AH battery backup system and analyze reliability of the network based on this system capacity. The reliability rates shown on table below are the mean values using IEEE STD

Table 5.10 Reliability input data of distributed generation components

Component type	Power generated	Average outage rate (f/yr/km), f_s	Mean time to repair (hr), r_s	Switching time (hr)
PV	400kw	0.696	3.9	1
Wind generator	100kw	0.174	3.9	1



Single line diagram of modified micro grid containing Hawassa 33kv feeder 10 distribution line

Fig 5.2: Single line diagram of modified micro grid containing Hawassa 33kv feeder 10 distribution line

Table 5.11: Load point output report for automated and micro grid containing Hawassa 33kv feeder 10 distribution line

Load Point Output Report						
Load Bus			Average Interrupting Rate	Average Outage Duration	Annual Outage Duration	EENS
ID	Load Sector	Connected Bus ID	f / yr	hour	hr / yr	MW hr / yr
L1	Residential	LB1	15.4100	2.70	41.55	2.06
L2	Residential	LB2	15.4100	2.70	41.55	1.24
L3	Residential	LB3	15.47	2.6936	41.67	0.92
L4	Residential	LB4	15.5300	2.69	41.79	1.00
L5	Residential	LB5	15.5900	2.69	41.91	2.43
L6	Residential	LB6	2.4400	2.00	4.88	0.60
L7	Residential	LB7	2.4400	2.00	4.88	0.21
L8	Commercial	LB9	2.9830	2.03	6.05	0.26
L9	Commercial	LB8	2.9850	2.05	6.11	0.42
L10	Industrial	LB10	2.9830	2.03	6.05	0.77
L11	Residential	LB11	2.9830	2.03	6.05	0.49
L12	Govt. & Inst.	LB12	11.7730	2.00	23.55	0.38
L13	Residential	LB13	11.7730	2.00	23.55	1.59
L14	Govt. & Inst.	LB14	11.7750	2.00	23.55	5.66
L15	Commercial	LB15	11.8030	2.00	23.61	0.92
L16	Residential	LB16	24.1560	1.57	37.99	1.61
L17	Residential	LB17	24.4260	2.00	48.85	1.04
						21.59

Table 5.12: system indices of automated and micro grid containing 33kv feeder 10 line

System indices	
SAIFI System Average Interruption Frequency Index	9.0924 f / customer.yr
SAIDI System Average Interruption Duration Index	19.4442hr / customer.yr
CAIDI Customer Average Interruption Duration Index	2.139hr / customer interruption
ASAI Average service Availability Index	0.9978pu
ASUI Average Service Unavailability Index	0.00222pu
EENS Expected Energy Not Supplied	21.392 MW hr / yr
AENS Average Energy Not Supplied	0.0133 MW hr / customer.yr

- ✓ From the figure above the pink color shows the voltage drop at branch point A-J is in acceptable range. Also the transformers at A, E and G shows pink color b/c it is upgraded so that not overloaded.

- ✓ Comparing with bench mark

SAIDI =19.4442, CAIDI=2.139, SAIFI =9.0924, and ASAI=99.78% shows it is a little improved by SAIDI = 77.25%, SAIFI=80.87% and EENS=77.17% from base case.

- ✓ Loss of Revenue due to Power Interruption(shading)

Cost of Energy = Power *time *tariff for electric

Cost of Energy = 0.6*1000*21.392 = 12,835.2 birr better save than before.

5.4 Cost benefit analysis of the study

A. For conductor replacement

- Replacing the conductor by 95mm² and upgrading the transformer

Conductor and transformer upgrading cost

- ✓ Total length = 91.7km , cost per meter=27.50(for 50mm²)
- ✓ Total cost = 91700*16.40=1,503,880 birr
- ✓ Total length = 91.7km , cost per meter=27.50(for 95mm²)
Total cost = 91700*27.50=2,521,750 birr
- ✓ 50kva transformer cost =182,885.92 birr
- ✓ 100kva transformer cost =228,806.20 birr
- ✓ 200kva transformer cost=305,476.92 birr
- ✓ Upgrading from 50kva to 100kva =45920.28
- ✓ Upgrading from 100kva to 200kva =76670.72

Total cost =2521.75+2*45920.28+76670.72 =2,690,261.28 birr

Revenue saved from minimizing the interruption =56,223.06 -12,835.2=43,387.86

Total revenue needed=2,690,261.28-1,503,880-43,387.86 =1,142,993.42 birr

B. For renewable distributed generation

- ✓ PV GENERATION

Table 5.13: Showing component price of 400kw PV power generation

No	Description	Quantity	Unit Price [Birr]	Total Price [Birr]
1	Module (250 Wp)	1600	22/wp	8,800,000
2	Cabling, Switch, Holder, Plug, Divider and PV panel support structure cost			10,000
3	400kw inverter	1	600,000	600,000
4	Direct cost of equipment			9,410,000
5	Installation cost (7%) of direct cost of the equipment			658,700
Total system cost				10,068,700

- ✓ WIND POWER GENERATION

Table 5.14: Showing component price of 100kw wind power generation

Component Description	QUANTITY	Component Unit Price [Birr]	Component Total Price [Birr]
Blades (three)	1	29, 740.11	29, 740.11
Hub	1	12, 894.31	12, 894.31
Pitch mechanisms and bearings	1	7, 098.8	7, 098.8

Main shaft	3	4, 117.86	12353.58
Main shaft bearing and block	3	2, 329.3	6987.9
Electrometric mounting system	3	540.73	1622.19
Generator isolation mount	3	180.24	540.72
Support structure	3	6, 807.64	20422.92
Generator cooling system	3	540.73	1622.19
Brake system hydraulics	3	1, 081.46	10190.67
Coupling	3	540.73	36020.88
Nacelle cover	3	3, 396.89	10731.39
Generator	3	12, 006.96	7528.62
Cable	3	3, 577.13	9691.53
Switch gear	3	2, 509.54	4284.24
Yaw derive and bearings	3	3, 230.51	110683.1
Control and safety system	3	1, 428.08	29033.01
Tower	3	36, 894.37	12353.58
Foundation	3	9, 677.67	6987.9
Total cost			415,945.59

THE TOTAL COST OF THE WIND GENERATOR EXCLUDING MAINTENANCE AND OPERATION COST WILL BE BIRR 415,945.59 BIRR

✓ Battery system

Table 5.15: Showing component price of Battery system

NO.	Component Description	Unit Price [Birr]	Total Price [Birr]
1	Lead Acid Deep Cycle Battery 4.762Ah of 300 pcs. totally 1428.6Ah	974.95	292,485

Total cost of RDG =10,068,700+415,945.59+292,485= 10,777,130.59 BIRR

CHAPTER SIX

RESULT AND DISCUSSION

6.1 Introduction

This thesis has illustrated serious reliability problem of Hawassa 33kv feeder 10 distribution line and recommended possible ways of solutions for the problems identified. These have been done through detail gathered and analyzed data obtained from the distribution substations. This thesis work has discussed reliability, design and operation and maintenance of Hawassa feeder 10 distribution lines.

6.2 Reliability and design practice for Hawassa distribution system

A study has been conducted thoroughly on the performance and design practice of the Hawassa feeder 10 distribution systems to identify causes for power interruptions.

The thesis work has been conducted with field observation and data collection. The collected data are a recorded data that includes peak load, type of faults, frequency and duration of interruption of single medium voltage (33kV) outgoing feeder of the distribution system.

It is found that over-loading, earth fault and short circuits are the major cause of interruptions in the distribution systems. It was found that some transformers are over loaded and not yet protected from the faults. Most of the interruptions reside from the transformer and related accessories like HRC fuses, oil and drop out fuse. Therefore, it is recommended to upgrade overloaded transformers and to install di-connectors at branching point and drop out fuse near to the distribution transformers.

The other most frequent cause of outage is earth fault that arises due to trees and structures in touch with hot lines of 33kV line (i.e. Clearance problem) which is called transient earth fault.

It has been identified that Hawassa feeder 10 distribution line is constructed with 50mm² AAC conductor which has unacceptable voltage drop 9.99%, this has to be corrected by re-conductoring the line with new 95mm² AAC conductor to improve the voltage drop to 4.99%. Also the calculated short circuit withstanding capacity of 50mm² conductor is 7.42KA which is below the rate of the short circuit fault that can exist in the secondary circuit equal to 14.009KA; replacing the line with 95mm² conductor having 14.106KA short circuit capacity is better.

From the analysis, it is observed that majority (80.3%) of the faults in Hawassa feeder 10 distribution network is due to short circuit, earth fault and over load, 15.52% is due to load shading (b/c of generation failure or blackout, operation and system overload when generated power is below demand) and the remaining 4.18% is due to line and distribution transformer overload.

The thesis work discusses the performance, design, reliability of Hawassa distribution system thoroughly to identify causes for power interruptions and customer dissatisfaction. In this thesis work a detailed analysis on the performance and design practice of distribution system have been carried out.

It is also observed that load loss of the feeder line with 50mm² AAC conductors is real 60.04kw and reactive 11.39kw, if it is 95mm² conductors the loss will be real 30.2kw and reactive would be 10kw which is better than the actual. This is only copper loss of the feeder at full load, excluding no load loss and distribution transformer copper and core loss.

6.3 Reliability indices analysis for Hawassa feeder 10 distribution network

The frequency of interruption and duration for Hawassa feeder 10 distribution networks for 12Months are analyzed and interpreted. Based the analyzed and interpreted frequency and duration of interruption a distribution reliability indices (SAIFI, SAIDI, CAIDI, and ASAI) calculation and analysis have been discussed thoroughly. The analyzed and calculated distribution reliability indices values have been compared with standard benchmark values.

From the calculation and analysis considered in reliability evaluation of Hawassa feeder 10 distribution network has an average value of. SAIDI=5129.022 min./cust., SAIFI=47.52interruptions/customer, CAIDI=107.94min./cust., ASAI=99.02 % and EENS=93.706mwh/yr Whereas the corresponding values in a USA standard are 240 minutes, 1.5 interruptions/customer, 123 minutes and 99.91% respectively.

A lower number for SAIFI, SAIDI and CAIDI indicates better reliability performance; i.e., a lower frequency of outages or shorter outage duration. A higher number indicates worse performance. Comparing the average SAIDI, SAIFI and CAIDI value of feeder 10 of Hawassa distribution with the benchmarks is high this shows that feeder 10 has worse performance. A higher percentage (approaching to 100%) for ASAI indicates better reliability performance; i.e., a typical customer expects to have power at all times. A lower percentage indicates worse performance. Comparing the average ASAI value of feeder 10 of Hawassa distribution with the benchmarks is low this shows that feeder 10 has worse performance. And also unavailability of energy per year 93.706 Mwh shows worse performance.

6.4 Reliability Improvement Strategies for Hawassa feeder 10 Distribution System

Reliability improvement for the feeder line has been classified in to three separate strategies

DESIGN ISSUE

In this section we will see the base case components capacity and their withstanding in case of high current, long distance travelling and over load as it is discussed before.

- ✓ As it is seen the average distance of the study feeder line travels 91.7km so that replacing the existing 50mm² AAC conductor by 95mm² AAC conductor is mandatory because of high voltage drop and high power loss also the higher conductor size the better to withstand short circuit fault and earth fault easily.
- ✓ Three existing distribution transformers are up graded to higher capacity in order to fulfill load demand

protection device and preventive maintenance system

Using this strategy for reducing frequency and duration of interruptions: by following two possible simplifying ways

1. Reduction of the number of faults

By tree trimming, Preventive maintenance, monitoring critical components, preventive replacement and protection against animal will decrease failure rate and number of interruption which intern decrease reliability indices.

2. Reduction of Time of Interruption

By Distribution network automation, System reconfiguration after the fault and Fault current detection in order to localize the fault in the network

Analyzing the reliability of Hawassa 33kv feeder 10 line by automated system using dropout fuse, isolators in distribution network shows reliability evaluation of Hawassa feeder 10 distribution network has an average value of. SAIDI=2762.784 min/cust. SAIFI=22.1837 inter./cust., CAIDI=124.56min./cust., ASAI=99.47 % and EENS=51.212mwh/yr that is comparing with base case reliability indices are improved by SAIDI = 46.13%,SAIFI=53.32% and EENS=45.35% of distribution system reliability measuring indices has been improved.

ADEQUACY ISSUE

In this thesis a combined 500kw power is generated using renewable distributed generation in high load density location that is around Arbegona town in the study to satisfy the customers power demand in case of both connecting with the utility grid and stand alone when there is power shading from utility. So that generation 400kw with PV generator accompanied with 1470AH battery system as back up and 100kw with wind generator, and analyzing reliability evaluation of feeder 10 distribution line containing renewable power generator has an average value of. SAIDI=1166.652 min/cust, SAIFI = 9.0924 interruptions/customer, CAIDI=128.34 min./cust., ASAI=99.78 % and EENS=21.392mwh/yr that is comparing with base case reliability indices are improved by SAIDI = 77.25%, SAIFI=80.87% and EENS=77.17% of distribution system reliability measuring indices has been improved.

CHAPTER SEVEN

CONCLUSSION, RECOMMENDATIONS AND FUTURE SCOPE

7.1 Conclusion

The aim of this thesis is to identify causes of interruptions and suggest possible solutions to the Hawassa feeder 10 distribution network. Furthermore in this thesis work a study and evaluation of the reliability and design of Hawassa feeder 10 power distribution systems is conducted. The collected data for study distribution network was analyzed in detail to evaluate the reliability of the design, operation, and reliability of Hawassa feeder 10 distributions.

From the substations fault record, it is concluded that most of the failures in the distribution system are due to short circuits, earth fault, over load, operation and system over load (i.e. when generated power is below the total demand other than blackout. The Hawassa feeder 10 reliability indices (SAIDI, SAIFI, CAIDI and ASAI) for eleven months (November 2015 to January 2015) have been calculated, analyzed and results have been presented in this thesis. The calculated results for SAIDI, SAIFI, CAIDI and ASAI are compared with benchmarks which verified Hawassa feeder 10 distribution grid is noncompliance with standards.

Furthermore, three potential solutions for the improvement of the reliability of the distribution system have been considered. The proposed solutions are design solution, Security (operation) and adequacy solution for reliability improvement strategy to Hawassa feeder 10 distribution network and have been further discussed in detail. The result shows improvement of the reliability of Hawassa feeder 10 distribution line by the proposed strategies.

7.2 Recommendation

Based on this thesis work the following recommendations are drawn

- ❖ The corporation has to better focus on improving the customer's satisfaction by installing equipment based on their ratings.
- ❖ It is strongly recommend that EEU has to use proper rated HRC fuses to protect the transformers from overload-damage and to improve the maintenance operation
- ❖ The corporation has little experience in documentation of performance data for the distribution feeders especially for secondary distribution network. It is therefore, strongly recommended that the corporation should improve data documentation, so that the reliability problems can be identified easily and solutions can be suggested as well.

- ❖ It is also important to give due attention for preventive maintenance to improve random power interruption, sustainability of equipment and to deliver reliable power to the customers.
- ❖ The case studies and analysis presented in this work is expected to contribute towards enhancing the reliability and resilience of the power grid. The investigation is very useful for distribution network planning as it quantifies the improvement in reliability indices by installing solar DG sizes and indeed recommending a large DG installation at various distances from the substation to remote load points.

7.3 Future work

- ❖ Since the location and the size of the RDG's can affect the reliability of the power systems, finding the optimal size and location of the DG's that will have the greatest reliability improvement can be investigated in future work. Common optimization techniques that consider some constraints such as the range of DG size and the boundary of the DG location in the distribution network can be used for this purpose.
- ❖ Taking into account various assumptions made in the analysis and the practical losses which may occur it is proposed that a practical system may be installed within the Hawassa feeder 10 distribution networks. The results obtained with the system should be verified with those from the simulation. The above work should be applied using other non-renewable energy sources available within Ethiopia.
- ❖ As research done on the Hawassa feeder 10 distribution systems is limited, it is important to make subsequent detailed studies to solve the distribution problems:
 - ✓ on design aspect of the distribution system
 - ✓ technical and none technical losses
 - ✓ maintenance optimization for the distribution Systems
 - ✓ reliability study of the distribution system
 - ✓ distribution automation separately by different researchers

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APPENDIX

Table: Hawassa substation distribution feeders' total interruption data in 2015G.C

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																		Frequency of Interruption (No.)	Duration of Interruption (Hr.)		
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL		PTOL				OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]
1	Hawassa	1 (15)	9.00	10.94	63.00	56.86	17.00	0.48	108.00	6.05	38.90	61.40	74.00	147.47	0.00	0.00	3.00	24.81	25.00	25.37	70.00	70.86	412.00	404.27
2	Hawassa	2 (15)	0.00	0.00	2.00	1.30	1.00	0.03	16.00	0.57	16.00	6.79	36.00	25.28	0.00	0.00	0.00	0.00	4.00	15.06	3.00	13.02	79.00	62.01
3	Hawassa	3 (15)	0.00	0.00	7.00	16.16	0.00	0.00	11.00	0.47	19.00	14.85	39.00	35.06	0.00	0.00	0.00	0.00	12.00	28.73	7.00	12.14	95.00	118.41
4	Hawassa	4 (15)	8.00	16.01	66.00	131.32	7.00	0.18	89.00	6.27	41.00	62.60	67.00	139.76	0.00	0.00	4.00	19.16	26.00	47.40	74.00	72.18	382.00	494.08
5	Hawassa	5 (15)	16.00	9.74	66.00	88.20	13.00	0.76	123.00	5.82	43.00	88.43	71.00	125.28	0.00	0.00	0.00	0.00	27.00	43.50	79.00	64.28	438.00	426.01
6	Hawassa	6 (15)	7.00	5.56	80.00	108.47	4.00	0.10	135.00	3.91	51.00	66.03	63.00	120.06	0.00	0.00	2.00	6.16	15.00	26.49	51.00	55.45	408.00	392.23
7	Hawassa	7 (15)	4.00	4.29	9.00	27.36	2.00	0.09	20.00	3.04	29.00	52.49	58.00	116.79	0.00	0.00	0.00	0.00	3.00	3.18	14.00	28.90	141.00	136.14
8	Hawassa	8 (15)	5.00	4.16	25.00	67.29	0.00	0.00	33.00	7.96	71.00	136.62	74.00	190.94	0.00	0.00	2.00	21.90	16.00	36.64	24.00	45.23	250.00	510.83
9	Hawassa	9 (33)	1.00	0.73	3.00	2.48	0.00	0.00	17.00	4.25	67.00	137.46	67.00	123.33	0.00	0.00	4.00	40.38	2.00	11.80	21.00	68.09	182.00	388.49
10	Hawassa	10 (33)	10.00	45.87	132.00	465.00	11.00	0.32	116.00	3.86	45.00	61.66	52.00	104.01	0.00	0.00	2.00	19.82	12.00	33.32	40.00	75.38	420.00	809.23
11	Hawassa	11 (33)	1.00	0.73	6.00	10.20	0.00	0.00	20.00	0.89	20.00	3.72	38.00	31.80	0.00	0.00	0.00	0.00	1.00	0.87	16.00	15.62	102.00	63.42
12	Hawassa	12 (15)	5.00	10.87	79.00	180.28	4.00	0.06	68.00	8.53	54.00	111.84	63.00	122.54	0.00	0.00	4.00	21.65	16.00	19.20	79.00	123.33	372.00	597.80
Sum			66.00	107.89	638.00	1154.99	59.00	2.03	795.00	91.32	494.00	804.07	702.00	1281.79	0.00	0.00	26.00	163.88	163.00	302.56	478.00	644.37	3281.00	4502.92

Table: Hawassa substation distribution feeders' interruption data in 2015G.C by month
December. up to Nov. 2015

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																		Frequency of Interruption (No.)	Duration of Interruption (Hr.)			
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL		PTOL				OP		
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	
1	Hawassa	1 (15 kv)	1	0.008	3	7.5526			6	0.4341									1	0.002	4	0.5291	15	8.53684	
2	Hawassa	2 (15 kv)					1	0.033	1	0.216													2	0.24896	
3	Hawassa	3 (15 kv)				1	0.0066			0.033													1	0.0396	
4	Hawassa	4 (15 kv)				6	26.567			6	2.4166											5	2.923	17	31.9041
5	Hawassa	5 (15 kv)	1	0.1	3	17.066	1	0.0348	9	2.1874								1	2.4836	3	2.7347	18	24.5767		
6	Hawassa	6 (15 kv)				4	14.441	1	0.033	4	0.0355							2	2.4826	3	1.8658	14	18.858		
7	Hawassa	7 (15 kv)				2	5.1046															2	5.1046		
8	Hawassa	8 (15 kv)	3	3.4193	1	4.5666												2	3.6322			6	11.6191		
9	Hawassa	9 (33 kv)																					0	0	
10	Hawassa	10 (33 kv)																					0	0	
11	Hawassa	11 (33 kv)																			1	0.816	1	0.816	
12	Hawassa	12 (15 kv)				7	12.519			1	0.0012							1	1.0035	1	0.015	10	12.5383		
Sum			5	3.5273	27	91.824	3	0.1008	27	5.2917	0	0	0	0	0	0	0	0	7	9.6048	17	8.8936	86	119.242	

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																		Frequency of Interruption (No.)	Duration of Interruption (Hr.)		
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL		PTOL				OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]
1	Hawassa	1 (15 kv)				3	2.8			4	0.2							6	1.6	4	12	17	16.599	
2	Hawassa	2 (15 kv)				1	0.7			3	0.1									1	9.9	5	10.615	
3	Hawassa	3 (15 kv)				1	0.5			1	0									2	8.3	4	8.809	
4	Hawassa	4 (15 kv)	1	3.8	4	16			2	0.4								2	3.8	5	6.2	14	29.9616	
5	Hawassa	5 (15 kv)				1	0.8			5	0.3							2	3.7	2	1.3	10	6.0426	
6	Hawassa	6 (15 kv)	1	1.3	2	0.6			5	0.2								1	0.7	2	0.9	11	3.706	
7	Hawassa	7 (15 kv)																1	0.5			1	0.47	
8	Hawassa	8 (15 kv)				1	0.6											2	4.2	1	8.1	4	12.93	
9	Hawassa	9 (33 kv)																				0	0	
10	Hawassa	10 (33 kv)	1	0.6	3	5.3	1	0	2	0.1								4	17	1	6.8	12	30.149	
11	Hawassa	11 (33 kv)																			1	6.1	1	6.08
12	Hawassa	12 (15 kv)				3	8.9			1	0							1	2.8	6	4	11	15.74	
Sum			3	5.6	19	36	1	0	23	1.4	0	0	0	0	0	0	0	0	19	35	25	63	90	141.1022

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																		Frequency of Interruption (No.)	Duration of Interruption (Hr.)	Remark		
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL		PTOL					OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]				F	D [Hr.]
1	Hawassa	1 (15 kv)				11	7.7	1	0	11	0.6							7	4.6			30	12.756		
2	Hawassa	2 (15 kv)								4	0.1							2	7.1			6	7.16		
3	Hawassa	3 (15 kv)																5	19			5	19.39		
4	Hawassa	4 (15 kv)				3	15			3	0.1							10	18			16	33.38		
5	Hawassa	5 (15 kv)	3	1.8	8	22	1	0	11	0.4								10	18			33	41.9266667		
6	Hawassa	6 (15 kv)				8	8.6			14	0.4							4	8.1			26	17.1133333		
7	Hawassa	7 (15 kv)								1	0							1	0.9			2	0.9		
8	Hawassa	8 (15 kv)				6	21			4	0.1							4	11			14	32.37		
9	Hawassa	9 (33 kv)																				0	0		
10	Hawassa	10 (33 kv)	1	2.4	14	49	2	0.1	8	0.3								4	8			29	60.0466667		
11	Hawassa	11 (33 kv)																				0	0		
12	Hawassa	12 (15 kv)				8	15	1	0	5	0.6							5	4.1			19	19.6826667		
Sum			4	4.3	58	138	5	0.2	61	2.6	0	0	0	0	0	0	0	0	52	99	0	0	180	244.725333	

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)						
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP				DLLOL		PTOL		OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Hawassa	1 (15 kv)			11	7.7	1	0	11	0.5									7	4.6	3	6.4	33	19.19266667
2	Hawassa	2 (15 kv)							4	0.1									2	7.1			6	7.16
3	Hawassa	3 (15 kv)																	5	19			5	19.39
4	Hawassa	4 (15 kv)			3	15			3	0.1									10	18	9	14	25	47.2
5	Hawassa	5 (15 kv)	3	1.8	8	22	1	0	11	0.4									10	18	8	27	41	68.80666667
6	Hawassa	6 (15 kv)			8	8.6			14	0.4									4	8.1	8	14	34	31.25333333
7	Hawassa	7 (15 kv)							1	0									1	0.9	1	1.5	3	2.43
8	Hawassa	8 (15 kv)			6	21			4	0.1									4	11	1	3	15	35.336
9	Hawassa	9 (33 kv)																					0	0
10	Hawassa	10 (33 kv)	1	2.4	14	49	2	0.1	8	0.3									4	8	5	5.1	34	65.16166667
11	Hawassa	11 (33 kv)																	1	0.9			1	0.866
12	Hawassa	12 (15 kv)			8	15	1	0	5	0.6									5	4.1	10	8.8	29	28.43266667
Sum			4	4.3	58	138	5	0.2	61	2.6	0	0	0	0	0	0	0	0	53	100	45	80	226	325.229

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)						
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP				DLLOL		PTOL		OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Hawassa	1 (15 kv)	1	1.65	5	2.08	2	0.05	17	0.63	3	1.27	8	26.3	0	0	4	12.4	3	7.78	7	2.2	51	54.3957
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	3	1.27	0	0	0	0	0	0	2	0.95	0	0	5	2.2167
3	Hawassa	3 (15 kv)	0	0	1	0.13	0	0	4	0.08	3	1.27	1	0.88	0	0	0	0	2	0.95	0	0	11	3.3166
4	Hawassa	4 (15 kv)	0	0	3	4.25	0	0	6	0.2	3	1.27	6	32.8	0	0	2	9.58	3	4.03	6	8.83	29	58.9334
5	Hawassa	5 (15 kv)	4	2.73	7	2.61	2	0.06	20	0.48	3	1.27	11	27	0	0	0	0	3	1.12	9	1.27	59	36.5742
6	Hawassa	6 (15 kv)	0	0	6	4.73	0	0	13	0.45	3	1.27	8	37.8	0	0	1	3.08	3	4.03	1	0.5	38	51.8351
7	Hawassa	7 (15 kv)	3	1.65	1	0.27	0	0	2	0.05	3	1.27	8	24.1	0	0	0	0	2	0.95	1	0.9	19	29.1493
8	Hawassa	8 (15 kv)	0	0	4	7.98	0	0	3	0.05	3	1.27	10	60	0	0	1	11	3	3.98	0	0	24	84.26
9	Hawassa	9 (33 kv)	0	0	0	0	0	0	1	0.02	3	1.27	7	32.4	0	0	2	20.2	1	5.9	0	0	14	59.7567
10	Hawassa	10 (33 kv)	0	0	7	14.2	0	0	4	0.09	3	1.27	5	31.8	0	0	1	9.91	0	0	0	0	20	57.2861
11	Hawassa	11 (33 kv)	0	0	0	0	0	0	0	0	3	1.27	0	0	0	0	0	0	0	0	0	0	3	1.2667
12	Hawassa	12 (15 kv)	1	2.25	2	22.9	0	0	3	0.12	3	1.27	9	29.2	0	0	2	10.8	3	4.03	7	27.5	30	98.0327
Sum			8	8.28	37	59.2	4	0.11	73	2.16	36	15.2	73	302	0	0	13	76.9	25	33.7	31	39.2	300	537.023

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)						
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP				DLLOL		PTOL		OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Hawassa	1 (15 kv)	0	0	3	1.863	0	0	10	0.187	6	2.216	4	13.28	0	0	0	0	0	0	1	0.08	24	17.6465
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	5	2.063	0	0	0	0	0	0	0	0	0	0	5	2.0633
3	Hawassa	3 (15 kv)	0	0	0	0	0	0	2	0.12	8	2.063	1	2.91	0	0	0	0	0	0	0	0	8	5.1133
4	Hawassa	4 (15 kv)	0	0	2	3.1	0	0	10	1.12	7	5.743	6	16.77	0	0	0	0	0	0	4	2.29	29	29.0267
5	Hawassa	5 (15 kv)	0	0	2	0.167	1	0.02	9	0.217	7	5.963	7	10.2	0	0	0	0	0	0	0	0	26	16.6734
6	Hawassa	6 (15 kv)	0	0	1	1.58	0	0	7	1.133	6	5.343	6	14.17	0	0	0	0	0	0	2	0.46	22	21.8632
7	Hawassa	7 (15 kv)	0	0	2	19.47	0	0	1	2.41	6	8.293	3	18.34	0	0	0	0	0	0	0	0	12	44.5166
8	Hawassa	8 (15 kv)	0	0	0	0	0	0	3	5.74	9	8.483	4	14.22	0	0	0	0	0	0	1	0.8	17	29.2099
9	Hawassa	9 (33 kv)	0	0	0	0	0	0	2	3.67	8	13.37	6	21.72	0	0	0	0	0	0	0	0	16	38.76
10	Hawassa	10 (33 kv)	0	0	6	23.49	0	0	9	0.32	6	2.333	3	21.18	0	0	0	0	0	0	6	8.86	30	56.9434
11	Hawassa	11 (33 kv)	0	0	0	0	0	0	0	0	8	2.063	0	0	0	0	0	0	0	0	0	0	5	2.0633
12	Hawassa	12 (15 kv)	0	0	7	22.82	0	0	9	6.02	7	9.493	7	29.28	0	0	0	0	0	0	5	5.91	36	73.4899
Sum			0	0	23	66.47	1	0.02	82	19.84	77	67.36	47	162.1	0	0	0	0	0	0	19	18.4	229	336.32

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)						
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP				DLLOL		PTOL		OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Hawassa	1 (15 kv)	2	2.43	4	4.2166	2	0.0467	12	0.5333	0	0	11	32.707	0	0	4	12.406	1	6.83	9	3.1787	45	82.348
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Hawassa	3 (15 kv)	0	0	1	0.1333	0	0	1	0.0333	0	0	0	0	0	0	0	0	0	0	0	0	2	0.1666
4	Hawassa	4 (15 kv)	0	0	1	3.8	0	0	7	0.23	1	2.38	10	32.933	0	0	2	9.58	1	3.08	6	6.59	28	58.493
5	Hawassa	5 (15 kv)	2	1.016	4	0.696	2	0.0633	11	0.2502	2	3.21	4	11.433	0	0	0	0	1	0.186	9	1.5163	35	18.3511
6	Hawassa	6 (15 kv)	0	0	3	0.996	0	0	12	0.3659	1	0.51	4	21.4	0	0	1	3.08	1	3.08	0	0	22	29.4319
7	Hawassa	7 (15 kv)	0	0	0	0	0	0	2	0.0493	0	0	4	17.633	0	0	0	0	0	0	0	0	6	17.6826
8	Hawassa	8 (15 kv)	0	0	4	7.98	0	0	3	0.0601	1	2.56	4	23.217	0	0	1	10.95	1	3.03	0	0	14	47.9867
9	Hawassa	9 (33 kv)	0	0	0	0	0	0	0	0	2	3.43	2	8.7	0	0	2	20.19	1	5.9	0	0	7	38.22
10	Hawassa	10 (33 kv)	0	0	7	5.1067	0	0	4	0.086	0	0	2	5.6467	0	0	1	9.91	0	0	0	0	14	28.7494
11	Hawassa	11 (33 kv)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	Hawassa	12 (15 kv)	1	3.35	0	0	0	0	2	0.0633	1	0.85	4	9.9167	0	0	2	10.826	1	3.08	6	26.627	17	53.6327
Sum			5	5.696	24	25.929	4	0.11	54	1.6814	8	12.84	45	167.69	0	0	13	76.942	7	25.166	30	37.91	190	354.96

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption														Frequency of Interruption (No.)	Duration of Interruption (Hr.)						
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP				DLLOL		PTOL		OP	
			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]	F	D [Hr.]			F	D [Hr.]	F	D [Hr.]	F	D [Hr.]
1	Hawassa	1 (15 kv)	2	4.16	0	0	1	0.06	2	0.06	3	7.5	10	43.617	0	0	0	0	2	1.56	0	0	20	67.157
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	2	0.03	1	1	3	6.44	0	0	0	0	0	0	0	0	6	7.47
3	Hawassa	3 (15 kv)	0	0	1	2.33	0	0	1	0.05	1	1	4	12.44	0	0	0	0	0	1	0.13	8	15.36	
4	Hawassa	4 (15 kv)	1	0.35	6	3.37	0	0	9	0.2	4	8.94	7	28.42	0	0	0	0	0	3	1.7047	30	40.8967	
5	Hawassa	5 (15 kv)	0	0	5	8.63	0	0	3	0.11	5	7.31	8	38.363	0	0	0	0	0	7	2.18	28	55.5333	
6	Hawassa	6 (15 kv)	0	0	7	3.83	0	0	6	0.19	7	11.93	8	18.433	0	0	0	0	0	2	2.01	30	36.3933	
7	Hawassa	7 (15 kv)	0	0	0	0	0	0	0	0	2	9.41	7	29.947	0	0	0	0	0</					

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																Frequency of Interruption (No.)	Duration of Interruption				
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL				PTOL		OP	
			F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D			F	D	F	D
1	Hawassa	1 (15 kv)	1	0.7	5	3.2	2	0	8	0.3	2	6.7	9	7.2	0	0	0	0	0	0	8	9.3	35	27.93
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	1	0.4	9	7.2	0	0	0	0	0	0	0	0	10	7.56
3	Hawassa	3 (15 kv)	0	0	1	8	0	0	1	0.1	0	0	9	7.2	0	0	0	0	0	0	0	0	11	15.24
4	Hawassa	4 (15 kv)	2	1.6	11	21	2	0	9	0.1	1	1.7	9	7.2	0	0	0	0	0	0	12	12	46	43.42
5	Hawassa	5 (15 kv)	0	0	4	0.9	3	0.5	11	0.2	2	18	12	18	0	0	0	0	0	0	15	9.5	47	47
6	Hawassa	6 (15 kv)	4	2.8	19	39	0	0	23	0.4	4	4.3	10	9.5	0	0	0	0	0	0	7	6.2	67	61.957
7	Hawassa	7 (15 kv)	2	2.6	0	0	0	0	0	0	2	3.1	9	7.2	0	0	0	0	0	0	4	8.4	17	21.23
8	Hawassa	8 (15 kv)	0	0	0	0	0	0	1	0	10	24	11	15	0	0	0	0	0	0	4	6.5	26	45.35
9	Hawassa	9 (33 kv)	0	0	0	0	0	0	1	0	11	27	11	15	0	0	0	0	0	0	3	25	26	66.227
10	Hawassa	10 (33 kv)	2	7.4	17	89	2	0	10	0.2	8	14	10	11	0	0	0	0	0	0	5	9.8	54	131.2
11	Hawassa	11 (33 kv)	0	0	0	0	0	0	0	0	2	0.1	9	7.2	0	0	0	0	0	0	2	0.9	13	8.2167
12	Hawassa	12 (15 kv)	1	5.1	3	2.1	1	0	3	0.1	9	35	7	11	0	0	0	0	0	0	13	18	37	71.333
Sum			12	20	60	163	10	0.5	67	1.4	52	136	115	121	0	0	0	0	0	0	73	105	389	546.03

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																Frequency of Interruption (No.)	Duration of Interruption				
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL				PTOL		OP	
			F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D			F	D	F	D
1	Hawassa	1 (15 kv)	1	0.86	8	2.37	6	0.25	14	0.27	17	37.57	17	9.48	0	0	0	0	0	0	16	20.97	79	71.77
2	Hawassa	2 (15 kv)	0	0	1	0.63	0	0	1	0.01	0	0	17	9.48	0	0	0	0	0	0	1	0.3	20	10.32
3	Hawassa	3 (15 kv)	0	0	0	0	0	0	1	0.08	5	10.32	17	9.48	0	0	0	0	0	0	1	0.35	24	20.23
4	Hawassa	4 (15 kv)	0	0	10	10.78	0	0	19	0.52	16	37.68	17	9.48	0	0	0	0	0	0	8	8.37	70	66.77
5	Hawassa	5 (15 kv)	2	1.57	10	7.48	1	0.05	18	0.35	14	40.63	17	9.48	0	0	0	0	0	0	10	5.05	72	64.61
6	Hawassa	6 (15 kv)	0	0	13	14.11	0	0	16	0.33	14	31.22	17	9.48	0	0	0	0	0	0	12	10.07	72	68.21
7	Hawassa	7 (15 kv)	0	0	1	0.71	0	0	2	0.06	3	19.92	17	9.48	0	0	0	0	0	0	3	5.72	26	35.88
8	Hawassa	8 (15 kv)	0	0	2	3.31	0	0	2	1.31	17	55.65	17	9.48	0	0	0	0	0	0	4	5.93	42	78.68
9	Hawassa	9 (33 kv)	0	0	1	0.6	0	0	0	0	17	55.48	19	13.89	0	0	0	0	0	0	3	7.33	40	77.17
10	Hawassa	10 (33 kv)	0	0	26	118.3	2	0.02	27	0.89	9	25.12	17	9.48	0	0	0	0	0	0	8	5.72	89	189.25
11	Hawassa	11 (33 kv)	0	0	1	0.6	0	0	0	0	0	0	17	9.48	0	0	0	0	0	0	0	0	18	9.98
12	Hawassa	12 (15 kv)	1	0.76	8	31.97	1	0.01	12	0.3	18	42.42	17	9.48	0	0	0	0	0	0	6	6.11	63	91.05
Sum			4	3.19	81	190.7	10	0.33	112	3.82	130	356	206	118.2	0	0	0	0	0	0	72	75.82	615	747.93

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																Frequency of Interruption (No.)	Duration of Interruption				
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL				PTOL		OP	
			F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D			F	D	F	D
1	Hawassa	1 (15 kv)	1	1.17	3	8.23	2	0.02	1	0.03	1	2.95	3	1.03	0	0	0	0	0	0	12	9.62	23	21.05
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	0	0	3	1.03	0	0	0	0	0	0	0	0	3	1.03
3	Hawassa	3 (15 kv)	0	0	1	5.03	0	0	0	0	0	0	3	1.03	0	0	0	0	0	0	3	3.37	7	9.43
4	Hawassa	4 (15 kv)	2	6.72	11	7.15	5	0.14	4	0.45	3	2.44	4	5.81	0	0	0	0	0	0	9	7.11	28	29.82
5	Hawassa	5 (15 kv)	1	0.68	8	4.54	1	0.03	7	0.41	3	5.49	5	8.81	0	0	0	0	0	0	10	5.86	26	29.52
6	Hawassa	6 (15 kv)	2	1.56	5	4.58	2	0.06	11	0.43	3	5.19	4	5.81	0	0	0	0	0	0	6	9.39	33	27.02
7	Hawassa	7 (15 kv)	0	0	2	1.64	2	0.09	4	0.15	6	8.78	4	5.81	0	0	0	0	0	0	1	2.96	18	19.43
8	Hawassa	8 (15 kv)	1	0.73	0	0	0	0	5	0.33	9	15.75	5	8.81	0	0	0	0	0	0	7	12.28	27	37.84
9	Hawassa	9 (33 kv)	1	0.73	1	1.7	0	0	7	0.29	8	18.28	5	8.81	0	0	0	0	0	0	10	31.89	32	51.7
10	Hawassa	10 (33 kv)	1	0.73	19	81.13	1	0.01	21	0.87	1	5.84	4	2.38	0	0	0	0	0	0	8	29.69	55	100.63
11	Hawassa	11 (33 kv)	1	0.73	1	2.85	0	0	7	0.29	0	0	4	5.81	0	0	0	0	0	0	2	0.92	15	10.6
12	Hawassa	12 (15 kv)	0	0	18	23.8	0	0	11	0.27	9	17	5	8.81	0	0	0	0	0	0	16	22.78	57	72.88
Sum			10	13.05	67	118.7	13	0.35	78	3.42	42	81.76	49	63.93	0	0	0	0	0	0	84	125.4	343	406.73

Item No.	Substation Name	Feeder Name	Frequency and Duration of Interruption																Frequency of Interruption (No.)	Duration of Interruption				
			DPEF		DPSC		DTEF		DTSC		TLP		SOL		GUP		DLLOL				PTOL		OP	
			F	D	F	D	F	D	F	D	F	D	F	D	F	D	F	D			F	D	F	D
1	Hawassa	1 (15 kv)	0	0	6	11.2	0	0	12	2.44	6	3.19	13	12.67	0	0	0	0	0	0	4	6.03	40	36.63
2	Hawassa	2 (15 kv)	0	0	0	0	0	0	0	0	8	2.04	4	1.15	0	0	0	0	0	0	1	2.96	11	6.16
3	Hawassa	3 (15 kv)	0	0	0	0	0	0	0	0	8	0.18	4	1.15	0	0	0	0	0	0	0	0	9	1.33
4	Hawassa	4 (15 kv)	2	2.62	6	5.49	0	0	11	0.36	6	4.78	8	6.4	0	0	0	0	0	0	7	4.63	40	24.28
5	Hawassa	5 (15 kv)	0	0	6	4.06	0	0	8	0.43	7	6.14	7	2.4	0	0	0	0	0	0	6	7.35	24	20.4
6	Hawassa	6 (15 kv)	0	0	4	7.53	1	0.01	10	0.82	13	6.39	6	3.69	0	0	0	0	0	0	8	9.93	42	27.77
7	Hawassa	7 (15 kv)	0	0	1	0.17	0	0	7	0.28	8	5.75	6	4.33	0	0	0	0	0	0	4	8.43	26	18.96
8	Hawassa	8 (15 kv)	0	0	1	0.26	0	0	8	0.31	14	16.14	14	14.64	0	0	0	0	0	0	6	8.61	43	38.96
9	Hawassa	9 (33 kv)	0	0	1	0.25	0	0	6	0.24	13	6.47	11	9.9	0	0	0	0	0	0	5	14.38	26	30.81
10	Hawassa	10 (33 kv)	1	4.53	9	23.6	1	0.01	19	0.84	17	10.27	4	1.15	0	0	0	0	0	0	6	5.26	57	48.60
11	Hawassa	11 (33 kv)	0	0	4	6.85	0	0	13	0.3	10	0.25	4	1.15	0	0	0	0	0	0	7	4.83	38	13.38
12	Hawassa	12 (15 kv)	1	0.66	16	24.3	0	0	14	0.46	6	3.36	8	6	0	0	0	0	0	0	8	3.66	63	38.33
Sum			4	7.71	54	83.72	2	0.02	108	6.18	111	63.76	86	86.03	0	0	0	0	0	0	62	80.04	429	306.46