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**POSTGRADUATE PROGRAM IN POWER SYSTEM AND ENERGY
ENGINEERING**

**STUDY THE IMPACT OF DISTRIBUTED GENERATION ON THE
RELIABILITY OF LOCAL DISTRIBUTION SYSTEM**

(Case study: Motta Distribution Substation)

BY

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HAWASSA, ETHIOPIA

July 28, 2020

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A Thesis Submitted to the School of Research and Graduate Studies of Hawassa University, Faculty of Electrical Engineering , Institute of Technology in Partial Fulfillment of the Requirements for the Degree of MASTERS in Power Systems and Energy Engineering in the School of Electrical and Computer Engineering.

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ABSTRACT

Electric distribution system power quality is a rising concern. Customers require higher quality service due to more sensitive electrical and electronic equipment's, and 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. The present Motta distribution substation has encountered frequent power interruptions and power quality problems. The interruptions are caused mainly by Permanent Short circuit (PSC), Transient Earth fault (TEF). There are also planned outages for operation and maintenance purpose. The substation's System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are 806 and 1,394.145, respectively. The substation is not reliable by the standard of Ethiopian Electric Agency (EEA) which set (SAIFI =20 and SAIDI= 25). This reliability gap calls for searching of effective methods for improving the reliability of the distribution system. This thesis presents impact of DG on reliability assessment at Motta distribution substation of 230/33 transformer two 33 kV radial outgoing feeders distribution and the base case reliability analysis using Monte Carlo and analytical enumeration system and has high loss of money that is 0.438 M\$/a and 0.444 M\$/a respectively for utility but Monte Carlo analysis is better than that of Analytical Enumeration. The improved reliable power distribution is due to the use of proper size and site of DG at the low voltage profile value bus of the distribution system by using probabilistic Monte Carlo simulation of reliability analysis and that of Enumeration analysis of the system using DIgSILENT power factory software. The NPC of DG is 20,831,473.21\$ which optimized using HOMER software at the required size and the reliability of the distribution system is improved after the use of DG that is reducing SAIFI, CAIFI by 97.8%, and SAIDI by 76%, increasing ASAI by 14.38% and reducing ASUI by 76% and reducing the total power loss to 0.32 MW. The cost analysis is done on this thesis by using the Monte Carlo reliability analysis output and the DG total net present cost (TNPC) so the payback period is less than five years that is 4.28 years which means that the project is profitable.

Keywords: - Power System Reliability, Distributed Generation, cost comparison.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	Meaning
I_l^{\max}	Maximum current capability of feeder l
V_k^{\max}	Maximum voltage at bus k
V_k^{\min}	Minimum voltage at bus k
I_l	Current flow in feeder l
P_k	Active power at bus k
Q_k	Reactive power at bus k
θ_{ik}	Angle of θ_{ik}
AC	Alternating Current
ACCI	Average Customer Curtailment Index
AENS	Average Energy Not Supplied Index
AFC	Alkaline Fuel Cell
Ah	Amp-Hour
ASAI	Average Service Availability Index
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CAIFI	Customer Average Interruption Frequency Index
CBE	Commercial Bank of Ethiopia
CELID	Customers Experiencing Longest Interruption Duration
CEMI	Customers Experiencing Multiple Interruptions
Chi	Outage cost (\$/KWh) of customer due to contingency
COE	Cost of energy
CO	Carbon Mono Oxide
CO ₂	Carbon Dioxide

DC	Direct Current
DEF	Distribution Earth fault
DG	Distributed Generation
DIGSILENT	Digital Simulation and Electrical Network
DMF	Direct Methanol Fuel cell
DSC	Distribution Short Circuit
EEA	Ethiopia Electric authority
EEPCO	Ethiopian Electric Power Corporation
EEU	Ethiopian Electric Utility
EIC	Expected Interruption Cost
ENS	Energy Not Supplied Index
FEA	Failure Effect Analysis
GA	Genetic Algorithm
H1	Height at the Measured of Wind Speed
H2	Height that Proposed which is
IEEE	International Electrical and Electronic Engineering
IOR	Index of Reliability
KV	Kilo Volt
KVA	Kilo Volt Ampere
KVAr	Kilo Volt Ampere Rating
La(i)	Average load connected to load point i
LOLE	loss of load expectation
LOLP	loss of load probability
MCFC	Molten Carbonate Fuel Cell
MCS	Monte Carlo simulation
MTTF	Mean Time to Failure

MTTR	Mean Time to Repair
MVA	Mega Volt Ampere
MVA _{rh}	Mega Volt Ampere Rating Hour
MW	Mega Watts
MWh	Megawatt Hour
N	Number of buses
N _h	Number of contingency
N _i	Total number of load point i
N _i	Number of feeders
NPC	Net present cost
NREL	National Renewable Energy Laboratory
PAFC	Phosphoric Acid Fuel Cell
PEF	Permanent Earth Fault
PEMFC	Proton Exchange Membrane Fuel Cell
Pf	Power Factor
PSC	Permanent Short Circuit
PSO	Particle Swarm Optimization
PV	Photovoltaic
RBTS	Reliability Bus bar Test System
R _h	Outage time of contingency h
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SOFC	Solid Oxide Fuel Cell
TEF	Transient Earth Fault
TNPC	Total Net Present Cost
U	Expected Annual Outage Time
USD	United States Dollar

V	Wind Speed m/s
Wh	Watt-Hours
WT	Wind Turbines
Y_{ik}	Element (I, k) in admittance matrix
δ_k	Voltage angle at bus k
Λ	Expected Failure Rate
Λ_h	Failure rate of contingency h

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Electricity is produced and delivered to customers through generation, transmission and distribution systems. Currently Ethiopian Electric Power Corporation (EEPCO) the 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. 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 [1, 2].

The power system is exposed to system abnormalities such as control failures, protection or communication system failures, and disturbances, such as lightning, and human operational errors. Therefore, maintaining a reliable power supply is a very important issue for power systems design and operation [3].

Electric distribution system power quality is a rising concern. Customers require higher quality service due to more sensitive electrical and electronic equipment's, and 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.

Distribution generation can be defined as the integrated use of small generation units directly connected to a distribution system or inside the facilities of a customer [4].

Motta distribution substation is found in Amhara Region, east (Misraq) Gojjam Zone near Motta city and on the secondary road that links Dejen with Bahir Dar overlooking the Abay River, this town has a latitude and longitude of 11°5'N 37°52'E with an elevation of 2,487 meters above sea level, which is the one that affected by power interruption and the distribution substation has three 33kv feeders that are Motta, Meltolemariyam and Astoryo.

Generally the economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service.

In the context of Motta substation, electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, The drop of the voltage, especially at the residential loads, is causing early failure of equipment's, 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.

1.2 Statement of the Problem

The issue of reliability is of great concern in our daily life; Ethiopian government is currently making all rounded effort to change the country's economic status from the current least developed level to a medium income level. Motta city administration works according to the government's agenda to change the peoples' life style and increase their income level. But, electric power interruption is becoming a day to day phenomenon. Even there are times customers experience multiple electric power interruptions in a day, it is really challenging to tolerate power interruption since it causes much revenue loss.

The economic and social effects of loss of electric service have significant impacts on both the utility supplying electric energy and the end users of electric service that is residential, commercial and industrial customers are victims of the problem, especially for factories and industries, within hours of interruption. So the root cause of this problem should first be identified and possible solution be given.

According to the collected data the reliability index that is outage frequency and outage duration hour of the site annually has 806 and 1394.14 respectively which is very much as compared to the EEPCO standard and losses around 22,347.415 Mwh/a amount of energy, considering this fact, in this thesis work, a comprehensive investigation of Motta power distribution problems will be conducted. So the root cause of this problem should first be identified and the possible solution will be investigated by integrating hybrid renewable distributed generation energy since according to World Bank report 2018 Ethiopia is the second comfortable country for renewable electric generation from sub-Saharan country and according to NASA surface metrology and solar energy RET screen data, Motta has average solar radiation of 6.56 kWh/m²/day and wind speed of 4 m/s, which is comfortable for generating hybrid energy and will do analysis of the effect of DG on the reliability of existing distribution system.

1.3 Objective of the Study

The main objective of this thesis work is to conduct a study and analysis of the reliability of Motta power distribution system and their improvement using renewable energy distributed generations.

1.3.1 Specific Objectives

- ❖ To make a detailed reliability analysis of the existing distribution system.
- ❖ To investigate the main causes of reliability problems of the present Motta substation.
- ❖ To identify possible solutions for those reliability problems.
- ❖ To model the distribution generation by finding estimated solar radiation and wind speed data of the selected site.
- ❖ Selection of an appropriate type of solar panel, wind turbines, inverter and batteries depending on size of distributed generation
- ❖ Optimization and sensitivity analysis of the solar-wind hybrid system using HOMER
- ❖ Comparison of the investment cost of the hybrid system against the cost of energy not supplied due to interruption.
- ❖ To compare the reliability and power loose of the substation with and without the penetration of renewable energy in present grid
- ❖ To draw relevant conclusions and recommendations that can be of use for the performance improvement of the Motta distribution system.

1.4 Scope and Limitations of the Thesis

This thesis covers, studying the current power system reliability problems of the substation, their causes, percentage of improvements gained by penetrating distributed generators to the present Motta distribution substation. The resources of DG are shown using Homer Energy software and the reliability models have been developed in DigSilent/Power Factory.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter is divided into two sections. The first section presents review of related works published in the area of DG placement, sizing technics and their impact on reliability of local networks, while the second section presents fundamental concepts that will enable the understanding of the basic aspects of distribution systems, distributed generation, load flow analysis, reliability analysis, etc.

2.2 Survey of Earlier Works

Fangxing and Nura [5] relied on a Monte Carlo simulator to analyze the impact of a distributed generation on distribution network reliability. The authors developed a simulator that mixes fault isolation, overload voltage, upstream and downstream isolation mechanisms. The simulator analyses the impact of distributed generation on network reliability and how it decreases overloads voltage and enhances network reliability. The simulation has been conducted in a fully automated power network.

Binendra Shakya [6] studied repair duration effects on distribution system reliability indices and customer outage costs, he 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. This research work then analyzes the effect of repair duration distributions on the expected customer costs and the system and reliability indices including annual outage duration at the load points using Monte Carlo simulation technique. Certain repair duration distributions caused expected customer outage costs to increase by 30% for the system and over 50% at certain load points. Some reliability indices were also directly affected by the application of repair duration distribution.

Darshnaben K Metra [7] studied the Analysis of Distributed Generation and Impact on Distribution System. The author testes different type of distributed generation on the system and observes there impact. he conclude as Even though Distributed Generation is beneficial to the society as electricity generated near the place of consumption, reduction of power losses

in the network, reduction of greenhouse gas emissions, creating the more competitive market, it increase reliability of power system, It is not always economically viable. The economic viability of Distributed Generation is depends on energy prices and measures taken by the national governments to stimulate Distributed Generation. Distributed Generation has greater impact on energy losses, voltage profile, flicker, and harmonics, short-circuit level, islanding, reliability and network protection.

N. Rugthaicharoencheep, et al. [8] studied Technical and Economic Impacts of Distributed Generation on Distribution System; it has a significant impact on the distribution systems. This impact may be either positively or negatively depending on the distribution system, distributed generator and load characteristics and also an overview of DG is briefly introduced. The technology of DG is also listed while the technical impacts and economic impacts are explained.

Bharath Kumar, et al. [9] analyzed Reliability Modeling of Power System components through Electrical Circuit Approach, electrical circuit analogy for reliability modeling of power system is presented. This electrical circuit approach for the reliability modeling gives the probability of power availability at the load bus. This is one of the reliability indices used to assess the quality of power system. In this analysis of two methods are proposed one through Series-parallel equivalent and star- delta conversion approach and another method is based on classical node elimination approach. The Classical node elimination method is used for power system analysis and has not been used so far for reliability analysis. The author use the IEEE 6 bus reliability test system to analyses the reliability and conclude as the three proposed methods gave similar results on power availability at load bus. The series-parallel & star-delta method is quite difficult for the reduction of complex networks whereas the node elimination method is easy even for large systems. Monte Carlo simulation for large systems will take large computation time compared to Node Elimination method.

Mohammad Al-Muhaini, et,al.[10] evaluating future power distribution system reliability including distributed generation, studies the impact of conventional and renewable distributed generation (DG) on the reliability of future distribution systems, even when the connection may not be simply radial. The variability of the power output of renewable DGs, such as wind and solar is included. The stochastic nature of the renewable resources and their influence on the reliability of the system are modeled and studied by computing the adequacy transition rate. An integrated Markov model that incorporates the DG adequacy transition rate, DG mechanical failure, and starting and switching probability is proposed and utilized to give

accurate results for the DG reliability assessment. The main DG is conventional generation, solar, and wind DG units. The technique used appears to be applicable to any renewable energy source. They conclude as the stochastic nature of the renewable DG power output and load demand is integrated successfully into the encoded Markov cut set algorithm. The DG operating in an islanded mode during outages can improve the interruption duration but can also lead to an increase in the interruption frequency. A renewable DG may increase the probability of experiencing inadequate power production due to the low capacity factor of many renewable based DGs.

M. D. Singh et.al. [11] analyzed Reliability Enhancement of Power System using Risk Index Estimation Technique, they present a simplified approach to evaluate the risk index whose minimization results in the enhancement of power system reliability. The risk indices evaluated in the paper includes mainly LOLP (loss of load probability) and LOLE (loss of load expectation) with more emphasis on LOLE as it indicates the expected number of days in the specified periods in which the daily peak load will exceed the available capacity. There are too many other reliability considerations to bridge the gap between the total generation and total load in any practical power system operation. The addition of generating units in electrical power systems is often viewed as a complex situation and the effects of unit addition on reliability are being investigated in the paper. The reliability indices for load points and the overall system performance have also been studied and a computer program has been developed to examine the effectiveness of the system under investigation by using C-language. The results of simulation runs provide justification for use of the program so developed for the purpose.

Khalesi and Javadian [12] study the reliability of a distribution network with distributed generation when the network load consumption and the power generation are following a probability distribution. Normal distribution function is used to model load consumptions and DG output power and Monte Carlo simulation is applied to evaluate average annual outage time of load points. It is important to notice that there are other approaches than analytical and Monte Carlo to assess the reliability of a power network.

Haakana et al. [13] proposed a sequential Monte Carlo simulator to assess the reliability of a medium voltage network. The developed simulator was able to evaluate the performance not only of an entire distribution network but also subsections/areas of it. Both fault repair time and fault frequency are modeled according to a Wei bull distribution offering an accurate model of the outages phenomena.

R. E. Brown, et al. [14], defines the positive impacts of DG units to the distribution network such as reactive power compensation to achieve voltage control, reduction of power losses, regulation and load power consumption tracking to support frequency regulation, spinning reserve to support generation outages and improvement in reliability through backup generation.

Minnan Wang and Jin Zhong [15] advocated two optimization models to obtain the optimal placements of DGs and capacitor banks to maintain better voltage profiles in distribution systems. First, the optimal DG placement problem was formulated as a modified optimal power flow problem, with an innovative mathematical representation of voltage profile optimization. Then the capacitor optimal placement problem was modeled and solved. Both models were tested on the IEEE 41 bus distribution system, which is a radial system. From their research they concluded that the strategic placement of DG units would have a strong influence on the voltage profile improvement of the distribution system and capacitor banks could be assigned optimally to procure a better voltage profile.

M. Abbagana, et, al. [16] also suggested a technique for optimal placement and sizing of a DG in a power distribution system using Differential Evolution (DE). In the optimization problem the DG sources were added to the network to mainly reduce the power losses and improve the voltage profile by supplying a net amount of power.

Borges and Falcao, [17] presented a method for optimal DG units allocation and sizing in order to minimize the primary distribution network losses and to guarantee acceptable reliability level and voltage profile. The optimization process is solved by the combination of GA techniques with methods to evaluate DG impacts in system reliability, losses and voltage profile. The authors report that the fitness evaluation function that drives the GA to the solution is the relation between the benefit obtained by the installation of DG units and the investment and operational costs incurred in their installation. The losses and voltage profile evaluation is based on a power flow method for radial networks with the representation of DG. The reliability indices have been evaluated based on analytical methods modified to handle multiple generations. The present methodology was applied to three different distribution systems and results showed that the proposed method is robust, with moderate computer requirements, and produce solutions satisfying the imposed constraints and presenting a considerable improvement in the used optimization criterion.

M. M. Aman et al. [18] used Particle Swarm Optimization (PSO) algorithm for simultaneous finding of optimum DG and shunt capacitor bank location and size in power systems. The proposed algorithm was tested on 12-bus, 30-bus, 33-bus and 69-bus radial distribution

networks. The result showed that the proposed methods had significantly reduced the power system losses as well as improving the overall loading factor.

2.3 Distribution Systems

The electric power systems can be separated into generation plant, generation sub-station, transmission system, sub-transmission and distribution sub-stations. Traditionally, generation is to supply the power to the transmission system which can be defined as the carrier of power from the generating stations to the sub-transmission system, at voltage levels of 230 kV or higher. The sub-transmission system then transfers the power at voltage levels between 66 kV to 132 kV to the distribution substation systems. Finally, the distribution substation system, at voltages under 33 kV, delivers electricity to the consumer[19]. Fig 2.1 illustrates a typical electric power system.

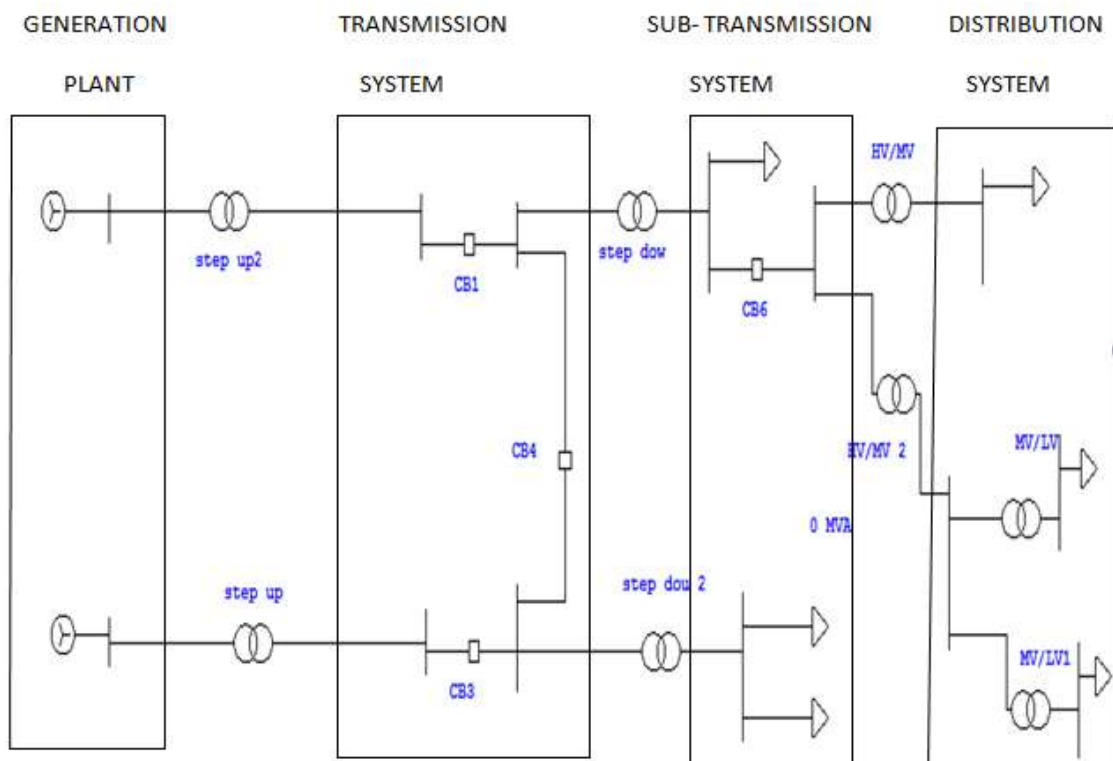


Fig.2.1: Basic Power System Structure

The distribution system can be separated into primary and secondary systems. The primary distribution system contains of distribution substations and feeders. The distribution substations step down power from the sub-transmission system to between 45 kV and 11 kV. The primary distribution main feeders branch out from the substation and then lateral feeders to serve local areas. From the lateral, distribution transformers step down the voltage again to the secondary level at which most customers are served, generally at 220/240 V single phase and 380 V three phase.

2.3.1 A Typical Configurations of Distribution System

An essential characteristic of distribution systems is their configuration, or how their lines are connected. There are three common configurations of distribution systems: radial, loop and meshed network [20]. Radial and loop configurations types of system are arranged in series or parallel or combinations of the two.

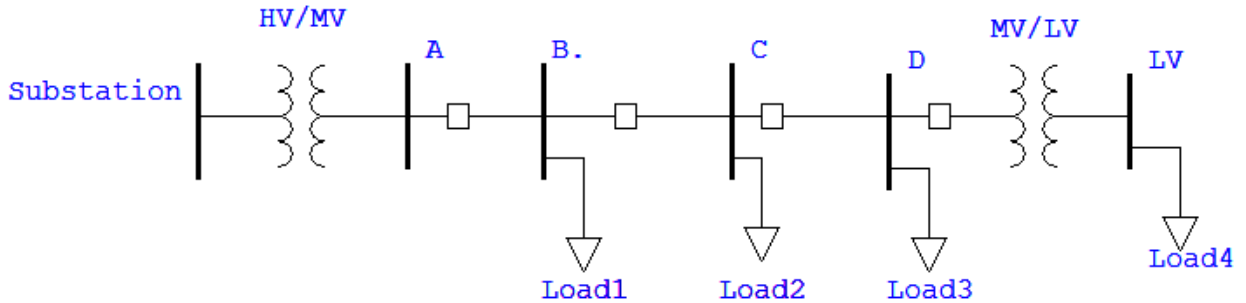


Fig.2.2: Radial Distribution System

Radial configuration of distribution system is the simplest and typically used arrangement for the electric utility company. A radial distribution system consists of a set of components, transformers, lines, protective devices, and buses as shown in Fig 2.2. In this type of system configuration, the distribution feeders leave the substation and passes through all the system area without connection to any other power supply. The simplicity of this type of distribution configuration allows the easy system performance analysis and also the planning issues related to maintenance, improvement or expansion of the system and it requires the least capital cost; however, it also has the lowest reliability, since any faults in the feeders will cause service interruptions at all points downstream.

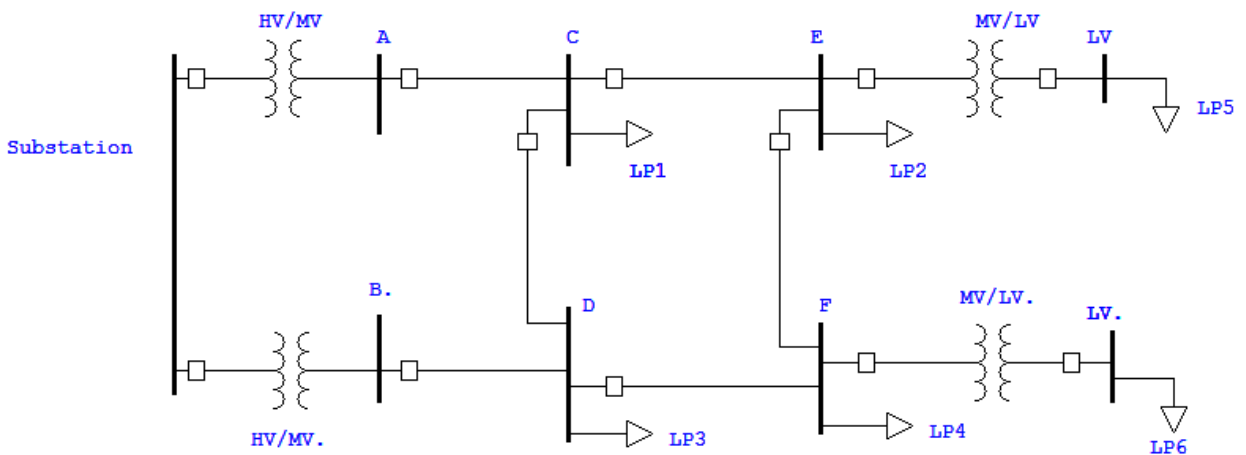


Fig.2.3: Distribution System - Meshed Configuration

Meshed distribution system configuration, it is more interconnected meaning that any two points are usually connected by more than one path and some lines form loops within the

system. A meshed configuration is generally more reliable because there is exists more than one path for the power to flow, if a line fails. Economically, the cost of a meshed system is the highest because of its numerous feeders with associated protection and control systems.

Fig 2.3 shows a meshed configuration of a distribution system. Loop configured distribution systems fall in between the two in terms of cost and reliability. A loop configuration can be described as two radial systems separated by a normally open switch, a failure of one of the two substation transformers the switch can be closed and one section of the distribution system energized through the other.

Distribution system design and planning is facing a major change in paradigm due to deregulation of the power industry, policy changes and advancements in DG technologies. A distribution system design and planning is the key to determine the best expansion strategies to provide reliable and economic services to the customer. In classical planning, the load growth typically is met by adding a new substation or upgrading the existing substation capacity along with their feeders. Today, the rapid advances in DG technology and their numerous benefits have made them an attractive alternative to the distribution companies in their planning tasks[21].

2.4. Distribution Substation

A distribution substation transfers power from the transmission system to the distribution system of an area. The input for a distribution substation is typically at least two transmission or sub transmission lines. Distribution voltages are typically medium voltage, between 2.4 kV and 33kV depending on the size of the area served and the practices of the local utility. Besides changing the voltage, the job of the distribution substation is to isolate faults in either the transmission or distribution systems. Distribution substations may also be the points of voltage regulation, although on long distribution circuits (several km/miles), voltage regulation equipment may also be installed along the line. Complicated distribution substations can be found in the downtown areas of large cities with high-voltage switching and backup systems on the low-voltage side[22].

2.5 Distributed Generation Background

Distributed Generation is a new technique based on renewable energy resources which will possibly participate as a vital entity of electric Power System. Distributed Generation can also be considered as power generation unit injected to distribution network by neglecting the transmission lines, hence decreasing the technical losses [23, 24].

The power generated from these DGs is not connected to the national grids as they range from few kilowatts (KW) to several megawatts (MW) [25, 26]. Radial distribution systems are much modest but are more exposed to outages instead of interconnected system. During normal operating conditions the loads accomplish its required power demand, but if any fault occurs, the circuit trips causing failure to power flow. Despite the fact that distribution systems have localized effects, statistics shows that distribution system failure affects the system as much as 85 to 90 percent towards the unavailability of supply to load as compared with failure of other parts of electric power system[27].

The IEEE defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system.

According to Georgilakis and Hatziaargyriou (2013), distributed generation (also called decentralized generation, dispersed generation, and embedded generation) is defined as a small generator or an electric power source connected unswervingly to the distribution network or on the customer site of the meter[28].

Ackermann et al., The difference between distribution and transmission networks is based on a legal definition. In most competitive markets, the legal definition for transmission networks is usually included as part of the electricity market regulation. Anything that is not defined under transmission network in the legislation is suitable to be regarded as distribution network. The definition of distributed generation does not define the rating of the generation source, as the maximum rating depends on the local distribution network conditions, e.g. voltage level. It is, however, useful to categorize distributed generation based on their different ratings. Therefore, a DG is understood to be a small unit of generator which could be located at the consumer-side of the distribution network in order to improve power/energy management schemes, and it is connected, operated and integrated into the system at distribution voltage levels [29].

El-Khattam & Salama, there are many kinds of DG application in the world today. From the constructional and technological points of view as shown in Figure 2.4, DGs can be classified into two groups namely; traditional and non-traditional generations [30].

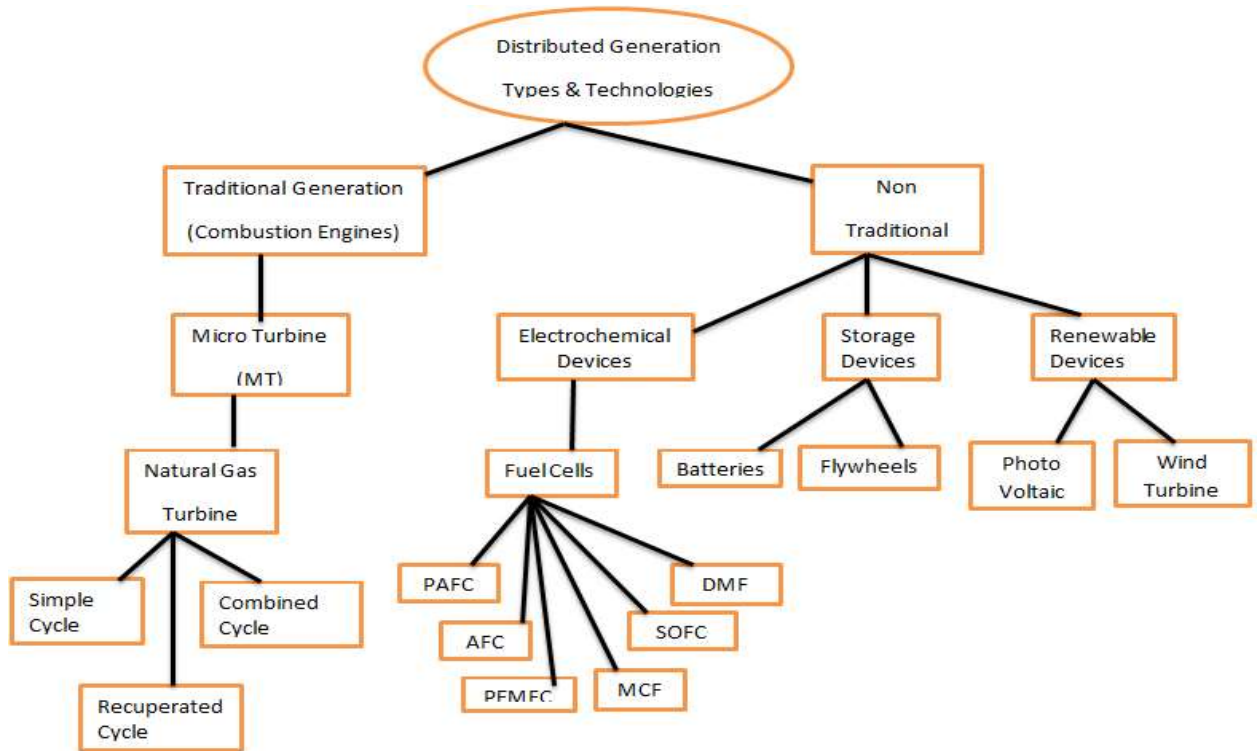


Fig.2.4: Types of Distributed Generation

A. Traditional distributed generation

These are mainly standard conventional generating systems which come in smaller units with smaller power ratings and can be directly integrated into the distribution voltage levels. They are basically combustion generators which are operated using non-renewable energy resources. They include micro-turbines, simple cycle gas turbines, recuperated gas turbines, combined cycle gas turbines, diesel generators and so on [30].

B. Non-traditional distributed generation

These are other types of non-conventional generating systems which come in small power ratings and can be integrated into the system at distribution voltage levels. They can be classified into storage devices, electromechanical devices and renewable energy devices as shown in Figure 2.4. Typical examples include Fuel cells, deep cycle batteries and flywheels, Photovoltaic (PV) modules, wind turbines (WT) and so on [30].

The different types of fuel cells are Proton Exchange Membrane Fuel Cell (PEMFC), Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Direct Methanol Fuel cell (DMF), Solid Oxide Fuel Cell (SOFC) and Molten Carbonate Fuel Cell (MCFC) [24].

DGs have shown a lot of advantages in power systems applications which are the major reason behind its widespread acceptance. Some major technical and economic benefits include [23].

- i. Reducing losses in the power system
- ii. Improvement of voltage profile
- iii. Increasing energy efficiency
- iv. Improving reliability and regional consequences of system failure
- v. Improving power quality and security
- vi. Deferred investments for upgrades of facilities
- vii. Lower operating cost because of peak shaving
- viii. Enhanced productivity
- ix. Deferred investment for upgrades facilities

Generally, the term Distributed Generation refers to any small scale electric power production technology that is integrated within distribution systems, near to the point of utilization. Distributed generators are connected to the medium or low voltage grid. They are not centrally planned and they are typically smaller than 30 MW [31], DG can be classified according to their size.

Size of DG is defined according to the reference [30]:

- Micro distributed generation between $1\text{Watt} < 5\text{kW}$
- Small distributed generation between $5\text{kW} < 5\text{ MW}$
- Medium distributed generation between $5\text{ MW} < 50\text{MW}$
- Large distributed generation between $50\text{MW} < 300\text{MW}$

2.5.1 Impact of DG on Power Losses

One of the major impacts of Distributed generation is on the losses in a feeder. The appropriate location of DG units in the existing system is an important criterion that has to be analyzed to be able to achieve a better reliability of the system with reduced losses. Integration of DG to the system changes traditional radial characteristic of the distribution system, because it introduces power source to the system. When the DG power is more than the downstream load, it sends power upstream reversing the direction of power flow and at some point between the DG and substation; the real power is zero due to reversal flow of power from DG. This is the reason of loss reduction into the distribution feeders. Therefore, the optimum location of DG units in the system reduces the losses. When the distribution feeders have high losses, integrating a number of small capacity DGs will show an important positive effect on the losses and have a great advantage to the distribution system. On the other hand, if large DG units are integrated, they must be considering the feeder capacity[32].

2.5.2 Impact of DG on Reliability Enhancement

Distribution system reliability assessment with DG is an important factor in the entire system operations. The optimal allocation of DG can improve the reliability of the system by serving as backup generation for some specific customers in case system interruption from the utility. Therefore, the distribution system reliability assessment with DG should be properly optimized, for example failure rate, energy availability, system component failure rates, the change in load demand and the DG locations. Integration of DG in the distribution system has positive and negative impacts on reliability indices and power quality. The positive impacts include faster restoration service to the customer and reduced voltage sags while the negative impacts could be sympathetic tripping, increased fuse blowing etc [32].

2.6 Distributed Generation Technologies

Energy resources are categorized as non-renewable (conventional) and renewable (non-conventional) energy resources. Technologies based on renewable energy include PV modules, geo-thermal system and wind turbines, whereas co-generation plants, fuel cells and heat engines are the technologies based on non-conventional resources [33], from this distribution generation resources the theses consider on PV and wind turbine hybrid systems.

A. photovoltaic system

A photovoltaic system (PV), converts the light energy received from the sun radiation to electric energy. Semi conducting materials are used to construct solar cells which are capable of transforming self-contained energy of photons into electricity when they are exposed to solar radiation. The cells are placed in an array that is either fixed or moving to keep tracking the sun to generate the maximum power[34]. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light, instead, they need large spaces and the initial cost is high.

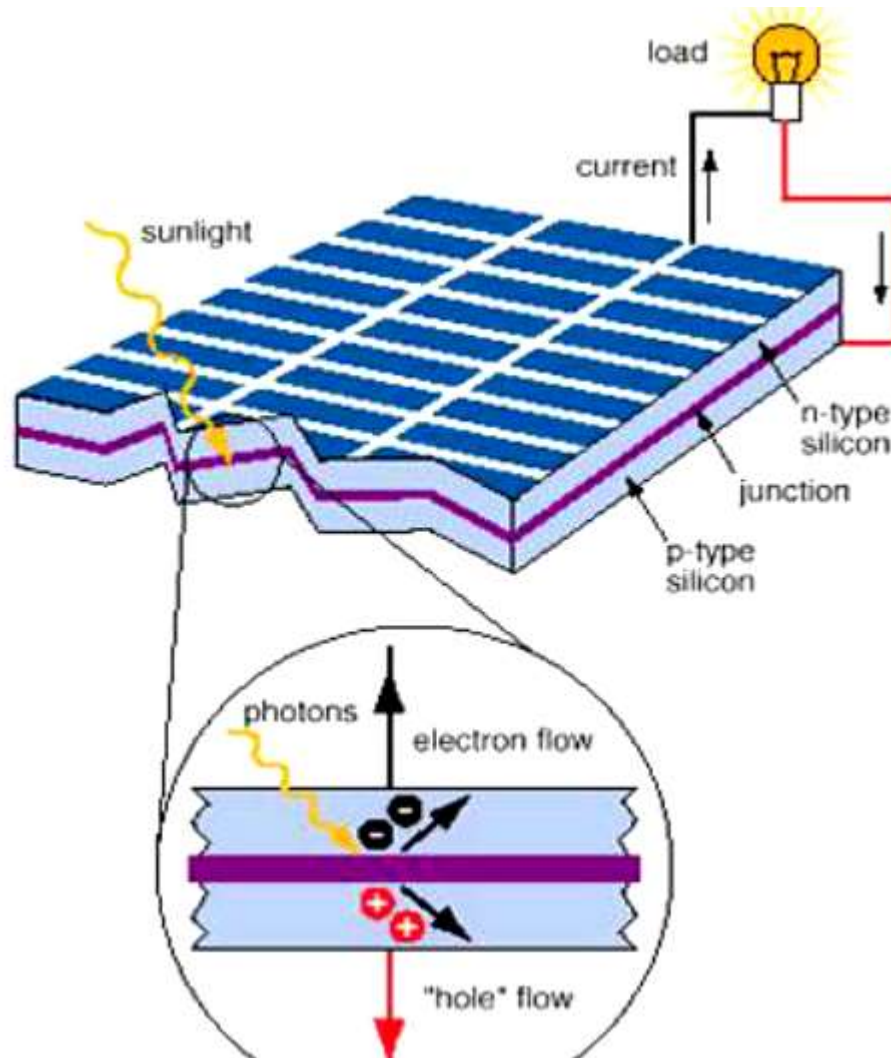


Fig.2.5: Schematic Diagram of a Photovoltaic System

B. Wind turbines

Wind turbines are capable of converting wind energy into electricity. The wind has high stochastic nature, which cannot be stored, thus, it must be handled according to this characteristic. A general scheme of a wind turbine is shown in Fig 2.5, where its main components are shown [34].

There are two conversion steps in wind turbines. First, the rotor takes the kinetic energy of the wind; convert it into mechanical torque in the shaft; and then the generator system converts this mechanical torque into electricity. Mostly, the generator system gives an AC output voltage which is dependent on the wind speed. As wind speed is not constant, the voltage generated must be transferred to DC and back again to AC with the aid of inverters. However, turbines with fixed wind speed can directly be connected to grid [34].

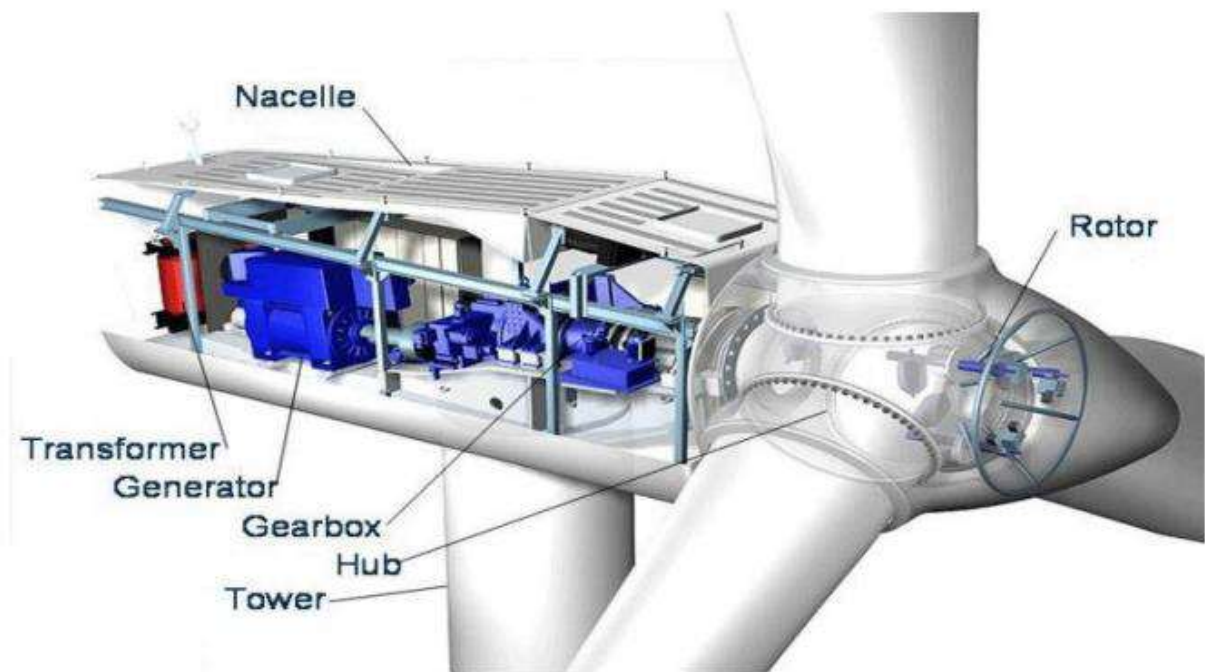


Fig.2. 6: Parts Wind Turbine

2.7 Modern Distribution System Planning With DG

The current existing distribution systems are seen to be passive networks units due to the unidirectional power flow from distribution substation to end users. Usually, distribution system upgrade is carried out with the aid of additional network components such as transformers, protective devices and transmission lines for meeting the load growth. The integration of DG units has been as one of the attractive option for distribution system due to the incentives and environmental considerations. Distribution system with DG units demand for dedicated operational strategies since the DG units located near the load centers can possibly change the direction of power flows and consequently modify system operations. It is very important to allocate DG units in distribution networks with comprehensive technical and economic considerations to avoid the overall degradation of system performance.

The method for radial distribution network reliability assessment planning based on a combination of the analytical and Monte Carlo simulation approaches. The analyzing procedure starts by applying the analytical method continued by applying the method of Monte Carlo simulation. The method takes into account the reliability indices, energy loss and interruption energy costs [35].

2.8 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) [6].

Reliability measures the power system's ability to supply electricity to its customers within accepted standards and in the magnitude desired, for the period of time intended, under the operating conditions required. There are two aspects of reliability:

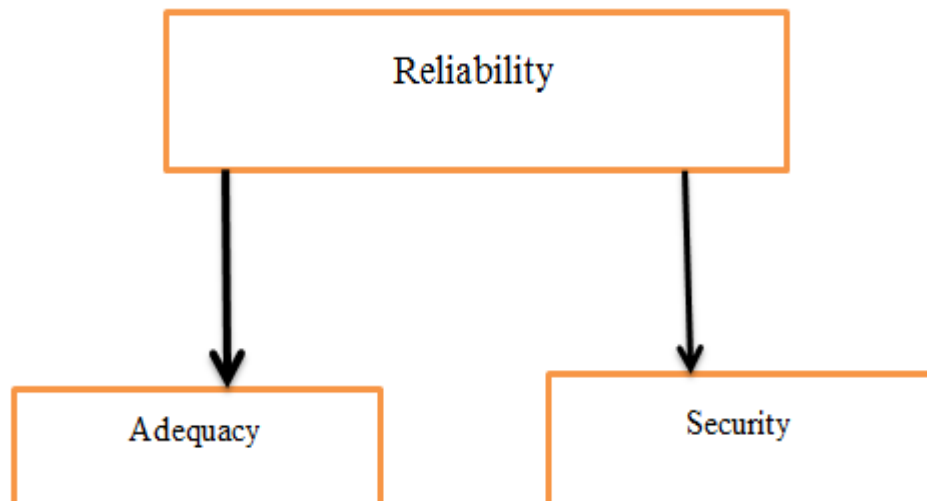


Fig.2.7: Two Aspects Reliability

Adequacy: refers to the existence of adequate generating, transmitting and distributing facilities within the system to satisfy the consumer load demand at all times; considering planned/ unplanned outages, it is assessed using the power flow (AC/DC) solutions [36].

Security: refers to the ability of the electric systems to react against to sudden disturbances arising within that system, such as earth fault and short circuit. It is assessed using dynamic calculation [36].

As a consequence, adequacy is particularly related with the planning of the grid and security is linked with the operation of the grid.

A power system consists of three hierarchies levels. These are generation, transmission and a distribution system. Reliability analysis and its evaluation technique is mainly developed at generation and transmission level than at distribution level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities has shown that the largest individual contribution for unavailability of supply is due to distribution system failure [37].

2.8.1 Reliability Indices

Power system reliability indices are used as a means of measuring the reliability of the individual as well as the overall system. Reliability indices typically consider such aspects as:

- The number of customers;
- The connected load;
- The duration of the interruption measured in seconds, minutes, hours, or days;
- The amount of power (kVA) interrupted; and
- The frequency of interruptions.

A. Customer-Oriented Indices

These indices are directly related to customers. Some of these indices are listed below. They are defined in IEEE Standard 1366 [38-40].

1. System Average Interruption Frequency Index (SAIFI):

System average interruption frequency index indicates the frequency of a sustained interruption experienced by the average customer served in a distribution system during a predefined period of time. It is determined by dividing Total Number of Customers Interruption by Total Number of Customers Served (interruption /Customer. yr).

$$SAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \dots \dots \dots \text{eq}(2.1)$$

Where

λ_i is the failure rate at load point i , and N_i is the number of customers found at load point i

2. Customer Average Interruption Frequency Index (CAIFI):

This index gives the average frequency of sustained interruptions for those customers experiencing sustained interruptions. The customer is counted once regardless of the number of times interrupted for this calculation

$$CAIFI = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers affected}} = \frac{\sum N_i}{\sum N_0} \dots \dots \dots \text{eq}(2.2)$$

Where N_0 is total number of customer interruptions and N_i is the number of customers found at load point i .

3. System Average Interruption Duration Index (SAIDI):

It is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information as to the average time the customers are interrupted. It is the sum of the restoration time for each interruption event times the number of interrupted customers for each interruption event divided by the total number of customers.

$$SAIDI = \frac{\text{Total number of customer interruptions duration}}{\text{Total number of customers served}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \dots \dots \dots \text{eq}(2.3)$$

Where U_i is the annual outage time at load point i and N_i is the number of customers at load point i .

4. Customer Average Interruption Duration Index (CAIDI)

It is the average time needed to restore service to the average customer per sustained interruption. It is the sum of customer interruption durations divided by the total number of customer interruptions.

$$CAIDI = \frac{\text{Sum of customer interruptions duration}}{\text{Total number of customers intrruption}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \dots \dots \dots \text{eq}(2.4)$$

Where λ_i is the failure rate at load point i , U_i is the annual outage time at load point i and N_i is the number of customers at load point i .

5. Average Service Availability Index (ASAI):

Average service availability index indicates the percentage of time in the defined reporting time horizon that the power has been provided to customer. It is determined by dividing Customer hours of available Service by Customers hours service Demands (%)

$$ASAI = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}} = \frac{\sum N_i \times 8760 - \sum N_i U_i}{\sum N_i \times 8760} \dots \dots \dots \text{eq}(2.5)$$

6. Average Service Unavailability Index (ASUI): This index is the complementary value to the average service availability index (ASAI).

$$ASUI = 1 - ASAI = \frac{\text{Customer hours of unavailable service}}{\text{Customer hours demanded}} = \frac{\sum N_i U_i}{\sum N_i \times 8760} \dots \dots \dots \text{eq}(2.6)$$

B. Load or Energy-Oriented Indices

1. Energy Not Supplied Index (ENS): This index represents the total energy not supplied by the system. Or the expected amount of energy not supplied due to capacity deficiency in the period of observation. It is the sum of each load times its outage duration (kWh/yr). And it is given by

$$ENS = \sum L_a(i)U_i \dots \dots \dots eq(2.7)$$

Where, $L_a(i)$ is the average load given by:

$$L_a(i) = L_p(i) \times L_f(i) = \frac{E_d(i)}{t} \dots \dots \dots eq(2.8)$$

LP is peak load demand, Lf is the load factor, and Ed is the total energy demanded in the period of interest t.

2. Average Energy Not Supplied Index (AENS): Average energy not supplied is the total Energy not supplied in system divided by total number of customers served (kWh/yr. customer).

$$AENS = \frac{\text{Total energy not supplied}}{\text{Total number of customers served}} = \frac{\sum L_a(i)U_i}{\sum N_i} \dots \dots \dots eq(2.9)$$

3. Average Customer Curtailment Index (ACCI): This index represents the total energy not supplied per affected customer by the system.

$$ACCI = \frac{\text{Total energy not supplied}}{\text{Total number of customers affected}} = \frac{\sum L_a(i)U_i}{\sum N_0} \dots \dots \dots eq(2.10)$$

Where: $L_a(i)$ is the average load, N_0 is the number of customers affected.

4. Expected Interruption Cost (EIC) Index is the cost of not supplied energy at that load point (\$/yr)

In this thesis, all the above Customer-Oriented and Load or Energy-Oriented reliability indices will be comparing before and after connecting DG.

2.8.2 Cost-Benefit Analysis

When a power is interrupted, both the utility and customers face interruption costs. When a customer faces such interruption, there is an amount of money that the customer is willing to pay to avoid the interruption and this amount is referred to as the customer cost of reliability. Such costs are of tangible and intangible types and also there is an opportunity cost. But assessing the interruption cost from the customer side is difficult. So to maximize the reliability, utility should balance their reinforcement cost for reliability improvement and the

customer cost for poor reliability. Therefore, the optimal level of reliability is said to be achieved when the sum of utility cost and the customer cost are minimum [41].

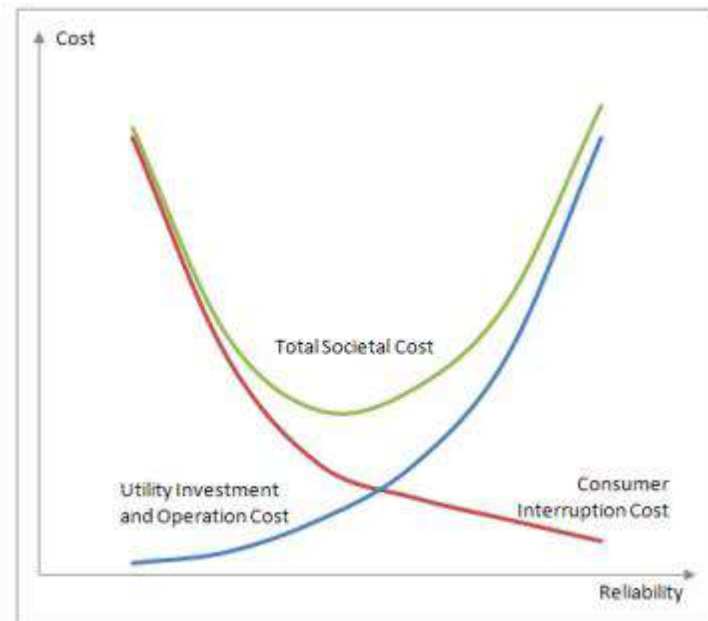


Fig.2. 8: Reliability Worth and Reliability

The above graph shows the cost of both customer and utility and it tell us that high reliability achieved by investing high cost.

2.9 Methods of Reliability Analysis

Reliability engineering with regard to distribution systems involves gathering outage data and evaluating system designs. The outage data collected from Motta distribution feeder including each failure event within the specified period of the year. The information recorded in a narrative form will translate into a statistical database. The outages are classified as forced and scheduled. Hence, data on failure rates and repair times of component used in the distribution system are compiled for reliability calculations. In addition, data on statistical information consisting of outages arising from the load shedding, system collapse, scheduled or unscheduled maintenance and hourly load shedding on each feeder will be collect. These data will be used to compute the reliability indices of total hours of outages, the number of interruptions (frequency) per day and Customer Orientation Indices (SAIFI, SAIDI, CAIDI, ASAI and ASUI) using equations discussed in the previous section.

Power system reliability indices can be calculated using a variety of methods. There are two main approaches applied for reliability evaluation of distribution system, namely Simulation (Monte Carlo) method and analytical methods. The simulation (Monte Carlo) method is based

on drawings from statistical distributions (Monte Carlo) and that of Analytical methods is based on solutions of mathematical models. The requirement of large number of drawings to obtain accurate results made this approach to be time consuming. The analytical approach is relies on the solutions of mathematical models on assumption of statistical distributions of failure rates and repair times.

There are three common reliability indices used in this method of reliability evaluation. These are: expected failure rate (λ), the average outage time(r), and the expected annual outage time (U), which are enough for the simple radial system. In distribution system whether the networks are radial or meshed, they are mostly operated radially and, this makes the assessment simple. The evaluation process becomes more sophisticated for parallel or meshed networks [42].

2.9.1 Numerical or Monte Carlo Simulation Methods

Monte Carlo simulation method is the most commonly utilized numerical method. In this method, simulation of physical relationship is used to analyze the random behavior of the system. The possible outcomes of this technique are not only average values like that of analytical methods, but also the expected probability distributions of reliability indices. The method provides the possibility to be applied to a more complicated component models, e.g. including effects of component aging. But this has its own side effect .i.e. increased computation time which makes the Markov models to be utilized much more often.

In addition to the analytical techniques, the simulation methods may also be used to estimate the output power and evaluate the reliability of a renewable generation system. Monte Carlo simulation consists of randomly sampling system states, testing them for acceptability and aggregating the contribution of loss of load states to the reliability till the coefficients of variation of these indices drop below pre-specified tolerances.

There are two approaches of MCS, sequential and random approaches. If the approach is applied for each hour of a year chronologically, the approach is called chronological approach while if the hours of study time taken at random, the approach tends to be random approach. Load flows, dispatch algorithms are the tools used for the simulation of randomly selected systems.

The results of these simulations are current flows, voltage levels and energy curtailment which are required for determination of necessary indices of power system reliability [40 & 41].

As previously pointed out, the major demerits of MCS are the requirement of several experiments to obtain accurate results. This makes the method to take large computational time. To reduce this large computational burden, several variance reduction techniques such as control varieties, importance sampling, stratified sampling and antithetic varieties, have been developed [43].

Software used to facilitate these work are:-

2.10 HOMER Software

The HOMER software is used to determine the optimal sizing and operational strategy for a hybrid renewable energy system based on three principal tasks which are simulations, optimization and sensitivity analysis. HOMER simulates the operation of the system based on the components chosen by the designer will perform the energy balance calculation based on the system configuration consisting several numbers and sizes of component. And simulates the system based on the estimation of installing cost, replacement cost, operation and maintenance cost, fuel and interest rate. The optimization process is done after simulating the entire possible solutions of hybrid renewable energy system configuration. HOMER display a list of configurations sorted based on the Total Net Present Cost (TNPC). It can be used to compare different types of system configuration from the lowest to the highest TNPC, the system configuration based TNPC is varied depending to the sensitivity variables that have been chosen by the designer. The HOMER software will repeat the optimization process for every selection of sensitivity variables for the hybrid renewable energy system. The sensitivity variables are such as the global solar, wind speed and the price of diesel fuel. Then, the list of various configurations of hybrid renewable energy will be tabulated from the lowest to the highest TNPC. The optimal solution of hybrid renewable energy system is referring to the lowest TNPC [44].

2.11 Power Factory

Power Factory is one of power system analysis software's, which is designed by the software developer Digilent. It models different aspects concerning the planning and operation of a power system. The well-known advantages of this software are its overall functional integration, for modeling of generation, transmission-, distribution- and industrial networks and its comprehensive user interface. Power Factory is also an important tool for studying the grid connection of new generation-technologies, has capable of analyzing the impact of distributed generation integration to the current grid network. It provides a combined classical

distribution system analysis functions such as unbalanced network, voltage drop calculation, load and generation modeling, selectivity analysis, etc. with the power of a highly modern analysis tool featuring dynamic simulation functions and reliability analysis [43].

DIgSILENT Power Factory is commercial power system software for use in

- Analysis of generation, transmission and distribution networks.
- Power flow calculations and dynamic simulations

2.11.1 Reliability Assessment under Power Factory

The assessment of reliability indices for the whole network or for the parts of it is associated to the capability of that network to supply the electricity demand of its customers in adequate availability. The Power Factory's reliability assessment module provides two distinct calculation functions for the analysis of network reliability under probabilistic conditions: known as network reliability assessment and voltage sag assessment.

Network reliability assessment: the probabilistic assessment of interruptions during an operating period of the power system. Network reliability assessment is used to determine expected interruption frequencies and annual interruptions costs, or to compare alternative network designs.

Voltage sag assessment: The probabilistic assessment of the frequency and severity of voltage sags during an operating period. It is used to determine the expected number of equipment trips due to deep sags.

The reliability assessments indices consist of the following reliability modules. These are: Failure modeling, Load modeling, System state production, Failure Effect Analysis (FEA), Statistical analysis and Reporting [43].

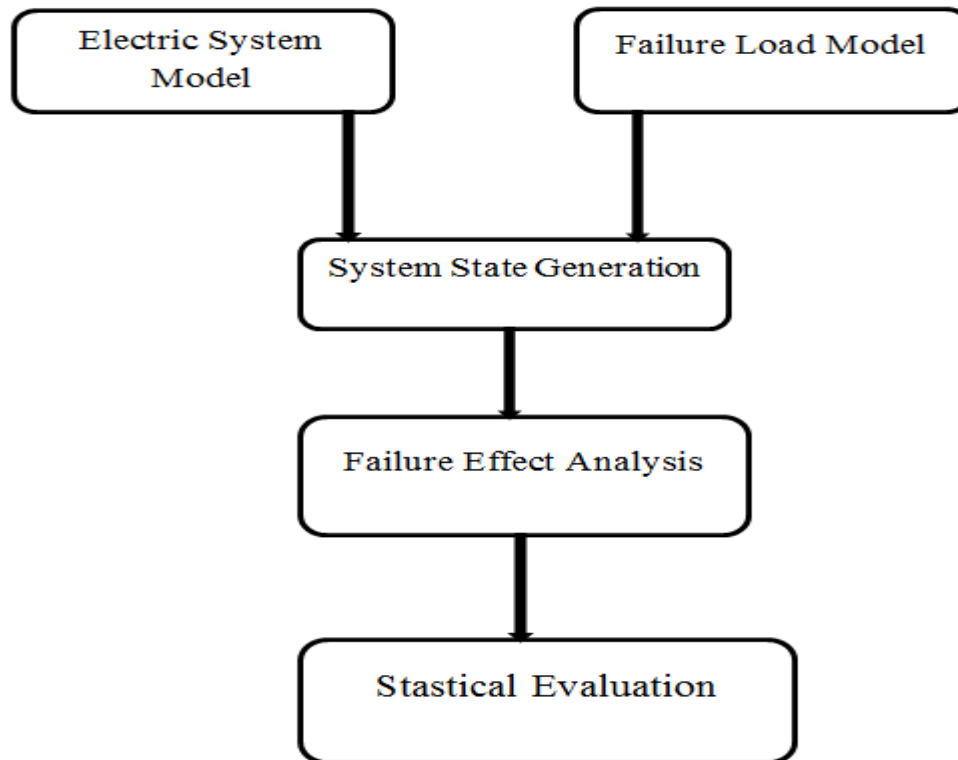


Fig.2.9: Reliability Analyses under Power Factory

The basic reliability analysis calculation flow diagram is shown in Figure 2.9. The failure models generally shows failure of components, that describe the way of component failures, frequency of failures and the time needed to repair them. The load models may include only a few possible load demands, or may be based on precise load forecast and growth conditions. System State is combination of one or more simultaneous faults and a specific load condition. The system state production module will use the failure models and load models to build a list of relevant system states. Each of these system states may have one or more faults. Then, the failure effect analysis module, FEA analyzes the faulted system states by imitating the system reactions to these faults, given the current load demands [42].

2.12 Network Reliability Assessment

Reliability analysis is an automation and probabilistic extension of contingency evaluation. The planner is not required to pre-define outage events, but can optionally select that all possible outages are considered for analysis. The relevance of each outage is considered using statistical data about the expected frequency and duration of outages according to component type. The effect of each outage is analyzed in an automated way, meaning that the software simulates the protection system and the network operator's actions to re-supply interrupted

customers. As statistical data regarding the frequency of each event is available, the results can be formulated in probabilistic terms.

An analytical assessment of the network reliability indices (transmission, sub-transmission or distribution level) is initiated by the following actions within PowerFactory.

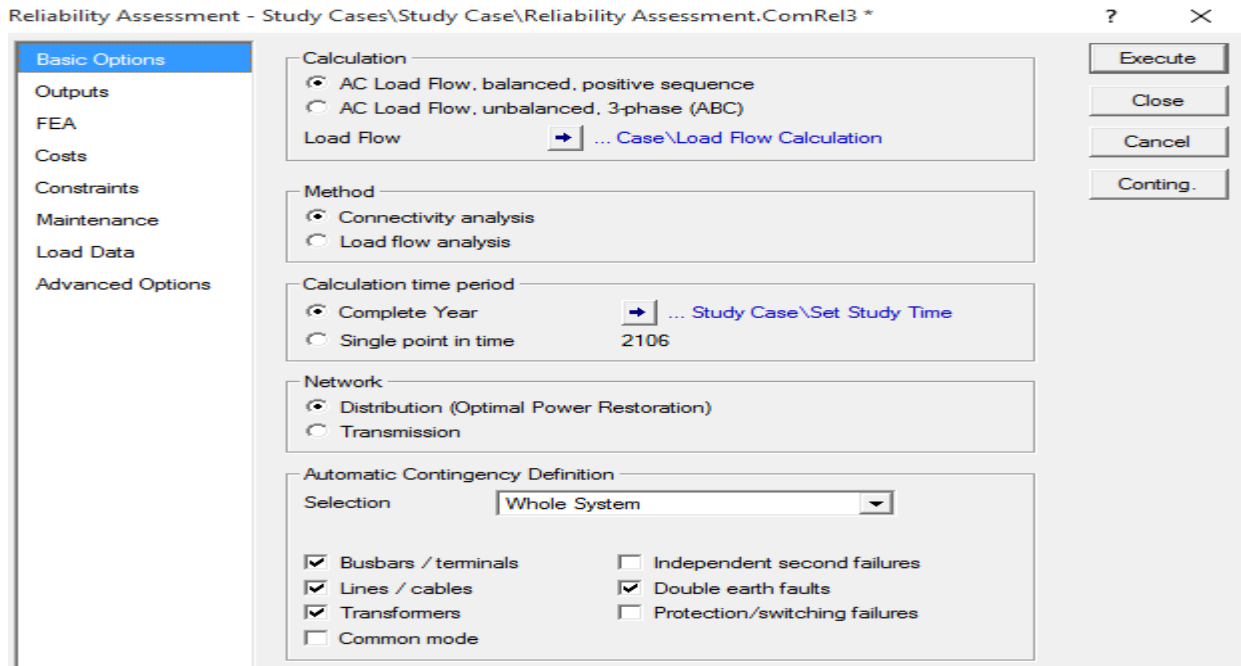


Fig.2.10: Reliability Analysis Interface

A reliability assessment will be started when the Execute button is pressed.

Outputs

The output option interface of PowerFactory is shown in figure 2.11 below.

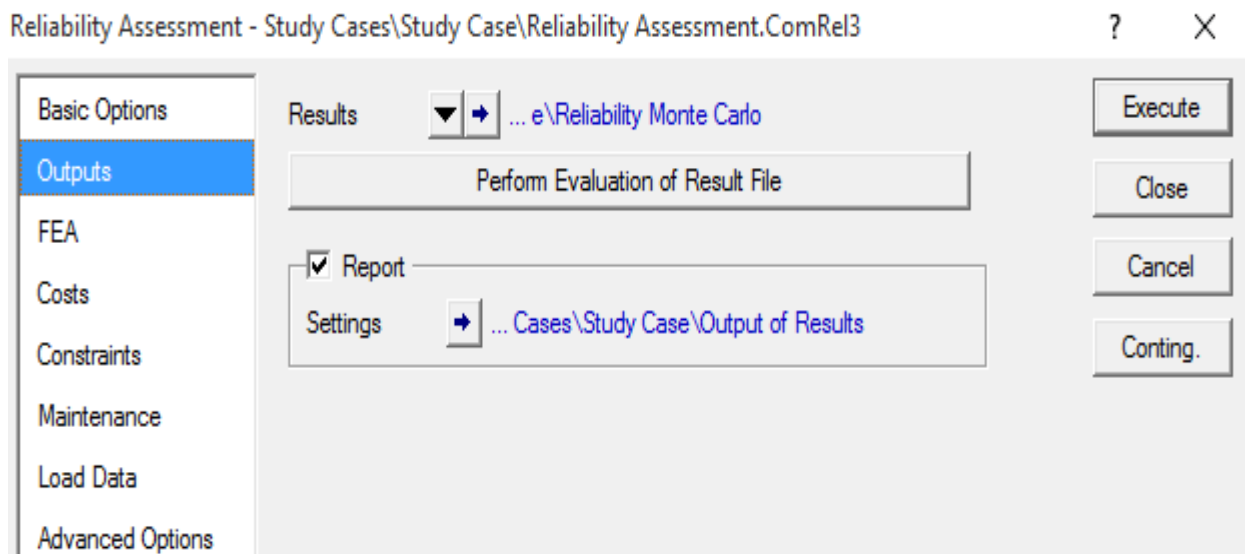


Fig.2.11: Output Tab of Reliability Assessment

CHAPTER THREE

METHODOLOGY DATA COLLECTION AND ANALYSIS

3.1 Introduction

Reliability analysis needs interruption duration, interruption frequency, total number of customers served, customers interrupted, loads connected and so on. So, under this chapter, the collected failure data and basic electrical data of power system equipment's with the specified methodology which are necessary for reliability analysis are presented. These data are analyzed to identify the current reliability status of the substation and to distinguish the main problems of interruption.

3.2 Methodology

Reliability engineering with regard to distribution systems involves gathering outage data and evaluating system designs. The outage data collected from Motta distribution feeder including of information on each failure event within the specified period of the year. The information recorded in a narrative form will translate in to a statistical database. The outages are classified as forced and scheduled. This study takes a stochastic approach to reliability evaluation.

Monte Carlo simulation method is used to generate an operating history of various components of the power system based on the measured parameters of the components. The two main parameters are Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR). The operating profiles of the components of the system, including the customer load profile, are superimposed to obtain an operation profile of the entire system from which the reliability indices are evaluated. The difference between the reliability indices obtained before and after the implementation of hybrid distributed generation units can serve as a guide to quantitatively understand the significance of the difference made by hybrid distributed generation units to the existing system. Thus, the analysis is done in two phases. In the first phase, the adequacy assessment is performed on the system with the system power represented only by the power generated by the utility controlled generation station. In the second phase, hybrid distributed generation (DG) units operating at various customer sites are included in the analysis.

The feasibility analysis of DG resources will be done by using Homer Energy software. The reliability model will be developed by using DIGSILENT Power Factory/ETAP by using analytical and Simulation (Monte Carlo) reliability analysis methods. Then the performance of the system before and after integrating the DG will be done by using DIGSILENT Power Factory/ETAP software.

3.3 Basic Data of Motta Substation

Motta substation has been supplied from main grid that is interconnected system (ICS) with Baherdar and Debre markose substation. Ethiopian Electric Power Corporation is a service provider of electric power in the country. A 230kV transmission line is strained into the substation then, the distribution system in the city has a primary voltage of 33 kV. And also, this voltage value is stepped down to 380V/220 in three phase and single phase respectively. The following one line diagram shows the overall system of the substation.

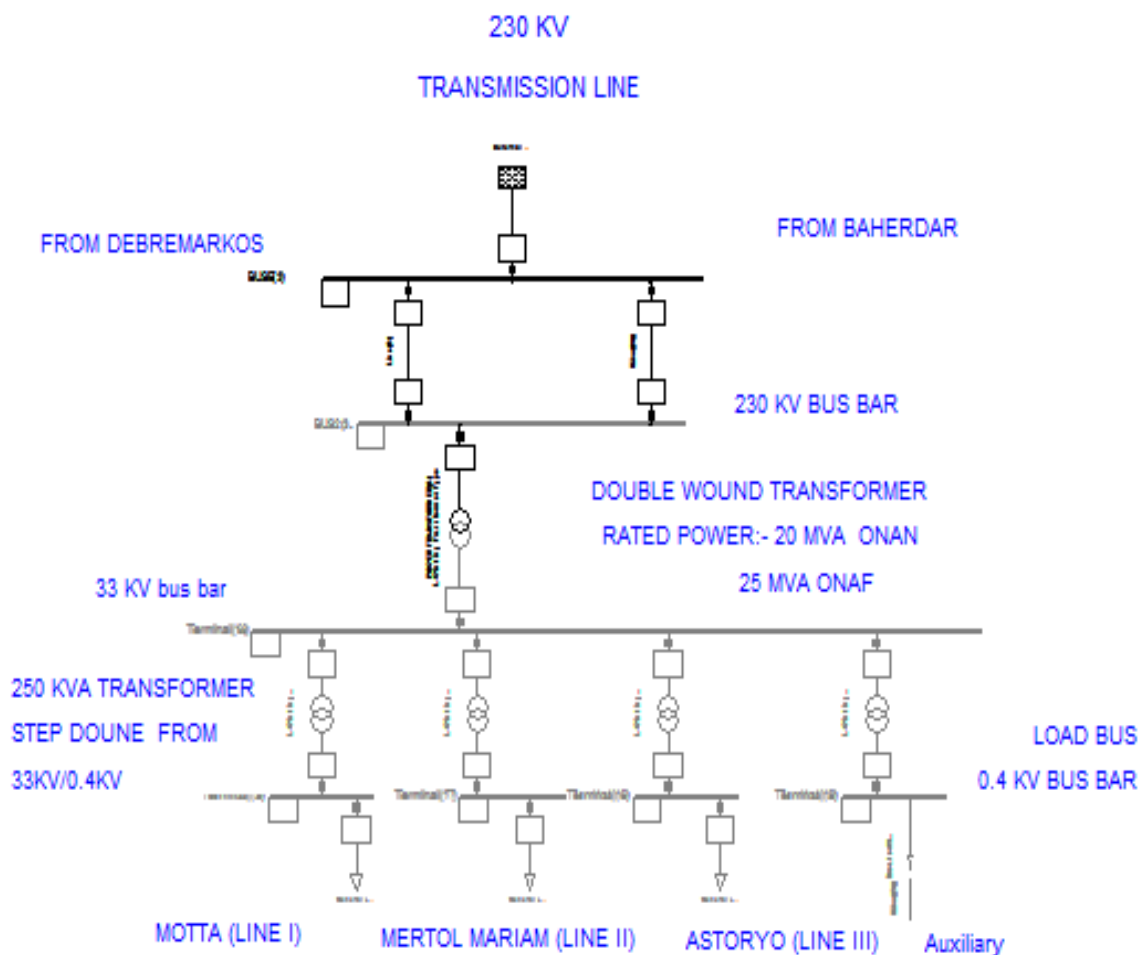


Fig.3.1: One Line Diagram of Motta Distribution Substation

The substation has 3 feeders as shown in the above one line diagram and the data for the substation is given in Table 3.1 below that contains the data of 3 feeders of the distribution network.

Table 3.1: Overview of Motta Substation Transformers

Name of the feeder	Transformer Voltage level (KV)	No of distribution transformers and ratings in (KVA)	Number of customer (N_i)	Conductor Type and Size
Motta 33/0.4		1*500	1	AAC 50mm ²
		1*400	1,056	AAC 50mm ²
		3*315	1,800	AAC 50mm ²
		15*200	2,764	AAC 50mm ²
		6*100	259	AAC 50mm ²
		10*50	1,116	AAC 50mm ²
		4*25	4	AAC 50mm ²
SUM		40 (6,045 KVA)	$\sum_{i=1}^n N_i = 7,000$	
Meltolemariya	33/0.4	1*800	1	AAC 50mm ²
		1*630	400	AAC 50mm ²
		2*400	448	AAC 50mm ²
		12*315	500	AAC 50mm ²
		18*200	643	AAC 50mm ²
		11*100	254	AAC 50mm ²
		8*50	278	AAC 50mm ²
		13*25	13	AAC 50mm ²
SUM		66(2,520KVA)	$\sum_{i=1}^n N_i = 2,537$	

Table 3.2: Annual Average Energy and Power Consumption

Feeder name	Average KVA	Average Active Power (KW)	Average Reactive Power (KVAr)	Average Active Energy (MWh)	Average Reactive Energy (MVArh)
Motta	925	832.5	402.2797	7292.7	3523.970172
Meltolemariya	1314.09	1182.685	571.5358233	10360.3206	5006.653608
Total	2239.09	2015.185	973.8155233	17653.0206	8530.62378

The annual average energy is calculated by the monthly average minimum and maximum active and reactive power of the substation that feed to the feeders and multiplies with the working hour.

From Table 3.2, the power factor of the substation can be determined. $Pf = \cos(\tan^{-1}(Q/P)) = \cos(\tan^{-1}(8530.62378/17653.0206)) = 0.9$.

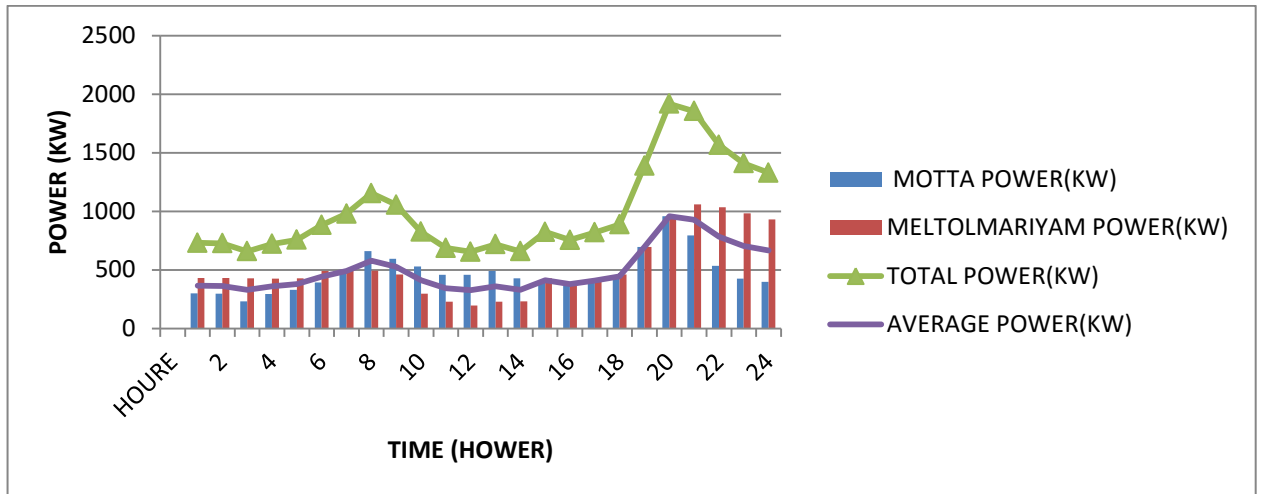


Fig.3. 2: Hourly Loads of Each Feeders of Motta Substation

As shown from hourly load of the fig 3.2, the minimum and maximum load of the feeders respectively are 196.02KW and 1059.52KW at feeder Meltolemariyam, and 230.3KW and 958.74KW at feeder Motta. The maximum load is observed during the night time in the range of 8:00 AM to 9:00 AM at feeder Motta, and from 9:00 AM to 10:00 AM at feeder Meltolemariyam. As you see the above fig 3.2 the overall maximum load is observed during night time from 8:00 AM to 9:00 AM which is 1.8MW.

3.4 Major Interruption Causes of Motta Distribution Substation

In Motta distribution substation, major faults occurring frequently are short circuit, earth fault, blackout, overload, under frequency. And there are planned outages for operational and maintenance purpose. The major faults occurring can either be of temporary and permanent type. Permanent or Sustained interruptions are long-duration interruptions which last longer than 5 minutes whereas interruptions with duration of less than 5 minutes are termed momentary interruptions [43]. Usually, only data on sustained interruptions is reported to the regulatory authority. Many of the distribution problems are temporary and mainly caused by tree, animal contact, and weather condition especially winds because of there is no line spacing between lines. They can easily be solved with little or no intervention from the system. Then by simply reclosing, the system will be re-energized. But permanent faults can't be restored by simple re-energizing. Permanent faults can be caused by Equipment malfunction, cable failure, down line or persistent tree contact [39].

Permanent (Sustained) interruptions can be classified as Planned and Unplanned Interruptions [43]. Planned interruptions (operational outages) occur mainly for the purpose of construction, preventative maintenance or repair. A planned interruption occurs at a selected time less inconvenient for the customers and the customers have been notified beforehand of the interruption. On the other hand, if the occurrence time of the interruption has not been selected, then the interruption is unplanned. Unplanned interruption occurs, for example, due to fault clearing, unwanted operation of the protection system or due to inadvertent initiation of opening operation of a switching device by a human.

Non-momentary interruption: are the results of the following faults

3.5 Distribution Short Circuit (DSC)

Short circuit is the most commonly used term to describe the cause of a power failure. It occurs when an electric current travels along a path that is different from the intended one in an electrical circuit. When this happens, there is an excessive electric current which can lead to circuit damage, fire, and explosion. In fact, short circuits are one of the primary causes of electrical fires throughout the world [27]. It also occurs when the insulation of the wiring used breaks down. It can also occur due to the presence of an external conducting material (such as water) that is introduced accidentally into the circuit. Electrical batteries can explode if they are subjected to a large current. Short circuits can even occur when electric motors are forced to

operate when the moving parts are jammed. This can result in abnormal buildup of current, ultimately leading to a short circuit.

3.6 Distribution Earth (Ground) Fault (DEF)

This fault occurs when there is a conducting connection between any electric conductor and any conducting material that is grounded or that may become grounded. Electricity always wants to find a path to the ground. In a ground fault, electricity has found a path to ground, but it is a path the electricity was never intended to be on, such as through a person's body [34]. The earth fault, caused by an insulation loss between a sentient conductor and an exposed conductive part, represents a plant engineering problem which may cause damage to the electrical installations and above all may danger for people; as a matter of fact, people could get in touch with an exposed-conductive-part not normally live but which, due to the fault, might have a dangerous potential to ground.

3.7 Distribution Line Overload

Increasing demands for electric power have caused existing power grids to become overloaded. Overloading is a public cause of line voltage fluctuations. Inadequate power generation and inadequate distribution systems are also causes of line voltage problems. Improper or poorly designed power regulating devices may create voltage fluctuations. Loose or corroded connections at the electric service user end can create voltage irregularities. The same conditions on the distribution power lines may also affect voltage. Many voltage fluctuation problems can be traced back to inadequate infrastructure [27].

3.8 Interruption Data from April 20/2009 to April 20/2010 E.C

Among the different types of power system faults, frequently occurring faults at Motta substation include permanent and transient earth fault, permanent and transient short circuit, and interruptions duet to operation/maintenance. Table 3.3 shows the duration and frequency of these different types of faults such as permanent Earth Fault (PEF), Permanent Short circuit (PSC), Transient Earth fault (TEF) and figure 3.3 shows total number of interruption and duration hour of each feeder and substation.

Table 3.3: Total Number of Interruption and Duration Hour of Feeders and Substation

Feeder Name	Frequency				Duration hour			
	PSC	TEF	Operational	Total	PSC	TEF	Operational	Total
Motta	309	223	174	706	389.09	100.02	169.06	658.17
Meltolemariya	540	232	134	906	1,334.06	480.33	315.33	2,130.12
Total	849	455	308	1,612	1,723.15	580.35	484.39	2,788.29

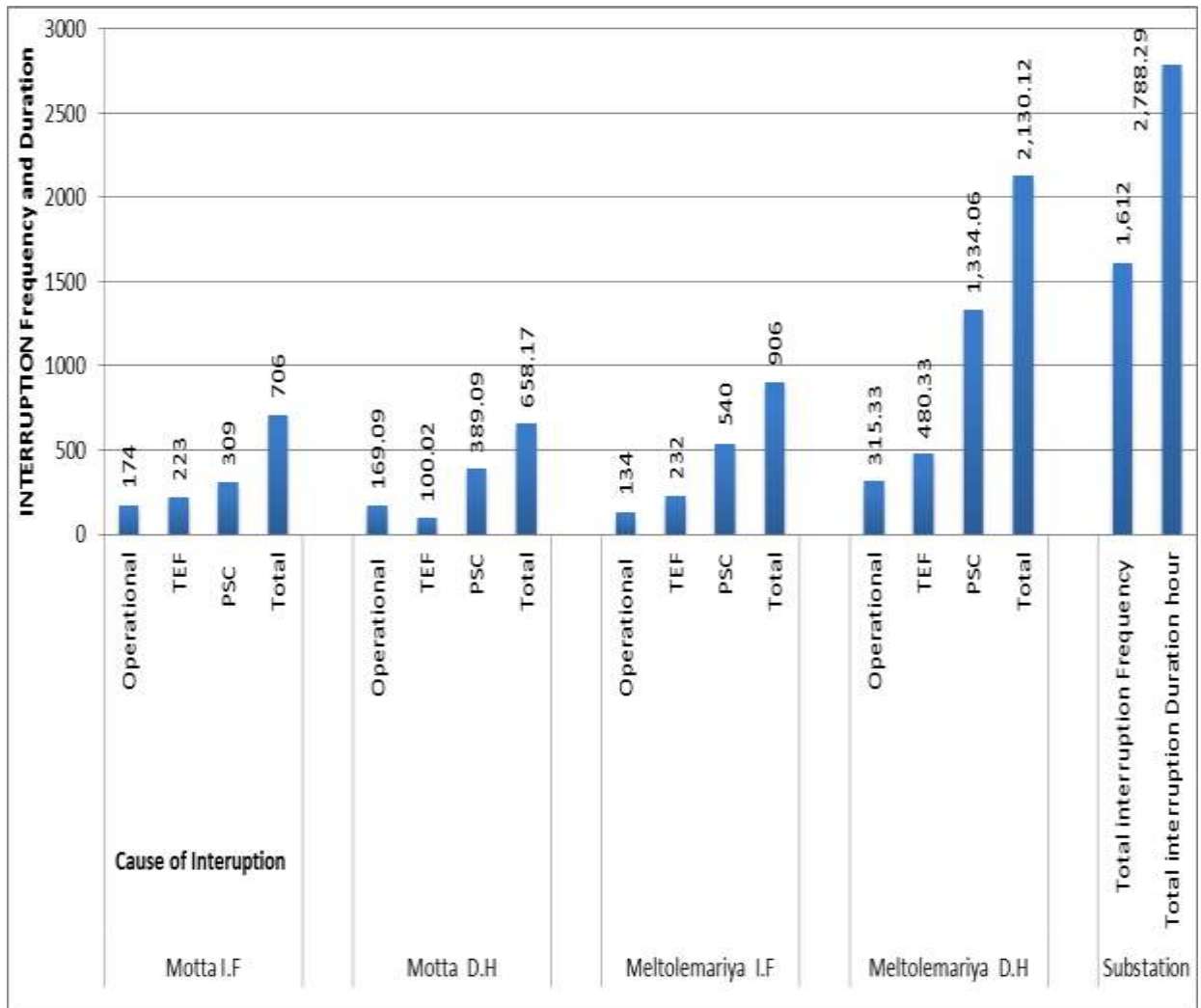


Fig.3.3: Total Number of Interruption and Duration Hour of Each Feeder and Substation

3.9 Base Case Reliability Analysis

The reliability indices of the existing substation can be calculated using equations (2.1) to (2.10), which are given in chapter two. Based on the data given in above Table 3.3, we can calculate the reliability indices of one complete year data from April 2017/18 (20/2009 E.C) to April 2018 /19 (20/2010 E.C). Therefore, Table 3.4, 3.5 and 3.6 show the reliability indices in April 2017/18 (20/2009 E.C) to April 2018 /19 (20/2010 E.C) and the average system respectively. The calculated value of substation reliability indices of each feeders are shown in Table 3.4, as a radial system with no meshed connections the failure rate (λ /year), the outage durations(hr) and average outage durations(hr/year).

Table 3.4: Radial System Reliability Indices for Main Feeders

Substation Feeders	Outage duration (hrs) / year	Interruption Occurrences	Failure rate λ (Failures/year)	Average outage U (hrs/year)
Motta	658.17	706	0.080594	53.04429
Meltolemariya	2,130.12	906	0.103425	220.3069

In the distribution system, there is no disconnects on the outgoing feeders. The only protections are the fuses that connect the main feeders and the lateral distributors. Hence, any fault on the main line will require the system to be isolated from the main breaker. The reliability assessment of each feeder can be calculated by considering the impact of each section and load point on the corresponding load point. Let us to examine the reliability assessment of the system.

First, the impact of each section failure on the load point's reliability is considered. Any section failure will result in power outage for load point since there are no disconnects on the main feeder lines. Then the outage duration r (hours) of each feeder and its failure rate λ (f/yr) is determined. Using the failure rate and outage duration, the annual outage duration U (hrs/yr) for each feeder is obtained.

Secondly, the impact of each lateral distributor's failure on the load point is considered. Since, each lateral is connected to the main feeder through fuse; a fault on any lateral will be

introducing impact on the other load point. If there is a fault on the load point, the power from the main feeder is shutdown to repair the fault; its reliability impact will be added to the system.

Adding the impact of each section and lateral distributor, the average failure rate, outage duration, and annual outage duration for the main feeders can be calculated as by using equation (3.1), (3.2) and (3.3).[]

$$\lambda_s = \sum_i \lambda_i \dots \dots \dots \text{eq (3.1)}$$

$$U_s = \sum_i \lambda_i r_i \dots \dots \dots \text{eq(3.2)}$$

$$r_s = \frac{u_s}{\lambda_s} \dots \dots \dots \text{eq (3.3)}$$

From the above equations the other parameters of each feeder were calculated as shown in the Table 3.5.

Table 3.5: The Main Feeder Availability and Unavailability Indices

Substation Feeders	N_I	λ_I	r_i	$\lambda_i N_i$	ASAI (%)	ASUI (%)
Motta	7,000	0.080594	658.17	56.89936	92.48	7.52
Meltolemariya	2,535	0.103425	2,130.12	93.70305	75.68	24.32
Sum	9,535				84.08	15.91

The load and energy based indices are calculated, using outage duration and average load of each feeders. Those are the expected Energy Not Supplied, the Average Energy Not Supplied and the Expected interruption Cost (EIC) values are shown in Table 3.7 based on EEPCO'S electricity tariff at Table 3.6 bellow. The priority order based on the EIC was used for load curtailment level; the EIC is the average monetary impact on the customers at a load point. This higher the EIC the higher priority this load may have, because a load curtailment at that load point will contribute to higher economic cost.

Table 3.6: EEPCO'S Electricity Tariff (Birr/Kwh) [44, 45]

Residential	Active Energy Range (kWh)	Price Rate (Birr/kWh)
	0-50	0.2730
	51-100	0.3564
	101-200	0.4993
	201-300	0.5500
	301-400	0.5666
	401-500	0.5880
	Above500	0.6943
Commercial	0-50	0.6088
	Above 50	0.6943
Low Voltage Time of Day Industry @ 15kv		
Peak		0.7426
Off-peak		0.5354
High Voltage Industry @ 132KV		
Peak		0.4736
Off peak		0.3664

Table 3.7: Expected Energy Not Supplied and Interruption Costs Indices for Each Feeder

Substation Feeders	Expected Energy not supplied (MW hr/yr)	Expected Interruption Cost EIC (Eth, Birr /yr)	Average Energy Not Supplied (MW hr/yr. ca.)
Motta	7, 828.155	4,148,922.15	1.101
Meltolemariya	14, 519.26	7,695,207.8	1.407
Total	22,347.415	11,844,129.95	2.508

As shown in Table 3.7, the total average energy not supplied and average cost of energy not supplied due to power interruption for one month at Motta distribution substation outgoing feeders is 22347.415 MWh and 11,844,129.95 Birr (0.438672 million USD) respectively. The total average cost of energy not supplied because of power interruption per year for the substation's outgoing feeders is $12 * 11,844,129.95 = 142.13$ million Birr or 5.264M USD using current currency rate of commercial bank of Ethiopia 1\$ is 27 Ethiopian birr.

Using the data from the above table, the overall base case reliability indices can be determined is shown in Table 3.8:

Table 3. 8: System Indices

Indices	Units	Value
SAIFI	Inter. / customer. Yr	806
SAIDI	Hrs / customer. Yr	1,394.145
CAIDI	Hrs / customer interruption	1.729
ASAI	%	84.08
ASUI	%	15.91
EENS	MWh/yr	22,347.415
EIC	m\$ /yr	0.4386715
AENS	KWh/ ca. yr	2.508

The reliability index of the main feeder provides different information and some indices are more important than others. The main feeder indices are useful in assessing the load point impact of system adjustments and provide input to reliability evaluation at the actual customer level. Furthermore, there are the system reliability indices which provide valuable information on the overall ability of the system to supply the customer load. Once we calculate the reliability indices then we have to compare it with the benchmark values of that network, in this case the calculation results are compared with benchmark value set by EEPCO. And also the result is compared with standards of different countries by selecting two most widely used reliability indices which are SAIFI and SAIDI values.

Table 3.9: Shows The Comparison of The Most Commonly Used Reliability Indices With Different Countries[45, 46].

Country	SAIFI (Int./Year/Customer)	SAIDI (Hr./Year/Customer)
United States	1.5	4
Australia	0.9	1.2
Denmark	0.5	0.4
France	1.0	1.03
Germany	0.5	0.383
Italy	2.2	0.967
Netherland	0.3	0.55
Spain	2.2	1.73
United Kingdom	0.8	1.5
Ethiopia	20	25
Motta substation	806	1,394.145

Standing from the above reliability index analysis we can generalize as follows:

1. SAIFI of the overall system as shown in Table 3.8 is 806 int. /yr. As per Ethiopian Electrical Agency's (EEA's) standard, SAIFI should not exceed 20 interruption per customer per year, which indicates that the current value is above the acceptable value by large margin. And also, when we compare the calculated SAIFI value with German standard, it is much greater than the maximum limit[39, 44]. This clearly indicates that there is serious reliability problem in the present Motta distribution substation.
2. SAIDI of the system is 1394.145 hours per customer per year. This shows that every customer experiences 1,394.145Hr per year. This proves that there is great reliability problem in the existing Motta distribution substation. As per (EEA), the SAIDI value should not exceed 25 hours per customer per year. The permissible SAIDI value in Germany is 0.383 hours per customer per year.
3. ASAI: It is the average service availability index which shows the fraction of time that a customer has received power during the reporting period. The power supply of the overall system is 84.08% available as shown in Table 3.5 However, this value is not still good enough since the ASAI value should be greater than 99.98% as per EEA's standard [34].

4. ENS: It indicates the un-served or unsold energy of each feeder. For the overall system, the total unsold energy was 22,347.415 MWh as given in Table 3.7.

5. AENS: This index represents the average energy not supplied per customer by the system. The overall system has an AENS value of 2.508 MWh per customer.

In general, based on the data analysis the following points can be drawn:

- The reliability of the Motta distribution substation does not meet the requirements set by the regulatory body that is Ethiopian Electric Agency (EEA).
- The reliability of Motta distribution substation is not good enough as compared to the international reliability indices of best experienced countries.
- There is high unavailability of services in the network.
- There is also much loss of Unsupplied Energy due to both planned and unplanned outages in the present power grid of Motta distribution substation
- Generally the utility losses around 142.13million Birr or 5.264 million USD during one year due to higher interruption and duration hour.

3.10 Site and Size of Distributed Generation

Objective Function:

The objective is to maximize generation capacity subject to the constraint outlined in equation (3.4) and to minimize the customer outage cost that can be written as follows in (3.5). This methodology ensures optimal use of the existing network assets, thus helping to meet the DG targets in a cost effective manner. Generation capacity should be allocated across the buses such that none of the technical constraints are breached and the capacity maximized. Therefore the proposed objective function is as shown in Equation (3.4).

$$J = \sum_{i=1}^N P_{DGi} \dots \dots \dots eq(3.4)$$

Where P is the DG capacity at the i bus and N is the number of buses.

$$Minimize EIC = \sum_{h=1}^{n_h} \sum_{i=1}^{n_i} (L_{a(i)} \lambda_h r_h C_{h(i)} \dots \dots \dots eq(3.5)$$

Where: $L_{a(i)}$ = average load connected to load point i

C_{hi} = outage cost (\$/kWh) of customer due to contingency h

λ_h = failure rate of contingency h

r_h = failure time of contingency

nh = number of contingency

ni = total number of load point i

The objective function J (MW), given in Equation (3.4) is maximized and EIC (\$/kWh), given in Equation (3.5) is minimized subject to the constraints, which are formalized below.

➤ Power flow constraint:

$$P_k = \sum_{i=1}^N Y_{ik} V_k V_i \cos(\theta_{ik} + \delta_k - \delta_i) \dots \dots \dots \text{eq(3.6)}$$

$$Q_k = - \sum_{i=1}^N [Y_{ik} V_k V_i] \sin(\theta_{ik} + \delta_k - \delta_i) \dots \dots \dots \text{eq(3.7)}$$

➤ The voltage of each bus k must be within standards limits

$$V_k^{min} \leq V_k \leq V_k^{max} \dots \dots \dots \text{eq (3.8)}$$

➤ Current transfer capability of feeder lines:

$$I_l \leq I_l^{max}; l \in (1,2,3 \dots \dots \dots N) \dots \dots \dots \text{eq (3.9)}$$

3.10.1 Placement of DG Based on load flow bus voltage

In order to restrict solution space to few buses, voltage sensitive buses are first identified by using the per unit value of each bus voltage of all the nodal and load side and compared to the expected standard value of minimum value 0.90 and maximum value of 1.005V.

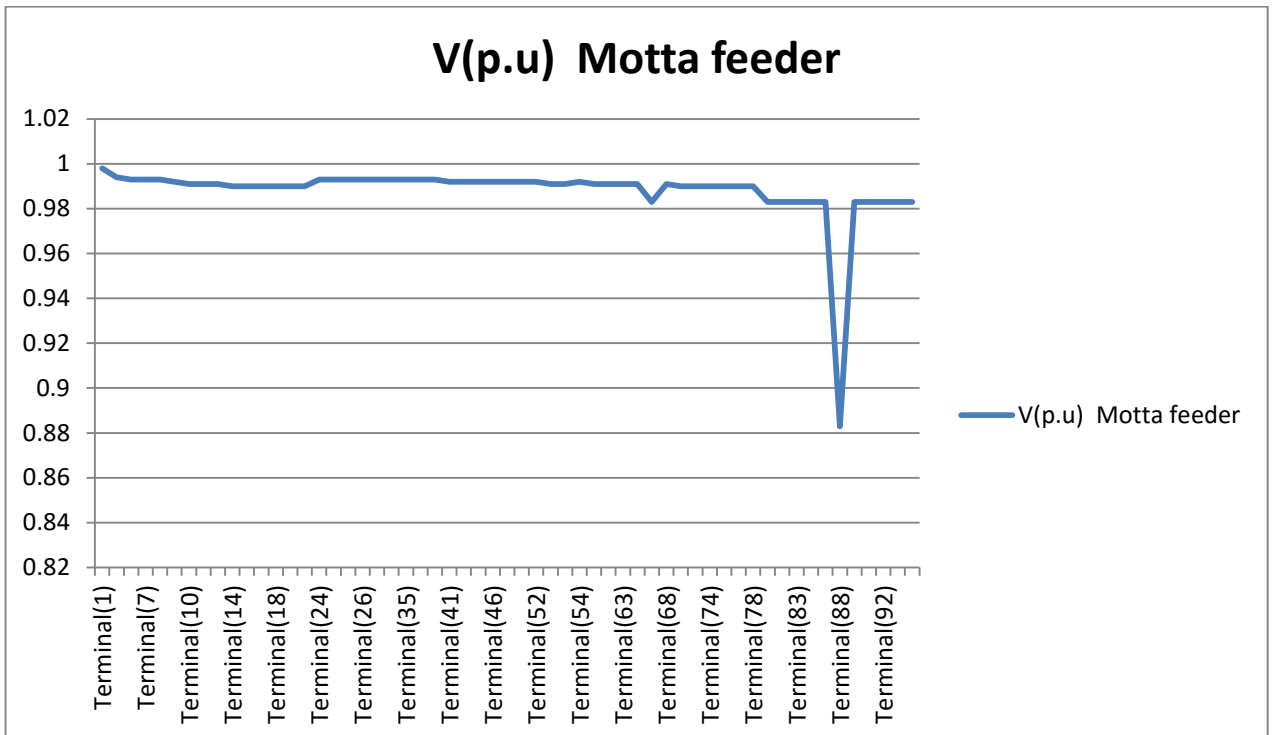


Fig.3.4: Bus Voltage value of Motta Distribution Feeder

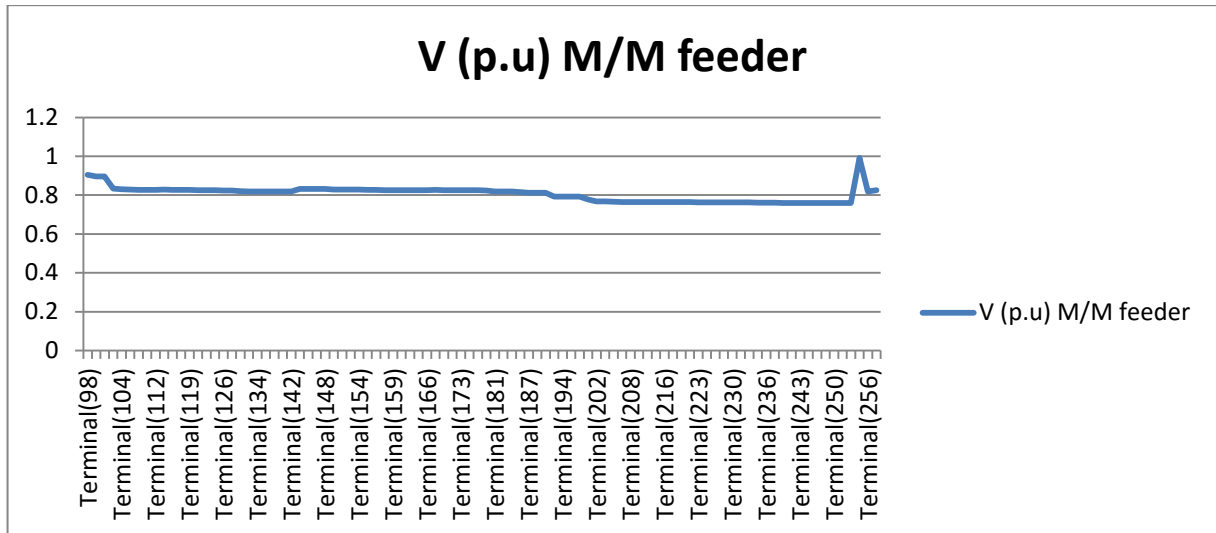


Fig.3.5: Bus Voltage value of Meltolemariyam Distribution Feeder

As seen from above fig 3.4 and 3.5 the base load flow feeders which are 0.88pu at bus number 88 of Motta feeder and 0.76pu at bus number 253 and 202 of Meltolemariyam feeder respectively. As compared to the standard of load flow bus voltage that is minimum value 0.90pu and that of maximum value 1.005pu voltage value Motta feeder is close to standard as compared to Meltolemariyam that is minimum value of 0.88pu and maximum value of 0.99pu and minimum value of 0.76pu to maximum value of 0.904pu respectively.

Generally Meltolemariyam feeder voltage profile is completely below of the standard and the bus that has low voltage value in both feeders is found fare from the station which is closed to more interruption is occurred as seen from above table 3.3 above temporary earth fault and permanent short circuit fault is cover the maximum reliability problem which is occurred fare from the station so the DG placement is related with the reliability because this two reliability causes are occurred always at the load side which is fare from the station.

3.11 Size of DG

To determine the optimal size of DG, the following steps are taken

1. First, the DG is placed at the bus with least voltage value
2. Keeping the power factor of DG constant which is 0.9 the same as the distribution system power factor, its size is varied from a minimum value to a value equal to feeder loading capacity in constant steps until the minimum system losses and reliability index value.
3. The DG size which results in minimum losses and reliability index is taken as optimal size of DG.

3.12 The change of Power loss and Reliability Index as DG size is varied

The value Motta distribution substation feeder distribution system of total active and reactive power loss and reliability index is decreases as the value of DG is increases from its minimum value to a value equal to feeder loading capacity at constant steps, the minimum system losses is at DG value of 2.1 MW active power at constant power factor of 0.9 which is the substation power factor as shown in table 3.10. When the value of DG increases above 2.1 MW the loss and reliability index of the system is increase because of that is what DG penetration limit that affects the power loss that has direct impact on energy not supplied.

Table 3.10: Power Loss and Reliability Index Variation as DG Increase

DG Value (MW)	Total power loss		Reliability			Comment
	Active (MW)	Reactive (MVar)	SAIFI (1/Ca)	SAIDI (h/Ca)	ENS (MWh/a)	
With Out DG	1.93	1.43	806.051958	1,394.545	22,347.415	
0.000001	1.02	0.66	801.215	1,386.10195	22,212.284	
0.005	1.02	0.65	772.8567	1,337.042	21,426.098	
0.05	0.99	0.64	605.5479	1,047.598	16,787.758	
0.1	0.95	0.63	549.14729	950.0248	15,224.147	
0.6	0.66	0.51	376.07453	715.8466	7,478.4494	
1.1	0.47	0.44	204.106437	388.5105	4,058.7692	
1.6	0.36	0.40	167.28643	318.4247	3,526.5828	
2.1	0.32	0.39	17.582090	334.670	3,496.499	Exact Size of DG
2.6	0.38	0.42	17.682090	334.675	3,501.5876	

3.13 Types of Accessible DG Technology around Feeders

As discussed in chapter two, there are different technologies or resources of distributed generation. Among those resources, the selection of a specific DG technology to a certain area depends on availability of resources, suitability to environment, and cost of DG technology. Different geographical areas have different resources, both renewable and non-renewables. For instance, the solar energy availability varies from place to place and the wind energy

resources vary due to the difference in wind speed of different areas. DG technologies also differ in their positive and negative impacts they have on the surrounding environment. One of the impacts is emission level of gases like, CO, CO₂ and etc. to the environment. The following table shows that emission levels and cost of various DG technologies. Cost of each technology is another factor. This is shown in Table 3.11.

Table 3.11: Emission Levels Different DG

Technology	Emission	Cost
PV	No	Moderate
Fuel cell	Low	High
Wind turbine	No harmful emission	Moderate
Diesel generator	High emission	Low
Micro turbine	Low	Moderate

Based on the above factors, the DG technologies selected in this thesis are wind /PV hybrid renewable energy system.

3.14 Wind /PV Hybrid Renewable Energy System

Hybrid wind and photovoltaic (PV) power generation are two of the most promising renewable energy technologies as duo are complimentary to each other and hence able to provide good and constant supply to meet the rise in demand [49].

Renewable energy sources have unpredictable random behaviors. However, some of them, like solar radiation and wind speed, have complementary profiles.

It has been reported that in weak grids, the wind/solar hybrid system is better than single wind or PV generation since it suppresses rapid change in the output power of the single source such as the wind turbine system. Grid interface of the hybrid system with battery storage improves system reliability[50, 51].

The hybrid energy system proposed consists of wind, solar power as depicted in Fig. 3.6. The energy system consists of a wind turbine generator, solar PV array, battery bank, grid power, load and an AC/DC converter. The hybrid system optimization is done by HOMER software.

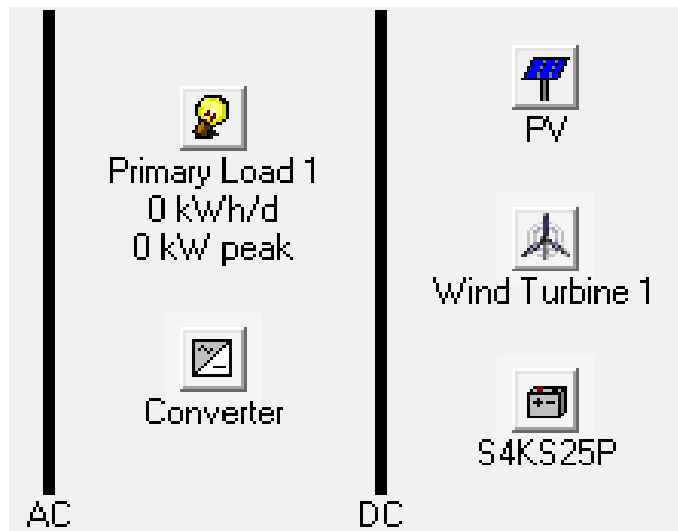


Fig.3.6: Schematic Diagram of Hybrid Energy System

3.15 About What the HOMER Does and Optimize

HOMER, the micro power optimization software developed by Mistaya Engineering, Canada for the National Renewable Energy Laboratory (NREL) USA, used in this analysis simplifies the task of evaluating designs of both off-grid and grid-connected power systems for a variety of applications. In designing a power system, many decisions about the configuration of the system are to be made: components to include in the system design, size of each component to use etc. The large number of technology options and the variation in technology costs and availability of energy resources make these decisions difficult. HOMER's optimization and sensitivity analysis algorithms make it easier to evaluate the many possible system configurations. HOMER allows the designer to compare many different design options based on their technical and economic merits. Recently, it is being used widely in the field of renewable energy. It can be used with any combination of wind turbines, PV arrays, run-of-river hydro power, biomass power, internal combustion engine generators, micro-turbines, batteries, and hydrogen storage, serving both electric and thermal loads. The advantage of HOMER is that it can involve also all costs such as the initial capital and the maintenance costs including pollution penalties [52].

The hybrid system has been designed based on the following steps:

1. Power requirement,
2. Availability of Solar and Wind Resources,
3. Configure the inputs for generating sustainable conditions
4. Simulations of the sustainable Hybrid Systems,
5. Chosen of the optimum system for fulfilling the consumer requirement.

3.16 Wind Turbine Generator Specification

Size: small (0.3 - 50 kW), Large (300 kW – 5 MW),

Efficiency: 20 – 40%,

Installed cost (\$/kW): large-scale (900 - 1,100), small-scale (2,500 - 5,000),

O&M cost (\$/kWh): 0.005

Wind speed: – Large turbine: 6 m/s at average sites – Small turbine: 4 m/s at average sites

Typical life of a wind turbine: 25 years

Determine the energy load required in watt-hours per day. Determine the hours per day of available wind at the site in hours/day. Then divide the energy needed by the number of available wind hours per day to determine the WTG size required. Calculate the cost of the WTG system needed for this application. Multiply the size of the WTG by \$4.5 per watt and cost estimated for WTG in \$ is calculated which includes inverter cost. Then multiply the subtotal by 0.2 (20%) to cover balance of system cost and finally total estimated WTG system cost is calculated.

3.17 Work Sheet-Estimating the Cost of Stand Alone Photo Voltaic System

To determine the load, available sunlight, array size, battery bank size: Determine the energy load required in watt-hours (Wh) per day. Multiply the number of watts the load will consume by the hours per day the load will operate. Multiply result by 1.5 which is to correct inverter loss so that total Wh per day required in Wh is obtained. Determine the hours per day of available sunlight at the site to obtain the total available sunlight in hrs/day. Divide the energy needed by the number of available sun hours per day to get total array size required in Watts. Multiply the load by 5. Then divide by the battery voltage amp-hour (Ah) to get total Battery Bank Required in Ah.

To calculate the cost of the PV system needed for this application. Multiply the size of the array by \$5 per watt to get cost estimate for PV array in \$. If a battery bank is used, multiply the size of the battery bank by \$1 per amp hour. If an inverter is used, multiply the size of the array by \$1 per rated watt.. Multiply the subtotal above by 0.2 (20%) to cover balance of system costs (wire, fuses, switches, etc.). Finally Total Estimated PV System Cost is calculated.

3.18 Wind and Solar Resources

The wind resource information was obtained from NASA, Surface meteorology and Solar Energy, a renewable energy resource web site [53] and Ethiopian metrological agency

Baherdar district and the site of feeder Motta is found 11°5'N 37°52'E and feeder Meltolemariya also found 10°51'N 38°16'E. It gives all the details of wind speed throughout year and it is plotted in the Fig.3.7 to Fig 3.10 below. The solar resource for the remote study area is also obtained from NASA. The monthly average solar irradiance is summarized in Fig.3.5. The wind speed is measured from 10m height so using the relation below equation 3.11 the value is taking from 70 m height.

$$V = \left(\frac{H_2}{H_1}\right)^\alpha * V_0 \dots \dots \dots eq (3.11)$$

Where H₁ is height at the measured of wind speed

H₂ is height that proposed which is 70m

V is wind speed m/s

α is the wind shear exponent between (0 – 1) which is (0.4) for a stable atmosphere

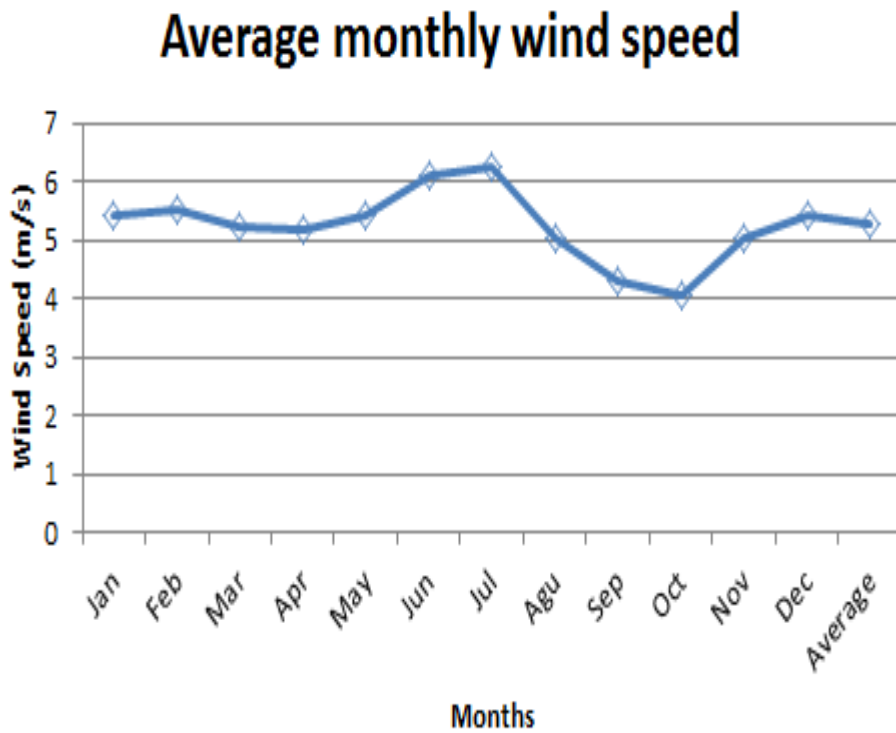


Fig.3.7: Average Monthly Wind Speed of Motta

As we see from the above wind speed fig 3.7 the highest wind speed is during July which is 6.25 m/s whereas the lowest is during October which is 4.05 m/s and the average wind speed is 5.253 m/s.

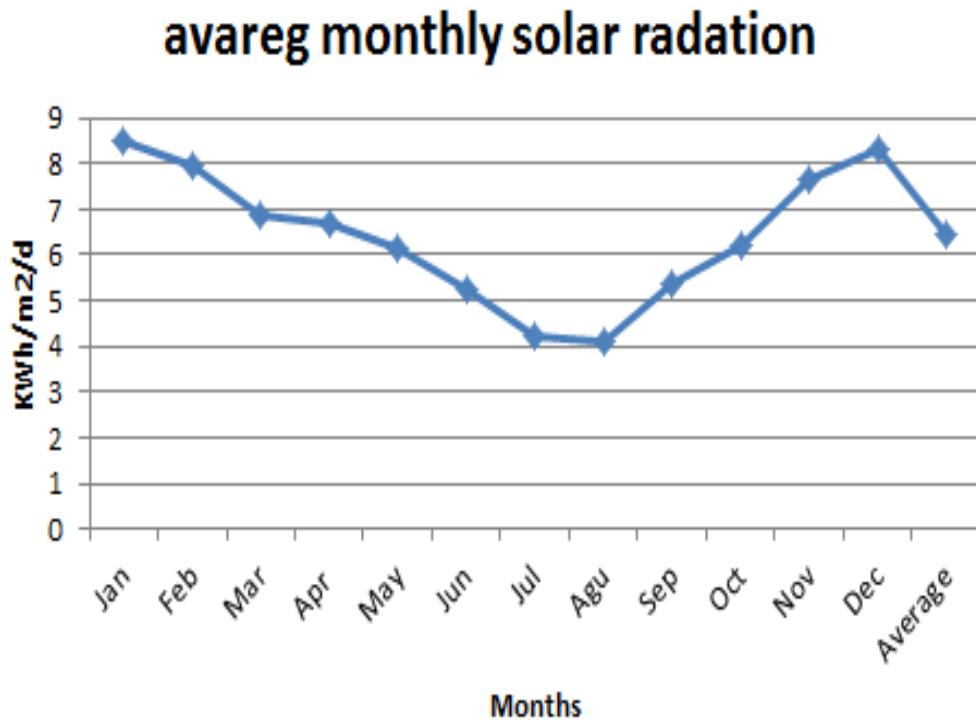


Fig.3.8: Average Monthly Solar Radiation of Motta

As we see the monthly average solar radiation the highest is during January and the lowest is during August which is 8.48 and 4.1 KWh/m²/d respectively and the average monthly solar radiation is 6.44 KWh/m²/d.

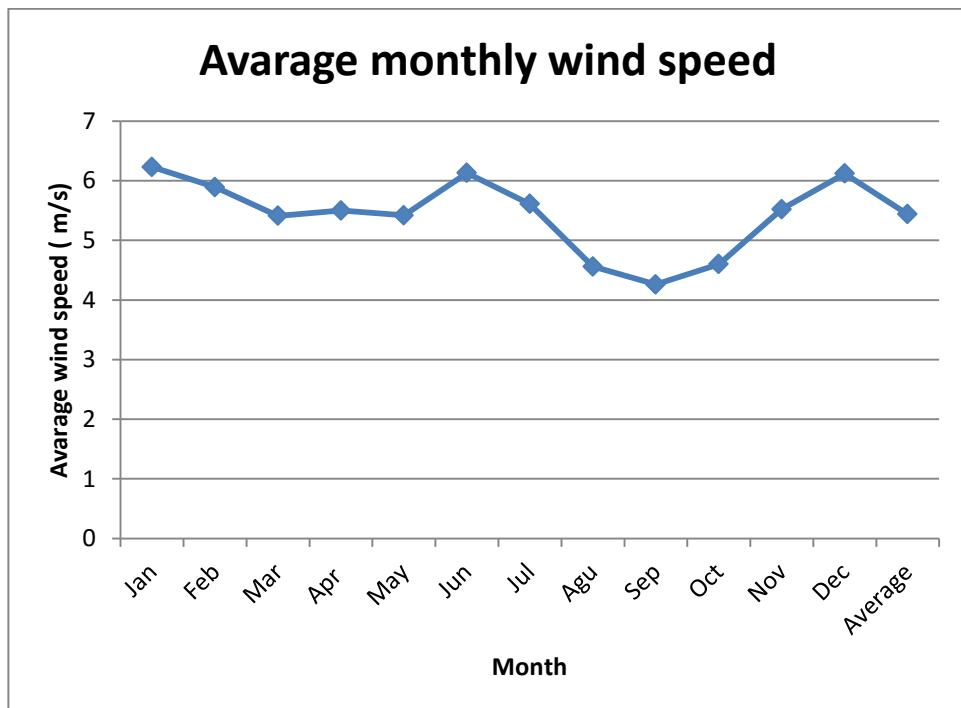


Fig.3.9: Average Monthly Wind Speed of Meltolemariyam

The monthly average wind speed around Meltolemariyam see from above fig 3.9 the maximum and minimum value is at January and September which has 6.23 and 4.26 m/s respectively with the monthly average value of 5.44 m/s.

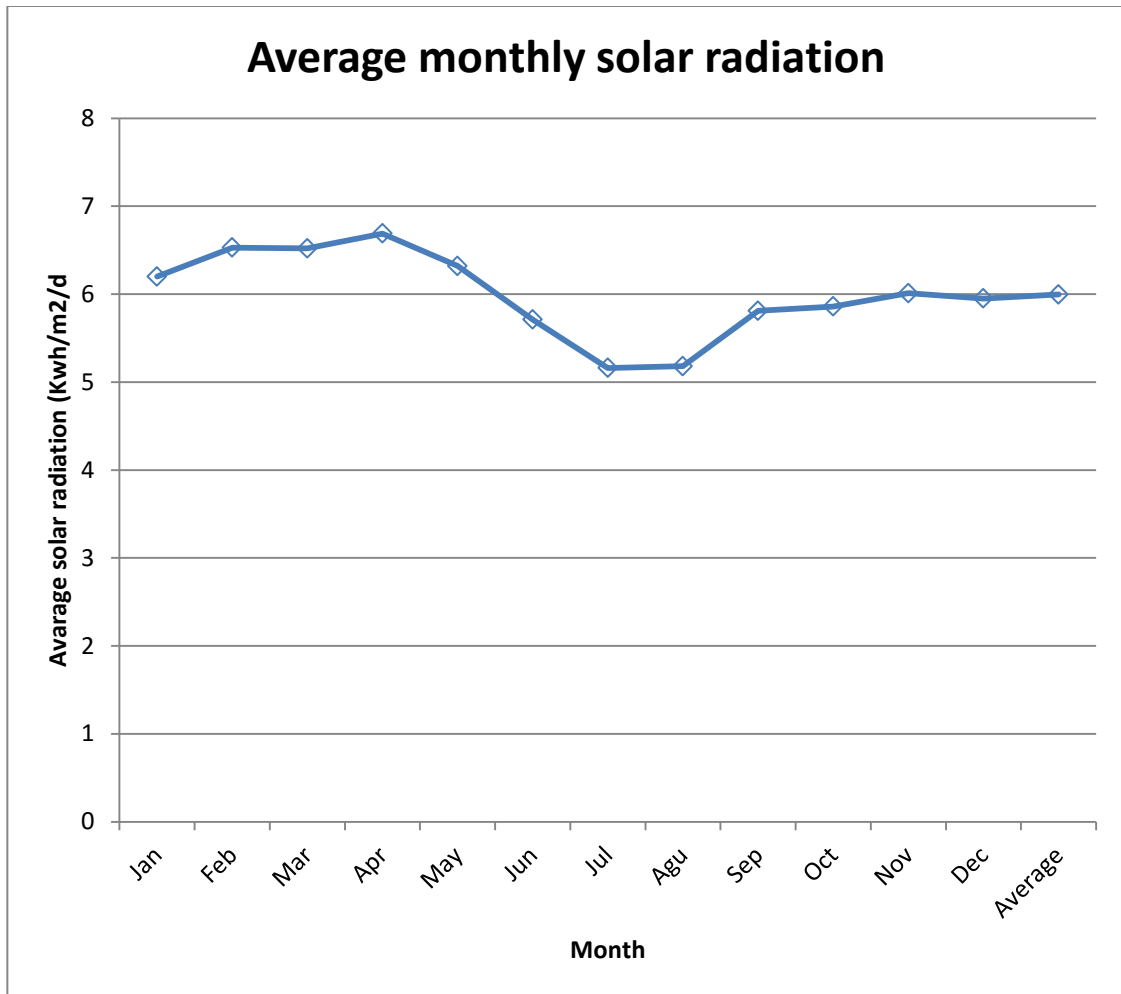


Fig.3.10: Average Monthly Solar Radiation of Meltolemariyam

The monthly average solar radiation around Meltolemariyam see from above fig 3.10 the maximum and minimum value is at April and July which has 6.69 and 5.16 KWh/m²/d respectively with the monthly average value of 5.99 KWh/m²/d.

Generally for the HOMER sensitivity analysis done by using the monthly wind speed and solar radiation of each site, the cost of each materials used for the hybrid system such as Battery, Solar panel, wind turbine, Convertor and also it requires the daily load curve of each feeder. But the daily load curve of each feeder is lower than the required distributed generation size so due to these consider the number of required materials for the hybrid system is increase and the total cost also increase in respective of DG demand.

Table 3.12: Technical data and study of assumptions of component [54, 55]

PV Array	DC
Capital cost	4000\$
Replacement cost	3000\$
O& M cost	0\$
Efficiency	15%
Lifetime	25 Year
Tracking system	No Tracking
Wind Generator	BWC Excel –s
Technology	AC
Power	10KW
Hub Height	70
Capital cost	30000\$
Replacement cost	25000\$
O& M cost	50\$
Lifetime	25 Year
Battery	DC
Technology	Vision 6FM200D
Capacity	2.4kwh
Nominal Capacity	200Ah
Voltage	12V
Min. state of charge	40%
Capital cost	900\$
Replacement cost	800\$
O& M cost	10\$
Efficiency	80%
Lifetime	12 year
Converter	AC/DC/AC
Capacity	200kw
Capital cost	700\$
Replacement cost	700\$
O& M cost	50\$
Efficiency	90%
Lifetime	15 year
System Data	
Project life time	25 year
Maximum annual capacity shortage	50%

CHAPTER FOUR

SIMULATION RESULTS AND DISCUSSION

4.1. Modeling of Distribution System

The single line diagram of the distribution substation network is shown in Fig. 4.1. The network is formed by two radial feeders, namely Motta and Meltolemariyam there distribution system of 33 kV Motta distribution substation, owned by Ethiopian Electric Utility (EEU).

The distribution system Reliability Bus bar Test system known as RBTS with some changes in the configuration of the system shown in Fig.4.1 has two outgoing feeders with their distribution system at the voltage level of 33 kV and 0.4 kV. It is assumed that 230 kV circuit breakers are operates successfully when required, disconnects are opened whenever possible to isolate a fault and the supply restored to as many load points as possible using appropriate isolators and the alternative supply is available. The change is that the existing system connected with DG units at the 33 kV bus of outgoing feeders and after low voltage transformers (33/0.4 kV) i.e. 0.4 kV. In this study, there is no restriction in the load transfer, meaning that DG units play a role exactly similar to a power source.

The following case studies are undertaken to the overall substation shown below

- Base case Monte Carlo and Enumeration total power loss and reliability analysis
- Monte Carlo and Enumeration Reliability analysis after DG is added at the bus which has least VSI
- Comparison of total power loss and the reliability without DG and with DG
- Comparison Motta distribution substation feeder system voltage with and without DG

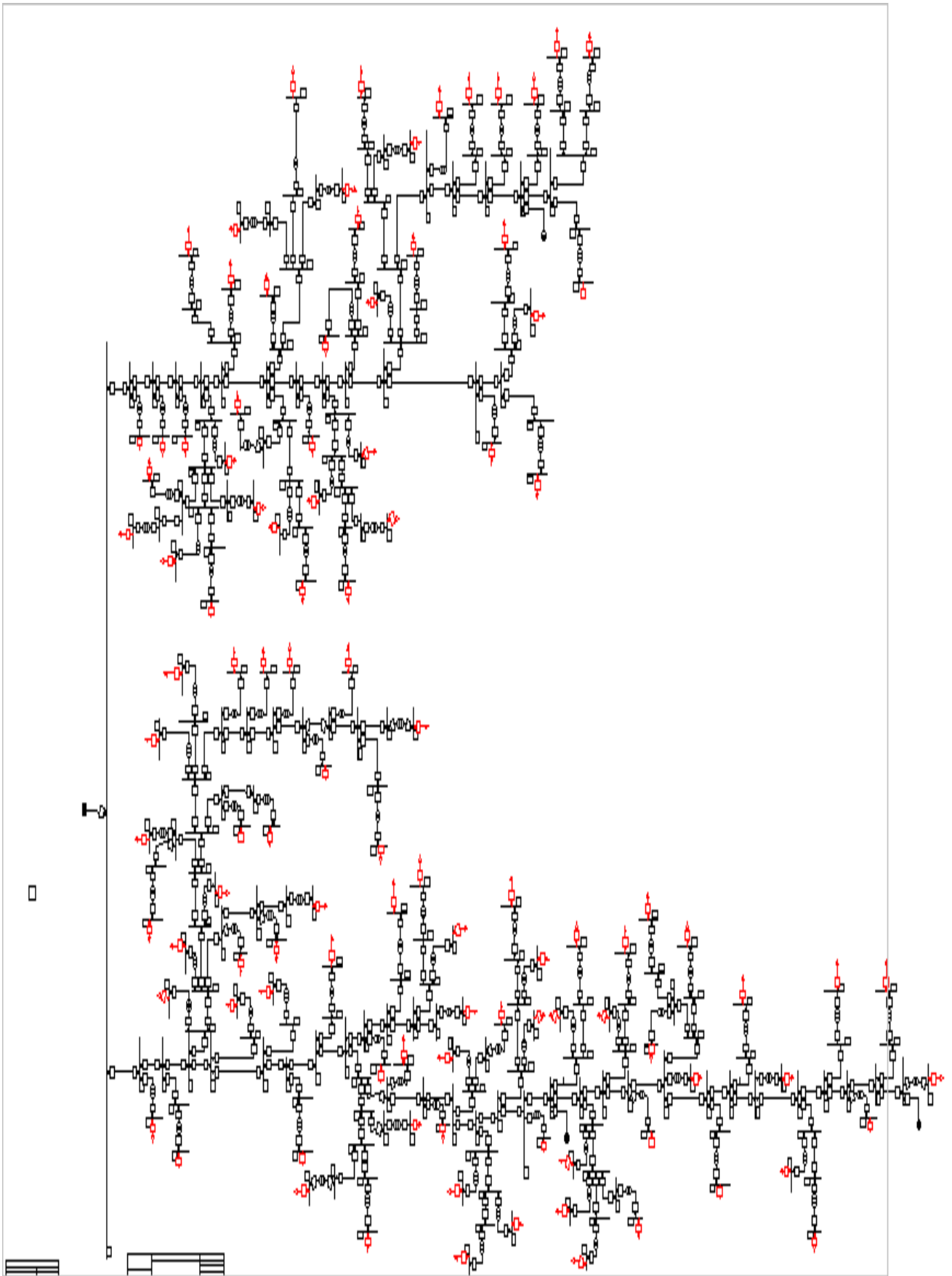


Fig.4.1: Motta Distribution Substation Feeder

4.2. Base Case Monte Carlo and Enumeration Reliability Analysis

The distribution system has reliability index analysis using Monte Carlo and Enumeration methods shown in table 4.1 below.

Table 4.1: Base Case Monte Carlo and Enumeration Reliability Index

Reliability Index	Monte Carlo simulation	Enumeration simulation	Percentage Change
SAIFI	806.051958 1/Ca	973.835596 1/Ca	-0.20815
CAIFI	806.051958 1/Ca	973.835596 1/Ca	-0.20815
SAIDI	1394.545 h/Ca	1577.134 h/Ca	-0.13093
CAIDI	1.730 h	1.620 h	0.063584
ASAI	0.8408053089	0.8199619000	0.02479
ASUI	0.1591946911	0.1800381000	-0.13093
ENS	22347.415 MWh/a	22628.459 MWh/a	-0.01258
AENS	2.508 MWh/Ca	2.539 MWh/Ca	-0.01236
ACCI	7.519 MWh/Ca	7.614 MWh/Ca	-0.01263
EIC	0.438 M\$/a	0.444 M\$/a	-0.0137
IEAR	0.020 \$/kWh	0.020 \$/kWh	0
ASIFI	1240.787088 1/a	1302.540786 1/a	-0.04977
ASIDI	2212.100734 h/a	2299.114470 h/a	-0.03934

As we see table 4.1 above Monte Carlo analysis is best than that of analytical enumeration analysis because each reliability index is improved that is:-

- SAIFI and CAIFI is improved by 20.81%
- SAIDI is improved by 13% and CAIDI is dis proved by 6.35% because

$$CAIDI = \frac{SAIDI}{CAIFI}$$
- ASAI is improved by 2.47% and ASUI is reduced by 13.09%.
- ENS and AENS are reduced by 1.25% and 1.23% respectively so the IEC is reduced by 1.37% at constant IEAR of 0.020\$/kWh
- ASIFI and ASIDI are improved by 4.9% and 3.9% respectively.

4.3. Reliability Monte Carlo and Enumeration Analysis after DG is added

Table 4.2: Monte Carlo and Enumeration Reliability Index with DG

Reliability Index	Monte Carlo simulation	Enumeration simulation	Percentage Change
SAIFI	17.582090 1/Ca	30.117159 1/Ca	71.29453324
CAIFI	17.582090 1/Ca	30.117159 1/Ca	71.29453324
SAIDI	334.670 h/Ca	562.347 h/Ca	68.0302985
CAIDI	19.035 h	18.672 h	-1.907013396
ASAI	0.9617956668	0.9358051769	-2.702288105
ASUI	0.0382043332	0.0641948231	68.0302147
ENS	3496.499 MWh/a	5780.192 MWh/a	65.31370379
AENS	0.392 MWh/Ca	0.649 MWh/Ca	65.56122449
ACCI	3.311 MWh/Ca	1.953 MWh/Ca	-41.01479915
EIC	0.069 M\$/a	0.113 M\$/a	63.76811594
IEAR	0.020 \$/kWh	0.020\$/kWh	0
ASIFI	13.896957 1/a	24.810774 1/a	78.53386177
ASIDI	346.107505 h/a	588.773111 h/a	70.1127836

As we see table 4.2 above Monte Carlo analysis is best than that of enumeration analysis after DG is added because each reliability index is improved that is:-

- SAIFI and CAIFI is improved by 71%
- SAIDI is improved by 68% and CAIDI is proved by 1.9 % because
$$CAIDI = \frac{SAIDI}{CAIFI}$$
- ASAI is improved by 2.7 % and ASUI is improved by 68 %.
- ENS and AENS are reduced by 65.31% and 65.56% respectively so the IEC is reduced by 63.76 % at constant IEAR of 0.020\$/kWh
- ASIFI and ASIDI are improved by 78.53% and 70.11% respectively.

From the above tables 4.1 & 4.2, it is observed that the total power loss and the reliability of the distribution substation are much more reduced. And from the comparison of the two reliability analysis methods that is Monte Carlo and Enumeration; Monte Carlo method is the one that improves the reliability before and after the distributed generation is add to the distribution substation feeders.

The distributed generation has positive impact on the distribution system with any analysis that is either Monte Carlo or Enumeration because as seen from the above table 4.1 and 4.2 the reliability is improved after distributed generation is added in the distribution system feeders with both reliability analysis methods.

Finally Monte Carlo simulation method is better for reliability analysis other than analytical enumeration at both base case before and after DG is added at the distribution substation feeders but the value of power loss is similar before distribution generation is added and after with both reliability analysis methods, so the comparison of power loss, reliability analysis before and after distributed generation is added and also cost effectiveness analysis of the system using distributed generation at the feeders of the distribution substation has directly correlated with Monte Carlo simulation method.

4.4. Comparison of Reliability without DG and with DG

Table 4.3: Reliability Index Comparison

Reliability index	Value		Percentage Change
	Without DG	With DG	
SAIFI	806.052	17.58209	97.81874
CAIFI	806.052	17.58209	97.81874
SAIDI	1394.545	334.67	76.00149
CAIDI	1.73	19.035	-1000.29
ASAI	0.840805	0.961796	-14.3898
ASUI	0.159195	0.038204	76.0015
ENS	22347.42	3496.499	84.3539
AENS	2.508	0.392	84.37002
ACCI	7.519	3.311	55.96489
EIC	0.438	0.069	84.24658
IEAR	0.02	0.02	0

While talking about the comparison of reliability index from table 4.3 the reliability with DG is the one that is using Monte Carlo method is taking above SAIFI and CAIFI are improved to 97% that the interruption frequency is reduced due to the use of DG, and the value of SAIDI is improved to 76% that the interruption duration is reduced by the use of DG, and the value of CAIDI is increased from 1.73 to 19.035 which is increased by 1000% because of the reduction of SAIDI.

The value of ASAI is increased from 84% to 96% and the value of ASUI is reduced from 15% to 3% because of the interruption frequency and duration is reduced these are caused by reducing the value of ENS from 22,347.415 MWh to 3,496.499 MWh per year in the same manner the AENS is reduced from 2.508 to 0.392 MWh/annum and the EIC that the utility loss is reduced from 0.438 to 0.069 MWh/ann at constant IEAR of 0.020 & because of the reduction of power loss and ENS.

4.5. Comparison of Customer-Oriented Reliability Indices

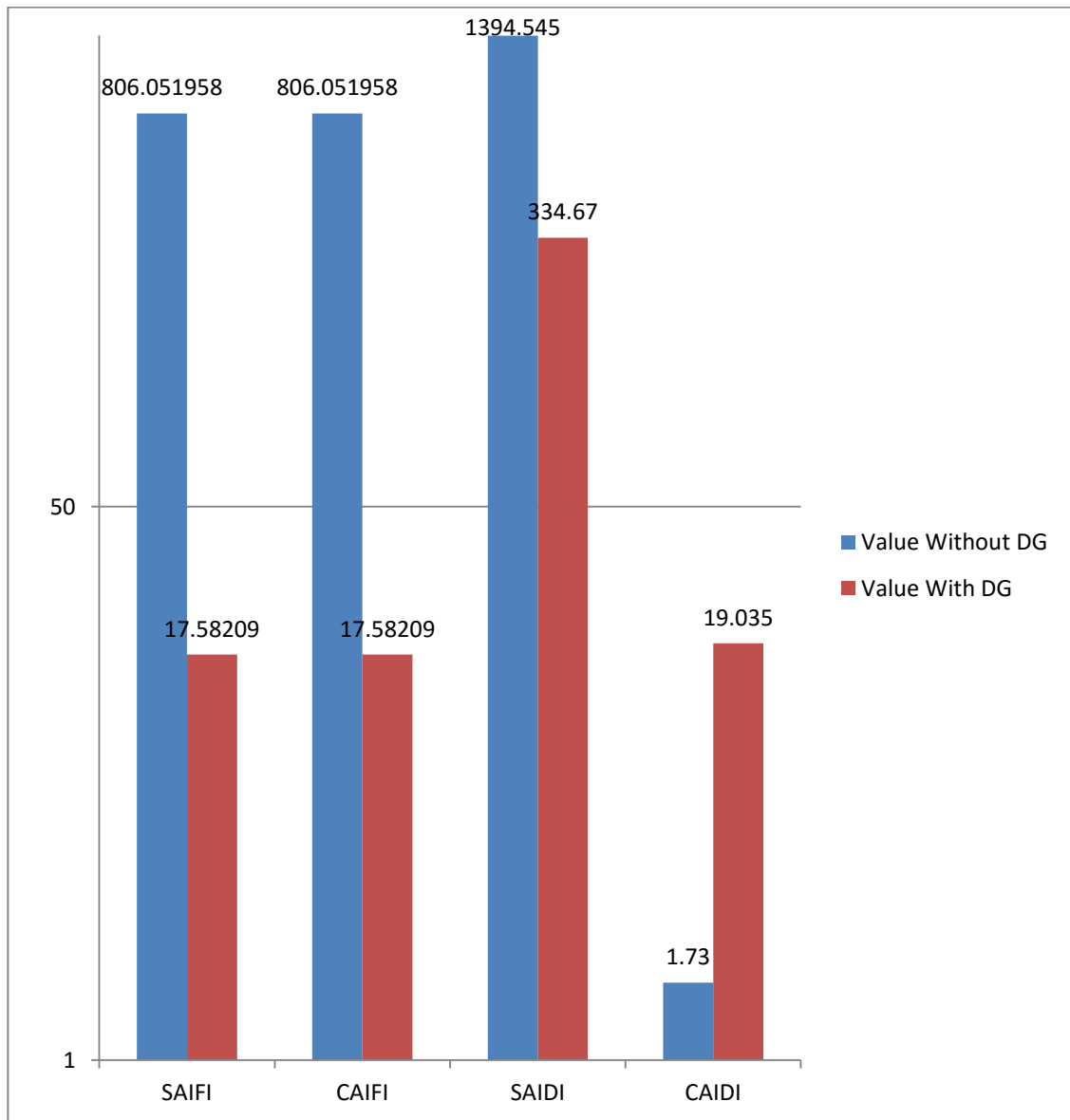


Fig.4.2: Customer-Oriented Reliability Indices with and with-out DG

The proposed method was applied to a 33 kV bus radial distribution system by installing DG at the bus of minimum bus voltage value of Motta feeder. Fig 4.2 above shows the customer-oriented reliability index without DG and with DG unit. From the figure, we can compare that the customer-oriented reliability index of radial distribution systems, installing the DG at the bus which has low voltage value of both at Motta and Meltolemariyam feeders with a size of 2.1 MW of active power with constant power factor of the distribution substation 0.9 and improve customer-oriented reliability indices that means reduce the SAIFI and CAIFI from 806.05 to 17.58, SAIDI from 1394.545 to 34.67 and increase CAIDI from 1.73 to 19.035.

4.6. Comparison Load or Energy-Oriented Reliability Indices

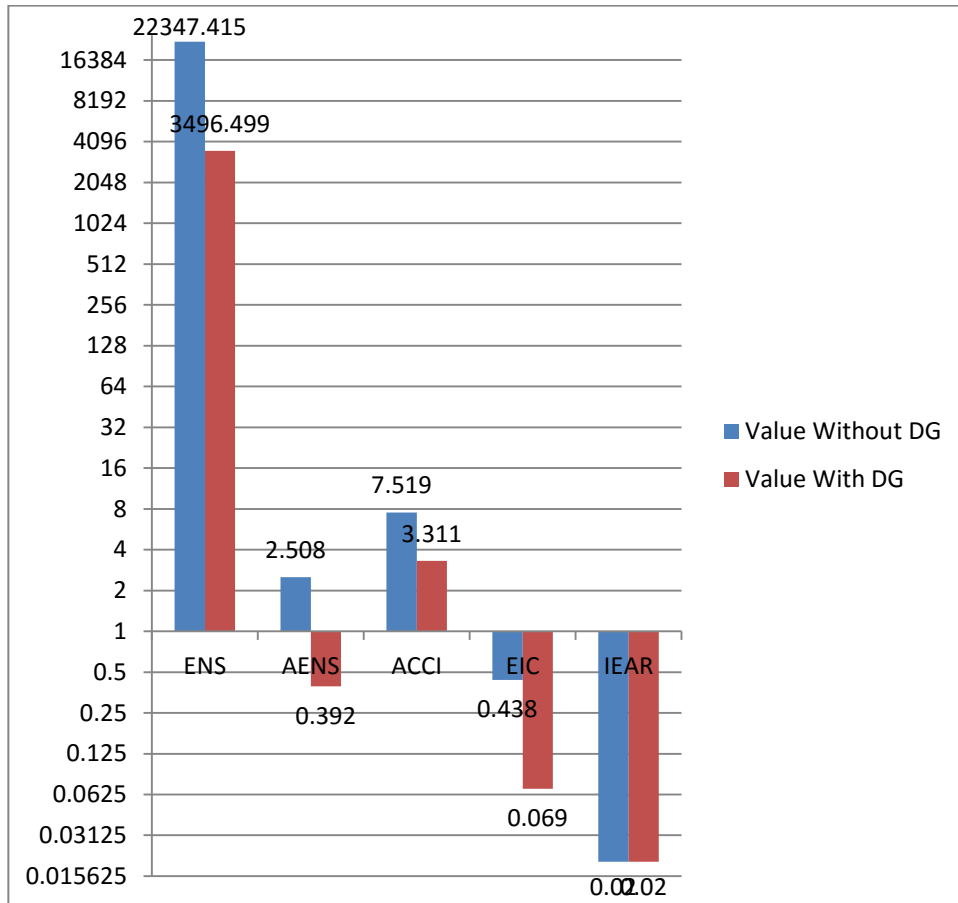


Fig.4.3: Energy-oriented reliability index with and with-out DG

The proposed method was applied to a 33 kV bus radial distribution system by installing DG at the bus of minimum bus voltage value of Motta feeder. Fig 4.3 bellow shows the energy-oriented reliability index without DG and with DG unit. From the figure, we can compare that the energy-oriented reliability index of radial distribution systems, installing the DG at the bus which has low voltage value of both at Motta and Meltolemariyam feeders with a size of 2.1 MW of active power with constant power factor of the distribution substation 0.9 and improve energy-oriented reliability indices that means reduce the ENS from 22347.415 to 3496.499, reduce AENS from 2.508 to 0.392, ACCI from 7.593 to 3.311 and reduce EIC from 0.438 to 0.069 at constant IEAR of 0.2\$.

Generally the distribution substation reliability index that is customer-oriented and energy-oriented reliability indexes see fig 4.2 and 4.3 respectively above has improved which means the placement of DG at the bus which has low voltage value and size of DG is related to the power loss has direct relation with the reliability of the distribution system.

4.7. HOMER Sensitivity Analysis of Hybrid Solar and Wind Distributed Generation

The required load curve the sensitivity analysis of DG is used the feeders load curve which is much more than the required DG load. But the only change is the number of solar panels and wind turbines used due to these the total cost of the system is changed respectively. The change is because of the size of DG required is 2.1MW whereas the sensitivity analysis is done using load curve of the Motta and Meltolemariyam feeders which are 0.458MW and 0.542MW respectively.

4.7.1. HOMER Sensitivity Analysis of Hybrid Solar and Wind DG of Motta

As we see from fig4.3 below the maximum power is covered by solar which is around 62% and the remaining 38% is covered by wind and the total NPC of DG is 1,081,946 \$ see fig 4.4 below.

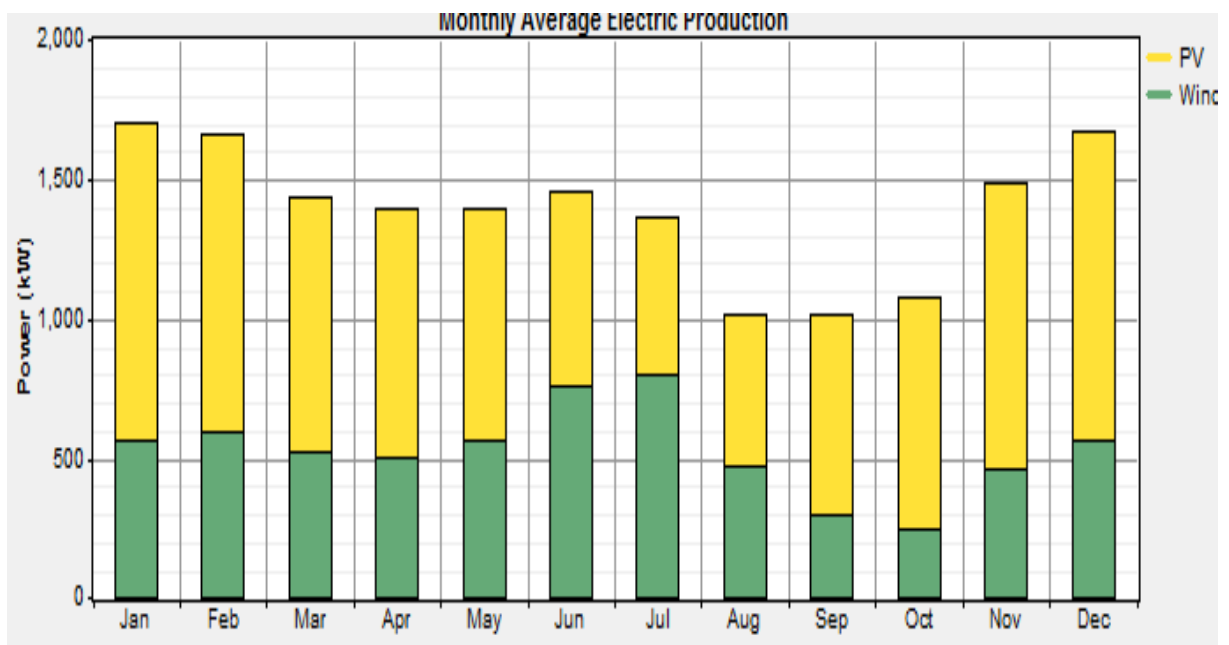


Fig.4.4: Monthly Average Electric Production of Motta DG

				PV (kW)	XLS	6FM200D	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage
				4000	300	100	11...	\$ 854,200	17,816	\$ 1,081,946	0.028	1.00	0.45
				4000	300	100	20...	\$ 854,364	17,820	\$ 1,082,165	0.028	1.00	0.45
				4000	300	100	30...	\$ 854,546	17,825	\$ 1,082,409	0.028	1.00	0.45
				4000	300	100	40...	\$ 854,728	17,830	\$ 1,082,653	0.028	1.00	0.45
				4000	300	100	60...	\$ 854,910	17,835	\$ 1,082,897	0.028	1.00	0.45
				4000	300	100	80...	\$ 855,092	17,839	\$ 1,083,140	0.028	1.00	0.45
				4000	300	100	10...	\$ 855,274	17,844	\$ 1,083,384	0.028	1.00	0.45
				4000	400	10	11...	\$ 1,000,600	20,314	\$ 1,260,276	0.032	1.00	0.45
				4000	400	10	20...	\$ 1,000,764	20,318	\$ 1,260,496	0.032	1.00	0.45
				4000	400	10	30...	\$ 1,000,946	20,323	\$ 1,260,740	0.032	1.00	0.45
				4000	400	10	40...	\$ 1,001,128	20,328	\$ 1,260,984	0.032	1.00	0.45
				4000	400	10	60...	\$ 1,001,310	20,332	\$ 1,261,227	0.032	1.00	0.45
				4000	400	10	80...	\$ 1,001,492	20,337	\$ 1,261,471	0.032	1.00	0.45
				4000	400	10	10...	\$ 1,001,674	20,342	\$ 1,261,715	0.032	1.00	0.45
				4000	400	20	11...	\$ 1,001,000	20,617	\$ 1,264,559	0.032	1.00	0.45
				4000	400	20	20...	\$ 1,001,164	20,622	\$ 1,264,778	0.032	1.00	0.45
				4000	400	20	30...	\$ 1,001,346	20,627	\$ 1,265,022	0.032	1.00	0.45
				4000	400	20	40...	\$ 1,001,528	20,631	\$ 1,265,266	0.032	1.00	0.45
				4000	400	20	60...	\$ 1,001,710	20,636	\$ 1,265,510	0.032	1.00	0.45
				4000	400	20	80...	\$ 1,001,892	20,641	\$ 1,265,754	0.032	1.00	0.45
				4000	400	20	10...	\$ 1,002,074	20,646	\$ 1,265,997	0.032	1.00	0.45
				4000	400	30	11...	\$ 1,001,400	20,917	\$ 1,268,790	0.032	1.00	0.44
				4000	400	30	20...	\$ 1,001,564	20,921	\$ 1,269,010	0.032	1.00	0.44

Fig.4.5: HOMER Sensitivity Analysis of Motta DG

4.7.2 HOMER Sensitivity Analysis of Hybrid DG of Meltolemariyam

The DG of Meltolemariyam as seen from fig.4.5 the maximum energy is covered by the solar which is 56% of the required and the wind turbine covers the rest 44%. And the total NPC of DG is 2,047,267\$ as seen from fig 4.6 below.

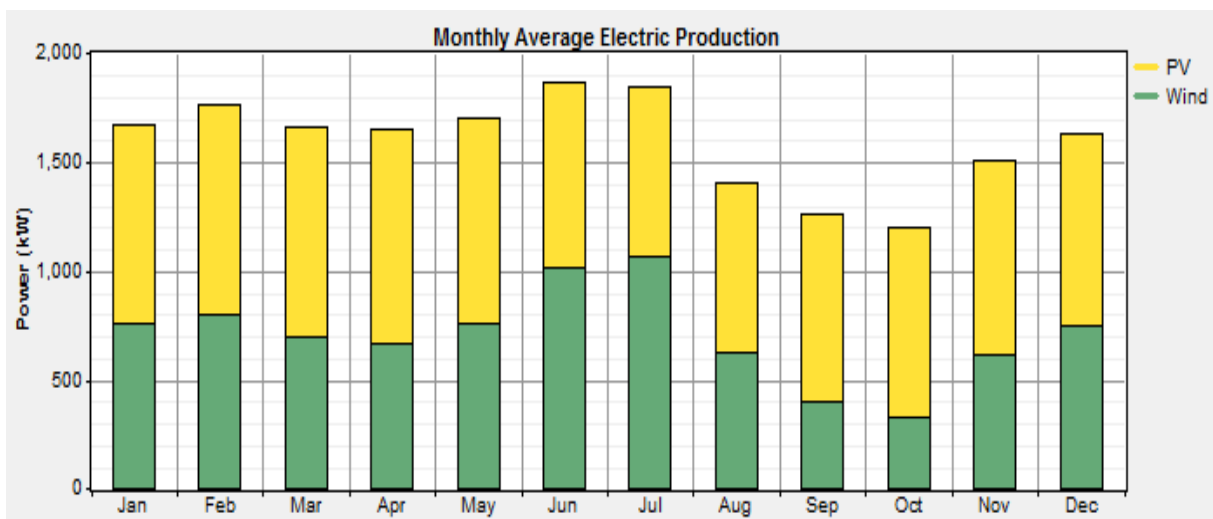


Fig.4.6: Monthly Average Electric Production of Meltolemariyam DG

				PV (kW)	XLS	6FM200D	Conv. (kW)	Initial Capital	Operating Cost (\$/yr)	Total NPC	COE (\$/kWh)	Ren. Frac.	Capacity Shortage
				4000	400	800	11...	\$ 920,200	88,167	\$ 2,047,267	0.050	1.00	0.45
				4000	400	800	20...	\$ 920,364	88,171	\$ 2,047,487	0.050	1.00	0.45
				4000	400	800	30...	\$ 920,546	88,176	\$ 2,047,731	0.050	1.00	0.45
				4000	400	800	40...	\$ 920,728	88,181	\$ 2,047,974	0.050	1.00	0.45
				4000	400	800	60...	\$ 920,910	88,186	\$ 2,048,218	0.050	1.00	0.45
				4000	400	800	65...	\$ 920,956	88,187	\$ 2,048,280	0.050	1.00	0.45
				4000	400	800	70...	\$ 921,002	88,188	\$ 2,048,342	0.050	1.00	0.45
				4000	400	800	80...	\$ 921,094	88,191	\$ 2,048,465	0.050	1.00	0.45
				4000	400	800	90...	\$ 921,186	88,193	\$ 2,048,588	0.050	1.00	0.45
				4000	400	800	10...	\$ 921,278	88,195	\$ 2,048,711	0.050	1.00	0.45
				4000	400	800	12...	\$ 921,462	88,200	\$ 2,048,958	0.050	1.00	0.45
				5000	400	800	11...	\$ 970,200	87,964	\$ 2,094,677	0.051	1.00	0.44
				5000	400	800	20...	\$ 970,364	87,968	\$ 2,094,896	0.051	1.00	0.44
				5000	400	800	30...	\$ 970,546	87,973	\$ 2,095,140	0.051	1.00	0.44
				5000	400	800	40...	\$ 970,728	87,978	\$ 2,095,384	0.051	1.00	0.44
				5000	400	800	60...	\$ 970,910	87,983	\$ 2,095,628	0.051	1.00	0.44
				5000	400	800	65...	\$ 970,956	87,984	\$ 2,095,689	0.051	1.00	0.44
				5000	400	800	70...	\$ 971,002	87,985	\$ 2,095,751	0.051	1.00	0.44
				5000	400	800	80...	\$ 971,094	87,988	\$ 2,095,874	0.051	1.00	0.44
				5000	400	800	90...	\$ 971,186	87,990	\$ 2,095,998	0.051	1.00	0.44
				5000	400	800	10...	\$ 971,278	87,993	\$ 2,096,121	0.051	1.00	0.44
				5000	400	800	12...	\$ 971,462	87,998	\$ 2,096,367	0.051	1.00	0.44
				6000	400	800	11...	\$ 1,020,200	87,818	\$ 2,142,812	0.052	1.00	0.44
				6000	400	800	20...	\$ 1,020,364	87,823	\$ 2,143,032	0.052	1.00	0.44

Fig.4.7: HOMER Sensitivity Analysis of Meltolemariyam DG

4.8. Cost Analysis

Engineering is always highly related with cost based on these to analyze the cost of these theses it considers two type of cost one is due to reliability because the EIC above is only due to interruption frequency and duration hour, the second one that consider hear also due to power loss using average cost of energy of EEPCO that consider at reliability 0.53 birr/Kwh which is $0.0196\$ \cong 0.020\$$ using current exchange rate of CBE.

Before introducing DG at the base case the utility lose 5,363,379.6USD which is 0.438m\$/yr due to only power interruption frequency from table 3.10 but there is power loss of 1.93MW which is 16,906.8 MWh energy.

The energy assessment rate = 0.020\$/Kwh, then utility lose 338,136\$ due to loss power

$$\begin{aligned}
 \text{Total utility lose} &= \text{lose due to power interruption} + \text{lose due to power loss} \\
 &= 5,363,379.6 + 338,136 \\
 &= 5,701,515.6\$
 \end{aligned}$$

The total cost of energy that the utility loose is $5,701,515.6\$ = 153,940,921.2$ Ethiopian Birr.

The cost of energy after introducing DG due to only power interruption is $839,159.76\$$, and from table 3.10 the lose energy is reduced to 0.32MW which is $2,803.2\text{MWh}$ energy.

Then using energy assessment rate = $0.020\text{m\$/kWh}$, the utility lose $56,046\$$.

$$\begin{aligned} \text{Total utility loose} &= \text{loose due to power interruption} + \text{loose due to power loss} \\ &= 839,159.76\$ + 56,046\$ \\ &= 839,215.824\$ \end{aligned}$$

The total cost of energy that the utility loose is $839,215.842\$ = 22,658,827.734$ Ethiopian Birr.

$$\begin{aligned} \text{Total utility saving} &= \text{Total utility loose before using DG} - \text{Total utility loose after using DG} \\ &= 5,701,515.6\$ - 839,215.842\$ = 4,862,299.758\$ \\ &= 131,282,093.466 \text{ Ethiopian Birr.} \end{aligned}$$

The total cost of the DG that used to improve the system reliability, power loss and voltage profile is the sum of the three DG that added at one bus of feeder Motta and at the two bus of feeder Meltolemariyam with the same size 2.1MW power and for 25 year project life time is calculated as follows.

The daily load curve that used for the sensitivity analysis is used the feeder load profile for each feeder that is 0.458MW and 0.542MW of each feeder has a cost of $1,081,946\$$ and $2,047,267\$$ Motta and Meltolemariyam respectively. When the power required is increased the only change is the number of panel and turbine is change due to these the total cost also increased, based on these,

For feeding 0.458MW power, total cost is $1,081,946\$$, so for 2.1MW is $4,957,279.855\$$ is required at the same daily solar radiation and wind speed of feeder Motta.

At feeder Meltolemariyam $2,047,267\$$ is required for feeding 0.542MW daily power, so for 2.1MW $7,937,096.677\$$ is required. But at these feeder the DG used is two so the total money is $15,874,193.35\$$.

Then the total NPC of the DG = sum [DG of Motta feeder +2*(DG of Meltolemariyam feeder)]

$$\begin{aligned} &= 4,957,279.855\$ + 2 * (7,937,096.677\$) \\ &= 20,831,473.21\$ \end{aligned}$$

$$\begin{aligned}
\text{Then payback period} &= \frac{\text{Total NPC of DG}}{\text{Annual saving}} \\
&= \frac{20,831,473.21\$}{4,862,299.758\$} \\
&= 4.284284 \cong 4 \text{ Year}
\end{aligned}$$

Then the utility is profitable by using the three DG for 25 year and the cost is repaired by four year and the utility collects excess money during remaining 21 years with reliable power supply for the customer.

CHAPTER FIVE

CONCLUSIONS, RECOMMENDATIONS AND FUTURE WORKS

5.1. Conclusions

This thesis analyzes reliability assessments of Motta distribution substation, based on reliability improvement, power loss minimization using the proper DG location and size. The reliability assessment and load flow analysis processes, using analytical, Enumeration and Monte Carlo Simulations (MCS) were conducted with radial distribution system of 33 kV two feeders (Motta and Meltolemariya).

The basic objective of the research is to perform reliability assessment of distribution substation system with DG units, by applying analytical approach and Monte Carlo Simulation method using the DIGSILENT and HOMER software tool for DG cost optimization. In the base case study it is seen that there is a higher outage as the load point is further from the supply point, therefore there a higher problem in term of reliability of the system and power loss; the consumer are not used energy that the utility loss is around EENS (22,347.415) and the utility lose 5,363,379.6\$ and 338,136\$ because power loss and of high overall system unavailability indices respectively. And the utility has a total loss of around \$ 5,701,515.6\$ or 153,940,921.2 Ethiopian birr annually.

The proposed solution is chosen for this research as and the option for improving the system reliability indices, Expected energy not supplied and the outage cost of interruptions. The installation of a DG at bus number 88 of the feeders Motta and at bus number 202 and 253 of feeder Meltolemariyam which has lest bus voltage value has great impact on over the entire distribution substation by reducing SAIFI and CAIFI by 97.8%, SAIDI by 76%, increasing ASAI by 14.38% and reducing ASUI by 76% and reducing the total power loss to 0.32 MW. Due to improving the reliability and power loss the money that the utility loose reduced from 5,701,515.6\$ to 839,215.842\$ which is from 153,940,921.2 to 22,658,827.734 Ethiopian birr annually.

The optimal cost of DG for producing 2.1 MW hybrid wind and solar power is for 25 years project life is much lower than the cost that the utility loose annually due to these the payback period is four year which means the utility is profitable with reliable power supply to the costumer for the next 21 years.

5.2. Recommendations

Reliability analysis requires: total number of customers, number of customers served, number of customers interrupted, loads connected, number of transformers and their ratings, and so on. So, power system faults, power system devices (lines, buses, transformers on each feeder, circuit breakers, and dis-connectors) and total number of customers served and interrupted should be correctly documented by station and the distance between each load also required but the station has not these data as much as possible EEPCO must documented during project worked. The distribution system covers large area and the distance between each load point is very far within the forest which is the cause of short circuit and as we see above around the distribution there is high wind so the distribution requires line spacing between each phase line or must use cable. And the other is the distribution system must have load protection because at the existing feeder distribution system when the fault happens at one load side it trips all the load of the feeder because of the absence of load protection in each load point. Around the distribution feeders EEPCO must give training to the peoples because one of the cause of power interruption is gap of knowledge means the peoples around the age from 10 - 20 playing by mark either the insulators or the lines and throw there rod ether it is wait or not and shoot or hoist ether of the two is considered as hero.

The other one EEPCO must add the technical workers at the district because when short circuit is happen at the 33kV line one of the phase is cut and out of the system during reconnect it only two or three workers are send to the place but not properly done it has high sag. So due to the presence of high wind and forest it happen short circuit again and during summer time the pole is under the system due to the sag conductor and killed peoples and other animals as the peoples around the place.

Finally recommends EEPCO to use the idea of this thesis and installing DG and increase his profitability with reliable power supply to the customer without any skirmish.

5.3. Future Works

Different distributed generation options other than PV and wind technologies can be studied for this substation's reliability improvement. In these thesis DG is used at the distribution of 33kV that is before it changed to 0.4kV or step down transformer as supportive of the distributed power in the future use DG at each customer as backup and observe their impact reliability, voltage profile and power loss.

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APPENDIX

APPENDIX A

System Reliability Index Analysis Results

Table A- 1: Reliability with-out DG

Reliability Assessment

Method	Monte Carlo analysis
Network	Transmission
Calculation time period	2106
Consider Maintenance	No
Fault Clearance Breakers	Use all circuit breakers
Switching procedures	Concurrently
Time to open remote controlled switches	1.00 min.

Automatic Contingency Definition

Selection	Whole System		
Busbars / terminals	Yes	Common mode	No
Lines / cables	Yes	Independent second failures	No
Transformers	Yes	Double earth faults	Yes
		Protection/switching failures	No

 | Study Case: Study Case | Annex: / 1 |

System Summary


System Average Interruption Frequency Index	: SAIFI = 806.051958 1/Ca
Customer Average Interruption Frequency Index	: CAIFI = 806.051958 1/Ca
System Average Interruption Duration Index	: SAIDI = 1394.545 h/Ca
Customer Average Interruption Duration Index	: CAIDI = 1.730 h
Average Service Availability Index	: ASAI = 0.8408053089
Average Service Unavailability Index	: ASUI = 0.1591946911
Energy Not Supplied	: ENS = 22347.415 MWh/a
Average Energy Not Supplied	: AENS = 2.508 MWh/Ca
Average Customer Curtailment Index	: ACCI = 7.519 MWh/Ca
Expected Interruption Cost	: EIC = 0.438 M\$/a
Interrupted Energy Assessment Rate	: IEAR = 0.020 \$/kWh
System energy shed	: SES = 0.000 MWh/a
Average System Interruption Frequency Index	: ASIFI = 1240.787088 1/a
Average System Interruption Duration Index	: ASIDI = 2212.100734 h/a
Momentary Average Interruption Frequency Index	: MAIFI = 0.000000 1/Ca

Table A- 2: Reliability with DG

		DIGSILENT	Project:
		PowerFactory	-----
		15.1.7	Date: 11/5/2019
Reliability Assessment			
Method	Monte Carlo analysis		
Network	Transmission		
Calculation time period	2106		
Consider Maintenance	No		
Fault Clearance Breakers	Use all circuit breakers		
Switching procedures	Concurrently		
Time to open remote controlled switches	1.00 min.		
Automatic Contingency Definition			
Selection	Whole System		
Busbars / terminals	Yes	Common mode	No
Lines / cables	Yes	Independent second failures	No
Transformers	Yes	Double earth faults	Yes
		Protection/switching failures	No
Study Case: Study Case		Annex:	/ 1
System Summary			
System Average Interruption Frequency Index	: SAIFI =	17.582090	1/Ca
Customer Average Interruption Frequency Index	: CAIFI =	17.582090	1/Ca
System Average Interruption Duration Index	: SAIDI =	334.670	h/Ca
Customer Average Interruption Duration Index	: CAIDI =	19.035	h
Average Service Availability Index	: ASAI =	0.9617956668	
Average Service Unavailability Index	: ASUI =	0.0382043332	
Energy Not Supplied	: ENS =	3496.499	MWh/a
Average Energy Not Supplied	: AENS =	0.392	MWh/Ca
Average Customer Curtailment Index	: ACCI =	3.311	MWh/Ca
Expected Interruption Cost	: EIC =	0.069	M\$/a
Interrupted Energy Assessment Rate	: IEAR =	0.020	\$/kWh
System energy shed	: SES =	0.000	MWh/a
Average System Interruption Frequency Index	: ASIFI =	13.896957	1/a
Average System Interruption Duration Index	: ASIDI =	346.107505	h/a
Momentary Average Interruption Frequency Index	: MAIFI =	0.000000	1/Ca

APPENDIX-B
Detail Interruption report

Table B- 1: Total Interruption Report of Motta Substation

NORTH WESTERN REGION								
Monthly Substation Fault report								
Substation Name <u>MOTTA</u>								
Month <u>MAY 2009 E,C - April 20/2010 E.C</u>								
Feeder Name	Frequency				Duration hour			
	PSC	TEF	Operational	Total	PSC	TEF	Operational	Total
Motta	309	223	174	706	389.09	100.02	169.06	658.17
Meltolemariya	540	232	134	906	1,334.06	480.33	315.33	2,130.12
Total	849	455	308	1,612	1,723.15	580.35	484.39	2,788.29

APPENDIX-C

DISTRIBUTION SYSTEM FEEDERS DATA

Table C- 1 Motta feeder line data

Branch No.	From Bus	To Bus	Trans rating (KVA)	conductor type	conductor length(KM)	R	X
1	1	2	25	AAC 50mm ²	0.56	0.4816	0.20272
2	2	3	200	AAC 50mm ²	14	12.04	5.068
3	3	4	315	AAC 50mm ²	0.35	0.301	0.1267
4	4	5		AAC 50mm ²	0.06	0.0516	0.02172
5	5	6		AAC 50mm ²	0.08	0.0688	0.02896
6	6	7		AAC 50mm ²	0.46	0.3956	0.16652
7	7	8	200	AAC 50mm ²	0.25	0.215	0.0905
8	8	9		AAC 50mm ²	0.4	0.344	0.1448
9	9	10		AAC 50mm ²	0.02	0.0172	0.00724
10	10	11		AAC 50mm ²	0.28	0.2408	0.10136
11	11	12	315	AAC 50mm ²	0.04	0.0344	0.01448
12	12	13		AAC 50mm ²	0.17	0.1462	0.06154
13	13	14	400	AAC 50mm ²	0.05	0.043	0.0181
14	5	15	200	AAC 50mm ²	0.32	0.2752	0.11584
15	15	16		AAC 50mm ²	0.24	0.2064	0.08688
16	16	17	50	AAC 50mm ²	0.2	0.172	0.0724
17	17	18	200	AAC 50mm ²	0.15	0.129	0.0543
18	6	19	100	AAC 50mm ²	0.62	0.5332	0.22444
19	19	20	100	AAC 50mm ²	0.6	0.516	0.2172
20	7	21		AAC 50mm ²	0.03	0.0258	0.01086
21	21	22	315	AAC 50mm ²	0.34	0.2924	0.12308
22	22	23	100	AAC 50mm ²	0.18	0.1548	0.06516
23	7	24	200	AAC 50mm ²	0.3	0.258	0.1086
24	24	25		AAC 50mm ²	0.21	0.1806	0.07602
25	25	26	25	AAC 50mm ²	0.04	0.0344	0.01448
26	9	27	200	AAC 50mm ²	0.22	0.1892	0.07964
27	27	28	200	AAC 50mm ²	0.29	0.2494	0.10498
28	28	29		AAC 50mm ²	0.04	0.0344	0.01448
29	26	30	50	AAC 50mm ²	0.34	0.2924	0.12308
30	10	31	50	AAC 50mm ²	0.26	0.2236	0.09412
31	31	32	100	AAC 50mm ²	0.31	0.2666	0.11222
32	11	33	200	AAC 50mm ²	0.39	0.3354	0.14118
33	33	34		AAC 50mm ²	0.17	0.1462	0.06154
34	34	35	200	AAC 50mm ²	0.05	0.043	0.0181
35	13	36	25	AAC 50mm ²	0.1	0.086	0.0362
36	36	37	500	AAC 50mm ²	0.03	0.0258	0.01086
37	16	38	200	AAC 50mm ²	0.28	0.2408	0.10136

38	16	39	200	AAC 50mm ²	0.03	0.0258	0.01086
39	39	40	200	AAC 50mm ²	0.04	0.0344	0.01448
40	21	41	200	AAC 50mm ²	0.06	0.0516	0.02172
41	25	42	25	AAC 50mm ²	0.01	0.0086	0.00362
42	25	43	200	AAC 50mm ²	0.01	0.0086	0.00362
43	29	44	50	AAC 50mm ²	1.8	1.548	0.6516
44	34	45		AAC 50mm ²	24	20.64	8.688
45	45	46		AAC 50mm ²	0.36	0.3096	0.13032
46	46	47	50	AAC 50mm ²	0.01	0.0086	0.00362
47	46	48	50	AAC 50mm ²	0.31	0.2666	0.11222
48	46	49	100	AAC 50mm ²	0.28	0.2408	0.10136
49	49	50		AAC 50mm ²	0.35	0.301	0.1267
50	50	51	50	AAC 50mm ²	0.32	0.2752	0.11584
51	50	52		AAC 50mm ²	0.28	0.2408	0.10136
52	52	53	50	AAC 50mm ²	0.3	0.258	0.1086
53	52	54		AAC 50mm ²	0.21	0.1806	0.07602
54	54	55	50	AAC 50mm ²	0.02	0.0172	0.00724
55	54	56		AAC 50mm ²	0.04	0.0344	0.01448
56	56	57	200	AAC 50mm ²	0.05	0.043	0.0181
57	56	58		AAC 50mm ²	0.35	0.301	0.1267
58	58	59	50	AAC 50mm ²	0.28	0.2408	0.10136
59	58	60	100	AAC 50mm ²	0.34	0.2924	0.12308

Table C- 2 Meletolemariyam feeder line data

Branch No.	From Bus	To Bus	Trans rating (KVA)	conductor type	conductor length(KM)	R	X
1	1	2	200	AAC 50mm ²	13	8.84	4.706
2	2	3		AAC 50mm ²	1	0.68	0.362
3	3	4		AAC 50mm ²	19	12.92	6.878
4	4	5		AAC 50mm ²	0.08	0.0544	0.02896
5	5	6		AAC 50mm ²	0.05	0.034	0.0181
6	6	7		AAC 50mm ²	0.42	0.2856	0.15204
7	7	8		AAC 50mm ²	0.2	0.136	0.0724
8	8	9		AAC 50mm ²	0.31	0.2108	0.11222
9	9	10		AAC 50mm ²	0.07	0.0476	0.02534

10	10	11	315	AAC 50mm ²	0.29	0.1972	0.10498
11	11	12	25	AAC 50mm ²	0.46	0.3128	0.16652
12	12	13		AAC 50mm ²	0.46	0.3128	0.16652
13	13	14		AAC 50mm ²	0.95	0.646	0.3439
14	14	15		AAC 50mm ²	6.85	4.658	2.4797
15	15	16	315	AAC 50mm ²	4.45	3.026	1.6109
16	16	17		AAC 50mm ²	3.91	2.6588	1.41542
17	17	18		AAC 50mm ²	0.38	0.2584	0.13756
18	18	19		AAC 50mm ²	5.06	3.4408	1.83172
19	19	20	200	AAC 50mm ²	0.14	0.0952	0.05068
20	20	21	315	AAC 50mm ²	0.56	0.3808	0.20272
21	21	22		AAC 50mm ²	0.51	0.3468	0.18462
22	22	23		AAC 50mm ²	0.51	0.3468	0.18462
23	23	24	400	AAC 50mm ²	0.02	0.0136	0.00724
24	24	25		AAC 50mm ²	0.07	0.0476	0.02534
25	25	26		AAC 50mm ²	0.18	0.1224	0.06516
26	26	27	630	AAC 50mm ²	0.24	0.1632	0.08688
27	27	28		AAC 50mm ²	0.04	0.0272	0.01448
28	28	29	400	AAC 50mm ²	1.31	0.8908	0.47422
29	3	30	200	AAC 50mm ²	5	3.4	1.81
30	4	31	200	AAC 50mm ²	2.05	1.394	0.7421
31	31	32	200	AAC 50mm ²	1	0.68	0.362
32	32	33	200	AAC 50mm ²	0.25	0.17	0.0905
33	33	34		AAC 50mm ²	1	0.68	0.362
34	34	35		AAC 50mm ²	2	1.36	0.724

35	35	36	100	AAC 50mm ²	3	2.04	1.086
36	36	37	25	AAC 50mm ²	1	0.68	0.362
37	5	38	315	AAC 50mm ²	0.17	0.1156	0.06154
38	6	39	25	AAC 50mm ²	0.01	0.0068	0.00362
39	7	40	200	AAC 50mm ²	0.12	0.0816	0.04344
40	8	41	315	AAC 50mm ²	0.11	0.0748	0.03982
41	9	42	315	AAC 50mm ²	0.24	0.1632	0.08688
42	42	43		AAC 50mm ²	0.45	0.306	0.1629
43	43	44		AAC 50mm ²	0.22	0.1496	0.07964
44	44	45	800	AAC 50mm ²	0.58	0.3944	0.20996
45	10	46		AAC 50mm ²	0.06	0.0408	0.02172
46	46	47		AAC 50mm ²	0.08	0.0544	0.02896
47	47	48	315	AAC 50mm ²	0.25	0.17	0.0905
48	14	49	100	AAC 50mm ²	14	9.52	5.068
49	49	50	200	AAC 50mm ²	0.36	0.2448	0.13032
50	50	51	100	AAC 50mm ²	0.24	0.1632	0.08688
51	15	52	200	AAC 50mm ²	0.01	0.0068	0.00362
52	52	53	100	AAC 50mm ²	0.45	0.306	0.1629
53	53	54	25	AAC 50mm ²	0.01	0.0068	0.00362
54	17	55	200	AAC 50mm ²	0.36	0.2448	0.13032
55	55	56	25	AAC 50mm ²	0.82	0.5576	0.29684
56	18	57	200	AAC 50mm ²	3	2.04	1.086
57	57	58	50	AAC 50mm ²	2.5	1.7	0.905
58	58	59	200	AAC 50mm ²	0.35	0.238	0.1267
59	19	60	200	AAC 50mm ²	2	1.36	0.724

60	60	61	25	AAC 50mm ²	0.42	0.2856	0.15204
61	21	62		AAC 50mm ²	0.01	0.0068	0.00362
62	62	63	25	AAC 50mm ²	0.2	0.136	0.0724
63	22	64	315	AAC 50mm ²	0.36	0.2448	0.13032
64	23	65	50	AAC 50mm ²	0.5	0.34	0.181
65	25	66	315	AAC 50mm ²	0.22	0.1496	0.07964
66	66	67	100	AAC 50mm ²	0.08	0.0544	0.02896
67	26	68	315	AAC 50mm ²	0.02	0.0136	0.00724
68	29	69	25	AAC 50mm ²	0.01	0.0068	0.00362
69	32	70	100	AAC 50mm ²	3.5	2.38	1.267
70	70	71	200	AAC 50mm ²	0.04	0.0272	0.01448
71	71	72	25	AAC 50mm ²	0.36	0.2448	0.13032
72	34	73	50	AAC 50mm ²	3	2.04	1.086
73	73	74	50	AAC 50mm ²	0.5	0.34	0.181
74	35	75	25	AAC 50mm ²	1	0.68	0.362
75	75	76	200	AAC 50mm ²	0.7	0.476	0.2534
76	36	77	100	AAC 50mm ²	6	4.08	2.172
77	77	78	50	AAC 50mm ²	1	0.68	0.362
78	78	79	50	AAC 50mm ²	2	1.36	0.724
79	79	80	315	AAC 50mm ²	0.56	0.3808	0.20272
80	80	81	100	AAC 50mm ²	1.35	0.918	0.4887
81	81	82		AAC 50mm ²	0.45	0.306	0.1629
82	82	83	25	AAC 50mm ²	0.26	0.1768	0.09412
83	82	84	315	AAC 50mm ²	0.04	0.0272	0.01448
84	43	85	100	AAC 50mm ²	0.45	0.306	0.1629

85	44	86	50	AAC 50mm ²	5	3.4	1.81
86	86	87	100	AAC 50mm ²	0.36	0.2448	0.13032
87	46	88	25	AAC 50mm ²	0.02	0.0136	0.00724
88	47	89	200	AAC 50mm ²	0.35	0.238	0.1267
89	13	90	50	AAC 50mm ²	6	4.08	2.172
90	90	91	100	AAC 50mm ²	0.36	0.2448	0.13032
91	58	92	25	AAC 50mm ²	0.54	0.3672	0.19548
92	62	93	200	AAC 50mm ²	0.05	0.034	0.0181
93	93	94	200	AAC 50mm ²	0.24	0.1632	0.08688