



**DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED
GENERATION AND NETWORK RECONFIGURATION**

Case study: Arbaminch Distribution system

MSc. Thesis

BY

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**DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED
GENERATION AND NETWORK RECONFIGURATION :A CASE STUDY AT
ARBAMINCH DISTRIBUTION SYSTEM**

BY

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DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

ABSTRACT

Power supply reliability is the basic issue for economic and technology development of the country. The sufficient or adequate and secure supply of power will assure the reliability of the system. Unreliability of the system occur due to high outage frequency and duration, system overload and unsecure system or protection system. When the distribution system is reliable, it has capacity to meet the demand of customer and operate under adverse condition. Arbaminch distribution system has encountered frequent power interruption and power quality problem. The interruptions are mainly caused by system overload and short circuit fault. The reliability of the distribution system is assessed based on the data from Ethiopian Electric Power Corporation. Arbaminich substation of feeder -05 is selected as case study, which has high rate of interruption. Feeder -05 has SAIDI value of 236.8386 Hr./cust. /yr. and SAIFI of 221.6338 f/cust. /yr. The reliability indexes values of feeder -05 are not within the ranges of bench marks of reliability requirement. This thesis focused on reliability improvement of distribution system with better placement of distributed generation and network reconfiguration. Particle swarm optimization algorithm is used for placement of DG, size and network reconfiguration. The algorithm is done using MATLAB 2016 software. Based on the availability in the area, efficiency, cost and emission level, Solar and Microturbine sources are used as distributed generation. The suitable site and size of DG are found at bus 10 with suitable size 4.5 MW. For network reconfiguration sectionalizing switch is used. Before reconfiguration the switch was placed at bus 20, 21, 22,23 and 24. During network reconfiguration switch changed to bus 3, 4,12,24 and 31. The reliability indices SAFI, SAIDI and EENS value improved by 82.81%,78.89% and 78.10% respectively after DG with reconfiguration used. Expected interruption cost before applying the proposed method is 9,758,852\$ /year. After the proposed method used expected interruption cost reduced to 2,995,270\$ /year. This indicates that, 6,763,582 \$/year is saved after using the proposed techniques.

Keywords: Distributed generation, reliability improvement, Network reconfiguration, MATLAB, ETAP

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List of Acronyms

ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
DG	Distributed generation
PSO	Particle swarm optimization
MVA	Mega volt Amp
Pbest	Personal best
Gbest	Global best
PDG	Distributed generation real power
QDG	Distributed generation reactive power
Pv	Voltage controlled buss
PL	Real power loss
Ploss	Power loss
V _i	Voltage at buss ith
V _k	Voltage at buss kth
V _n	Receiving end voltage
V _o	Sending end voltage
X	Reactance of the branch
Z	Impedance of the branch
Y	Admittance of the branch

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The primary goal of a power system is to provide sufficient energy to consumers at a reasonable cost and with reasonable assurance of reliability. In the last few years, power distribution networks have expanded rapidly in terms of scale and technology. Here as result, utility companies must aim to meet their customers' reliability needs with the best strategic planning and lowest possible cost. The term reliability refers to a system's ability to provide a sufficient supply of electricity resources. Because of the rising cost of interruption and fault outages, reliability analysis of distribution networks is not a new subject in the electric power industry; many experimental studies have been conducted [1].

In comparison to generation and transmission systems, the distribution network system has gained less attention in terms of reliability studies in the past. The reason for this is that generation and transmission systems are costly, and lack of adequate supply can have far-reaching social and environmental implications. A distribution system, on the other hand, is marginally less expensive than the other two because its consequences are localized. The distribution system contributes the most to the unavailability of electrical service to consumers, according to consumer failure figures from most utilities [2].

It's critical to assess and evaluate the reliability of power system networks in order to make the most reliable and efficient decisions possible, especially in terms of planning, operation, and maintenance. The aim of a power system is to provide reliable and cost-effective electricity to its customers. The cost of interruption and power outages can have a significant economic effect on the utility and its customers, so it's critical to plan and maintain a reliable power delivery system. Customers will be directly impacted by distribution system power outages and failures. Even though the generation and transmission systems are very reliable, unreliable distributions provide low electricity to consumers [3].

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This method uses ETAP simulation software to analysis the reliability of the system and distributed generation placement and network reconfiguration to increase reliability.

The case study of the distribution system investigation and simulation is carried out on Arbaminch substation which consists of four 15 KV and two 33 KV Outgoing feeders. Assess the performance of the present system and proposed allocation of DG and network reconfiguration to the system that have high reliability indices. The alternative which gives low reliability indices (SAIDI, SAIFI, CAIDI and EENS) and interruption costs are being assessed.

1.2 Statement of the Problem

Power distribution system is a main part of power system that provide power to the customer. Distribution system power outage and failures would directly impact on the customers. Even though the generation and transmission systems are highly efficient, the distribution system fails to provide enough energy to consumers. Ethiopian Electric power cooperation delivers power to customer; it tries to improve power delivery mechanism. Power distribution system in Arbaminch town has challenging issues to meet customer demand in required reliability standard. The power interruption impacts customers, critical infrastructures like industries and business enterprise. It also has impact on equipment damage and lead to maintenance issues. Reliability of power distribution system in Arbaminch town is a challenging issue and it continues as it is unless appropriate improvement solution is not found for the problem. Some of the faults recorder in the Arbaminch substation that occur on distribution system are [Appendix III]:

- Distribution system overload (DSOL)
- Distribution Temporary Short Circuit (DTSC)
- Distribution Permanent Short Circuit (DPSC)
- Distribution Permeant Earth Fault (DPEF)
- Distribution Temporary Earth Fault (DTEF)

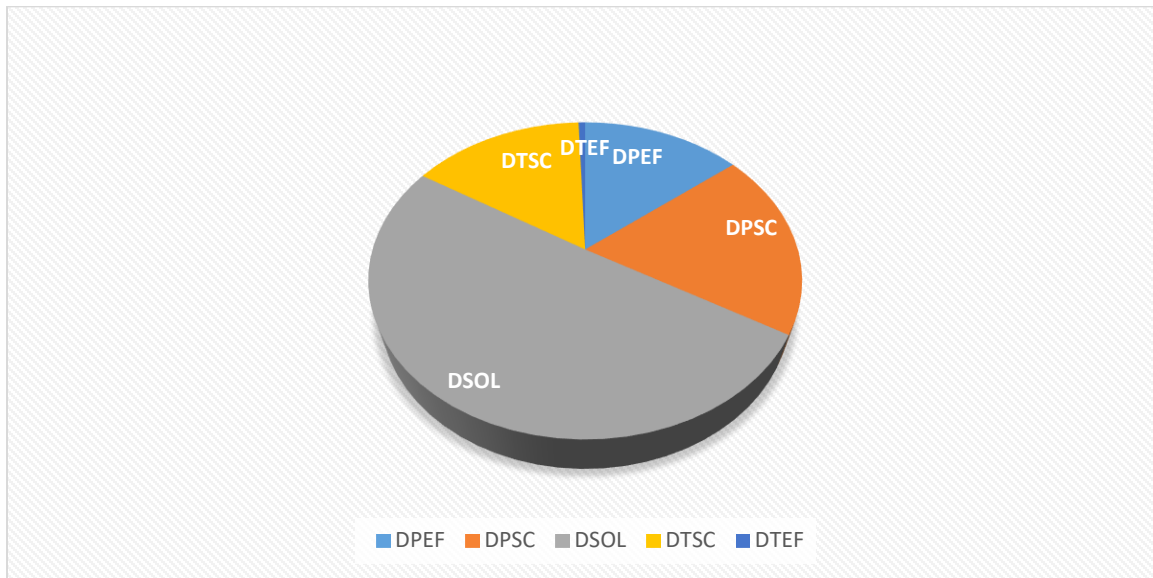


Figure 1.1 Types of faults

Among those faults system overload and short circuit faults occur frequently compared to other faults. Increasing demand for electric power has caused existing grids to become overloaded. Inadequate power generation and inadequate distribution system are also causes of line voltage problems. When the system has heavy loading or tripping of any one of its lines in the grid may cause the reduction of receiving end voltage. If the voltage is decreased beyond the limit overload problem and voltage instability may occur on the system. In Arbaminch distribution system most of the time Supply interruption and under voltage occur in the system. This leads to overload problem and voltage instability on the system. As the load demand increases; increasing of generation capacity is needed in order to increase social welfare and to make the system more reliable. This study tries to address distribution system reliability improvement methods that can be allocation of DG unit and network reconfiguration into the feeder to improve the reliability.

1.3 Objectives

Distribution system reliability issues are the main concern of the study. This thesis seeks into the current system reliability issues, challenges and effective improvement methods for reliability issues.

1.3.1 General Objective

The main objective of this study is to improve reliability of radial distribution system using Network reconfiguration and distributed generation integration.

1.3.2 Specific Objective

The specific objectives are:

- Reliability analysis and model the distribution system.
- Collect interruption frequency and duration.
- Develop Reliability model to evaluate improvement on distribution system reliability.
- Allocation of DG unit to improve the distribution system reliability.
- Implement network reconfiguration.
- Analysis reliability indices with and without DG and network reconfiguration.

1.4 Methodology

In this thesis work the methodology goes starting with problem identification and detail literature review is conducted from books and magazine. Problem identification is the first step toward solving the problem. Arbaminch distribution substation is selected as case study area. Generally, the following methodology will be followed:

- Technical data collection from Arbaminch substation such as interruption duration, frequency, types of faults and cause of faults.
- Calculate the reliability indices using mathematical calculation based on the collected interruption frequency and duration data.
- Using particle swarm optimization algorithm optimal sizing and location of DG will be done in MATLAB 2016.
- Using ETAP 16.0.0 software model the existing system with DG. By adding DG to the selected feeder, see how the reliability indices are improved. The existing system will be modeled with DG.
- Reconfiguration of the system will be done using ETAP software.

- The result from the model will be used to compare how much the reliability is improved by adding DG to the feeder and Reconfiguration of the system.
- Cost analysis will be done to estimate the revenue saved after the reliability is improved.

The results will be presented in tabular and graph form and analyzed will be done. Finally, conclusion and recommendation will be drawn.

1.5 Scope of the study

This study will cover the current reliability problem causes in Arbaminich distribution system and improving methods by penetrating distributed generator and reconfiguration of the system. Analyzing reliability indices of the all feeder using mathematical calculation that makes to know which feeder is highly affected. Solar and Micro turbine are used as DG sources in the area. Particle swarm optimization is used to identify the size and location of DG in the distribution network. Reliability model will be developed using ETAP software.

1.6 Significance of the study

This study is expected to have the following outcome:

- Increase reliability of the system by reducing the interruption.
- Reduce energy interruption cost.
- Enhance the power supply for the society.
- Reduce power interruption influence on the customer.
- Increase the economy of the society and enhance industry sectors.

1.7 Thesis Layout

This thesis has been classified into five chapters.

Chapter One – This chapter introduces background of the study, statement of the problem, objective of the study, significant of the study, methodology and scope of study discussed.

Chapter Two – This chapter consists of theoretical background and literature review of reliability analysis and improvement. It also includes about distribution generation and types of distribution technologies.

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Chapter Three – This chapter discussed Reliability Evaluation Methodology. It includes reliability analysis methods, network reconfiguration, particle swarm optimization techniques and back and forward load flow analysis.

Chapter Four – Data collection and analysis of the case study area briefly discussed.

Chapter Five- This chapter discussed the simulation result based on the objective of the study.

Chapter Six – This chapter discussed conclusion and recommendation for future works based on the simulation result.

CHAPTER TWO

Theoretical Background and literature review

2.1. Introduction

Power quality and reliability are the two most critical concepts in a power system, and they are intertwined. Sinusoidal voltage with no waveform distortion, amplitude variation, or frequency variation may be used to describe power efficiency. Reliability of the power systems can be defined based on continuity of services, customer satisfaction and vulnerability of system. Reliability can be divided in to two parts: adequacy and security. Adequacy is related with capacity to meet customer demand and security refers to the ability of the protection system to withstand small disturbance. To say the distribution system is reliable, have sufficient capacity to meet the demand (adequacy) and operate under adverse conditions (security). Distribution system reliability issues are related with equipment outages and customer interruptions.

All equipment and customers are energized in the normal operating conditions. The normal operating condition of system can be disrupted by scheduled and unscheduled events. The scheduled events can be by power shading and maintenance of equipment. Unscheduled events are caused by due to human error, trees or outage and interruption. There are indices which are used to evaluate whether the system is reliable or not [4].

2.2. Distribution system

Distribution systems serve as the link from the distribution substation to the customer. This system provides the safe and reliable transfer of electric energy to various customers throughout the service territory. The connection between the distribution substation and the consumer is established by distribution systems. Such system ensures that electric energy is distributed safely and efficiently to a range of customers throughout the service territory. The distribution systems start with a medium-voltage three-phase circuit, generally about 33-15KV, and end with a lower secondary three-phase or single-phase voltage, usually below 0.38 KV, at the customer's basis, usually at the meter.

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Overhead and underground circuits are typically used in a mix of branching laterals from the station to the various customers in distribution feeder circuits. The circuit is designed to meet a variety of requirements, including required peak load, voltage, distance to customers, and other local conditions such as terrain, visual regulations, and customer requirements. Such branching laterals can be operated in a radial or looped configuration, in which two or more parts of the feeder are connected, typically via a normally open distribution switch [5].

The distribution system may also be divided into three distinct subsystems [6].

- Distribution substation
- Primary distribution system
- Secondary distribution system
 - **Distribution substations**

The distribution substation receives power from transmission or sub transmission lines and provides that power to distribution feeders that originate in the substation. The feeders emanate radial from the substation to supply to the load. In the substation, one or more transformers are always present to reduce the voltage to the primary distribution voltage level. These transformers will always be three-phase banks, or three single-phase banks connected in three-phase mode.

- **Primary Distribution**

The feeders that emerge from the substation and supply power to one or more secondary distribution systems comprise the primary distribution system. These feeders are typically three-phase circuits. In rural areas, feeders are almost always radial from the substation to the loads, and they are almost always radial in residential areas. Feeders can be looped in large urban areas, particularly commercial and business districts where reliability is critical

- **Secondary Distribution**

Laterals, also known as taps or branches in the industry, branch from the main feeder. The laterals could be three-phase, single-phase, or both (one phase from the single-phase feeder and a neutral). Fuse protection is typically used on laterals to ensure that faulted laterals do not cause feeder interruption.

2.3 Distributed Generation

Distributed Generation (DG) includes any form of electrical generator that generates power and can operate in parallel with the utility distribution system or is designed to operate independently from the utility system and can supply power to loads that can also be supplied by the utility electrical system. In distributed electricity small and micro generators are connected directly to factories, offices, and households and to lower voltage distribution networks. DG is used to enhance the reliability of distribution system that reduces line losses, providing alternative sources of supply and providing environmental benefits [7].

Electricity which not required by the directly connected consumers is fed into the active distribution network to meet demand. Distributed generation sources can be renewable and non-renewable energy sources. Based on Environmental prospective, use of renewable energy sources reduces emissions. Distribution Generation can improve distribution network reliability, voltage profile and reduce power losses. DG is classified based on generating unit size, which is based on different literatures [8]:

- DG size is defined as from few kilowatts to 100MW.
- DG size can be between 500 KW to 1 MW.
- The electric power Research Institute (EPRI) considers few KW to 50 MW.
- According to International council on Large Electric systems, distributed generation units with a maximum capacity of 50 MW to 100 MW.

There are many types of distributed energy sources. Some of these are solar (PV), wind turbines, fuel cells, Micro-turbine etc. The types of DG help to make decision with regard to which kind of technology is suitable and availability in the area.

1) Photovoltaic system

A semiconductor, such as silicon crystal, is used to make a solar or photovoltaic (PV) cell. The photovoltaic cell is intended to convert light energy into electric current. It is a specially designed diode, which is an electronic component with positively and negatively charged fields that force the movement of electric current in only one direction. The diode junction is the boundary between the negative and positive fields. Once light hits the exposed active surface of the cell, the

semiconductor material absorbs a portion of the light energy. When energy knocks electrons out of their positive and negative states in the silicon crystal, allowing them to freely flow. Some of the electrons have enough energy to cross the diode junction and cannot return to positions on the other side of the junction without passing through an external circuit. This flow of electrons is referred to as current, and current can be drawn off for external use by placing metal contacts on the top and bottom of the photovoltaic cell. Because the current obtained from these devices is small and the voltage is low, they must be connected in large series parallel arrays (solar panels) if a useful amount of energy is to be covered. The system generates DC voltage, which is then converted to AC by an inverter. For storage, the system can make use of a battery [9].

The silicon wafer of the photovoltaic solar cell facing the sun consists of the electrical contacts and is coated with an anti-reflective coating that helps absorb the sunlight efficiently. The electrical contact provides the connection between the semiconductor material and the external electrical load, such as light bulb or battery. When sunlight shines on a PV cell, photons of light strike the surface of semiconductors composition to help to establish a path of the freed electrons. This creates a flow of electrons forming an electrical current which starts to flow over the surface of the photovoltaic solar cell. To collect these electrons, metallic strips are placed across the surface of the photovoltaic cell, forming the positive connection. The negative connection to the cell is formed by a layer of aluminum or molybdenum metal on the back of the PV cell, which is the side away from the incoming sunlight. Then there are two electrical connectional current flows in a photovoltaic solar cell, one positive and one negative [10].

2) Micro- turbine

Microturbine is small combustion turbine that burns gaseous or liquid fuel to drive an electrical generator. It has integrated generators and power electronics that are generally supported either by air or liquid lubricated bearings. The micro turbine generates high frequency AC power that is rectified by a power electronics package into utility grid quality phase AC power. Micro turbine has four main components: compressor, combustion chamber, turbine blades and drive shaft. The compressors operate by taking in the surrounding air at one end of the micro turbine and then compressing the air by increasing the air's pressure and density. This compression releases enormous amount of heat energy and high-pressure exhaust gases [11]. The exhaust gases are discharged

through exhaust vents into a series of turbine fans which in turn spin the drive shaft at high speeds. Micro turbines can run on a wide range of gaseous and liquid fuels and emit very little nitrogen oxide. The electrical efficiency of micro turbines ranges between 25 and 30 percent. Despite the fact that the most recent combined cycle gas turbines can achieve maximum output efficiencies close to 60 percent [12].

2.4 Benefit of Distributed Generation

A customer may decide to install a distributed generator for a variety of reasons. DG can be used to generate a customer's entire electricity supply; for peak shaving that is generating a portion of a customer's electricity onsite to reduce the amount of electricity purchased during peak price periods); for standby or emergency generation (as a backup to wires owners power supply); as a green power source (using renewable technology); or for increased reliability. DG can be constructed at the load location that it may reduce the need for large infrastructures or upgrades. A facility can use DG units to reduce environmental emissions from generating power. Important DG characteristics for green power applications include low emissions, High efficiency and low maintenance costs. The following are a list of that potential interest to electrical utilities and their customer [13].

- **Continuous power**

In this application, the DG generates some or all its power on a relatively continuous basis. Characteristics of continuous power include [14,15]:

- High electric efficiency
- Low variable maintenance cost
- Low emissions

Currently, DG is being utilized most often in continuous power capacity for industrial applications such as food manufacturing, plastics, rubber, metals and chemical production.

- **Combined Heat and power**

It referred as cooling, heating and cogeneration, this DG technology is operated at least 600 hours per years to allow a facility to generate some or all its power. The heat is used for water heating, space heating, steam generation or other thermal needs. DG characteristics for combined heat and power include:

- High useable thermal output
- Low variable maintenance cost
- Low emissions

As with continuous power, CHP is mostly used by industry clients, with a small portion of overall installations in the commercial sector.

- **Peaking power**

In a peaking application, DG is operated between 200-3000 hours per years to reduce overall electricity costs. Units can be operated to reduce the utility's demand charges, to defer buying electricity during high-price periods, or to allow for lower rates from power providers by smoothing site demand.

- Low installed cost
- Quick start up
- Low fixed maintenance costs

- **Green power**

A facility can use DG units to reduce environmental emissions from generating power. DG characteristics for green power application

- Low emissions
- High efficiency
- Low variable maintenance costs

- **Premium power**

DG is used to provide electricity service at a higher level of reliability power quality than typically availability from the grid. The growing premium power market presents utilities with an opportunity to provide a value-assed service to their clients.

2.5 Reliability Challenge in Distribution system

Power system reliability can be affected by different aspects that can be natural or human faults. The reliability issues and reliability measures to be taken become non periodic. There are certain conditions that influence reliability of power system.

Time varying load nature of distribution networks affects the aging rate of system equipment. These decrease the lifetime of the equipment, as result of increased failure rates. As loading increases, switching between systems connections are made which also puts equipment to increased switching rate sparks causing overheating occurs. Other conditions are network structure; radial networks are mostly vulnerable to failure and power outage. Interconnection between distribution networks enables closing and opening of sectionalizing switch and ties switches. The sectionalizing and ties switch also influence the reliability of a system.

Environmental conditions such as human errors, natural disasters make the prediction of reliability of a system difficult. Natural phenomena increase aging of system component equipment. Reliability of a system modelling at different weather conditions influences the result of the analysis. Load forecasting issues face probabilistic nature which can lead to miscalculation. For this reason, system reliability is dependent to random modelling and non-concrete estimation of environmental conditions [16].

2.6 Literature Review

In this section distribution system reliability issues and enhancement methods are discussed from the research publication. Power interruption is a serious problem in the country and it affects economic growth and development of the country. The distribution system also did not get attention compared to generation and transmission system, that affects the customers need. In order

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to meet the need of customers the distribution system needs improvement to increase the reliability efficiency and service quality.

A. K Saha and R. Bhugwandeem [17] have proposed methods to improve reliability of distribution network by means of network reconfiguration. They used failure effect analysis (FEA) to Evaluate the reliability of the system. The study used tie switch and sectionalize switch for reconfiguration purpose and changing the status of the switch such as normally closed switch changed to normally open switch and normally open switch changed to normally closed. They considered voltage limit and thermal limit of the components. They compared the result with the bench mark to check how the reliability is improved after the proposed method used. The study did not consider any optimization algorithm for network reconfiguration case and other reliability improvement option.

P. Pavmi and SN. Singh [18] have studied a method to improve reliability of distribution network using distributed generation and network reconfiguration. They used probabilistic model for reliability assessment cases. The paper use search based algorithm for network reconfiguration, DG sizing and location. The reconfiguration and DG sizing and location is done using integer programming MATLAB code. The analysis carried out three cases such as: base case alone, DG alone and reconfiguration alone. The study didn't consider voltage and thermal limitation of the components. They also didn't consider types of DG used in the study.

D. Taja and S. Saheb [19] have present method to improve reliability of distribution system using network reconfiguration and distributed generation placement. The authors use voltage sensitivity index to optimally reconfigure the network and for DG sizing and placement. They carried out four case based from the analysis such as: base case alone, DG alone, network reconfiguration alone and DG and network reconfiguration. The study didn't consider DG technology sources in the paper.

N. Nubee and Sabir [20] has studied the impact of distributed generation on distribution system using analytical approach and sequential Monte Carlo simulation. In the study, the DG connected to the line when it is needed. Due to this the author analysis, there is not interconnection problem in the line or the DG did not affect the protection system of the existing line. The study did not consider size of DG and technology of DG. It also did not use optimization algorithm for network reconfiguration and DG sizing and location.

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N. Rugthaichoroencheap and T. Langtharthag [21] have studied method to improve the reliability of distribution system with optimal placement of DG. The authors used Tabu search algorithm and reliability worth analysis for DG sizing and location. The authors suggest using the proposed methods reliability of the system improved and cost of interruption reduced. The study did not considered types of DG technology used in the method.

G.V.K Murthy et al [22] has studied reliability improvement of distribution system using distributed generation. The study use ABC algorithm for optimal DG sizing and compared with PSO algorithm. The study compared the result with existing system or without DG integration to the system. The author analyzed using ABC algorithm the reliability indices reduced more than PSO algorithm. The study did not select DG technology for the study.

A.B. Alkuhayli [23] has studied reliability Evaluation of distribution system containing renewable distributed generation. The author used Monte Carlo simulation algorithm to Evaluate the network. The study used solar, wind and gas turbine as distributed generation source. To evaluate the reliability of the system three case carried out: without DG, with DG and with energy storage system. The author did not use optimization algorithm for DG sizing and location.

Yu sun, M. Bollen and G. Ault [24] have proposed methods to improve reliability of distribution system using Distributed Generation. The study uses analytical method to study reliability of individual customers. The relationship between reliability of distribution system and Distributed Generation with island operation capability has been presented. A comparison has been used for reliability between three cases: without connecting Distributed generation or Distributed Generation with islanding operation, Distributed Generation with Disconnecter and Distributed Generation with Breaker. The interruption frequency is improved in Distributed Generation with Disconnecter case compared with base case and Distributed Generation with breaker case. The authors did not use optimization algorithm for DG sizing and location. The study didn't consider DG technology sources in the paper.

CHAPTER THREE

Reliability Evaluation methodology

3.1 Distribution system reliability Analysis

Power system reliability is the ability to deliver electricity to all points of power utilization within acceptable limits of power flow constraints. The capability of power system is, to supply power to its customers with fewer interruption durations. Basically, distribution reliability is an added effect of system adequacy and system security. These two features determine power availability in distribution network and high probability of a load being energized.

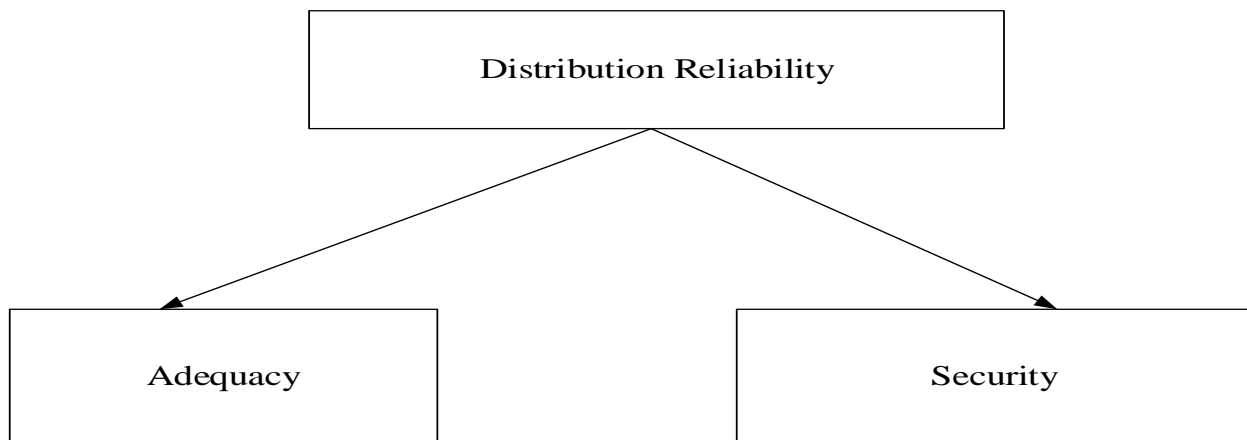


Figure 3.1 Distribution system reliability and subdivision [25]

The ability to provide electric power in static-dynamic situations is associated with reliability in power systems, and this providence must be performed in a continuous and qualified manner for both parties, i.e. the provider and the customer. The reliability has two sub-concepts as “system adequacy and “system security”. When it comes to system adequacy, adequate facilities are kept on hand in the system to meet customer demands or system requirements. System security refers to the ability to respond to potential disruptions within the system. To measure system performance, the electric utility industry has developed performance measure of system reliability. These reliability indices measure system outage duration, frequency, availability and response time.

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The average load point failure rate, average load point outage duration, and average annual load point time or unavailability are the basic load-point reliability indices used to predict distribution system reliability. These three parameters can be used to calculate a wide range of system indices. The system reliability indices may be customer-oriented such as system average interruption duration of interruption on monthly basis or annual calculations. Reliability analysis can also be conducted using failure rates and outage duration of system component. Some of the reliability indices are SAIFI, SAIDI, CAIDI, ASAI [26].

- **System Average Interruption Duration Index (SAIDI)**

This is commonly referred to as customer minutes of interruption and is designed to provide information about the average time the customers are interrupted.

$$\text{SAIDI} = \frac{\text{customer interruption durations}}{\text{Total Number of Customers served}}$$

$$\text{SAIDI} = \frac{(\sum r_i \times N_i)}{NT} \quad (3.1)$$

Where

N_i - Number of interrupted customers for each interruption event during reporting period.

NT - Total number of customers served for the area being indexed

r_i - Restoration time for each interruption event during reported period.

i - An interruption event

- **System Average Interruption Frequency Index (SAIFI)**

This index is designed to give information about the average frequency of sustained interruptions per customer over a predefined area.

$$\text{SAIFI} = \frac{\text{Total number of customer interruption}}{\text{Total number of customer served}}$$

$$\text{SAIFI} = \frac{(\sum N_i)}{NT} \quad (3.2)$$

Where

N_i - Number of interrupted customers for each interruption event during reporting period.

N_T - Total number of customers served for the area being indexed

i - An interruption event

- **Customer Average Interruption Duration Index (CAIDI)**

Represents the average time required to restore service to average customer per sustained interruption.

$$CAIDI = \frac{\text{Customer interruption durations}}{\text{Total number of customer interruptions}}$$

$$CAIDI = \frac{(\sum r_i \times N_i)}{(\sum N_i) / N_T} = \frac{SAIDI}{SAIFI} \quad (3.3)$$

- **Average Service Availability Index (ASAI)**

Represent average service availability index

$$ASAI = \frac{\text{Customer hour of availability service}}{\text{Customer hour demand}} \quad (3.4)$$

3.2 Reliability Evaluation

Reliability analysis in distribution system is used to show if the system is reliable or not, which scheme will fail less and systems investment to improve it. Reliability in power system is divided in to two basic aspects that are system adequacy and system security. In the case of system adequacy, adequate facilities are held on hand in the system to meet customer demands or system requirements. System security refers to the ability in responding to possible disturbance that may occur within the system.

Reliability evaluation of distribution systems consists of two main approaches, simulation and analytical methods.

The Monte Carlo methods consume much time due to large number of drawing in order to obtain accurate results. The fault distribution from each component is given by a statistical distribution of failure rates and outage times.

3.2.1 Simulation Methods (Monte-Carlo)

This provides both average value of the load point and probability distribution of the load point and system indices. Monte-Carlo simulation can be divided into two types: state sampling and time sequential techniques. The time sequential Monte-Carlo simulation technique can be applied to any stochastic system. This time sequential simulation process can be used to examine and predict actual patterns in simulated time, as well as to gain the probability distributions of the varied reliability variables and approximate the predicted or average value of all such indices. Using random number generators and the probability distributions of the element failure and restoration parameters, an artificial history that shows the up and down times of the system elements is generated in chronological order. The artificial history of the system yields the system reliability indices and their probability distributions. Basic equipment such as distribution lines/cables and transformers, as well as protection elements, are examples of distribution system elements (disconnects switch, fuses, breakers and alternate supplied). The two state models can be used to represent line sections and transformers in general. Where the up state indicates that the element is operational and the down state indicates that the element is ineffective due to failure [27].

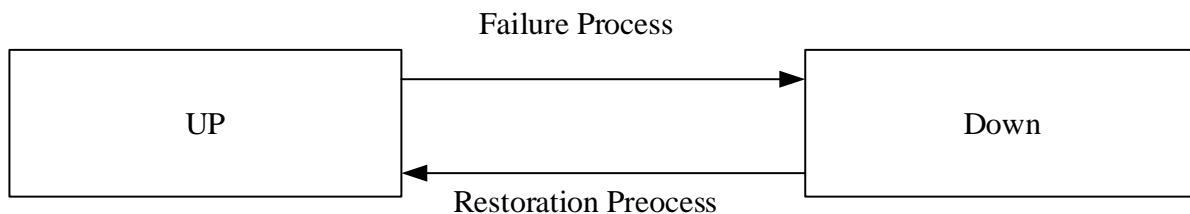


Figure 3.2 State Space Diagram of Element [27]

The time to failure is defined as the length of time the element remains in the up state (TTF). The time the element is in the down state is referred to as restoration time, and it can be either time to repair (TTR) or time to replace. The failure process is the transition from the up to the down state. The transition from up to down state can be caused by an element failing or by the removal of

elements for maintenance [28]. The failure of an element or the removal of elements for maintenance can cause the transition from up to down state. It creates a large history variation of different cases (bad years, average years, or good years), all of which are presented in the MCS sample years with varying probability. It provides a probabilistic model of reliability indices wherein the mean value and standard deviation can be calculated. The unsustainable historical background has been a two-state model in which either the component is energized or de-energized in the up state. The time to failure (TTF) is referred to as the up state, while the time to repair (TTR) or time to switch is referred to as the down state (TTS) [29].

The process is random therefore is needed to use random variables between 0 and 1 to calculate TTF and TTR for each component.

$$TTF_i = \frac{\ln(ui)}{\lambda} * 8760h \quad (3.5)$$

$$TTR_i = -\ln(ui) * MTTR_i h \quad (3.6)$$

Where

λ_i failure rate

$MTTR_i$ mean time to repair

3.2.2 Analytical Methods (Mathematical Models)

The analytical method looks at how the load points would be affected if a component fails. The three basic indices are used to predict the load point reliability of a distribution system are used to predict the load point reliability of a distribution system are failure rate (λ), outage time (r) and annual unavailability (U). Analytical techniques assess reliability of the system using direct numerical solutions. The expected loss of load calculated using capacity outage probability combined with the system load characteristics. The most commonly used analytical methods for assessing reliability [30]:

- State space method
- Contingency enumeration method

- Minimal cut set method

3.2.2.1 State Space Method

The modelling of components is typically based on an up and down state. That is, m (up-time or mean time to failure: MTTF), r (down-time or mean time to repair: MTTR) and T (cycle time which is the sum of the up and down-time). The state space consists of all possible state; Figure 3.3 describe for single components system. Where λ and μ are the system transition rates.

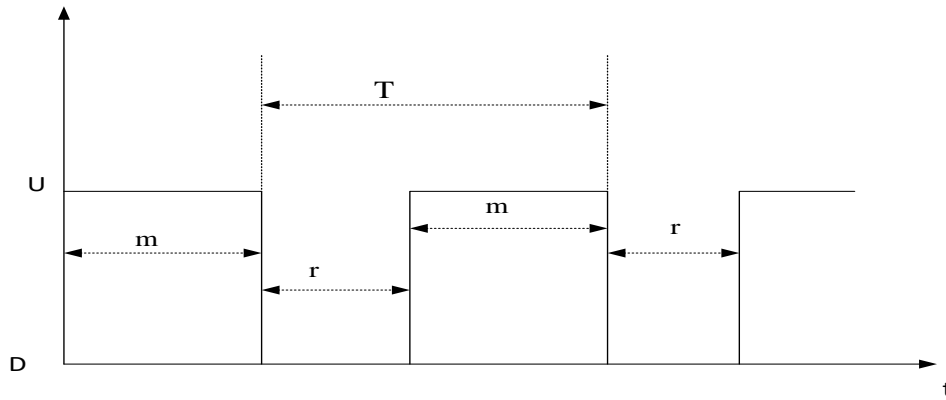


Figure 3.3 State Space Model [30]

3.2.2.2 Contingency Enumeration Method

The contingency enumeration method is another analytical method, which assesses the reliability through analysis of selected number of contingencies. Consideration of all possible contingencies is unrealistic in most cases due to extensive computational time, implying the importance of the selection procedure. The contingency selection must be done carefully, because every disregarded contingency adds to the inaccuracy of the evaluation. Easy way to perform the selection is to consider all contingencies up to a specified order. If the second order is selected, all combinations of up to two failed components are considered. When important contingencies of higher order are identified, these can be added to the contingency list. System to consider as composing important contingencies are related to system specific criteria, where system consisting of two subsystems interconnected via three lines, outage of three lines compose an important contingency. Load flow calculation for each contingency led to identify possible problems caused by contingencies. Some of the identified system problems might be repairable with corrective actions, such as generation

rescheduling. Load shedding must take place if system problem cannot solve. Load shedding strategy is highly relevant for the results of each load points, since a systems power inadequacy could theoretically be solved by load shedding at any load point. Contingencies that causes local problems are less sensitive to the load shedding strategy chosen.

3.2.2.3 Minimum Cut Set Method

Minimum cut set methods are used to evaluate the reliability of specific load points in the power system. The method shortens computation time by concentrating on system contingencies that are relevant for the selected load points rather than the entire system. Components of minimum cut behave like they connected in parallel and series. In series connection failure of one minimum cut set causes system failure whereas in parallel all must fail to cause system failure.

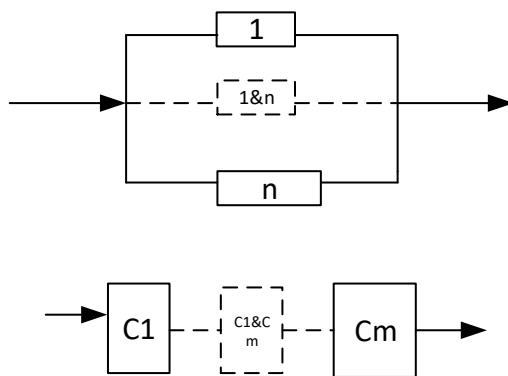


Figure 3.4 Minimum cut set consisting of n & m components [30]

3.3 Root Cause Analysis of Distribution System

There is various problem faced with the existing Arbaminch power distribution network. Arbaminch substation is selected due to the availability of load supply data. Various faults occur in Arbaminch substation it frequently causes interruption. The causes of the interruptions are:

Technical problem: Technical problems are interruption that cause due to failure of distribution system equipment. Outages or line disconnections by the service provider for maintenance or repair are also operational cases. Technical problems are transformer and arrestor explosion, oil leakage from transformer tank, aging of wood towers and breaker failure to trip.

External causes: External causes are different from technical problems that occur due to failure of equipment. It's a result of natural phenomena or human errors on distribution system from external. There are different causes of interruption in the distribution system. Some momentary faults are difficult to detect the types of faults and what cause them. The reason is the distribution system works in manual fault clearing and fault detection mechanisms are traditional. The main types of faults causing interruption in the current distribution system are:

Permanent Earth fault (PEF)

Permanent Earth fault is due to the distribution line or equipment getting in contact with the ground directly or indirectly for long time. Such types of faults are cause by transformer oil leakage and connection to earthing wire. Distribution line in contact with trees and branches causes faults. Underground cable water leakage also one of the faults that cause interruption in the distribution networks.

Temporary Earth Fault (TEF)

Such faults happen frequently during rainy season because of the supporting steel structure gets in contact with distribution line and water leaking to insulator cubs that result in interruption. Wind blows distribution line to each other that lie on the trees and branches cause temporary faults. This type of fault does not persist long and results circuit breaker to trip.

Permanent short circuit (PSC)

These types of faults happen when the distribution lines contact each other. One distribution line falls onto nearby lines causing short circuit due to untightened fixation of power lines to tower. The existence of high voltage and medium voltage lines in close range of distance experience electric field forces. The forces that occur between the line narrows the air gap across the line. Broken tree branch touching the two lines at the same time also cause short circuit.

Temporary short circuit (TSC)

The distribution line contacts each other due to wind crate short circuit and it cause the breaker to trip. A similar event occurs during tree movement by wind crating contact with distribution lines. The tree touches two lines same time causing line to line faults. Moreover, contact of bird's dead

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on lines and stormy rain season caused interruption. The rain pushes the dielectric strength of the air beyond limit this form corona and the circuit breaker trips as a result of this till the rain stops.

Distribution lines overload (DLOL)

High tension on distribution line, disconnect sections of power networks. To investigate demand imbalance newly emerging firms and business centers consumption must know. Circuit breakers trip to avoid damage on the line during public festival customer time of use there will be high consumption of power. High demand crates time shifting of supply by the dispatch center. For this case deliberate sectional disconnection of load points is undertaken.

System Overload (SOL)

Faults in generation plants cause power shortage to deliver all loads. Some generation plants faced technical problems and power deliver to the load had been short. System overload also occur due to demand imbalance and shortage of power during peak hour. Increasing demand for electric power have caused existing grids to become overloaded. In adequate power generation and inadequate distribution system are also causes of line voltage problems. When the system has heavy loading or tripping of any one of its line in the grid may cause the reduction of receiving end voltage. If the voltage is decreased beyond the limit overload problem and voltage instability may occur on the system.

Interruption occurs for various reasons in addition to the above causes. During maintenance, power is interrupted to customer downstream of the point under maintenance. These customers will be affected till the maintenance process is finished. The reason is there is no alternative way to supply the downstream customer. In addition to above case interruption occurs for various cases. During maintenance, power is interrupted to customer downstream of the point of maintenance. Additionally, the distribution system is not automated. It works on the level of manual restoration. Fault location techniques and manual fault clearing mechanism take time. For instance, overhead lines contact each other because of wind that results in locking out of circuit breaker and takes times for manual restoration. Equipment failure is also another form of power outage. Cooling system oil leakage earthed a transformer, transformer fire ignition due to overheating, explosion

of underground cable and aging of cable carrying tower causing short circuit resulted in feeder line interruption. Loose line connection loose arm connection to the tower has occurred frequently. The other problem for lengthy power outage was fault tracing due to breaker lock out in substation.

3.4 Reliability Cost Benefit Analysis

The ability to incorporate cost analysis and quantitative reliability assessment into a common structured framework is provided by reliability cost/worth assessment. Reliability cost refers to the investment needed to attain assured level of adequacy. Reliability worth is the benefit derived by the utility; customer satisfied because of higher reliability [31].

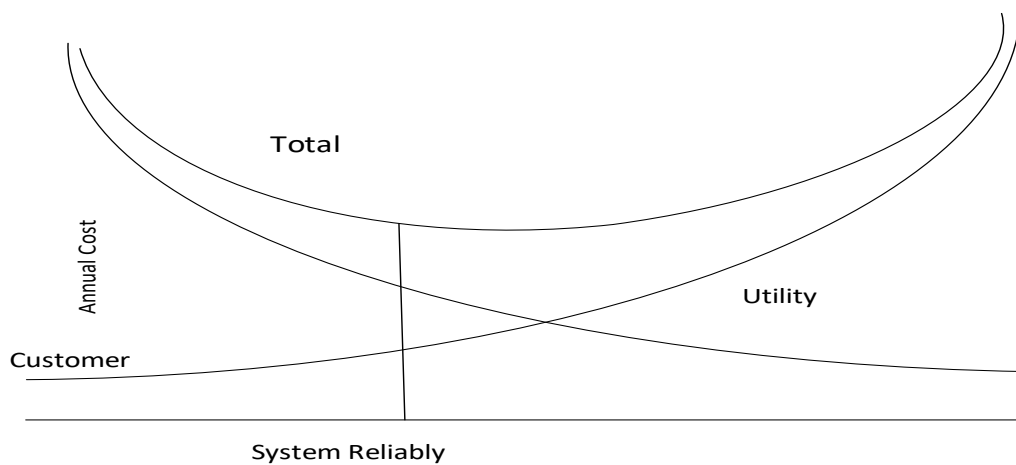


Figure 3.5 Cost worth analysis of system reliability [32]

The figure shows that to get higher reliability, the system cost increase with higher investment cost and the customer interruption costs due to higher reliability will decrease. Customer interruption costs, on the other hand, will be reduced. reliability of the system. The sum of these two costs is the total cost to society. The total cost to society is the sum of these two costs. There is a minimum point in the resulting total cost curve which indicates the optimal target level of reliability. Reliability worth/cost analysis is performed to find this optimal point.

3.5 Distributed Generation Technology Selection

There are different types of distributed generation technology as discussed above. Distributed generation can be renewable and non-renewable energy sources. Selection of DG for a certain area

is based on availability of resources in the area, cost, effectiveness and efficiency of the resource. Resources availability varies from area to area due to geographical location. Some areas have solar energy resource based on solar radiation in the area and others have wind and geothermal based on wind speed and places. Different types of DG resources have different level of emissions of gas and cost. In this work distribution system reliability analysis is assessed using distributed generation like PV and Micro turbine.

3.5.1 Photovoltaic system

A p-n junction in the layer of semiconductor forms a photovoltaic cell structure that can convert solar energy into electrical energy. Weather data (irradiance and temperature) are used as input data for PV modelling. For modelling, it is necessary to analyse the influence of different factors on photovoltaic cells and to take consideration the characteristics given by producers. The model takes in to account the variation of the photoelectric current. when the radiation and temperature changes, the variation of the diode saturation current will change. The ideal solar cell as shown on the Figure 3.6, semiconductor diode connected with series and parallel resistance [33].

3.5.1.1 Mathematical Modelling of Photovoltaic system

A photovoltaic module is made up of several interconnected solar cells that are encased in one unit. Modeling the solar cell is necessary in order to predict the power extracted from solar modules as well as the module current-voltage (I-V) characteristics. When the temperature and radiation change, the model accounts for variations in the photoelectric current as well as changes in the diode saturation current [34].

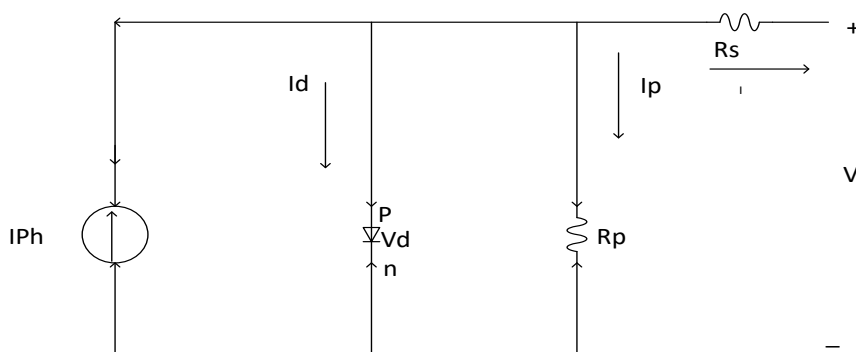


Figure 3.6 Equivalent circuit of a PV cell [34]

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I_{ph} is the photocurrent; I_d is the diode current, which is proportional to the saturation current,

$$I_d = I_o \left[\exp \left(\frac{V}{A \cdot N_s \cdot V_T} \right) - 1 \right] \quad (3.7)$$

V is the voltage imposed on the diode

$$V_T = K \cdot \frac{T_c}{q} \quad (3.8)$$

I_o is the reverse saturation or leakage current of the diode (A),

$V_{Tc} = 26 \text{ mV}$ at 300k for silicon cell,

T_c is the actual cell temperature (k),

K Boltzmann constant $1.381 \cdot 10^{-23} \text{ J/k}$, q is electron charge ($1.602 \cdot 10^{-19} \text{ C}$).

V_T is called the thermal voltage because of its exclusive dependence of temperature.

N_s is the number of PV cells connected in series.

A is the ideality factor and it depends on PV cell technology.

All the terms by which, V is divided under exponential function are inversely proportional to cell temperature. Thermal voltage (V) represented by a and ideal factor depend on PV cell technology.

$$a = \frac{N_s \cdot A \cdot K \cdot T_c}{q} = N_s \cdot A \cdot V_T \quad (3.9)$$

Series resistance R_s and parallel resistance R_p are take into consideration because of their impact on the efficiency of the PV cell and the PV module.

$$I_d = I_o \left[\exp \left(\frac{V + I \cdot R_s}{a} \right) - 1 \right] \quad (3.10)$$

By applying Kirchhoff law, current will be obtained by

$$I = I_{ph} - I_d - I_p \quad (3.11)$$

I_p is the current leak in parallel resistor. According to the equations, the output current of a module containing N_s , cells in series will be

$$I = I_{ph} - I_o \left[\exp \left(\frac{V + I.R_s}{a} \right) - 1 \right] - \frac{V + R_s I}{R_p} \quad (3.12)$$

$$V_d = V + I R_s \quad (3.13)$$

In the equation, I_{ph} represent a current source crated by photocurrent, I_o is saturated current, v is output voltage, V_d is diode voltage, q is electron charge, R_s denotes a series resistance, R_p is the shunt resistance across the diode, T is considering the cell temperature, n is a deviation factor from the ideal p-n junction diode.

In a photovoltaic device, the battery is a key factor. By allowing the storage of excess energy from the PV array, it functions as a dumper and provides energy for loads at night or on non-sunny days. As it supplies the loads with constant voltage, it can be regarded as a stabilizer. Lead acid batteries mostly used in PV system. Many phenomena can actually occur, such as Charging and discharging. During such processes, several parameters vary: voltage, current, density, Resistivity, temperature, etc.

$$E_B(t+1) = E_B(t)(1 - \sigma) + \text{surplus power} * \eta_{BC} \text{ charging mode} \quad (3.14)$$

$$E_B(t+1) = E_B(t)(1 - \sigma) - \text{deficit power} / \eta_{BD} \text{ discharging mode} \quad (3.15)$$

Where,

E_B is energy of the battery, η_{BC} , η_{BD} charge and discharge efficiency of the battery and σ is battery self-discharge rate.

3.5.1.2 Meteorological Data of Solar Radiation

The solar energy generation is mostly weather dependent, since the total amount of solar radiation varies with weather condition. Table 3.1 shows annual metrological solar data, as shown from the data annual daily radiation is 5.70kWh/m²/d. This shows the solar energy resource is available in the area. Table 3.1 shows amount of solar radiation in the area, it indicates the radiation is varying

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when months change but average radiation is 5.70 Kwh/m²/d. In the below figure 3.7 annual solar radiation of the area using Homer software.

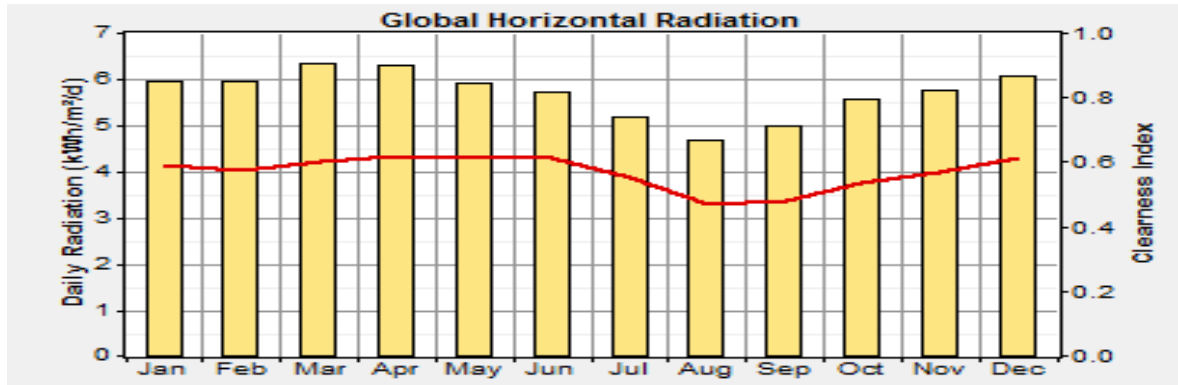


Figure 3.7 Annual solar radiation

Table 3.1 Meteorological Data of Solar [35]

Month	Air Temperature °C	Relative humidity %	Daily solar radiation-horizonal KWh/m ² /d	Atmospheric Pressure kpa
January	22.2	36.3	5.96	83.8
February	23.3	33.8	6.33	83.8
March	23.6	41.6	6.30	83.8
April	22.0	56.9	5.91	83.8
May	20.3	67.1	5.71	83.9
June	19.6	65.7	5.19	84.0
July	18.7	66.5	4.68	84.1
August	18.9	65.2	4.97	84.1
September	19.8	61.8	5.55	84.0
October	20.0	61.4	5.77	83.9
November	20.6	50.5	6.07	83.9
December	21.4	41.4	5.97	83.9
Annual	20.9	54.0%	5.70	83.9

3.5.2 Micro Turbine

In single shaft Microturbine design compressor and turbine are mounted on same shaft as the permanent magnet synchronous generator. This is high speed low torque turbine. Due to high speed PMSG generates high Frequency A.C. voltage ranging from 1500-4000 Hz which is first

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rectified and then converted into the usable frequency of 50HZ using PWM inverter. Rectification and inversion of generated voltage from A.C. to D.C. and then D.C. to A.C. results into incorporation of Power electronics circuits. This makes the power conditioning somewhat more complicated and to overcome the challenges originated thus, needs proper designing of power electronics interface. On the other hand, the split shaft design of Microturbine incorporates turbine on the first shaft in a straight line that drives the compressor while a power turbine on the second shaft that drives the gearbox and conventional electrical generator. This arrangement rotates the generator at 3600 rpm and the use induction generator avoids the use of power conditioning circuit. Due to two shafts the speed is low in the latter arrangement [36].

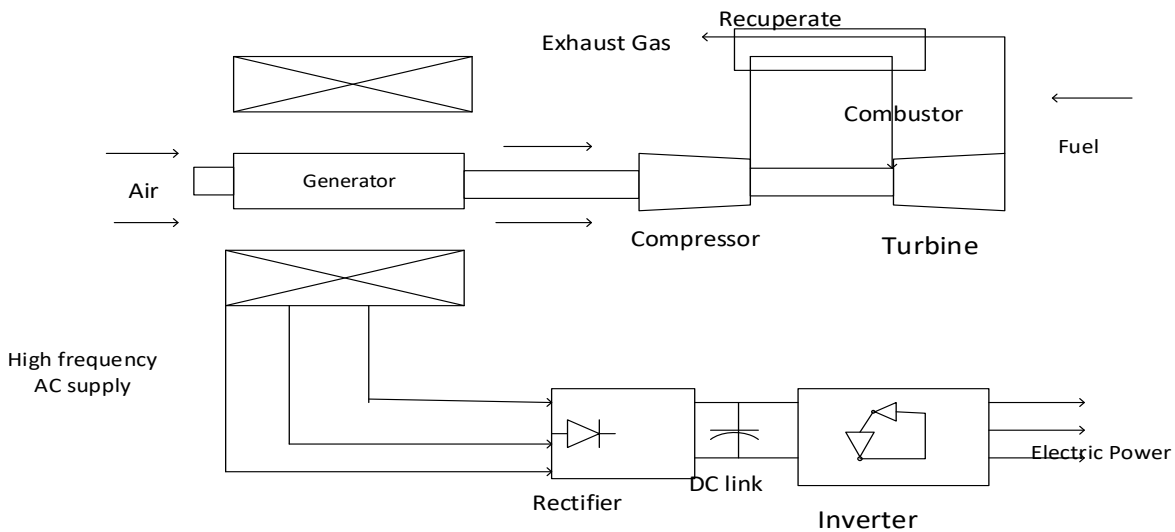


Figure 3.8 Single shaft Microturbine generation System [36]

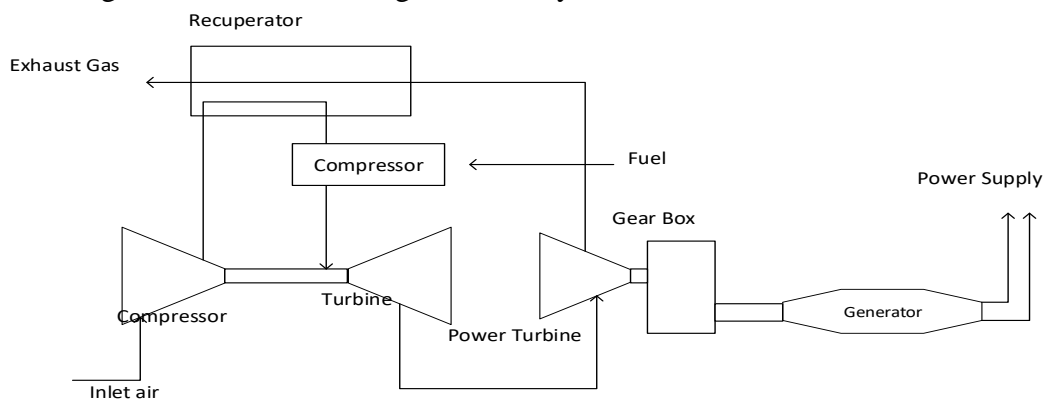


Figure 3.9 Split shaft Microturbine generation system [37]

3.6 Distributed Generation Placement and Sizing Methods

Distributed generation to the existing network has significant impact to system reliability. However, inappropriate sizing and location has negative impact to the protection system. DG optimal location and sizing are key to achieve positive impact to the system [38,39,40]. The real power loss reduction is required in distribution system efficient power system operation. Power loss can be calculated using equation (3.16).

$$PL = \sum_{i=1}^n \cdot \sum_{j=1}^n A_{ij}(P_i P_j + Q_i Q_j) + B_{ij}(Q_i P_j - P_i Q_j) \quad (3.16)$$

Where

$$A_{ij} = \frac{R_{ij} \cos(\delta_i - \delta_j)}{V_i V_j}$$

$$B_{ij} = \frac{R_{ij} \sin(\delta_i - \delta_j)}{V_i V_j}$$

Where

P_{ij} and Q_{ij} are real and reactive power injected in bus i and j .

R_{ij} is line resistance between bus i and j .

V_{ij} is voltage.

δ angle at bus i and j .

The reliability parameter considered are Expected energy not supplied (EENS) and Expected outage cost (ECOST)

$$EENS = \sum_i \sum_k L_k h_i t_i \quad (3.17)$$

$$ECOST = \sum_i \sum_k L_k h_i C_{ik} t_i \quad (3.18)$$

Where

t_i is interruption time

L_k is load

h_i is failure rate

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C_{ik} is customer interruption cost with interruption duration.

To ensure, distribution system works securely with DG connection, operational constraints are considered when selecting DG location. Some of the constraints for DG location and sizing are: Power quality constraints, voltage limit constraints on the bus and Generation capacity of DG.

Power quality constraints

The active and reactive power of the grid expressed as follow:

$$P_{\text{grid},j} + \sum_{i=1}^{NDG} P_{ijDG} = P_{D,j} + P_{\text{loss},j} \quad (3.19)$$

$$Q_{\text{grid},j} + \sum_{i=1}^{NDG} Q_{ijDG} = Q_{D,j} + Q_{\text{loss},j} \quad (3.20)$$

Where

$P_{\text{grid},j}$ and $Q_{\text{grid},j}$ is active and reactive power from the substation at the j^{th} loading

$P_{D,j}$ and $Q_{D,j}$ is demand active and reactive power by the load

P_{ijDG} and Q_{ijDG} are active and reactive power generated by the DG

Voltage constraints at the bus

The voltage at all bus have to be controlled

$$V_{\min} \leq V_j \leq V_{\max} \quad (3.21)$$

Where

V_{\min} and V_{\max} the Upper and Lower boundaries of voltage at the bus.

Generation capacity of DG

Some of the constraints for DG capacity limit and power flow analysis are as follow:

$$P_{DG_i}^{\min} \leq P_{DG_i} \leq P_{DG_i}^{\max} \quad (3.22)$$

$$Q_{DG_i}^{\min} \leq Q_{DG_i} \leq Q_{DG_i}^{\max} \quad (3.23)$$

The constraints show the weight of feeder section that is the proposed DG locations. The constraint is considered in objective function as penalty factor as follow:

$$PF = \sum_{k=1}^{NDG} W_{fs,k} \quad (3.24)$$

Where:

N_{DG} is the number of DGs and $W_{fs,k}$ is weight of the feeder section in which DG is connected.

3.7 Particle Swarm Optimization

Particle swarm optimization is population based optimization tool is used population based finding procedure when individuals called particles change with time. In PSO, particles fly around in a multidimensional search space. Each particle modifies its location during the flight within its own experience (this value is called P_{best}), which according to the experience of the nearby particle (this value is called G_{best}), allowing use of the best position where it and its neighbor have found. One of the advantages of particle swarm optimization over other derivative-free methods is the reduced number of parameters to tune and constraints acceptance. Fig. 3.10 illustrates a two-dimensional representation of one particle, 'i', movement between two positions. It can be observed how the particle best position, P_{best} , and the group best position, G_{best} , influence the velocity of the particle at the next iteration [41].

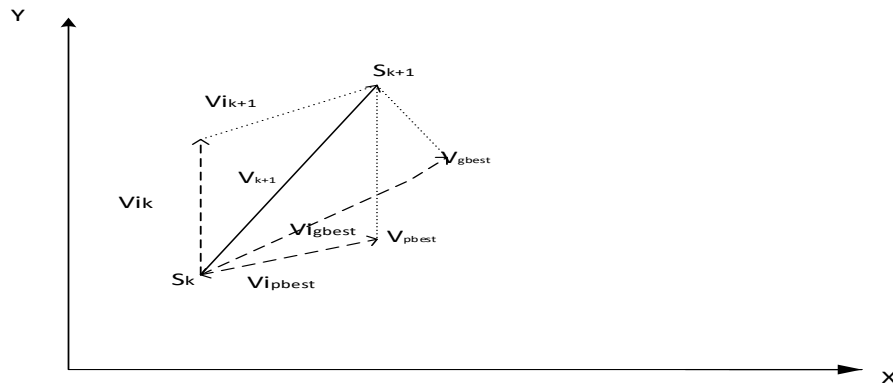


Figure 3.10 Two-dimension representation of particle movement [41]

Each particle in the search space in PSO has solution and fitness, speed, its own best position, and its best position. The individual swarm member is called a particle. The particle has its own dimensionally organized location, and the swarm is carried out by the particles. Fitness is the function (objective function) used to determine the consistency of the solution as an interface between the optimal problem and the physical one. There are two words in the search space that are modified for each iteration. The first is the position that the fitness function returns in the search

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space as the best one for a particular position P_{best} . In the meantime, the second is the location in the search space returned by the fitness function as the best for the entire swarm G_{best} . Upper and lower velocity limits for the movement of particles in the search space can also be regarded as constraints V_{max} and V_{min} .

In PSO, dimensional space represented each particle, $X_i = (X_i^1, X_i^2, \dots, X_i^n)$ represent the position and $V_i = (V_i^1, V_i^2, \dots, V_i^n)$ represent velocity of i^{th} particle.

The velocity is modified at each iteration and used to update the location, as shown in the following equation:

$$V_{i+1} = \omega V_i + C_1 r_1 (P_{best} - X_i) + C_2 r_2 (G_{best} - X_i) \quad (3.25)$$

In the range of zero to one, where r_1 and r_2 are two random variables, c_1 and c_2 are positive constants which determine how much further PSO particles are mostly from P_{best} and G_{best} , ω is inertia weight, ωV is the inertia that keep the particle motion in the same directions $C_1 r_1 (P_{best} - X_i)$ is the individual impact that improves personal and $C_2 r_2 (G_{best} - X_i)$ is impact the particle to move in the direction of the best near direction [42].

The algorithm's convergence is governed by inertia weight, which is selected in an acceptable manner to provide a good balance between global and local search. The value of ω , is used for improving the convergence efficiency, while the low value rises the algorithm's relevant data. The linear equation of inertia that can be used in PSO is:

$$\omega = \omega_{max} - ((\omega_{max} - \omega_{min}) * (\frac{iter}{maxiter})) \quad (3.26)$$

The optimization process of PSO for optimal DG sizing and placement steps can be:

- (i) Input system data, line data, voltage and bus number: in this step maximum - minimum allowed voltage and DG size range is specified. Population size and iteration are initialized
- (ii) Calculation of fitness function: the fitness function is calculating the summation of individual particle.

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- (iii) Calculate P_{best} and G_{best} at each iteration for all population. P_{best} is the lower fitness for the current iteration. The lowest fitness P_{best} is compared with the pervious iteration and conducted as G_{best} .
- (iv) After calculation of P_{best} and G_{best} , the new velocity and position are calculated for the next iteration. The new location will then be changed again. Here, the algorithm gets back to phase 2 if the condition does not reach the specified accuracy.
- (v) At last, the optimal output or optimal value is set as G_{best} .

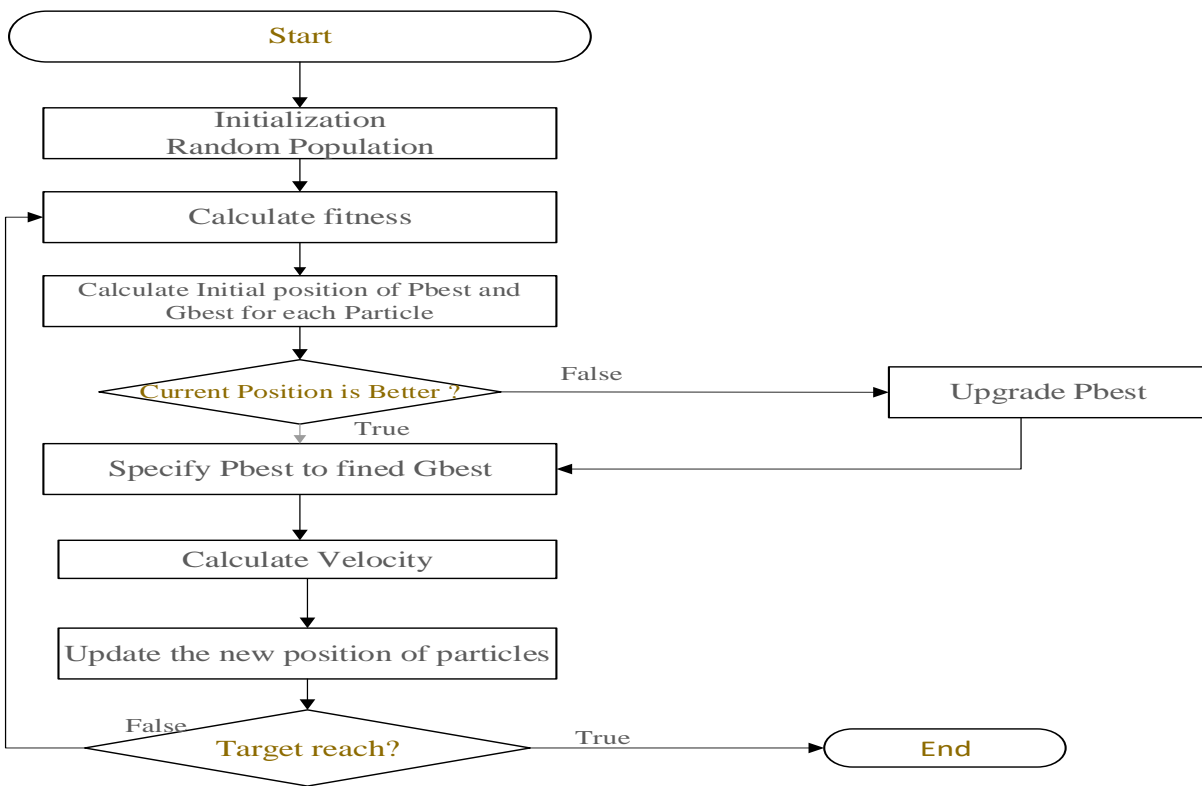


Figure 3.11 particle swarm optimization algorithm flow chart [42]

3.8 Network Reconfiguration

Network reconfiguration is the key to improve operation performance of distribution system. It is also used for isolating faults and restore services beside decreasing loss and balancing system load. It is done by changing the opening and closing status of the sectional and tie switch. It can improve the performance of the system using different objectives and constraints. Distribution system

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reliability improvement is one of the main objectives of the constraints. Distribution network reconfiguration is cost effective and efficient way to enhance the reliability of the system. There are some normally closed and normally open switch, in the existing distribution system [43]. Two types of switches are used in distribution system, sectionalizing and tie switch. Reconfiguration of existing system can alter the performance of the network in either a positive or adverse way. For the reconfiguration which is used, tie turn shift can bring Small improvements to the network to ensure the radial Maintaining of the system. It may result high power loss and affect the security of the system if it is not configuring optimally. It is also important to check the system voltage and thermal limit before proceeding the configuration process [44]. There is different network configuration algorithm such as genetic algorithm, particle swarm algorithm and neuro-fuzzy, etc.

Optimal distribution network reconfiguration using PSO algorithm steps can be:

- (i) Add load bus data line data, reliability data and voltage and thermal limit of the line. Initialize population, position and random velocities, P_{best} and G_{best} .
- (ii) Calculate inertia, update velocity and particles coordination.
- (iii) Calculate fitness function load flow using backward forward algorithm and reliability assessment.
- (iv) Update P_{best} , G_{best} and particle velocity.
- (v) Evaluate fitness function and select best fitness of all particles.
- (vi) Terminate if the iterations are reached its maximum.
- (vii) Set G_{best} at the best fitness

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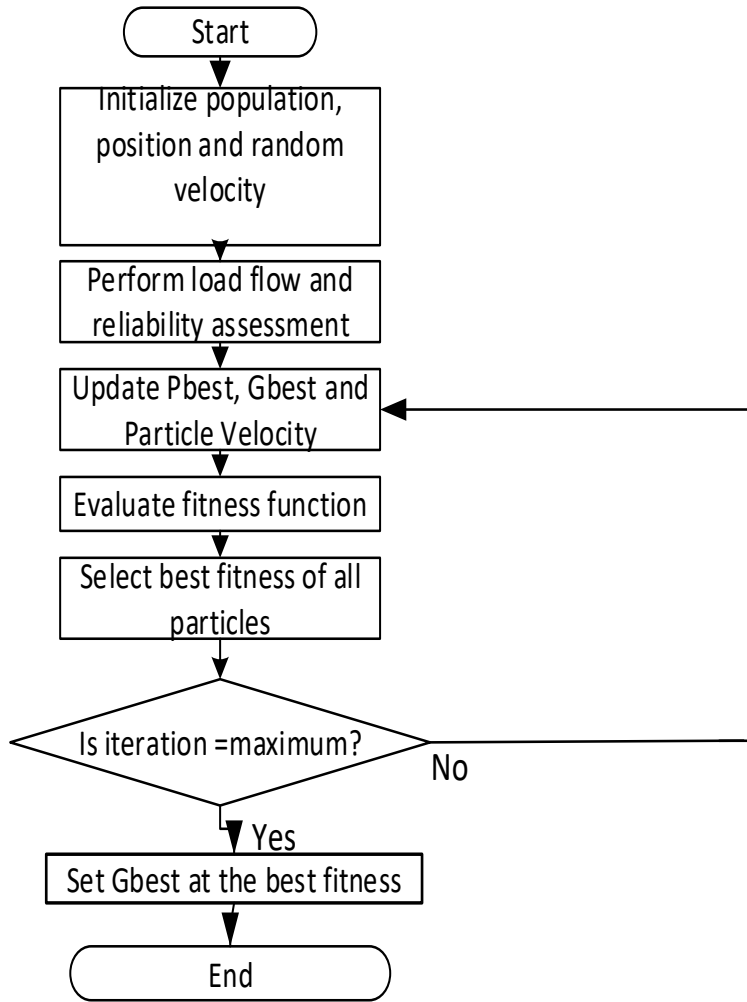


Figure 3.12 Flow chart of Network reconfiguration [44]

The reliability index used to measure the reliability of the system in this work is ENS. The objective function considered in this work is ENS.

$$f_{obj1} = ENS = \sum_{j=2}^{Nc} ENS_j = \sum_{j=2}^{Nc} P_j \times \sum_{\substack{i=1 \\ i \neq j}}^{nb} \lambda_{ij} \times l_{ij} \times t_{ij} \quad (3.27)$$

where

P_j is the active power of the unpowered load point

n_b is the number of radial configuration branches.

N_c is the total number of customers

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λ_{ij} , l_{ij} and t_{ij} are failure rate, repair and length of the line.

Minimizing ENS index contribute to maximization of reliability of the system. The configuration with the lowest index is the most reliable. Constraints related to the voltage of the network nodes and to the transients of the currents in the lines are called security constraints.

The voltage constraints are stated in the following:

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (3.28)$$

Where

V_i is the voltage at node 'i'

V_i^{\min} is minimum voltage at the node 'i'

V_i^{\max} is maximum voltage at the node 'i'

In addition to voltage constraints, current constraints are considered in constraint formulation.

The current transmitted through the branches must not exceed the steady state thresholds. It is stated as:

$$I_{ij} \leq I_{ij}^{\max} \quad (3.29)$$

Where I_{ij} is current in branch (i, j) and I_{ij}^{\max} is the maximum current in the branch.

The other constraint used is topology constrains that meets for mentioned criteria. When topology constraints are translated into graph theory, the desired radial topology must be equivalent to a spanning tree that models the general structure of a network. To ensure compliance with these constraints, this spanning tree must adhere to the following.

$$Nb_{\text{ closed lines}} = N - 1 \quad (3.30)$$

$$\forall X_i, X_j \in N, \exists \{C_i \cup C_j\}, \text{ let } \prod_k^n Z_{ik} \cdot \prod_k^n Z_{jk} = 1 \quad (3.31)$$

Where

$Nb_{\text{ closed lines}}$ is number of closed network branches

N is total number of nodes

$C_i \cup C_j$ is unique path connecting node i and node j

Z_{ik}, Z_{jk} topological states (0/1) of the branches

k is index of the branch

3.9 Back and Forward Load Flow Analysis

Forward/backward sweep-based load flow algorithm used for radial network and consists of forward and backward sweep process. It is an iterative method in which, at each iteration two computational stages are performed. The load flow can be solved iteratively from two set of equations. The first set of equations to measure the power flow through the branches, beginning from the last branch and continuing to the root node in the backward direction [45].

For the measurement of the voltage magnitude and angle of each node starting from the root node and continuing in the forward direction towards the last node, the other set of equations are used.

The forward sweep is essentially a measurement of voltage drop with potential changes to currents or power flow. Nodal voltages are changed to those in the last in a forward sweep starting from branches in the first layer. The aim of forward propagation is to measure, starting from the feeder source node, the voltages at each node. The voltage of the feeder substation is set at its real value. The effective power is kept constant in each branch during the forward propagation to the value obtained in the backward cycle [46].

The backward sweep, with potential voltage changes, is essentially a current or power flow solution. It begins with the branches in the last layer and passes to the branches that are related to the root node. In the backward propagation calculation, the modified effective power flows are obtained in each branch by considering the node voltages of the previous iteration. This implies the voltage values acquired in the forward during the backward propagation, the direction is kept constant and modified power flows are transmitted backward along the feeder in each branch using the backward path. This means that at the extreme end node, backward propagation begins and continues to the source node. The backward/forward sweep approach is now reformulated in a way appropriate for iterative process convergence analysis. Consider a branch is connected between

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the nodes 'k' and k+1. The active power (P_k) and reactive power (Q_k) that flow through the branch from node 'k' to node 'k+1' can be calculated backward from the last node shown as,

$$P_k = P'_{k+1} + r_k (P_{k+1}^2 + Q_{k+1}^2) / V_{k+1}^2 \quad (3.32)$$

$$Q_k = Q'_{k+1} + X_k (P_{k+1}^2 + Q_{k+1}^2) / V_{k+1}^2 \quad (3.33)$$

Where

$$P'_{k+1} = P_{k+1} + P_{Lk+1}$$

$$Q'_{k+1} = Q_{k+1} + Q_{Lk+1}$$

P_{Lk+1} and Q_{Lk+1} are loads that connected to at node K+1, P_{k+1} and Q_{k+1} are reactive and real power flow from node K+1.

CHAPTER FOUR

DISTRIBUTION SYSTEM DATA COLLECTION AND ANALYSIS

4.1 CASE study

Arbaminch is town located in southern Ethiopia, in southern region. The town has latitude and longitude of 7.07^0 N and 38.05^0 E. Arbaminch substation receives power from Wolayta II substation via 132 KV power line supplies electric power to Arbaminch town and nearby areas. In the substation 132 KV is stepped down to 33 KV and 15 KV feeders. These 33 KV outgoing feeder supply power for two woreda and 15 KV outgoing feeder supply power for Arbaminch town. The substation consists of two 33KV and four 15 KV outgoing feeders. The outgoing feeders has distribution transformers and stepdown in to 0.38 KV three phase or 220-volt single phase. It has two power transformer that is 16MVA, 132/33 KV and 20MVA, 132/15 KV.

Reliability analysis needs interruption duration, interruption frequency, total number of customers served and so on. These data are analyzed to identify the current reliability status of the substation and the main problem of interruption. In this thesis two-year interruption duration, interruption frequency and Total number of customers served is collected from EEU.

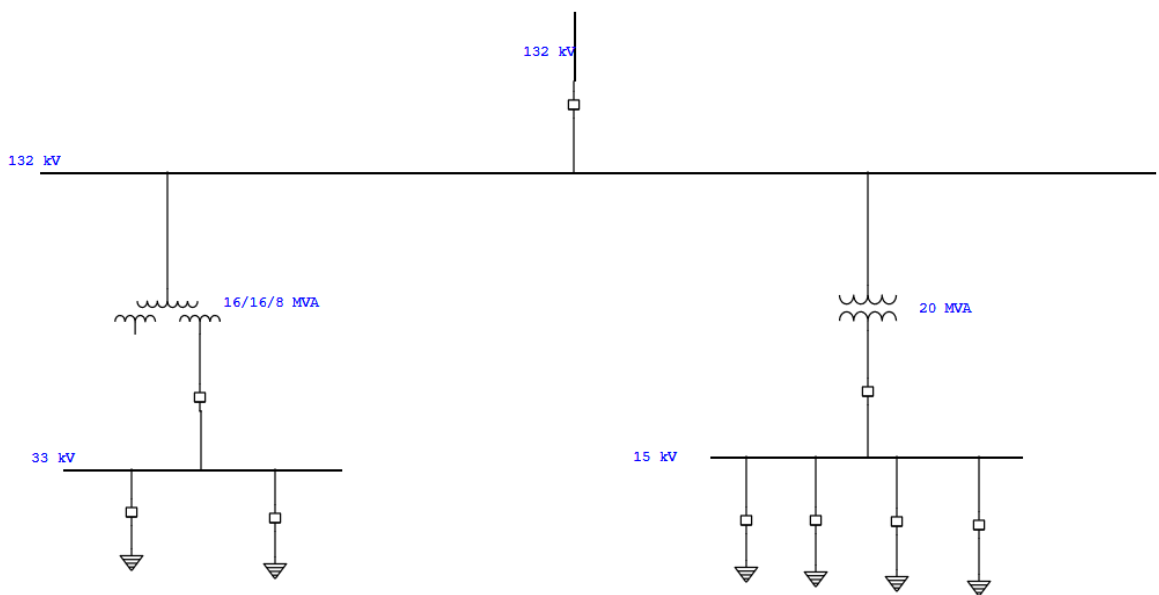


Figure 4.1 Single line diagram of Arbaminch substation

The distribution system modelled using ETAP software as shown in Figure 4.1. There is one 132KV main bus bar that corresponds to substation transformer shown in the figure 4.1 which is connected to 132/15KV transformer through four 15KV and 132/33KV transformer through two 33KV feeders. All the feeders operate as radial system.

4.2 Data Collection

The data have been collected from Arbaminch substation and Hawassa regional office. The collected data based on types of fault, number of transformer and ratings, interruption frequency and duration for two consecutive years, peak load and feeder length. The substation outgoing feeder types of faults, interruption frequency and duration can be seen at Appendix III.

4.3 Interruption Data

In Arbaminch distribution system types of faults, frequency and duration that occur in each feeder, taken from the substation. Table 4.1 and 4.2 Show types of faults, frequency and duration. This categorization enables to identify what types of reliability measures must be taken to improve reliability of distribution system. Average values of frequencies and durations are assumed to conclude which fault has induced higher interruption in the system. In the distribution system permanent faults mostly occur than temporary faults. From the data distribution system overload, distribution permanent short circuit and distribution permanent earth fault were a major cause of interruption. Table 4.1 and Table 4.2 show frequency and duration of different types of faults that occur in distribution system. The faults are Permanent Earth Fault (PEF), Permanent Short Circuit (PSC), Temporary Earth Fault (TEF), Temporary Short Circuit (TSC) and System Overload (SOL).

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Table 4.1 Types of faults interruption frequency

Fault type	2010-2011 E.C (2017/18G.C)	2011-2012 E.C (2018/19G.C)
DPEF	1080	1103
DPSC	1455	1505
DSOL	3828	3808
DTSC	1170	1200
DTEF	45	105
Total	7578	7723

Table 4.2 Types of faults interruption Duration

Fault type	2010-2011 E.C (2017/18G.C)	2011-2012 E.C (2018/19G.C)
DPSC	1667.37	1007.6
DSOL	2400.16	1901.3
DPEF	120.96	82.4
DTSC	76.21	45.5
DTEF	40.5	7.6
Total	4305.2	3044.4

The faults mostly are caused by technical problems of the distribution system external factor from environment. The external factor from the environment is manmade errors like car accidents, fire ignitions, etc. according to the data, most of the faults that occurred in Arbaminch distribution system is permanent short circuit and temporary short circuit faults. All the interruption durations are treated as sustained interruption because of the recording is made based on frequency and for how long the interruption stays. Distribution temporary earth fault (DTEF) occurs frequently but the power unavailability it caused is relatively low. In turn, permanent short circuit has imposed an average high duration and frequent of interruption.

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The contribution of each types of fault in the total interruption is depicted in figure 4.2. In terms of frequency of occurrence, permanent short circuit fault involved 19% of average interruption in the distribution system. System overload cause 51% of power unavailability. Temporary earth fault compares to other very small part in the interruption data, i.e., 1% of contribution in frequency.

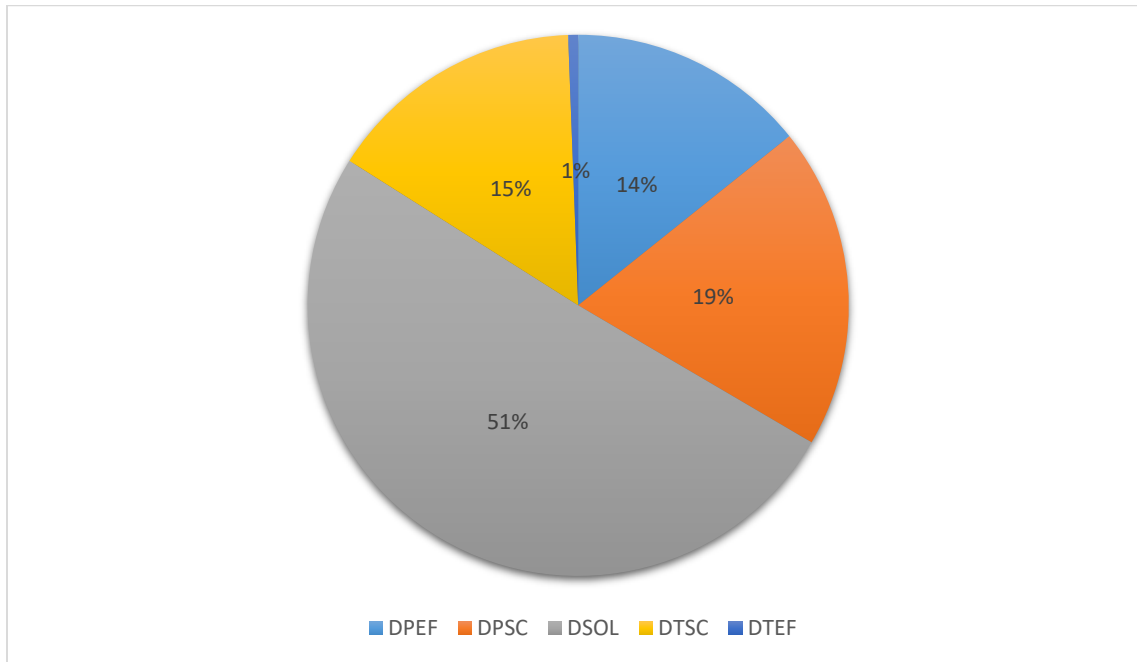


Figure 4.2 Frequency of types of faults percentage

As shown in the below figure 4.3 Duration types of fault percentage, in terms of duration of fault occurrence, system overload faults take high percentage that is 56% of power unavailability in the system. The distribution permanent short circuit fault duration involves 38% of interruption in distribution system. Distribution earth faults duration takes less percentage compared to other types of faults.

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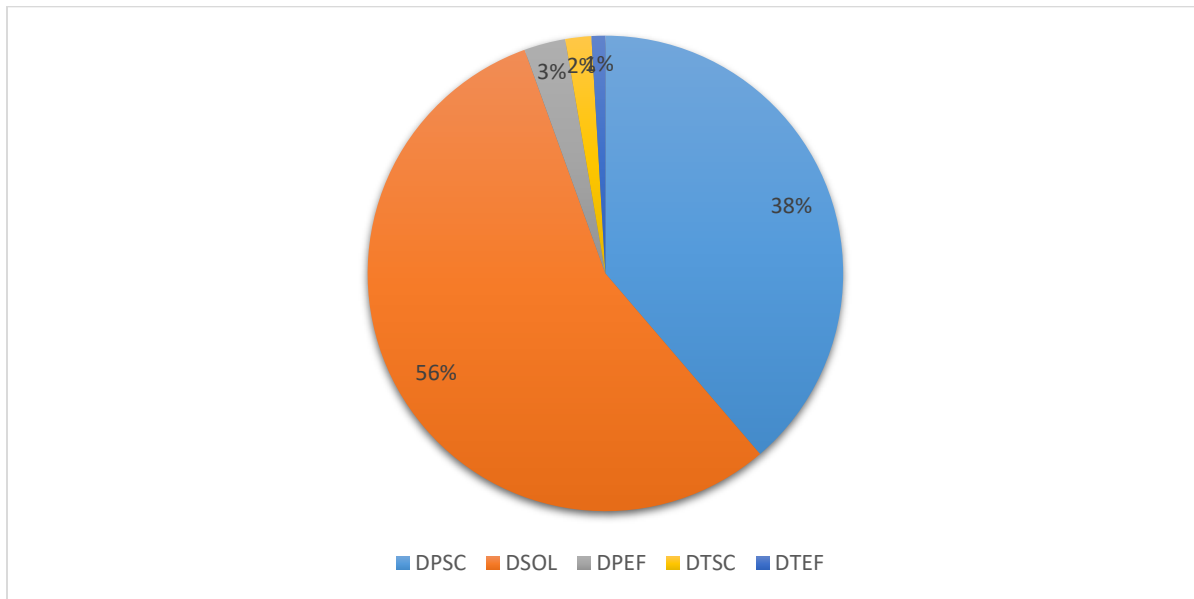


Figure 4.3 Duration of types of fault percentage

According to the data, most of the faults that occurred in Arbaminch distribution line are system over load and short-circuit and temporary short circuit faults.

4.4 Reliability Evaluation of Arbaminch Substation

As discussed earlier, distribution system interruption cause can be technical problem. Table 4.3 and Table 4.4 show frequency and duration of sustained interruption at Arbaminch distribution system. The interruption frequency is high in 2018/19 G.C (2011-2012) than the interruption occurs in 2017/2018 G.C (2010/2011). In the year 2018/19, Arbaminch distribution system had frequent power interruption and the total duration of interruption of all the feeders in Arbaminch was high as shown in Table 4.4.

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Table 4.3 Interruption Frequency of planned and unplanned outage of 2017-1018 and 2018-2019 (G.C)

Feeder name	2017-2018(G.C) (Int/yr.)	2018-2019 (G.C) (Int/yr.)	Average Freq.(Int/yr.)
Feeder 01	82	106	94
Feeder 02	48	56	52
Feeder 03	34	72	53
Feeder 05	121	191	150
Feeder 06	79	92	86
Feeder 07	65	75	70
Total	429	579	505

Table 4.4 Interruption Duration of planned and unplanned outage of 2017 -2018 and 2018-2019(G.C)

Feeder name	2017-2018(G.C) (Hr.)	2018-2019 (G.C) (Hr.)	Average Dur. (Hr.)
Feeder 01	110.8	128.945	119.87
Feeder 02	46.67	77.75	62.2
Feeder 03	44.08	109.11	76.6
Feeder 05	208.95	208.95	208.95
Feeder 06	116.763	158.47	137.62
Feeder 07	101.64	118.55	110.1
Total	628.903	801.775	715.34

As shown from above table 4.3 and 4.4 the interruption duration and frequency of all feeders for two years is registered. From the table, the interruption frequency and duration relatively increase compared to the previous years. Compared to the others feeder 05 interruption frequency and duration is high, it indicates there is high power unavailability in the area.

4.5 Calculation of Reliability Indices

The reliability indices are used to indicate the status of the system. if the system has high reliability indices, it can be concluded that the system has reliability issues. Reliability indices are calculated to show general reliability characteristics of distribution system.

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In this section reliability indices are calculated for each feeder. There are different types of reliability indices, but in this section common reliability indices are used to determine the reliability such as, SAIFI, SAIDI, CAIDI and ASAI. These indices are calculated using equation 3.1,3.2 and 3.3.

In table 4.5, reliability indices of all outgoing feeder is presented in the following year. The SAIFI, SAIDI, CAIDI and ASAI. As shown in the table the reliability indices of feeder 05 has high reliability indices compared to other feeders. The basic reliability indices, SAIFI, SAIDI, CAIDI and ASAI value 221.6336 (fr./cus/yr), 236.8386 (hrs./cus/yr), 1.069 and 0.9730 respectively. From the calculation feeder-05 has high reliability indices, this indicate it has reliability issue.

Table 4.5 Reliability Indices 2017/18 (G.C)

Feeder name	SAIDI (Hr./cust. /Yr)	SAIFI (ini. /cust. /Yr)	CAIDI(Hr./Int)	ASAI (PU)
Feeder -01	117.945	82.234	1.43.42	0.9852
Feeder -02	115.547	97.456	1.186	0.9911
Feeder -03	109.11	72.234	1.5105	0.9875
Feeder -05	232.367	120.205	1.9330	0.9720
Feeder -06	140.95	120.325	1.1737	0.9761
Feeder -07	116.763	119.45	0.9812	0.9866

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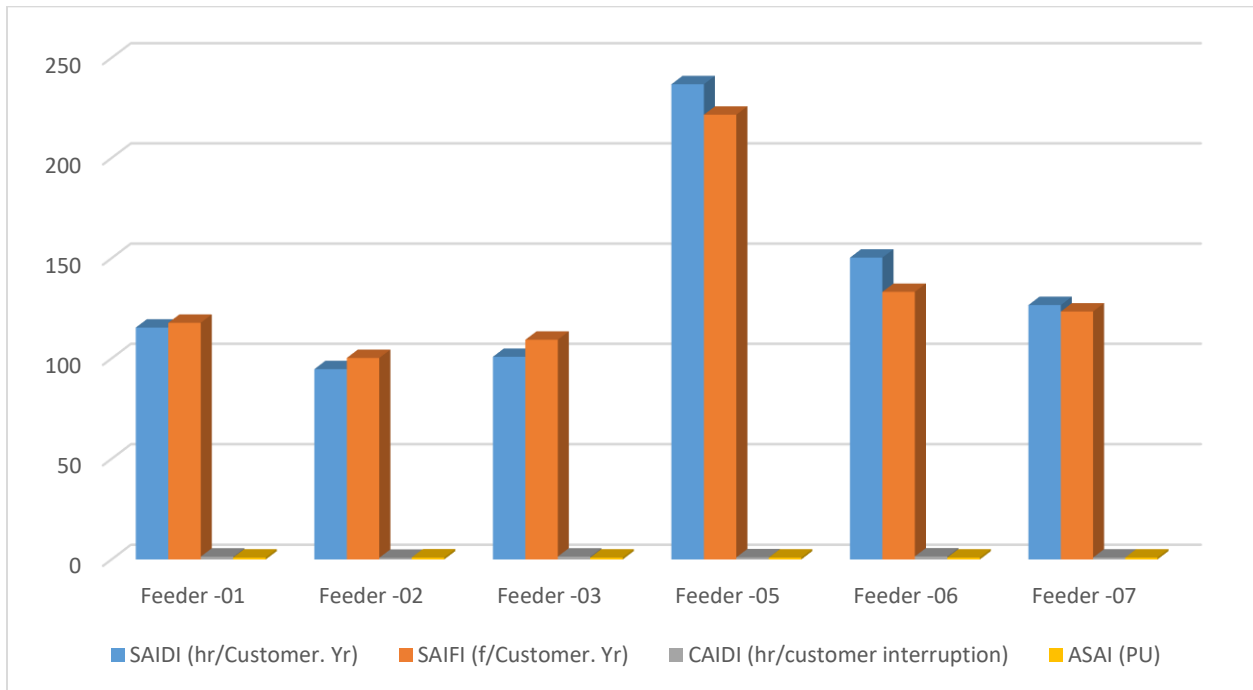


Figure 4.4 Reliability Indices 2017/18 (G.C)

In table 4.5, outgoing feeder reliability indices presented for year 2017/18 (G.C). The SAIFI, SAIDI, CAIDI and ASAI values are calculated and feeder-05 has the value of 220.205 (fr./cus/yr), 232.367 (hrs./cus/yr), 1.053 and 0.9720 respectively. Case studies provide appropriate information of reliability to obtain the system reliability index. ETAP software calculates reliability indices and Reliability indices of the substation can be calculated using interruption frequency and duration data for two years (2010EC and 2012EC). The data obtained has only sustained interruptions in frequency and duration because of that only sustained interruption are considered. SAIDI and SAIFI are the best-known reliability measures.

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Table 4.6 Reliability Indices 2018/19 (G.C)

Feeder name	SAIDI (hr/Customer. Yr)	SAIFI (f/Customer. Yr)	CAIDI (hr/customer interruption)	ASAI (PU)
Feeder -01	115.432	117.789	0.978	0.9778
Feeder -02	94.677	100.264	0.944	0.9946
Feeder -03	100.823	109.345	0.922	0.9644
Feeder -05	236.8386	221.6336	1.069	0.9730
Feeder -06	150.33	133.235	1.1283	0.966
Feeder -07	126.67	123.432	0.9616	0.9818

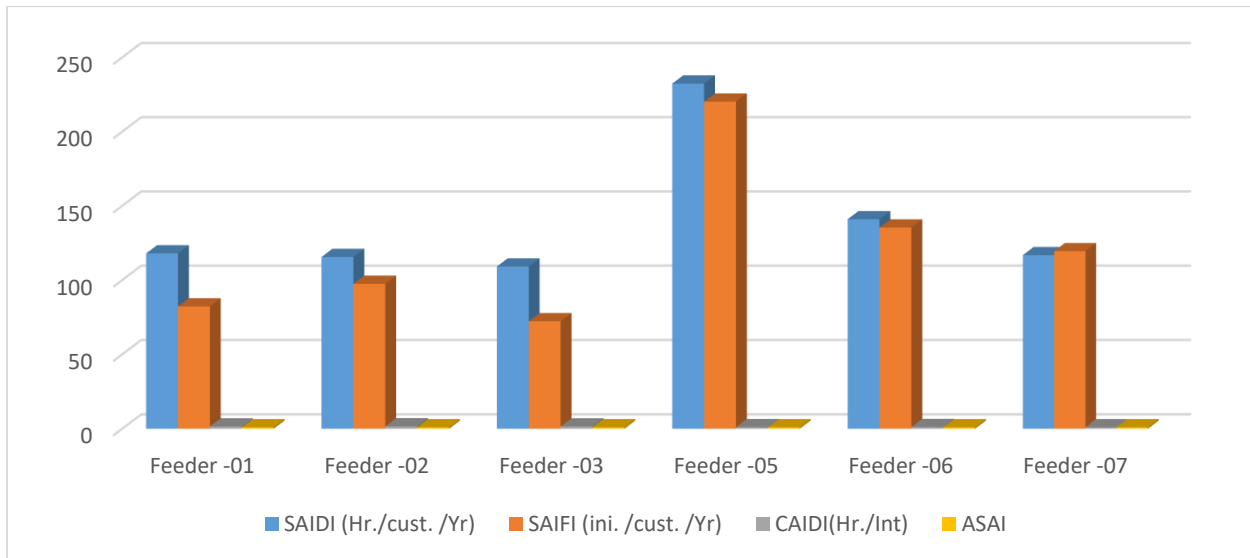


Figure 4.5 Reliability Indices 2018/2019

Table 4.6 shows reliability indices of the outgoing feeder for year 2018/19 (G.C). The SAIFI, SAIDI, CAID and ASAI values are increased compared to the previous year.

4.6 Comparison of Reliability Indices with Bench Mark

Reliability bench marks are needed to compare if the system has reliability issue or to compare with the standard. The main purpose of reliability standard bench marks is used to identify or assess minimum or average performance of distribution network. There are different recommended values of reliability standards. According to benchmarking report on the quality of electricity supply, the reliability indices values of five countries are shown in Table 4.7. These countries give high emphasis to power quality and reliability. The three basic reliability indices, SAIDI, SAIFI and ASAI for each country are shown in the table. The higher number of reliability indices indicate the lower reliability performance that is high interruption frequency and duration. A lower reliability index shows the better reliability performance and lower interruption duration and frequency. Comparing Arbaminch distribution system with the bench mark it has lower reliability performance. As shown in the table 4.7 Arbaminch distribution system has high reliability indices or worst reliability performance, even it has lower reliability performance than the standard bench mark of Ethiopia.

Table 4.7 Standard Bench Mark of different countries [47]

Country	SAIDI	SAIFI	ASAI
Austria	1.2	0.9	99.97
Denmark	0.4	0.5	99.98
France	1.03	1.0	99.97
Germany	0.383	0.5	99.99
Italy	0.967	2.2	99.99
Netherlands	0.55	0.3	99.97
Spain	1.733	2.2	99.96
UK	1.5	0.8	99.96
Ethiopia	25	20	99.425

4.7 Cost of Distributed Generation installation

After selection of distributed generation location and size based on peak load of the line, cost estimation of distributed generation is as followed. There are different types of distributed generation technologies as discussed in chapter two. The distributed generation type is selected

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based on the availability in the area, efficiencies and cost. The availability of distributed generation varies based on geographical areas. Some areas or geographical location for example there is solar energy sources are available or there is high solar radiation in the area. Wind energy also varies based on wind speed in the area. Distributed generation also selects based on their positive and negative impact on the environment. The other factor for selecting DG technology is cost. As seen in the below table PV, fuel cell, wind and Microturbine have high level of Emission. When considering cost, Diesel generators has low installation costs than others. Considering cost, Emission level and availability of resource in the area PV and Microturbine are selected as source of distributed generation in this thesis.

Table 4.8 Cost and Emission Level of Distributed Generation [48]

Technologies	Emission level	Cost
PV	No	Moderate
Fuel cell	Low	High
Wind turbine	No	Moderate
Diesel Generator	High	Low
Microturbine	Low	Moderate

Table 4.9 Cost of Microturbine [49]

	System					
	1	2	3	4	5	6
Nominal Capacity (kW)	30	65	200	250	333	1000
Net Capacity (kW)	28	61	190	240	320	950
Equipment Costs						
Gen set Package	\$53,100	\$112,900	\$359,300	\$441,200	\$566,400	\$1,188,600
Heat Recovery	\$13,500	\$0	\$0	\$0	\$0	\$275,000
Fuel gas compression	\$8,700	\$16,400	\$42,600	\$0	\$0	\$164,000
Total Equipment (\$)	\$75,300	\$129,300	\$401,900	\$441,200	\$566,400	\$1,627,600

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(\$/kW)	\$2,689	\$2,120	\$2,120	\$1,840	\$1,770	\$1,710
Installation Costs						
Labor/Materials	\$22,600	\$28,400	\$80,400	\$83,800	\$101,900	\$293,000
Project & Construction Mgmt.	\$9,000	\$15,500	\$48,200	\$52,900	\$68,000	\$195,300
Engineering and Fees	\$9,000	\$15,500	\$44,200	\$48,500	\$56,600	\$162,800
Project Contingency	\$3,800	\$6,500	\$20,100	\$22,100	\$28,300	\$81,400
Financing (int. during const.)	\$700	\$1,200	\$3,700	\$4,100	\$5,100	\$14,800
Total Other Costs (\$)	\$45,100	\$67,100	\$196,600	\$211,400	\$259,900	\$747,300
(\$/kW)	\$1,611	\$1,100	\$1,035	\$881	\$812	\$787
Total Installed Cost (\$)	\$120,400	\$196,400	\$598,500	\$652,600	\$826,300	\$2,374,900
(\$/kW)	\$4,300	\$3,220	\$3,150	\$2,720	\$2,580	\$2,500

Table 4.9 shows cost estimation of basic Microturbine package with various size. The cost consists of equipment and installation cost with electric power capacity. Hence, to estimate the cost of DG size of 4.5MW, the DG technology selected in this thesis was solar and Microturbine, based on the availability in the area, environmental effect, efficiency and cost of installation. The contribution of Microturbine is made to be 25% that is 1.3 MW and solar 75% that is 3.2MW. The reason for this classification is based on efficiency and cost of the technologies.

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Table 4.10 Power rating and cost of various Module types [50]

Solar Panel Brand	Peak Power watts	Price per watt	Total cost	Poly Mono Thin film	Module efficiency	Country of Manufacture
Qcells 325 watt Mono Half-cell Black frame	325	\$0.50	\$162.50	M	19.05%	USA
Peimar SG310M-BF	310	\$0.52	\$160	M	19.05%	Italy
LONGI LR4-60HPB-350M	350	\$0.54	\$188	M	19.20%	Malaysia
Trina Solar TSM-310-DD05H.05(II)	310	\$0.54	\$168	M	18.70%	China
Trina Solar TSM-325-DD05H.05(II)	325	\$0.56	\$182	M	19.10%	China
Canadian 395 watt silver Frame Bifacial Module	395	\$0.63	\$250.29	M	18.54%	Italy
Astronergy CHSM6612M-370 solar Panel	370	\$0.69	\$270	M	19.10%	Germany
REC 355A Black Alpha	355	\$0.73	\$258	M	20.30%	Singapore
Canadian Solar Cs6P-245P	245	\$0.93	\$277	Poly	14.61%	China
Sharp ND-250Qcs	250	\$1.1	\$275	Poly	15.3%	USA

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Sun tech PLUTO 240-WDE	250	\$0.90	\$275	M	14.90	USA
Canadian Solar Cs6P-235P	235	\$ 0.98	\$ 225	Poly	14.61%	China

As shown in the above Table 4.10 Equipment cost of various types PV module with their efficiency and Manufactured country are stated. The performance of PV module stated according to their maximum power output. Based on cost, rating and efficiency Astronergy CHSM6612M-370 solar Panel is selected for this work. The cost of solar power is summation of cost of Panel, cost of inverter and cost of Battery. The cost of solar module, inverter and Battery for this work is 3,188,918.92\$, 2,335,135.14\$ and 4,679,920\$ respectively.

Table 4.11 Installation cost of DG

Equipment	Capacity	Unit cost (\$)	Total cost
Solar/PV	3.2MW		
PV module		270\$/W	2,335,135.14\$
Inverter		0.18\$/W	982,800\$
Battery		137\$/KW	4,679,920\$
Microturbine	1.3MW	2500 \$/KW	2,571,300\$
Total cost			10,569,155.14\$

Table 4.11 has shown cost of Solar /Microturbine with Capacity that generate. Based on the flow chart in the previous chapter, MATLAB code for DG sizing, location and reconfiguration developed. Using ETAP 16.0.0 software reliability analysis of feeder five is done. Here, four case are developed which are base case alone, DG integration, network reconfiguration alone and DG integration with network reconfiguration. The proposed methods were executed for reliability improvement of distribution system.

CHAPTER FIVE

SIMULATION RESULTS AND DISCUSSION

5.1 Introduction

In this thesis ETAP software is used for reliability analysis. It is used for generation, transmission, distribution and industrial system analysis. It provides a reliable central protection settings database and management system for the complete power system substation data, both to manage the various control parameters and to centrally store substation related information and data, based on NET technology. PSO algorithm is used for proper DG sizing, placing and network reconfiguration. Proper DG technology is selected based on availability and efficiency. The simulation is made in MATLAB (R2016a version) software using PSO algorithm for finding optimal DG location, sizing and network reconfiguration. Reconfiguration of network is done by optimal placement of devices and switches.

In this case two DG sources, which are Micro turbine and PV, are selected based on availability, cost and efficiency. As shown in chapter three reliability analysis, feeder five has high reliability indices. Reliability indices for feeder five SAIFI, CAIDI, SAIDI AND EENS are calculated without DG connected and network reconfiguration. Reliability analysis with DG connected to the feeder is compared with reconfiguration of system.

In this chapter modelling and simulation of the case study distribution system is performed using ETAP 16.0.0 software.

5.2 Case Study Modelling of Distribution System

Arbaminch substation has been supplied from Wolayta II substation via 132KV. The incoming line is connected to double bus bar at Arbaminch substation. It has two power transformer which are 16MVA, 132/33 KV and 20MVA, 132/15 KV. The substation consists of two 33KV and four 15 KV outgoing feeders. The substation has four outgoing feeders of 15kv lines which supply power to 15/0.4kv transformer which feed to different customers such as residential, commercial and industrial. The two 33kv outgoing feeders feed to the area. In order to limit the scope of study area, feeder five is selected based on its vulnerability to frequent power interruption and long

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outage duration. In the previous chapter the two-year power interruption data shows feeder five has high interruption duration and frequency than others. The radial configuration of feeder five has thirty-four bus. The single line diagram of the network is shown in the Fig 5.1.

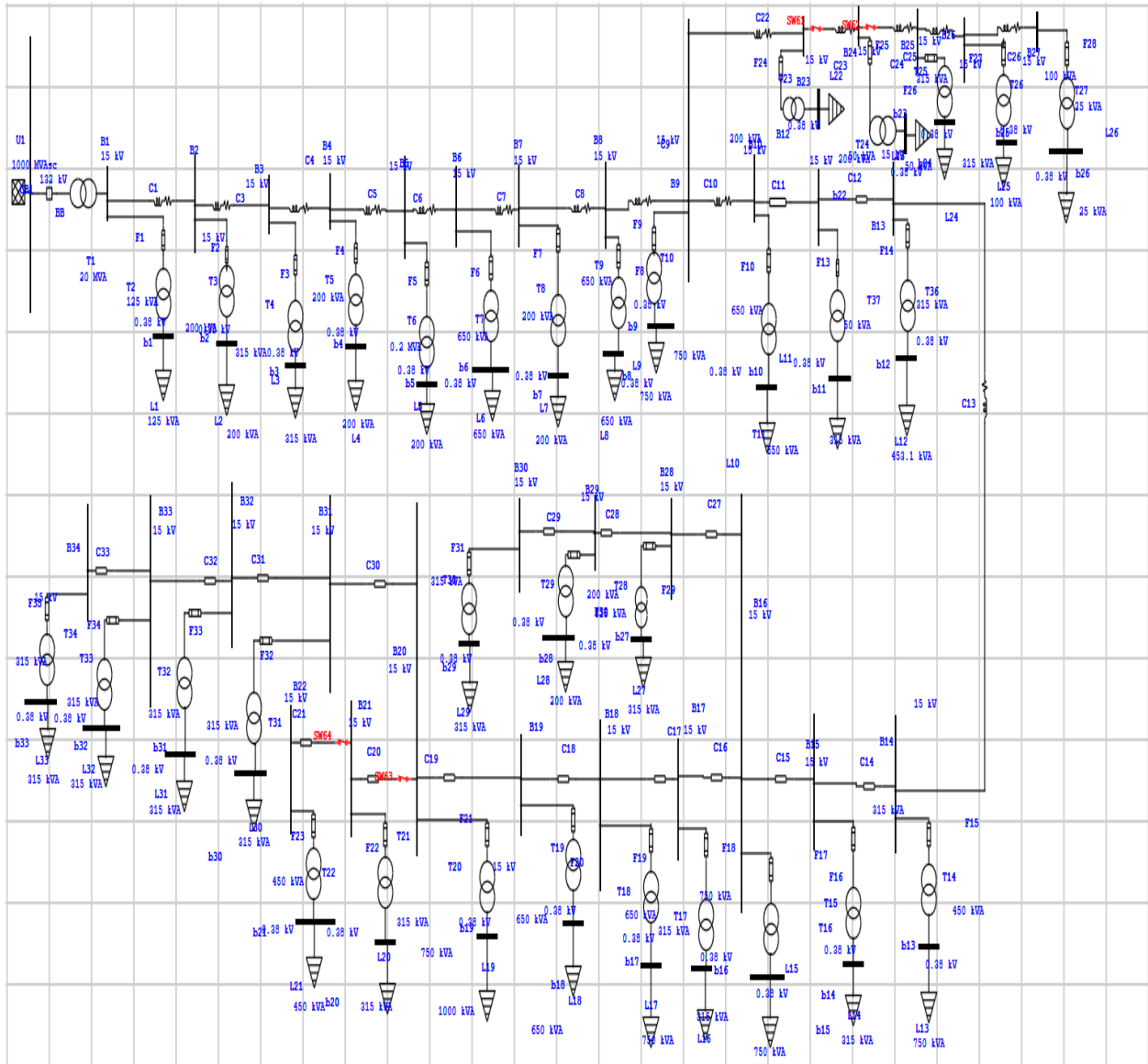


Figure 5.1 Single line diagram feeder five

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5.2.1 Case I: Base case alone

The single line diagram of feeder 05 was modelled using ETAP 16.0.0 software and reliability analysis has been performed without integrating DG and applying network reconfiguration. From the analysis, the reliability indices in the feeder is higher. As shown in the below table, SAIFI, SAIDI and EENS values are high. There is also high service unavailability at the feeder as the average service availability 97.30% which is below the bench mark (i.e. ASAI should be greater than 99.98%).

Table 5.1 Reliability analysis base case alone

Cases	SAIFI (f /cus. Yr)	SAIDI (hr./cus. Yr)	EENS(MW hr / yr)	ECOST (\$ / yr)	ASUI(pu)	ASAI (pu)
Base case	221.6336 f/cus. Yr	236.8386 hr./cus. Yr	2888.075 MW hr / yr	9,758,852.00 \$ / yr	0.02704 pu	0.9730 pu

The revenue losses from expected interruption cost at the feeder is also high as it could be seen from analysis result report. Expected interruption cost is \$9,758,852 and expected energy not supplied is also high. From the analysis it shows that the feeder is highly unreliable.

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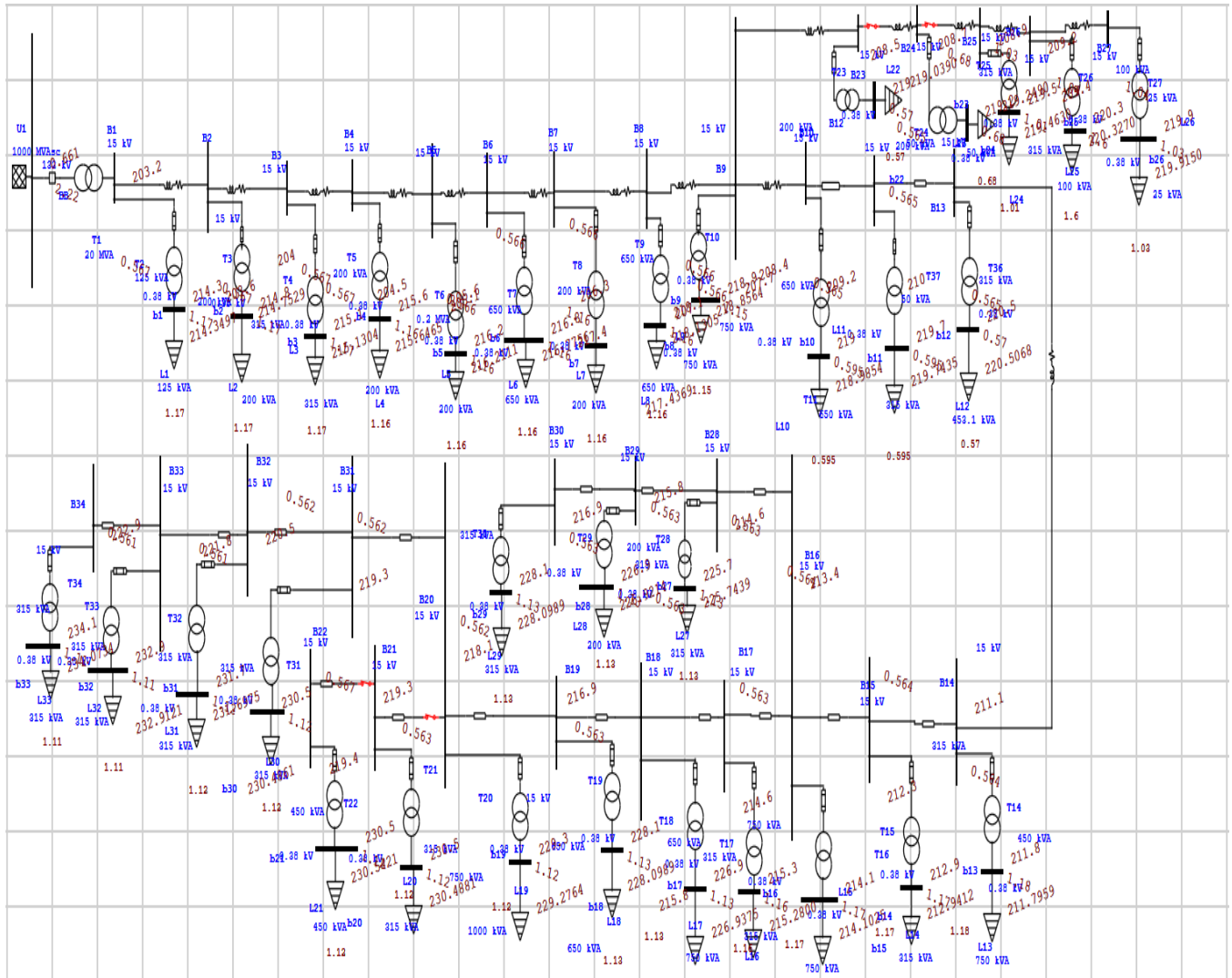


Figure 5.2 reliability analysis of feeder- 05 base case alone

5.2.2 Case II: DG integration alone

Distributed generations are key part of power system that are used to enhance the reliability of the network. Optimal DG sizing and location was performed using PSO algorithm as discussed in chapter three. As shown in the below table of reliability analysis result report, the reliability of the system is improved. DG is located at bus 10 with size 4.5MW using Particle swarm optimization techniques. The reliability indices SAIFI, SAIDI and EENS are decreased compared to base case alone analysis. The SAIFI, SAIDI and EENS values are improved by 42.95%,47.95% and 35.44%

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compared to base case alone. The ECOST value is 49.98% decreased compared to base case alone analysis. The system availability is also increased (ASAI) after DG integrated to the system.

Table 5.2 Reliability analysis DG integration alone summery result

Cases	SAIFI	SAIDI	EENS	ECOST	ASUI	ASAI
Base case	221.6336 f /cus. Yr	236.8386 hr./cus. Yr	2888.075 MW hr / yr	9,758,852.00 \$ / yr	0.02704 pu	0.9730 pu
With DG	136.9567 f /cus. Yr	126.4380 hr./cus. Yr	1864.358 Mwh /yr	4,880,489 \$ / yr	0.01563 pu	0.9844 pu

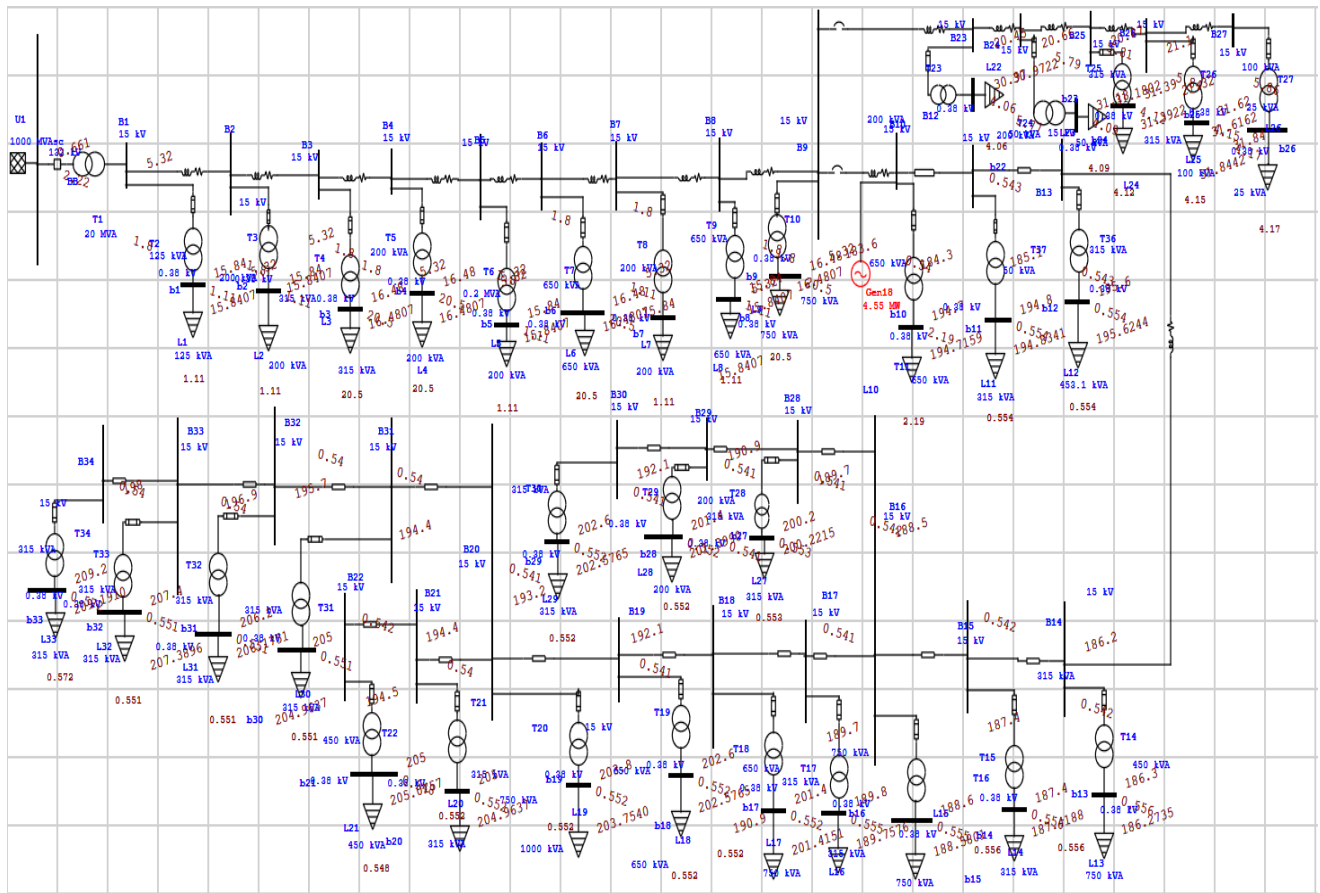


Figure 5.3 reliability analysis DG integration alone

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5.2.3 Case III: Network Reconfiguration alone

Optimal distribution network reconfiguration alone was done in the feeder using MATPOWER 7.1 power flow analysis software by applying particle swarm optimization techniques. The reconfiguration uses sectionalizing switches in the bus. The new switch position is 3, 4, 12, 24 and 31 after reconfiguration. As seen in figure 5.4, using ETAP software reliability analysis performed after the network is reconfigured. As shown in the below table all the reliability indices is improved compare to base case alone. The SAIFI, SAIDI and EENS values are improved by 40.52%, 33.52% and 35.62% respectively. The expected energy cost (ECOST) value is decreased to 43.43% as compared to Base case alone. The system availability index is also improved compared to base case alone. The system reliability is improved compared to base case alone. As seen in the below Table 5.3 all the indices values have changed, after reconfiguration performed.

Table 5.3 Reliability analysis reconfiguration case alone summery result

Cases	SAIFI	SAIDI	EENS	ECOST	ASUI	ASAI
Without DG	221.6336 f/cus. Yr	236.8386 hr./cus. Yr	2888.075 MW hr / yr	9,758,852.00 \$ / yr	0.02704 pu	0.9730 pu
With Network reconfiguration	131.5674 hr/cus. Yr	157.4412 hr/cus. Yr	1859.322 MW hr / yr	5,520,118.00 \$ / yr	0.01797 pu	0.9820 pu

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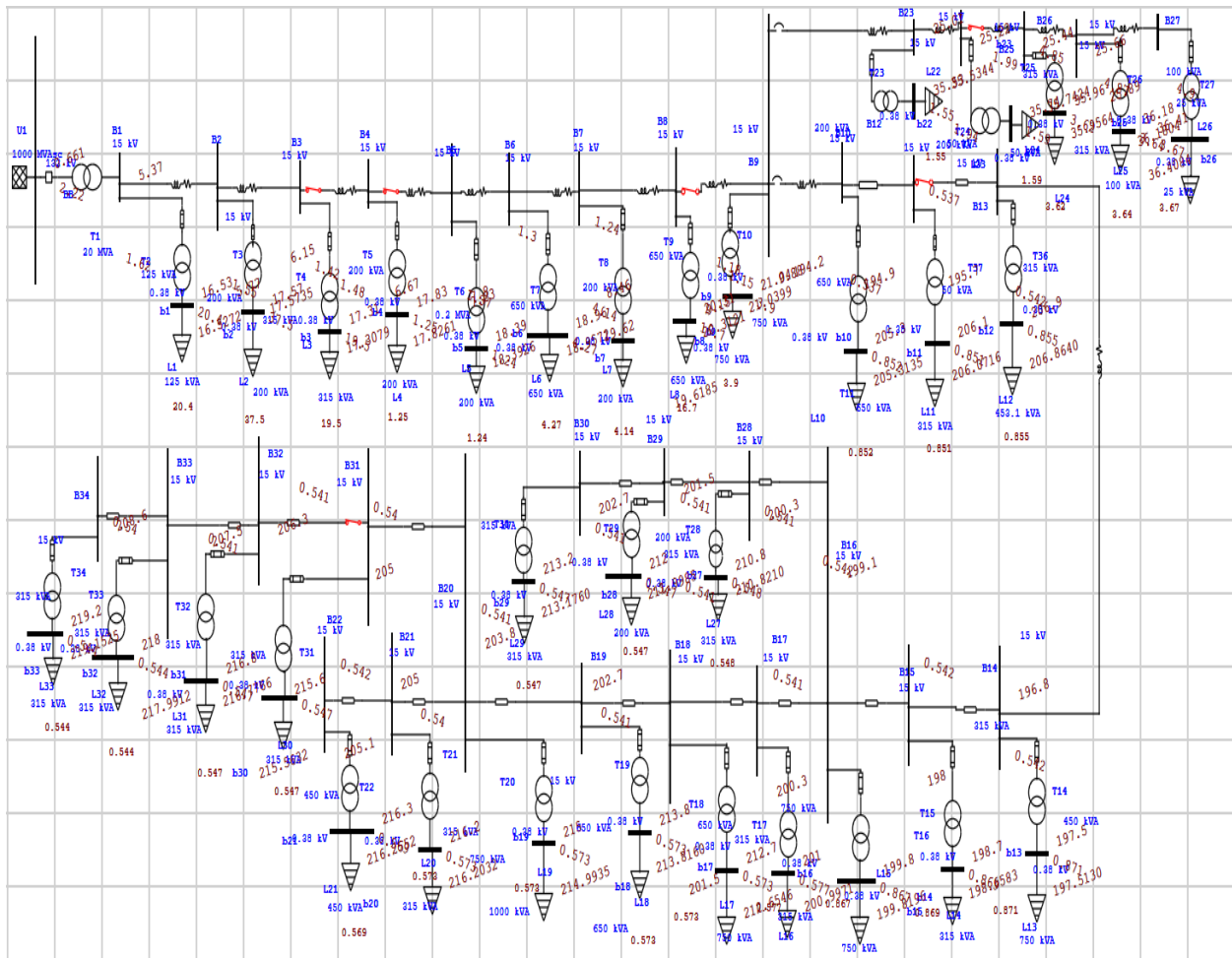


Figure 5.4 reliability analysis network reconfiguration alone

5.2.4 Case IV: DG integration simultaneously with Network Reconfiguration

The reliability analysis of distribution network using DG integration and network reconfiguration are separately discussed before. When using separately, it cannot achieve appreciable result to improve reliability of the feeder. Network reconfiguration techniques with DG integration can significantly improve reliability of the feeder. As shown in table 5.4, the reliability of the feeder improved. The SAIFI, SAIDI and EENS values are improved by 82.81%, 78.89% and 78.10% respectively. As observed in the figure 5.5, the reliability indices value decreased in each case compare to base case alone. The value of expected energy not supplied is also decreased compared to others. In Case IV, the basic reliability indices are decreasing compared to the other three cases.

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The reliability is highly improved in case IV compared to others. The value of expected energy not supplied is highly decreased

Table 5.4 Reliability analysis DG integration and Network Reconfiguration summary result

Cases	SAIFI	SAIDI	EENS	ECOST	ASUI	ASAI
Without DG	236.8386 f./cus. Yr	221.6368hr ./cus. Yr	2888.075 MW hr / yr	9,758,85 200 \$ / yr	0.0270 4 pu	0.9730pu
Network reconfiguration with DG	44.3658f /cus. Yr	61.4099hr/c us. Yr	701.008M W hr / yr	2,995,270 \$ / yr	0.9930p u	0.00701 pu

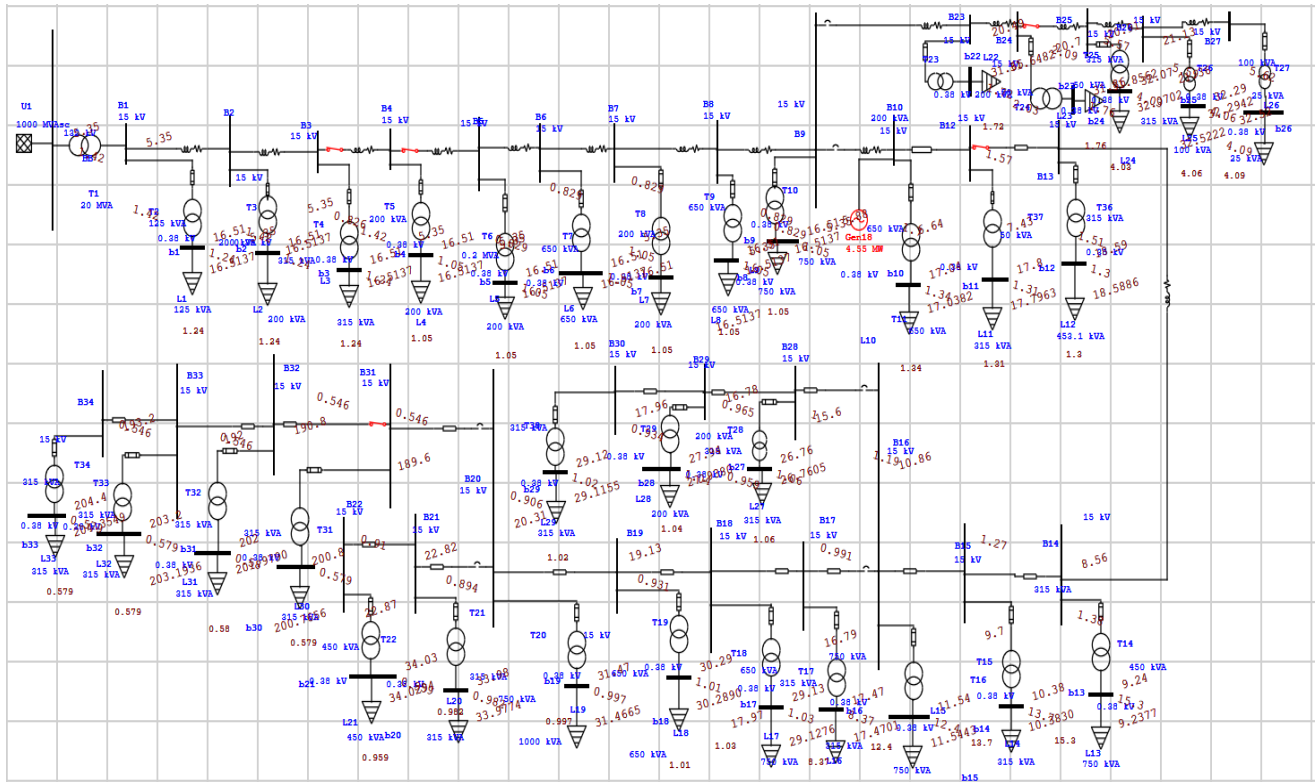


Figure 5.5 reliability analysis DG integration with network reconfiguration

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In general, the result from all cases are summarized and presented in the below Table 5.6. The results show that each method has impact in the system reliability, when they are applied separately, the feeder reliability improved. However, it has been observed that network reconfiguration with DG integration has grater improvement in the reliability of the feeder.

Table 5.5 Reliability indices summary

Case	SAIDI (Hr./cust. /Yr)	SAIFI (ini. /cust. /Yr)	EENS(MW hr/yr)	ECOST (\$/yr)	ASUI (PU)	ASAI (PU)
Base case alone	236.8386	221.6336	2888.075	9,758,85200	0.02704	0.9730pu
DG integration alone	136.9567	136.9567	1864.358	4,880,489	0.01563	0.9844
Network reconfiguration alone	157.4412	131.5674	1859.322	5,520,118.00	0.01797	0.9820
Network reconfiguration with DG	61.4099	44.3658	701.008	2,995,270	0.9930	0.00701

The figures 5.6,5.7,5.8 and 5.9 shows, the reliability indices compared in each case with base case value have been presented. It shows each reliability indices comparison with the base case and with other cases. In Figure 5.6, 5.7, 5.8 and 5.9, most commonly used indices comparison done each case with base case. The figures clearly show the reliability indices value changed in each cases. The values gradually decreasing in each case compared to base case. As seen in the all figures, DG with Network configuration case has great improvement compared to other cases in each reliability indices. When comparing Network reconfiguration to DG integration case, the reliability indices value decreased more in DG case than Network reconfiguration case. Simultaneously using DG and Network reconfiguration case, it gives considerable result than separately using DG and Network reconfiguration.

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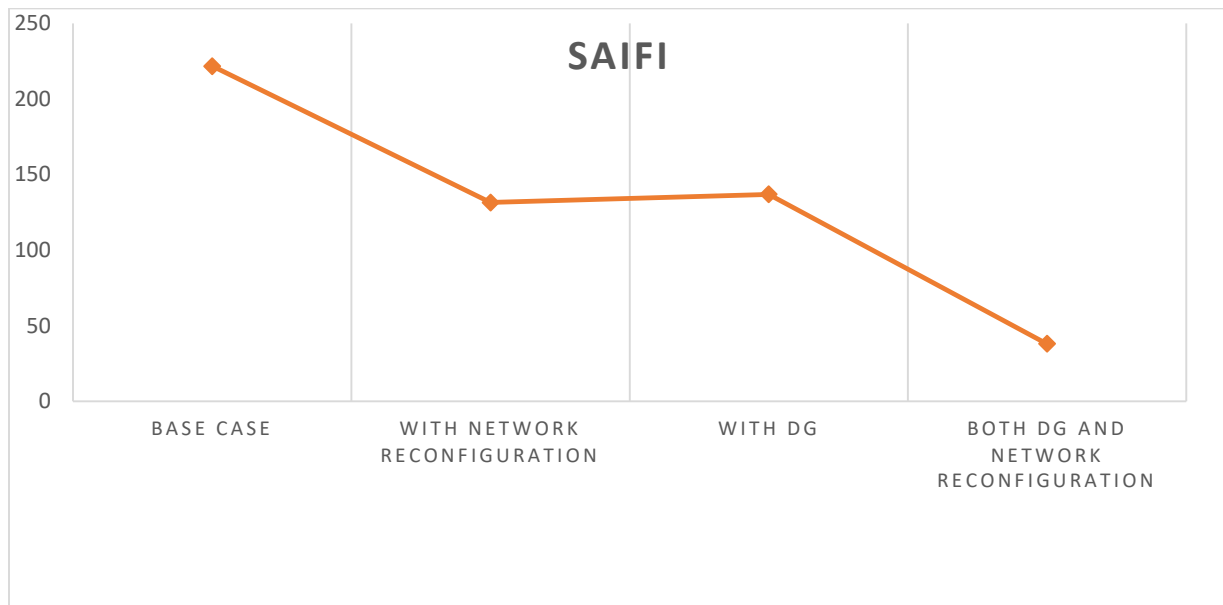


Figure 5.6 Summary Result of SAIFI

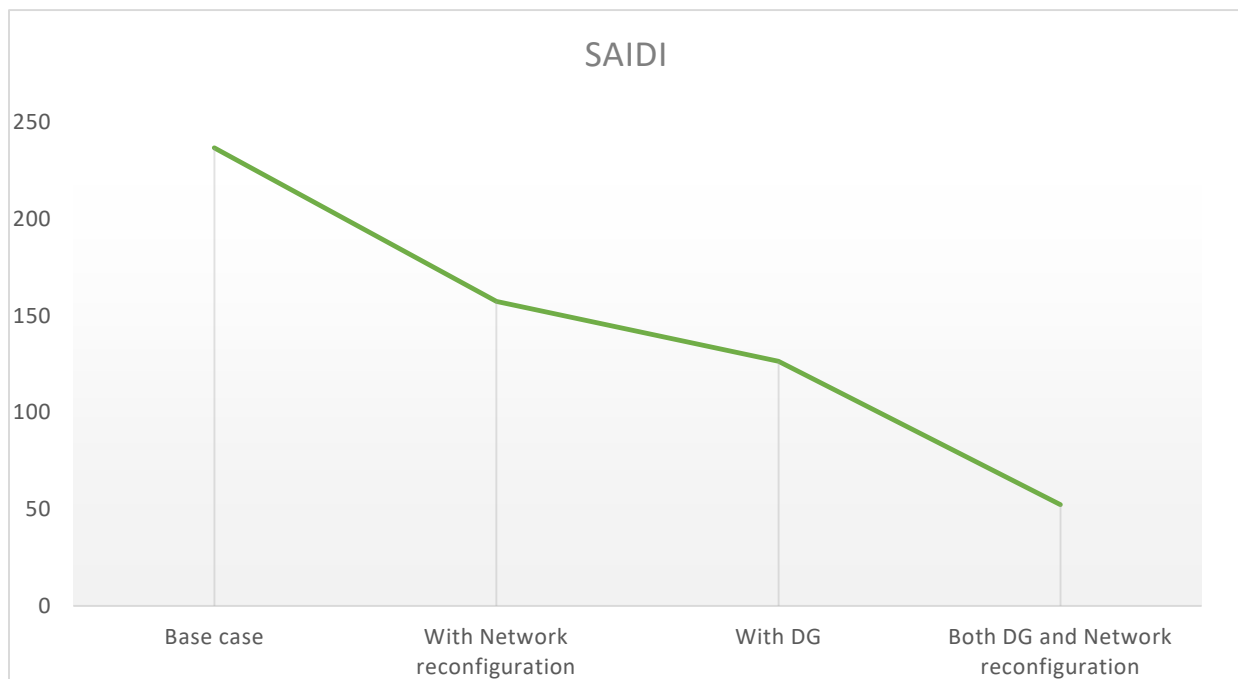


Figure 5.7 Summary Result of SAIDI

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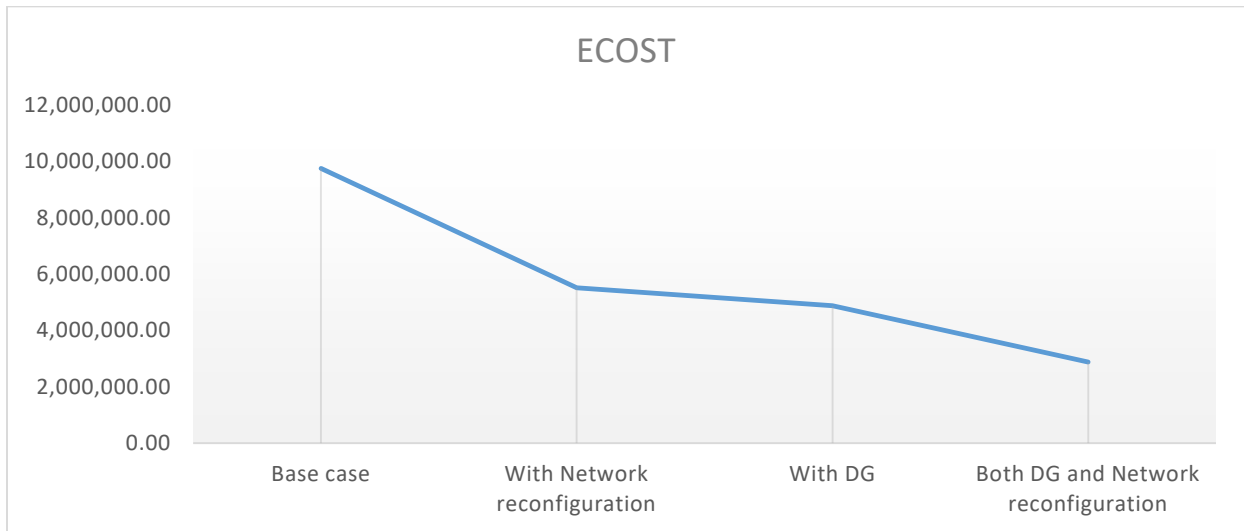


Figure 5.8 Summary Result of ECOST

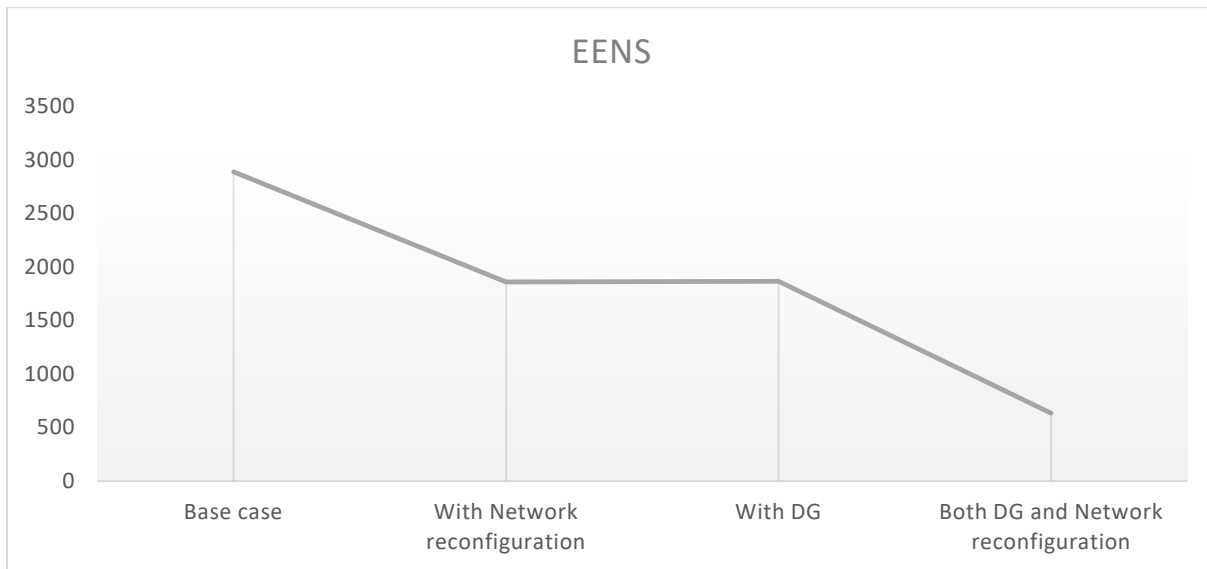


Figure 5.9 Summary Result of EENS

The Particle Swarm (PSO) algorithm results are compared with Genetic algorithm (GA) to verify the quality of solution generated. Comparison of PSO with GA algorithm in case of DG integration is shown in Table 5.6 for all case. Optimal DG location and size reduces reliability indices corresponding to the objective function are shown in Table. From the table it shows that in PSO

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case all the reliability indices significantly improved than GA case. The simulation results show that by using PSO algorithm, most of the time better quality result is obtained.

Table 5.6 Comparing PSO with GA algorithm in case of DG

Algorithm	Bus No.	DG size (MW)	SAIFI (f/cus. Yr)	SAIDI (hr./cus. Yr)	EENS (Mwh /yr)	ASUI (pu)	ASAI (pu)	ECOST (\$ / yr)
PSO	10	4.5	126.4360	136.9567	1864.358	0.01563	0.9844	4,880,489
GA	7,24	2.55,2.04	160.3465	175.3241	2843.573	0.026	0.9740	5,110,489

Table 5.7 shows, Network reconfiguration using Particle swarm algorithm and Genetic algorithm. From the simulation result it indicates that, using PSO algorithm tie switch is in new location and using GA also the location of the switch is changed. Result shows that optimal network reconfiguration using the two algorithm observed different values. All the reliability indices improved more in case of PSO than GA.

Table 5.7 Comparing PSO with GA algorithm in case of Network reconfiguration

Algorithm	sectionalizing switch location after reconfiguration Bus No.	SAIFI (f/cus. Yr)	SAIDI (hr./cus. Yr)	EENS (Mwh /yr)	ASUI (pu)	ASAI (pu)	ECOST (\$ / yr)
PSO	3,4,12,24,31	131.5674	157.4412	1859.322	0.01797	0.9820	5,520,118
GA	15,16,20,21,25	181.8104	197.6752	1889.774	0.019	0.9810	7,720,118

5.3 Cost analysis and Payback Period

The cost effectiveness is determined, the difference of expected interruption cost (ECOST) before and after applying the proposed method. Before the proposed method used, 9,758,852 \$/year lost due to interruption. After the proposed method used, expected interruption cost (ECOST) is reduced to 2,995,270 \$/year. This indicate that, 6,763,582 \$/year is saved after using the proposed techniques. The total capacity of distributed generation (DG) is 4.5 MW. Cost of DG including cost of Microturbine and PV installation cost, operation and maintenance total cost is \$10,569,155.14. Total revenue loss due to interruption is distribution system is 9,758,852 \$/year. Dividing the total cost of DG with interruption cost, it will be 1.08. This indicate the cost of DG can be paid back within 1 year.

CHAPTER SIX

6.1 Conclusion

In this thesis, the main objective is to improve the reliability of distribution system using distributed generation and network reconfiguration. Arbaminch distribution system is selected in this study because it has high distribution system reliability problem. Different types of data are collected from the substation such as interruption frequency, interruption duration, types of faults occur in the area, peak load, outgoing feeder voltage and number of transformer. After collecting data, the major cause of interruption in the distribution system is analyzed and investigated. From the analysis it is observed that, system over load and permanent short circuit fault occur frequently than the other types of faults.

The reliability indices such as SAIDI, SAIFI, CAIDI and EENS have been calculated and analyzed for all outgoing feeders. The calculated result is used to compare which feeder has high interruption or reliability problem as compared to others. Using the result of comparison, the study is focused on feeder-05, it has high reliability indices. The result was compared with standard benchmarks of the other countries.

ETAP16.0.0 software is used to model the existing system single line diagram. Different input data is used to model and analyze in this software. Some of the input data is transformer rating, cable size, number of bus and failure and repair rate.

To enhance the reliability of the system, distributed generation (DG) and reconfiguration is used in four cases. The DG location, sizing and reconfiguration is done using PSO algorithm. The reliability indices value changed after integrating DG and reconfiguration. In this study four cases are used to analyze such as base case alone, DG integration alone, Network reconfiguration alone and DG and network reconfiguration alone. From the four cases, DG and reconfiguration is the best case where common reliability indices of SAIFI, SAIDI, EENS and ECOST value improved by 82.81%, 78.89% and 78.10% respectively.

6.2 Recommendation

The reliability improvement of distribution system with integration of DG and network reconfiguration is covered in this thesis. In this work it has been determined that DG integration has positive impact on reliability of the system. As seen in this research, distributed generation technology especially renewable energy based DG option should be promoted by the power company to enhance the system accuracy. Therefore, it is recommended that EEU should make the distribution system more reliable to satisfy the need of customers.

The EEU should correctly document all distribution data, which is required for reliability analysis such as total number of customer in each line, number of transformer, number of breaker soon. So I recommend the EEU to document all data in computerized manner. Electric power utility company should use smart technologies in distribution system to minimized faults and satisfy customer demand.

6.3 Future Work

The future research works that would be on the area of reliability improvement using DG and Network reconfiguration are presented. This thesis work uses radial distribution circuit model, it can include other types of network such as ring and meshed type distribution circuit model. DG can be used for backup or peak shaving purpose, there should be control system between the grid and distributed generation. Different types of distributed generation option other than PV and Microturbine can be studied for this distribution system reliability improvement.

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Appendix –I MATLAB code for DG Location and sizing

```
Clear

n=load('loaddata.m'); % Load data
T=load('linedata.m'); % line data
st=length(l);
dt=length(m);
g=0;
c=0;
MVAb=100;
KVAb=15;
Z=(KVAb^2)/(MVAb); % Base case to calculate PU value
%% for unit value
for i=1:br
R(i,1)=(T(i,4))/Z;
Y(i,1)=(T(i,5))/Z;
end
for i=1:no
    P(i,1)=(n(i,2))/(1000*MVAb);
    Q(i,1)=(n(i,3))/(1000*MVAb);
end
R;
Y;
P;
Q
%% Load flow analysis
D=zeros(st, dt);
for i=1:st
    r=t(i,2)
    u=t(i,3)
    for j=1:dt
        if r==j
            D(i,j)=-1;
        end
        if u==j
            D(i,j)=1;
        end
    end
end
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
    end
end
D;
f=1;
for i=1:st
    d=0;
    for j=1:dt
        if D(j,i)==-1
            d=1;
        end
    end
end
if d==0
    endnode(e,1)=i
    f=f+1;
end
endnode
w=length(endnode)
for j=1:w
    a=2;
    f=endnode(j,1)
% while (f~=1)
    for o=1:no
        if(a~=1)
            k=1;
            for i=1:st
                if ((D(i,a)==1) && (k==1))
                    a=i;
                    k=2;
                end
            end
            k=1;
            for i=1:dt
                if ((D(a,i)==-1) && (k==1))
                    a=i;
                    g(a,e)=i;
                    e=e+i;
                    k=3;
                end
            end
        end
    end
end
end
for i=1:w
    g(i,1)=endnode(i,1)
end
p=length(g(1,:))
for i=1:p
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
j=1
for k=1:st
    for t=1:p
        if g(i,t)==k
            g(i,t)=g(i,j)
            g(i,j)=k
            j=j+1
        end
    end
end
end
for k=1:br
    e=1
    for i=1:w
        for j=1:p-1
            if(g(i,j)==k)
                if g(i,j+1)~=0
                    bcj(k,a)=g(i,j+1)
                    a=a+1
                else
                    bcj(k,1)=0
                end
            end
        end
    end
end
end
bcj
for i=1:st-1
    for j=h:-1:1
        for k=j:-1:2
            if bcj(i,j)==bcj(i,k-1)
                bcj(i,j)=0
            end
        end
    end
end
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
        end
    end
    bcj
    Y=length(bcj(:,1))
    cb=length(bcj(1,:))
    for i=1:Y
        for j=1:cb
            if cbj(i,j)==0&&j~=ab
                if cjb(i,j+1)~=0
                    cbj(i,j)=cbj(i,j+1)
                    cbj(i,j+1)=0
                end
            end
            if cbj(i,j)~=0
                cbj(i,j)=cbj(i,j)-1
            end
        end
    end
    end
    bcj;
    b=length(bcj)
    for i=1:no
        vb(i,1)=0.99
    end
for s=1:10
    for i=1:no
        cln(i,1)=conj(complex(P(i,1),Q(i,1)))/(vb(i,1))
    end
    cnl
    for i=1:br
        br(i,1)=cln(i+1,1)
    end
    br
    XY=length(bcj(1,:))
    for i=br-1:-1:1
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
    for k=1:XY
        if adjcb(i,k)~=0
            u=adjcb(i,k)
            br(i,1)=br(i,1)+br(u,1)
        end
    end
end
end
end
iterations=5      % dimension of Iteration
inertia=1.0
correction_factor=2.0
swarms=30;        %crating swarm value
swarm=zeros(30,7); % Crating zero matrix
step=1
for i=1:30
    swarm(step,1:7)=i
    step=step+1
end
swarm(:,7)=1000;
swarm(:,5)=0;
swarm(:,6)=0;
for iter=1:iterations
    for uu=1:swarms
        swarm(uu,1)=swarm(uu,1)+swarm(uu,5)/1.2;
        swarm(uu,2)=swarm(uu,2)+swarm(uu,6)/1.2;
        u=swarm(uu,1);
        v=swarm(uu,2);
        for i=1:no
            nlc(i,1)=conj(complex(P(i,1),Q(i,1)))/(vb(i,1));
        end
        nlc
        for i=1:br
            Ibr(i,1)=nlc(i+1,1);
        end
    end
end
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
Ibr;
Ibr1=Ibr;
XY=length(adjcb(1,:));
for i=br-1:-1:1
    for k=1:XY
        if adjcb(i,k)~=0
            u=adjcb(i,k)
            Ibr(i,1)=Ibr(i,1)+Ibr(u,1)
        end
    end
end
end
end

Ibr
Ibr2=Ibr;
Real=3715;
Reac=2300;
AP_Power=sqrt((Real)^2+(Reac)^2);
DG_penetration=20/100; % DG Penetration for DG
AP_power=AP_Power*DG_penetration;
AP_PU=AP_power/(1000*MVA);
P_factor=0.90; % Power factor
Real_power_=AP_PU*P_factor;
React_power=(AP_PU*(sin(acos(P_factor)))));
for ii=32:-1:26
    for jj=Real_power
        for kk=25:-1:2
            Ibr=Ibr2;
            DG_location=ii; % Location for DG

            DG_size=complex(Real_power_,React_power_*(-
1)); % size for DG
            Ibr(kk,1)=DG2_size;
```

```
end  
end  
end
```

Appendix –II: MATLAB code for Network reconfiguration

```
clc  
tic  
n=20;  
dim=5;% Dimension of searching space  
x=load('swarm34.m');% Creating a swarm  
vnew=rand(n,dim);% Creating a randomized initial velocity  
sig=zeros(n,dim);  
vold=vnew;  
fitness=zeros(1,n);  
pbest=load('swarm34.m');% Creating pbest matrice  
gbest=[4 3 14 23 19];% Introducing a randomized gbest  
wmax=0.9;  
wmin=0.4;  
r1=rand(n,dim);% Creating a randomized matrice, size (20x3)  
r2=rand(n,dim);% Creating a randomized matrices, size (20x3)  
iter=0;  
maxiter=40;% Maximum iteration  
tap=[9 10 11 12 28 30 31 0 0  
      4 5 6 7 8 2 3 32 33  
      13 14 15 34 0 0 0 0 0  
      16 17 18 19 28 29 0 0 0  
      20 21 22 23 24 25 26 27 0];  
ta=tap';  
% Establish the incidence matrix  
data=loadcase(case34);  
doc=data.branch;  
nhanh=34;  
nut=30;  
matrix=zeros(nhanh,nut);  
    nutdau=doc(:,1);  
    nutcuoi=doc(:,2);  
for i=1:nhanh  
matrix(i,nutdau(i))=1;  
matrix(i,nutcuoi(i))=1;
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```
end

% Calculating fitness function for pbest
fpbest=zeros(1,n);
for i=1:n
    fpbest(i)=50000;
end
% Main loops
while iter<maxiter
    iter=iter+1;
    w=wmax-(wmax-wmin)*iter/maxiter;% Specialize the weight
coefficient
    c1=2*rand(1);
    c2=2*rand(1);
    % Updating velocity
    vold=vnew;
    for i=1:n
        for j=1:dim
            vnew(i,j)=w*vnew(i,j)+c1*r1(i,j)*(pbest(i,j)-
x(i,j))+c2*r2(i,j)*(gbest(j)-x(i,j));
            if abs(vnew(i,j))==abs(vold(i,j))
                vnew(i,j)=rand(1,1).*vnew(i,j);
            end
        end
    end
    % Updating particles' coordinate
    for i=1:n
        for k=1:dim
            sig(i,k)=length(nonzeros(ta(:,k)))/(1+exp(-vnew(i,k)));
            x(i,k)=ta(ceil(sig(i,k)),k);
        end
    end
    % Calculating fitness function for each particle
    y=x';
    for k=1:n
        hop=loadcase(case34) ; matran=matrix;
        for i=1:dim
            hop.branch(y(i,k),11)=0;
            matran(x(k,i),:)=0;
        end
        % Check on constraint of radial distribution network
        for j=1:length(matrix(1,:))
            for i=1:length(matrix(1,:))
                if sum(matran(:,i))==1
                    row=find(matran(:,i));
                    matran(row,:)=0;
                end
            end
        end
        if sum(sum(matran))==0
```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```

        result=runpf(hop);

fitness(k)=sum(result.branch(:,14)+result.branch(:,16))*1e3;
        end
    end
    % Updating pbest
    for k=1:n
        if fitness(k)<fpbest(k)
            pbest(k,:)=x(k,:);
            fpbest(k)=fitness(k);
        end
    end
    % Calculating fitness function for gbest
    u=gbest';
    hop=loadcase(case34);
    for i=1:length(u)
        hop.branch(u(i),11)=0;
    end
    result=runpf(hop);
    fgbest=sum(result.branch(:,14)+result.branch(:,16))*1e3;
    gbestvolt=result.bus(:,8);
    minvolt=min(gbestvolt);
    % Updating gbest
    for k=1:n
        if fpbest(k)<fgbest
            gbest=pbest(k,:);
        end
    end
end
% Calculating initial configuration
bandau=loadcase(case34);
o=[20 21 22 23 24];
for i=1:length(o)
    bandau.branch(o(i),11)=0;
end
ketqua=runpf(bandau);
tonthat=sum(ketqua.branch(:,14)+ketqua.branch(:,16))*1e3;
dienap=ketqua.bus(:,8);
dienapmin=min(dienap);
gbestvolt;
a=sort(gbest);
legend('Before Reconfig','After Reconfig')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp('=====')
disp('***** SIMULATION RESULTS OF 34 BUS DISTRIBUTION
NETWORK *****')

```

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

```


disp('=====')
disp('=====')
disp('          BEFORE RECONFIGURATION          AFTER RECONFIGURATION')
disp('-----')
disp(['sectionalize switches:          ', num2str(o), ' ',
      ', num2str(a)])
disp('-----')

toc
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')
disp(' ')

```

Appendix –III: INTERRUPTION frequency and Duration

Table 1: interruption duration and frequency (2010-2011 E.C) from EEU

Southern Region Monthly Power Interruption Report												
										2010 E.C		
No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	2	1.2	12	1.2	1	0.5	2	1.3	12	21.2
		Line2	3	2.3	10	2.3	2	1.2	3	2.3	10	22.3
		Line3	4	4	4	4	2	0.25	3	1.5	14	14
		Line5	6	12	6	12	3	2.3	4	4.5	16	22
		Line6	3	6	3	6	4	2.5	5	5.3	13	16
		Line7	1	4.5	1	4.5	1	0.5	2	1.5	11	14.5
1 reported Period(month/year)			September 2010 E.C									
2 Name of the town			Arbaminch									
No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	2	5	10	8.5	2	1.3	3	3.5	14	24.2
		Line2	6	8	12	7.5	3	2.2	1	1.5	13	22.3
		Line3	3	9.3	15	12.5	2	2.4	2	2.1	14	14.5
		Line5	4	12	13	14.5	2	2.5	2	2.3	13	12
		Line6	2	6	16	17	1	1.3	4	4.5	10	18.7
		Line7	7	11.2	11	10.5	2	2.3	4	4.3	22	14.6
1 reported Period(month/year)			October 2010 E.C									
2 Name of the town			Arbaminch									

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	12	13.5	2	1.2	2	2.5	26	25.2
		Line2	2	5.6	14	15.5	1	0.3	3	2.5	23	32.3
		Line3	8	7	10	12	2	2.3	4	4.5	34	24
		Line5	4	12	16	17.5	2	3.5	5	5.5	26	12
		Line6	5	15	18	19	1	1.2	2	3.5	23	26
		Line7	6	3.2	17	20	3	4.5	5	5.5	21	24.5

1 reported Period(month/year) November 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	13	14.5	1	1.5	2	2.5	32	25.2
		Line2	4	3.5	14	15.5	2	2.5	3	3.5	33	32.3
		Line3	3	12.4	13	12.4	3	2.5	3	3.2	24	26
		Line5	5	10.2	15	10.2	1	1.5	2	3.5	26	19
		Line6	6	7	16	17	3	2.5	3	4.5	23	26
		Line7	7	12	17	19	2	2.3	4	5.1	31	28

1 reported Period(month/year) December 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	11	15	16.5	2	1.5	3	3.5	22	25.2
		Line2	5	11.2	11	13	1	0.5	4	4.5	23	32.3
		Line3	6	12	12	14	2	1.5	5	4.2	14	26
		Line5	7	14	14	15.5	3	3.5	5	4.5	16	19
		Line6	3	8	11	12.5	3	1.5	4	3.5	23	26
		Line7	2	8.5	10	11	1	1.3	3	2.3	11	28

1 reported Period(month/year) January 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	5	5.5	11	12.5	2	1.5	4	5.5	30	25.2
		Line2	6	8.7	15	16.5	1	0.5	5	4.5	31	32.3
		Line3	7	12	10	13	2	1.5	6	5.5	25	26
		Line5	8	16.2	14	15	3	2.5	5	4.5	30	19
		Line6	9	8	9	10	1	2.5	4	3.5	37	26
		Line7	2	10	13	14	2	1.4	5	2.5	22	28

1 reported Period(month/year) February 2010 E.C

2 Name of the town Arbaminch

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	8	15	17	1	1.5	5	5.5	22	34.6
		Line2	3	12	12	15	2	2.5	4	4.5	33	35
		Line3	5	6.2	11	13	2	2.5	5	5.5	24	26
		Line5	2	5.2	15	16	3	3.5	5	5.5	16	25
		Line6	5	7.5	16	17	2	2.5	6	5.5	23	27
		Line7	7	12	18	20	3	1.5	4	4.5	24	33

1 reported Period(month/year) March 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	5.2	12	14	1	1.5	5	5.5	34	30
		Line2	2	5.2	15	16	2	2.5	6	5.5	33	36.5
		Line3	3	4.5	16	17	1	1.5	5	5.5	14	27
		Line5	7	8.5	17	18	2	2.5	6	5.5	29	30
		Line6	2	4	18	20	3	1.5	5	4.5	32	36
		Line7	8	7	15	17	2	2.5	6	5.5	25	33

1 reported Period(month/year) April 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	7	12	18	19.5	2	2.5	5	4.5	31	34.2
		Line2	2	16	11	13	1	1.5	6	6.5	31	35
		Line3	3	15.2	12	15.5	2	2.5	4	4.5	15	27
		Line5	2	7	10	13	2	2.5	5	5.5	26	30
		Line6	4	8	9	11	2	1.5	5	4.5	31	37
		Line7	3	9	10	13	1	2.5	5	5.5	20	25

1 reported Period(month/year) May 2010 E.C

2 Name of the town Arbaminch

No.	Substaton Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	6	17	18	2	1.5	5	4.5	28	32
		Line2	4	6.2	18	20.5	3	2.5	6	5.5	22	31
		Line3	2	4.5	11	15	1	1.5	5	5.5	14	20
		Line5	1	5.5	12	14	2	2.5	4	5.2	17	19
		Line6	3	5	10	13	2	1.5	6	6.5	13	15
		Line7	3	10	12	14	1	1.5	4	5.5	26	24.5

1 reported Period(month/year) June 2010 E.C

2 Name of the town Arbaminch

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substation Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	11	14	1	1.5	4	3.5	32	35
		Line2	4	3.5	15	17	2	2.5	6	5.5	33	34
		Line3	5	4.6	10	15	1	1.5	5	2.4	24	30
		Line5	7	12	11	14	3	2.5	4	3.5	16	20
		Line6	9	8	13	15	2	2.5	5	5.5	13	24
		Line7	3	3.6	10	14	3	1.5	5	4.5	20	25


1 reported Period(month/year) July 2010 E.C

2 Name of the town Arbaminch

No.	Substation Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	8	16.2	10	11.5	2	1.5	4	2.5	30	35
		Line2	5	10.2	15	16.5	1	0.5	4	4.5	34	38
		Line3	2	3.4	12	15	3	1.2	5	4.5	22	25
		Line5	3	3	10	12	3	1.5	5	4.2	16	19
		Line6	1	0.4	15	18	1	0.5	5	3.5	27	31
		Line7	2	2.5	16	17.5	2	1.5	4	3.5	28	32

1 reported Period(month/year) August 2010 E.C

2 Name of the town Arbaminch



Southern Region Monthly Power Interruption Report

2011 E.C

No.	Substation Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	15	16.5	2	1.5	5	5.5	34	30
		Line2	4	3.5	11	13	1	0.5	4	4.5	33	36.5
		Line3	3	12.4	12	14	2	1.5	5	5.5	14	27
		Line5	5	10.2	14	15.5	3	2.5	5	5.5	29	30
		Line6	6	7	11	12.5	1	2.5	6	5.5	32	36
		Line7	7	12	10	11	2	1.4	4	4.5	25	33

1 reported Period(month/year) September 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Fedder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	8	16.2	11	14	2	1.5	5	4.5	34	30
		Line2	5	10.2	15	17	3	2.5	6	6.5	33	36.5
		Line3	2	3.4	10	15	1	1.5	4	4.5	14	27
		Line5	3	3	11	14	2	2.5	5	5.5	29	30
		Line6	1	0.4	13	15	2	1.5	5	4.5	32	36
		Line7	2	2.5	10	14	1	1.5	5	5.5	25	33

1 reported Period(month/year) October 2011 E.C

2 Name of the town Arbaminch

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	17	18	2	2.5	2	1.3	14	24.2
		Line2	4	3.5	18	20.5	1	1.5	3	2.3	13	22.3
		Line3	5	4.6	11	15	2	2.5	3	1.5	14	14.5
		Line5	7	12	12	14	2	2.5	4	4.5	13	12
		Line6	9	8	10	13	2	1.5	5	5.3	10	18.7
		Line7	3	3.6	12	14	1	2.5	2	1.5	22	14.6

1 reported Period(month/year) November 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	11	11	14	1	0.5	3	3.5	26	25.2
		Line2	5	11.2	15	17	2	1.2	1	1.5	23	32.3
		Line3	6	12	10	15	2	0.25	2	2.1	34	24
		Line5	7	14	11	14	3	2.3	2	2.3	26	12
		Line6	3	8	13	15	4	2.5	4	4.5	23	26
		Line7	2	8.5	10	14	1	0.5	4	4.3	21	24.5

1 reported Period(month/year) December 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	8	18	19.5	2	1.2	2	2.5	22	25.2
		Line2	3	12	11	13	1	0.3	3	3.5	23	32.3
		Line3	5	6.2	12	15.5	2	2.3	3	3.2	14	26
		Line5	2	5.2	10	13	2	3.5	2	3.5	16	19
		Line6	5	7.5	9	11	1	1.2	3	4.5	23	26
		Line7	7	12	10	13	3	4.5	4	5.1	11	28

1 reported Period(month/year) January 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	5	5.5	15	17	1	1.5	5	5.5	31	34.2
		Line2	6	8.7	12	15	2	2.5	6	5.5	31	35
		Line3	7	12	11	13	2	2.5	5	5.5	15	27
		Line5	8	16.2	15	16	3	3.5	6	5.5	26	30
		Line6	9	8	16	17	2	2.5	5	4.5	31	37
		Line7	2	10	18	20	3	1.5	6	5.5	20	25

1 reported Period(month/year) February 2011 E.C

2 Name of the town Arbaminch

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	6	12	1.2	2	1.3	2	2.5	32	25.2
		Line2	4	6.2	10	2.3	3	2.2	3	2.5	33	32.3
		Line3	2	4.5	4	4	2	2.4	4	4.5	24	26
		Line5	1	5.5	6	12	2	2.5	5	5.5	26	19
		Line6	3	5	3	6	1	1.3	2	3.5	23	26
		Line7	3	10	1	4.5	2	2.3	5	5.5	31	28

1 reported Period(month/year) March 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	8	16.2	15	16.5	2	1.5	5	5.5	22	25.2
		Line2	5	10.2	11	13	1	0.5	4	4.5	23	32.3
		Line3	2	3.4	12	14	2	1.5	5	5.5	14	26
		Line5	3	3	14	15.5	3	2.5	5	5.5	16	19
		Line6	1	0.4	11	12.5	1	2.5	6	5.5	23	26
		Line7	2	2.5	10	11	2	1.4	4	4.5	11	28

1 reported Period(month/year) April 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	3	4.5	12	1.2	2	1.5	5	4.5	34	30
		Line2	2	5.6	10	2.3	1	0.5	6	5.5	33	36.5
		Line3	8	7	4	4	3	1.2	5	5.5	14	27
		Line5	4	12	6	12	3	1.5	4	5.2	29	30
		Line6	5	15	3	6	1	0.5	6	6.5	32	36
		Line7	6	3.2	1	4.5	2	1.5	4	5.5	25	33

1 reported Period(month/year) May 2011 E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	11	11	14	2	1.5	4	3.5	31	34.2
		Line2	5	11.2	15	17	1	0.5	6	5.5	31	35
		Line3	6	12	10	15	3	1.2	5	2.4	15	27
		Line5	7	14	11	14	3	1.5	4	3.5	26	30
		Line6	3	8	13	15	1	0.5	5	5.5	31	37
		Line7	2	8.5	10	14	2	1.5	5	4.5	20	25

1 reported Period(month/year) June 2011 E.C

2 Name of the town Arbaminch

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	4	8	15	16.5	2	1.5	4	5.5	32	25.2
		Line2	3	12	11	13	1	0.5	5	4.5	33	32.3
		Line3	5	6.2	12	14	2	1.5	6	5.5	24	26
		Line5	2	5.2	14	15.5	3	2.5	5	4.5	26	19
		Line6	5	7.5	11	12.5	1	2.5	4	3.5	23	26
		Line7	7	12	10	11	2	1.4	5	2.5	31	28

1 reported Period(month/year) July 2011E.C

2 Name of the town Arbaminch

No.	Substation Name	Feeder Name	Frequency and Duration of interruption									
			DPEF		DPSC		DTEF		DTSC		DSOL	
			F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)	F	D (Hr)
	Arbaminch	Line1	7	12	15	17	1	1.5	3	3.5	12	21.2
		Line2	2	16	12	15	2	2.5	4	4.5	10	22.3
		Line3	3	15.2	11	13	3	2.5	5	4.2	14	14
		Line5	2	7	15	16	1	1.5	5	4.5	16	22
		Line6	4	8	16	17	3	2.5	4	3.5	13	16
		Line7	3	9	18	20	2	2.3	3	2.3	11	14.5

1 reported Period(month/year) August 2010E.C

2 Name of the town Arbaminch

Table 2 Load data of Arbaminch town from EEU

Ethiopian Electric Power		Ethiopian Electric Power Load Data																		
No	Feeder Name	Active Power		Energy		Out going /MV distribution Line (Feeder)..														
		min	peak	kWH	(KVARH)	List/Name of MV distribution Line (Feeder)	voltage Level in KV	Length of the Feeder in [KM]	Feeder installed capacity in [A] (in substation)/feeder Capacity	Installed MV distribution line/feeder capacity in [A]	CT Ratio & its Setting	Cable Size in [MM ²]	Name of supplying substation	Peak load of the MV distribution Feeder in [MW]	demand on the feeder in [MW]	CK Breaker Capacity in [A]	CT Ratio & its Setting	Cable Size in [MM ²]	Current Peak Load in [MW]	
	Arbaminch Trafo feeder 15KV	2.1	8.6	4032280	2046460															
	Arbaminch Trafo feeder 33KV	0.2	1.9	567600	118800															
1	South	F1	15	2	150	150/5	150/5	120	Arbaminch	2.6	2.1885	1250						300	0.73	
2	South	F2	15	14	150	150/5	150/5	120	Arbaminch	2.4	2.7035	1250						300	2.28	
3	South	F3	15	12	150	150/5	150/5	120	Arbaminch	3.12	3.813	1250						300	3.12	
4	South	F5	15	65	150	150/5	150/5	120	Arbaminch	2.7	4.947	1250	600/5					300	2.28	
5	South	F6	33	70	150	150/5	75-150/1	120	Arbaminch	1		1250						300	1	
6	South	F7	33	140	150	150/5	75-150/1	120	Arbaminch	1.6	3.19675	1250	200-400/1					300	1.6	

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

Appendix –IV: ETAP Report

Table 3: Base case alone

Project:	ETAP	Page: 1
Location:	16.0.0C	Date: 13-07-2021
Contract:		SN: 4359168
Engineer:	Study Case: RA	Revision: Base
Filename: Basecasealone1		Config.: Normal

SUMMARY

System Indexes

ACCI	kVA / customer	
AENS	87.5174 MW hr / customer.yr	
ALII	kVA pu	
ASAI	0.9730 pu	
ASUI	0.02704 pu	
CAIDI	1.069 hr / customer interruption	
CTAIDI	hr / customer	
ECOST	9,758,852.00 \$ / yr	
EENS	2888.075 MW hr / yr	
IEAR	3.379 \$ / kW hr	
SAIDI	236.8386 hr / customer.yr	
SAIFI	221.6338 f / customer.yr	

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

Table 4: with DG integration

Project:	ETAP	Page:	1
Location:	16.0.0C	Date:	13-07-2021
Contract:		SN:	4359168
Engineer:	Study Case: RA	Revision:	Base
Filename: with DG		Config:	Normal

SUMMARY

System Indexes

ACCI	kVA / customer
AFNS	56.4957 MW.hr / customer.yr
ALII	kVA pu
ASAI	0.9844 pu
ASUI	0.01563 pu
CAIDI	1.083 hr / customer interruption
CTAIDI	hr / customer
ECOST	4,880,489.00 \$ / yr
EENS	1864.358 MW hr / yr
IEAR	2.618 \$ / kW hr
SAIDI	136.9567 hr / customer.yr
SAIFI	126.4380 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

Table 5: Network reconfiguration alone

Project:	ETAP	Page: 1
Location:	16.0.0C	Date: 13-07-2021
Contract:		SN: 4359168
Engineer:	Study Case: RA	Revision: Base
Filename: networkreconfiguration		Config.: Normal

SUMMARY

System Indexes

ACCI	kVA / customer	
AENS	56.3431 MW hr / customer.yr	
ALII	kVA pu	
ASAI	0.9820 pu	
ASUI	0.01797 pu	
CAIDI	1.197 hr / customer interruption	
CTAIDI	hr / customer	
ECOST	5,520,118.00 \$ / yr	
EENS	1859.322 MW hr / yr	
IEAR	2.969 \$ / kW hr	
SAIDI	157.4412 hr / customer.yr	
SAIFI	131.5674 f / customer.yr	

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

DISTRIBUTION SYSTEM RELIABILITY IMPROVEMENT USING DISTRIBUTED GENERATION AND NETWORK RECONFIGURATION

Table 6: DG and Network reconfiguration

Project:	ETAP	Page: 1
Location:	16.0.0C	Date: 13-07-2021
Contract:		SN: 4359168
Engineer:	Study Case: RA	Revision: Base
Filename: final		Config.: Normal

SUMMARY

System Indexes

ACCI	kVA / customer
AENS	22.3428 MW hr / customer.yr
ALII	kVA pu
ASAI	0.9924 pu
ASUI	0.00758 pu
CAIDI	1.415 hr / customer interruption
CTAIDI	hr / customer
ECOST	3,026,028.00 \$ / yr
EENS	737.314 MW hr / yr
IEAR	4.104 \$ / kW hr
SAIDI	66.3609 hr / customer.yr
SAIFI	46.9061 f / customer.yr

ACCI	System Average Customer Curtailment Index
AENS	Average Energy Not Supplied
ALII	System Average Connected kVA Interrupted per kVA of Connected Load Served
ASAI	Average service Availability Index
ASUI	Average Service Unavailability Index
CAIDI	Customer Average Interruption Duration Index
CTAIDI	System Customer Total Average Interruption Duration Index
ECOST	Expected Interruption Cost
EENS	Expected Energy Not Supplied
IEAR	Interruption Energy Assessment Rate
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index

