Reliability Analysis and Improvement of Electric Power Distribution System Using Network –Reconfiguration: A Case Study of Debre Berhan Power Distribution System.

A Thesis Submitted to Adama Science and Technology University, School of Electrical Engineering and Computing, Electrical Power and Control Engineering Program in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical Power Engineering

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First and foremost, the glory goes to the ALMIGHTY **GOD**; through him all things are possible. Because without the help of God nothing is done.

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Abstract

A stable and reliable electric power supply system is an inevitable pre-requisite for the technological and economic growth of any nation. Due to this, utilities must strive and ensure that the customers are getting the reliable power supply. In this thesis the reliability of Debre Berhan Distribution System was done on both 15 and 33kV system to assess the performance of the existing system. Moreover predictive reliability analysis for the future system considering optimal placement of switches have been analyzed. For predictive reliability analysis fuzzy logic based optimization was selected and applied which delivers optimal number and placement of sectionalizer switches. The installation of sectionalizer switches in strategic places reduces the outage time in case of abnormal conditions and improves the reliability of the network. This alternative which gives low system average interruption duration index (SAIDI), system average interruption frequency index (SAIFI) and customer average interruption duration index (CAIDI) are being assessed and considered. The reliability analysis indicated that of 15kV of Sheno feeder could be further improved by installation of optimal placement of switches and ETAP software simulation has also been used for both initial optimal network configurations.

As the result of the optimal placement of switches the number and location of sectionalize switches SAIFI and SAIDI are reduced from 145.2115faiure / cust.yr, 322.0554 hr./cust.yr to 132.7942failure / cust.yr & 266.8047 hr./cust.yr. From the test results, the proposed technique presents better interruption cost in comparison with that of the existing system 64,806.06 $/yr. to 57,346.57 $ / yr. (11.5 %) reduction along with improvement in reliability indices.

The method is implemented and tested on Sheno feeder of Debre Berhan town distribution network. Results of both initial and optimal configuration of expected energy not supplied (EENS) was improved from 1788.014 MWh. /yr. to 1533.75 MWh. /yr.

Key words: Distribution Reliability, Network Reconfiguration, fuzzy logic optimization, distribution system reliability improvement.

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Abbreviations and Symbols

ABC	Artificial bee colony
AENS	Average energy not supplied
ANN	Artificial neural network
ASAI	Average service availability index
ASCI	Average System Curtailment Index
BPSO	Binary particle swarm optimization
CAIDI	Customer average interruption duration index
CLS	Connected load to the section
DG	Distributed Generation
DER	Distribution Energy resources
DNR	Distribution Rework Reconfiguration
EENS	Expected energy not supplied
EEPCO	Ethiopian electric power corporation
ECOST	Expected interruption cost
ETAP	Electrical Transient Analyzer Program
FCEP	Fuzzy Controlled Evolutionary Programming
FES	Fuzzy Expert System
FL	Fuzzy Logic
FMEA	Failure Modes Effects and Analysis
FOR	Forced outage rate
GA	Genetic Algorithm
HLI	Hierarchical Level I
HLII	Hierarchical Level II
HLIII	Hierarchical Level III

IEAR	Interrupted energy assessment rate
IEEE	Institute of Electrical and Electronics Engineers
KV	kilo volt
MWh	Mega Watt hour
MAIFI	Momentary Average Interruption Frequency Index
MTBF	Mean Time between Failures
MTTF	Mean Time to Failure
MTTF	Mean time to repair
PRA	Predictive reliability analysis
PSO	Particle swarm optimization
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
SIB	Number of Siblings
SPSO	Selective particle swarm optimization
SL	Section length
TS	Tabu Search

Symbols

λ	Expected failure rate
r	Average outage time
U	Expected annual outage time
μ	Expected repair rate
La	Average connected load

CHAPTER ONE

INTRODUCTION

1.1 Background

The basic function of an electric power system is to supply customers with electricity. Modern society demands that electrical energy should be as economical as possible with a reasonable degree of continuity and quality. The continuity of energy supply can be increased by improved system structure, increased investment during the planning phase, operating phase or both. Over-investment can lead to excessive operating costs.

A Power system has a number of generating stations of different types interconnected by a system of transmission lines, sub transmission lines and distribution networks to supply different types of loads to various consumers. The distribution system is an important part that provides the final links between the utility and the customers. Most distribution systems in practice have a single-circuit main feeder and are radially configured [1]. The radial distribution system is widely used because of its simple design, generally low cost and supportive protection scheme. This configuration suggests from a reliability point of view that all components between a load point and the supply point must work and therefore poor reliability can be expected as the failure of any single component causes the load points to be disconnected.

Reliability of an electric power distribution system is defined as 'the ability to deliver uninterrupted service to the end customers'. Reliability is an integral component of modern power system design, planning and control [2]. The reliability in a distribution system can be improved by network reconfiguration, which is accomplished by closing normally-open switches and opening normally closed switches. These switches play an important role in reducing interruption durations in the event of a system failure. Two types of switches are normally installed along the main feeders and laterals sectionalizing switches (normally closed switch) and tie switch (normally open switch). The former is a device that isolates a faulted part from the system so that the healthy part can still be electrically supplied. The latter is a device that recovers loads that has been disconnected by transferring some of the loads to other supporting distribution feeders without violating operation and engineering constraints.

The techniques used in distribution system reliability evaluation can be divided into two basic categories - analytical and simulation methods. The difference between these methods is in the way the methodology uses the input data in which the reliability indices are evaluated. Analytical techniques represent the system by simplified mathematical models derived from mathematical equations and evaluate the reliability indices using direct mathematical solutions. Simulation techniques, estimate the reliability indices by simulating the actual process and stochastic behavior of the system. Therefore, this method treats the problem as a series of real experiments conducted in simulated time.

Reliability Improvement Strategy has to be developed for each utilities depending upon their requirements. Also with strategies, Outage mitigation technique in distribution system is to be used and this can be classified in two categories namely; Electric and Non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis and these techniques includes addition of protective devices (recloser and fuses) and switching devices (manual and automated switches), system reconfiguration, feeder upgrading and integration of distributed generation. On the other hand, non-electric mitigation techniques do not have any impact on other engineering analysis tools and can be evaluated solely with reliability studies and these techniques includes vegetation management, installation of lightning arresters and animal guards [4]. The impact and the efficiency of the mitigation techniques could be assessed through quantitative reliability evaluation of the distribution system such as; measuring of the past performance and predicting the future performance.

This thesis focuses on the evaluation of the distribution system of Debre Berhan town distribution system. This is to assess whether there is already a need for the switching scheme to be reconfigurated or not. The computed reliability indices such as System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI), Customer Average Interruption Duration Index (CAIDI) and Average Service Availability Index (ASAI) with the Average System Curtailment Index (ASCI) will be used as a basis on why the protective scheme of the system is going to be reconfigurated. Maintaining a specific level of reliability is very important so that the customer satisfaction is high as possible and the efficiency of the system will improve.

1.2 Distribution System Reliability and Related Concepts

Power system reliability evaluation can be used to provide a measure of the overall ability of a power system to perform its intended function. The concept of reliability can be subdivided into the two main aspects of system adequacy and system security [3, 5]. System security relates to the ability of the system to respond to disturbance arising within the system. System adequacy relates to the existence of sufficient facilities within the system to satisfy the customer demands within the system operating constraints. This includes the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities to transport the energy to the actual customer load points.

1.3 Reliability Cost/Worth Concepts

The other main relevant issue for the analysis of quality of power supply is the fact that the level of system reliability is interrelated with the economic aspects. Reliability costs are used for reviews and request for rate increase. The economic analysis of system reliability can be a very useful planning tool in determining the capital expenditures required to improve the real value of additional (and incremental) investment in to the system [3]. It is necessary to combine the reliability criteria with certain cost considerations.

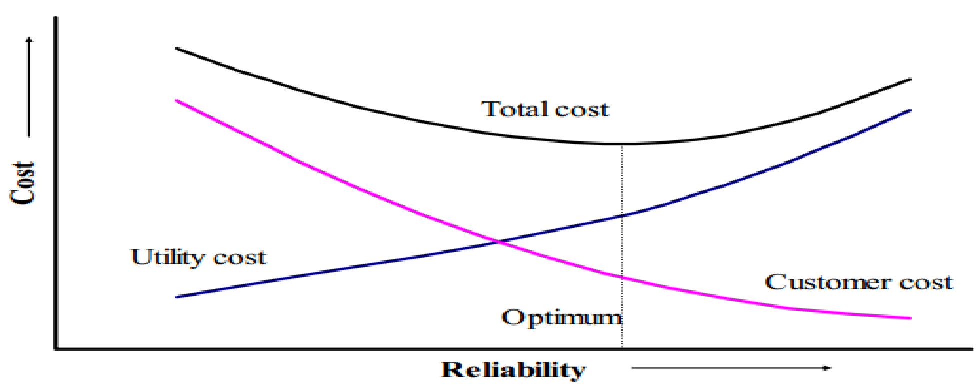


Figure 1.1 Costs According To Reliability

As shown in Figure 1.1, the utility cost, i.e. investment cost, maintenance cost and operating cost, increases while the socio-economic customer interruption cost decreases with increase in the level of service reliability. The total cost is the sum of the two curves. The optimum level of reliability occurs at the point of lowest total cost.

1.**4 Overview of Debre-Berhan town Distribution system**

The town of Debre Berhan is located at 09041^{O}N latitude and 39031^{O}E longitude, 130 km from Addis Ababa on the main road Addis Ababa- Dessie -Mekele road in the Amhara region, north shoa administrative zone, and district of Debre Berhan Zuria.

The Debre-Berhan town Distribution system has started since 1969 in G.C from mini hydropower of Abogedam which is found at the north of river Veresa and from diesel source. Currently in Debre Berhan town distribution systems there are 15,266 customers from these 1940 of them are commercial customers, 13,165 customers are residential and 161 of them are higher industry customers, street lights and others. These loads mainly supplied from a single substation. This substation has seven (7) radially configured feeders.

The feeders in the town are configured radially with voltage level of 33 kV and 15 kV primary feeders. 33 kV feeders have three outgoing lines, these are: Sheno, Enway and AliuAmba and15 kV feeders have four outgoing lines such as blanket factory, Ankober, Mendida and Sheno. These feeders are connected to a total of more than 170 distribution transformers; most of them are pole mounted, for further step down to 380 V three-phase and 220 V single-phase for secondary distribution purpose.

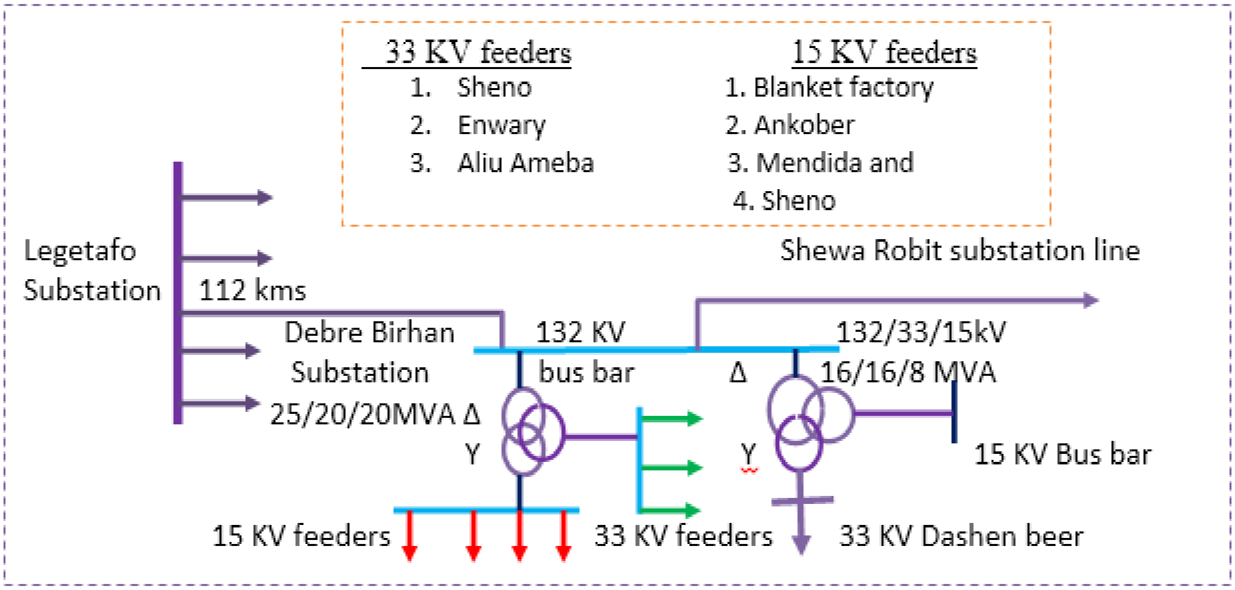


Figure 1.2 Single Line Diagram of Debre –Berhan Substation

1.5. Statement of the Problem

Electricity networks are a critical part of our energy infrastructure and power utility company has the responsibility to ensure that they are developed consistently and in a manner that meets future demands of society and customers. The process of network development should be directed towards a long term vision aligned with the expectations of the present and future customers.

The main existing problem of electric power utilities in developing countries today is that the power demand is increasing rapidly whereas supply growth is constrained by scarce resources, environmental problems and other societal concerns. This has resulted in a need for more extensive justifications of the new system facilities, and improvements in production and use of electricity**.** Currently in Debre Berhan there are frequent interruption which affects both the utility and customer due to this unplanned and unwanted interruptions. There are many cause of this unplanned interruptions in this substation.

An intelligent placement of protection devices, sectionalizers and switches in the distribution Feeders has significant impact on reliability improvement and this will be further assessed along with the outage mitigation techniques for the distribution system. Therefore, in this thesis, the distribution system of Debre –Berhan town has been considered, particularly focusing on Debre-Berhan district's distribution system.

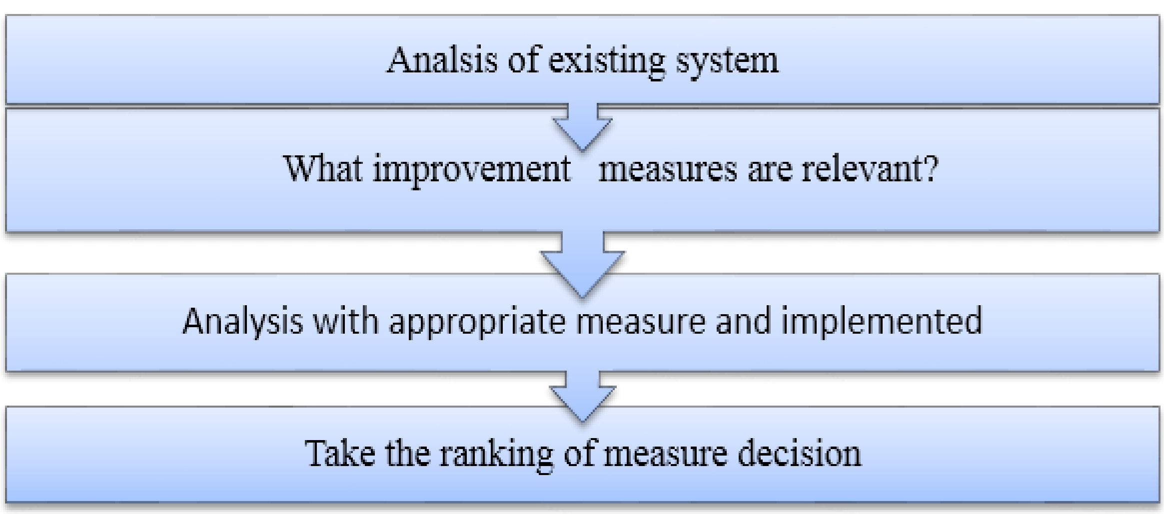


Figure 1.3 Identification of Problems and Analysis of Measures

1.6 Objectives of the Thesis

1.6.1 General Objective

The main objective of this thesis is to assess and evaluate the methods of reliability improvement of Debre Berhan town distribution system and utilization of artificial intelligence optimization (AI) or fuzzy logic techniques to improve system reliability by making the optimal configuration of the existing distribution network. The main goal of this master thesis work is to develop, evaluate and assesses a framework for reliability improvement of distribution systems in Debre-Berhan town.

1.6.2 Specific Objective

- To study the reliability problems in Debre Berhan electrical distribution system.
- To model a feeder in the distribution system and analyze it using an appropriate software for reliability improvement.
- To develop an optimal configuration for the network and evaluate its performance and reliability improvement of Debre Berhan distribution system by simulating with ETAP.
- Comparison of the results obtained from the existing and optimal configuration in order to determine the extent of reduction of reliability indices.

1.7 Significance of the Thesis

The main importance of this thesis is to reduce reliability indices for improving system performance in a given distribution system. When a network reconfiguration algorithm is implemented, reliability indices will be reduced.

Generally the expected importance of this study is:

- To indicate the influence of power interruption on economy of both customers and utility.
- To assess average duration and frequency of power interruption per year in the system.
- To apply fuzzy logic optimization (FL) systems for improvement of system reliability.
- To show the feasibility of this distribution feeder network reconfiguration on reliability improvement with comparing other approaches.

Thus the main aim of this study is to present a methodology for network reconfiguration to search optimal configuration for Debre Berhan distribution system that minimizes interruption costs and simultaneously improves reliability.

1.8 Scope This Thesis Work

It is focused on:

i. Applying AI optimization (fuzzy logic optimization) for improving system performance by finding where the benefit of installing sectionalizers switches.

ii. Using fuzzy logic optimization with mat lab to analyze the optimal placement of switches for reliability improvement.

iii. Using the ETAP software simulation on the distribution network, in order to minimize the customer reliability indices based on fuzzy expert system outputs.

1.9 Methodology

The following methodology is adopted for carrying out this thesis as follows:

i. Collection and analysis of data for radial distribution network from EEPCO of Debre Berhan distribution system district office.

ii. Applying artificial intelligence for performing optimal placement of switches for the given radial distribution network or the switching placement problem based on fuzzy logic technique which was implemented Using MATLAB software.

iii. Based on ii, reliability indices simulation carried out with ETAP software to compare the initial and optimal configuration of distribution network.

iv. Develop a predictive reliability model of the study area using distribution analysis soft wares. The model is calibrated to represent the area's existing reliability.

v. In general the following figure summarizes the methodology used in this thesis.

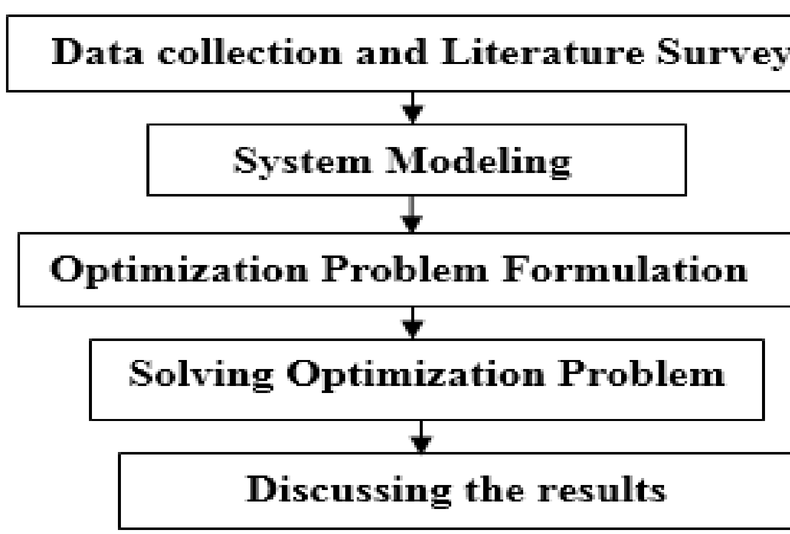


Figure 1.4 Summary of the Methodology

1.10 Thesis Outline

The content of this thesis is briefly explained as follow, chapter 1 provides a brief description about back ground, statement of problem, objectives, research methodologies, scope and overview of study areas of the research. Chapter 2 discussed about distribution literature review of system reliability, distribution system configurations, and system reconfigurations methods. Reliability analysis methods, reliability evaluation, methods of reliability improvement in distribution system for optimization purpose, reliability performance and reliability improvement strategy are explained briefly in this chapter.

Chapter 3 deals about reliability analysis and modeling. Mathematical derivation of distribution system reliability indicators and ETAP mathematical modeling. In Chapter 4 data collection and analysis and fuzzy logic optimization methodology are clearly discussed. Chapter5 described about result and discussions of the results are presented. Conclusion recommendation and future work were presented in Chapter 6.The appendices include, two year substation monthly power interruption reports, load distribution of selected feeders and Reliability indices of each selected feeders. Finally resources used for this work are given on the references.

CHAPTER TWO

LITERATURE REVIEWS

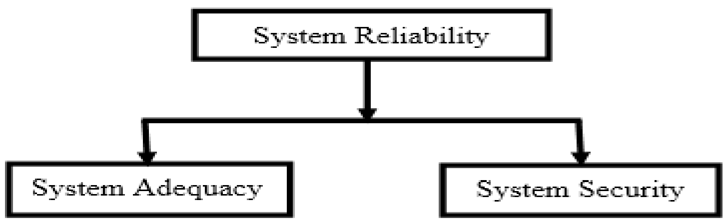
This review of literature contains two core ideas of distribution system reliability assessment based literatures and the methods of distribution system network reconfigurations which is mainly focused in this thesis work clearly.

2.1 Distribution System Reliability

Electric power is a vital element in any modern economy. The availability of a reliable power supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution system have to be reconfigurated, operated and maintained accordingly. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system, hence, improving distribution reliability is the key to improving customer reliability [3].

There are two main approaches applied for reliability evaluation of distribution system, namely Monte Carlo Simulation method based on drawings from statistical distributions and Analytical methods based on solutions of mathematical models. The Monte Carlo techniques are Simulation method; however, it is normally time consuming due to large number of drawings necessary in order to obtain accurate results. The usual method of evaluating the reliability indices is an analytical approach based on failure modes assessment and the use of equations for series and parallel networks. The common indices used for evaluation are the expected failure rate (λ), the average outage time(r), and the expected annual outage time (U) which are adequate to the simple radial system.

Tempa Dorji [3] in paper entitled “Reliability assessment of distribution systems including a case study on Wang due Distribution system in Bhutan”, in this paper he used a probabilistic approach to estimate different improvement techniques to increase the reliability of distribution system. Power system reliability is defined as ability of electrical power system to supply the system load with reasonable continuity and quality of supply. Major subdivisions of power system reliability are system adequacy and system security as shown in Figure 2.1. The term adequacy relates to the existence of sufficient facilities within the system to satisfy the consumers load demand and system operational constraints. Thus, adequacy majorly deals with static conditions and not the dynamic and transients of power system. Security is associated with system dynamics and disturbances in the system. Security is therefore related to the response of the system to perturbations it is subjected to. The concept of power-reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as system reliability which is shown in Figure.



Figures 2.1 System Reliability Subdivision [3]

Reliability assessment and improvement of electric power distribution system has been studied by different researchers using different approaches (methodologies). Some of these are reviewed as follows:

Chaichan Pothisarn etal [5] in paper makes analysis of reliability with the inclusion of DG. They used DIGSILENT to analyze the impact of reliability with the installing DG into the distribution system. They used only the size of load, and the distance of load which are factors able to impact to SAIFI, SAIDI, and interruption cost but they didn’t consider the branch of the main section as the input variable. Bisrat Gezahegn [6] thesis in the title of distribution substation feeder fault section estimation &fault type identification in Debre Berhan distribution system. In this project he used a probabilistic approach to estimate the voltage profile and found the fault current at different point of feeder segments with different fault type were simulated with power world simulator software. He did not evaluate the cause of fault that were contributing.

Bordin Bordeerath [7], in his paper entitled “reliability evaluation of composite Systems with renewable energy sources”, presented simple effective methodologies for accelerating Monte Carlo simulation (MC) in power system reliability assessment and also studied the impact of correlation between generated renewable power and loads towards estimated reliability indices.

C.H. Lin, Member, IEEE, C.S. Chen [9] in entitled with, "Optimal Switching Placement for customer interruption cost minimization" a new approach by using the immune algorithm to solve the optimal placement of line switches for distribution systems has been proposed. The objective function is formulated by considering the customer interruption cost and investment cost of line switches.

Xuebei Yu [10] he discusses in this thesis on the reliability enhancement in power distribution systems. An algorithm was built to realize optimal relay setting for several test systems. Both overcurrent relays and distance relays and their coordination were considered in the optimization problem. In addition, fuse saving scheme was applied to avoid long-time power outage. The cost benefited due to this relay setting was not evaluated.

Dan Zhu [15] described the concept of a fluctuation environment to describe the failure rate of distribution system components. The techniques presented in these papers were approximations which provided results within a few percent of those obtained using more theoretical techniques, such as Markov processes but these techniques had their own problem to fit to the target.

Benyamin Moradzadeh, [30], in his paper entitled "Optimal Distribution Reconfiguration and Demand Management" has shown how it is possible to find optimal state of the switches for which the observed network has smaller total losses and smaller total customer interruption costs. This approach can also be applied to weakly-meshed system be removing the radiality constraint for particular cycles in the system.

2.2 Distribution System Configurations

All distributions of electrical energy are done by constant voltage system. It is important to distribute power to consumers at constant voltage levels [4].

I. **Radial main distribution systems**: There are several configurations of distribution systems. Most distribution circuits are radial. Radial circuits have many advantages :
   - Easier voltage control
   - Easier prediction and control of power flows
   - Lower cost

A radial system is connected to only one source of supply and is exposed to many interruption possibilities. The most important of which are those due to overhead line or underground cable failures or transformer failures. Each event may be accompanied by a long interruption.

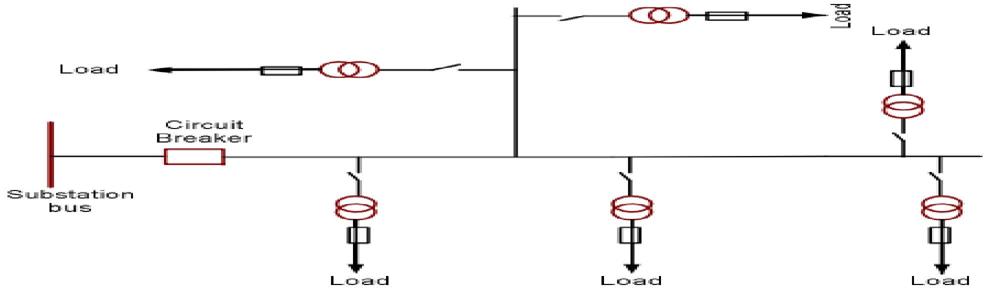


Figure 2.2 Radial Distribution System [3]

This is the simplest distribution circuit and has the lowest initial cost. However, it suffers from the following drawbacks.

- The end of the distributors nearest to the feeder point will be heavily loaded.
- The customers at the distant end of the distribution would be subjected to serious voltage fluctuations when the load on the distributor is changed.
- The customers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder distributor cuts off supply to the customers who are on the side of the fault away from the substation. Thus the reliability of this system is low.

II. Ring main distribution system

In this system the primaries of the transformers form a loop. The loop circuit starts from the substation bus bars, make a loop through the area to be served, and returned to the substation. The figure below show the single line diagram of ring main system for a.c distribution where a substation supplies to the closed feeder LMNOPQRS. The distributors are tapped from M, O, & Q of the feeders through distribution transformer.

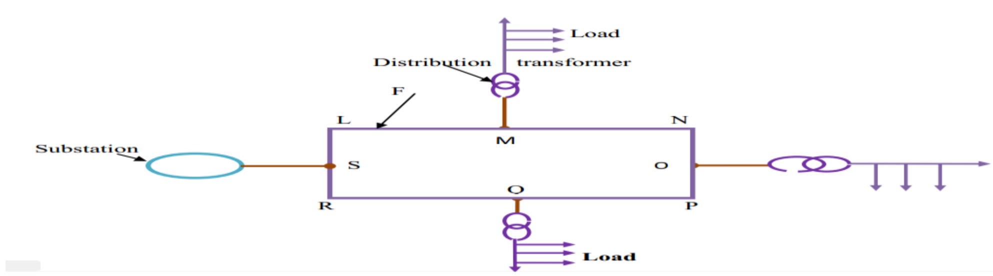


Figure 2.3. Ring Feeder with Two Energy Sources

The ring main system has the following advantages:

- There are very less voltage fluctuation at customer terminals.
- Increase the service reliability.
- The system is very reliable as each distributor is fed from two feeders.

In case of fault in any section of feeder the continuity of supply is maintained. For instance if the fault occurs at point **F** of section SLM of the feeder. The section SLM of the feeder can be isolated for repair and at the time continuity supply to the customer is maintained through the feeder SRQPONM.

III. Interconnected distribution system

When the feeder ring is energized by two or more than two generating stations or substations, it is called inter connected system [14]. The inter-connected system has the following advantages:

- ✓ It increases the service reliability.
- ✓ Any area fed from one substation during peak load hours can be fed from the other substation. This reduces reserve power capacity and increase efficiency of the system.

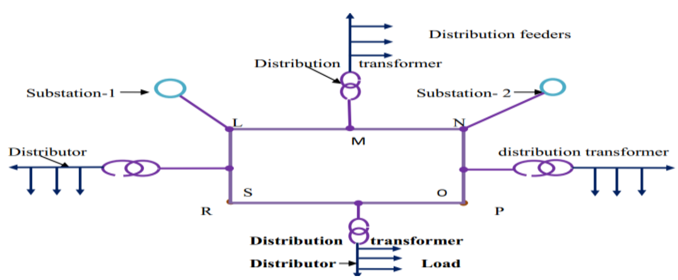


Figure 2.4 Interconnected System Single Line Diagrams

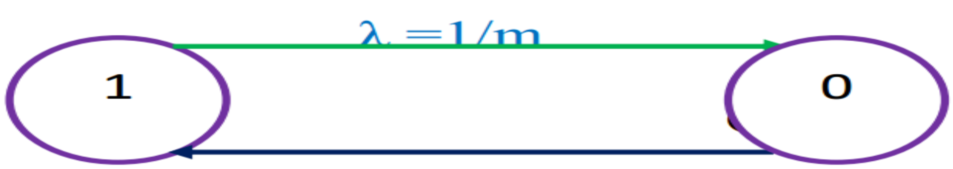
2.3 Markov Chain Model

A Markov model is quite popular in the quantitative reliability analysis, and that is suitable to give fair idea about reliability analysis principle. On the basis of Markov models formulas can be developed and used to calculate the reliability of the radial distribution network. It basically operates with two central concepts

- Failure frequency (λ)
- Repair time (r)

It is assumed for example that a component-wise reliability can only be in one of the following conditions; Condition 1: Component is in the function (in); Condition 2 Component is in repair (out). This is illustrated in two state model diagram in figure 2.5 represented by “0’’ (component in failed state) and “1’’ (component is in a normal state).

The two main approaches used are analytical and simulation. The vast majority of techniques have been analytically based and simulation techniques have taken minor role in specialized applications [4]. The main reason for this is because simulation generally requires large amount of computing time, and analytical models and techniques have been sufficient to provide planners and designers with results needed to make objective decisions. Analytical techniques represent the system by a mathematical model and evaluate the reliability indices from this model using direct numerical solutions. A Markov model is quite popular in the quantitative reliability analysis, and that is suitable to give fair idea about reliability analysis principle. On the basis of Markov models, a simple formula can be developed that can be used to calculate the reliability of the radial distribution network. The method is called like duration-frequency technique, and the starting point is the failure of the individual component. In a so-called stationary Markov process, it basically operates with two central concepts Failure frequency (λ) Repair time (r). It is assumed for example that a component-wise reliability can only be in one of the following conditions; Condition 1: Component is in the function (in); Condition 2: Component is in repair (out). This is illustrated in two state model diagram in figure 2.5 represented by 0(component in failed state) and 1(component is in a normal state).



In condition μ=1/r Out condition

Figure 2.5 Transition Diagram of Component States

λ = fault frequency

m = mean time to failure

μ=repair frequency

r = mean time to repair

The figure 2.6 illustrates expected functional and outage time for a component (so called state cycle).The system can be represented by Markov process and equations developed for the probabilities of residing in each state in terms of state transition rates are as follows[5].

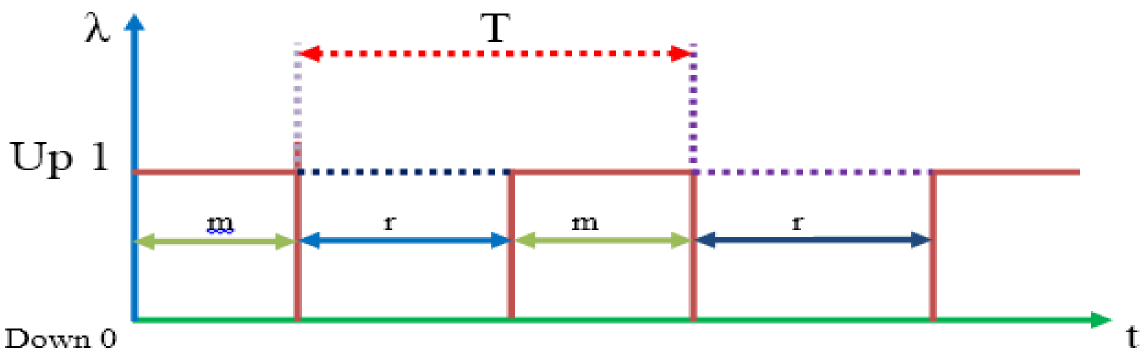


Figure 2.6 Average State Cycle

Definitions: Mean-time-to-failure (MTTF): MTTF is described as the time to failure counted from the moment the component begins to operate to the moment it fails. Figure.3.1 shows typical time to failure and time to repair cycle of a component. Mean-time-to-Repair (MTTR): MTTR is the time counted from the moment the component fails to the moment it is returned back to an operable condition. Failure rate: The failure rate is the reciprocal of the mean time to failure.

2.3.1 Series System

Most distribution systems in Debre -Berhan are basically designed, constructed and operated in radial system. A radial system basically consists of set of series components like; breakers, lines, switches, transformers and at the end of 'Customers'. In the series structure all components must be intact for the system to function, while in the parallel structure both must fail for the system to stop functioning.

2.3.2 Parallel System

In this case the failure modes of the load point involve overlapping outages, i.e. two or more components must be on outage at the same time in order to interrupt a load point. It is assumed that the failures are independent and that restoration involves repair or replacement, the equations used to evaluate the indices of the overlapping outage.

2.4 Power Quality, Reliability and Availability

Power quality is an ambiguous term that means many things to many people. From a consumer perspective, a power quality problem might be defined as any electric supply condition that causes appliances to malfunction or prevents their use. From a utility perspective, a power quality problem might be viewed as non-compliance with various standards such as RMS voltage or harmonics. Perfect power quality is a perfect sinusoid with constant frequency and amplitude. The power Quality is affected when a voltage waveform is distorted by transients or harmonics changes its amplitudes or deviates in frequency [8].Customer interruptions are power quality concern since it reduces voltage to zero.

Reliability is primarily concerned with customer interruptions and is therefore a subset of power quality. Availability is defined as the percentage of time a voltage source is uninterrupted. The hierarchy of power quality, reliability and availability is shown in figure 2.7. The figure indicates availability is a subset of reliability and reliability is a subset of power quality. Power quality deals with any deviation from a perfect sinusoidal voltage source. Reliability deals with interruptions.

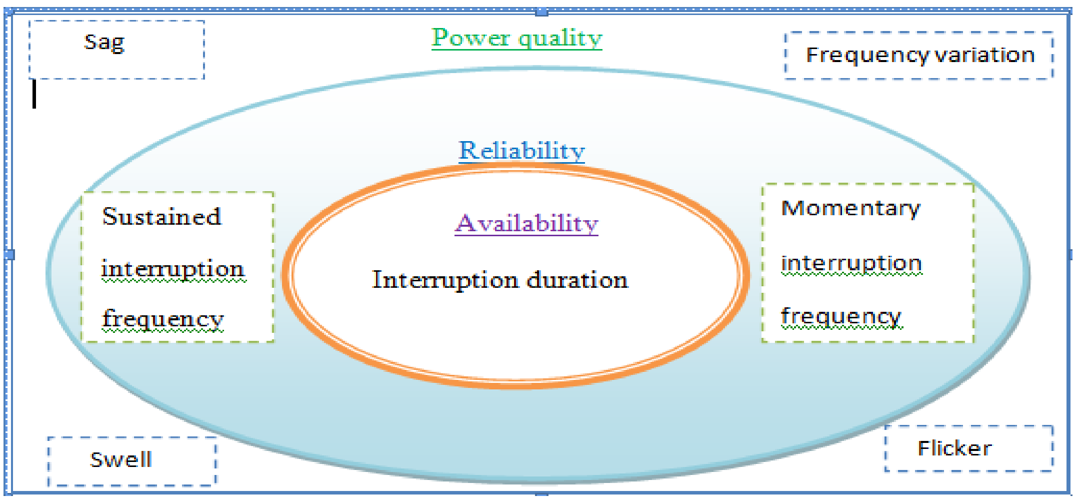


Figure 2.7 Hierarchy of Power Quality, Reliability and Availability

2.4.1 Power Qualities

There are two dominant concepts in existing power quality definitions, both derived from the definitions of quality as a more general category. The first concept is user-related, and defines power quality with regard to the end-user satisfaction with the service provided.

The International Organization for Standardization (ISO) defines quality as: the ability of a product or service to satisfy user's needs. Similarly, the standard [8] defines quality of service as: a collective effect of service performance which determines the degree of satisfaction of a user of the service.

2.4.2 Reliability

Distribution reliability primarily relates to equipment outages and customer interruptions. In normal operating conditions, all equipment (except stand by) is energized and all customers are energized. Schedule and unscheduled events disrupt normal operating conditions and can lead to outages and interruptions. The unscheduled events are caused either due to human error or due to equipment failures. The schedule events are meant for periodic maintenance of the equipment and shall be notified in advance to the customers [3], [4].From definition of reliability, power outages are one of the measures of reliability performance. Unavailability of power can be reduced in two ways: 1) by reducing the frequency of power outages or 2) By reducing the outage time.

2.4.3 Availability

Availability is the probability of something being energized and Unavailability is the probability of not being energized. It is most basic aspect of reliability and is typically measure in percent or per unit. Unavailability can be computed directly from interruption duration information. If a customer experiences 10 hours of interrupted power in a year, unavailability is equal to 10 /8760 = 0.110% (8760 hours in a year). Then availability is equal to 100% - 0.11% = 99.89%.

2.5 Reliability Improvement Methods

The main purpose of reliability data quantification and information extraction is to take reliability improvement measures. Reliability of distribution system can be improved by increasing distribution system protection, decreasing equipment failure, system automation, installment of reclosing and switching devices and system configuration. System automation improves short interruption duration [4]. Restoration time of momentary outage event will be small. Hence the duration that an outage will last will be diminished. Similarly system configuration produces effective improvement in reliability. During occurrence of fault that lasts long, distribution system can be configured into set of network topologies. Distribution network will have alternative supplying network after reconfiguration.

2.5.1 Application of Distribution network reconfigurations (optimal Placement of Switches)

Distribution network reconfiguration is an important tool to reduce the reliability indices, system's power loss, and to do the load balancing in distribution system. This operation is to transfer load from one feeder to another, which will significantly improve the overall system operating conditions. Configuration must be done from time to time, since the line distribution shows different characteristics as each distribution feeder consists of residential, commercial and industrial type, load. Some sections of the light distribution system loaded at specific times of the day and many loaded at other times.

In a distribution system, each feeder has a different mixture of commercial, residential, and industrial type loads. These load types have different daily patterns which make the peak load of feeders occur at different times. In normal operating conditions, part of loads can be transferred from heavily loaded to relatively less heavily loaded feeders by network reconfiguration. Distribution feeders contain number of switches that are normally closed (sectionalized switches) and switches that are normally open (tie switches). Distribution network reconfiguration is the process of altering the topological structure of distribution network by closing the open/ close status of sectionalizing and tie switches. When the operation conditions change, network reconfiguration is performed by the opening/closing of the network switches under the constraints of transformer capacity, feeder thermal capacity, voltage drop and radiality of the network. The distribution network reconfiguration is a complex combinatorial optimization problem. This is because there are multiples of constraints which must not be violated while finding an optimal or near optimal solution to that problem.

2.6. Methods of Distribution Network Reconfigurations

2.6.1 Heuristic Optimization Methods

Heuristic and Meta-heuristic techniques are the randomized searching procedures. It is described that swarm optimization techniques and evolutionary techniques are the parts of it. In next section, and Genetic Algorithms, fuzzy logic, and artificial neural network are described in details. Several methods have been proposed to solve the reconfiguration problem.

Reza Baradaran Hendi, etal [19] this paper has presented an optimization problem to minimize the total cost of reliability of distribution network by optimal placement of fault indicators. The customer interruption cost, and the investment cost, repair and keeping cost of fault indicators are considered as the parameters of the objective function. The artificial immune algorithm was used to solve the proposed formulation.

Gustavo Darnels Ferreira (etal) [20] in his paper discusses on reliability as all aspects of customer interruptions, including momentary interruptions. A methodology for multi-objective optimization is proposed to minimize SAIFI, SAIDI indices simultaneously. This goal was achieved considering both the optimized allocation of protective devices and switches, and the definition of the protection scheme to be employed in the recloser and substation breaker, fuse saving or fuse blowing.

Hamed Hashemi Dezaki etal [20] in this paper discussed, a novel method was proposed to evaluate the proper allocation of protective devices, which is based on the sensitivity analysis. Using the method in this paper, decision making about the system reliability decrement is possible when an available protective device is removed or malfunctions.

Safri [22] described an algorithm that is based on network portioning into groups of load buses such that the line section losses between the groups of nodes are minimized, the proposed method overcomes the size restriction imposed by reconfiguration techniques. By dividing the distribution network into groups of buses, the combinatorial nature of reconfiguration problem is overcome while simultaneously minimizing losses.

2.6.2 Genetic Algorithm (GA)

Andrew Chipper field, Carlos Fonseca [21] it described GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GAs operates on a population of potential solutions applying the principle of survival of the fittest to produce (hopefully) better and better approximations to a solution. It combines the adaptive nature of the natural genetics or the evolution procedure of organs with functional optimization. The simple feature of GA makes it suitable for different multi objectives optimization problem. The principle problem in using GA rests on an efficient coding and decoding mechanism of the chromosome representing the distribution network and the structure of fitness function.

Nematollah Dehghani, Rahman Dashti [23] in paper entitled “presented an effective application of the genetic algorithm optimization to practical distribution system automation”, one location may satisfy an objective function subject to a specific reliability index. However, adding reliability index as a constraint can result in different optimum locations. Multiple reliability indices were combined to form an objective function using the concept of a composite index in which the weights and target values of each index must be determined.

J. Moshtagh, S. Ghasemi [32] in paper "Non-dominated sorting genetic algorithm is essentially a modified form of conventional GA", like conventional GA, it also uses selection, crossover and mutation operator to create mating pool and offspring population. They used an algorithm based on NSGA-II has been proposed for solving the reconfiguration problem in power distribution systems. The advantage of the proposed NSGA-II based technique is that it does not require any weighting factor (as needed in a conventional GA based technique). The simulation results for two typical IEEE distribution power systems showed that a new topology for the open/closed status of the switches was attained. In addition to the optimal reduction of power losses, the load balancing on the branches were also optimally improved. The voltage drop in the system was also reduced to its minimum value.

2.6.3 Fuzzy Logic Method

In [24] described a calculation strategy that allows determining the optimal number and placement of sectionalizing switches in MV radial distribution networks, in correspondence to technical, regulatory and economical aspects. A formulation that takes into account the investment, maintenance and power interruption costs has been developed, seeking for a reduction in total costs while taking care of the regulatory and technical aspects. A multicriteria optimization procedure allows incorporating in the calculating process various quality indicators which can be either global or individual indexes. This way of formulation makes the proposal flexible as well as applicable to allow including aspects that were not considered in this papers.

T. Juhana Hashim etal [25] discussed the implementation of a fuzzy logic based coordinated voltage control for a distribution system connected with distributed generations (DGs). The connection of DGs has created a challenge for the distribution network operators to keep the voltage in the system within its acceptable limits. Intelligent centralized or coordinated voltage control schemes have proven to be more reliable due to its ability to provide more control and coordination with the communication with other network devices. In [26] proposed a new type of evolutionary search methodology is proposed for determining the minimum loss configuration of a radial distribution system. To improve the performance of evolutionary programming a fuzzy controlled evolutionary programming (FCEP) based on heuristic information has been proposed. The designed mutation fuzzy controller adaptively adjusts the mutation rate during the evolutionary process. This method reduces combinatorial explosive switching problem into a realizable one and reduces the switching combination to a few number. A mutation fuzzy logic controller is developed to speed up the evolutionary process by adaptively adjusting the mutation rate.

The following advantages of the fuzzy systems are to be selective [39]:

- capacity to represent inherent uncertainties of the human knowledge with linguistic variables;
- simple interaction of the expert of the domain with the engineer designer of the system;
- easy interpretation of the results, because of the natural rules representation;
- easy extension of the base of knowledge through the addition of new rules;
- Robustness in relation of the possible disturbances in the system.

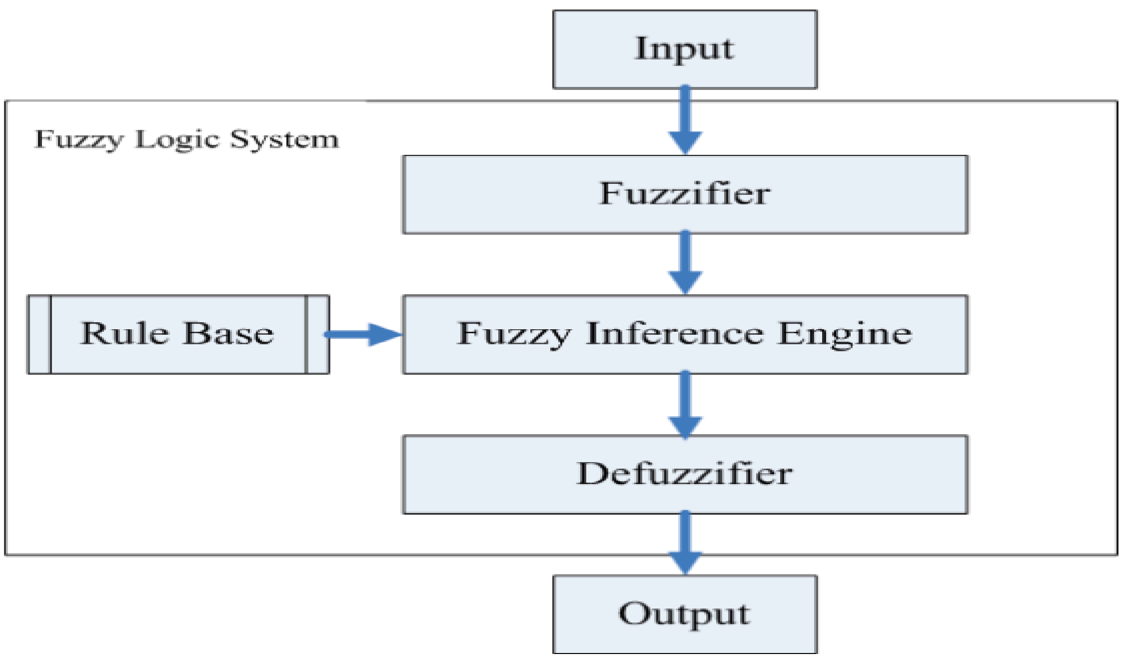


Figure 2 .8 Structure of Fuzzy Logic System

2.6.4 Artificial Neural Network

It presented the strategy of feeder reconfiguration to reduce the power loss by artificial neural network (ANN). This approach developed is basically different where are the aspects that the load transfer and the corresponding load flow solution during the search process are not required. The training set of ANN is the optimal system topology corresponding to various load patterns which minimizes the load under given conditions.

2.6.5 Particle Swarm Method

Khalil and Alexander v. Gorpinich [27] presented a new simple algorithm for solving the distribution network reconfiguration (DNR) problem. This algorithm is a simple modification to the binary particle swarm optimization (BPSO) called selective particle swarm optimization (SPSO). The search space for proposed algorithm is a set of branches (switches) which are normally closed or normally opened, this search space may be dissimilar for different dimensions.

V.Selve, Dr.G.Baskar,B, B, etal [28], discussed about network reconfiguration is aimed at maximizing the reliability of power supplied to the customers. Binary particle swarm optimization (BPSO) is used to determine optimal configuration of switches in network in order to maximize reliability at load points. In the presented work, probabilistic reliability models of the components are used to estimate the future behavior of the distribution system in terms of the reliability of supplying power to its customers.
Madoni .Syahputra, Imam Robandi, Mochamad Ashari [29] described a methodology for optimal reconfiguration of radial distribution network with the presence of DER using improved PSO algorithm. The methodology was based on minimizing active power losses and improving voltage quality in order to enhance distribution system performance. The methodology was tested on an IEEE model of 33-bus radial distribution network test system.

2.6.6 Tabu Search Method

In [36] proposed a Tabu Search algorithm for the reconfiguration of distribution systems for minimizing the real power losses. A new characterization of the neighborhood structure avoids the exploration of an excessive number of configurations, thus reducing the computational effort without reducing the quality of the generated configurations.

One of the main characteristics of the TS algorithm is the use of memory, which can be of short term or long term. In the short term memory, the attributes of the solutions are stored such that solutions that contain the attribute forbidden are rejected. This strategy prevents the occurrence of cycling. However, it can prevent a good quality solution from being accepted.

2.6.7 Simulated Annealing Method

Young-Jae Jeon, Jae-Chul Kim [34] presented an efficient algorithm for loss minimization by using an automatic switching operation in large scale distribution systems. Simulated annealing is particularly well suited for a large combinatorial optimization problem since it can avoid local minima by accepting improvements in cost. However, it often requires a meaningful cooling schedule and a special strategy, which makes use of the property of distribution systems in finding the optimal solution.

2.6.8 Ant Colony Optimization Method

R. Srinivasa Rao, (etal) [31] a new population based artificial bee colony algorithm (ABC) was proposed to solve the network reconfiguration problem in a radial distribution system. The main advantage of ABC algorithm is that it does not require external parameters such as cross over rate and mutation rate etc., as in case of genetic algorithms, differential evolution and other evolutionary algorithms and these are hard to determine in prior. The other advantage is that the global search ability in the algorithm is implemented by introducing neighborhood source production mechanism which is a similar to mutation process.

Wiwat Tippachon, Dulpichet Rerkpreedapong [33], presented a multi-objective optimization technique for placement of switches and protective devices in electric power distribution systems. The reliability indices and total cost were considered as the objective functions to be simultaneously minimized in order to identify the number and location of switches, reclosers and fuses to be installed in the selected distribution system. The technical limitations are also taken into account as the optimization constraints including coordination conditions of series protective devices and the circuit topology of feeders. In this paper, the model of distribution feeder consisting of main and lateral sections is represented by a tree graph. The set theory is used to describe the feeder topology including locations of load points and protective devices. As a result, the values of SAIFI, SAIDI and total interruption cost used as the objectives in this research can be conveniently determined.

2.7. Application of Genetic Algorithm to Network Reconfiguration (Placement of Switches)

Electrical distribution networks are built as interconnected meshed networks. However, they are arranged to be radial in operation. Their configurations may be varied with manual or automatic switching operations so that all of the loads are supplied with reduced reliability indices and power loss [23, 25]. Optimization is way of minimizing or maximizing objective function subjected to defined constraints. All solutions obtained with this method must be compounded to the constraints and objective function has to be computable. The target solution obtained in this situation is stated as optimal solution.

Reconfiguration also relieves the overloading of the network components. Feeder reconfiguration is performed by opening sectionalizing (normally closed) and closing tie (normally open) switches of the network. These switching are performed in such a way that the radiality of the network is maintained and all the loads are energized. Genetic algorithms use the principle of natural evolution and population genetics to search and arrive at a high quality near global solution. The required design variables are encoded into a binary string as a set of genes corresponding to chromosomes in biological system. Unlike traditional optimization techniques that require one starting solution, GA uses a set of chromosomes as initial solutions [37].

2.8 Reconfiguration for Restoration Algorithm

When system reliability needs to be evaluated more closely, multiple failures should be taken into account, and an actual reconfiguration for restoration analysis should be carried out as part of this assessment. In this work, a research effort has been devoted to developing a reconfiguration for restoration program. Distribution reconfiguration studies could be divided into following [30]:

- Capacitor placement
- Network reconfigurations
- Voltage and reactive control
- Optimal placement of switches
- Distributed generation placement
- Service restoration

In this research, optimal placement of switches is the major concern. Service restoration aims at minimizing service downtime to out-of-power loads during post fault conditions. The location of protective components on the distribution system and their response to failures can have an important impact on reliability indices. Protective devices together with switches will be referred to as sectionalizing devices. Sectionalizing devices are used to group components. Thus, a sectionalizing device is any component that is designed to break the electrical circuit topology.

CHAPTER THREE

RELIABILITY ANALYSIS AND MODELING

Reliability analysis of electrical distribution system is considered as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans that cost wise were comparable considering system investment and cost of losses. There are two main approaches applied for reliability evaluation of distribution system, namely Simulation approaches and Analytical approaches [5]. The usual method of evaluating the reliability indices is an analytical approach based on failure modes assessment and the use of equations for series and parallel networks. The common indices used for evaluation are.

- The expected failure rate (λ)
- The average outage time (r), and
- The expected annual outage time (U)

Which are adequate to the simple radial systems, in distribution system whether the networks are radial or meshed, mostly they are operated in radials since it is simple to assess.

3.1 Distribution System Reliability Indices

Reliability indices are statistical aggregations of reliability data for a well-defined set of loads, components or customers. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, substation service territory, or feeder. This section presents some basic reliability indices that were used in this thesis as general terms for quantitative measure of reliability. Some of these indices could be evaluated using computer program. They are therefore defined as follows:

3.1.1 Load Point Indices

The basic distribution system reliability indices of a load point *p* are average failure rate λ_p, average outage duration r_p and annual outage time *U*. These three basic indices are calculated using the principle of series systems and given by:

$$\lambda p = \sum_{i=1}^{n} \lambda_i \qquad 3.1$$

$$U = \sum_{i=1}^{n} \lambda_i r_i \qquad 3.2$$

$$rp = \frac{U}{\lambda p} = \lambda_i r_i / \sum_{i=1}^{n} \lambda_i \qquad 3.3$$

Where n = number of outage events affecting load point p

λ_i = failure rate of component i (failure/yr or, in short, f/yr)

r_i= repair time of component i (hr.).

3.1.2 System Reliability Indices

The electric utility industry is moving toward a deregulated, competitive environment where utilities must have accurate information about system performance to ensure that maintenance dollars are spent wisely and that customer expectations are met. To measure system performance, the electric utility industry has developed several measures of reliability. These reliability indices include measures of outage duration, frequency outages, system availability [4].The most common distribution indices include the System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), System Average Interruption Frequency Index (SAIFI), Momentary Average Interruption Frequency Index (MAIFI), Customer Average Interruption Frequency Index (CAIFI) Customers Interrupted per Interruption Index (CIII), and the Average Service Availability Index (ASAI).

1) The System Average Interruption Frequency Index (SAIFI) (interruption/yr.)

The index represents the average number of sustained interruptions experienced by a customer in a unit time (generally per year). The definition of service area is flexible in the sense that the number of customers and the interruptions experienced by them changes with the definition of the enclosed area. For instance, a feeder SAIFI indicates the average number of interruptions a customer serviced by the particular feeder would experience in a year. Similarly SAIFI reported for a substation or a distribution system encloses the total customers in the service area. The system average interruption frequency index is given in Equation (3.4)

$$\mathrm{SAIFI} = \frac{\text{Total Number of Customer Interruption}}{\text{Total Number of Customers Served}} = \frac{\Sigma\,(\lambda_i\,N_i)}{\Sigma\,N_i} \qquad 3.4$$

where, λ_i is the failure rate and Ni is the number of customers at load points i.

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

The index indicates the average time a customer has an interruption during a time cycle (1 year). It is usually specified in customer minutes or customer hours of interruption /year. SAIDI (system average interruption duration index) is the average interruption duration per customer served as given in Equation (3.5). It is determined by dividing the sum of all customer interruption durations during a year by the number of customers served.

$$\text{SAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customers}} \qquad 3.5$$

Where Uithe annual outage time and Ni is is the number of customers at load point i.

SAIDI can be improved by reducing the number of interruptions or the duration of the interruptions.

3) Customer Average Interruption Duration Index (CAIDI) (h/interruption)

Customer Average Interruption Duration Index (CAIDI) is the average interruption duration for those customers interrupted during a year. It is determined by dividing the sum of all customer interruption durations by the number of customers experiencing one or more interruptions over a one year period. The index is the ratio of SAIDI to SAIFI as given in Equations (3.6). It represents the average time taken to restore service to the customers when a sustained interruption occurs.

$$\text{CAIDI} = \frac{\text{Sumof Customer Interruption Durations}}{\text{Total Number of Customers Interruptions}} = \frac{\Sigma\,(\mathrm{U}_i\,\mathrm{N}_i)}{\Sigma\,\lambda_i\,\mathrm{N}_i} = \frac{\text{SAIDI}}{\text{SAIFI}} \qquad 3.6$$

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

4) Average Service Available Index (ASAI)

The average service availability index (ASAI) gives the fraction of time the customer has power during the reporting time. Higher ASAI values reflect higher levels of reliability. Equation (3.7) is used to calculate the value of ASAI for a given service area.

$$\text{ASAI} = \frac{8760\ \text{Hours/year} - \text{CAIDI}}{8760\ \text{Hours/year}} \qquad 3.7$$

5) Average Service Unavailable Index(ASUI)

$$\text{ASUI} = 1 - \text{ASAI} = \frac{\text{SAIDI}}{8760\ \text{Hours/year}} \qquad 3.8$$

6) Expected Energy not supplied index (EENS)

$$\text{EENS} = \sum \text{L}_i * \text{U}_i \qquad 3.9$$

Where Li and Ui respectively are the average connected load and the average annual outage time at load point i.

(7) Average Energy not supplied index (AENS) (KWh/yr.)

$$\text{AENS} = \frac{\text{Total Energy not Supplied}}{\text{Total Number of Customers Served}} = \frac{\sum \text{L}_i \text{ U}_i}{\sum \text{N}_i} \qquad 3.10$$

The first five indices are customer-oriented indices and the last two are load and energy-oriented indices. These indices can be used not only to assess the past performance of a distribution system but also to predict the future system performance.

3.2 Power Outage Cost Evaluation

Power outage cost is the cost of customers and utility due to power interruption as discussed in chapter one. A variety of methods can be utilized to evaluate customer impacts due to interruption. These methods can be grouped, based on methodological approach used, into three broad categories, namely; various analytical evaluations, case studies of black outs, and customer surveys. Even if a single approach has not been universally applied, customer surveys are the main approach to determine specific information for outage cost evaluation purposes. In practice, the cost of interruption from the customer's perspective is related to the nature and degree to which the activities interrupted are dependent on electrical supply. In turn, this dependency is a function of both customer and interruption characteristics. Customer characteristics include type of customer, nature of customers' activities, size of operation and other demographic data, demand and energy requirements, energy dependence as function of time of day, etc. Interruption characteristics include duration, frequency, and time of occurrence of interruptions; whether an interruption is complete or partial, if advance warning or duration information is supplied by the utility; and whether the area affected by outage is localized.

3.3 Impacts of Improvement Techniques and Protection System on Reliability

A properly coordinated protection system is vital to ensure that an electricity distribution network can operate within predetermined requirements for safety for individual items of equipment, staff and public, and the network overall. Suitable and reliable equipment should be installed on all circuits in electrical power system. A better over-current protection scheme can reduce number of customers affected by temporary and permanent faults. So, historical data can be used to quantify improvements and predict the best locations for sectionalizing devices for reliability improvements. Adding numbers of re-closer at optimal locations can reduce SAIFI and SAIDI but it should be economically viable. The location and installation of number of Auto re-closer, Switches, Load Break Switches and Sectionalizers either manual or automatic helps to reduce fault rate, repair time and sectioning time which directly reduces the impacts on the system when fault occurs.

3.4 Reliability Evaluation

The ultimate goal of reliability analysis should be to answer questions like: Is the system reliable enough? Which schemes will be effective? And where high capital should spent to improve the system? Reliability in power system can be divided in to two basic aspects; historical and predictive. The predictive reliability is then followed to predict the changes in reliability measures after a change in system configuration or any improvement strategy is planned to be implemented.

3.4.1 Historical Reliability Assessment

Two approaches to reliability evaluation of distribution systems are normally used, namely, historical assessment and predictive assessment [3]. Historical assessment involves the collection and analysis of distribution system outage and customer interruption data. It is essential for electric utilities to measure actual distribution system reliability performance levels and define performance indicators to assess the basic function of providing cost-effective and reliable power supply to all customer types. Historical assessment generally is described as measuring the past performance of a system by consistently logging the frequency, duration, and causes of system component failures and customer interruptions.

3.4.2 Predictive Reliability Analysis

The predictive reliability analysis (PRA) estimates the future performance of the distribution system based on system topology and failure data of the components. Its assessment provides a basis to select the best options from several computing alternatives. The main advantage of the

PRA is its ability to forecast the reliability impacts of the system expansion and to quantify the impact of the reliability improvement projects.

The improvement methods can be; load transfer between feeders, new feeder tie points, feeder automation, replacement of aging equipment, changing the configuration of the system and changing the connection scheme of feeders. A number of alternatives are considered and the one which gives best result in term of reliability and minimum energy interrupted shall be chosen for the future system.

3.4.2.1 Electric improvement techniques

These techniques have direct impact on the distribution system and affect the distribution system analysis. This technique includes: addition of protective devices (re-closers and fuses) and switching devices, system reconfiguration and feeder reconnecting.

(a) Reclosing devices, sectionalizers switches

Re-closers: They are protective devices which have two basic functions on the system reliability and over current protection. Mostly they are mainly used for reliability reasons. Reclosing was normal for all utilities since most lines were overhead and most temporary faults could be cleared by the re-closer before the fuse operated. Most of the overhead faults are temporary in nature any feeders with primarily overhead exposure should be protected by a reclosing relay on its main circuit breaker. Placing a line recloser on a feeder will improve the reliability of all the upstream customers by protecting them from downstream faults. However, the placement of the re-closer should be such that a maximum benefit is obtained to improve reliability.

Automatic Sectionalizers: Automatic sectionalizers automatically de-energize a faulted section so that non-faulted line sections can be safely energized. It helps to overcome the coordination problems of other protection devices like fuse and reclosers near substations. When the fault current exceeds the pre-set value, the sectionalizers will open instantaneously in order to isolate the fault to restore power back to non-faulted line segment customers. This also helps to save the fuse from blowing which is also known as a “fuse saving” scheme.

Sectionalizing and Tie Switch: Sectionalizing switches are basically used to make or break loads under normal conditions. They are used for immediate restoration of power to healthy part of distribution system. Similarly, the tie switch is normally open switch applied for network reconfiguration. In case of power failure, distribution network is routed to alternative power supplying path by the use of Tie switches. Both sectionalizing and tie switches are applied in primary distribution network to reduce power interruption. The sectionalizing and Tie switches can improve the SAIDI and CAIDI of a feeder.

Load Break switch: The installation of additional Load Break switch at strategic locations would be more beneficial for making step restoration of the system at the time of fault. The installation of load break switch have the potential to improve reliability by allowing faults to be isolated and the customer service to be restored before the fault is repaired.

System configuration: A distribution system can be reconfigured by changing the location of the normally open switches, effectively changing the allocation of the customers and the flow of power for the effective feeders. It is not only improves reliability, but, also minimizes the losses and the operation costs.

3.5 Distribution System Failures Cause Analysis

Outages in distribution systems caused by different factors significantly impact the reliability of the systems. It is important to investigate these outages. Specifically, analysis of reliability performance of the distribution system over the past year related to outages caused by different factors is very useful for the utilities .The supply interruptions in this thesis are referred to as outages or failures. These denote the state of a component when it is not available to perform its intended function due to some event directly associated with the component.

The general definition of failure can be structured as figure 3.1. Failure can be divided primarily into damaging faults and non-damaging faults. Outages caused by damaging faults are usually called permanent forced outages, while outages caused by non-damaging faults are categorized again after the action of restoration into [4]:

(i) Transient forced outages when the system is restored by automatic switching and the outage time is negligible, and

(ii) Temporary forced outages when the system is restored by a manual switching or fuse replacement.

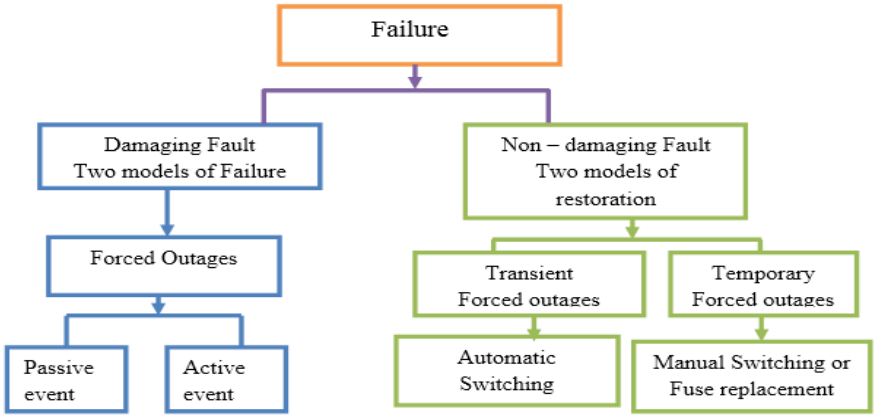


Figure 3.1 Definitions of Failure

Long interruptions are often caused by damaging faults (permanent faults) and short interruptions are often caused by transient faults. Furthermore, damaging faults can be separated into two models of failure; Passive failure and active failure defined as follows:

An active failure of an item is the one which causes the operation of the protection devices around it and results in the opening of one or more fuses.

Definition: An additional active failure is a failure mode that occurs when a component fails actively and causes interruption through its impact on other components.

A passive failure is a failure that is not an active failure. The failed item (component) by an active failure is consequently isolated and protection breakers are re-closed. This leads to service restoration to some or all of the load points. However, for the passive failure, service is restored by repairing or replacing the failed component (or by re-closing a disconnector and using another feeder for supply). The outage time of a failure is made up of various items depending on the cause. Figure 3.2 shows two different time sequences following active and passive failures. As can be seen in the figure, the active failures can be restored by either repair or replacement, or by switching.

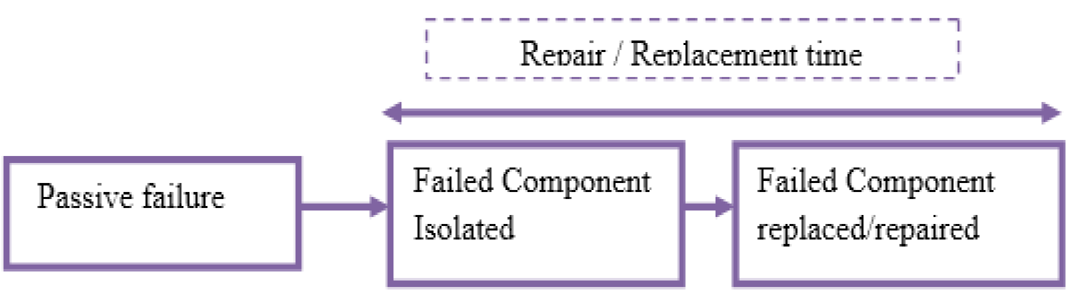


Figure 3.2 Total Time for Repair/Replacement of Passive Failure

3.6 Factors Influencing Power System Reliability

The factors influencing power system reliability can be broken down into four categories. They are component reliability, system configuration, environmental conditions, loading [7].

3.6.1 Component Statistics

A power system consists of various components, such as lines, cables, transformers, breakers, switches, reactors, and capacitors. Any single component outage may cause a partial or even entire system outage. The availability of component functionally is characterized by failure rates and repair or replacement times.

Reliability of a power supply system can be assessed statistically, based on the information on past system performance and use of historical data and records, or it can be assessed stochastically, based on a prediction analysis and use of probabilistic variables and parameters

3.6.1.1 Failure Rate

Hazard function *h(t)* is the conditional probability of failure in time interval '*t'* to (*t+dt*), given that there was no failure at time '*t'* divided by the length of the time interval *dt*.

$$\mathrm{h(t)} = \frac{\mathrm{f(t)}}{\mathrm{R(t)}} \qquad 3.11$$

Where f (t) is probability density function and R (t) is reliability function. The cumulative hazard function h (t) is the conditional probability of failure in the interval 0 to't'.
If the total number of failures during the time interval 0 to t.

$$\mathrm{H\ (t)} = \int_0^t h(\tau)\mathrm{d}\tau \qquad 3.12$$

Hazard function is also referred as hazard rate or instantaneous failure rate in reliability theory. It is very important for power system design engineers, repair and maintenance people. Hazard rate is a function of time and it is a bathtub-shaped function shown figure 3.3 Component failures can be divided into aging failures and chance failures. Aging failure is a conditional failure that depends on the component's history. Figure 3.3 shows a bathtub curve of a component's failure rate change during its life time. An aging failure can happen suddenly after a component enters its Wear-out period. Figure 3.5 indicates that a component failure rate is not a constant. Failure rate distributions are different from component type to component type. Some expensive components, like transformers, come with a set of reliability data provided by the manufacturer, including the component's life cycle statistical distribution. Nowadays, the infant mortality period of some expensive components is usually consumed by manufacturers so that when these components are put into service they are already in a reliable state.

The occurrence of failures of a component will vary during its lifetime and is often being visualized using a "bathtub curve" (see illustration in Figure 7)

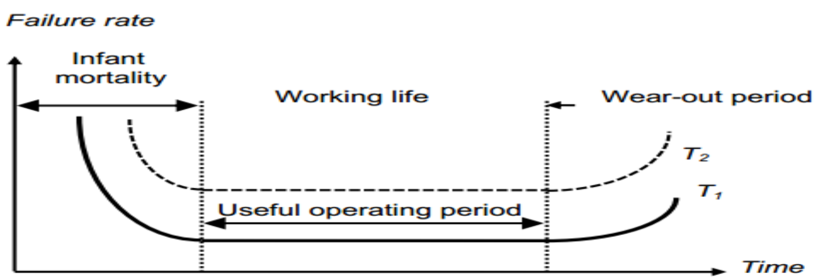


Figure 3.3 Bath-Tub Component's Life

The life of components follow three major periods:

1. Infant mortality period or decreasing failure rate period.

$$h\ (t) = -\lambda t \qquad 3.13$$

2. Useful life period or constant failure rate period

$$h\ (t) = \lambda \qquad 3.14$$

3. Wear-out period or increasing failure rate period

$$h(t) = \lambda t \qquad 3.15$$

Many components in power systems exhibit constant failure rate during their lifetimes, this occurs at the end of the early failure region. Burn-in is performed by subjecting components to stress slightly higher than the expected operating stress for a short period in order to weed out the failure due to manufacturing defects.

The CDF of the life of a component is represented by:

$$F\ (t) = P\ [T \leq T] \qquad 3.16$$

And

$$R\ (t) = 1 - F\ (t) \qquad 3.17$$

the reliability is

$$F(t) = P[T>t] \qquad 3.18$$

Thus, the hazard rate function is

$$h(t) = \frac{f(t)}{R(t)} \qquad 3.19$$

3.6.1.2 Repair Time

There are no good models for repair time (or down time), since the repair time for failed equipment depends upon many things, such location, crew dispatch policy, different failed parts in a type of component and so on. One of the common practices is to use the exponential model, which assumes reparations are statistically independent events and the repair time can be represent by the global average. Historical data shows that the repair time is also affected by weather conditions. Stormy conditions usually prolong the process of customer down time.

3.6.2 System Configurations

System configurations include various issues, including topology, transportation capacity, protection/coordination schemes, and DG placement.

3.6.3 Time-varying Load

The load demands in distribution systems vary from time to time, and each class of customers follows a different pattern.

3.6.4 Environmental Conditions

Power system components are exposed to various weather conditions and hazards. Animals, motor vehicle accidents, rain, ice, and tree contact can all lead to faults and failures. Environment dependent failures may be of short duration.

3.7 Failure Modes and Effects Analysis (FMEA)

In order to determine the system's reliability, it is important to have a strategic methodology for defining the impact of different events. One qualitative analysis principle, called Failure Modes Effects and Analysis (FMEA), is a bottom-up technique that is effective to identify component failures within a system [4]. A successful FMEA helps to identify each failure mode, probability of occurrence of each failure mode, and necessary actions required to mitigate such failure modes. The steps followed in FMEA are listed as follows:

- Identify all failure modes.
- Figure out their probability of occurrence λ.
- Select a contingency and its impact on all loads
- Weigh the impact of contingency by multiplying with λ.
- Follow the previous steps to the rest of all contingencies.
- Sum the contribution of all individual contingencies.

3.8 Reliability Improvement Strategy

Due to increase in dependence on electricity and the growth of sensitive loads in all customer sectors (residential, commercial and industrial) the requirement of continuous power supply increases. The first step to maximize reliability is identifying the root cause of the outages. The main strategy to improve reliability and power quality to customers are to eliminate faults and then to minimize the effect of faults on customers even if it occurs. After developing the reliability improvement strategy, it is important to apply the interruption improvement techniques in order to obtain better results. The improvement techniques can be basically classified into two categories, electric and non-electric. Figure 3.4 shows a simple radial distribution system consisting of transformers, transmission lines (or feeders), breakers, fuses, and disconnects. Disconnects and transmission lines such as s1 and l2 are designated as a main section. The main sections deliver energy to the different power supply points. An individual load point is normally connected to a power supply point through a transformer, fuse and lateral transmission line. A combination such as f_1, t_2, and l_5 is called a lateral section. A simple distribution system is usually represented by a general feeder which consists of n main sections, n lateral sections, and a series component as shown in Figure 6. In this feeder, S_i , L_i , M_i , and L_{pi} represent series component i , lateral section i , main section i; and load point i , respectively. Li could be a transmission line, a line with a fuse or a line with a fuse and a transformer. Mi can be a line, a line with one disconnect switch, or a line with disconnect switches on both ends.

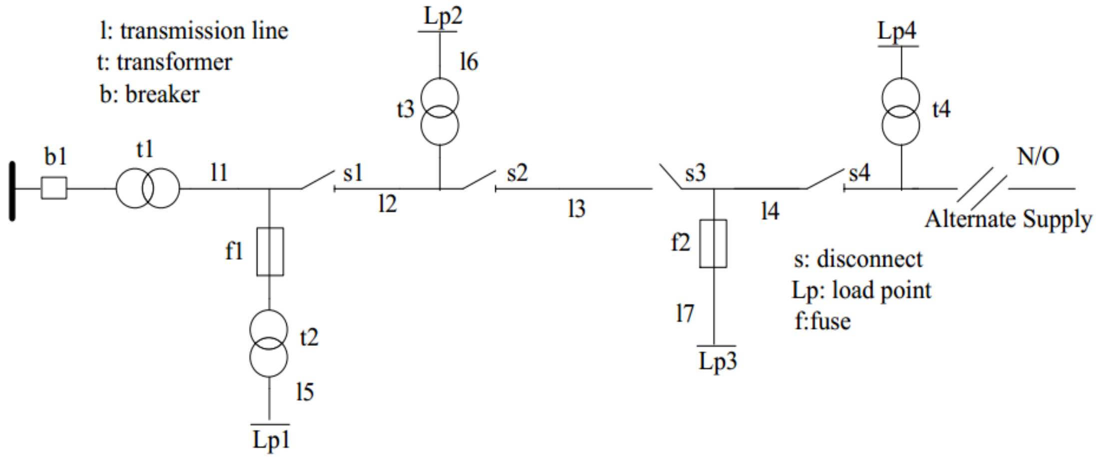


Figure 3.4 Simple Distribution System [3]

A simple distribution system is usually represented by a general feeder which consists of n main sections, n lateral sections and a series component as shown in Figure 3.7. In this feeder, Si, Li, Mi and Lpi represent series component i, lateral section i, main section i and load point I respectively. Li could be a transmission line, a line with a fuse or a line with a fuse and a transformer. Mi can be a line, a line with one disconnect switch or a line with disconnect switches on both ends.

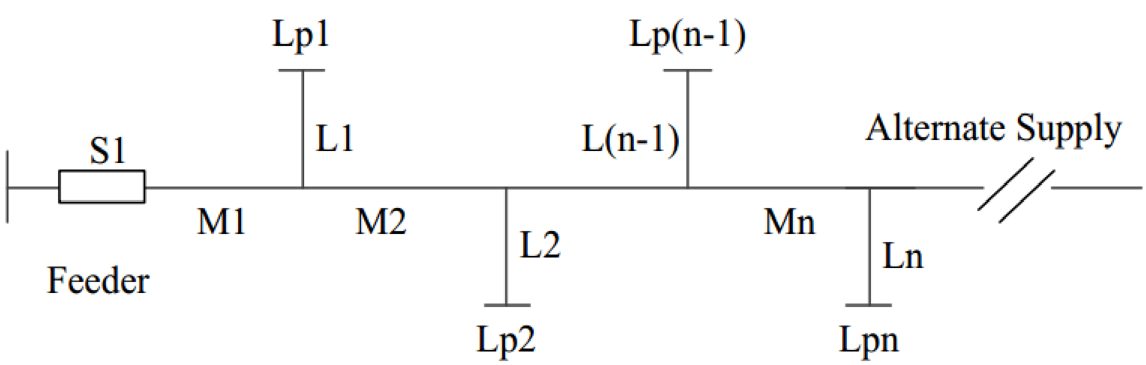


Figure 3.5 General Feeder

3.9 Modeling of Debre Berhan Distribution System with ETAP software

ETAP software powerful electrical engineering analysis and management tools established as a world leader in power system design, analysis, and monitoring [40].

Modeling: To model the system with ETAP software Sheno (15kV) feeder is selected for modeling. This feeder is selected from the other feeders because the unknown cause to failure recorded is lower than the other feeders as shown in Table 4.2. To calculate the failure rate of each component in the feeder for active failure rate and passive failure rate the fault rate data and its cause is required. In order to model the feeder the cumulative load, sample feeder line, for each type of transformer one sample and other component and devices are modeled. The reliability analysis and assessment using ETAP software for radial and looped systems is a very efficient analytical algorithm. The algorithm is used based on the reliability evaluation and component modeling presented in probabilities all listed below in equations. Model reliability characteristics of each component defined parameters and settings are calculated. To model distribution system reliability analysis the following assumptions are considered:

a. Only AC systems are considered.
b. All switching devices operate successfully when required.
c. Switching devices can be opened whenever possible to isolate a fault.
d. All failures are statistically independent. The reliability indices which are used to calculate for each component in component modeling are expressed as follow.

1. Expected Failure Rate (λ):

$$\lambda = \frac{\text{number of outage on component in a given time}}{\text{total time component in operation}} \qquad 3.20$$

λ is the frequency of load interruption per year. As shown in equation. It is the sum of the active failure rate (λ_A) and passive failure rate (λ_p).

Active failure rate causes the operation of the protection device around the failed component (like short-circuit fault) or is the failure of the component itself that restore services after replacement.

2. Mean time to repair (MTTR) (r): r is the time (hours) required to repair a component outage and/or restore the system in to normal operating state.

$$\text{MTTR} = r \qquad 3.21$$

3. Expected Repair Rate (μ):

μ, is the frequency of a repair

$$\mu = \frac{8760}{\mathrm{MTTR}} \qquad 3.22$$

4. Mean Time to Failure (MTTF):

MTTF is expected time (years) that the component will be in failure.

$$\mathrm{MTTF} = \frac{1}{\lambda} \qquad 3.23$$

- Mean Time Between Failure (MTBF)

MTBF is the expected time (years) between a component failure.

$$\mathrm{MTBF} = \mathrm{MTTF} + \frac{\mathrm{MTTR}}{8760} \qquad 3.24$$

6. Forced Outage Rate (FOR) The basic parameter used is the probability of finding the component on forced outage at some distant time in the future. Its unavailability is evaluated from the previous indices equation:

$$\mathrm{FOR} = \mathrm{U} = \frac{\mathrm{MTTR}}{8760 * \mathrm{MTTF} + \mathrm{MTTR}} = \frac{\mathrm{MTTR}}{\mathrm{MTBF}} * 8760 \qquad 3.25$$

7. Expected Energy not supplied index at load point (EENS)

Where Lai, and Ui, are the average connected load and the average annual outage time at load point i respectively.

8. Expected interruption cost index at load point (ECOST):

$$\mathrm{ECOSTi} = Li \sum_{j£Ne}^{n} \mathrm{f(rij)} * \ \lambda\mathrm{ej} \qquad 3.26$$

ECOST is the cost of not supplied energy at that load point. Interrupted Energy assessment Rate index at load point {IEAR ($/KWh)}.

$$\mathrm{IEARi} = \frac{\mathrm{ECOSTi}}{\mathrm{EENS}} \qquad 3.27$$

The IEAR is important index in order to identify the weak points of the network. The failure rates and repair duration of different components such as transformers feeder circuit breakers, s bars, feeder lines, isolators and fuses are summarized in table 4.1 below.

ETAP Algorithm: Figures 3.6 and 3.7 show the algorithm for distribution network reliability assessment using ETAP and Sheno feeder of Debre Berhan Distribution Network in ETAP environment respectively.

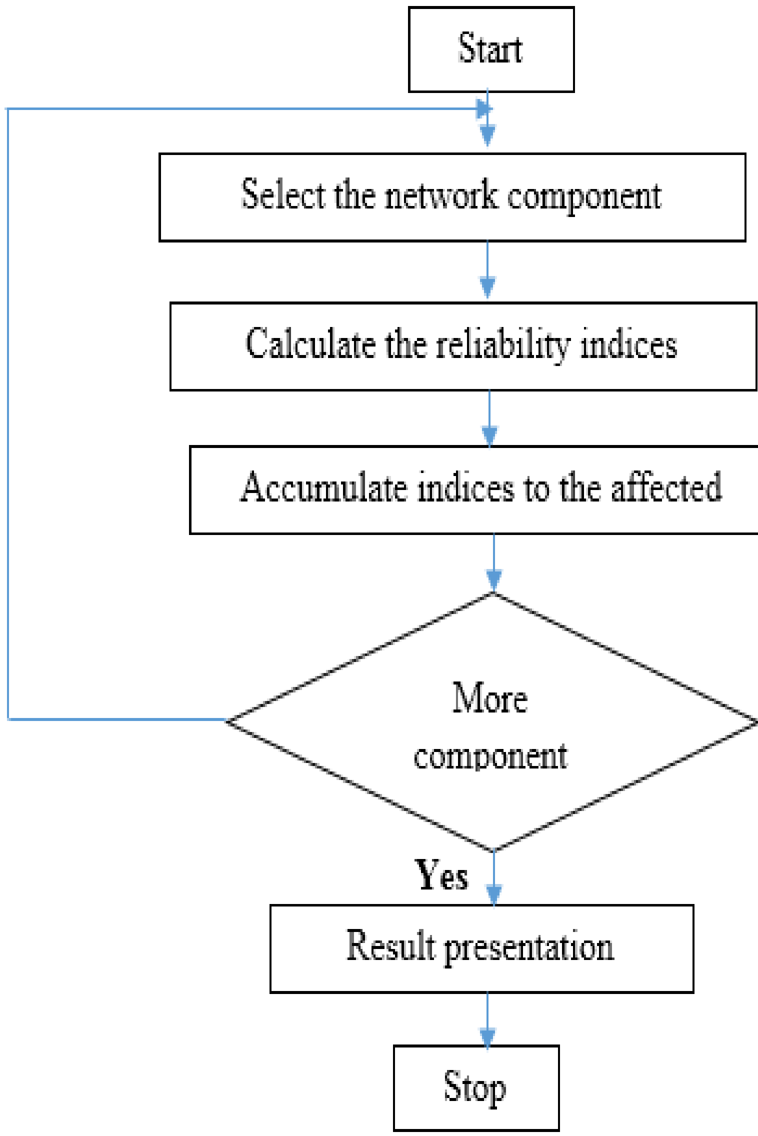


Figure 3.6 ETAP Algorithm for Calculation of Reliability Indices

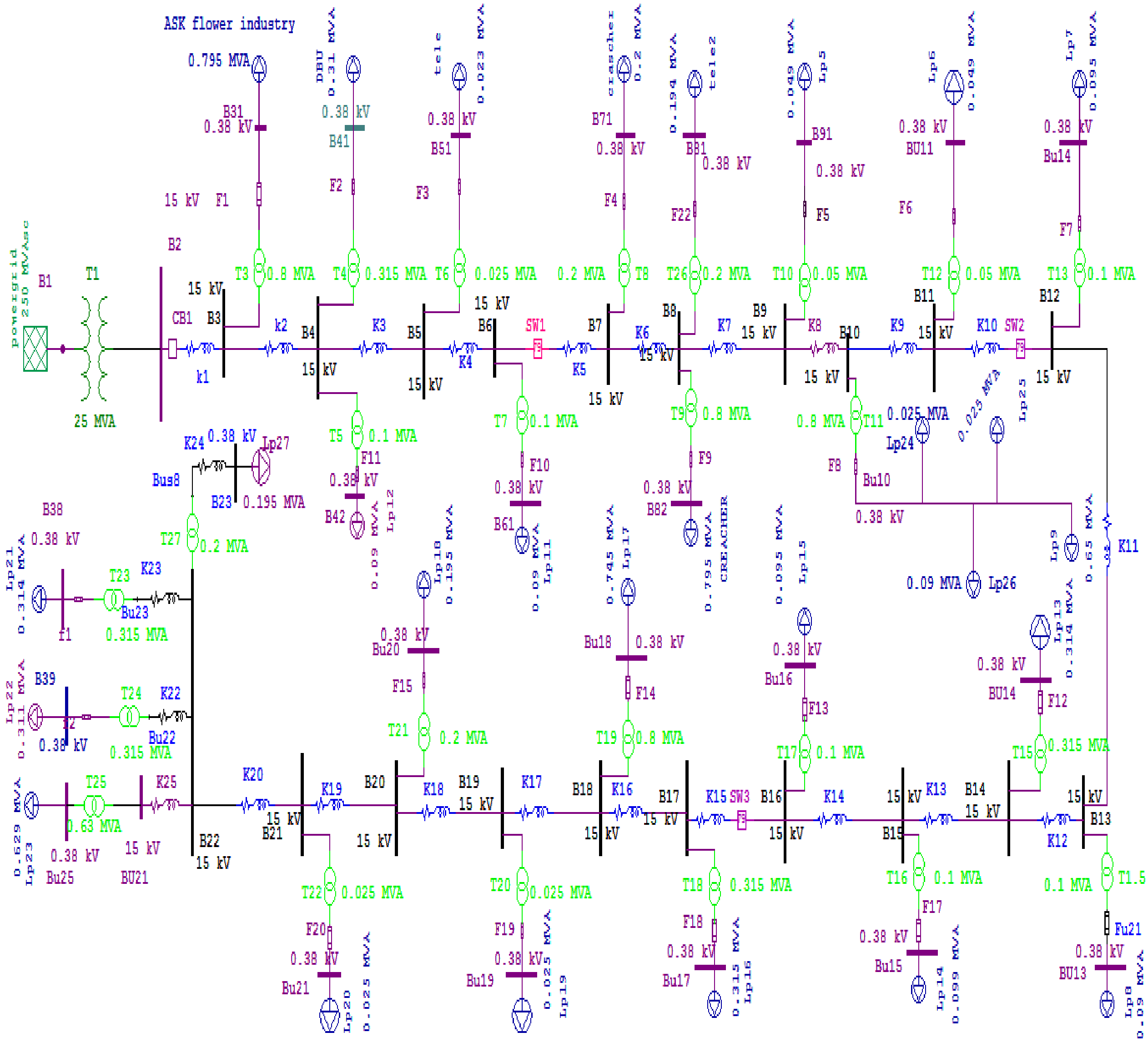


Figure 3.7 Modeling of Sheno Feeder

CHAPTER FOUR

DATA COLLECTION, ANALYSIS AND METHODOLOGY

To evaluate and assess the reliability of the distribution system the historical statistics data of power interruption frequency and duration is required. For this thesis data are collected from EEPCO Debre Berhan district monthly report data. From Debre Berhan substation of the two years (2006 and 2007) data are taken for selected four feeders. In the report every permanent and temporary power interruptions, duration of each power outages with their cause in each month are included [appendix A].

4.1 Reliability Assessment of the Existing System

4.1.1. Historical Reliability Assessment:

Two approaches to reliability evaluation of distribution systems are normally used, namely, historical assessment and predictive assessment [3]. Historical assessment involves the collection and analysis of distribution system outage and customer interruption data. It is essential for electric utilities to measure actual distribution system reliability performance levels and define performance indicators to assess the basic function of providing cost-effective and reliable power supply to all customer types. Historical assessment generally is described as measuring the past performance of a system by consistently logging the frequency, duration, and causes of system component failures and customer interruptions.

4.1.1.1 Data Collection and Analysis

To make the evaluation and assessment of the reliability of the distribution system the historical statistics data of power interruption frequency and duration is required. For this particular thesis all data are collected from Debre Berhan district utility. In Debre Berhan electrical power distribution system four feeders are selected to study the reliability assessment. These four selected feeders are Sheno (15KV), Enwary (F2) and AliuAmba (F3) and Ankober they are selected because of:

- They fed power to all kind of loads such as industrial, commercial, and domestic.
- High numbers of customers are connected with them.
- Served more Debre Berhan town customers than the other feeders.

Monthly report data: From Debre Berhan substation (district) of the town monthly power interruption of the four selected feeder reported to the district. From the report the two years 2014(2006) and 2015(2007) data are taken from the region for selected four feeders. In the report every permanent and temporary power interruptions, duration of each power outages with their cause are included [appendix A].

4.2 Study of Debre Berhan Power Distribution System

The existing power distribution in Debre Berhan town is radial distribution system type. Power is delivered to the customer from the utility in a one path way. There are no laterals and interconnection or mesh type network topology. Even though radial power distribution system is less costly in terms of design and protection, it's vulnerable to disturbance hence less reliable. Because of its radiality this substation has a frequent interruption to the customer. Due to this reason the mesh or interconnected distribution is highly recommended to improve customer based reliability and power availability.

Debre Berhan substation has seven outgoing feeders. It works in 15kV&33kV voltage level in the secondary side of the substation transformer. The figure below shows that different rating of transformers used for each feeder.

Table 4.1 Number of Transformers and Rating of Each Transformer

Feeder 's Name	Capacity (KVA)								
	25 KVA	50 KVA	100 KVA	160 KVA	200 KVA	315 KVA	630 KVA	800 KVA	1250 KVA	Total
Sheno(15kv)	3	2	8	-	4	6	1	3	-	27
Enwary	6	10	5	-	14	1	-	-	1	37
Aliu- Ameba	5	8	6	-	5		1	1	-	26
Ankober	3	10	5	-	13					31
Sheno(33kv)	6	3	5	-	-	1	-	-	-	15
Mendida	3	5	7	1	8	1			1	33
Blanket factory	-	-	-	-	-	--	-	-	2	2
Total (KVA)	650	1900	3600	160	8800	2835	1260	3200	5000	171

Total rating of transformers=650+1900+3600+160+8800+2835+1260+3200+5000=24.905MVA

4.2.1 Major Causes of Power Interruption for Four Feeders

A first step to eliminate faults is identifying the source cause for failures. In order to improve reliability of electrical distribution system, so that it is necessary to know the great contributing factors to the power outage in the system [5]. Historical data summarize the actual performance of an electric distribution system. The basic data item is a system failure, which is a component outage or a customer interruption. The customer interruption has been defined and recorded in terms of the primary causes of the interruption.

In the analysis, the contributions of the dominant causes to the equipment failures are calculated and compared for different years. From historical data of two year record in the report there are many cause of power interruption as shown Table 4.2.From monthly report of the year there are a number of causes for power interruption in the table only the major causes are listed.

Table 4.2: Major causes of power interruption for each four feeders

s.no	Feeders	Major cause of power outage					
		Components failure	For maintenance	Windy rain	Animals Contact	Fallen tree	Unknown
1	Sheno (F1)	38	25	6	5	6	22
	Outage cause (%)	37.97	27.85	3.79	2.53	3.79	24.05
2	Enwary(F2)	39	28	5	5	4	20
	Outage cause (%)	36.71	22.78	6.33	3.79	5.06	25.32
3	AliuAmba(F3)	37	25	6	8	8	20
	Outage cause (%)	34.17	25.32	3.79	6.33	6.33	24.05
4	Ankober	45	20	10	5	5	29
	Outage cause (%)	34.17	25.32	3.79	6.33	6.33	24.05

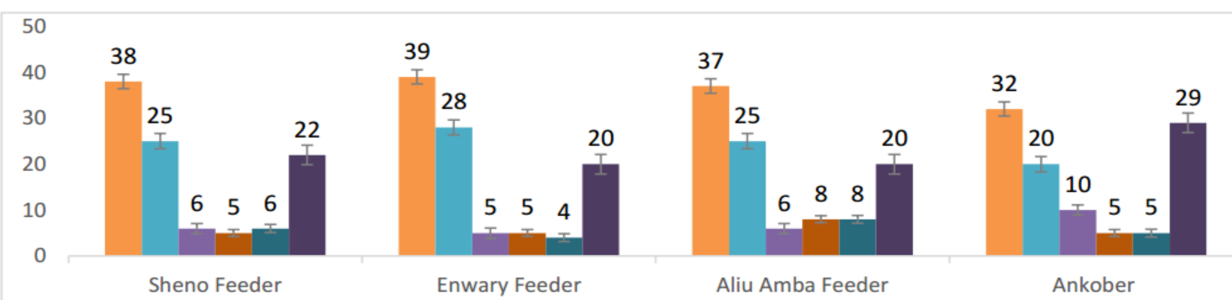


Figure 4.1 Cause of Failure in Debre Berhan Distribution System

4.3 The Switch Allocation Optimization

4.3.1 Fuzzy Expert System to Switch Allocation Problem

Proposed method: The proposed Fuzzy Logic Controller for benefit of switching allocation in Sheno (15kV) feeder consists of three Linguistic Inputs i.e.

1. Number of Siblings (SIB)
2. Connected Load (CLS) to the section and
3. Section line Length (SL)

All the above input variable generate one output variable i.e. benefit of switching allocation. The proposed Fuzzy Logic Controller inference engine is designed using 27 rules. The rules formed in this research are derived from the common sense. Every Linguistic inputs and outputs has a set of membership functions. The MF used for all inputs and output are triangular MF.

The objective function is to minimize the total interruption cost given in (equation4.1), subject to the following two constraints:

The system is still radially operated and

All the load points are still electrically supplied.

$$\text{Minimize}=\text{ECOST}_i=L_i\sum_{j£Ne}^{n} f(rij) * \lambda ej \qquad 4.1$$

$$\text{Cost benefit} = \text{ECOST}_i\text{-FC} \qquad 4.2$$

Where FC= Switching Installation Cost

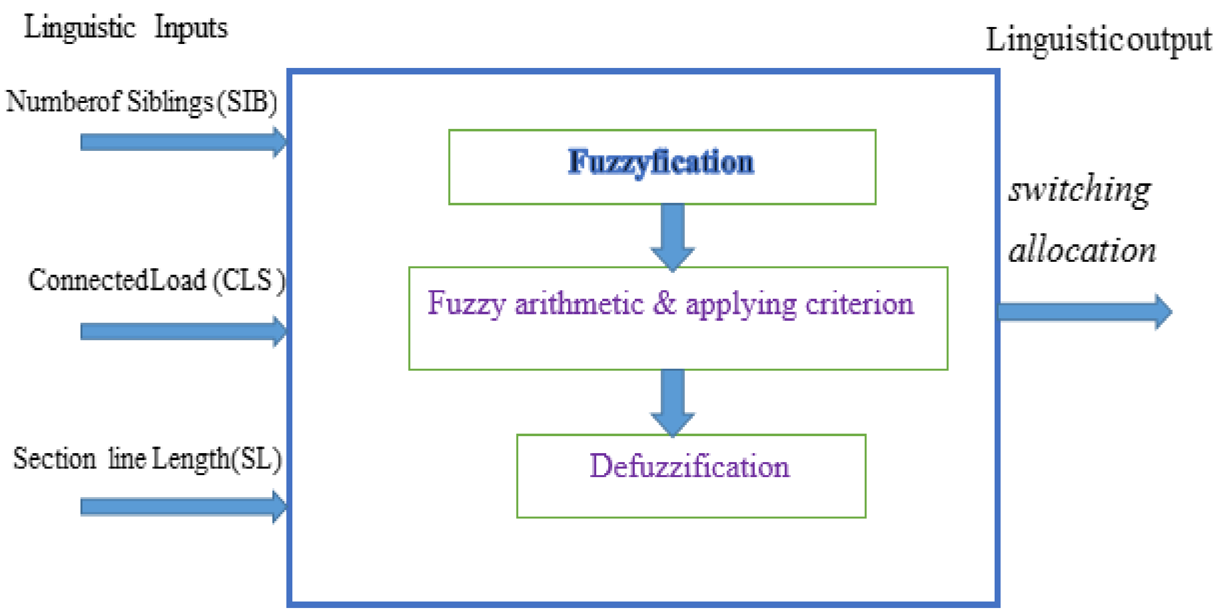


Figure 4.2. Fuzzy Logic Control for Benefit of Switching Allocation

The Fuzzy Expert System (FES) was developed to solve specialist human tasks, inside a specific knowledge domain. The heuristic knowledge about a system can be used to help to build a good project. In this thesis, a FES is used to evaluate the benefit of switch installation in the given of a feeder sections. The FES applied to solve this problem has the follows input variables:

- Number of Siblings (SIB): This is a normalized measure of the branching that is occurring at the beginning of the section being considered.
- Connected Load (CL): This is a normalized measure of how much load is connected to the section being considered.
- Section Length (SL): This is a normalized measure of the length of the section being considered. In the representation of the input variables were used three triangular fuzzy sets: small, medium and large. As shown in figure 4.4.

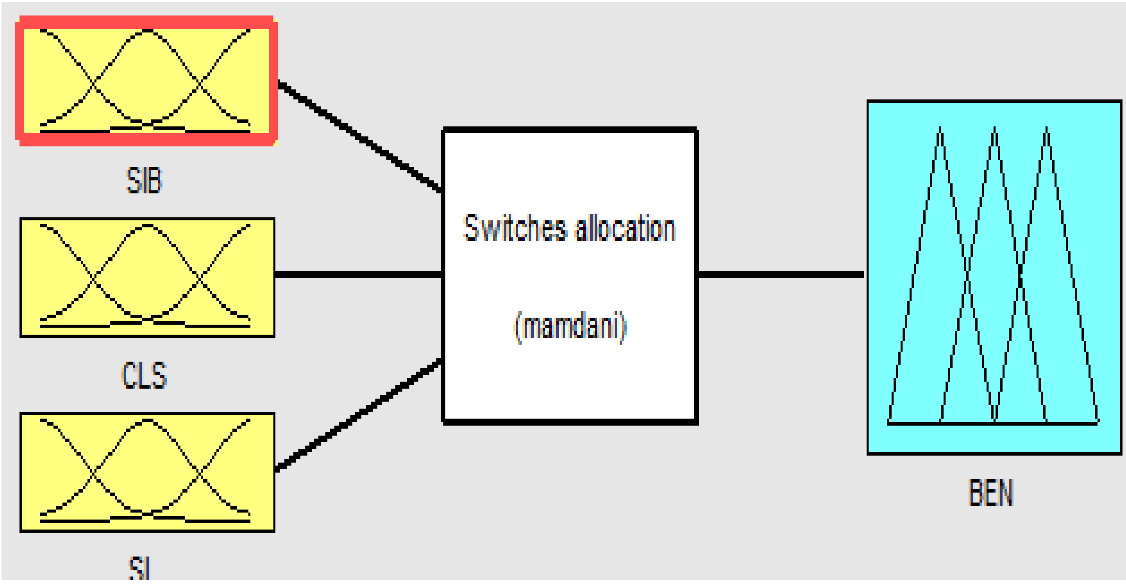


Figure 4.3 FIS for Switching Allocation Problems

The output variable, that represents the benefit of switch installation for a particular section (BEN), is formed by five triangular fuzzy sets: very small, small, medium and large and very large. The figure 4.4 shows the fuzzy sets to the output variable.

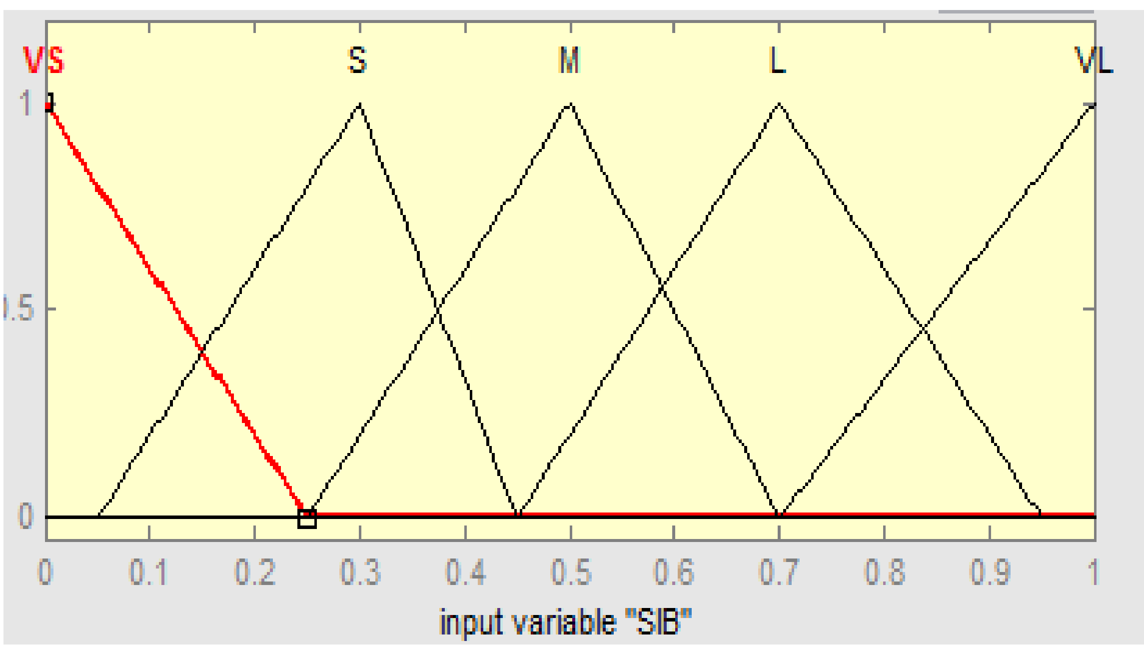


Figure 4.4 Fuzzy Set Used To Output Variables

Table 4.3 The Sets of Rules Used For Allocation of Switches

Rule number	**Linguistic Inputs**			**Linguistic output**
	SIB	**CLS**	**SL**	**Benefit of switch allocation**
1	Very Small	Very Small	Very Small	Very small
2	Very Small	Very Small	Small	Very small
3	Very Small	Very Small	Large	Very small
4	Very Small	Small	Very Small	Very small
5	Very Small	Large	Medium	Medium
6	Very Small	Large	Very Large	Large
7	Small	Very Small	Very Small	Very small
8	Small	Very small	Small	Very small
9	Small	Small	Large	Medium
Rule number	**Linguistic Inputs**			**Linguistic output**
	SIB	**CLS**	**SL**	**Benefit of switch allocation**
10	Small	Small	Very large	Medium
11	Small	Small	Very large	Large
12	Medium	Small	Medium	Small
13	Very Small	Medium	Medium	Medium
14	Medium	Medium	Medium	Medium
15	Medium	Medium	medium	Medium
16	Medium	Large	medium	Medium
17	Large	Large	Large	Large
18	Medium	Large	medium	Large
19	Large	Large	Large	Very Large
20	Very Large	Very small	Large	Medium
Rule number	**Linguistic Inputs**			**Linguistic output**
	SIB	**CLS**	**SL**	**Benefit of switch allocation**
21	Medium	Large	Very Large	Very Large
22	Very small	Large	Large	Medium
23	Small	Medium	Large	Large
24	Medium	Medium	Large	Large
25	Large	Large	Large	Very Large
26	Very Large	Very Large	Very large	Very Large
27	Large	Large	Very Large	Very Large

Table 4.3 Fuzzy Rules to FES, Where VS=Very Small, S=Small, M=Medium, L=Large VL=Very Large and BEN=Benefit of Switch Allocation

1. If (SIB is very small) and (CLS is very small) and (SL is very small) then (BEN is VS)
2. If (SIB is very small) and (CLS is very small) and (SL is small) then (BEN is VS)
3. If (SIB very small) and (CLS is very small) and (SL is large) then (BEN is VS)
4. If (SIB is very small) and (CLS is small) and (SL is very small) then (BEN is VS)
5. If (SIB is very small) and (CLS is medium) and (SL is large) then (SL is medium)
6. If (SIB is very small) and (CLS is medium) and (SL is very large) then (BEN is large)
7. If (SIB is small) and (CLS is very small) and (SL is very small) then (SL is VS)
8. If (SIB is small) and (CLS is very small) and (SL is small) then (BEN is verge small)
9. If (SIB small) and (CLS is small) and (SL is large) then (BEN is medium)
10. If (SIB is small) and (CLS is small) and (SL is medium) then (BEN is small)
11. If (SIB is small) and (CLS is small) and (SL is very large) then (BEN is large)
12. If (SIB is medium) and (CLS is Small) and (SL is medium) then (BEN is small)
13. If (SIB is very small) and (CLS is medium) and (SL is medium) then (BEN is small)
14. If (SIB is small) and (CLS is medium) and (SL is medium) then (BEN is medium)
15. If (SIB is medium) and (CLS is medium) and (SL is medium) then (BEN is medium)
16. If (SIB is medium) and (CLS is large) and (SL is medium) then (BEN is medium)
17. If (SIB is large) and (CLS is large) and (SL is large) then (BEN is large)
18. If (SIB is medium) and (CLS is large) and (SL is medium) then (BEN is medium)
19. If (SIB is large) and (CLS is very large) and (SL is large) then (BEN is very large)
20. If (SIB is very large) and (CLS is very small) and (SL is large) then (BEN is medium)
21. If (SIB is medium) and (CLS is large) and (SL is very large) then (BEN is very large)
22. If (SIB is very small) and (CLS is large) and (SL is large) then (BEN is medium)
23. If (SIB is small) and (CLS is medium) and (SL is large) then (BEN is Large)
24. If (SIB is medium) and (CLS is medium) and (SL is large) then (BEN is large)
25. If (SIB is large) and (CLS is large) and (SL is large) then (BEN is very large)
26. If (SIB is very large) and (CLS is very large) and (CLS is very large) then (BEN is VL)
27. If (SIB is large) and (CLS is very large) and (SL is very large) then (BEN is VL)

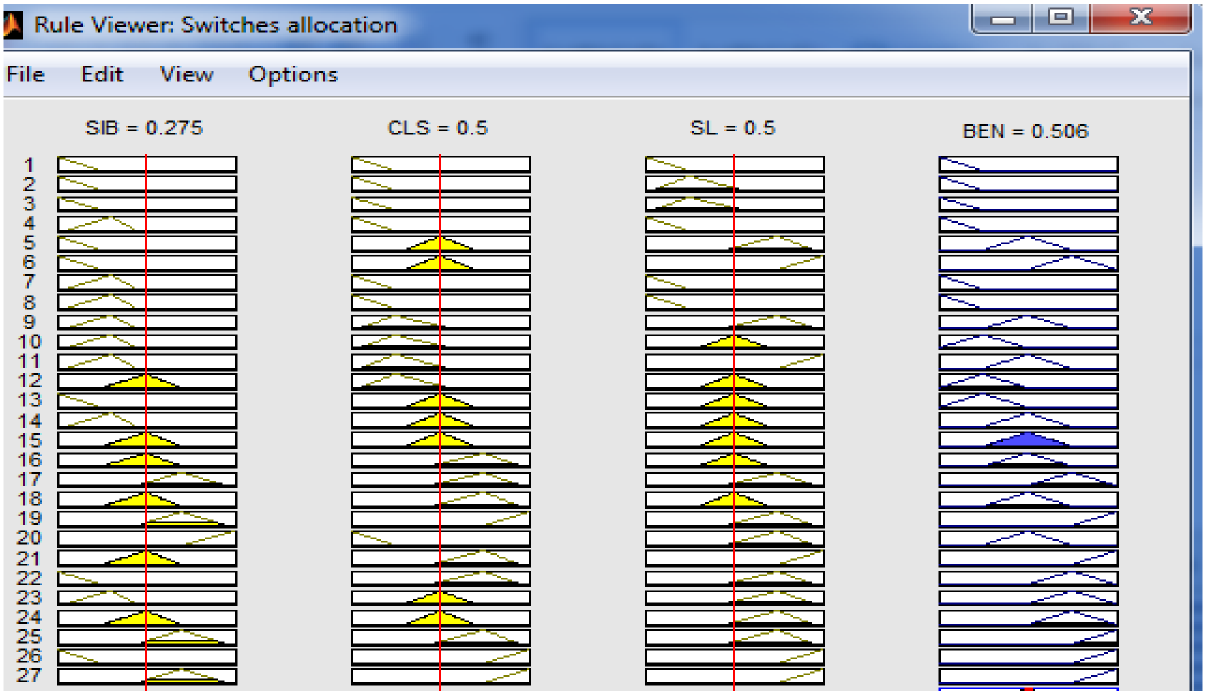


Figure 4.5 Rule Viewer for Allocation of Switches on Line Segment of Sheno Feeder (15KV)

After defining the fuzzy sets to the input and output variables, the fuzzy rules must be generated for the FES. The fuzzy rules for this problem is shown in Table 4.3. Fuzzy inference is used to determine the output value (B_i), which is a number in the interval between 0 and 1. This value is evaluated for every section of the network and represents the worth of installing a switch in this section. In the inference process, every input variable (that is originally non-fuzzy) is converted into a fuzzy number based on the fuzzy sets that represents the input variables.

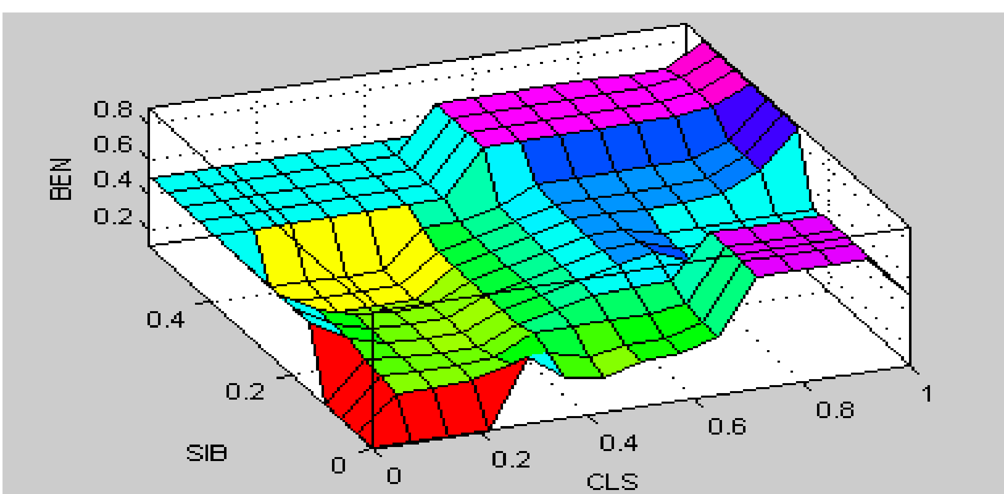


Figure 4.6 Surface Viewer for Switch Allocation Problem

Table 4.4 The Benefit of Switch Installation Indexes.

Section NO	Length	Normalized value	Connected load(KVA)	Normalized Value	BEN index
L1	0.45	0.100	0	0.000	0.09
L2	0.05	0.011	630	0.788	0.5
L3	1.5	0.333	415	0.519	0.408
L4	4.5	1	100	0.125	0.5
L5	2.5	0.556	25	0.031	0.5
L6	4.45	0.989	315	0.394	**0.581**
L7	2.95	0.656	800	1.000	**0.88**
L8	2.1	0.467	400	0.500	0.466
L9	4.4	0.978	800	1.000	**0.887**
L10	0.75	0.167	50	0.063	0.103
L11	0.15	0.033	100	0.125	0.232
L12	2.95	0.656	800	1.00	**0.880**
L13	0.45	0.100	100	0.125	0.0946
L14	0.25	0.056	100	0.125	0.375
L15	1	0.222	100	0.125	0.115
L16	0.45	0.100	315	0.394	0.469
L17	2.8	0.656	800	1.000	**0.582**
L18	0.3	0.067	25	0.031	0.152
L19	0.25	0.056	200	0.250	0.291
L20	4.45	0.989	630	0.788	**0.887**
L21	4.4	0.978	25	0.031	0.325
L22	0.8	0.178	315	0.394	0.324
L23	0.15	0.033	315	0.394	0.325
L24	2	0.444	200	0.250	0.291
L25	0.45	0.100	630	0.788	0.333

The fuzzy rules for this problem is shown in Table 4.4 fuzzy inference is used to determine the output value (B_i), which is a number in the interval between 0 and 1. From the result of fuzzy logic shown in Table 4.4 the line segments which require sectionalizer switches were determined.

CHAPTER FIVE

SMULATION RESULTS AND DISCUSSION

At present, in many electric utilities, acceptable levels of service continuity are determined by comparing the actual interruption frequency and duration indices with arbitrary targets. For example, monthly reports on service continuity statistics produced by many utilities contain the arbitrary targets of system reliability indices for performance comparison purposes. This is valuable for power system operation and planning, and gives the possibility to utilize the accessible recourses in efficient way.

The reliability of a power system is affected highly by population of connected customers (urban and rural areas) and the nature and type of customers this study concerns on reliability of urban feeders. Based on the recorded data the average reliability indices of the existing system are calculated and summarized in Table 5.3.

5.1 Historical Reliability Assessment of the Existing System

5.1.1 Analytical Result

Most of loads in Debre Berhan town are supplied from a single substation, consists of seven feeders. The monthly interruption duration and frequency of the four selected feeders is shown in appendix A (1-4). The power interruptions of each feeder is recorded when the outgoing circuit in the substation breaker is open, when all customers connected to the feeder are interrupted. The interruptions occurred at each load point of transformer connection point and service line of customers is not included. The number of power outages and durations of each feeder for the year of 2006 is summarized as shown in table and figure below.

Based on the recorded data the average reliability indices of the existing system are calculated and summarized in Table 5.1. It shows average reliability indices, like SAIFI , SAIDI ,CAIDI , ASAI and ASUI CAIDI values are also calculated for four selected feeders for the year 2014/ (2006 E.C)

The reliability of a power system is affected highly by population of connected customers (urban and rural areas) and the nature and type of customers this study concerns on reliability of urban feeders. The selected feeders also feed the rural area around the town but, compared to the customers live in the town they are few in number. Based on the recorded data the average reliability indices of the existing system are calculated and summarized in table 5.1 the common reliability indices of each selected feeder are calculated.

Table 5.1 Reliability Indices of Four Feeders in 2006

Feeder name	SAIFI (interruption /yr.)	SAIDI (Hr. /yr.)	CAIDI (Hr. /Int.)	ASAI
Sheno (15kV)	146	322.933	2.18	0.9999779
Aliu-Ameba	112	169.667	1.514884	0.999827
Enwary	118	157.417	1.334042	0.999848
Ankober	139	308.8667	2.2202	0.986643

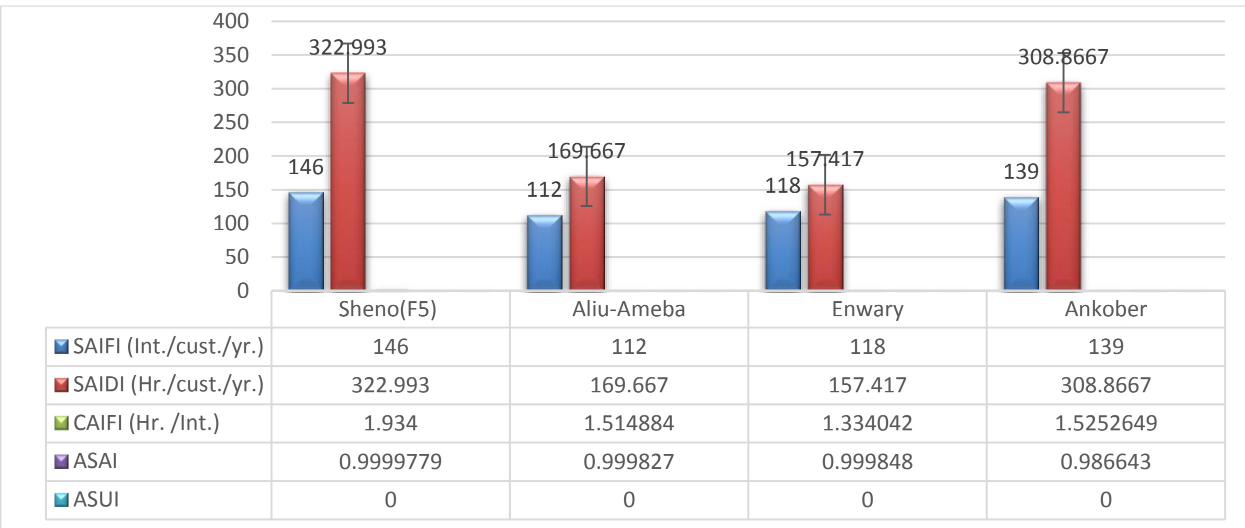


Figure 5.1 Reliability Indices of Four Feeders in 2006 E.C

The System Average Interruption Frequency Index (SAIFI) and System average Interruption Duration Index (SAIDI) are the main indicators for the performance of electric power distribution networks. Different utilities typically keep track of customer reliability by using reliability indices. These are average customer reliability values for a specific area. The result shown in table 5.1 is calculated based on feeder's service area. From the result the value of SAIFI and SAIDI are extremely higher than the value recorded indifferent literatures for different countries. In the other way the calculated value of CAIDI is minimum than the other utility values. CAIDI is an indication of repair time of the faults caused for interruption. Means the number of failure outages is very high but the maintenance time is less .The average service availability index (ASAI) of the system is 0.996574 in the year 2006 for selected four feeders. This just gives the overall picture of the whole system in the area and not the localized problem (feeder wise). The indices help us to establish the chronological changes in the system performance and therefore help us to identify the weak areas and the need of reinforcement. This data will also help us to make predictive analysis for the future system.

Table 5.2 Average Reliability Indices of All Feeders for the Year 2015/ (2007 E.C)

Feeder name	SAIFI (Int./cust./yr.)	SAIDI (Hr./cust./yr.)		CAIDI (Hr. /Int.)	ASAI
Sheno(15kV)	149	328.856		2.3863	0.9958
Aliu-Ameba	118	170.69		1.446525	0.999834
Enwary	121	156.7		1.295	0.999852
Ankober	136	312.8667		2.30069	0.999832

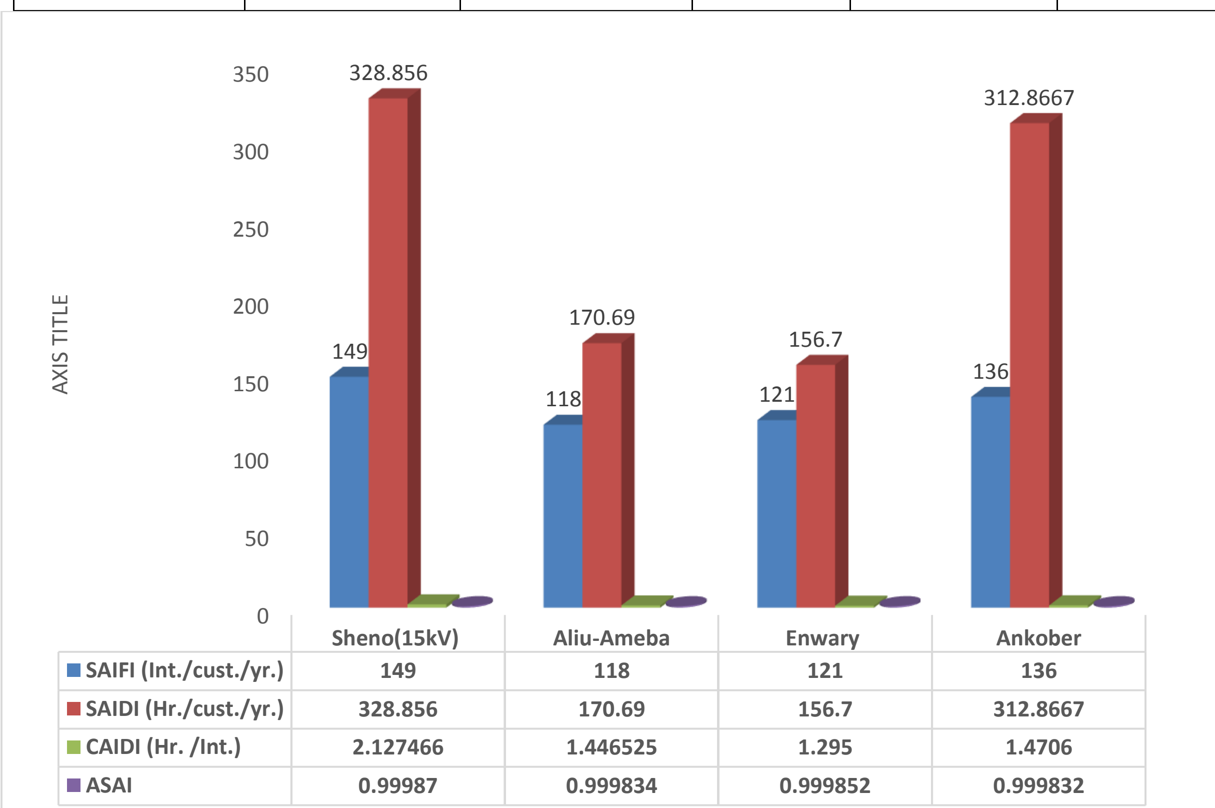


Figure 5.2 Four Feeders Reliability Indices in 2007 E.C

Table 5.3 Analytical Calculated Average Values for Four Selected Feeders for the Year 2006&2007

s.no	Feeders	Indices	Years	
			2006	2007
1	Sheno (F**5**)	SAIFI (interruption. /yr.)	146	149
		SAIDI (hr. /yr.)	322.933	328.856
		CAIDI (hr./interruption)	2.211	2.207
		ASAI (%)	0.9999779	0.9958
2	Aliu-Ameba	SAIFI (interruption. /yr.)	112	118
		SAIDI (hr. /yr.)	169.667	170.69
		CAIDI (hr./interruption)	1.514884	1.4465
		ASAI (%)	0.999827	0.999834
3	Enwary	SAIFI (interruption. /yr.)	118	121
		SAIDI (hr. /yr.)	157.417	156.7
		CAIDI (hr./interruption)	1.334042	1.295
		ASAI (%)	0.999848	0.999852
4	Ankober	SAIFI (interruption./yr)	139	136
		SAIDI (hr. /yr.)	308.8667	312.8867
		CAIDI (hr./interruption)	1.5252649	2.3006
		ASAI (%)	0.986643	0.999832

Table 5.4 European Reliability Performance [38]

COUNTRY	SAIDI	SAIFI
Austria	72 hr./yr.	0.9 interruption /yr.
Denmark	24 hr./yr.	0.5 interruption /yr.
France	62 hr./yr.	1.0 interruption /yr.
France	23 hr./yr.	0.5 interruption /yr.
Italy	58 hr./yr.	2.2 interruption /yr.
Netherlands	33 hr./yr.	0.3 interruption /yr.
Spain	104 hr./yr.	2.2 interruption /yr.
UK	90 hr./yr.	0.8 interruption /yr.

5.1.2 Software Simulation Result

5.1.2.1 ETAP Software Modelling and Simulation Result for Sheno (15kv) Feeder

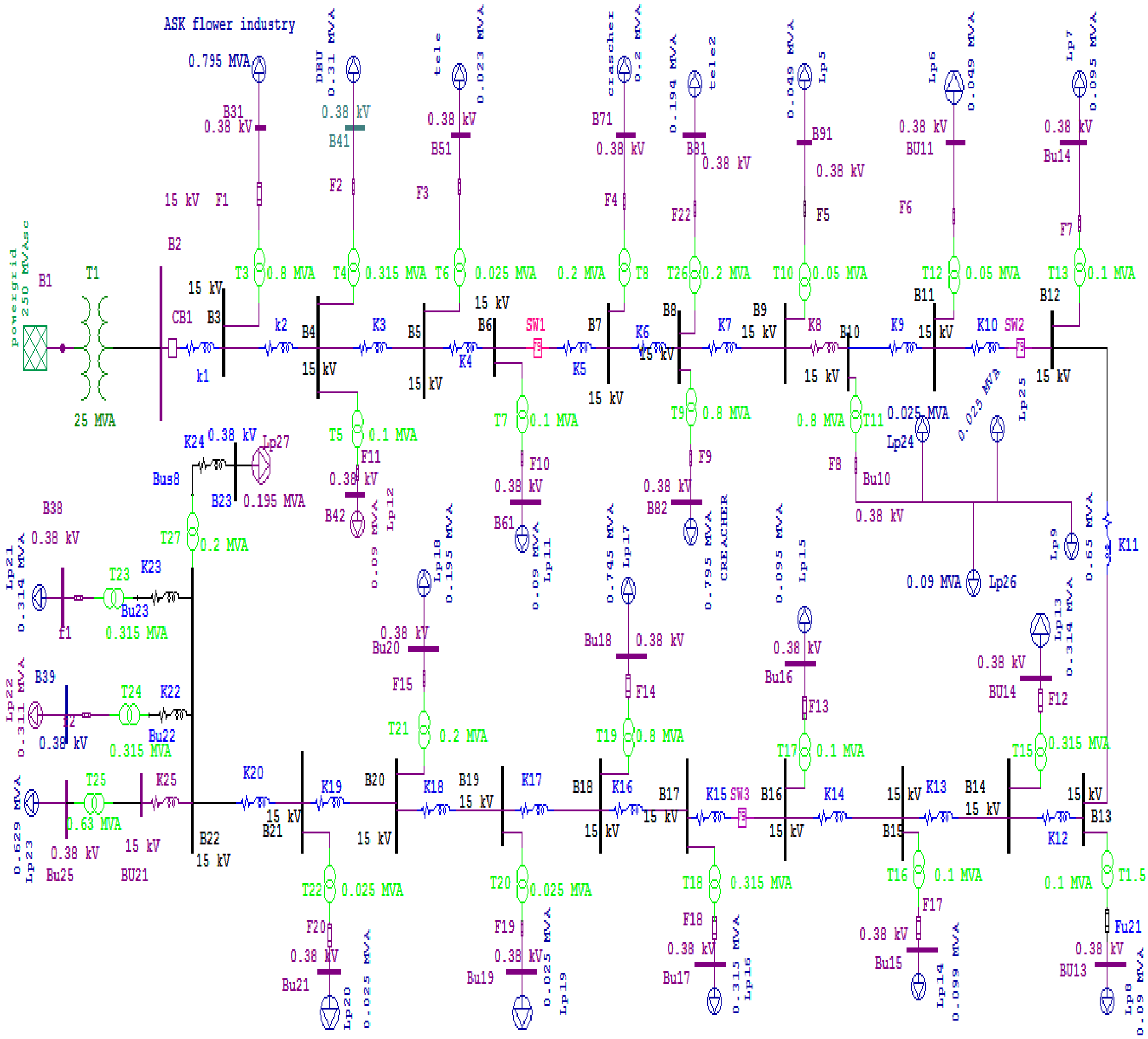


Figure 5.3 Existing Sheno (15kv) Feeder Configuration

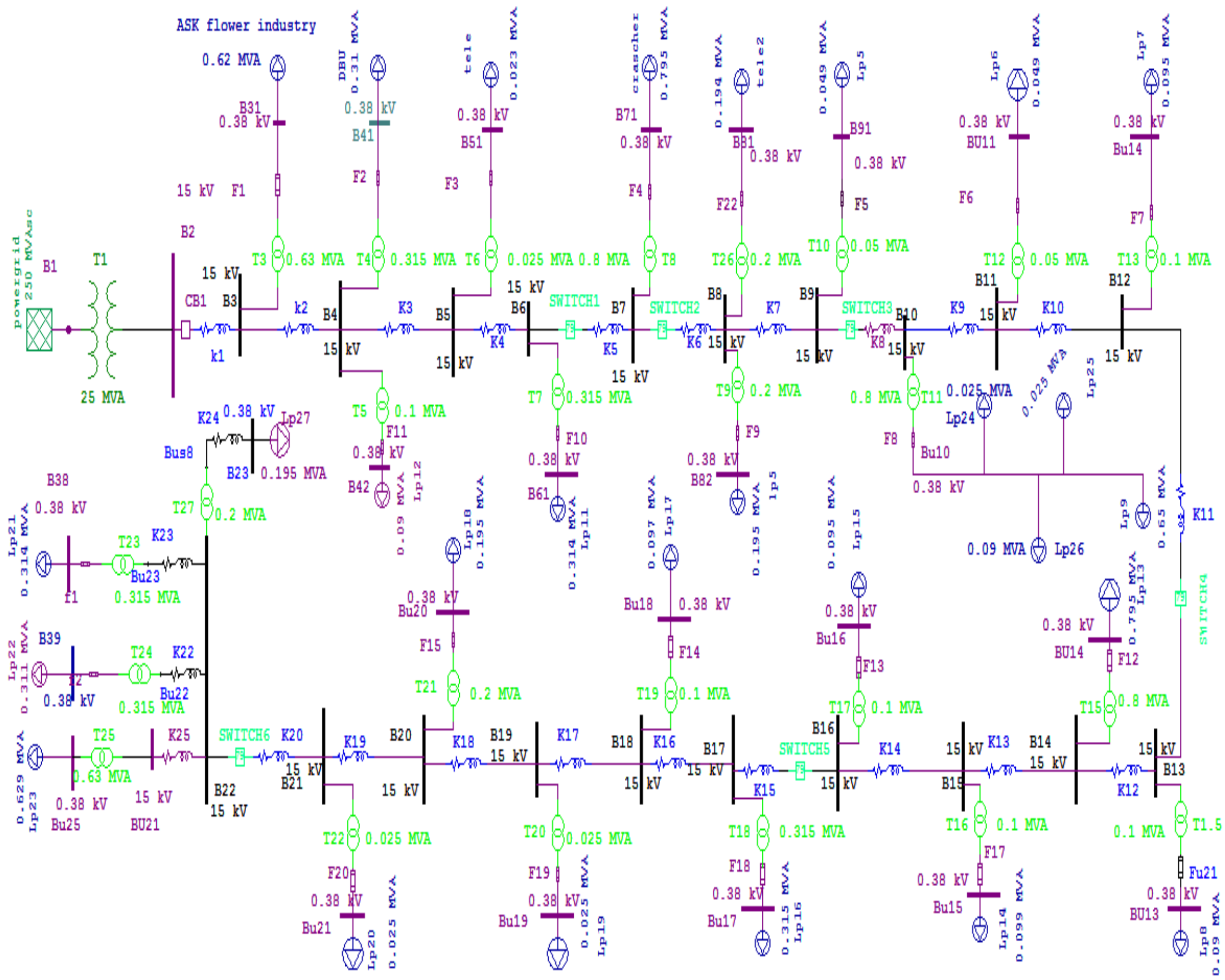


Figure 5.4 Optimal Sheno (15KV) Feeder Configuration

As shown in Figure 5.4 the optimal number of sectionalizers switches have been optimized to six switches that means three additional switches are important to the given test feeder.

Sector Interruption Cost

Sector Name	Interruption Duration Minutes	Cost $/kW
Agricultural	**1.00**	**0.06**
	20.00	**0.34**
	60.00	**0.65**
	240.00	**2.06**
	480.00	**4.12**
Commercial	**1.00**	**0.38**
	20.00	**2.97**
	60.00	**8.55**
	240.00	**31.32**
	480.00	**83.01**
Govt. & Inst.	**1.00**	**0.04**
	20.00	**0.37**
	60.00	**1.49**
	240.00	**6.56**
	480.00	**26.04**
Industrial	**1.00**	**1.63**
	20.00	**3.87**
	60.00	**9.09**
	240.00	**25.16**
	480.00	**55.81**
Office & bldg.	**1.00**	**4.8**
	20.00	**9.88**
	60.00	**21.06**
	240.00	**68.83**
	480.00	**119.20**

Residential	**1.00**	**0.00**
	20.00	**0.09**
	60.00	**0.48**
	240.00	**4.91**
	480.00	**15.69**

Reliability worth can be quantified in forms of customer interruption costs. Customer interruption costs provide an indirect measure of monetary losses associated with a power failure and are served as input data for cost implications and worth assessments of system planning and operational decisions. The calculation of customer interruption costs requires distribution reliability indices of the load points and customer interruption cost data and simulating using ETAP software.

Customer interruption cost data, compiled from customer surveys, are used to develop a sector customer damage function (SCDF). The SCDF is a function of customer class and outage duration, which can be used to estimate monetary loss incurred by customers due to power failure. The above result shows the SCDF for seven sectors of customers for five discrete outage durations. The outage cost generated using ETAP software.

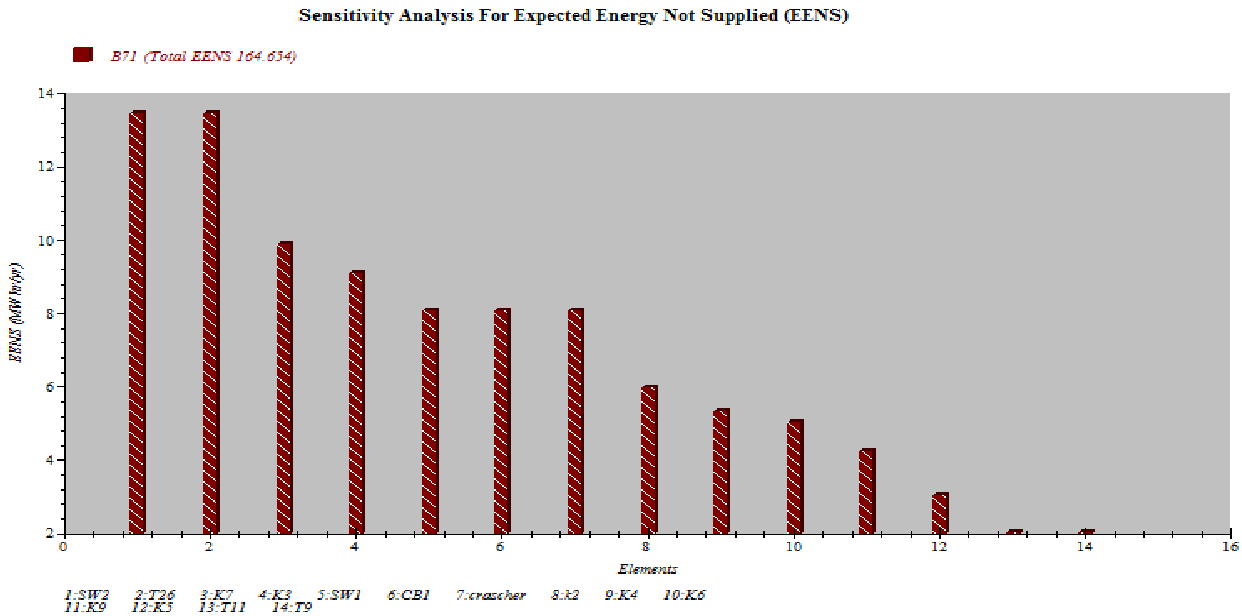


Figure 5.5 EENS Simulated Result for Sheno (15kv) Feeder

This Figure 5.5 indicated that the ranking order of components which are contributing to the EENS of the distribution system.as indicated above SW2, T26, K7 SW1 are the most ranking of component that are frequently interrupted.

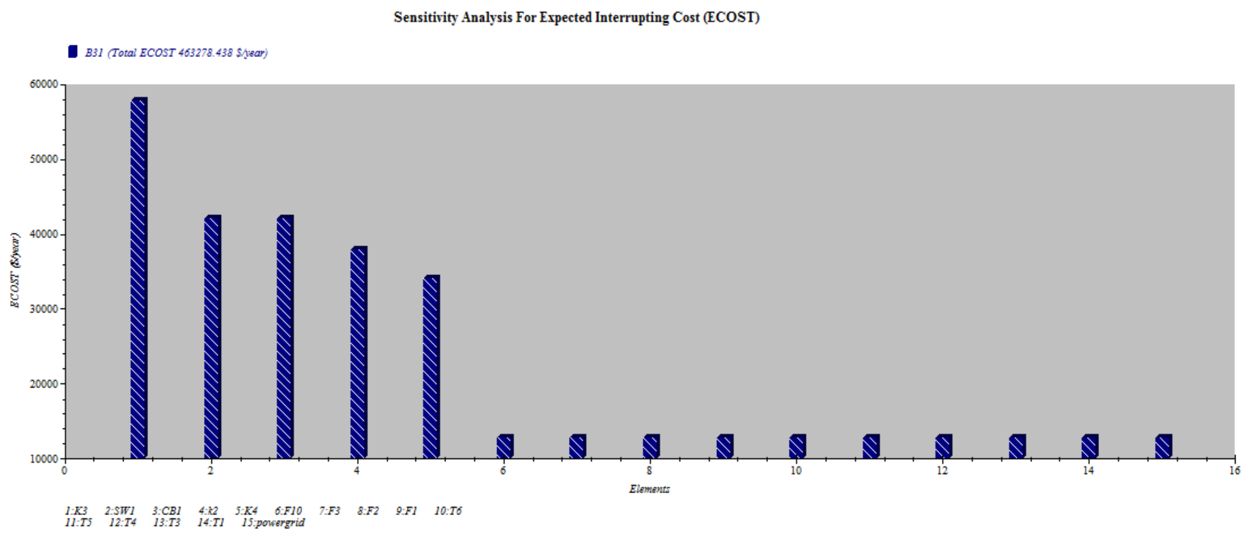


Figure 5.6 ECOST Simulated Result for Sheno (15kv) Feeder

This Figure5.6 showed that the ranking order of components which are contributing to the ECOST of the distribution system as indicated above K3, SW3, K2 etc. are the most ranking of component that are frequently interrupted.

5.2 Simulation Result for both Initial and Optimal Configuration

Table 5.5 Comparison Different Cases of System Reliability Indices

Reliability indices	Case- I Without switch of Sheno feeder	Case-II Initial configuration of Sheno feeder(base case)	Case-III Optimal configuration Of Sheno feeder	Improvement (%)
SAIFI	210.8677 f / cust.yr	145.2115f / cust.yr.	132.7942 f / cust.yr	8.55
SAIDI	459.2445 hr. / cust.yr	322.0554 hr. / cust.yr	266.80474hr./cust.yr	17.16
CAIDI	2.178 hr. / Interruption	2.218hr. / Interruption	2.009hr. / cust. Int.	9.4
ASAI	0.9476 per unit	0.9632per unit	0.9695 pu	0.63
ASUI	0.05243 per unit	0.03676 per unit	0.03046 pu	30
EENS	2589.602 MWh./yr.	1788.014 MWh./yr.	1496.764 MWh./yr.	15.73
ECOST	19,376.84$/yr.	64,806.06 $/yr.	57,346.57 $ / yr.	11.5
AENS	92.4858 MWh. /yr.	63.8577 MWh./yr.	53.4559 MWh./yr.	16.3

The number of sectionalizer switches for Sheno feeder before optimization (in the initial configuration) were three switches. After optimization (in the optimal configuration) the number of sectionalizers switches are changed from four switches to six switches. To reach to Ethiopian reliability standard the whole system should be integrated with distributed generation.

Switch installation cost (FC) =3*2719=8157 Birr and

ECOST reduction 64,806.06$ / yr. -57346.57$ / yr. =7459.46$ / yr. (156,649.29birr).Therefore, benefit cost= ECOST-FC=156,649.29 Birr-8157 Birr=148,492.29 Birr

CHAPTER SIX

Conclusions, Recommendations and Future Work

6.1. Conclusion

The research presented in this thesis mainly focused on decreasing the system reliability indicators in Debre Berhan distribution system. The reliability of distribution system can be improved by using different improvement techniques. To select the appropriate and relevant improvement method for a particular system the first step was making reliability assessment; through the assessment process using different approaches and reliability indices that shows the performance of the system was evaluated. For identifying the improvement techniques which are relevant to the system predictive reliability alternatives are suggested. Moreover, the major causes for power interruptions are identified and the cost incurred by customers and utility are evaluated.

In this thesis both the historical and predictive reliability analysis of Debre Berhan town distribution system were carried out. The most common reliability indices, which include SAIDI, SAIFI, EENS, and ASAI, are used to measure the performance of the distribution system. The results obtained for the historical analysis of the study area for the years 2006 and 2007E.C showed that the system reliability indices of the study area indicate poor performance, related to other European countries as [38].

The reliability improvement techniques suggested as predictive reliability can minimize the power outage frequency and duration. This improvement has a great impact socially and economically both for the utility and the consumers. This research seeks to model the impact of optimal switch to distribution system reliability .The reliability assessment in this work is carried out with analytical approach and ETAP software simulation. The analytical approach presents the reliability measures like SAIFI and SAIDI during the course of an average year. Hence, the mean values of SAIFI and SAIDI for distribution systems with optimal placement are obtained.

The reduction in reliability indicators in distribution system is achievable through the use of optimal placement of distribution system switches. Optimal switches arrangement in the network provides a reduction of unsupplied energy to customers, and costs associated with expected energy not supplied. Selection of their number may depend on cost change of unreliability power supply or funds amounts allocated for investments by the distribution operator network

To solve the problem of optimal number of switch allocation, FES optimization method is selected. To illustrate the performance of the proposed algorithm, an actual Sheno (15kV) feeder overhead line of Debre Berhan distribution system was selected as the test system.

From the result obtained by analysis the data using different methods in the previous chapter it can be concluded as follows:

- To assess and evaluate reliability of the system analytical and simulation methods are implemented for the Sheno (15kV) feeder and the value obtained by analytical methods for SAIFI, SAIDI and CAIDI are 146.5 Failure /cust.yr, 325.8945 hr. /yr., and 2.209 respectively, similarly by simulation method the value obtained are 145.2115 Failure /cust.yr., 322.0554 hr. /yr. and 2.218 which are almost the same; it approves that the reliability parameters (indices) analysis are done in proper way.
- The reliability improvement techniques suggested as predictive reliability can minimize the power outage frequency and duration this improvement has a great impact socially and economically for both the utility and the consumers.

6.2 Recommendation

The quality and reliable power supply has a dominant factor in the development of the country socially and economically since, every technology used by customers is dependable on electrical power. To supply reliable and efficient power for the customers the power system networks could be planned, redesigned and reconnected by evaluating their past performance. To achieve this goal reliability assessment is necessary for system planning based on reliability cost and worth assessment approach. It provides an opportunity to justify future system expansion and service improvement.

The following recommendations are given depending on practical observations and analysis on Debre Berhan town distribution system:

- All Debre Berhan town distribution system feeders are connected in radial, purely radial feeders with no alternate supply capability are usually used for small loads or rural systems. Thus the connection scheme should be changed into open loop connection schemes.
- As practically observed almost all protection device have no good covering and since the space between phases are narrow it can be shorted easily even by windy rain drops and a single leaves of trees which can be the main cause for power interruptions so they should have proper coverings.
- The fuses are placed with their designed rated value to protect the system even direct connection is also done which is dangerous for the system though such visible mistakes must be avoided in the system.
- The improvement techniques such as reconnection of the scheme and replacing old components are economical alternatives for further improvement using additional recloser, sectionalizers-switches and load break switches in cost effective locations are the main alternatives.

6.3. Future Work

Future work may lie in a deeper analysis of impact of reliability with different size of DGs at different locations. Further, when different types of DGs are considered, the results may be different. For instance, the photovoltaic have an output patterns affected by sun light, and the distributed wind generators have an output patterns greatly affected by the wind. Hence, the time of possible component failure will have an impact on whether reconfiguration with DG is possible or not.

Another important extension of this work is to identify possible approaches to identify the optimal location of DGs considering reliability measures. Since the government propose project which can generate 100 MW wind power plant it will enable the system more reliable. If you consider system reliability indices, perhaps with a weighted average of multiple indices like SAIFI and SAIDI, as the objective function to minimize, this will be non-linear and noncontiguous optimization problem with respect to DG size and location. If some heuristic rules such as sensitivity of SAIFI and SAIDI with DG sizes and location can be identified from research works similar to this one, it can significantly simplify the optimization model. Therefore, it will be easier to combine the reliability measures as part of a Multiobjective optimization considering reliability, power losses, environmental impact, and so on.

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Appendix-A

Table A: Detail Interruption Report for Selected Four Feeders {2006 E.C (2014)}.

Table A-1. Sheno 15 KV (F5)

S. NO	Date	Type of fault (relay acted)		Time								
				Interruption			Reconnection			Difference (Δt)		
				Hrs.	min	sec	Hrs.	min	sec	Hrs.	min	sec
1	03/01/06	EF	shedding	10	30	0	12	30	0	2	0	0
2	08/01/06	EF	maintenance	06	30	0	07	30	0	1	0	0
3	10/01/06	EF	,,	08	00	0	09	30	0	1	30	0
4	13/01/06	EF	Bird	11	30	0	13	30	0	2	0	0
5	15/01/06	EF	Load shad.	16	30	0	17	30	0	1	0	0
6	20/01/06	EF	Line broken	11	20	0	12	00	0	0	3	0
7	21/01/06	EF	maintenance	14	30	0	14	50	0	0	20	0
8	23/01/06	EF	Fallen tree	11	30	0	13	40	0	2	10	0
9	25/01/06	EF	maintenance	01	30	0	03	30	0	2	0	0
10	28/01/06	EF	shedding	08	30	0	09	30	0	1	0	0
11	30/01/06	EF	maintenance	08	30	0	10	35	0	2	05	0
12	01/02/06	O.C	Sheno line	12	30	0	14	0	0	1	30	0
13	02/02/06	EF	Broken line	12	00	0	13	40	0	1	40	0
14	04/02/06	EF	Birds	09	10	0	12	30	0	3	20	0
15	05/02/06	SC	Shedding	08	30	0	09	30	0	1	0	0
16	06/02/06	EF	maintenance	08	30	0	10	35	0	2	05	0
17	06/02/06	EF	Un known	08	30	0	10	35	0	2	05	0
18	10/02/06	Loose	shedding	18	10	0	20	40	0	2	30	0
19	11/02/06	EF	maintenance	08	30	0	10	35	0	2	05	0
20	12/02/06	OI	,,	09	10	0	12	30	0	3	20	0
21	13/02/06	OC	maintenance	16	20	0	17	50	0	1	30	0
23	16/02/06	OI	maintenance	06	05	0	07	10	0	1	05	0
24	19/02/06	SC	Broken line	17	10	0	17	20	0	0	10	0
25	22/02/06	,,	maintenance	19	0	0	20	0	0	1	0	0
26	25/02/06	SC	Car	18	10	0	19	20	0	1	10	0
27	26/02/06	EF	Birds	06	30	0	06	35	0	0	05	0
28	27/02/06	EF	maintenance	07	40	0	07	45	0	0	05	0
29	29/02/06	SC	maintenance	07	40	0	07	45	0	0	05	0
30	02/03/06	O.C	Unknown	10	05	0	10	10	0	0	05	0
31	05/03/06	,,	Un known	14	30	0	14	40	0	0	10	0
32	07/03/06	EF	Fallen tree	12	45	0	13	0	0	0	15	0
33	09/03/06	,,	shedding	07	30	0	12	05	0	4	25	0
34	11/03/06	O.C	Shedding	08	15	0	08	20	0	0	05	0

35	12/03/06	EF/SC	Un known	10	25	0	10	28	0	0	03	0
36	14/03/06	„	Un known	14	30	0	14	40	0	0	10	0
37	15/03/06	EF	Fallen tree	12	45	0	13	0	0	0	15	0
38	16/03/06	„	shedding	07	30	0	10	40	0	3	10	0
39	17/03/06	OI	maintenance	08	0	0	12	0	0	4	0	0
40	18/03/06	OI	Unknown	12	10	0	12	20	0	0	10	0
41	21/03/06	EF	Un known	08	45	0	09	20	0	0	35	0
42	22/03/06	EF	maintenance	18	0	0	21	10	0	3	10	0
43	23/03/06	OI	’’	11	10	0	11	20	0	0	10	0
44	24/03/06	„	Shedding	06	45	0	07	45	0	1	0	0
45	25/03/06	„	Un known	14	30	0	14	33	0	0	03	0
46	26/03/06	EF	Fallen tree	06	40	0	06	55	0	0	15	0
47	29/03/06	„	Un known	14	30	0	14	40	0	0	10	0
48	30/03/06	EF	Fallen tree	07	10	0	08	25	0	0	15	0
49	05/03/06	„	Shedding	08	30	0	11	05	0	2	25	0
50	09/04/06	„	maintenance	03	10	0	04	20	0	1	10	0
51	12/04/06	EF	Shading	18	0	0	20	0	0	2	0	0
52	13/04/06	„	maintenance	10	05	0	13	05	0	3	0	0
53	17/04/06	EF/SC	Birds	18	0	0	20	0	0	2	0	0
54	21/04/06	„	Broken line	07	10	0	11	10	0	4	0	0
55	23/04/06	EF/SC	maintenance	20	0	0	21	30	0	1	30	0
56	24/04/06	„	Un known	15	05	0	17	05	0	2	0	0
57	28/04/06	„	maintenance	07	05	0	10	10	0	3	05	0
58	02/05/06	„	Shedding	08	40	0	12	15	0	3	35	0
59	07/05/06	„	maintenance	07	33	0	09	36	0	2	03	0
60	08/05/06	OI	maintenance	10	30	0	11	20	0	0	50	0
61	09/05/06	„	unknown	14	0	0	14	03	0	0	03	0
62	15/05/06	EF/SC	Un known	12	50	0	13	0	0	0	10	0
63	19/05/06	„	maintenance	09	10	0	12	0	0	2	55	0
64	20/05/06	OC	Un known	11	05	0	12	0	0	0	55	0
65	23/05/06	OI	Technical fault	18	00	0	10	40	0	0	40	0
66	27/06/06	EF	Un known	08	20	0	09	30	0	1	10	0
67	04/06/06	EF	Shedding	07	25	0	12	0	0	4	35	0
68	05/06/06	EF	„	15	05	0	15	55	0	0	50	0
69	05/06/06	EF	„	18	45	0	22	0	0	3	15	0
70	11/06/06	OI	maintenance	12	0	0	18	0	0	6	0	0
71	12/06/06	OC	maintenance	13	45	0	14	10	0	0	35	0
72	16/06/06	EF/SC	„	12	20	0	12	55	0	0	35	0
73	16/06/06	O.C	Un known	16	45	0	18	10	0	1	25	0
74	17/06/06	„	Shedding	09	15	0	12	10	0	2	55	0
75	19/06/06	„	„	15	0	0	16	0	0	1	0	0
76	21/06/06	EF	„	17	15	0	17	40	0	0	25	0
77	22/06/06	O.C	Un known	09	45	0	10	55	0	1	05	0
78	23/06/06	„	Feeder O.L	10	25	0	11	10	0	0	55	0

79	25/06/06	,,	L. O.L	5	0	0	16	0	0	1	0	0
80	28/06/06	EF/SC	,,	17	15	0	17	40	0	0	25	0
81	02/07/06	,,	maintenance	07	0	0	12	0	0	5	0	0
82	05/07/06	EF	maintenance	08	10	0	12	10	0	2	0	0
83	12/07/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
84	16/07/06	OC	Birds	18	0	0	21	25	0	3	25	0
85	17/07/06	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
86	20/07/06	OI	Feeder O.L	18	0	0	22	10	0	4	10	0
87	21/07/06	EF	maintenance	11	20	0	13	30	0	2	10	0
88	23/07/06	EF	Broken line	08	30	0	10	30	0	2	40	0
89	24/07/06	OI	Feeder O.L	20	00	0	21	45	0	1	15	0
90	26/07/06	OC	Birds	18	0	0	21	25	0	3	25	0
91	27/07/06	OI	maintenance	09	0	0	10	15	0	1	15	0
92	28/07/06	O.C	Shedding	16	10	0	17	20	0	1	10	0
93	29/07/06	OI	Animals	11	0	0	13	10	0	2	10	0
94	08/08/06	EF/SC	Un known	09	20	0	11	30	0	2	10	0
95	11/08/06	EF	maintenance	06	30	0	09	30	0	3	0	0
96	15/08/06	OC	Un known	11	30	0	11	33	0	0	03	0
97	18/08/06	EF	Shedding	06	30	0	09	30	0	3	0	0
98	20/08/06	OC	Un known	09	30	0	10	30	0	1	0	0
99	22/08/06	EF	Feeder O.L	18	30	0	18	34	0	0	04	0
100	28/08/06	OC	maintenance	09	35	0	10	50	0	1	15	0
101	29/08/06	EF	Feeder O.L	06	30	0	09	30	0	3	0	0
102	01/09/06	EF	maintenance	08	0	0	08	24	0	0	24	0
103	02/09/06	,,	maintenance	08	10	0	09	40	0	1	30	0
104	05/09/06	EF	’’	17	10	0	17	40	0	0	30	0
105	09/09/06	OI	Shedding	07	0	0	12	0	0	5	0	0
106	10/09/06	OC	maintenance	08	10	0	12	10	0	2	0	0
107	13/09/06	EF	Shedding	07	20	0	12	0	0	4	40	0
108	23/09/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
109	25/09/06	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
110	26/09/06	O.C	Un known	16	10	0	17	20	0	1	10	0
111	26/09/06	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
112	14/09/06	OI	’’	14	25	0	14	29	0	0	04	0
113	03/10/06	,,	,,	10	30	0	11	30	0	1	0	0
114	05/10/06	,,	Un known	12	00	0	13	30	0	1	30	0
115	08/10/06	,,	Animals	13	35	0	13	55	0	0	20	0
116	09/10/06	,,	Feeder O.L	18	30	0	19	45	0	1	15	0
117	11/10/06	,,	LOL	16	30	0	17	30	0	1	0	0
118	14/10/06	EF	maintenance	18	0	0	19	22	0	1	22	0
119	11/10/06	OI	Feeder O.L	10	30	0	11	55	0	1	25	0
120	16/10/06	EF	Wind	09	20	0	09	42	0	1	22	0
121	18/10/06	OC	Windy rain	08	10	0	09	50	0	1	40	0
122	27/10/06	,,	maintenance	08	10	0	09	40	0	1	30	0
123	21/10/06	EF	’’	17	10	0	17	40	0	0	30	0

124	02/10/06	OI	Shedding	07	0	0	12	0	0	5	0	0
125	11/10/06	EF	Shedding	07	20	0	12	0	0	4	40	0
126	24/10/06	OI	Feeder O.L	18	00	0	21	25	0	3	25	0
127	25/10/06	OI	Feeder O.L	07	00	0	12	0	0	5	0	0
128	26/10/06	O.C	Un known	15	10	0	16	20	0	1	10	0
129	02/11/06	OC	Un known	10	30	0	10	34	0	0	04	0
130	03/11/06	,,	,,	06	30	0	09	30	0	3	0	0
131	04/11/06	EF	maintenance	11	0	0	12	0	0	1	0	0
132	05/11/06	,,	,,	12	10	0	13	40	0	1	30	0
133	05/11/06	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
134	07/11/06	OI	’’	14	25	0	15	30	0	1	05	0
135	09/11/06	OI	’’	14	25	0	15	30	0	1	05	0
136	10/11/06	OC	maintenance	09	30	0	10	30	0	1	0	0
137	11/11/06	,,	Feeder O.L	06	30	0	09	30	0	3	0	0
138	12/11/06	EF	maintenance	08	0	0	08	22	0	0	22	0
139	13/11/06	,,	Un known	09	10	0	09	30	0	0	20	0
140	14/11/06	OI	Feeder O.L	15	30	0	16	30	0	1	0	0
141	15/11/06	EF	Wind	16	0	0	16	20	0	0	20	0
142	16/11/06	OC	Windy rain	10	10	0	10	50	0	0	40	0
143	17/11/06	,,	maintenance	09	10	0	09	40	0	0	30	0
144	18/11/06	EF	’’	17	10	0	17	13	0	0	02	0
145	20/11/06	OC	maintenance	08	10	0	12	10	0	2	0	0
146	21/11/06	EF	Shedding	12	30	0	18	0	0	5	30	0
147	22/11/06	EF	Shedding	07	20	0	12	0	0	4	40	0
148	23/11/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
149	24/11/06	OI	LOL	18	0	0	21	25	0	3	25	0
150	25/11/06	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
151	02/12/06	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
152	03/12/06	OI	’’	14	25	0	15	30	0	1	05	0
153	04/12/06	OC	maintenance	09	30	0	10	30	0	1	0	0
154	05/12/06	EF	Un known	13	0	0	14	20	0	1	20	0
155	07/12/06	,,	maintenance	10	10	0	10	50	0	0	40	0
156	08/12/06	OI	Feeder O.L	20	30	0	22	30	0	2	0	0
157	09/12/06	EF	Wind	10	30	0	11	30	0	1	0	0
158	11/12/06	OC	maintenance	16	30	0	17	30	0	1	0	0
159	13/12/06	EF	maintenance	10	0	0	10	20	0	0	20	0
160	14/12/06	,,	maintenance	03	40	0	04	50	0	1	10	0
161	15/12/06	OI	Feeder O.L	05	30	0	06	30	0	1	0	0
162	17/12/06	OC	Windy rain	11	10	0	13	50	0	1	40	0
163	18/12/06	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
164	19/12/06	O.C	Un known	15	10	0	16	20	0	1	10	0
165	21/12/06	OI	’’	14	25	0	15	30	0	1	05	0
167	24/12/06	EF	maintenance	08	0	0	09	30	0	0	30	0
168	25/10/06	,,	maintenance	10	10	0	10	50	0	0	40	0
169	27/11/06	EF	Wind	04	0	0	04	03	0	0	03	0

Table A-2. AliuAmba 33 KV Feeder

S. NO	date	Type of fault (relay acted)	Cause of fault	Time								
				Interruption			Reconnection			Difference (Δt)		
				Hrs	min	sec	Hrs	min	sec	Hrs	min	sec
1	05/02/06	EF	Shedding	09	10	0	11	50	0	1	40	0
2	06/02/06	EF	,,	15	40	0	16	25	0	0	45	0
3	02/03/06	OI	Maintenance	08	05	0	08	10	0	0	05	0
4	04/03/06	EF	Shedding	09	50	0	11	40	0	0	50	0
5	06/03/06	OI	Maintenance	07	35	0	07	45	0	0	10	0
6	10/03/06	E.F	To open sect	16	05	0	16	15	0	0	10	0
7	14/04/06	OI	Maintenance	19	0	0	19	45	0	0	45	0
8	15/05/06	O.C	Shedding	11	50	0	15	0	0	0	10	0
9	18/05/06	OI	Maintenance	09	25	0	10	45	0	1	10	0
10	19/05/06	OI	Maintenance	14	0	0	15	10	0	1	10	0
11	19/05/06	EF	,,	15	15	0	17	30	0	1	15	0
12	20/05/06	EF	,,	10	05	0	10	40	0	0	35	0
13	23/05/06	EF	Un known	11	10	0	11	35	0	0	25	0
14	25/05/06	O.C	Shedding	18	50	0	21	25	0	3	35	0
15	26/05/06	OI	”	15	40	0	16	0	0	0	40	0
16	02/06/06	EF	”	09	30	0	12	30	0	3	0	0
17	04/06/06	EF	”	08	10	0	09	50	0	1	40	0
18	10/06/06	EF	”	11	50	0	15	50	0	4	0	0
19	13/06/06	EF	Open line s.w	09	30	0	14	50	0	4	20	0
20	15/06/06	OI	Maintenance	08	15	0	10	15	0	2	0	0
21	18/06/06	EF	Un known	09	10	0	11	50	0	1	40	0
22	23/06/06	EF	Maintenance	15	40	0	16	25	0	0	45	0
23	24/06/06	OI	,,	08	05	0	08	10	0	0	05	0
24	25/06/06	EF	,,	09	50	0	11	40	0	0	50	0
25	27/06/06	OI	,,	07	35	0	07	45	0	0	10	0
26	29/06/06	E.F	,,	16	05	0	16	15	0	0	10	0
27	02/07/06	OI	Maintenance	19	0	0	19	45	0	0	45	0
28	05/07/06	O.C	Shedding	11	50	0	15	0	0	0	10	0
29	08/07/06	OI	Maintenance	09	25	0	10	45	0	1	10	0
30	11/07/06	OI	Maintenance	14	0	0	15	10	0	1	10	0
31	12/07/06	EF	Birds	15	15	0	17	30	0	1	15	0
32	13/07/06	EF	Un known	10	05	0	10	40	0	0	35	0
33	17/07/06	EF	Maintenance	11	10	0	11	35	0	0	25	0

34	18/07/06	O.C	Shedding	18	50	0	21	25	0	3	35	0
35	20/07/06	OI	”	15	40	0	16	0	0	0	40	0
36	22/07/06	EF	”	09	30	0	12	30	0	3	0	0
37	23/07/06	EF	”	08	10	0	09	50	0	1	40	0
38	29/07/06	EF	”	11	50	0	15	50	0	4	0	0
39	30/07/06	EF	Broken line	09	30	0	14	50	0	4	20	0
40	08/08/06	OI	Maintenance	08	15	0	10	15	0	2	0	0
41	11/08/06	EF	„	09	10	0	11	50	0	1	40	0
42	12/08/06	EF	„	15	40	0	16	25	0	0	45	0
43	13/08/06	OI	„	08	05	0	08	10	0	0	05	0
44	15/08/06	EF	„	09	50	0	11	40	0	0	50	0
45	16/08/06	OI	„	07	35	0	07	45	0	0	10	0
46	17/08/06	E.F	„	16	05	0	16	15	0	0	10	0
47	18/08/06	OI	Maintenance	19	0	0	19	45	0	0	45	0
48	19/08/06	O.C	Un known	11	50	0	11	55	0	0	05	0
49	22/08/06	OI	Maintenance	09	25	0	10	45	0	1	10	0
50	25/08/06	OI	Maintenance	14	0	0	15	10	0	1	10	0
51	29/08/06	EF	Broken pha	15	15	0	17	30	0	1	15	0
52	04/09/06	EF	„	10	05	0	10	40	0	0	35	0
53	08/09/06	EF	Un known	11	10	0	11	35	0	0	25	0
54	10/09/06	O.C	Shedding	18	50	0	21	25	0	3	35	0
55	15/09/06	OI	”	15	40	0	16	0	0	0	40	0
56	19/09/06	EF	”	09	30	0	12	30	0	3	0	0
57	27/09/06	EF	”	08	10	0	09	50	0	1	40	0
58	29/09/06	EF	”	11	50	0	15	50	0	4	0	0
59	30/09/06	EF	Broken line	09	30	0	14	50	0	4	20	0
60	08/10/06	OI	Maintenance	08	15	0	10	15	0	2	0	0
61	10/10/06	OI	Un known	07	35	0	07	45	0	0	10	0
62	14/10/06	E.F	Shedding	16	05	0	16	15	0	0	10	0
63	25/10/06	OI	Maintenance	19	0	0	19	45	0	0	45	0
64	28/10/06	O.C	L .shading	11	50	0	15	0	0	0	10	0
65	05/11/06	OI	Maintenance	09	25	0	10	45	0	1	10	0
66	06/11/06	OI	Maintenance	14	0	0	15	10	0	1	10	0
67	09/11/06	EF	Windy rain	15	15	0	17	30	0	1	15	0
68	13/11/06	EF	Wind	10	05	0	10	40	0	0	35	0
69	20/11/06	EF	Shedding	11	10	0	11	35	0	0	25	0
70	24/11/06	O.C	Shedding	18	50	0	21	25	0	3	35	0
71	04/12/06	OI	”	15	40	0	16	0	0	0	40	0
72	05/12/06	EF	”	09	30	0	12	30	0	3	0	0
73	12/12/06	EF	Broken line	08	10	0	09	50	0	1	40	0
74	14/12/06	EF	Open section	11	50	0	15	50	0	4	0	0
75	18/12/06	EF	Shedding	09	30	0	14	50	0	4	20	0
76	26/12/06	OI	Maintenance	08	15	0	10	15	0	2	0	0
77	27/12/06	EF	”	11	50	0	15	50	0	4	0	0
78	28/12/06	EF	”	09	30	0	14	50	0	4	20	0

79	**30/12/06**	**OI**	**Maintenance**	**08**	**15**	**0**	**10**	**15**	**0**	**2**	**0**	**0**
80	**17/08/06**	**E.F**	**,,**	**16**	**05**	**0**	**16**	**15**	**0**	**0**	**10**	**0**
81	**18/08/06**	**OI**	**Maintenance**	**19**	**0**	**0**	**19**	**45**	**0**	**0**	**45**	**0**
82	**19/08/06**	**O.C**	**Un known**	**11**	**50**	**0**	**15**	**0**	**0**	**0**	**10**	**0**
83	**22/08/06**	**OI**	**Maintenance**	**09**	**25**	**0**	**10**	**45**	**0**	**1**	**10**	**0**
84	**25/08/06**	**OI**	**Maintenance**	**14**	**0**	**0**	**15**	**10**	**0**	**1**	**10**	**0**
85	**29/08/06**	**EF**	**Broken pha**	**15**	**15**	**0**	**17**	**30**	**0**	**1**	**15**	**0**
86	**04/09/06**	**EF**	**,,**	**10**	**05**	**0**	**10**	**40**	**0**	**0**	**35**	**0**
87	**08/09/06**	**EF**	**Un known**	**11**	**10**	**0**	**11**	**35**	**0**	**0**	**25**	**0**
88	**10/09/06**	**O.C**	**Shading**	**18**	**50**	**0**	**21**	**25**	**0**	**3**	**35**	**0**
89	**15/09/06**	**OI**	**”**	**15**	**40**	**0**	**16**	**0**	**0**	**0**	**40**	**0**
90	**19/09/06**	**EF**	**”**	**09**	**30**	**0**	**12**	**30**	**0**	**3**	**0**	**0**
91	**27/09/06**	**EF**	**”**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
92	**29/09/06**	**EF**	**”**	**11**	**50**	**0**	**15**	**50**	**0**	**4**	**0**	**0**
93	**30/09/06**	**EF**	**Broken line**	**09**	**30**	**0**	**14**	**50**	**0**	**4**	**20**	**0**
94	**08/10/06**	**OI**	**Maintenance**	**08**	**15**	**0**	**10**	**15**	**0**	**2**	**0**	**0**
95	**10/10/06**	**OI**	**Un known**	**07**	**35**	**0**	**07**	**45**	**0**	**0**	**10**	**0**
96	**14/10/06**	**E.F**	**L. shading**	**16**	**05**	**0**	**16**	**15**	**0**	**0**	**10**	**0**
97	**25/10/06**	**OI**	**Maintenance**	**19**	**0**	**0**	**19**	**45**	**0**	**0**	**45**	**0**
98	**28/10/06**	**O.C**	**L .shading**	**11**	**50**	**0**	**15**	**0**	**0**	**0**	**10**	**0**
99	**05/11/06**	**OI**	**Maintenance**	**09**	**25**	**0**	**10**	**45**	**0**	**1**	**10**	**0**
100	**06/11/06**	**OI**	**Maintenance**	**14**	**0**	**0**	**15**	**10**	**0**	**1**	**10**	**0**
101	**09/11/06**	**EF**	**Windy rain**	**15**	**15**	**0**	**17**	**30**	**0**	**1**	**15**	**0**
102	**13/11/06**	**EF**	**Wind**	**10**	**05**	**0**	**10**	**40**	**0**	**0**	**35**	**0**
103	**20/11/06**	**EF**	**shedding**	**11**	**10**	**0**	**11**	**35**	**0**	**0**	**25**	**0**
104	**24/11/06**	**O.C**	**Un known**	**18**	**50**	**0**	**21**	**25**	**0**	**3**	**35**	**0**
105	**04/12/06**	**OI**	**”**	**15**	**40**	**0**	**16**	**0**	**0**	**0**	**40**	**0**
106	**05/12/06**	**EF**	**”**	**09**	**30**	**0**	**12**	**30**	**0**	**3**	**0**	**0**
107	**12/12/06**	**EF**	**Broken line**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
108	**20/11/06**	**EF**	**shedding**	**11**	**10**	**0**	**11**	**35**	**0**	**0**	**25**	**0**
109	**24/11/06**	**O.C**	**Un known**	**18**	**50**	**0**	**21**	**25**	**0**	**3**	**35**	**0**
110	**04/12/06**	**OI**	**”**	**15**	**40**	**0**	**16**	**0**	**0**	**0**	**40**	**0**
111	**05/12/06**	**EF**	**”**	**09**	**30**	**0**	**12**	**30**	**0**	**3**	**0**	**0**
112	**12/12/06**	**EF**	**Broken line**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**

Table A-3. Enwary 33 KV Feeder

S. NO	Date	Type of fault (relay acted)	Cause of fault	Time								
				Interruption			Reconnection			Difference (Δt)		
				Hrs	min	sec	Hrs	min	sec	Hrs	min	sec
1	05/02/06	EF	Shedding	08	10	0	10	20	0	2	30	0
2	15/02/06	O.C	Maintenance	09	10	0	09	40	0	0	30	0
3	01/03/06	EF	Un known	08	45	0	09	10	0	0	25	0
4	01/03/06	EF	Shedding	09	10	0	09	15	0	0	05	0
5	05/03/06	EF	Wind	17	05	0	17	10	0	0	05	0
6	06/03/06	OI	Maintenance	08	30	0	08	40	0	0	10	0
7	06/03/06	EF	Un known	09	40	0	09	55	0	0	15	0
8	07/03/06	EF	Maintenance	09	30	0	09	50	0	0	20	0
9	16/03/06	OI	Maintenance	10	40	0	10	50	0	0	10	0
10	19/03/06	O.C	’’	15	15	0	17	25	0	2	05	0
11	24/04/06	OI	Maintenance	11	10	0	11	35	0	0	25	0
12	26/04/06	EF	Shedding	10	15	0	10	20	0	0	05	0
13	28/04/06	EF	Maintenance	12	10	0	12	20	0	0	10	0
14	01/05/06	EF	L .shading	21	0	0	21	20	0	0	20	0
15	05/05/06	O.C	Maintenance	12	40	0	14	40	0	2	0	0
16	07/05/06	OI	Maintenance	15	20	0	16	025	0	1	05	0
17	09/05/06	EF	Un known	10	20	0	10	50	0	0	30	0
18	01/06/06	EF	Broken line	15	35	0	14	55	0	0	20	0
19	03/06/06	OI	Maintenance	10	30	0	10	55	0	0	25	0
20	05/06/06	EF	Unknown	16	10	0	16	40	0	0	30	0
21	07/06/06	EF	Shedding	06	50	0	07	30	0	0	40	0
22	07/06/06	EF	Open section	02	20	0	04	40	0	2	0	0
23	08/06/06	EF	Un known	11	35	0	11	50	0	0	15	0
24	09/06/06	EF	Maintenance	12	20	0	14	35	0	2	15	0
25	12/06/06	OI	Maintenance	13	50	0	14	40	0	0	50	0
26	14/06/06	EF	Shedding	10	05	0	10	45	0	0	40	0
27	18/06/06	EF	L. shading	11	35	0	12	20	0	0	45	0
28	20/06/06	EF	Maintenance	14	20	0	14	50	0	0	30	0
29	24/06/06	EF	shedding	11	30	0	12	30	0	1	0	0
30	28/06/06	OI	Shedding	18	50	0	19	20	0	0	30	0
31	30/06/06	OP	Maintenance	11	40	0	12	0	0	0	20	0
32	05/07/06	EF	Heavy rain	00	40	0	07	10	0	6	30	0
33	15/07/06	O.C	Wind	09	10	0	09	55	0	0	45	0
34	16/07/06	EF	Windy rain	16	05	0	18	20	0	2	15	0
35	18/07/06	EF	Un known	06	0	0	18	0	0	6	0	0

36	**19/07/06**	**EF**	**Unknown**	**16**	**10**	**0**	**16**	**40**	**0**	**0**	**30**	**0**
37	**19/07/06**	**EF**	**Wind**	**06**	**50**	**0**	**07**	**30**	**0**	**0**	**40**	**0**
37	**20/07/06**	**EF**	**Maintenance**	**02**	**20**	**0**	**04**	**40**	**0**	**2**	**0**	**0**
39	**21/07/06**	**EF**	**Un known**	**11**	**35**	**0**	**11**	**50**	**0**	**0**	**15**	**0**
40	**22/07/06**	**EF**	**Maintenance**	**12**	**20**	**0**	**14**	**35**	**0**	**2**	**15**	**0**
41	**23/07/06**	**OI**	**Maintenance**	**13**	**50**	**0**	**14**	**40**	**0**	**0**	**50**	**0**
42	**25/07/06**	**EF**	**shedding**	**10**	**05**	**0**	**10**	**45**	**0**	**0**	**40**	**0**
43	**26/07/06**	**EF**	**Maintenance**	**11**	**35**	**0**	**12**	**20**	**0**	**0**	**45**	**0**
44	**27/07/06**	**EF**	**Maintenance**	**14**	**20**	**0**	**14**	**50**	**0**	**0**	**30**	**0**
45	**28/07/06**	**EF**	**shedding**	**11**	**30**	**0**	**12**	**30**	**0**	**1**	**0**	**0**
46	**29/07/06**	**OI**	**Un known**	**18**	**50**	**0**	**19**	**20**	**0**	**0**	**30**	**0**
47	**30/07/06**	**OP**	**Maintenance**	**11**	**40**	**0**	**12**	**0**	**0**	**0**	**20**	**0**
48	**04/08/06**	**EF**	**Heavy rain**	**00**	**40**	**0**	**07**	**10**	**0**	**6**	**30**	**0**
49	**06/08/06**	**O.C**	**Wind**	**09**	**10**	**0**	**09**	**55**	**0**	**0**	**45**	**0**
50	**08/08/06**	**EF**	**Windy rain**	**16**	**05**	**0**	**18**	**20**	**0**	**2**	**15**	**0**
51	**09/08/06**	**EF**	**Un known**	**06**	**0**	**0**	**18**	**0**	**0**	**6**	**0**	**0**
52	**10/08/06**	**EF**	**Unknown**	**16**	**10**	**0**	**16**	**40**	**0**	**0**	**30**	**0**
53	**12/08/06**	**OI**	**L.O.L**	**06**	**50**	**0**	**07**	**30**	**0**	**0**	**40**	**0**
54	**14/08/06**	**EF**	**Maintenance**	**02**	**20**	**0**	**04**	**40**	**0**	**2**	**0**	**0**
55	**19/08/06**	**EF**	**Un known**	**11**	**35**	**0**	**11**	**50**	**0**	**0**	**15**	**0**
56	**20/08/06**	**EF**	**Maintenance**	**12**	**20**	**0**	**14**	**35**	**0**	**2**	**15**	**0**
57	**24/08/06**	**OI**	**Broken line**	**13**	**50**	**0**	**14**	**40**	**0**	**0**	**50**	**0**
58	**25/08/06**	**EF**	**shedding**	**10**	**05**	**0**	**10**	**45**	**0**	**0**	**40**	**0**
59	**26/08/06**	**EF**	**Un known**	**11**	**35**	**0**	**12**	**20**	**0**	**0**	**45**	**0**
60	**28/08/06**	**EF**	**Maintenance**	**14**	**20**	**0**	**14**	**50**	**0**	**0**	**30**	**0**
61	**29/08/06**	**EF**	**shedding**	**11**	**30**	**0**	**12**	**30**	**0**	**1**	**0**	**0**
62	**30/08/06**	**OI**	**shedding**	**18**	**50**	**0**	**19**	**20**	**0**	**0**	**30**	**0**
63	**11/09/06**	**OP**	**Maintenance**	**11**	**40**	**0**	**12**	**0**	**0**	**0**	**20**	**0**
64	**12/09/06**	**EF**	**Heavy rain**	**00**	**40**	**0**	**07**	**10**	**0**	**6**	**30**	**0**
65	**16/09/06**	**O.C**	**Wind**	**10**	**10**	**0**	**10**	**55**	**0**	**0**	**45**	**0**
66	**17/09/06**	**EF**	**Windy rain**	**16**	**05**	**0**	**18**	**25**	**0**	**2**	**20**	**0**
67	**19/09/06**	**EF**	**Un known**	**07**	**0**	**0**	**18**	**0**	**0**	**5**	**0**	**0**
68	**21/09/06**	**EF**	**Birds**	**06**	**50**	**0**	**07**	**35**	**0**	**0**	**45**	**0**
69	**22/09/06**	**EF**	**Maintenance**	**03**	**20**	**0**	**05**	**20**	**0**	**2**	**0**	**0**
70	**22/09/06**	**EF**	**Un known**	**11**	**30**	**0**	**11**	**50**	**0**	**0**	**20**	**0**
71	**23/09/06**	**EF**	**Maintenance**	**13**	**20**	**0**	**15**	**35**	**0**	**2**	**15**	**0**
72	**24/09/06**	**OI**	**’’**	**13**	**50**	**0**	**14**	**30**	**0**	**0**	**40**	**0**
73	**25/09/06**	**EF**	**shedding**	**10**	**05**	**0**	**10**	**45**	**0**	**0**	**40**	**0**
74	**26/09/06**	**EF**	**Un known**	**11**	**35**	**0**	**12**	**20**	**0**	**0**	**45**	**0**
75	**27/09/06**	**EF**	**Open section**	**14**	**20**	**0**	**14**	**50**	**0**	**0**	**30**	**0**
76	**28/09/06**	**EF**	**L. shading**	**11**	**30**	**0**	**12**	**30**	**0**	**1**	**0**	**0**
77	**02/10/06**	**OI**	**L. shading**	**18**	**50**	**0**	**19**	**20**	**0**	**0**	**30**	**0**
78	**03/10/06**	**OP**	**maintenance**	**11**	**40**	**0**	**12**	**0**	**0**	**0**	**20**	**0**
79	**04/10/06**	**OI**	**Shedding**	**18**	**50**	**0**	**19**	**20**	**0**	**0**	**30**	**0**
80	**08/10/06**	**EF**	**Unknown**	**16**	**10**	**0**	**16**	**40**	**0**	**0**	**30**	**0**

81	12/10/06	EF	Wind	06	50	0	07	30	0	0	40	0
82	14/10/06	EF	Maintenance	02	20	0	04	40	0	2	0	0
83	19/10/06	EF	Un known	11	35	0	11	50	0	0	15	0
84	20/10/06	EF	Maintenance	12	20	0	14	35	0	2	15	0
85	24/10/06	OI	Maintenance	13	50	0	14	40	0	0	50	0
86	25/10/06	EF	Un known	10	05	0	10	45	0	0	40	0
87	26/10/06	EF	shedding	11	35	0	12	20	0	0	45	0
88	27/10/06	EF	Maintenance	14	20	0	14	50	0	0	30	0
89	08/11/06	EF	Maintenance	11	30	0	12	30	0	1	0	0
90	09/11/06	OI	Shedding	18	50	0	19	20	0	0	30	0
91	10/11/06	OP	Maintenance	11	40	0	12	0	0	0	20	0
92	11/11/06	EF	Heavy rain	00	40	0	07	10	0	6	30	0
93	16/11/06	O.C	Wind	09	10	0	09	55	0	0	45	0
94	17/11/06	EF	Windy rain	16	05	0	18	20	0	2	15	0
95	18/11/06	EF	Un known	06	0	0	18	0	0	6	0	0
96	19/11/06	EF	Unknown	16	10	0	16	40	0	0	30	0
97	22/11/06	OI	L.O.L	06	50	0	07	30	0	0	40	0
98	24/11/06	EF	Maintenance	02	20	0	04	40	0	2	0	0
99	25/11/06	EF	Un known	11	35	0	11	50	0	0	15	0
100	26/11/06	EF	Maintenance	12	20	0	14	35	0	2	15	0
101	27/11/06	OI	Broken line	13	50	0	14	40	0	0	50	0
102	28/11/06	EF	shedding	10	05	0	10	45	0	0	40	0
103	02/12/06	EF	Maintenance	11	35	0	12	20	0	0	45	0
104	04/12/06	EF	Maintenance	14	20	0	14	50	0	0	30	0
105	07/12/06	EF	shedding	11	30	0	12	30	0	1	0	0
106	08/12/06	OI	Un known	18	50	0	18	50	0	0	05	0
107	09/12/06	OP	Maintenance	11	40	0	12	0	0	0	20	0
108	10/12/06	EF	Heavy rain	00	40	0	07	10	0	6	30	0
109	11/12/06	O.C	Wind	09	10	0	09	55	0	0	45	0
110	15/12/06	EF	Windy rain	16	05	0	18	20	0	2	15	0
111	19/12/06	EF	Un known	06	0	0	18	0	0	6	0	0
112	21/12/06	SC	Birds	06	50	0	07	30	0	0	40	0
113	20/12/06	EF	Maintenance	02	20	0	04	40	0	2	0	0
114	21/12/06	EF	Un known	11	35	0	11	50	0	0	15	0
115	24/12/06	EF	Maintenance	12	20	0	14	35	0	2	15	0
116	25/12/06	OI	,,	13	50	0	14	40	0	0	50	0
117	26/12/06	EF	,,	11	05	0	11	45	0	0	40	0
118	29/12/06	EF	Shedding	11	35	0	12	20	0	0	45	0

Table A.4. Ankober 15 KV

S. NO	date	Type of fault (relay acted)	Cause of fault	Time								
				Interruption			Reconnection			Difference (Δt)		
				Hrs	min	sec	Hrs	min	sec	Hrs	min	sec
1	09/01/06	EF	maintenance	12	30	0	13	30	0	1	0	0
2	10/01/06	EF	maintenance	06	30	0	07	0	0	0	30	0
3	11/01/06	„	shedding	16	10	0	18	40	0	2	30	0
4	15/01/06	OI	maintenance	09	10	0	12	30	0	3	20	0
5	17/01/06	SC	maintenance	17	20	0	18	50	0	1	30	0
6	17/01/06	OI	maintenance	05	30	0	06	10	0	0	40	0
7	19/01/06	SC	Un known	12	05	0	12	10	0	0	05	0
8	20/01/06	„	maintenance	09	0	0	10	0	0	1	0	0
9	21/01/06	OI	Shedding	12	20	0	13	45	0	1	15	0
10	22/01/06	EF	Birds	09	30	0	09	35	0	0	05	0
11	24/01/06	EF	maintenance	07	00	0	07	45	0	0	45	0
12	25/01/06	OI	L. shading	08	55	0	12	0	0	3	05	0
13	26/01/06	O.C	Fallen tree	10	05	0	10	10	0	0	05	0
14	27/01/06	O.C	shedding	08	15	0	08	20	0	0	05	0
15	29/01/06	„	maintenance	12	45	0	13	45	0	1	0	0
16	30/01/06	„	Un known	14	30	0	14	40	0	0	10	0
17	07/02/06	EF	Fallen tree	12	45	0	13	0	0	0	15	0
18	08/02/06	„	Shading	07	30	0	12	05	0	4	25	0
19	11/02/06	OI	maintenance	08	0	0	12	0	0	4	0	0
20	12/02/06	OI	Bird	12	10	0	12	20	0	0	10	0
21	13/02/06	OC	Shedding	19	15	0	20	25	0	1	10	0
22	16/02/06	OC	Broken phas	14	40	0	14	50	0	0	10	0
23	17/02/06	EF	Un known	08	45	0	09	20	0	0	35	0
24	18/02/06	EF	maintenance	18	0	0	21	10	0	3	10	0
25	19/02/06	OI	’’	11	10	0	11	20	0	0	10	0
26	20/02/06	OC	shedding	07	50	0	12	40	0	4	50	0
27	26/02/06	OI	Un known	09	0	0	12	0	0	3	0	0
28	27/02/06	EF	shedding	18	0	0	21	0	0	3	0	0
29	28/02/06	„	SC	07	05	0	12	05	0	5	0	0
30	02/03/06	„	Shedding	08	40	0	12	15	0	3	35	0
31	05/03/06	„	maintenance	07	35	0	13	25	0	5	50	0
32	07/03/06	OI	OC	10	30	0	11	20	0	0	50	0
33	08/03/06	„	Un known	12	0	0	18	0	0	6	0	0
34	09/03/06	„	maintenance	07	05	0	13	0	0	0	55	0
35	11/03/06	EF	Un known	07	50	0	07	30	0	0	40	0
36	13/03/06	OI	L.O.L	12	30	0	18	0	0	5	30	0
37	14/03/06	EF	Shedding	07	25	0	12	0	0	4	35	0
38	15/03/06	EF	„	15	05	0	15	55	0	0	50	0

39	18/03/06	EF	SC	18	45	0	22	0	0	3	15	0
40	21/03/06	OI	OI	12	0	0	18	0	0	6	0	0
41	26/03/06	OC	maintenance	13	45	0	14	10	0	0	35	0
42	28/03/06	EF	„	14	0	0	15	0	0	1	0	0
43	30/03/06	EF	„	12	20	0	12	55	0	0	35	0
44	02/04/06	O.C	„	16	45	0	18	10	0	1	25	0
45	07/04/06	„	shedding	09	15	0	12	10	0	2	55	0
46	09/04/06	„	„	15	0	0	16	0	0	1	0	0
47	11/04/06	EF	Un known	17	15	0	17	40	0	0	25	0
48	02/04/06	„	maintenance	07	0	0	12	0	0	5	0	0
49	05/04/06	EF	maintenance	08	10	0	12	10	0	2	0	0
50	10/04/06	EF	shedding	12	30	0	18	0	0	5	30	0
51	11/04/06	EF	Un known	07	20	0	12	0	0	4	40	0
52	13/04/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
53	14/04/06	OC	„	18	0	0	21	25	0	3	25	0
54	17/04/06	OI	„	07	0	0	12	0	0	5	0	0
55	18/04/06	O.C	shedding	15	10	0	16	20	0	1	10	0
56	19/04/06	OI	Feeder O.L	18	0	0	22	10	0	4	10	0
57	20/04/06	OI	Un known	15	25	0	16	30	0	1	05	0
58	22/04/06	OC	maintenance	09	30	0	10	30	0	1	0	0
59	23/04/06	EF	Feeder O.L	06	30	0	09	30	0	3	0	0
60	25/04/06	EF	Un known	08	0	0	08	04	0	0	04	0
61	27/04/06	„	maintenance	08	10	0	09	40	0	1	30	0
62	28/04/06	EF	’’	17	10	0	17	40	0	0	30	0
63	29/04/06	OI	shedding	07	0	0	12	0	0	5	0	0
64	30/04/06	OC	SC	08	10	0	12	10	0	2	0	0
65	03/05/06	EF	Shedding	12	30	0	18	0	0	5	30	0
66	06/05/06	EF	„	07	20	0	12	0	0	4	40	0
67	07/05/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
68	08/05/06	OI	„	18	0	0	21	25	0	3	25	0
69	10/05/06	OI	SC	07	0	0	12	0	0	5	0	0
70	11/05/06	O.C	Un known	16	10	0	17	20	0	1	10	0
71	12/05/06	„	Feeder O.L	18	0	0	22	10	0	4	10	0
72	13/05/06	OI	’’	14	25	0	14	29	0	0	04	0
73	15/05/06	OC	maintenance	09	20	0	10	20	0	1	0	0
74	17/05/06	„	Feeder O.L	10	30	0	13	30	0	3	0	0
75	18/05/06	EF	maintenance	08	0	0	08	22	0	0	22	0
76	19/05/06	„	maintenance	08	10	0	09	50	0	1	40	0
77	20/05/06	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
78	21/05/06	EF	Wind	08	0	0	08	22	0	0	22	0
79	23/05/06	OC	Windy rain	08	10	0	09	50	0	1	40	0
81	25/05/06	„	maintenance	08	10	0	09	40	0	1	30	0
81	27/05/06	EF	’’	17	10	0	17	40	0	0	30	0
82	28/05/06	OI	Shedding	07	0	0	12	0	0	5	0	0
83	30/05/06	OC	maintenance	08	10	0	12	10	0	2	0	0

84	**01/06/06**	**EF**	**shedding**	**12**	**30**	**0**	**18**	**0**	**0**	**5**	**30**	**0**
85	**02/06/06**	**EF**	**OC**	**07**	**20**	**0**	**12**	**0**	**0**	**4**	**40**	**0**
86	**04/06/06**	**OI**	**Feeder O.L**	**18**	**30**	**0**	**21**	**45**	**0**	**3**	**15**	**0**
87	**05/06/06**	**OI**	**SC**	**18**	**0**	**0**	**21**	**25**	**0**	**3**	**25**	**0**
88	**09/06/06**	**OI**	**Feeder O.L**	**07**	**0**	**0**	**12**	**0**	**0**	**5**	**0**	**0**
89	**10/06/06**	**O.C**	**Un known**	**15**	**10**	**0**	**16**	**20**	**0**	**1**	**10**	**0**
90	**15/06/06**	**„**	**Feeder O.L**	**18**	**0**	**0**	**22**	**10**	**0**	**4**	**10**	**0**
91	**17/06/06**	**OI**	**’’**	**14**	**25**	**0**	**15**	**30**	**0**	**1**	**05**	**0**
92	**19/06/06**	**OC**	**maintenance**	**09**	**30**	**0**	**10**	**30**	**0**	**1**	**0**	**0**
93	**22/06/06**	**„**	**Feeder O.L**	**06**	**30**	**0**	**09**	**30**	**0**	**3**	**0**	**0**
94	**24/06/06**	**EF**	**maintenance**	**08**	**0**	**0**	**08**	**22**	**0**	**0**	**22**	**0**
95	**27/06/06**	**„**	**„**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
96	**29/06/06**	**OI**	**Feeder O.L**	**06**	**30**	**0**	**09**	**30**	**0**	**3**	**0**	**0**
97	**06/07/06**	**EF**	**Wind**	**08**	**0**	**0**	**08**	**22**	**0**	**0**	**22**	**0**
98	**07/07/06**	**OC**	**Windy rain**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
99	**08/07/06**	**„**	**maintenance**	**08**	**10**	**0**	**09**	**40**	**0**	**1**	**30**	**0**
100	**09/07/06**	**EF**	**’’**	**17**	**10**	**0**	**17**	**40**	**0**	**0**	**30**	**0**
101	**10/07/06**	**OI**	**Windy rain**	**07**	**0**	**0**	**12**	**0**	**0**	**5**	**0**	**0**
102	**11/07/06**	**OC**	**maintenance**	**08**	**10**	**0**	**12**	**10**	**0**	**2**	**0**	**0**
103	**12/07/06**	**EF**	**shedding**	**12**	**30**	**0**	**18**	**0**	**0**	**5**	**30**	**0**
104	**13/07/06**	**EF**	**„**	**07**	**20**	**0**	**12**	**0**	**0**	**4**	**40**	**0**
105	**15/07/06**	**OI**	**Feeder O.L**	**18**	**30**	**0**	**21**	**45**	**0**	**3**	**15**	**0**
106	**20/07/06**	**OI**	**„**	**18**	**0**	**0**	**21**	**25**	**0**	**3**	**25**	**0**
107	**22/07/06**	**OI**	**Feeder O.L**	**07**	**0**	**0**	**12**	**0**	**0**	**5**	**0**	**0**
108	**23/07/06**	**O.C**	**Un known**	**15**	**10**	**0**	**16**	**20**	**0**	**1**	**10**	**0**
109	**24/07/06**	**„**	**Feeder O.L**	**18**	**0**	**0**	**22**	**10**	**0**	**4**	**10**	**0**
110	**25/07/06**	**OI**	**’’**	**14**	**25**	**0**	**15**	**30**	**0**	**1**	**05**	**0**
111	**26/07/06**	**OC**	**maintenance**	**09**	**30**	**0**	**10**	**30**	**0**	**1**	**0**	**0**
112	**27/07/06**	**„**	**Feeder O.L**	**06**	**30**	**0**	**09**	**30**	**0**	**3**	**0**	**0**
113	**04/08/06**	**EF**	**maintenance**	**08**	**0**	**0**	**08**	**22**	**0**	**0**	**22**	**0**
114	**05/08/06**	**„**	**maintenance**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
115	**06/08/06**	**OI**	**Feeder O.L**	**06**	**30**	**0**	**09**	**30**	**0**	**3**	**0**	**0**
116	**07/08/06**	**EF**	**Wind**	**08**	**0**	**0**	**08**	**22**	**0**	**0**	**22**	**0**
117	**08/08/06**	**OC**	**Windy rain**	**08**	**10**	**0**	**09**	**50**	**0**	**1**	**40**	**0**
118	**10/08/06**	**OI**	**Feeder O.L**	**07**	**0**	**0**	**12**	**0**	**0**	**5**	**0**	**0**
119	**12/08/06**	**O.C**	**Un known**	**15**	**10**	**0**	**16**	**20**	**0**	**1**	**10**	**0**
120	**16/08/06**	**„**	**Feeder O.L**	**18**	**0**	**0**	**22**	**10**	**0**	**4**	**10**	**0**
121	**19/08/06**	**OI**	**Heavy rain**	**14**	**25**	**0**	**15**	**30**	**0**	**1**	**05**	**0**
122	**21/08/06**	**OC**	**maintenance**	**09**	**30**	**0**	**10**	**30**	**0**	**1**	**0**	**0**
123	**24/08/06**	**„**	**Feeder O.L**	**06**	**30**	**0**	**09**	**30**	**0**	**3**	**0**	**0**
124	**01/09/06**	**EF**	**Shading pro**	**12**	**30**	**0**	**18**	**0**	**0**	**5**	**30**	**0**
125	**02/09/06**	**EF**	**Un known**	**07**	**20**	**0**	**12**	**0**	**0**	**4**	**40**	**0**
126	**03/09/06**	**OI**	**Feeder O.L**	**18**	**30**	**0**	**21**	**45**	**0**	**3**	**15**	**0**
127	**09/09/06**	**OI**	**Feeder O.L**	**18**	**0**	**0**	**21**	**25**	**0**	**3**	**25**	**0**
128	**11/09/06**	**OI**	**Feeder O.L**	**07**	**0**	**0**	**12**	**0**	**0**	**5**	**0**	**0**

129	16/09/06	O.C	Un known	15	10	0	16	20	0	1	10	0
130	19/09/06	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
131	24/09/06	OI	’’	14	25	0	15	30	0	1	05	0
132	26/09/06	OC	maintenance	09	30	0	10	30	0	1	0	0
133	27/09/06	,,	Feeder O.L	06	30	0	09	30	0	3	0	0
134	28/09/06	EF	maintenance	08	0	0	08	22	0	0	22	0
135	02/10/06	,,	maintenance	08	10	0	09	50	0	1	40	0
136	04/10/06	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
137	05/10/06	EF	Wind	08	0	0	08	22	0	0	22	0
138	06/10/06	OC	Windy rain	08	10	0	09	50	0	1	40	0
139	09/10/06	,,	maintenance	08	10	0	09	40	0	1	30	0
140	13/10/06	OC	maintenance	08	10	0	12	10	0	2	0	0
141	14/10/06	EF	OC	12	30	0	18	0	0	5	30	0
142	16/10/06	EF	Shedding	07	20	0	12	0	0	4	40	0
143	19/10/06	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
144	21/10/06	OI	Un known	18	0	0	21	25	0	3	25	0
145	22/10/06	OI	,,	07	0	0	12	0	0	5	0	0
146	02/11/06	O.C	Un known	15	10	0	16	20	0	1	10	0
147	04/11/06	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
148	08/11/06	,,	Feeder O.L	06	30	0	09	30	0	3	0	0
149	09/11/06	EF	maintenance	08	0	0	08	22	0	0	22	0
150	10/11/06	,,	maintenance	08	10	0	09	50	0	1	40	0
151	11/11/06	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
152	12/11/06	EF	Wind	08	0	0	08	22	0	0	22	0
153	13/11/06	OC	Windy rain	08	10	0	09	50	0	1	40	0

Table B: Detail Interruption Report for Sheno Feeder {2007E.C (2015)}.

Sheno feeder (F5)

s.no	Date	Types of fault (relay acted)	Cause of fault	Interruption Time (hrs)	Reconnection Time (Hrs)	Difference (Hrs)	Line load (kw)	Un sold Energy (KWh)
1	03/01/07	EF	maintenance	15:30	17:30	02:00	1200	2400
2	08/01/07	EF	Phase broken	08:40	12:00	03:20	1100	3580
3	12/01/07	EF	Shedding	10:25	11:25	01:00	920	920
4	14/01/07	EF	Unknown	06:50	09:10	02:20	840	1960
5	19/01/07	EF	maintenance	04:00	6:00	02:00	840	1680
6	22/01/07	OI	Broken line	08:30	9:20	00:50	1200	1000
7	24/01/07	OI	Shedding	13:50	15:10	02:20	2600	3466.6
8	25/01/07	OI	maintenance	08:30	09:30	01:00	540	540
9	27/01/07	OI	unknown	08:25	17:50	09:25	1100	10358
10	30/01/07	EF	Shedding	08:30	09:30	01:00	940	940
11	03/02/07	OI	Un known	08:00	09:55	01:55	540	6434.9

12	12/02/07	OC	Line section	10:05	12:05	2:00	730	1460
13	13/02/07	OI	Shedding	10:50	12:00	1:10	1500	1750
14	02/04/07	EF	maintenance	07:00	15:00	9:00	990	8910
15	02/04/07	EF	Birds	03:10	03:40	00:30	1000	500
16	14/04/07	EF	Line section	07:20	08:20	01:00	1200	1200
17	19/04/07	EF	Un known	08:00	09:00	01:00	1700	1700
18	02/05/07	EF	maintenance	08:00	10:00	02:00	1100	2200
19	05/05/07	EF	Un known	08:25	09:45	01:20	500	166.6
20	13/05/07	OC	maintenance	07:50	08:40	00:50	730	608.3
21	18/05/07	OI	Shedding	08:00	10:00	02:00	1100	2400
22	23/05/07	EF	,,	08:00	09:30	01:30	840	1260
23	03/06/07	,,	L.O.L	08:30	08:00	01:00	1700	1700
24	07/06/07	EF	maintenance	17:30	18:30	01:00	1200	1200
25	13/06/07	EF	Un known	08:00	09:30	09:30	1200	1800
26	18/06/07	EF	maintenance	14:00	14:30	00:30	1600	800
27	23/06/07	OC	maintenance	08:55	09:55	01:00	1200	1200
28	27/06/07	OI	Bird	13:50	15:10	01:20	2600	3466.6
29	04/07/07	OI	Unknown	10:33	10:55	00:22	630	231
30	13/07/07	EF	maintenance	08:20	09:20	01:00	580	580
31	18/07/07	,,	L. shading	08:30	08:30	01:20	1950	2600
32	27/07/07	,,	Broken line	13:00	15:00	02:00	1200	2400
33	03/08/07	,,	maintenance	17:00	18:00	01:00	1100	1100
34	12/08/07	,,	,,	14:30	15:55	1:25	1200	1700
35	15/08/07	EF	Wind	10:25	11:25	01:00	920	920
36	23/08/07	OI	Windy rain	15:30	16:00	00:30	1500	750
37	28/08/07	OC	Un known	14:00	14:30	00:30	1500	750
38	02/09/07	OI	Birds	09:10	10:30	01:20	1620	2159.9
39	03/09/07	EF	Juru line	13:30	17:15	03:45	540	2025
40	07/09/07	EF	Un known	14:15	16:45	02:30	560	1400
41	12/09/07	EF	maintenance	14:00	14:30	00:30	1500	750
42	18/10/07	OI	Broken phase	13:30	17:15	03:45	540	2025
43	23/10/07	EF	maintenance	08:05	10:05	2:00	730	1460
44	27/10/07	OC	Windy rain	11:50	13:00	1:10	1500	1750
45	04/10/07	EF	maintenance	07:00	15:00	9:00	990	8910
46	13/10/07	EF	L. shading	04:10	04:40	00:30	1000	500
47	18/10/07	OI	Cha-cha line	07:20	08:20	01:00	1200	1200
48	24/11/07	OP	maintenance	08:30	09:30	01:00	1700	1700
49	03/11/07	EF	Shedding	08:00	10:00	02:00	1100	2200
50	10/11/07	O.C	maintenance	09:05	11:20	02:15	1320	2750
51	13/11/07	EF	Heavy rain	11:30	11:00	00:30	1500	750
52	03/11/07	EF	maintenance	8:00	08:30	00:30	1200	600
53	07/11/07	OI	Un known	12:30	14:30	2:00	540	1080
54	13/11/07	EF	maintenance	11:30	12:00	00:30	1500	750
55	18/11/07	OI	maintenance	14:00	15:00	01:00	1500	150
56	23/11/07	EF	Animals	09:10	10:10	01:00	1620	1620

57	**27/12/07**	**OI**	**Shedding**	**08:30**	**14:15**	**03:45**	**540**	**2025**
58	**04/12/07**	**EF**	**maintenance**	**14:45**	**16:45**	**02:00**	**560**	**1120**
59	**13/12/07**	**EF**	**Un known**	**09:00**	**11:00**	**02:00**	**540**	**1080**
60	**18/12/07**	**EF**	**Shedding**	**06:05**	**08:05**	**02:00**	**730**	**1460**
61	**24/12/07**	**EF**	**Wind**	**06:00**	**07:30**	**01:30**	**1500**	**1750**
62	**03/12/07**	**OI**	**Windy rain**	**07:00**	**14:00**	**7:00**	**920**	**6440**
63	**10/12/07**	**OP**	**maintenance**	**08:10**	**08:40**	**00:30**	**1500**	**750**

Appendix B

Initial configuration of Sheno (15kV) single line diagram with Visio

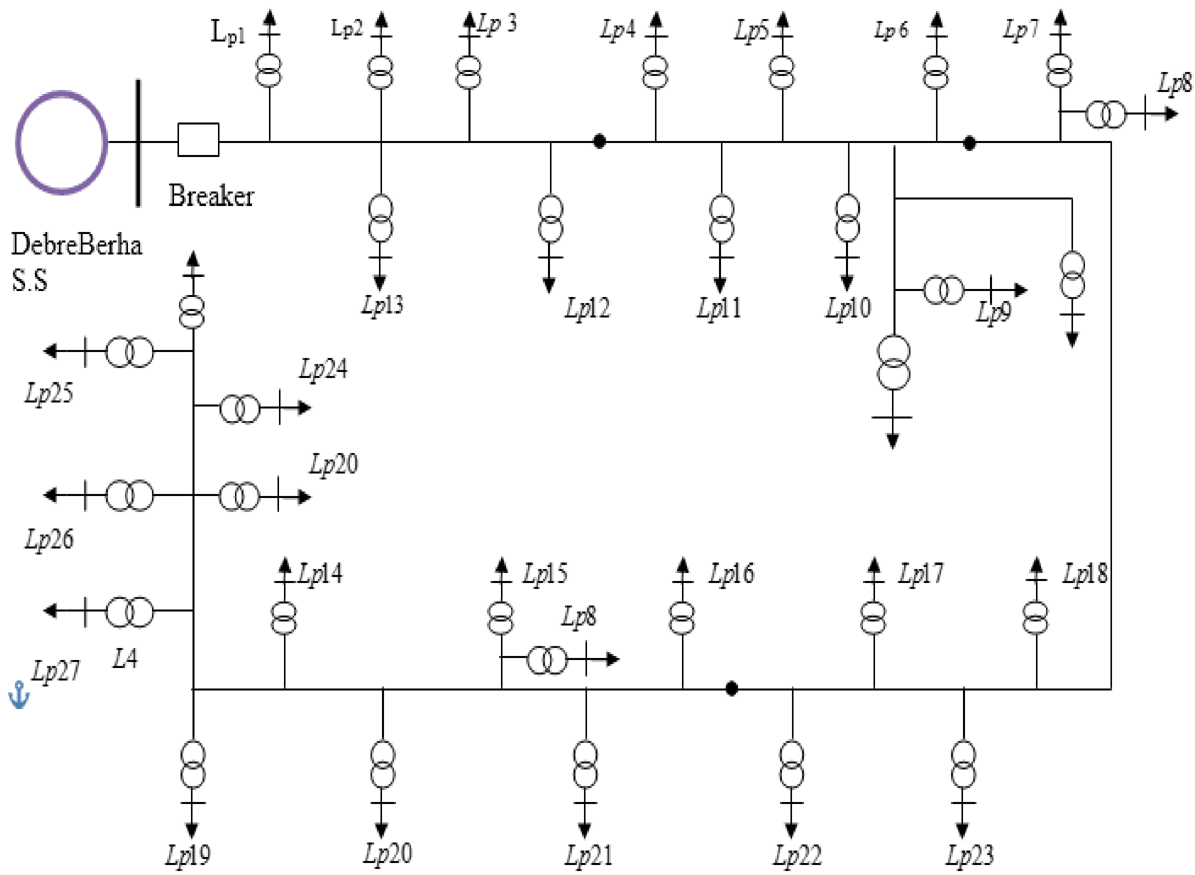

Table: component reliability data

Component type	Failure rate (f/yr.)	Repair time (hrs.)	Switching time
Transformer			
132/15 KV	1.99	1.5	1
15/0.4 KV	1.99	1.5	1
Breaker			
132 KV	1.99	1.5	1
15 KV	1.99	1.5	1
Bus bar			
132 KV	1.99	1.5	
15 KV	1.99	1.5	
Feeder line(15 KV)		1.5	1
Isolator(15 KV)	1.99	1.5	1
Fuse (00.4 KV)	1.99	1.5	1