ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ASSESSMENT AND IMPROVEMENT OF RELIABILITY OF ELECTRICAL POWER DISTRIBUTION SYSTEM

CASE STUDY: - SHENO 15 kV DISTRIBUTION FEEDER, DEBRE BERHAN

By

Meron Alebachew

THESIS SUBMITTED TO ADDIS ABABA INSTITUTE OF TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

ELECTRICAL POWER ENGINEERING

ADVISOR:

Prof – N.P SINGH

Date: Oct, 2019

ADDIS ABABA, ETHIOPIA

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Declaration

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

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

Prof N.P. Singh ____________________

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Acknowledgment

Foremost, I would like to express my sincere gratitude to my advisor Prof. N.P. Singh for his patient guidance, enthusiastic encouragement and useful critiques of this thesis work. My grateful thanks also extend to all staffs of EEU, Debre Berhan distribution office, for their help in collecting data needed. Special thanks should be given to Mr.Mekuanent Assefa and Mr. Daniel for enabling me to visit their offices to observe their daily operations.

My last but not the least gratitude; goes to my family and friends for their valuable support, contractive recommendation and encouragement throughout my study.

Abstract

Distribution feeders are to deliver energy consistently to customers as electric power distribution systems reliability is a foremost concern to any electric power utility company. Power utility companies are working to provide reliable power through many systems. This thesis assesses the reliability of an electric power distribution feeder named **Sheno 15 kV** distribution feeder among the feeders that supplies an electric power to Debre Berhan city, an old city in Ethiopia. Power interruption data on daily basis for a period of two years on the feeder was collected and analyzed for the main causes of interruptions along with other two feeders namely Eneway and Aliyu Amba. Based on the data collected, system reliability indices (**SAIFI, SAIDI, CAIDI, ASAI, EENS and ECOST**) of the feeder were calculated using both mathematical and simulation methods andthe obtained results are **103.1271 f/customer.yr, 289.7872 hr/ customer.yr, 2.81 hr/customer interruption, 0.9669 Pu, 1361.01 MWhr/yr and 5,820,054 $/y**r respectively. These values indicate poor reliability of the feeder when the results obtained are compared with averages of some countries. Currently, power utilities are trying to provide reliable electric power to their customers through many possible ways. Studying these methods; the method of adding a distributed wind power seems better option for our case study. Predictive reliability assessment of the feeder under study with the added distributed wind power along with possible locations of connection is performed and the results showed much improvement in system reliability indices of the feeder at bas bar 34(B34). These are **36.9719 f/customer.yr, 107.6154 hr/ customer.yr, 2.911 hr/ customer interruption ,0.9877 Pu , 579.565 MWhr/yr and 2,758,927 $/yr**. Afterwards, the cost of realizing this method of reliability improvement for the distribution feeder has been performed. The cost analysis showed that reliability improvement with the help of distributed wind power can be realized economically.

Keywords: - Distribution Feeder, Power Interruption, Predictive Reliability Assessment

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List of Abbreviations

AC (ac).......................Alternating Current

ACCI ....Average Customer Curtailment Index,

AENS ....Average Energy Not Supplied

ASAI ....Average System Availability Index

ASCI ....Average System Curtailment Index

CAIDI ....Customer Average Interruption Duration Index

CAIFI ....Customer Average Interruption Frequency Index

CDF............................Customer Damage Function

DC (dc) ....Direct Current

ECOST.......................Expected Interruption Cost Index

EENS ....Expected Energy Not Supplied

EEU............................Ethiopian Electric Utility

ENS ....Energy not supplied index/ Energy Not Served

ETAP..........................Electrical Transient Analyzer Program

FOR............................Forced Outage Rate

GWhr..........................Giga Watt Hour

IEAR ....Interrupted Energy Assessment Rate Index

IEEE ....Institute of Electrical and Electronics Engineering

km ....Kilo Meter

kv............................... Kilo Volt

kVA............................ Kilo Volt Ampere

kWhr ....kilo Watt Hour

La ....Average Load

Lf .... Load factor

Lp .... Peak Load Demand.

MTBF.........................Mean Time between Failures

MTTR ....Mean Time to Repair

MW ....Mega Watt

SAIDI.........................System Average Interruption Duration Index

SAIFI..........................System Average Interruption Frequency Index

TVET ....Technical and Vocational Educational Training

Chapter 1 Introduction

1.1Background

Electric power utility companies basically must provide customers both large and small with adequate electric power and deliver the system load requirement. Modern society demands that electrical energy should be as economical as possible with adequate degree of continuity and quality. **Reliability** can simply be described as the ability of the system to provide an adequate supply of electrical energy for the period of time intended under the operating conditions encountered**.** The term power system reliability broad it also includes all aspects of the ability to the system to satisfy the customer load requirements [17]. There exists a sensible subdivision of the system reliability in two basic features of power system: -

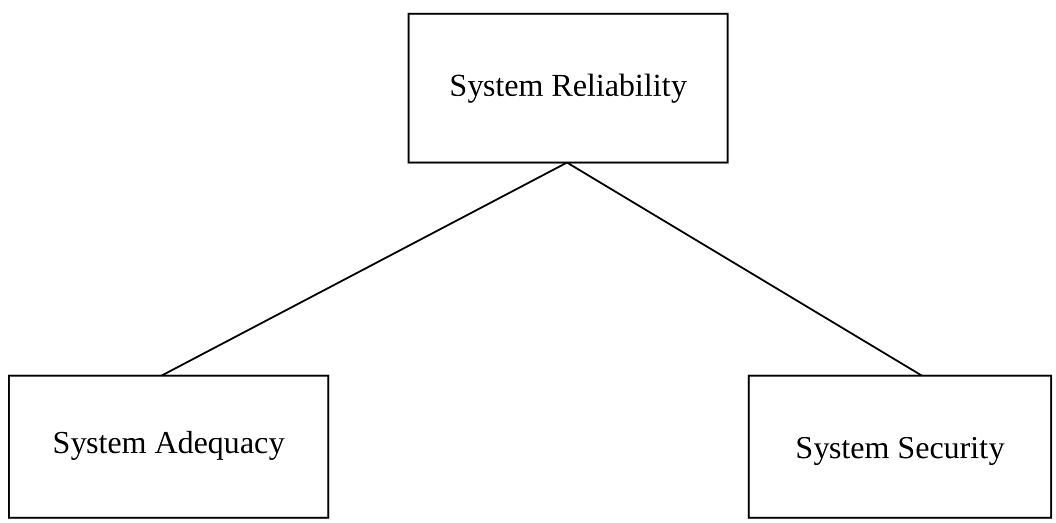


Figure 1 Classification of System Reliability

Adequacy is used to describe the existence of adequate facilities with the system to assure the customer load demands are satisfied. These include the facilities essential to generate adequate energy and the associated transmission and distributed facility needed to transport the energy to the actual customer load points. On the other side**,** the term **Security** is related to the capacity of the electric power system to react to instabilities emanating from the system itself. Therefore, security is linked with the response of the system to whatever perturbation it is subject to.

Most of the probabilistic approaches presently on hand for electric power system reliability evaluations are in the field of adequacy evaluation. The major techniques presented in this thesis will also be in this domain.

An extensive amount of effort is necessary to maintain an electric power supply within the requirements of different types of consumers. Some of requirements of a good quality distribution system are [3]

I. **Safety: -** the safety factor usually requires a voltage low enough to be safe when the electric energy is utilized by an ordinary consumer.

II. **Smooth and even flow of power: -** A steady, uniform, non-fluctuating power is highly desirable for power purposes. A direct current system fills these requirements admirably; however, it is cannot travel long distances to supply power economically at utilization voltage. Alternating current systems deliver power in a fluctuating manner following the cyclic variations of the voltage generated. Such fluctuations of power are not objectionable for heating, lighting and small motors, but are not entirely satisfactory for some devices to operate such as large motors which must deliver mechanical power steadily require a steady input of electric power. The solution for this may be supplying electricity to the motors by two or three circuits, each supplying a part of the power whose fluctuations are purposely made not to occur at the same time, thereby lessening or damping out the effect of the fluctuations. Each of these two or three separate alternating current circuits are referred to as a single phase circuit and are often combined into one poly-phase (two or three) circuit.

III. **Proper voltage: -** one imperative requirement of a good quality distribution system is that voltage variation at consumer's terminal must be as low as possible. High voltage often causes permanent failure of appliances like lamps. Therefore, a good distribution system should ensure that the voltage variation is +/- 6% of the customers' utilization voltage.

IV. **Availability of power on demand: -** power must be available to the consumers in any amount that they may require from time to time. The distribution system must be capable of continuously delivering consumers in their load demands by trailing load patters to predict in advance those major load changes that follow the known schedules with the help of the operating staff as of the as electric power cannot be stored

V. **Reliability: -** Nowadays the dependence of life on electric power is inevitable. This reliance calls for reliable power; however, electric power like any other man-made thing cannot be absolutely reliable. Hence, reliability can be improved to a considerable extent by applying means like interconnected system, reliable automatic control system or providing additional reserve facilities.

VI. **Economy: -** An economical electric power necessitates the minimum use of conductors for delivery of electric energy usually through the use of higher voltage where conditions allow and providing a common return path for the connection of two or more circuits to eliminate excess conductors.

Electricity networks are and will continue to be a critical part of our energy infrastructure and everyone have responsibility to ensure that they are developed consistently and in a manner that is developed towards a long term vision aligned with the expansions of the present and future customers load demands. However; today in developing countries, power demand is increasing rapidly while supply growth is constrained. This is due to scarce resources, environmental problems and other societal concerns. In general, the power system is vulnerable to abnormalities such as control failures, protection or communication system failures and disturbances such as lightening and human operational errors. The loss of electric power has significant economical and social effects on both the utility supplying electric energy and the end users of electric service. Major power outage costs may be in the order of millions or billions of dollars. With growing acceptable level of reliability, quality and safety at economical price, the utility have to take the major role to improve the systems continuously depending upon the needs of the customers.

1.2 Statement of the Problem

The foremost purpose of any electrical system is to supply both large and small customers with economical and reliable electrical energy as much as possible; also the proper operation and longevity of the system are essential rudiments for continued satisfaction. It is also necessary that both demand and supply considerations are appropriately viewed and included in the system. Intuitively, power system adequacy is related to this issue i.e. forecasting load demand and capacity of supply.

Usually the electric power system reliability assessments are conducted on the functional zones electric power i.e., generation system, transmission system and distribution system. Assessments are also made in the combined generation and transmission systems; this is referred as composite or bulk system reliability evaluation. In generation system reliability evaluation, generation adequacy analysis is performed to determine the capacity of the total system generation in order to meet the load requirements. It does not provide the reliability indices for individual load points. On the other hand, the distribution system reliability evaluation is usually conducted separately

In early days, distribution systems reliability modeling and evaluation have received considerably less attention compared to the generation and the transmission system reliability modeling and evaluation. The reasons behind are that a distribution system is relatively cheap as compared to generating stations and the transmission systems which are capital intensive and distribution system reliability issues and its effects are localized while generation and the transmission inadequacy can have extended consequences. However, due to its high impact on the cost of electricity and its high association with customer satisfaction, the distribution system reliability is the most important in the electric power industry. Repetitive analysis conducted on the customer electric power failure data of most utilities confirm that the distribution system makes the greatest contribution to the unavailability of supply to a customer i.e. up to 90% of all customer reliability problems. Improving distribution reliability is therefore the solution to improving customer reliability. This thesis focuses on studying the reliability of an electrical power distribution feeder in Debre Birhan town.

1.3 Objectives of the Study

The main objective of this study is to carry out the reliability analysis of an electrical power distribution systems and investigate the methods for its improvement.

The specific objectives of this thesis are:

- To study, model and evaluate the reliability of the existing power distribution system of Sheno 15kV distribution feeder in Debre Berhan town.
- To analyze and examine the causes of power distribution systems reliability problems in Sheno 15kV distribution feeder in Debre Berhan town with the available reliability indices.
- To investigate and recommend methods for improvement of the reliability indices.
- To carry out reliability analysis of the system with the proposed method.
- To estimate the cost of implementing the proposed method of reliability improvement.

1.4 Literature Review

Reliability as a general term is tied with interruptions. The ability of an electric system to carry out its functions under ordinary and intense conditions is referred Reliability. Distribution system must provide continued power supply to customers without interruption to be reliable. The IEEE 1366 standard define distribution system reliability as measurement of keeping lights on however; there are various events that disrupt normal operation of the distribution system leading to power outages, while end users expect good reliability and expectations keep rising.

Normally the operating conditions all equipment's except stand by equipment's are energized and all utility customers are energized. Distribution system reliability primarily relates to these equipment's outage leading to customer interruptions. There exist many causes that degrade distribution system reliability. Events whether scheduled or unscheduled disrupt normal operating conditions and may lead to power outages and interruptions. The unscheduled events are usually due to either human error or equipment failures. The schedule events shall be notified in advance to the customers and are intended for periodic maintenance of the equipment.

Power quality problems on the utility power system are caused by faults, with most of them on the distribution system. In the distribution system, most failures and disruptions occur more or less frequently due to causes like **interruptions;** which may be **momentary or sustained.**

Momentary or temporary interruptions

IEEE 1366 standard categorize faults lasting less than 5 minutes as momentary interruptions. Most momentary faults may not necessarily cause a power outage. Most utility companies do not account momentary interruptions in reliability study due to the difficulty of knowing when they took place.

Sustained or permanent interruptions

According to IEEE 1366 standard customers are out of power for a period greater than 5 minutes in case of sustain interruption. This sort of fault is normally characterized by open circuits and will result in power outage.

Mostly sustained interruptions and momentary interruptions are the causes of interruptions for residential customers while voltage sags and momentary interruptions are the main problems for commercial and industrial customers. Momentary interruption results electronic industrial equipment to trip off, leading to costly production losses. Generally, an interruption whose duration is greater than five minutes is often considered as reliability issue, whereas interruptions whose duration is less than five minutes are a power quality concerns. Power quality problem from a consumer perspective, can be described as any electric power supply problem that may cause appliances to malfunction or prevents their use. From a utility perspective, a power quality problem might be seen as non-compliance with various standards such as RMS voltage or harmonics. Perfect power quality is with a sinusoidal voltage source with constant frequency and amplitude. Any change in amplitude (transients) or deviation in frequency (harmonics) of a voltage waveform can be taken as power quality issue.

Utilities must find a balance between cost and power quality provided to the customer. Power quality concerns are becoming more frequent with the proliferation of sensitive modern electronic equipment’s and automated processes. Power quality problems are basically divided into many categories such as **interruptions, sage, swells, transients, noise, flicker, harmonic distortion and frequency variations.**

Reliability is primarily concerned with customer interruptions and is therefore a subset of power quality. This relationship can be shown in the figure below. Availability is the percentage of time a voltage source is uninterrupted. It is the probability of something being energized whereas unavailability is the probability of not being energized. It is the most fundamental feature of reliability and is typically expressed in percent or per unit.

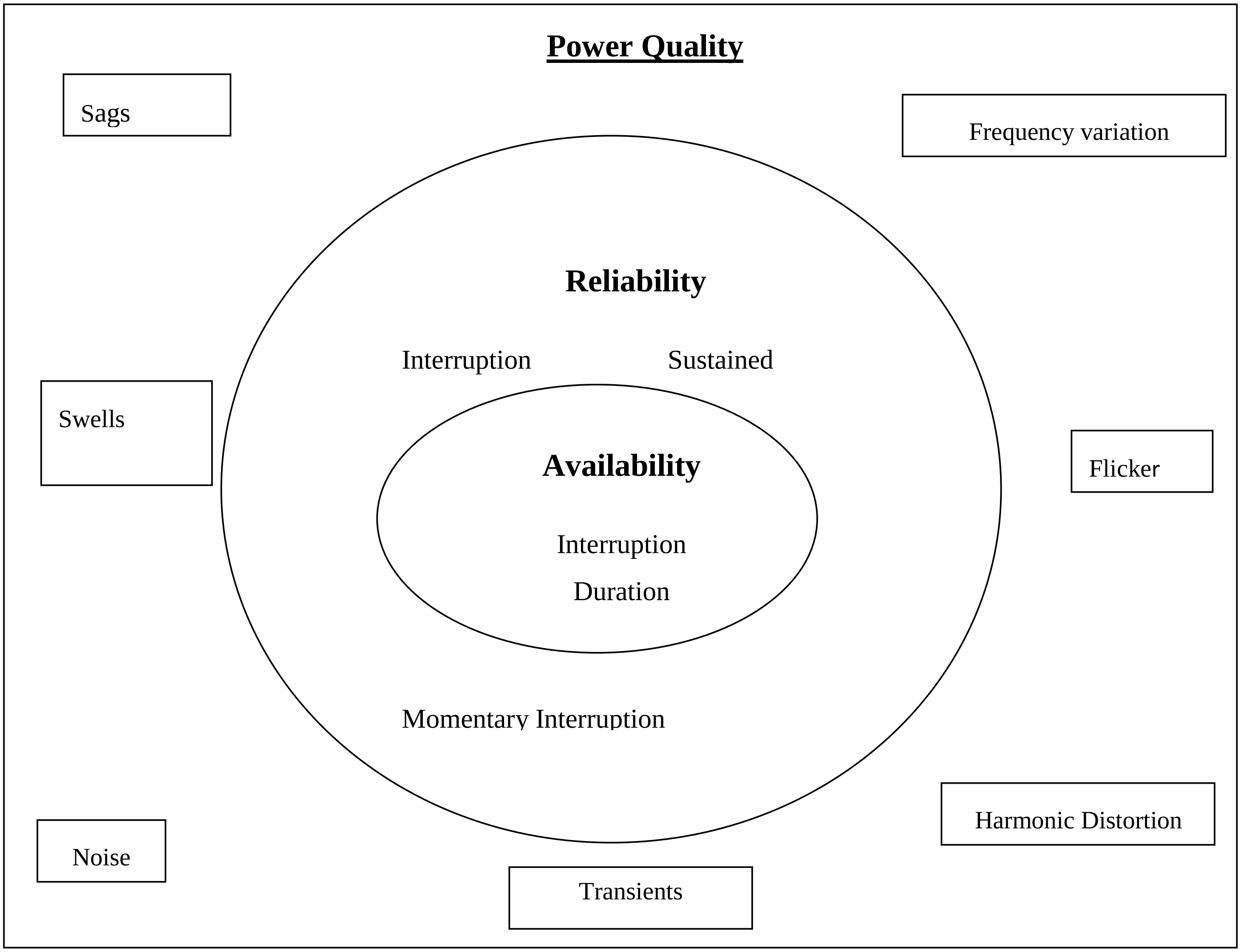


Figure 2 Hierarchy of Power Quality, Reliability and Availability

Outage in distribution systems caused by different factors significantly impacts 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(s) related to outages caused by different factors is very useful for the utilities. 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. Failure can be divided primarily into damaging faults and non-damaging faults. The general classification is presented as below.

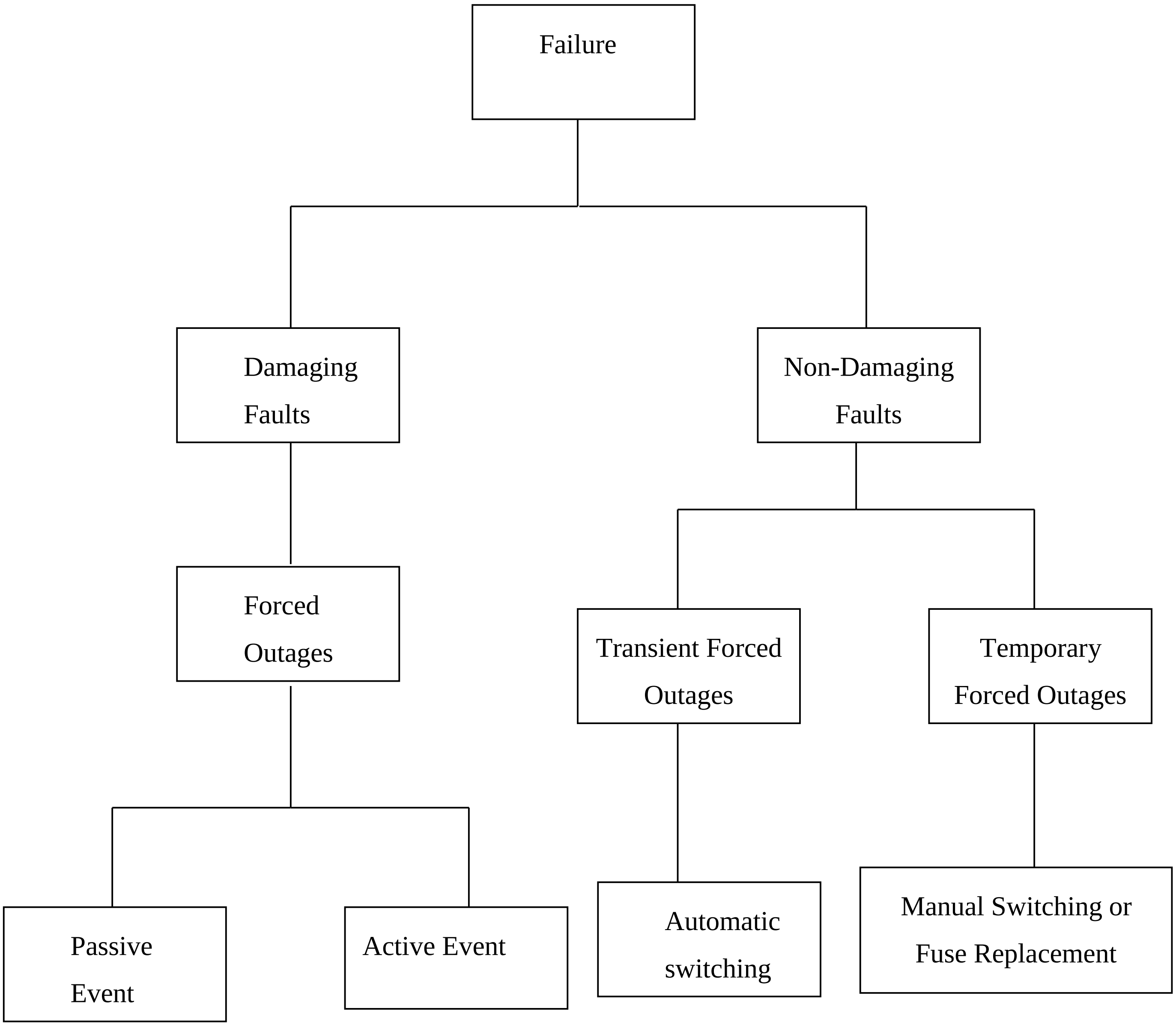


Figure 3 Distribution System Failures General Classifications

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 transient or temporary forced outage; these are outages for which the causes are not permanent. A branch of tree touching the line due to breeze or windy air can be an example. For such kind outages, the circuit breakers remain closed while relays are reset and lines reclosed.

i. **Transient forced outages:** - which occurs when the system is restored by automatic switching and the outage time is negligible, and

ii. **Temporary forced outages: -**which occur when the system is restored by a manual switching or fuse replacement

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

i. **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.

ii. **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 dis connector using another feeder for supply. An active failure can be restored by either repair or replacement, or by switching.

1.5 Significance and Scope of the Study

Generally, this thesis work is thought to be helpful to both the electric power serving utility and to its customers' in

- Identifying the main causes of power interruption and related problems arising frequently in power distribution system.
- Maintaining reliable and trusted relationship between them.
- Saving large amount of money that is lost during power interruption.
- Showing the use of this type of study for future planning of a new and/ or an expanded distribution system.
- To use this type of study by customers in locating different type of industries.

And the scope of the study would be

- Only distribution system reliability will be analyzed, neither generation system nor transmission system reliability evaluations will be conducted.

- Due to time and resource limitations only; one feeder that is observed to be mostly affected by power interruptions will be selected.
- Only the effect of the feeder line with regard to reliability will be considered. The effect of distribution system components will not be considered.

1.6 Methodology

The foremost aim of this study is to evaluate reliability of distribution system by computing the generally accepted reliability indices used in the distribution system and see how reliability could be improved in the distribution system. Reliability indices, such as the system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI) and customer average interruption duration index (CAIDI) together provide a full indicator of the reliability of a utility's electric distribution system to measure long-term electric service performance. These reliability indices are statistical aggregations of reliability data for a set of loads, components or customers.

Different reliability parameters are used in the distribution system reliability evaluation among these, reliability indices that are frequently used are: -

- System Average Interruption Duration Index (SAIDI)
- Customer Average Interruption Duration Index (CAIDI)
- System Average Interruption Frequency Index (SAIFI)
- Customer Average Interruption Frequency Index (CAIFI)
- Average System Availability Index (ASAI)
- Energy Not served (ENS)
- Average Energy Not Supplied, AENS

Reliability statistics obtained from the above indices are the quantitative basis for good decision making and are excellent for self-evaluation. The following block diagram describes the method adopted here in this thesis to help in doing so.

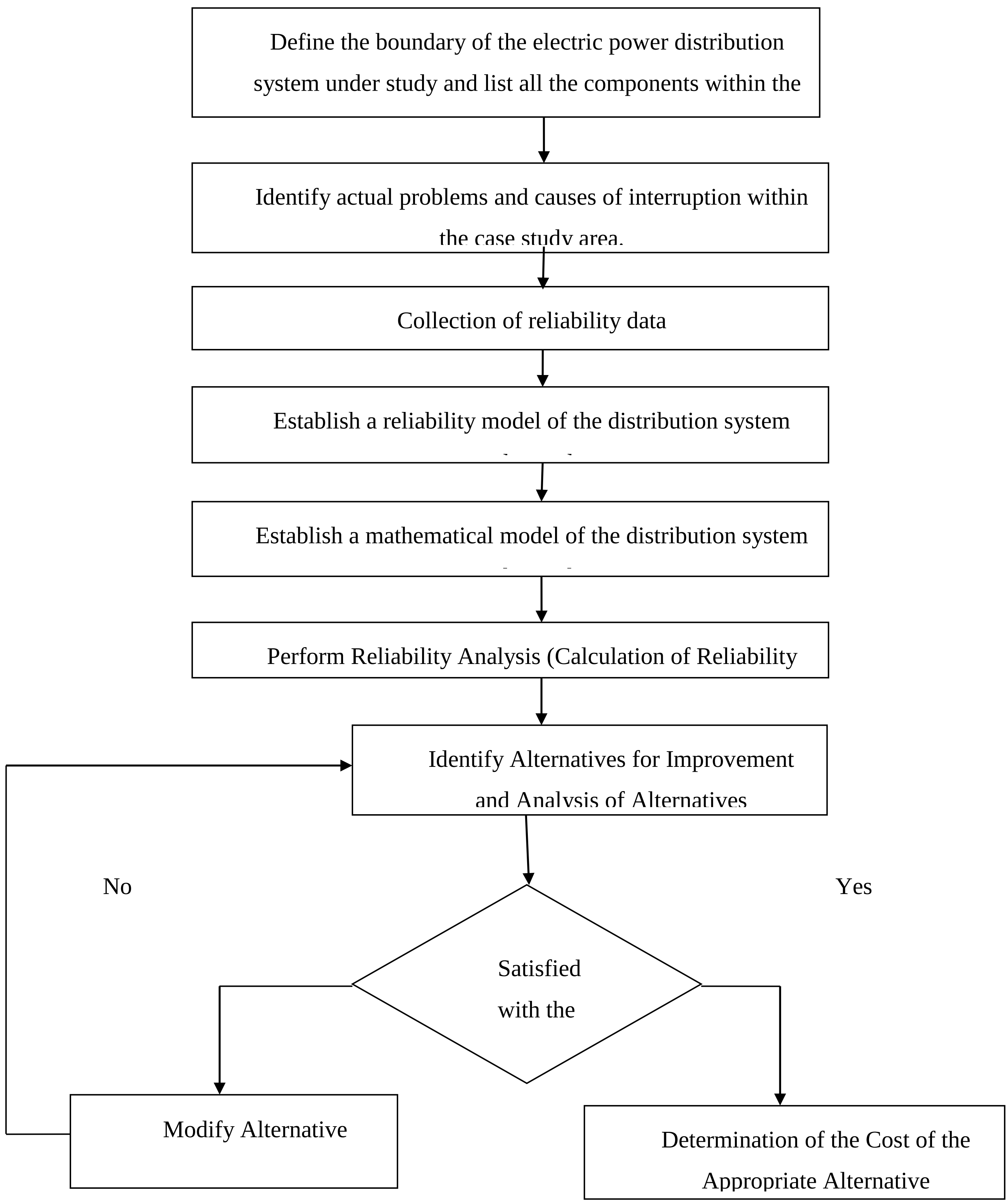


Figure 4 Flow Chart of the General Methodology

1.7 Organization of the thesis

The thesis work should be done in a brief explanation that provides a clear flow right through. Chapter 1 is the introduction chapter that presents background, problem definition, and objectives of the study, literature review related to the problem, methodology employed in tackling the problem at hand, significance and scope of the study. Following these, chapter 2 tries to discuss how reliability of a power system can be evaluated using reliability indices, reliability analysis methods of a power distribution system, and lastly about the available reliability improvement methods. Chapter 3 then presents overview information of the area understudy and tries to identify and analyze the main causes and effects of power interruptions from the collected interruption data, and by developing model of the feeder under study reliability evaluation of the case study area has been done using both analytical and simulation methods at the end of this chapter Simulation studies' using reliability improvement method was found necessary after the result of the reliability analysis has been compared with some benchmarks. The cost of implementing the reliability improvement method has also been calculated under chapter 4. Lastly, chapter 5 takes us to the final section where conclusion, recommendation and future work related to the thesis are presented.

Chapter 2 Reliability Analysis of Distribution Systems

2.1 Introduction

Today, developing countries electric power demand is increasing rapidly whereas utilities supply growth is constrained by scare resources, environmental problems and other societal concerns electric power utility is to be reliable, these problems have to be mitigated.

Most power system interruptions are due to distribution systems failures, so it is crucial for electric power utility companies to carry out progressive evaluation to assess the level of reliability and figure out way of improvement trough giving answers to questions like; is the system reliable enough? Which schemes will be effective? And where shall high capital should be spent to improve the system? It is a must for electric utilities to measure actual distribution system reliability performance levels and define performance indicator to assess the basic function of providing cost-effective and reliable power supply to all customer types.

2.2 Reliability Indices

Any electrical power system is evaluated based on its reliability. Reliability is evaluated by reliability indices. Most distribution reliability indices are average values indicating particular reliability characteristics of the complete system, part of the system, substation or a feeder however; full treatment is not usually practicable.

Basically, distribution system reliability parameters can be categorized as **Load Point Indices** and **System Based Reliability Indices [8].** System indices measure the overall reliability of the system whereas load point indices measure the expected/average number of outage and the duration of outage for individual customers.

Load point indices- load point average/expected failure rate (λ), the average outage time (r) and average annual unavailability or outage (U) are the basic load point indices**.**

$$\textbf{i. Average Failure rate}(\boldsymbol{\lambda}) = \frac{\text{Number of Interruptions}}{\text{Number of Interruption Years}} \qquad (2.1)$$

$\textbf{ii. Avarage outage time (r) or mean time to repair (MTTR)}: -$ is the time (hours)required to repair a component outage and/or restore the system in to normal operating state.

.

$$\text{MTTR(r)} = \frac{\text{Total Duration of Interruptions}}{\text{Toatal number of Interrupions}} \qquad (2.2)$$

$$\textbf{iii. Average Annual outage time}(\mathbf{u}) = (\lambda * \text{MTTR}) \qquad (2.3)$$

$\textbf{iv. Average Repair rate}(\boldsymbol{\mu})$: -is the frequency of a repair

$$\mu = \frac{8760}{\text{MTTR}} \qquad (2.4)$$

$\textbf{v. Mean time to failure (MTTF)}: -$is expected time that the component will be in failure.

$$\text{MTTF} = \frac{1}{\lambda} \qquad (2.5)$$

$\textbf{vi. Mean time between failure(MTBF)}: -$ is the expected time between component failures.

$$\text{MTBF} = \frac{\text{Total System Operating Time}}{\text{Number of Interrupions}} = \text{MTTF} + \frac{\text{MTTR}}{8760} \qquad (2.6)$$

These reliability indices are used in reliability analysis for each component in component modeling.

System Reliability Indices- These type of reliability indices are the ones which utilities commonly used in order to quantify the performance of their systems consists of interruption indices and energy based indices.

Interruption Indices

i. ***System Average Interruption Duration Index (SAIDI)***

is commonly referred to as customer minutes of interruption or customers' hours, and is the most often used performance measurement designed to provide information about the average time that the customers are interrupted under sustained interruption.

To calculate SAIDI, the below formula is generally adopted i.e. the number of interrupted customers during each the interruption time period is multiplied by the duration of the interruption to obtain individual customer-minutes of interruption. The total sum of all interruption customer-minutes is then divided by the total customers served to calculate the SAIDI value.

$$\text{SAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customer Served}} = \frac{\Sigma(N_i * r_i)}{N_T} \quad (2.7)$$

Where,

Σ = Summation function.

r_i = Outage time or Restoration time of each interruption i.

N_i = Number of customers interrupted by each interruption i.

N_T = Total number of customers served by the utility.

SAIDI is usually calculated on monthly or yearly basis; however, it can also be for any other time period.

ii. ***System Average Interruption Frequency Index (SAIFI) -*** is intended to express the average number of times that a utility customer comes across an outage during any time period under study. The SAIFI is the fraction of the total number of customers interrupted and the total number of customers served, hence a dimensionless quantity. SAIFI is given by

$$\text{SAIFI} = \frac{\text{Sum of the Number of Customer Interrupted}}{\text{Total Number of Customer Served}} = \frac{\Sigma N_i}{N_T} \quad (2.8)$$

Where,

Σ = Summation function.

N_i = number of customers interrupted by each interruption i.

N_T= Total number of customers served by the utility.

iii. ***Customer Average Interruption Duration Index (CAIDI): -*** used to express the average time to restore service to customers after an arbitrary outage. Calculation of CAIDI is similar to SAIDI except that the denominator in this case is the number of customers interrupted.

$$\text{CAIDI} = \frac{\text{Sum of Customer Interruption Durations}}{\text{Sum of the Number of Customer Interrupted}} = \frac{\text{SAIDI}}{\text{SAIFI}} = \frac{\Sigma(N_i * r_i)}{\Sigma N_i} \quad (2.9)$$

Where,

Σ = Summation function.

r_i= Outage time or Restoration time of each interruption i.

N_i = number of customers interrupted by each interruption i.

iv. ***Customer Average Interruption Frequency Index (CAIFI): -*** the trends in customers interrupted and the number of customers affected by an outage out of total customers served base are measured by the average number of interruption per customer interrupted per year or is simply the number of interruptions that occurred divided by the number of customers affected by the interruptions.

$$\text{CAIFI} = \frac{\text{Sum of the Number of Customer Interruptions}}{\text{Sum of the Number of Customer Interrupted}} = \frac{\Sigma N_0}{\Sigma N_i} \quad (2.10)$$

Where,

Σ = Summation function

N_0 = Number of interruptions in a year.

N_i = number of customers interrupted by each interruption i.

v. ***Average service availability index (ASAI): -*** this term is the ratio of the total number of service available customer hours during a given time period to the total hour the customer demanded service. It is usually referred as **Service Reliability Index**. The ASAI index can be calculated for any time period but usually on either monthly bases (730 hours) or a yearly basis (8,760). Generally, ASAI is computed by

$$ASAI = \frac{\text{Customer Hours of Available Service}}{\text{Customer Hours Demanded}} = \frac{(N_T * T) - \Sigma(r_i * N_i)}{(N_T * T)} * 100\% \qquad (2.11)$$

Where

Σ = Summation function.

T = Time period under study, hours.

r_i = Outage time or Restoration time of each interruption i.

N_i = number of customers interrupted by each interruption i.

N_T = Total number of customers served by the utility.

Energy Based Indices: -Two of the oldest distribution reliability indices, **ASIDI** and **ASIFI** weight customer based on connected KVA instead of weighing each customer equally

i. Average System Interruption Duration Index (ASIDI)

$$ASIDI = \frac{\text{Sum of Connected KVA Hours of Interruption}}{\text{Total Conneted KVA Served}} = \frac{\Sigma(r_i * L_{ji})}{L_T} \qquad (2.12)$$

Where

Σ = Summation function.

r_i = Outage time or Restoration time of each interruption i at load point j.

L_{ji} = Connected kVA load interrupted at load point j by each Interruption i.

L_T = Total connected kVA load served.

ii. Average System Interruption Frequency Index (ASIFI)

$$ASIFI = \frac{\text{Sum of Connected KVA Interrupted}}{\text{Total Conneted KVA Served}} = \frac{\Sigma L_{ji}}{L_T} \quad (2.13)$$

Where

Σ = Summation function.

L_{ji} = Connected kVA load interrupted at load point j by each Interruption i.

L_T = Total connected kVA or load served.

ASIFI is sometimes used to measure distribution performance in areas that serve power to relatively few customers having relatively large concentration of load, predominantly industrial or commercial customers.

iii. Energy Not Supplied Index(ENS)

$$ENS = \text{sum of (Average load demanded} * \text{Average outage time)} = \Sigma(L_a(j) * r_i) \quad (2.14)$$

Where

Σ = Summation function.

L_a (j) = Average load connected to load point j.

r_i = Outage time or Restoration time of each interruption i at load point j.

iv. Average Energy Not Supplied(AENS) or Average System Curtailment Index(ASCI)

$$AENS = \frac{\text{Total Energy Not Supplied}}{\text{Total Number of Customer Served}} = \frac{\Sigma(L_a(j) * r_i)}{N_T} \quad (2.15)$$

Where,

Σ = Summation function.

$L_a(j)$ = Average load connected to load point j.

r_i = Outage time or Restoration time of each interruption i at load point j.

N_T = Total number of customers served by the utility.

v. Average Customer Curtailment Index, ACCI

$$\text{ACCI} = \frac{\text{Total Energy Not Supplied}}{\text{Sum of the Number of Customers Interrupted}} = \frac{\Sigma(L_a(j) * r_i)}{\Sigma N_i} \tag{2.16}$$

Where,

Σ = Summation function.

$L_a(j)$ = Average load connected to load point j.

r_i = Outage time or Restoration time of each interruption i at load point j.

N_i = number of customers interrupted by each interruption i.

2.3 Distribution System Reliability Evaluation

There are two main approaches useful for reliability evaluation of distribution system, namely **analytical method and simulation method**. Analytical method is based on solution of mathematical models whereas simulation method is based on drawings from statistical distribution with the help of a software program.

Mathematical model of symbolizing the system under study must be generated to compute the reliable indices by means of direct numerical solution in analytical approach. Both the load point reliability indices and system reliability indices are normally computed annually. These indices are functions of the component **failure rates, repair time** and **restoration times** within the year and are random values due to the stochastic nature of a power system. Before starting the calculation of the reliability indices of a distribution system; a logic describing the relation between the components and their fault contribution to different load points in the system i.e. the reliability topology shall be generated [7]. Information regarding the reliability of the individual component in the distribution system must be available to be able to give these input variables. Then the expected values from the statistical distribution of failure rates, repair times and restoration times for all components in the system will be generated. Probability distribution is often implemented for a complete representation of these indices. The associated analytical techniques for both radial and meshed distribution system configurations are as follows

i. **Radial (Series) Distribution System: -** this type of system consists of set of series electronic components like; a line, switches, transformers, breakers and at the end a customer. In the series configuration to be in function all the components involved must be intact. The following equations are used to evaluate the basic indices in a radial distribution system

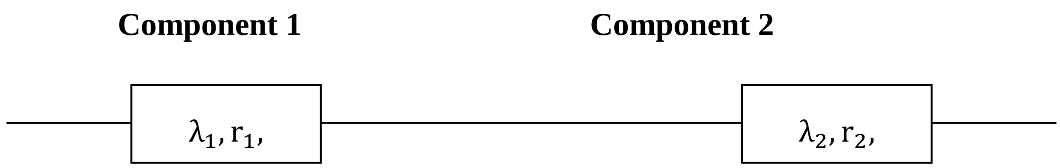


Figure 5 Mathematical Model for two components in Series

- **The expected(average) failure rate of the system, λ_s**

$$\lambda_s = \lambda_1 + \lambda_2 + \lambda_3 + \cdots = \sum \lambda_i \qquad (2.17)$$

Where,

λ_s= expected (average) failure rate of the system.

λ_i= expected (average) failure rate of load point i

- **The average outage time of the system, r_s (hr)**

$$r_s = \frac{(r_1 * \lambda_1 + r_2 * \lambda_2 + r_3 * \lambda_3 + \cdots + r_n * \lambda_n)}{\lambda_1 + \lambda_2 + \lambda_3 + \cdots} = \frac{\sum (r_i * \lambda_i)}{\sum \lambda_i} = \frac{U_s}{\lambda_s} \qquad (2.18)$$

If $\lambda_1 \lambda_2 r_1 r_2 << \lambda_1 r_1$ or $\lambda_2 r_1 r_2$

Where,

r_s= expected (average) outage time of the system

r_i= expected (average) outage time of load point i.

λ_i= expected (average) failure rate of load point i.

λ_s= expected (average) failure rate of the system.

U_s= expected (average) annual outage time of the system.

- **The expected (average) annual outage time of the system, U_s**

$$U_s = r_s * \lambda_s = f_s * r_s \qquad (2.19)$$

Where,

U_s= expected (average) annual outage time of the system.

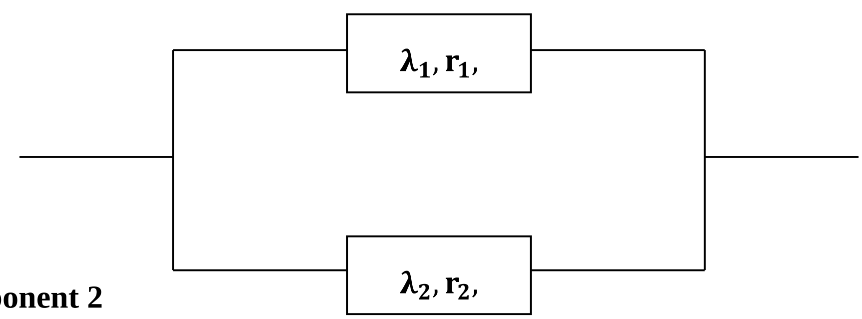
r_s= average outage time of the system.

λ_s= average failure rate of the system.

f_s= average frequency of the system.

i. **Meshed (Parallel) Distribution System: -**in the parallel structure for the system not to operate or for a load to be in failure mode; it must involve overlapping outages, i.e all the components in parallel experience independent outage at the same time for a power to be interrupted to load point at the far end. The evaluation of the reliability indices of the overlapping outage for a two components in parallel distribution system are with the use of the below equations.

Component 1



Component 2

Figure 6 **Mathematical Model for two components in parallel**

- **The expected(average) failure rate of the system, λ_s**

$$\lambda_s = \frac{\lambda_1 * \lambda_2(r_1 + r_2)}{1 + \lambda_1 * r_1 + \lambda_2 * r_2} = \lambda_1 * \lambda_2(r_1 + r_2) \qquad (2.20)$$

Since, usually $\lambda_1 * r_1$ and $\lambda_2 * r_2$ << 1

Where,

λ_s= expected (average) failure rate of the system.

λ_1= expected (average) failure rate of load point1.

λ_2= expected (average) failure rate of load point 2

r_1= expected (average) outage time of load point1.

r_2=expected (average) outage time of load point 2.

- **The average outage time of the system, r_s (hr)**

$$r_s = \frac{r_1 + r_2}{r_1 * r_2} \qquad (2.21)$$

Where,

r_s= expected (average) outage time of the system.

r_1= expected (average) outage time of load point1.

r_2= expected (average) outage time of load point 2.

- **The expected (average) annual outage time of the system, U_s**

$$U_s = r_s * \lambda_s = f_s * r_s \qquad (2.22)$$

Where,

U_s= expected (average) annual outage time of the system.

r_s= average outage time of the system.

λ_s= average failure rate of the system.

f_s= average frequency of the system.

Generally, the concept of reliability encircles all the efforts to be able to deliver electricity to all load points in the amount desired for utilization and within generally acceptable standards. Many utilities use the above mentioned reliability indices to track and evaluate the utility or a region or a circuit level of performance. While some commercial and industrial customers ask utilities for their reliability indices when location a facility. The IEEE1366 defined reliability indices are generally acceptable, which formulates them as useful benchmarks and as long term average system performance indicators.

Therefore, reliability analysis has to be carried out at regular interval during operation period of power system in order to monitor the customer requirement satisfaction at desired levels. The evaluation of reliability could be done through historical reliability assessment or predictive reliability assessment. Historical reliability 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. It mainly involves the collection of distribution system outage and customer interruption data and analysis of these data. Whereas, predictive assessment tries to estimate the future level of performance of the distribution system based on available failure data of the components in the system and system configuration. It provides a basis to select the best options among several computing alternatives. This assessment approach also provides the ability to quantify and forecast the impact of the reliability improvement alternatives and the reliability of future system expansion.

2.3 Factors Affecting Reliability of Distribution system

Various power system aspects affect the reliability of distribution system. Mainly it's very difficult to mathematically represent a failure source. Natural and human fault sources are stochastic and hard to model. Thus reliability issues and reliability measures to be taken become non-periodic. There are certain major conditions that influence power system reliability. The factors influencing power system reliability can be categorized in to four [17]

i. **Condition of System Equipment-** an ordinary power system integrate various components, such as lines, cables, transformers, breakers, switches, reactors, and capacitors. The condition of an electrical component can be a combination of three factors

- Performance of a piece of equipment/s:- depends on construction, manufacturing mounting and preventive maintenance

- Maintainability: - which is the possibility to detect failures, to reach and restore the component/s. The time to be taken for maintenance of any electrical component under faulty condition is affected by detection of the fault localization, accessibility, manageability

- Security of the maintenance: - depends on the availability of spare parts, maintenance equipment, and the availability and ability of the maintenance staff.

Hence; any electrical component can only be in one of the following two conditions; **Condition 1:** component is in function (in) or **condition 2:** component is in failed state or in repair (out). The following state cycle diagram illustrates the expected functional and outage times of a component.

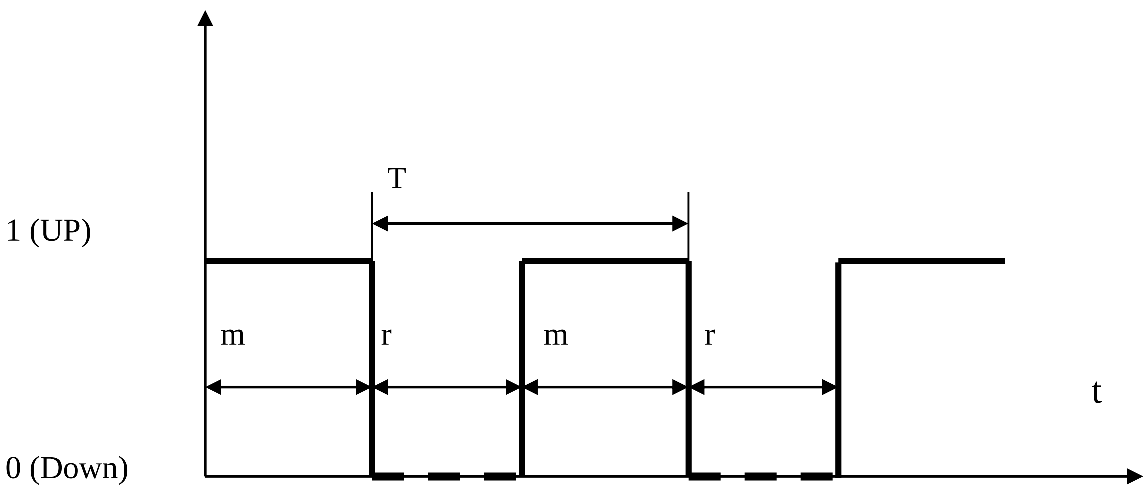


Figure 7 Component's Average State Cycle

Where, m=mean time to failure (MTTF) = 1/λ

R=mean time to repair (MTTR) = 1/μ

M +R=T = mean time between failures (MTBF) = 1/f

T = cycle time = 1/f

F= cycle frequency = 1/T

As seen from the figure the condition of an electrical component is described quantitative lt by using of two basic terms

- Failure rate (λ)
- Mean time to repair (MTTR)

Any single component outage may cause a partial or even entire outage. The availability of component functionally is characterized by these terms. Power system reliability 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 variable and parameters. Therefore, the different procedures take in to account the available or collected data and records of outages i.e. frequency, causes, locations, consequences, etc. that resulted in failure of system components and as a result interruptions power supply to the end-users.

Failure rates (λ) and means repair times (i.e. MTTR) are two basic inputs of various procedures for reliability assessment. In available literature, reported values of these two input data vary in wide ranges (based on the type of network and type of component), which will have strong impact on the outputs of the applied reliability assessment procedures. Failure rate modelling and repair time prediction is a very difficult task. Failure and repair rates of different equipment have different wear out curves and life time curves. Hence it's a challenge in estimating reliability of a system. Only general equipment operation assumption of failure rates, normal operation and wear out time can be modelled like that of bath- tub component life time curve, below in figure 8.

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*.

$$h(t) = \frac{F(t)}{R(t)} \tag{2.23}$$

Where f (t is the probability density function and R (t) is the 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.

$$\mathrm{H}\ (\mathrm{t}) = \int_0^t h(\tau)\mathrm{d}\tau \tag{2.24}$$

Hazard function is also called as hazard rate or instantaneous failure rate. It is very important for power system design engineers, repair and maintenance people. Hazard rate is a bathtub-shaped function of time as shown in figure 8.

Component failure can be divided into aging failures and chance failures [21]. Aging failure is a conditional failure that depends on the component's history. Figure 8 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. It 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 provide 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 in to service they are already in a reliable state. The occurrence of failures of a component will vary during its life time and is often being visualized using a ``bathtub curve`` as presented below. The life of components follows three major periods

1. Infant mortality period or decreasing failure rate period

$$h\ (t) = -\lambda t \qquad (2.25)$$

2. Useful life period or constant failure rate period

$$h\ (t) = \lambda \qquad (2.26)$$

3. Wear = out period or increase failure rate period

$$h\ (t) = \lambda t \qquad (2.27)$$

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.

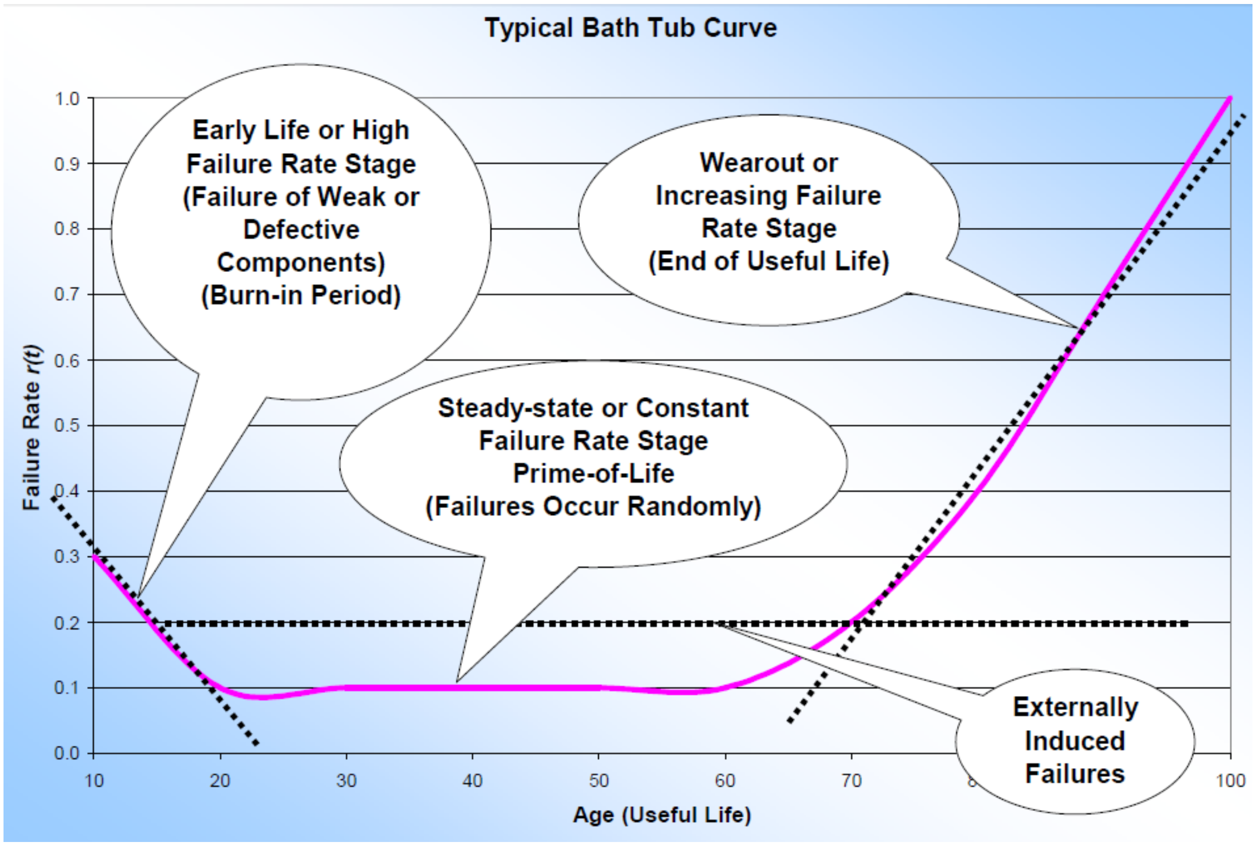


Figure 8 Curve of Representing Component's Life

The cumulative distribution functions (CDF) of the life of a component is given as:

$$F(t) = P(T \leq T) \qquad (2.28)$$

$$R(t) = 1 - F(t) \qquad (2.29)$$

The reliability is

$$F(t) = P(T > t) \qquad (2.30)$$

Thus, the hazard rate function can be expresses by equation 2.24 given above

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 as 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 usually prolong the process of customer down time.

i. **Time Varying Load**: - The load demands in distribution system vary from time to time, and each class of customers follows a different pattern. The loading condition changes the system reliability in two different ways. First, excess load speeds up system equipment aging. Overloaded equipment's are subjected to overheating and tension. This decrease the life time of the equipment because of increased failure rates. Second, loading condition change the power interchange capability among the adjacent circuits. For many load points, there are alternative sources of power if switching operations are permitted. If so; because of load increase, switching between system connections are made which also puts equipment to increase switching rate; sparks and overheating occur. Therefore, system reliability is influenced by the loading variation of distribution network [18]

ii. **Environmental condition: -** power system components are exposed to various weather conditions and hazards. Animals, motor vehicle accidents, rain; ice and tree contact can all lead to fault and failures. Environment dependent failures may be of short duration. However, during such events, the probability of failures of components increases dramatically. Some of the main environmental conditions are: -

    Weather: - weather has significant impact on reliability. It causes more outage in the electrical distribution system. Severe weather like wind, windy rain and heavy rain usually are the causes of the falling of distribution conductors and poles.

    The swinging of the line conductor can cause faults when they touch other. Lighting causes significant damage to all structures like metal poles and overhead lines. Therefore, to reduce interruption due to swinging, enough gaps must be maintained between conductors by increasing the span length of transmission poles. Also ground cables and surge arresters should be mounted on top of poles in order to protect these lines.

Human Errors: - there are many ways in which a human can cause interruption in the distribution system. These interruptions can be categorized into schedule or unscheduled. Scheduled interruption occurs when part of the radial distribution system has to have maintenance or be upgraded. During maintenance, it might require equipment to be de-energized and all the customers downstream of that equipment will be interrupted. Even when fed by an alternative source, these customers experience momentary interruption due to switching after de-energizing the circuit. The utility company shall notify its customers in advance prior to maintenance

Unscheduled interruption may occur due to human error, public unawareness, car accident, tree trimmers, or fire one example is accidentally operating wrong manual switch. Other errors include the falling of tree branches while trimming trees, also vehicle accident can cause a significant impact on failure rates of distribution lines and cause damage to the poles bringing power lines to the ground.

Also fire can cause significant damage to the distribution lines. Power conductors start to anneal and lose its electrical, as well as mechanical, strength due to fires. Different distribution conductors are mounted on wooden poles which are susceptible to fire and they may fall down due to the loss of mechanical strength due to the heat. If fire catches wooden poles and reaches the top of poles, it may damage line conductors as well as electrical instruments, like transformers, circuit breakers etc. Using fences and fire resistant poles may reduce the impact of these factors.

Birds and Animals: - Birds and large animals like cows, horses and hyena can cause problems and hence, impact the reliability of the electrical distribution system. Birds cause faults in systems by bridging the conductors with their wings. To prevent roosting, protective anti-roosting structures, like cones structure, should be placed on top of poles. Also large animals usually lean on or rub on poles or guy wired making poles lean and this reduce the reliability as the chance of collapsing poles increase. Building fences around the poles can be the solution in such reliability problems.

Many utility companies have given increased attention, especially with weather dependent failures. It is difficult to develop an accurate model for the catastrophic environment since its probability of occurrence and the impact range can only be based on a rough estimate. Usually weather condition modeling is better designed than the other environmental conditions since historical weather data is always available.

iii. **Distribution System Configuration**: - all distribution of electrical energy is done by constant voltage system. To distribute power to consumers at constant voltage levels and with degrees of reliability that is appropriate to the various type of uses one of the below discussed distribution system configuration is used. The pros and cons of each of these configurations with respect to reliability are discussed as below.

Radial main distribution system*:* - Large amount distribution circuits available are radial configuration. Radial circuits have advantages like simplest distribution circuit, easy voltage control, easier prediction and control of power flows and lowest initial cost over networked circuits.

A radial system is connected to only one source of supply and is exposed to many long interruption possibilities. The most important of which are those due to overhead line or underground cable failures or transformer failures. Thus, it is known to suffer from drawbacks like

- The end of the distributors nearest to the feeder point will be loaded heavily.
- The customers at the far end of the distribution may experience serious voltage fluctuations when the load on the distributor fluctuates.
- The customers are dependent on a single feeder and single distributor. Therefore, any fault occurring on the feeder distribution interrupts supply to the customers who are far away from the substation. Thus the reliability of this system is low.

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 return to the substation. This system has advantage like very less voltage fluctuation at customer side and increased the service reliability.

Interconnected distribution system: - when the feeder ring is supplied by two or more than two generation stations or substations, it is referred as interconnected system [14]. This type of system configuration increases the service reliability and any area fed from one substation can be fed from the other substation in the case of peak load hours resulting increase in efficiency of the system.

Redial network are mostly vulnerable to failure and power outage. Any failure in system component results in entire power failure. Interconnectivity between distribution networks enables closing and opening of sectionalizing switches and ties switches. This switch also influences the system reliability as failure at some point in the network can lead to outage in other part of the network

Utilities in a venture to supply power at an economic price with and adequate level of reliability, often faces challenges to balance the high level of reliability at relatively low cost, since these two aspects counters each other. It cost money for a utility company to improve reliability of its system. The money spent is usually for use of new electric power system facilities, and making improvement introduction and use of electricity. This is however; if the utility company is willing to invest to improve reliability of its system i.e. if significant benefit regarding electric power reliability can be attained. Decision-making depends on many aspects such as social, economic, environmental and government considerations etc. making it a difficult task.

2.4 Reliability Improvement Methods

The main purpose of reliability data quantification and information extraction is to take reliability improvement measure. Reliability of distribution system can be enhanced by increase distribution system protection, decrease equipment system automation, installing switching and reclosing devices and system reconfiguration [18]

Increase in protection device gives option of selective protection system thus; any failure in some part of distribution network may not have an effect on other portion of distribution network. For many momentary faults occurring in distribution system, installation of re-closer in overhead lines can avoid sustained interruption by reconnection line outages after self-cleaning of the fault. This way restoration time of momentary outage event will be small i.e. the duration that an outage will last will be diminishing hence, reclosing and switching devices proved patterns to help to localize fault points and disconnect faulted line. This achieves pushing a fault event to affect a few numbers of customers only. Sectionalizing devices also enable way of choosing supplying path during contingency.

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. These topologies provide alternative path for power flow. Configuration can be important during maintenance and permanent fault event, during disconnection of a portion of distribution system for maintenance. Existence of alternative way of supplying the customer enables reconfiguration, hence customers experience little outage time. Also, network reconfiguration capability of a system enables customers' power access and reduction in un-served energy of the system. Sectionalizing and tie switch system option create path searching alternative with the existing laterals. This improves supply reliability and power availability. This is also related to fault searching mechanism with remote control capability to identify which line to connect and disconnect by changing status (ON/OFF) of sectionalizing switches, network reconfiguration is established. Such capability improves reliability by reduce duration and frequency of interruption [11]

Chapter 3 Modeling and Reliability Analysis of Sheno 15kV Distribution Feeder

3.1 Introduction

Reliability with regard to power distribution systems is the probability that an item or collection of items like feeders, transformer, insulation, feeder pillar, distribution line, poles, fuse, isolator, connections etc. will perform satisfactorily, under all conditions during a given period of time. Quantitatively, reliability is the probability of success or availability of supply. This is performed by defining reliability through indices. Reliability indices are parametric quantities used to assess the performance levels of electrical power distribution systems so as to make it suitable for scientific analysis. These indices typically consider such aspects as the number of customers interrupted, the duration of the interruption measured in minutes or hours and the frequency of interruptions. The reliability of a distribution system is said to be described by a complete set of indices such as SAIFI, SAIDI, CAIFI, CAIDI, ASAI, ENS, EENS etc. One of these indices is not sufficient to completely measure reliability of power supply since each focus on specific aspect of reliability. In this thesis, the first seven indices are used to assess and quantify the reliability of electric power distribution system in Debre Berhan town. This is performed analytically i.e. direct numerical calculation and by simulation using a helpful software named ETAP; a powerful electrical engineering analyzer and management tool established as a world leader in power system design, analysis, and monitoring [8].

For computing common reliability parameters in the process of evaluating any simple radial system; the subsequent steps will be followed

1. Get feeder topology.
2. The number and location of the switches, load points, and line segments.
3. Average failure rates of each segment and load lines.
4. The number of customers connected and the average consumption of each load.
5. The average repair time of automatic or manual switches.
6. Identify switches to operate to isolate faults.
7. Total switch operation time.
8. Identify loads affected by feeder outage.

9. Compute number of customers with power outage.
10. Calculate reliability indices.

Since the distribution systems in Debre Berhan are basically designed, constructed and operated in radial system the above steps are necessarily followed in the next sections

3.2 Overview of Debre Berhan Distribution System

Electric utilities, like other service organizations, rely on customer surveys to assess the quality of their services and customer relations. Customer ratings for quality and reliability of service reflect their sentiments about frequency of outages and duration of outages. The area under study in this thesis is a small town known **Debre Berhan** where all types of electric power consumers i.e. residential, commercial and industrial are available. The area is chosen for this study as the town is nowadays becoming more populated and more businesses and commercial centers and industries are being located demanding the electric power utility more and more electric power.

Debre Berhan, one of the oldest cities of Ethiopia, was founded by **Emperor Zara Yaqob in 1456**. It is a city and woreda in central Ethiopia located in the Semien Shewa Zone of the Amhara Region, about 120 kilometers north east of Addis Ababa on the paved highway to Dessie. The town has a latitude and longitude of 9°41′N 39°32′E / 9.683°N 39.533°E / 9.683; 39.533Coordinates: 9°41′N 39°32′E / 9.683°N 39.533°E / 9.683; 39.533 and an elevation of 2,840 meters. It was an early capital of Ethiopia and afterwards, with Ankober and Angolalla, was one of the capitals of the kingdom of Shewa. Today, it is the administrative center of the Semien Shewa Zone of the Amhara Region.

Figure 9 Geological Map of Debre Berhan

Table 1 Basic Information Regarding Debre Berhan

Country	Ethiopia
Region	Amhara
Zone	North Shewa
Founded	7 March 1456
Founded by	Zara Yaqob
Total Area	75 Km^2
Elevation	2840 m
Population	
Total	92,887
Density	1239/ Km^2
Households	14,547

Debre Berhan received electricity in 1955, during the Emperor Haile Selassieregime, when a 90 kW hydro-electric power station was put into service; by 1965, the installed electrical capacity in the town was 125 kVA and annual production 103,000 kWh.

Currently the town has eight elementary, three high and two preparatory government owned schools and seven elementary and one private high schools. One TVET, one Poly-Technic college, one Health science college and a university also exists. There exists one main government owned hospital, two health center one private hospital and about eleven private owned clinics. Industry in the town is growing fast in recent years; factories of different kind are being constructed and put to work, some of these are Dashen Beer Factory, Habesha Beer Factory, Aqua-safe Water Bottling Factory, Debre Berhan Wood Work Factory, Samsung Refrigerator Assembling Factory, and the well-known Debre Berhan Blanket Factory. The city is also known to have wind energy potential. Presently about 400 MW of this potential is to be exploited by a company called Terra Global Energy Developers, LLC. The project has been developed and is under construction since 2014G.C

Currently, electric power in Debre Berhan is provided by **Ethiopian Electric Services office,** Debre Berhandistrict office. The district has one bulk substation in the city that is fed from "Legetafo" substation with a 132 kV three phase power line. The town's electric power service has two branch districts; district no 1, administrate two Kebeles' and district no 2, administrate seven kebeles' electric power demand.

The district office consisting of mainly three Technical Advisors, four Emergency Workers and eight-watt meter Readers. The most common major problems so far faced by the office are overload of old distribution lines and transformers, existence and falling of old poles and distribution lines. A crew of workers is organized from the district office workers and Ethiopian Electric Services office workers i.e. from head office, Addis Ababa, and tried to observe and study existing problems. After gathering enough data, the crew finalized that the following points are must.

- Upgrading of the existing overloaded transformers such as 315 kVA to 630 kVA, 200 kVA to 315 kVA and one 100 kVA to 200 kVA
- Replacing the old poles and lines by new and
- New transformers are needed for those customers who are from center from distribution.

Table 2 Number of Electric Power Customers in Debre Berhan

Number and Type of Electric Power Customers in Debre Berhan Town		
Residential	**Commercial**	**Industrial**
13,262	1600	191

The distribution system of Debre Berhan city follows what we call a radial system consisting of three main sections identified as

i. A primary section- provides the main power connection to the substation from a high voltage source; **"Legetafo"** in 132 kV, three phase line. This circuit is provided with switching and interrupting devices.

Figure 10 Debre Berhan Distribution Substation

ii. A transformer section - since a distribution substation is the delivery point of electric power in large industrial or commercial applications, it consists of one or more power transformer banks together with the necessary voltage regulating equipment, current transformers, buses, and switchgear.

In Debre Brehan, the incoming feeder voltage level is stepped-down to lower levels by distribution substation power transformers. There are two power transformers that are located for this purpose at the distribution substation. As the high voltage line enters the power transformers with three windings it is stepped-down to 33 kV on one side and 15 kV in the other.

iii. A secondary section- primary of distribution feeders originates here at the secondary bus of the distribution substation power transformers. The circuit of primary distribution system consists of portion of power network between the distribution substation and the utilization transformers.

The general distribution scheme at the substation is presented by a one line diagram as below.

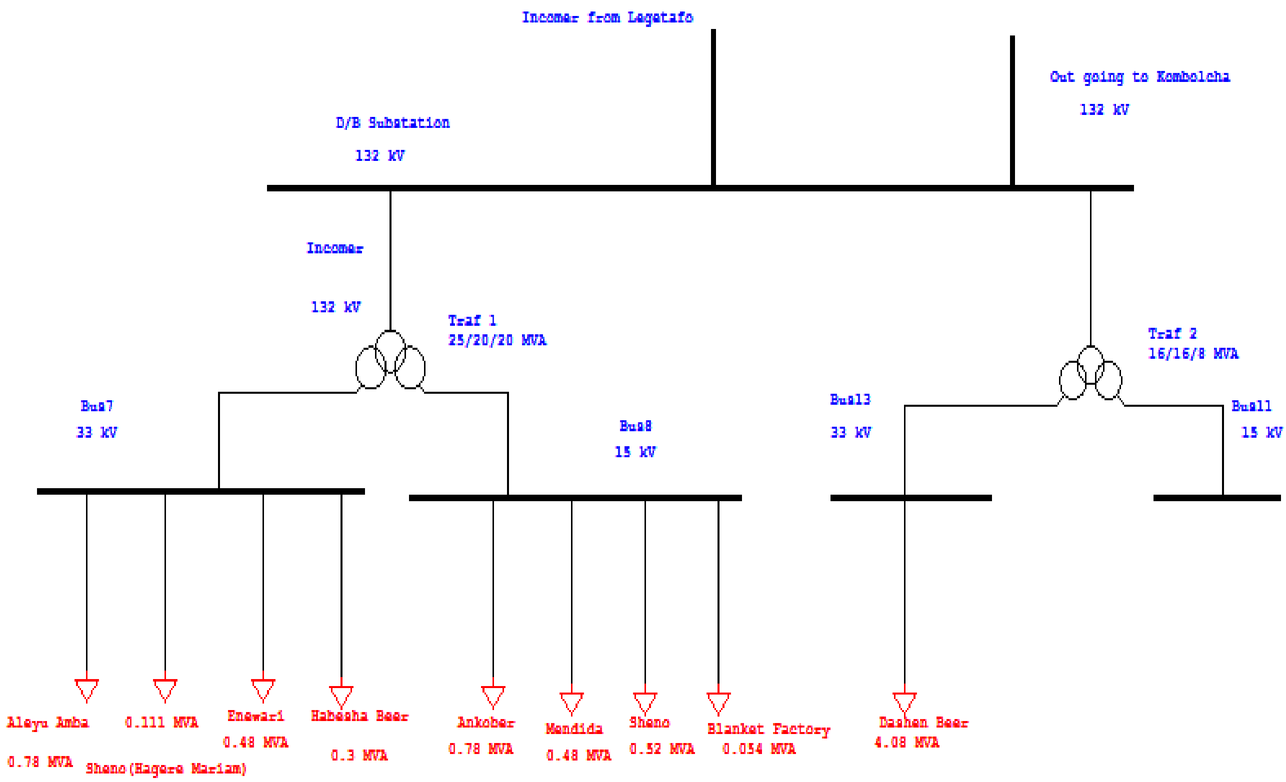


Figure 11 General Scheme of Debre Berhan Town Distribution System

As can be seen from above figure, currently, there are eight distribution feeders for industrial, commercial and residential purpose and one distribution feeder that is being used for primary load i.e. Dashen Beer Factory. The loading conditions of these feeders are presented below.

Table 3 Feeders Outgoing from Debre Berhan Substation

Nₒ	Name of the feeder	Feeder Line Voltage(kV)	Feeder Load Current(A)	Load (MW)
1	Ankober	15	120	2.4
2	Mendida	15	90	1.8
3	Sheno 15 kV	15	120	2.4
4	Blanket Factory	15	90	1.8
5	AleyuAmba	33	90	3.96
6	Sheno(Hagere Mariam)	33	95	4.26
7	Enewari	33	90	3.86
8	Habesha Beer	33	87	3.96
9	Dashen Beer	33	175	7.92

The table below shows the different rating of transformers used under each feeder.

Table 4 Number and Rating of Transformers under Individual Feeder

Feeder Name	Transformer Capacity(kVA)									
	25	50	100	160	200	315	630	800	1250	Total
Ankober	3	10	5	-	13	-	-	-	-	31
Mendida	3	5	7	1	8	1		1		33
Sheno 15 kV	3	2	6	-	4	5	1	4	-	25
Blanket Factory	-	-	-	-	-	-	-	-	2	2
AleyuAmba	5	8	6	-	5	-	1	1	-	26
Sheno(Hagere Mariam)	6	3	5	-	-	1	-	-	-	15
Enewari	6	10	5	-	14	1	-	-	1	37
Dashen Beer										

Due to the time and resource limitations, the Debre Berhan town distribution system reliability analysis has to be performed on a restricted area or a feeder. As mentioned before, there are eight radial feeders that serve an electrical power demand for all types of customers and one feeder that is used for industrial customer named Dashen Beer Brewery. Out of these nine feeders available; **Sheno 15** kV **Feeder (F5)** has been chosen as a case study for reliability analysis in this thesis. This feeder is selected due to its better availability of data in terms of distribution scheme, type and rating of distribution system components, interruption data i.e. number and duration of outages and causes of interruptions.

It is observed and reported that the most common electrical power distribution system ofDebre Berhan city has been under frequent interruptions due to faults because of reasons like

- Distribution system Equipment failures
- Human errors and Animal contact
- Line and feeder overload
- Weather conditions

Insulators, lines, poles and arresters usually fail due to many reasons like aging, over load, lack of preventive maintenance, shortage of replacing equipment or lack of spare parts for maintenance after fault. Population of the area can be blamed for causing many interruptions. Tree trimmers have frequently caused faults by bringing down distribution poles and lines due to lack of unawareness and negligence. Car accidents have caused damage to many poles and lines along with associated distribution system components. In addition, lack of adequate resource has setback the idea to expand the existing distribution system in order to accommodate the increasing demand for electricity. This has resulted in line and feeder overloads; which in turn has caused many component overloads and finally failures.

As the feeder under study i.e. Sheno 15 kV feeder is among the feeders present in Debre Berhan town electric power distribution system; then it has been observed that most of the existing interruption problems and their causes in the distribution system of the town are also observed in this specific feeder. Interruption data of the feeder along with other two feeders for the year 2014 G.C has been obtained from the utility and presented in the appendix. With the help of these data the main causes that resulted in these interruptions can easily be summarized with the help of the chart below.

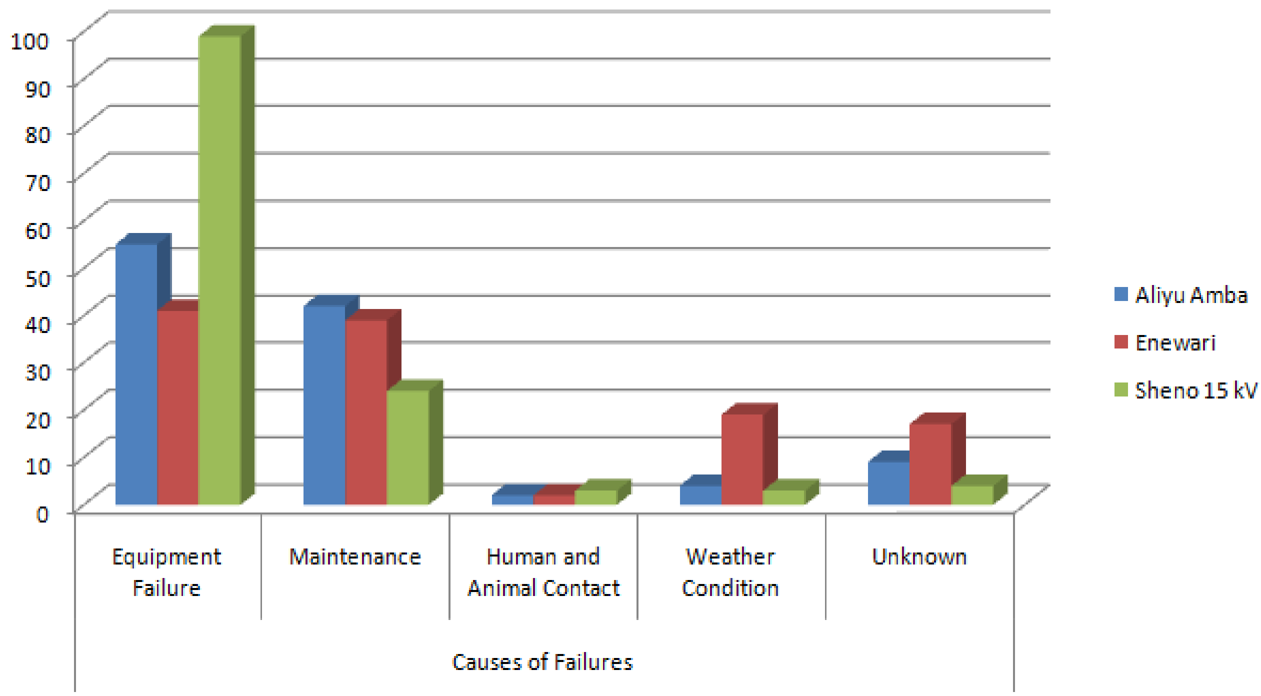


Figure 12 Interruptions Causes for Aliyu Amba, Enwari and Sheno15 kVPower Distribution feeders

3.3 Evaluation of Reliability Indices of Existing Sheno 15 kV Distribution Feeder

Reliability engineering with regard to distribution systems involves gathering huge volume of huge failure data on number of outages, causes of outages, number and type of customers served, type and rating of equipment's' involved etc.

Collection of data regarding reliability of Debre Berhan town electric power distribution system has been performed first by contacting the responsible personnel from to the utility i.e. EEU district office in the town for an informal discussion to inform them the purpose of this thesis and requesting for assistance in providing the required data which might be helpful in order to carry out the work. Then making site surveys to the town's electric power substation and distribution systems was necessary also for reliability study. All these collected has been presented underneath.

Table 5 Type of Customers Under Sheno 15 kV Feeder

Type of customers	Load points
Residential	LP1,LP2,LP3,LP6,LP7,LP8,LP9,LP10,LP12,LP14,LP16, LP19,LP20, LP21,LP22
Commercial	LP4,LP5, LP11,LP13, LP15,LP17, LP18,Tele
Industrial	ASK Flower,Crasher1,Crasher2
Gov. & Inst.	D/B University
Office & Bldg.	Tele2

Table 6 Number of Customers and Average Load at Each Load Point Under Sheno 15 kV Feeder

Load Point	Distance from Substation (km)	Number of Customers Connected	Average Load Connected(MVA)
LP1	16.4	87	0.05
LP2	22.9	84	0.05
LP3	23.65	102	0.09
LP6	18.5	74	0.03
LP7	18.5	74	0.03
LP8	18.5	98	0.09
LP9	18.5	211	0.65
LP10	23.8	101	0.09
LP12	27.2	104	0.1
LP14	28.45	159	0.31
LP16	31.4	113	0.03
LP19	36.7	108	0.2
LP20	36.7	149	0.31
LP21	36.7	137	0.31
LP22	36.7	188	0.63

LP4	0.5	20	0.09
LP5	6.5	16	0.09
LP11	26.75	41	0.31
LP13	27.45	32	0.09
LP15	28.9	62	0.75
LP17	31.7	41	0.19
LP 18	31.95	6	0.03
Tele	2	1	0.02
D/B University	0.5	1	0.31
Tele 2	13.45	1	0.19
Ask Flower Industry	0.45	1	0.795
Crasher 1	9	1	0.2
Crasher 2	13.45	1	0.795

The outage data for the feeder consists of information on each failure event of the feeder for the period of two years; from January to December, 2014 and 2015 G.C. i.e. daily outages along with possible causes and duration of outages are presented in the Appendix A1 and A4.

Using the model developed in the previous section and the data available in the appendix, failure rate, MTTR and annual outage duration for the feeder can be calculated using the equations 2.1, 2.2 and 2.3 respectively. Since the recorded data available does not give the specific location of interruptions, we have to assume that all section of the feeder contributed to the interruptions occurred equally. To estimate the failure rate of the line per kilometer, the total number of outages should be divided by the feeder length as indicated below.

$$\text{i. Failure rate}(\lambda)\text{ Per Km} = \frac{\text{Number of Interruptions}}{(\text{Total feeder length}) * (\text{Number of Interruption years})}$$

$$= \frac{133 + 117}{(36.7) * (2)} = \frac{250}{73.4} = 3.406 \ \frac{\text{f}}{\text{Km. year}}$$

$$\text{ii. MTTR} = \frac{\text{Total Duration of Outages}}{\text{Total Number of Outages}}$$

$$= \frac{490.673 + 210.681}{133 + 117} = 2.805 \frac{\text{hrs}}{\text{f}}$$

iii. Average Annual outage time$(\mathrm{u}) = (\lambda * \mathrm{MTTR})$

$$= ((3.406 * 36.7) * \ 2.805) = (125 * 2.805) \ \ = 350.625 \ \frac{\mathrm{hrs}}{\mathrm{year}}$$

We can see from the one-line diagram of the feeder that there exist three switches which tend to divide the feeder in to four load sections at different distance from the substation. These sections will contribute to the interruptions recorded differently changing the above indices and other load point indices. Using the data available regarding these sections, the table shows us how.

Table 7 Computed Basic Load Point Reliability Indices, for the Years2014 and 2015 G.C on Sheno 15kV Feeder

Section Number (i)	Section Length (km)	Section Distance from Substation, (km)	Number of Customers	Section Peak Load, L_{ipeak} (MVA)	Section Failure Rate, λ_i(f/year)	Annual Outage Duration, r_i(hr)
1	6.5	6.5	39	1.308	22.139	62.011
2	17.15	23.65	631	2.077	80.552	225.626
3	3.8	27.45	380	0.693	93.495	261.879
4	9.25	36.7	963	2.756	125.00	350.125
Total	36.7		2013	6.834		

From the above calculated load point reliability indices and all the necessary data available system reliability indices like SAIFI, SAIDI, CAIDI, ASAI, ASUI, EENS and AENS can easily be calculated analytically using equation 2.7 through 2.15

Table 8 Computed System Reliability Indices for the Years 2014 and 2015 G.C on Sheno 15kV Feeder

System Indices	Value
SAIFI	103.127 f/customer. year
SAIDI	288.859 hr/customer. year
CAIDI	2.801 hr/customer interruption
ASAI	0.967Pu
ASUI	0.0329 Pu
EENS	1356.93MW hr/year
AENS	0.674 MW hr/customer. year

3.4 Modeling of Existing Sheno 15 kV Distribution Feeder Using ETAP

Feeders of distribution systems deliver power from distribution substations to customers. A feeder normally begins with a feeder breaker at the substation point, and the main components of a feeder include lines, poles, a breaker, switches and fuses, transformers, and insulators. The selected feeder in this thesis is a simple radial distribution feeder that serves an electric power for a total of 2013 customers of different types under several load points. It is mentioned that the first step in reliability assessment is to define the boundary of the network (feeder) under study. In doing so, it has been found necessary to give main descriptions and if possible the one-line diagram of the electrical power distribution system topology the feeder under assessment. (figure 14) drawn using the software ETAP.

ETAP is a fully integrated ac and dc electrical power system analysis tool. The reliability analysis using ETAP provide distribution system reliability level for radial and looped systems with a very efficient algorithm [14]. This algorithm helps accumulate reliability indices for each load point from each component giving outages to the load point. In doing so the underlying statistical assumptions and input parameters are necessary

Main Statistical Assumption

- Assumes 100% reliability performance from generation and transmission.
- All failures are statistically independent.
- All failures are repaired before next fault occurs.
- All switching devices operate successfully when required
- Switching devices can be opened whenever possible to isolate a fault.
- Power supply can be restored to provide power to as many load points as possible using the appropriate switching action.

Input Parameters

- Name, type and rating of distribution components like power grid, transformers, bus bars, transmission lines, loads and fuses.
- Failure rate and MTTR of each component.
- Length of transmission lines.
- Number of loads under each lumped load.
- Load sector of lumped load.

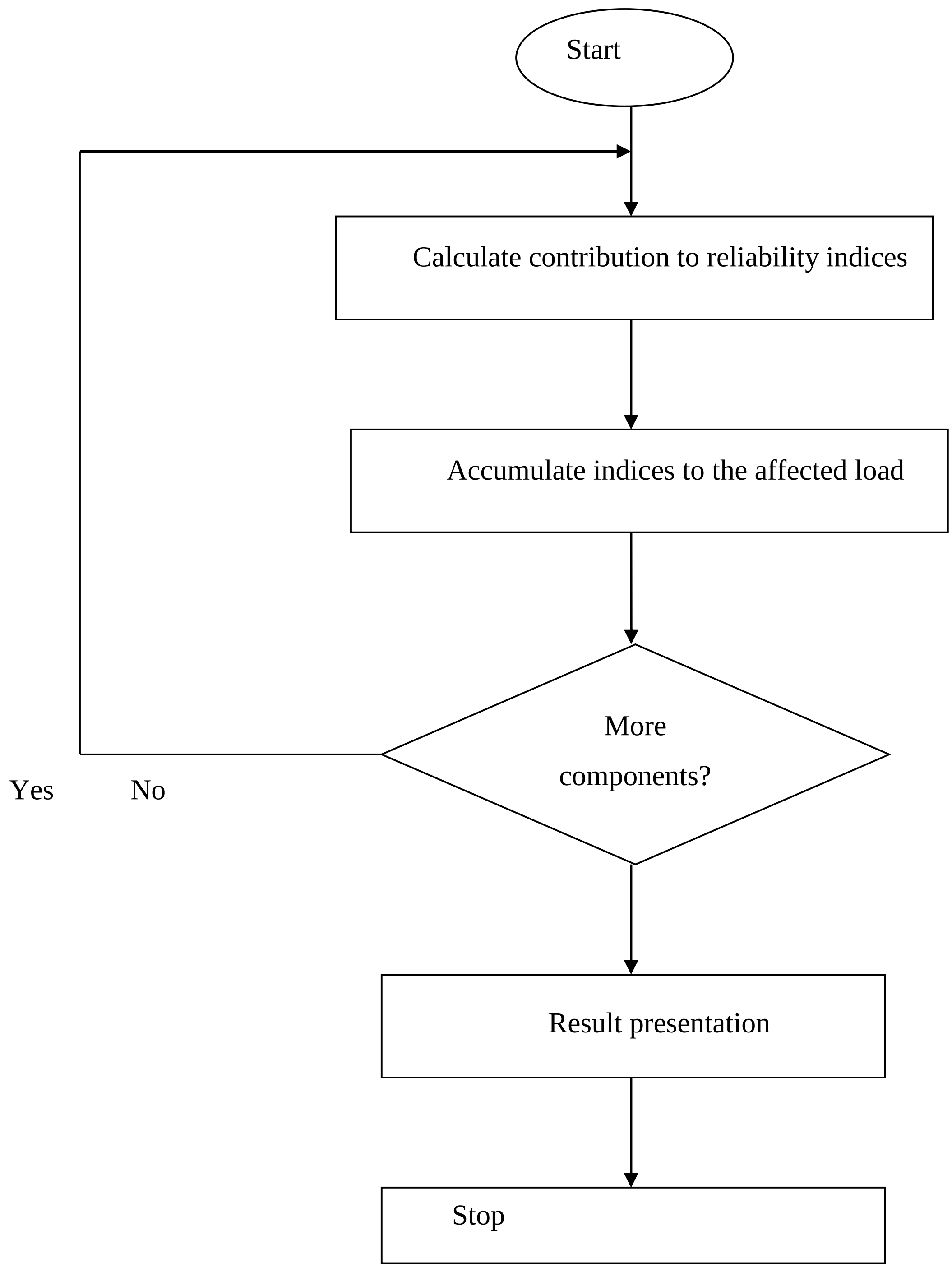


Figure 13 Flow Chart of ETAP Algorithm

These inputs for each component present under the distribution feeder along with the one-line diagram of the distribution system under study are now sufficient for modeling the feeder and afterward to carry out reliability analysis using ETAP by obtaining the total accumulated reliability indices from the fault contribution of each component available.

As can be observed from the one-line diagram on figure 14 in general Sheno 15 kV distribution feeder can be described as: -

- ❖ Radial (series) network.
- ❖ No reserve (redundant) connections.
- ❖ All faults are isolated by the upstream circuit breakers, by the first or the second depending on the probability of malfunction of the circuit breaker.

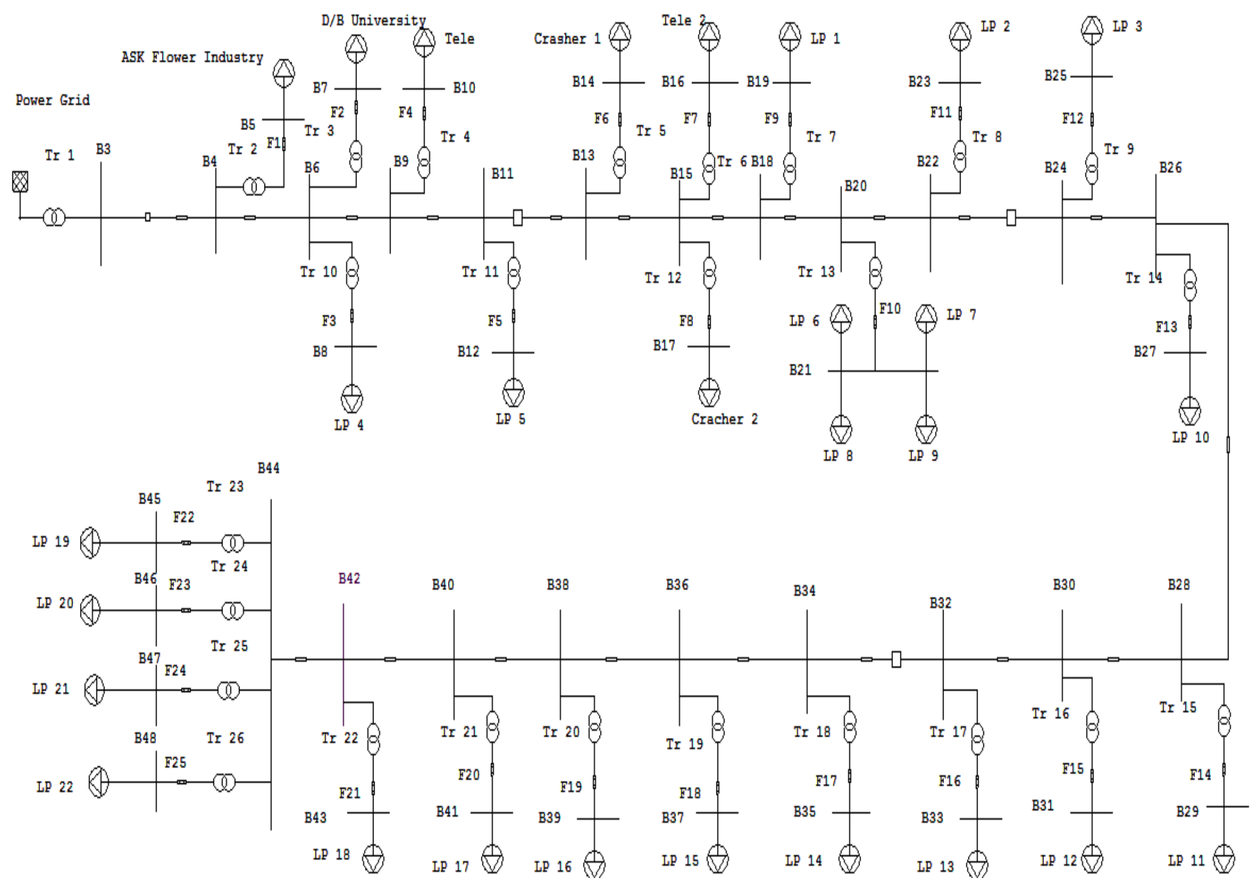


Figure 14 One Line Diagram of Sheno 15 Kv Feeder Network on ETAP

3.5 Reliability Evaluation of Existing Sheno 15 kV Distribution Feeder Using Software Model

The main objective of this simulation method is to perform reliability analysis of the present existing distribution system of the feeder namely Sheno 15 kV distribution feeder by computing common reliability indices and see to whether or not these indices are near to the accepted benchmarks.

Now it is time to use ETAP for the purpose of reliability analysis by simulation method. Reliability analysis and assessment using ETAP software is a very efficient analytical algorithm for radial and looped system through modeling [7]. In thesis, it is desired to evaluate the reliability of a single feeder specifically, that of Sheno 15 kV, in doing so it is a must to model the feeder under study by modeling of the components involved like the power supply, the feeder itself with a sample feeder line, the cumulative load of load points, the number and rating of transformers, bus bars, protective and switching devices as shown in the one-line diagram below. Then all the necessary model component parameters are defined and calculated reliability characteristics of each component involved are inserted for analysis.

Using the model developed earlier (figure 14) and all the above listed input parameterssimilar results with the analytical calculation have been obtained for the existing configuration of Sheno 15 kV distribution feeder by simulation method using ETAP as shown in the appendix (Appendix B1).

Having found the results of both methods now it is time to make judgment and move to the next step if found necessary. Reliability benchmarks make this task easy since they are the standards against which analyzed reliability indices are compared with by defining the minimum accepted reliability indices a feeder or a distribution network is said to be reliable enough [1]. Lower values of reliability indices i.e. SAIFI, SAIDI, CAIFI, CAIDI, indicates that a feeder or a distribution system is reliable while higher values of those indices indicates that poor reliability of a feeder or a distribution system. Below is a table presenting the reliability indices benchmarks of different countries along with the values obtained for Sheno 15kVfeeder.

Table 7 Reliability Indices Benchmarks

No	Country	SAIFI (f/customer.yr)	SAIDI (hrs/yr)	CAIDI (hrs/customer interruption)
1	Egypt	1.33	57.27	42.97
2	India	4.57	12.2	2.67
3	Japan	0.25	3.86	5.58
4	Kenya	22.5	216.3	9.61
5	Nigeria	1.24	2.71	2.20
6	Turkey	10.92	8.83	0.81
7	**Sheno 15 kV**	**103.127**	**288.859**	**2.801**

From the table above, it is easy to see that the values of all of Sheno 15 kV distribution feeder show an immense variation when compared with others; indicating poor reliability. This validation of reliability of the existing distribution feeder under study helps to evaluate the performance in service continuity of the serving utility in the town since the configurations of all the feeders of the town are similar, symptomatic of the necessity for the application of reliability improvement methods.

Chapter 4Simulation Studies and Analysis of Results

4.1 Introduction

The main target of any distribution system reliability analysis is defined by the two general categories of any distribution system reliability analysis i.e. frequency and duration of customer outages. In the case of poor reliability like this study, the key concept exists in focusing in these two parameters. From the available wide choices of reliability improvement techniques, the choice should tend to decrease the frequency of interruption since it is found to be much higher from the values of the benchmarks. The frequency of outage of an electric power is influenced by factors such as system design, capital investment, maintenance, and weather condition. Focusing in one of these factors helps in minimizing the frequency of outage and in turn for reliability improvement. It has been mentioned earlier that the location that is Debre Berhan have wind power resource. This thesis tries to ensure reliability of Sheno 15 kV distribution feeder by making use of this resource.

4.2 Reliability Improvement Using Wind Power Generator

According to Terra global energy company, there exists 400MW wind power resource at a place named Kundi, about 30km from Debre Berhan. The company is currently locating turbines with 2MWpower each. The power generated is planned to be supplied to Debre Berhan town. Therefore, making use of this resource as an additional (redundant) power source would seem a more fitting solution to the problem at hand without investing too much money. To see how the existing distribution feeder under study reacts to the proposed method of reliability improvement let us use one of the wind turbines with 2MW transmissible power and a nominal voltage of35kV.

4.3 Reliability Evaluation of Sheno 15kV Distribution Feeder with Wind Power Generator

Now the question is where this wind energy resource should be connected in the feeder to make it reliable solution by improving the values of main system indices like SAIFI, SAIDI, CAIDI, ASAI, EENS and ECOST. In the reliability analysis performed on the feeder under study we can easily see that as the load point is further away from the power grid average failure rate and annual outage increases while average duration time tends to decrease this is due to the failure rate of the feeder is given as per kilometer. The answer to the earlier question of optimal location for the connection of the wind power generator lies in this key observation.

As can be seen in the one-line diagram of the feeder below there are four possible locations for connecting the wind power resource. By making a connection to these possible locations and simulating with the help of ETAP an optimal location for improving system reliability will be looked for. At a point of connection between the wind turbine and the grid a circuit breaker for the disconnection of the whole wind farm is found necessary and a voltage transformer to step down the transmitted voltage level to the voltage level of the feeder understudy i.e. 15 kV are necessary. A Short Circuit analysis is used below to determine the magnitude of short circuit current the system is capable of producing. This magnitude is then used to select an overcurrent protective device (OCPD), The wind power generator is known to be 2MW at 0.8 power factor and nominal voltage 35 kV at 50Hz.

The Generator KVA = 2000kW/ 0.8 = 2500KVA

Full load current(FLC) = 2500KVA/(1.73 * 35kV) = 41.288A

Short circuit current(Is.c) = FLC/X', Where X'' is generator sub transient reactance= 0.16 Pu Therefore, the short circuit current (Is.c)= 41.288A/ 0.16 = 258.05A.

The circuit breaker which is needed in the connection of the wind power generator to the feeder has to have an interrupting rating greater than260 A.

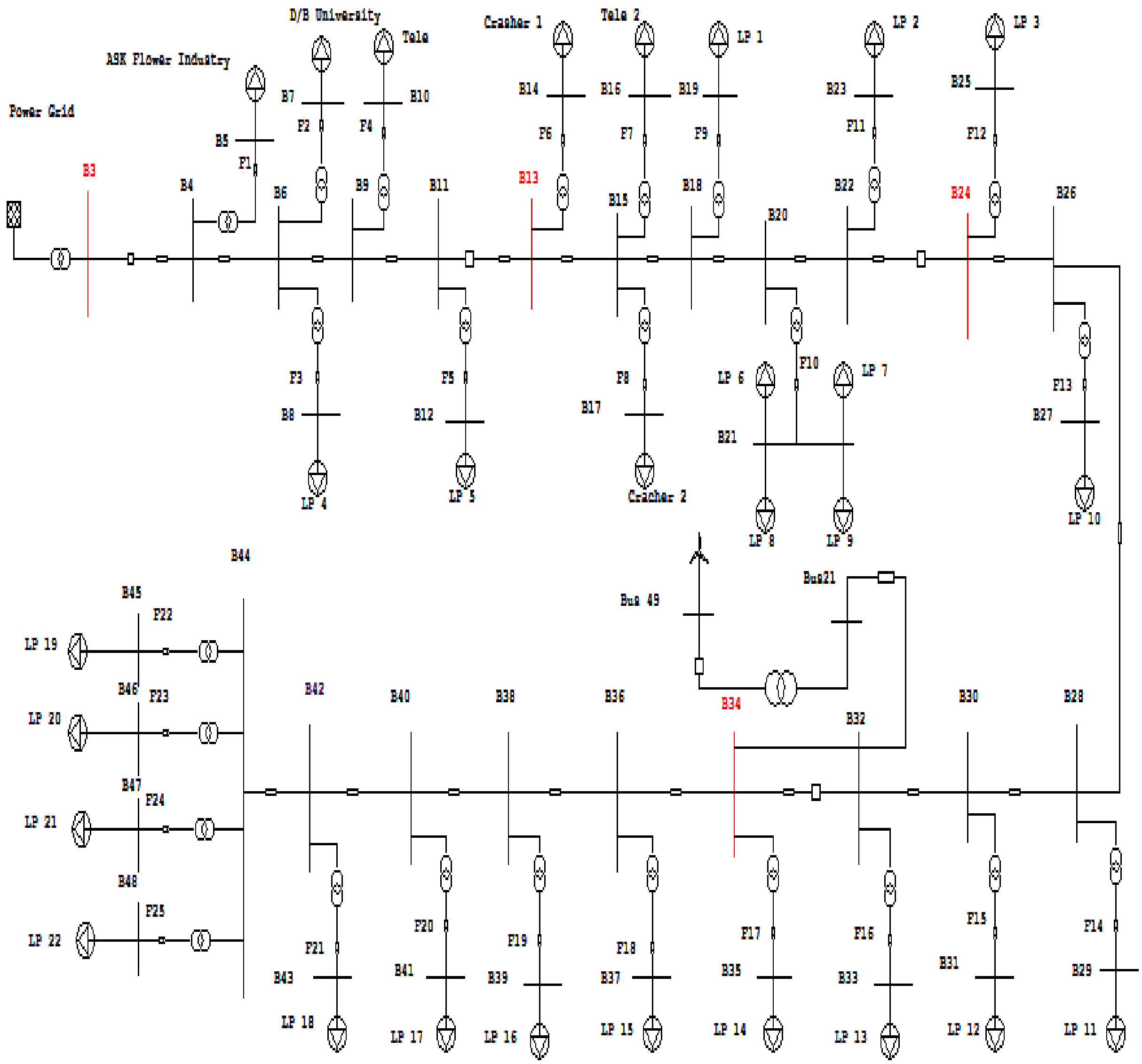


Figure 15 One Line Diagram of Sheno 15kV Feeder Showing Possible Locations for Locating of the Wind Power Generator

Table 8 Simulation Result for Possible Locations of Wind Power Generator

System Reliability Indices	Proposed Locations of Distributed Wind Power Generator				
	Base case	**At B3**	**At B13**	**At B24**	**At B34**
SAIFI (f/customer.yr)	103.1271	104.6271	82.888	43.4468	36.9719
SAIDI(hr/cust.yr)	289.7872	301.7872	240.5457	127.2794	107.6154
CAIDI(hr/cust.interr)	2.81	2.884	2.902	2.930	2.911
ASAI(Pu)	0.9669	0.9655	0.9725	0.9855	0.9877
EENS(MW hr/yr)	1361.01	1426.607	1137.931	666.376	579.565
ECOST ($/yr)	5,820,054	6,190,229	4,892,543	3,080,269	2,758,927

4.4 Analysis of Results

Comparing the simulation result obtained for all possible locations of distributed wind power (Appendix B1 through B5) and observing the column chart below, it is straightforward to notice that the values of system indices did not show that much of improvement when the wind resource is connected near the main supply, while connecting the resource at the other end tend to decrease the system indices. Hence it is advisable to connect the distributed wind power resource at one of these locations, preferably at bus bar 34(B34). At this location the value of all main system reliability indices improved tremendously from the values of the base case and all other possible locations.

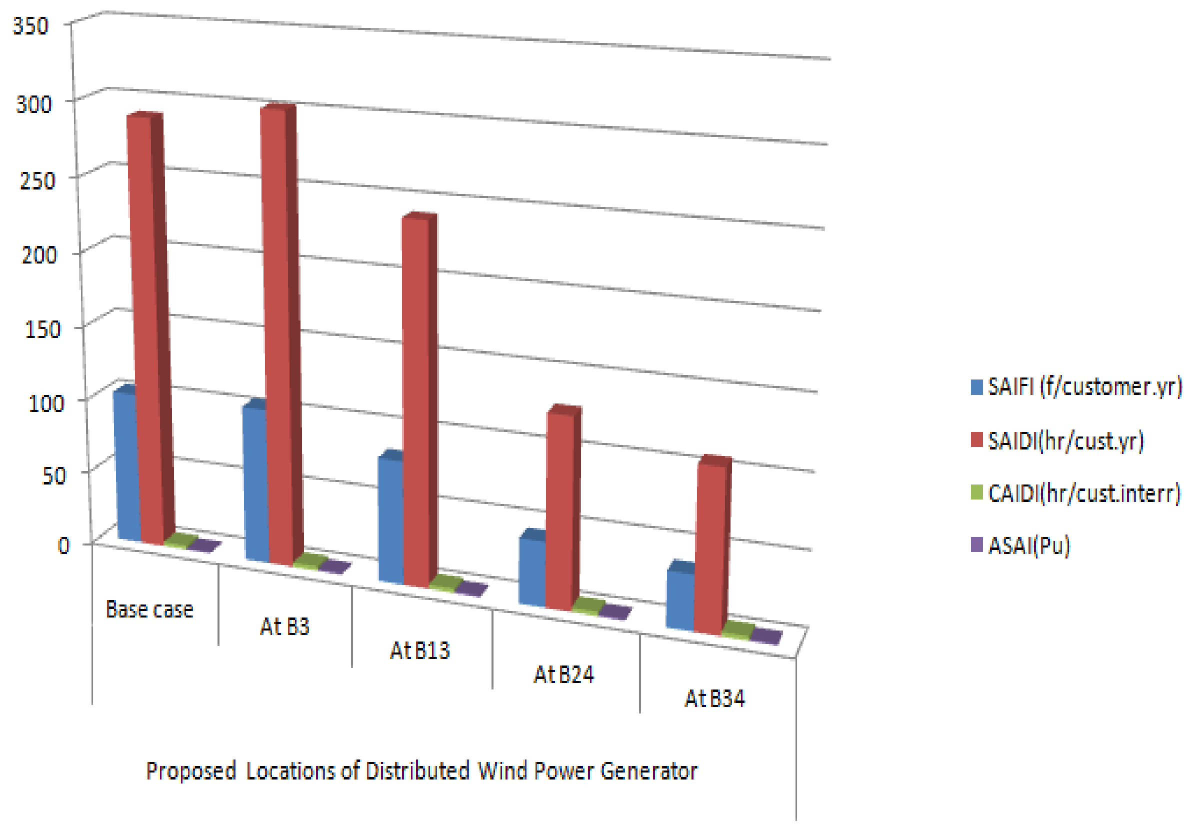


Figure 16 Comparisons of System Indices for Possible Location of Distributed Wind Power Generator

4.5 Cost of Implementation of Proposed Method of Reliability Improvement

The costs for grid connection a wind energy resource can be divided into the costs of local electrical installation and the costs for connecting the wind farm to the electrical grid. In our case since the plan of exploiting the available wind power resource was a target since 2014G.C most of the work of local electrical installation has been performed and also the necessary equipment's for connection to the grid at the substation are already available.

However, we have identified that connecting this resource at the substation or near the substation doesn't seem to improve the reliability of Sheno 15kV distribution feeder, so additional transformer and circuit breaker are necessary to connect this resource to optimal the location that makes the feeder more reliable i.e. at bus bar 34.

Operation and maintenance costs constitute a sizeable share of the total annual costs of a wind turbine. These are costs are related to a limited number of cost components, including insurance, regular maintenance, repair, spare parts, administration. For a new turbine, these costs may easily make up 20-25 percent of the total liveliest cost per kWh produced over the lifetime of the turbine. If the turbine is fairly new, the share may only be 10-15 per cent, but this may increase to at least 20-35 per cent by the end of the turbine's lifetime.

To estimate operation and maintenance costs the experiences of United States, is adopted i.e. around USD 0.01 per kWh (USD 10/MWh) of wind power produced, over the total lifetime of a turbine. Assuming a total full load hour 1500- 1700 hrs, the average total wind power produced by the wind power generator will be 3200MWh.

Table 9 Cost of Implementing Reliability Improvement with Wind Power Generator

No	Item	Description	Unit Price($)
1	Wind Turbine	2MW wind Power generator,O&M	32,000
2	Circuit Breaker	Three phase ac 50 Hz outdoor high voltage circuit breaker with short circuit current 258 A	800
3	Transformer	ZTELEC 25MVA,35 kV/15 kV, three Phase pole mounted oil immersed	2500
		Total Cost	**35,300**

Comparing the cost of implementing this method of reliability improvement method with the cost of not supplying electricity (ECOST)due to the unavailability of electric power in Sheno 15 kV feeder, it can be said that it is wise to put into practice the proposed method of reliability improvement for the feeder under study.

Chapter 5 Conclusions, Recommendations and Future Work

5.1 Conclusions

In modern electricity the significance of reliability for both the utility and the customers is not a question. The main issue of this thesis lies in this aspect. An old city in Ethiopia known by the name of Debre Berhan is chosen. All the data that are considered to be essential are collected from the power serving utility in the town i.e. EEU district office. Some of the data are number and duration of interruption, cause of interruptions, number and rating of electrical distribution equipment's etc. From the available distribution feeders Sheno 15kV distribution feeder has been selected for reliability analysis. To do so, interruption data for the year 2014 and 2015 G.C has been collected. In studying the main causes of interruptions in the town, interruption data of this feeder along with data of other two feeders has been analyzed and equipment failures, maintenance, human and animal contact and weather conditions has been observed to take the major role. After this the feeder under study has been modeled mathematically for reliability analysis. The one-line diagram of the feeder has also been developed and historical reliability analysis has been performed using both analytical and simulation methods. A fairly similar result has been obtained in both the methods. The main reliability indices like SAIFI, SAIDI, CAIDI, EENS has been chosen as the major scales. All the above reliability indices indicated unreliability (presented in Appendix B1); hence the necessity of improvement method wasn't a doubt.

From wide choice reliability improvement methods for a radial network using what is at hand seems a better choice. This is making use of distributed wind power available near the town; and performing preventive reliability analysis with optimal placing showed much improvement in the above listed major reliability indices (presented in Appendix B2 through B5). And lastly this improvement method suggested is found to be economical for both the utility and customers after analyzing the cost associated with implementation of the method. Therefore, with the help of this a method the distribution feeder can be able to serve a reliable electric power to the customers under it economically and this in turn proves the use of such a method for improving reliability of electrical distribution system is worthwhile.

5.2 Recommendations

In a world where the dependency on electric power is showed by loss of millions and billions of dollars within a minute of unavailability of electric power, reliability should be the main agenda to all the utilities serving electricity or planning to do so. A reliable electric power can be served with the help of system planning, periodic load forecasting, and future system expansion.

Based on the observations in the period of study; the following recommendations regarding Debre Berhan distribution system can be given.

- The method of recording and keeping interruption data should be systematic in incorporating all the information like fault location, component failure data, presenting schematic representation of feeders, keeping uniformity in recording data e.t.c.
- The utility should give more priority to measures like replacing old and overloaded equipment's with new and rated ones, on performing periodic preventive maintenances, conducting periodic load forecasting along with system expansion where necessary as the city is quickly growing and populated now days.
- The utility along with its employees have to involve more in making such kind of studies more practical and assist the utility to achieve the goal of satisfying the customers with a reliable electric power.
- Creating awareness in the minds of the rural people of the town and the people around regarding the use and risk associated with electric poles and lines is another issue to be addressed.
- Reliability analysis of the town distribution system as a whole is advised.

5.3. Suggestions for Future Work

A radial electrical power distribution network is known by its poor reliability. All the distribution feeders in Debre Berhan are radial with no alternative supply facing reliability problems, therefore reconfiguration of these networks to a ring network or an interconnected network may solve the problem of unreliability. As long plan reliability assessment by reconfiguration of a single sample distribution feeder or the whole distribution network is intended.

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Appendix A: - Interruption Data for AliuAmba, Enwary and Sheno15 kV feeder

Table A-1 Interruption Data for Sheno15kV feeder for the Year 2014 G.C

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	2/1/2014	I>>	short circuit	15	40	0	18	40	0	4	0	0
2	4/1/2014	,,	Shading	12	45	0	13	45	0	1	0	0
3	7/1/2014	EF	Birds	12	45	0	13	0	0	0	15	0
4	9/1/2014		Maintenance	10	5	0	11	25	0	1	20	0
5	13/1/2014	OI	Unknown	12	10	0	12	20	0	0	10	0
6	19/1/2014	EF	Unknown	8	45	0	9	20	0	0	35	0
7	20/1/2014	,,	Earth fault	6	0	0	15	55	0	9	55	0
8	24/1/2014	EF	maintenance	18	0	0	21	20	0	3	10	0
9	29/1/2014		Short ckt	16	30	0	18	30	0	2	0	0
10	1/2/2014		Earth fault	8	50	0	11	50	0	3	0	0
11	2/2/2014	OI	’’	11	10	0	11	20	0	0	10	0
12	8/2/2014	OC	Shading	7	50	0	12	40	0	4	50	0
13	13/2/2014	OI	Shading	9	0	0	12	0	0	3	0	0
14	19/2/2014	EF	Shading	18	0	0	21	0	0	3	0	0
15	24/2/2014	Maintenance	Breaker damage	7	30	0	7	30	0	24	0	0
16	27/2/2014	,,	Shading	7	5	0	12	5	0	5	0	0
17	28/2/2014	,,	Shading	8	40	0	12	15	0	3	35	0
18	2/3/2014		Short ckt	19	5	0	20	0	0	0	55	0
19	5/3/2014		Short ckt	14	55	0	18	25	0	3	30	0
20	6/3/2014		Short ckt	10	10	0	14	55	0	4	45	0
21	10/3/2014	I>>	short circuit	20	0	0	8	30	0	12	30	0
22	15/3/2014		Earth fault	15	0	0	16	45	0	1	45	0

23	15/3/2014	I>>	short circuit	17	35	0	18	35	0	1	0	0
24	16/3/2014		Short ckt	14	40	0	14	40	0	4	0	0
25	18/3/2014		Short ckt	8	0	0	9	15	0	1	15	0
26	25/3/2014	EF	Unknown	7	50	0	9	50	0	2	0	0
27	27/3/2014	Ie>>	earth fault	13	40	0	17	40	0	3	0	0
28	30/3/2014		Short ckt	15	5	0	18	35	0	2	30	0
29	1/4/2014	I>>	short circuit	16	30	0	18	5	0	1	35	0
30	7/4/2014	I>>	short circuit	7	0	0	11	0	0	4	0	0
31	8/4/2014	EF	over current	15	5	0	15	55	0	0	50	0
32	11/4/2014	OI	maintenance	12	0	0	18	0	0	6	0	0
33	13/4/2014	OC	maintenance	13	45	0	14	10	0	0	35	0
34	14/4/2014	Ie>>	earth fault	22	10	0	9	25	0	12	15	0
35	18/4/2014	I>>	short circuit	9	40	0	16	40	0	7	0	0
36	20/4/2014	Ie>>	earth fault	20	0	0	20	30	0	0	30	0
37	22/4/2014	Ie>>	earth fault	10	5	0	13	35	0	3	30	0
38	22/4/2014	Ie>>	earth fault	14	0	0	17	0	0	3	0	0
39	26/4/2014	O.C	,,	16	45	0	22	10	0	4	25	0
40	3/5/2014	Ie>>	earth fault	18	35	0	16	0	0	10	25	0
41	6/5/2014	,,	over current	15	0	0	16	0	0	1	0	0
42	6/5/2014	Ie>>	earth fault	18	33	0	11	30	0	15	57	0
43	9/5/2014	I>>	over current	9	10	0	9	20	0	0	10	0
44	13/5/2014	OI	Shading	7	15	0	13	0	0	5	45	0
45	17/5/2014	EF	,,	17	15	0	17	40	0	0	25	0
46	20/5/2014		Short ckt	4	45	0	6	10	0	1	25	0
47	21/5/2014		Short ckt	10	0	0	13	0	0	3	0	0
48	24/5/2014		Maintenance	10	0	0	10	40	0	0	40	0
49	29/5/2014		Damage on the bus bar	9	50	0	11	50	0	2	0	0
50	1/6/2014	,,	Shading	9	15	0	12	10	0	2	55	0
51	2/6/2014	,,	maintenance	7	0	0	12	0	0	5	0	0
52	4/6/2014	I>>	short circuit	16	0	0	16	15	0	0	15	0

53	5/6/2014	EF	maintenance	8	10	0	12	10	0	2	0	0
54	10/6/2014	EF	Shading pro	12	30	0	18	0	0	5	30	0
55	11/6/2014	EF	Shading pro	7	20	0	12	0	0	4	40	0
56	12/6/2014	EF	shading	12	0	0	18	0	0	6	0	0
57	17/6/2014	OI	Earth fault	18	30	0	21	25	0	3	15	0
58	24/6/2014	OC	Earth fault	18	0	0	21	25	0	3	35	0
59	25/6/2014	OI	short circuit	7	0	0	12	0	0	5	0	0
60	26/6/2014	O.C	L. shading	15	10	0	16	20	0	1	10	0
61	26/6/2014	OI	Earth fault	18	0	0	22	0	0	4	0	0
62	4/7/2014	Load shading	Shading	16	55	0	20	55	0	4	0	0
63	5/7/2014		Short ckt	8	20	0	9	5	0	0	45	0
64	5/7/2014		Earth fault	9	50	0	16	0	0	6	10	0
65	7/7/2014	OI	wind	15	25	0	16	30	0	1	5	0
66	8/7/2014		Maintenance	14	35	0	17	0	0	2	25	0
67	11/7/2014	OC	maintenance	9	30	0	10	30	0	1	0	0
68	12/7/2014	Ie>>	earth fault	7	50	0	13	35	0	5	45	0
69	16/7/2014	EF	,,	14	0	0	15	0	0	1	0	0
70	17/7/2014	EF	over current	10	30	0	12	30	0	2	0	0
71	19/7/2014		Maintenance	13	55	0	15	20	0	1	25	0
72	22/7/2014		Earth fault	8	0	0	11	55	0	3	55	0
73	23/7/2014	Ie>>	earth fault	9	0	0	9	30	0	0	30	0
74	26/7/2014	Ie>>	earth fault	7	15	0	7	45	0	0	30	0
75	27/7/2014	Ie>>	earth fault	8	32	0	14	32	0	6	0	0
76	30/7/2014	EF	Load shad.	11	30	0	13	30	0	2	0	0
77	1/8/2014	O.C	maintenance	12	30	0	14	0	0	1	30	0
78	2/8/2014	I>>	short circuit	12	15	0	14	15	0	2	0	0
79	4/8/2014	Loose	Load shad.	18	10	0	20	40	0	2	30	0
80	7/8/2014	EF	,,	12	20	0	12	55	0	0	35	0
81	8/8/2014	Ie>>	earth fault	7	15	0	7	40	0	0	25	0
82	8/8/2014	EF	shading	18	45	0	22	0	0	3	15	0

83	10/8/2014	OI	maintenance	9	10	0	12	30	0	3	20	0
84	12/8/2014		Short ckt	13	40	0	18	0		4	20	0
85	14/8/2014	I>>	short circuit	20	20	0	24	10	0	3	50	0
86	15/8/2014		Earth fault	15	0	0	16	45	0	1	45	0
87	19/8/2014	OI	short circuit	12	30	0	18	0	0	5	30	0
88	20/8/2014	EF	Shading	7	25	0	12	0	0	4	35	0
89	22/8/2014		Short ckt	8	0	0	10	15	0	2	15	0
90	24/8/2014	OC	maintenance	16	20	0	17	50	0	1	30	0
91	24/8//2014		Earth fault	6	0	0	10	40	0	4	40	0
92	26/8/2014		Maintenance	9	0	0	11	0	0	2	0	0
93	28/8/2014		Short ckt	13	15	0	18	20	0	5	5	0
94	29/8/2014		Earth fault	15	0	0	19	15	0	4	15	0
95	1/9/2014		Short ckt	12	45	0	13	50	0	1	5	0
96	5/9/2014	Maintenance	Maintenance	8	0	0	18	0	0	10	0	0
97	6/9/2014	OI	maintenance	11	5	0	12	10	0	1	5	0
98	8/9/2014	EF	windy rain	14	5	0	14	10	0	0	5	0
99	11/9/2014	,,	maintenance	19	0	0	20	0	0	1	0	0
100	12/9/2014	OI	L.shading	12	25	0	13	40	0	1	15	0
101	12/9/2014	EF	Birds	6	30	0	6	35	0	0	5	0
102	15/9/2014	Operation	Maintenance	14	40	0	18	15	0	3	55	0
103	18/9/2014	I>>	short circuit	7	0	0	8	0	0	1	0	0
104	20/9/2014		Maintenance	14	0	0	17	0	0	4	0	0
105	22/9/2014	EF	maintenance	7	40	0	7	45	0	0	5	0
106	25/9/2014		Short ckt	13	0	0	17	0	0	4	0	0
107	30/9/2014	OC	Broken phase	14	40	0	14	50	0	0	10	0
108	2/10/2014	OI	L.shading	8	55	0	12	0	0	3	5	0
109	3/10/2014	O.C	Fallen tree	10	5	0	10	10	0	0	5	0
110	10/10/2014	OI	maintenance	8	0	0	12	0	0	4	0	0
111	14/10/2014		Earth fault	13	0	0	18	0	0	5	0	0
112	15/10/2014	O.C	L. shading	8	15	0	8	20	0	0	5	0
113	20/10/2014		Earth fault	17	10	0	19	10	0	2	0	0

114	23/10/2014	,,	Shading	7	30	0	12	5	0	4	25	0
115	27/10/2014	OC	L.Shading	19	15	0	20	25	0	1	10	10
116	2/11/2014	,,	Unknown	14	30	0	14	40	0	0	10	0
117	8/11/2014		Earth fault	8	0	0	10	0	0	2	0	0
118	11/11/2014	Ie>>	earth fault	0	35	0	10	0	0	9	25	0
119	17/11/2014	I>>	short circuit	9	25	0	9	55	0	0	30	0
120	18/11/2014	Ie>>	windy rain	15	20	0	16	40	0	1	20	0
121	24/11/2014		maintenance	10	45	0	11	15	0	0	30	0
122	26/11/2014	I>>	short circuit	7	0	0	7	50	0	0	50	0
123	30/11/2014		load shading	10	20	0	11	30	0	1	10	0
124	4/12/2014	I>>	short circuit	7	10	0	9	40	0	2	30	0
125	4/12/2014	I>>	short circuit	9	10	0	9	20	0	0	10	0
126	5/12/2014	I>>	short circuit	16	0	0	16	15	0	0	15	0
127	11/12/2014	Ie>>	earth fault	8	0	0	14	30	0	6	30	0
128	14/12/2014	Ie>>	earth fault	22	10	0	9	25	0	12	15	0
129	15/12/2014	I>>	short circuit	4	2	0	8	0	0	3	58	0
130	17/12/2014	I>>	maintenance	13	50	0	16	50	0	3	0	0
131	21/12.2014	I>>	short circuit	16	30	0	18	5	0	1	35	0
132	25/12/2014	I>>	short circuit	15	40	0	10	40	0	19	0	0
133	26/12/2014	I>>	short circuit	7	0	0	11	0	0	4	0	0

Table A-2. Interruption Data for AliuAmba 33 kV Feeder for the Year 2014 G.C

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	05/02/14	EF	L .shading	09	10	0	11	50	0	1	40	0
2	06/02/14	EF	,,	15	40	0	16	25	0	0	45	0
3	02/03/14	OI	Maintenance	08	05	0	08	10	0	0	05	0
4	04/03/14	EF	L .shading	09	50	0	11	40	0	0	50	0
5	06/03/14	OI	Maintenance	07	35	0	07	45	0	0	10	0
6	10/03/14	E.F	To open sect	16	05	0	16	15	0	0	10	0
7	14/04/14	OI	Maintenance	19	0	0	19	45	0	0	45	0
8	15/05/14	O.C	L .shading	11	50	0	15	0	0	0	10	0
9	18/05/14	OI	Maintenance	09	25	0	10	45	0	1	10	0
10	19/05/14	OI	Maintenance	14	0	0	15	10	0	1	10	0
11	19/05/14	EF	,,	15	15	0	17	30	0	1	15	0
12	20/05/14	EF	,,	10	05	0	10	40	0	0	35	0
13	23/05/14	EF	Un known	11	10	0	11	35	0	0	25	0
14	25/05/14	O.C	L. Shading	18	50	0	21	25	0	3	35	0
15	26/05/14	OI	”	15	40	0	16	0	0	0	40	0
16	02/06/14	EF	”	09	30	0	12	30	0	3	0	0
17	04/06/14	EF	”	08	10	0	09	50	0	1	40	0
18	10/06/14	EF	”	11	50	0	15	50	0	4	0	0
19	13/06/14	EF	Open line s.w	09	30	0	14	50	0	4	20	0
20	15/06/14	OI	Maintenance	08	15	0	10	15	0	2	0	0
21	18/06/14	EF	Un known	09	10	0	11	50	0	1	40	0
22	23/06/14	EF	Maintenance	15	40	0	16	25	0	0	45	0
23	24/06/14	OI	,,	08	05	0	08	10	0	0	05	0
24	25/06/14	EF	,,	09	50	0	11	40	0	0	50	0
25	27/06/14	OI	,,	07	35	0	07	45	0	0	10	0
26	29/06/14	E.F	,,	16	05	0	16	15	0	0	10	0

27	02/07/14	OI	Maintenance	19	0	0	19	45	0	0	45	0
28	05/07/14	O.C	L .shading	11	50	0	15	0	0	0	10	0
29	08/07/14	OI	Maintenance	09	25	0	10	45	0	1	10	0
30	11/07/14	OI	Maintenance	14	0	0	15	10	0	1	10	0
31	12/07/14	EF	Birds	15	15	0	17	30	0	1	15	0
32	13/07/14	EF	Un known	10	05	0	10	40	0	0	35	0
33	17/07/14	EF	Maintenance	11	10	0	11	35	0	0	25	0
34	18/07/14	O.C	L .Shading	18	50	0	21	25	0	3	35	0
35	20/07/14	OI	”	15	40	0	16	0	0	0	40	0
36	22/07/14	EF	”	09	30	0	12	30	0	3	0	0
37	23/07/14	EF	”	08	10	0	09	50	0	1	40	0
38	29/07/14	EF	”	11	50	0	15	50	0	4	0	0
39	30/07/14	EF	Broken line	09	30	0	14	50	0	4	20	0
40	08/08/14	OI	Maintenance	08	15	0	10	15	0	2	0	0
41	11/08/14	EF	,,	09	10	0	11	50	0	1	40	0
42	12/08/14	EF	,,	15	40	0	16	25	0	0	45	0
43	13/08/14	OI	,,	08	05	0	08	10	0	0	05	0
44	15/08/14	EF	,,	09	50	0	11	40	0	0	50	0
45	16/08/14	OI	,,	07	35	0	07	45	0	0	10	0
46	17/08/14	E.F	,,	16	05	0	16	15	0	0	10	0
47	18/08/14	OI	Maintenance	19	0	0	19	45	0	0	45	0
48	19/08/14	O.C	Un known	11	50	0	15	0	0	0	10	0
49	22/08/14	OI	Maintenance	09	25	0	10	45	0	1	10	0
50	25/08/14	OI	Maintenance	14	0	0	15	10	0	1	10	0
51	29/08/14	EF	Broken pha	15	15	0	17	30	0	1	15	0
52	04/09/14	EF	,,	10	05	0	10	40	0	0	35	0
53	08/09/14	EF	Un known	11	10	0	11	35	0	0	25	0
54	10/09/14	O.C	Shading	18	50	0	21	25	0	3	35	0
55	15/09/14	OI	”	15	40	0	16	0	0	0	40	0
56	19/09/14	EF	”	09	30	0	12	30	0	3	0	0
57	27/09/14	EF	”	08	10	0	09	50	0	1	40	0

58	29/09/14	EF	”	11	50	0	15	50	0	4	0	0
59	30/09/14	EF	Broken line	09	30	0	14	50	0	4	20	0
60	08/10/14	OI	Maintenance	08	15	0	10	15	0	2	0	0
61	10/10/14	OI	Un known	07	35	0	07	45	0	0	10	0
62	14/10/14	E.F	L. shading	16	05	0	16	15	0	0	10	0
63	25/10/14	OI	Maintenance	19	0	0	19	45	0	0	45	0
64	28/10/14	O.C	L .shading	11	50	0	15	0	0	0	10	0
65	05/11/14	OI	Maintenance	09	25	0	10	45	0	1	10	0
66	06/11/14	OI	Maintenance	14	0	0	15	10	0	1	10	0
67	09/11/14	EF	Windy rain	15	15	0	17	30	0	1	15	0
68	13/11/14	EF	Wind	10	05	0	10	40	0	0	35	0
69	20/11/14	EF	L .shading	11	10	0	11	35	0	0	25	0
70	24/11/14	O.C	L .Shading	18	50	0	21	25	0	3	35	0
71	04/12/14	OI	”	15	40	0	16	0	0	0	40	0
72	05/12/14	EF	”	09	30	0	12	30	0	3	0	0
73	12/12/14	EF	Broken line	08	10	0	09	50	0	1	40	0
74	14/12/14	EF	Open section	11	50	0	15	50	0	4	0	0
75	18/12/14	EF	L .shading	09	30	0	14	50	0	4	20	0
76	26/12/14	OI	Maintenance	08	15	0	10	15	0	2	0	0
77	27/12/14	EF	”	11	50	0	15	50	0	4	0	0
78	28/12/14	EF	”	09	30	0	14	50	0	4	20	0
79	30/12/14	OI	Maintenance	08	15	0	10	15	0	2	0	0
80	17/08/14	E.F	,,	16	05	0	16	15	0	0	10	0
81	18/08/14	OI	Maintenance	19	0	0	19	45	0	0	45	0
82	19/08/14	O.C	Un known	11	50	0	15	0	0	0	10	0
83	22/08/14	OI	Maintenance	09	25	0	10	45	0	1	10	0
84	25/08/14	OI	Maintenance	14	0	0	15	10	0	1	10	0
85	29/08/14	EF	Broken pha	15	15	0	17	30	0	1	15	0
86	04/09/14	EF	,,	10	05	0	10	40	0	0	35	0
87	08/09/14	EF	Un known	11	10	0	11	35	0	0	25	0
88	10/09/14	O.C	Shading	18	50	0	21	25	0	3	35	0

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

Table A-3. Interruption Data for Enwary 33 kV Feeder for the Year 2014 G.C

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	05/02/14	EF	L-shading	08	10	0	10	20	0	2	30	0
2	15/02/14	O.C	Maintenance	09	10	0	09	40	0	0	30	0
3	01/03/14	EF	Un known	08	45	0	09	10	0	0	25	0
4	01/03/14	EF	L .shading	09	10	0	09	15	0	0	05	0
5	05/03/14	EF	Wind	17	05	0	17	10	0	0	05	0
6	06/03/14	OI	Maintenance	08	30	0	08	40	0	0	10	0
7	06/03/14	EF	Un known	09	40	0	09	55	0	0	15	0
8	07/03/14	EF	Maintenance	09	30	0	09	50	0	0	20	0
9	16/03/14	OI	Maintenance	10	40	0	10	50	0	0	10	0
10	19/03/14	O.C	’’	15	15	0	17	25	0	2	05	0
11	24/04/14	OI	Maintenance	11	10	0	11	35	0	0	25	0
12	26/04/14	EF	L .shading	10	15	0	10	20	0	0	05	0
13	28/04/14	EF	Maintenance	12	10	0	12	20	0	0	10	0
14	01/05/14	EF	L .shading	21	0	0	21	20	0	0	20	0
15	05/05/14	O.C	Maintenance	12	40	0	14	40	0	2	0	0
16	07/05/14	OI	Maintenance	15	20	0	16	025	0	1	05	0
17	09/05/14	EF	Un known	10	20	0	10	50	0	0	30	0
18	01/06/14	EF	Broken line	15	35	0	14	55	0	0	20	0
19	03/06/14	OI	Maintenance	10	30	0	10	55	0	0	25	0
20	05/06/14	EF	Unknown	16	10	0	16	40	0	0	30	0
21	07/06/14	EF	L. shading	06	50	0	07	30	0	0	40	0
22	07/06/14	EF	Open section	02	20	0	04	40	0	2	0	0
23	08/06/14	EF	Un known	11	35	0	11	50	0	0	15	0
24	09/06/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
25	12/06/14	OI	Maintenance	13	50	0	14	40	0	0	50	0
26	14/06/14	EF	Shading	10	05	0	10	45	0	0	40	0

27	18/06/14	EF	L.shading	11	35	0	12	20	0	0	45	0
28	20/06/14	EF	Maintenance	14	20	0	14	50	0	0	30	0
29	24/06/14	EF	L.shading	11	30	0	12	30	0	1	0	0
30	01/07/14	OI	L.shading	18	50	0	19	20	0	0	30	0
31	05/07/14	OP	Maintenance	11	40	0	12	0	0	0	20	0
32	15/07/14	EF	Heavy rain	00	40	0	07	10	0	6	30	0
33	25/07/14	O.C	Wind	09	10	0	09	55	0	0	45	0
34	26/07/14	EF	Windy rain	16	05	0	18	20	0	2	15	0
35	29/07/14	EF	Un known	06	0	0	18	0	0	6	0	0
36	30/07/14	EF	Unknown	16	10	0	16	40	0	0	30	0
37	12/08/14	EF	Wind	06	50	0	07	30	0	0	40	0
37	14/08/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
39	19/08/14	EF	Un known	11	35	0	11	50	0	0	15	0
40	20/08/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
41	24/08/14	OI	Maintenance	13	50	0	14	40	0	0	50	0
42	25/08/14	EF	Shading	10	05	0	10	45	0	0	40	0
43	26/08/14	EF	L. shading	11	35	0	12	20	0	0	45	0
44	27/08/14	EF	Maintenance	14	20	0	14	50	0	0	30	0
45	28/08/14	EF	L. shading	11	30	0	12	30	0	1	0	0
46	29/09/14	OI	L. shading	18	50	0	19	20	0	0	30	0
47	30/09/14	OP	Maintenance	11	40	0	12	0	0	0	20	0
48	04/09/14	EF	Heavy rain	00	40	0	07	10	0	6	30	0
49	06/09/14	O.C	Wind	09	10	0	09	55	0	0	45	0
50	08/09/14	EF	Windy rain	16	05	0	18	20	0	2	15	0
51	09/09/14	EF	Un known	06	0	0	18	0	0	6	0	0
52	10/09/14	EF	Unknown	16	10	0	16	40	0	0	30	0
53	12/10/14	OI	L.O.L	06	50	0	07	30	0	0	40	0
54	14/10/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
55	19/10/14	EF	Un known	11	35	0	11	50	0	0	15	0
56	20/10/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
57	24/10/14	OI	Broken line	13	50	0	14	40	0	0	50	0

58	25/10/14	EF	Shading	10	05	0	10	45	0	0	40	0
59	26/10/14	EF	L. shading	11	35	0	12	20	0	0	45	0
60	28/10/14	EF	Maintenance	14	20	0	14	50	0	0	30	0
61	07/11/14	EF	L. shading	11	30	0	12	30	0	1	0	0
62	10/11/14	OI	L. shading	18	50	0	19	20	0	0	30	0
63	11/11/14	OP	Maintenance	11	40	0	12	0	0	0	20	0
64	12/11/14	EF	Heavy rain	00	40	0	07	10	0	6	30	0
65	16/11/14	O.C	Wind	09	10	0	09	55	0	0	45	0
66	17/11/14	EF	Windy rain	16	05	0	18	20	0	2	15	0
67	19/11/14	EF	Un known	06	0	0	18	0	0	6	0	0
68	21/11/14	EF	Birds	06	50	0	07	30	0	0	40	0
69	09/12/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
70	12/12/14	EF	Un known	11	35	0	11	50	0	0	15	0
71	15/12/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
72	18/12/14	OI	’’	13	50	0	14	40	0	0	50	0
73	20/12/14	EF	Shading	10	05	0	10	45	0	0	40	0
74	22/12/14	EF	L. shading	11	35	0	12	20	0	0	45	0
75	23/12/14	EF	Open section	14	20	0	14	50	0	0	30	0
76	24/12/14	EF	L. shading	11	30	0	12	30	0	1	0	0
77	27/12/14	OI	L. shading	18	50	0	19	20	0	0	30	0
78	28/12/14	OP	maintenance	11	40	0	12	0	0	0	20	0
79	29/12/14	OI	L. shading	18	50	0	19	20	0	0	30	0
80	30/07/14	EF	Unknown	16	10	0	16	40	0	0	30	0
81	12/08/14	EF	Wind	06	50	0	07	30	0	0	40	0
82	14/08/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
83	19/08/14	EF	Un known	11	35	0	11	50	0	0	15	0
84	20/08/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
85	24/08/14	OI	Maintenance	13	50	0	14	40	0	0	50	0
86	25/08/14	EF	Shading	10	05	0	10	45	0	0	40	0
87	26/08/14	EF	L. shading	11	35	0	12	20	0	0	45	0
88	27/08/14	EF	Maintenance	14	20	0	14	50	0	0	30	0

89	28/08/14	EF	L. shading	11	30	0	12	30	0	1	0	0
90	29/09/14	OI	L. shading	18	50	0	19	20	0	0	30	0
91	30/09/14	OP	Maintenance	11	40	0	12	0	0	0	20	0
92	04/09/14	EF	Heavy rain	00	40	0	07	10	0	6	30	0
93	06/09/14	O.C	Wind	09	10	0	09	55	0	0	45	0
94	08/09/14	EF	Windy rain	16	05	0	18	20	0	2	15	0
95	09/09/14	EF	Un known	06	0	0	18	0	0	6	0	0
96	10/09/14	EF	Unknown	16	10	0	16	40	0	0	30	0
97	12/10/14	OI	L.O.L	06	50	0	07	30	0	0	40	0
98	14/10/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
99	19/1014	EF	Un known	11	35	0	11	50	0	0	15	0
100	20/10/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
101	24/10/14	OI	Broken line	13	50	0	14	40	0	0	50	0
102	25/10/14	EF	Shading	10	05	0	10	45	0	0	40	0
103	26/10/14	EF	L. shading	11	35	0	12	20	0	0	45	0
104	28/10/14	EF	Maintenance	14	20	0	14	50	0	0	30	0
105	07/11/14	EF	L. shading	11	30	0	12	30	0	1	0	0
106	10/11/14	OI	L. shading	18	50	0	19	20	0	0	30	0
107	11/11/14	OP	Maintenance	11	40	0	12	0	0	0	20	0
108	12/11/14	EF	Heavy rain	00	40	0	07	10	0	6	30	0
109	16/11/14	O.C	Wind	09	10	0	09	55	0	0	45	0
110	17/11/14	EF	Windy rain	16	05	0	18	20	0	2	15	0
111	19/11/14	EF	Un known	06	0	0	18	0	0	6	0	0
112	21/11/14	EF	Birds	06	50	0	07	30	0	0	40	0
113	09/12/14	EF	Maintenance	02	20	0	04	40	0	2	0	0
114	12/12/14	EF	Un known	11	35	0	11	50	0	0	15	0
115	15/12/14	EF	Maintenance	12	20	0	14	35	0	2	15	0
116	18/12/14	OI	,,	13	50	0	14	40	0	0	50	0
117	20/12/14	EF	Shading	10	05	0	10	45	0	0	40	0
118	22/12/14	EF	L. shading	11	35	0	12	20	0	0	45	0

Table A-4. Interruption Data for Sheno 15 kV Feeder for the Year 2015 G.C

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	30/01/2015	EF	L-shading	14	20	0	14	50	0	0	30	0
2	01/02/2015	O.C	Maintenance	11	30	0	12	30	0	1	0	0
3	10/02/2015	Loose	Un known	18	50	0	19	20	0	0	30	0
4	04/02/2015	OI	L .shading	11	40	0	12	0	0	0	20	0
5	04/02/2015	OC	Wind	00	40	0	07	10	0	6	30	0
6	06/02/2015	OI	Maintenance	09	10	0	09	55	0	0	45	0
7	06/02/2015	EF	Un known	16	05	0	18	20	0	2	15	0
8	08/02/2015	,,	Maintenance	06	0	0	18	0	0	6	0	0
9	11/02/2015	OI	Maintenance	06	50	0	07	30	0	0	40	0
10	12/02/2015	EF	’’	02	20	0	04	40	0	2	0	0
11	14/02/2015	EF	Maintenance	11	35	0	11	50	0	0	15	0
12	20/02/2015	OI	L .shading	12	20	0	14	35	0	2	15	0
13	02/03/2015	O.C	Maintenance	13	50	0	14	40	0	0	50	0
14	04/03/2015	O.C	L .shading	10	05	0	10	45	0	0	40	0
15	04/03/2015	,,	Maintenance	11	35	0	12	20	0	0	45	0
16	05/03/2015	,,	Maintenance	14	20	0	14	50	0	0	30	0
17	07/03/2015	EF	Un known	11	30	0	12	30	0	1	0	0
18	10/032015	,,	Broken line	18	50	0	19	20	0	0	30	0
19	11/03/2015	OI	Maintenance	11	40	0	12	0	0	0	20	0
20	11/03/2015	OI	Unknown	18	50	0	19	20	0	0	30	0
21	13/03/2015	OC	L. shading	16	10	0	16	40	0	0	30	0
22	16/03/2015	EF	Load shad.	11	30	0	13	30	0	2	0	0
23	17/03/2015	O.C	maintenance	12	30	0	14	0	0	1	30	0
24	18/03/2015	Loose	Load shad.	18	10	0	20	40	0	2	30	0
25	19/03/2015	OI	maintenance	09	10	0	12	30	0	3	20	0
26	20/03/2015	OC	maintenance	16	20	0	17	50	0	1	30	0

27	02/04/2015	OI	maintenance	11	05	0	12	10	0	1	05	0
28	24/04/2015	EF	Un known	14	05	0	14	10	0	0	05	0
29	28/04/2015	,,	maintenance	19	0	0	20	0	0	1	0	0
30	02/05/2015	OI	L.shading	12	25	0	13	40	0	1	15	0
31	07/05/2015	EF	Birds	06	30	0	06	35	0	0	05	0
32	07/05/2015	EF	maintenance	07	40	0	07	45	0	0	05	0
33	08/05/2015	OI	L.shading	08	55	0	12	0	0	3	05	0
34	09/05/2015	O.C	Unknown	10	05	0	10	10	0	0	05	0
35	03/06/2015	O.C	L. shading	08	15	0	08	20	0	0	05	0
36	03/06/2015	,,	Shading	12	45	0	13	45	0	1	0	0
37	04/06/2015	,,	Un known	14	30	0	14	40	0	0	10	0
37	05/06/2015	EF	Fallen tree	12	45	0	13	0	0	0	15	0
39	05/06/2015	,,	Shading	07	30	0	12	05	0	4	25	0
40	11/06/2015	OI	maintenance	08	0	0	12	0	0	4	0	0
41	12/06/2015	OC	Maintenance	13	50	0	14	40	0	0	50	0
42	13/06/2015	EF	Shading	10	05	0	10	45	0	0	40	0
43	16/06/2015	EF	L. shading	11	35	0	12	20	0	0	45	0
44	16/06/2015	O.C	Maintenance	14	20	0	14	50	0	0	30	0
45	17/06/2015	,,	L. shading	11	30	0	12	30	0	1	0	0
46	19/06/2015	,,	L. shading	18	50	0	19	20	0	0	30	0
47	21/06/2015	EF	Maintenance	11	40	0	12	0	0	0	20	0
48	02/07/2015	,,	Heavy rain	00	40	0	07	10	0	6	30	0
49	05/07/2015	EF	Wind	09	10	0	09	55	0	0	45	0
50	10/07/2015	EF	Windy rain	16	05	0	18	20	0	2	15	0
51	11/07/2015	EF	Un known	06	0	0	18	0	0	6	0	0
52	23/07/2015	OI	Unknown	16	10	0	16	40	0	0	30	0
53	24/07/2015	OC	L.O.L	06	50	0	07	30	0	0	40	0
54	25/07/2015	OI	Maintenance	02	20	0	04	40	0	2	0	0
55	26/07/2015	O.C	Un known	11	35	0	11	50	0	0	15	0
56	26/07/2015	OI	Maintenance	12	20	0	14	35	0	2	15	0
57	27/08/2015	OI	Broken line	13	50	0	14	40	0	0	50	0

58	28/08/2015	OC	Shading	10	05	0	10	45	0	0	40	0
59	11/09/2015	EF	L. shading	11	35	0	12	20	0	0	45	0
60	24/09/2015	EF	maintenance	08	0	0	08	22	0	0	22	0
61	27/09/2015	,,	maintenance	08	10	0	09	40	0	1	30	0
62	21/09/2015	EF	’’	17	10	0	17	40	0	0	30	0
63	02/09/2015	OI	Shading	07	0	0	12	0	0	5	0	0
64	05/09/2015	OC	maintenance	08	10	0	12	10	0	2	0	0
65	10/09/2015	EF	Shading pro	12	30	0	18	0	0	5	30	0
66	11/09/2015	EF	Shading pro	07	20	0	12	0	0	4	40	0
67	23/09/2015	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
68	24/09/2015	OI	Feeder O.L	18	0	0	21	25	0	3	25	0
69	25/09/2015	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
70	26/09/2015	O.C	Un known	16	10	0	17	20	0	1	10	0
71	26/09/2015	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
72	14/09/2015	OI	’’	14	25	0	14	29	0	0	04	0
73	15/09/2015	OC	maintenance	09	20	0	10	20	0	1	0	0
74	17/10/2015	,,	Feeder O.L	10	30	0	13	30	0	3	0	0
75	24/10/2015	EF	maintenance	08	0	0	08	22	0	0	22	0
76	27/10/2015	,,	maintenance	08	10	0	09	50	0	1	40	0
77	11/10/2015	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
78	16/10/2015	EF	Wind	08	0	0	08	22	0	0	22	0
79	18/10/2015	OC	L. shading	08	10	0	09	50	0	1	40	0
80	27/10/2015	,,	Unknown	08	10	0	09	40	0	1	30	0
81	21/10/2015	EF	Wind	06	50	0	07	30	0	0	40	0
82	02/10/2015	OI	Maintenance	02	20	0	04	40	0	2	0	0
83	05/10/2015	OC	Un known	11	35	0	11	50	0	0	15	0
84	10/10/2015	EF	Maintenance	12	20	0	14	35	0	2	15	0
85	11/10/2015	EF	Maintenance	13	50	0	14	40	0	0	50	0
86	23/10/2015	OI	Shading	10	05	0	10	45	0	0	40	0
87	24/10/2015	OI	Feeder O.L	18	0	0	21	25	0	3	25	0
88	25/10/2015	OI	Feeder O.L	07	0	0	12	0	0	5	0	0

89	26/11/2015	O.C	Un known	15	10	0	16	20	0	1	10	0
90	26/11/2015	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
91	14/11/2015	OI	’’	14	25	0	15	30	0	1	05	0
92	15/11/2015	OC	maintenance	09	30	0	10	30	0	1	0	0
93	17/11/2015	,,	Feeder O.L	06	30	0	09	30	0	3	0	0
94	24/11/2015	EF	maintenance	08	0	0	08	22	0	0	22	0
95	27/11/2015	,,	maintenance	08	10	0	09	50	0	1	40	0
96	11/11/2015	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
97	16/11/2015	EF	Wind	08	0	0	08	22	0	0	22	0
98	18/11/2015	OC	Windy rain	08	10	0	09	50	0	1	40	0
99	27/11/2015	,,	maintenance	08	10	0	09	40	0	1	30	0
100	21/11/2015	EF	’’	17	10	0	17	40	0	0	30	0
101	02/11/2015	OI	Shading	07	0	0	12	0	0	5	0	0
102	05/11/2015	OC	maintenance	08	10	0	12	10	0	2	0	0
103	10/11/2015	EF	Shading pro	12	30	0	18	0	0	5	30	0
104	11/11/2015	EF	Shading pro	07	20	0	12	0	0	4	40	0
105	23/11/2015	OI	Feeder O.L	18	30	0	21	45	0	3	15	0
106	24/11/2015	OI	Feeder O.L	18	0	0	21	25	0	3	25	0
107	25/11/2015	OI	Feeder O.L	07	0	0	12	0	0	5	0	0
108	26/11/2015	O.C	Un known	15	10	0	16	20	0	1	10	0
109	26/12/2015	,,	Feeder O.L	18	0	0	22	10	0	4	10	0
110	14/12/2015	OI	’’	14	25	0	15	30	0	1	05	0
111	15/12/2015	OC	maintenance	09	30	0	10	30	0	1	0	0
112	17/12/2015	,,	Feeder O.L	06	30	0	09	30	0	3	0	0
113	24/12/2015	EF	maintenance	08	0	0	08	22	0	0	22	0
114	27/12/2015	,,	maintenance	08	10	0	09	50	0	1	40	0
115	11/12/2015	OI	Feeder O.L	06	30	0	09	30	0	3	0	0
116	16/12/2015	EF	Wind	08	0	0	08	22	0	0	22	0
117	18/12/2015	OC	Windy rain	08	10	0	09	50	0	1	40	0

Appendix B.:-ETAP Reliability Output for Sheno 15kV Feeder

B-1: - Base Case

Project:	ETAP	Page: 1
Location:	12.6.0H	Date: 11-11-2019
Contract:		SN:
Engineer:	Study Case: RA	Revision: Base
Filename: sheno		Config.: Normal

SUMMARY

System Indexes

SAIFI	103.1271 f / customer.yr
SAIDI	289.7872 hr / customer.yr
CAIDI	2.810 hr / customer interruption
ASAI	0.9669 pu
ASUI	0.03308 pu
EENS	1361.010 MW hr / yr
ECOST	5,820,054.00 $ / yr
AENS	0.6761 MW hr / customer.yr
IEAR	4.276 $ / kW hr

B-2: -Wind Power Generator at B3

Project:	**ETAP**	Page: 1
Location:	12.6.0H	Date: 11-11-2019
Contract:		SN:
Engineer:	Study Case: RA	Revision: Base
Filename: sheno		Config.: Normal

SUMMARY

System Indexes

SAIFI	104.6271	f / customer.yr
SAIDI	301.7872	hr / customer.yr
CAIDI	2.884	hr / customer interruption
ASAI	0.9655	pu
ASUI	0.03445	pu
EENS	1426.607	MW hr / yr
ECOST	6,190,229.00	$ / yr
AENS	0.7087	MW hr / customer.yr
IEAR	4.339	$ / kW hr

B-3: - Distributed Wind Power at B13

Project:	**ETAP**	Page: 1
Location:	12.6.0H	Date: 11-11-2019
Contract:		SN:
Engineer:	Study Case: RA	Revision: Base
Filename: sheno		Config.: Normal

SUMMARY

System Indexes

SAIFI	82.8880 f / customer.yr
SAIDI	240.5457 hr / customer.yr
CAIDI	2.902 hr / customer interruption
ASAI	0.9725 pu
ASUI	0.02746 pu
EENS	1137.931 MW hr / yr
ECOST	4,892,543.00 $ / yr
AENS	0.5653 MW hr / customer.yr
IEAR	4.300 $ / kW hr

B-4:- Distributed Wind Power at B24

Project:	**ETAP**	Page: 1
Location:	12.6.0H	Date: 11-11-2019
Contract:		SN:
Engineer:	Study Case: RA	Revision: Base
Filename: sheno		Config.: Normal

SUMMARY

System Indexes

SAIFI	43.4468 f / customer.yr
SAIDI	127.2794 hr / customer.yr
CAIDI	2.930 hr / customer interruption
ASAI	0.9855 pu
ASUI	0.01453 pu
EENS	666.376 MW hr / yr
ECOST	3,080,269.00 $ / yr
AENS	0.3310 MW hr / customer.yr
IEAR	4.622 $ / kW hr

B-5: - Distributed Wind Power at B34

Project:	**ETAP**	Page: 1
Location:	12.6.0H	Date: 11-11-2019
Contract:		SN:
Engineer:	Study Case: RA	Revision: Base
Filename: sheno		Config.: Normal

SUMMARY

System Indexes

SAIFI	36.9719 f / customer.yr
SAIDI	107.6154 hr / customer.yr
CAIDI	2.911 hr / customer interruption
ASAI	0.9877 pu
ASUI	0.01228 pu
EENS	579.565 MW hr / yr
ECOST	2,758,927.00 $ / yr
AENS	0.2879 MW hr / customer.yr
IEAR	4.760 $ / kW hr