ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTING

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

RELIABILITY ANALYSIS AND REDESIGN OF POWER DISTRIBUTION SYSTEM (CASE STUDY OF NAZARETH DISTRIBUTION SYSTEM)

A Thesis is Submitted to the School of Electrical Engineering and computing of Adama Science and Technology University in Partial Fulfillment of the Requirements for Degree of Masters of Science in Electrical Engineering

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Declaration

I, declare that this Master's thesis is my original work and has not been presented for fulfillment of requirement for degree in this or other university, all sources and materials used for this thesis have been recognized and undersigned.

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Abstract

Low Electrical Power Reliability is a serious problem in our country. System reliability problems are caused by interruptions of power distribution system which leads to damage of electrical and electronics equipment and affecting the production time of the customers. This paper attempts to analyze reliability of existing Nazareth distribution system, identify the problems of low system reliability, and give the solutions to reduce the interruptions and redesign of power distribution system to increase the system reliability. The Reliability Analysis of existing system carried out by Analytical methods and simulation using the data collected from the distribution substation and utility service sectors as input. Distribution reliability indices such as SAIFI, SAIDI and ASAI have been analyzed thoroughly on power distribution system and the analyzed distribution reliability indices values have been compared with standard benchmark values and comparison indicates that Nazareth distribution system is unreliable. To improve the reliability of the network, proper maintenance strategy and redesign of distribution system is necessitated. In this paper redesigning of existing 15kV/2×25MVA power distribution system has been made and replaced by 33kV/5×50MVA one and the result of simulated redesigned distribution system indices of SAIFI in numbers per customer year, SAIDI in hours per customer year and ASAI in % in year improved from 956.33, 923.3, and 89.46% to 2.75, 38.72 and 99.56 respectively. Using Electrical Transient and Analysis Program (ETAP) software, the reliability analysis of the redesigned distribution system and the existing system has been simulated and compared and the result obtained reveals that the reliability of the system is improved and its marginal difference with benchmarked one reduced significantly.

Keywords: - Distribution System, Reliability Analysis, Reliability indices, Distribution System Design, ETAP

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List of Abbreviation

A	Ampere
AAC	All Aluminum Conductor
AC	Alternating current
ANSI	American National Standards Institute
ASAI	Average System Availability Index
ASIDI	Average System Interruption Duration Index
ASIFI	Average System Interruption Frequency Index
CAIDI	Customer Average Interruption Duration Index
CB	Circuit Breaker
CELID	Customers Experiencing Longest Interruption Duration
CEMI	Customers Experiencing Multiple Interruptions
DC	Direct Current
EC	Ethiopian Calendar
EEP	Ethiopian Electric Power
EEU	Ethiopian Electric Utility
EF	Earth Fault
EPM	Electrical preventive Maintenance
Esl	effective service length
ETAP	Electrical Transient and Analysis Program
GTA	Graph Trace Analysis
HRC	High Rupture Capacity
HV	High Voltage
Hz	Hertz
IEC	International Electro-technical Commission
IEEE	Institute of Electrical and Electronics Engineers

IOR	Index of Reliability
ISO	International Standard Organization
KA	Kilo Ampere
KV	Kilo Volt
KVA	Kilo Volt Ampere
KW	Kilo Watt
LDC	Load Dispatch Center
LV	Low Voltage
Mm	millimeter
MVA	Mega Volt Ampere
MW	Mega Watt
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
N_i	Number of customer interrupted
NL	Neutral Loose
OC	Over Current
OHL	Overhead Line
OV	Over Voltage
OC	Over Current
PL	Phase Loose
REO	Request of Emergency Office
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCkt	Short Circuit
SCP	Single Contingency Policy
SOL	System over Load
V	Volt

CHAPTER ONE

INTRODUCTION

1.1 Background

The distribution system is part of the electric power system that links the bulk transmission system and the individual customers. Approximately 80 percent of outages experienced by the customers are due to failures in the distribution system. It is therefore important to understand the impact of the outages on the customer outage costs and the system reliability [1].

The power distribution system is made up of sub-transmission lines, power transformers, 33kV lines, 15kV lines, distribution transformers, LV Lines, etc. Distribution substations monitor and adjust circuits within the system [2]. Currently Ethiopian Electric Power system has 400kV, 230kV, 132 kV primary transmission systems and 66kV, 45kV as sub transmission system and 33kV and 15kV as distribution system. At all the 66 or 45kV substations power transformers of various ratings like 25 /12 /6.3/3MVA are installed for step down of voltage to 15kV for feeding to Distribution Transformers. The outgoing feeders are connected in radial fashion. Mostly 33kV and 15kV overhead conductors are used for feeding 60 to 70 distribution transformers on each 33kV and 15kV feeder. The voltage is then further reduced by distribution transformers to the utilization voltages of 380 volts three-phase or 220 volts single-phase supply required by most users [3].

Substations are fenced yards with switches, transformers and other electrical equipment's. Once the voltage has been lowered at the distribution substation, the electricity flows to industrial, commercial, and residential centers through the distribution system. Conductors called feeders reach out from the distribution substation to carry electricity to customers. At key locations along the distribution system, voltage is lowered by distribution transformers to the voltage needed by customers or end-users. Electric distribution system power quality is a growing concern. Customers require higher quality service due to more sensitive electrical and electronic equipment. The effectiveness of a power distribution system is measured in terms of efficiency,

service continuity or reliability, service quality in terms of voltage profile and stability and power distribution system performance [2].

In Ethiopia, electric power interruption is becoming a day to day phenomenon. Even there are times that electric power interruption occurs several times a day, not only at the low voltage but also at the medium voltage distribution systems. The drop of the voltage, especially at the residential loads, is causing early failure of equipment's, blackening of light bulbs, and decreased efficiency and performance of high-power appliances. Damage of electronic devices and burning of light bulbs have also occurred due to over voltages [4].

The continuity of energy supply can be increased by improved system structure, increased investment during the planning phase, operating phase or both. It is evident therefore that the reliability and economic constraints are related. Reliability is the probability that the system will perform its intended function under specified working condition for a specified period of time. Reliability is a real number between 0 and 1; that is, at any time $0 \leq R(t) \leq 1$ [5].

Power distribution system standards and design guidelines are the minimums acceptable criteria's for the design of efficient, economical, durable, maintainable, and reliable electrical power supply and distribution systems. Clarifications of baseline design criteria, standards, policy, and guidelines are provided by Institute of Electrical and Electronics Engineers (IEEE), International Electro-technical Commission (IEC), National Electrical Code (NEC), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), or International Standard Organization (ISO) [6].

1.2 Statement of problem

Power interruption due to earth fault, short circuit, over load, under frequency, request of emergency offices and order of load dispatch centre which accounts 425, 457, 103, 9 and 1556 in numbers per year during feeder faulted respectively those has been affect the reliability of the system and becomes causes of earlier failure for domestic equipments, light bulbs and reduction in efficiency and performance of power equipments. On the other hand, in industrial and commercial sectors also it reduces the production time which leads them to low profit by losing

their production time. In addition to this, during peak load hours, some industrial and commercial equipment do not operate satisfactorily due to insufficient power supply.

In this paper attempts has been made on reliability analysis of existing Nazareth 132/15KV power distribution system, on techniques how to improve the reliability indices to the benchmark and redesign of power distribution system.

1.3 Objectives

1.3.1. General Objectives

The main objective of this thesis work is to perform a reliability analysis and design of Nazareth power distribution system.

1.3.2. Specific Objectives

- Assess the existing system reliability and performance of power distribution system.
- Identify the causes of low system reliability of the distribution system.
- Redesigning of existing power distribution system to improve system reliability and capacity of power distribution system.

1.4 Significance of the study

The significant of this thesis are to improve the system reliability, reducing the customer's interruption and related purposes.

1.5 Scope of study

This study focuses on the analysis of 15kV Nazareth distribution system. The scopes of this thesis are:-

- Predictive analysis of the existing distribution network of 15KV system by analytical methods.
- Analysis of SAIFI, SAIDI and ASAI for distribution system. Compare indices with benchmarks and indentify the causes of low system reliability
- Recommendation proper way of maintenance and operation of power distribution system which reduces system interruption.
- Power distribution system redesign to improve system reliability

CHAPTER TWO

LITERATURE REVIEW

Electric power is a vital element in any modern economy. The availability of a reliable power supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution system have to be upgraded, operated and maintained accordingly [7].

The research indicated that users were utilizing a wide variety of tools and techniques with different analysis results. Furthermore, the only recommended methodology presented in IEEE Std 493 since 1980 was the ‘‘series and parallel’’ reliability methodology and the minimal cut-set method which estimated the frequency and duration of load point interruptions [8]. These analytical approaches are applied to the IEEE Gold Book standard network in a series of papers to determine the accuracy of their results and how closely they can verify operational anomalies [8].

The Monte Carlo techniques are normally very “time” consuming due to large number of drawings necessary in order to obtain accurate results. The fault contribution from each component is given by a statistical distribution of failure rates and outage times [9].

Another technique of reliability evaluation is the Markov process which is one of the common techniques employed in reliability analysis [8]. The application of Markov Chains in the power system reliability field was illustrated in Reference [10]. However, the Markov approach is limited in application because of computer storage requirements and the rounding errors which occur in the solution of large systems. This report presents a reliability analysis method that combines set theory and Graph Trace Analysis (GTA), which provides a rapid reliability evaluation, assuming single failures at a time. Unlike the Markov process, this method utilizes

iterators to manage computer memory, which enables it to handle computations for large systems [10].

The two main approaches used are analytical and simulation. The vast majority of techniques have been analytically based and simulation techniques have taken minor role in specialized applications. The main reason for this is because simulation generally requires large amount of computing time, and analytical models and techniques have been sufficient to provide planners and designers with results needed to make objective decisions. Analytical techniques represent the system by a mathematical model and evaluate the reliability indices from this model using direct numerical solutions. They generally provide expectations indices in a relatively short computing time [7].

As a most researchers and journals presented above the markov has a drawback of limited application and requires large computer memory, Graph Trace Analysis has drawback of assuming a single failure at time and Monte Carlo simulation has a drawback of very time consuming while the analytical method has advantageous over those methods by having sufficient to provide planners and designers with results needed to make objective decisions. Thus using those researchers as reference in thesis work also analytical methods of reliability analysis will be used which represents the system by mathematical model and evaluates the reliability indices from this model using direct numerical solutions. After the reliability analyzed by analytical methods it is evaluated again by using Electrical Transient and Analysis (ETAP) software to check whether analytical methods work properly.

Inspection and maintenance of the equipment of a power distribution system require a large expenditure of financial and human resources. This is a critical issue for a utility to ensure that their spending money will improve equipment performance and system reliability. Maintaining a specific level of reliability and high level of customer satisfaction is difficult for a utility within a limited maintenance budget. Therefore, a sound asset management policy for identifying poor performing equipment and allocating the budget for maintenance is required [10].

As part of asset management, this thesis applies an optimized method of maintenance scheduling. A spreadsheet-based reliability evaluation tool and a technique for estimating recloser's

reliability [8] are used to determine the best schedule for maintenance of multiple reclosers on a system. Reclosers that are most likely to degrade system reliability are scheduled for maintenance first, followed by those with lower effects on reliability [2].

The optimization method consists of two stages which are performed sequentially during design of power distribution feeder. The first is an electrical assessment of the proposed configuration. That is followed by an economic assessment of the design. Before the electrical assessment can be done, some preliminary steps must be taken. The first preliminary step is the determination of the ampacity required for the feeder [11].

A good starting point for determining feeder ampacity is to determine the average load density in kVA/mi^2 for the feeder's service territory. The load density for an existing area is readily available from historical metering data, but it is wise to adjust this known value for anticipated future changes in the load – say over a 5-7 year horizon. Let this adjusted average load density be a constant value throughout the entire feeder service area for illustrative purposes. In practice, non-uniform load densities and spot loads could be incorporated, but these considerations tend to complicate the process, and will be avoided [11].

The largest amount of contingency capacity that would ever need to be reserved is 50% (Gönen 1986, P. 235). At a 50% contingency capacity reserve, any feeder would be able to backup another entire feeder at any loading level without thermal overload. Distribution network refers to those 22kV or 11kV network supplying electricity to Customers through cable or Overhead Line (OHL). The network configuration would directly affect the supply reliability. Of the three types of configuration, the closed ring configuration provides the highest possible supply reliability. Each customer substation has dual supply and so a single circuit fault would not cause any supply interruption. It is, in fact, aligned with "N-1" approach. In the ring configuration, each feeder is protected by either high-speed feeder protection or pilot wire protection with back up over current and earth fault (OC/EF) protection equipped in the primary substation [12]. In this thesis also N-1 contingency capacity policy will be used by considering 10% contingency capacity of the feeder during the fault or interruption occur to the other feeder of similar size.

CHAPTER THREE

METHODOLOGY

Due to the nature of case study it is started by reviewing the related literature to investigate of quality and reliability problem of power distribution system and power distribution literatures.

3.1 Data collection

Collecting of recent important information and recorded data by operators during the interruption occurred due to distribution system fault like earth fault, short circuit, overload, under frequency, and other interruption like request of emergency office and order of load dispatch centre on the feeders or single equipment failure at some point through the feeder from Nazareth distribution substation and Nazareth utility service offices which are secondary data for this work. Interviews with respective professionals at distribution substation and utility sectors have been considered and site visit. The information obtained from interviews from professionals how they work on maintenance schedule, what type of problems are occurred, what action they take to correct the problem, how they manage the demand of customer during peak load and similar information. In general the following methodology would be followed as shown in the figure 3.1

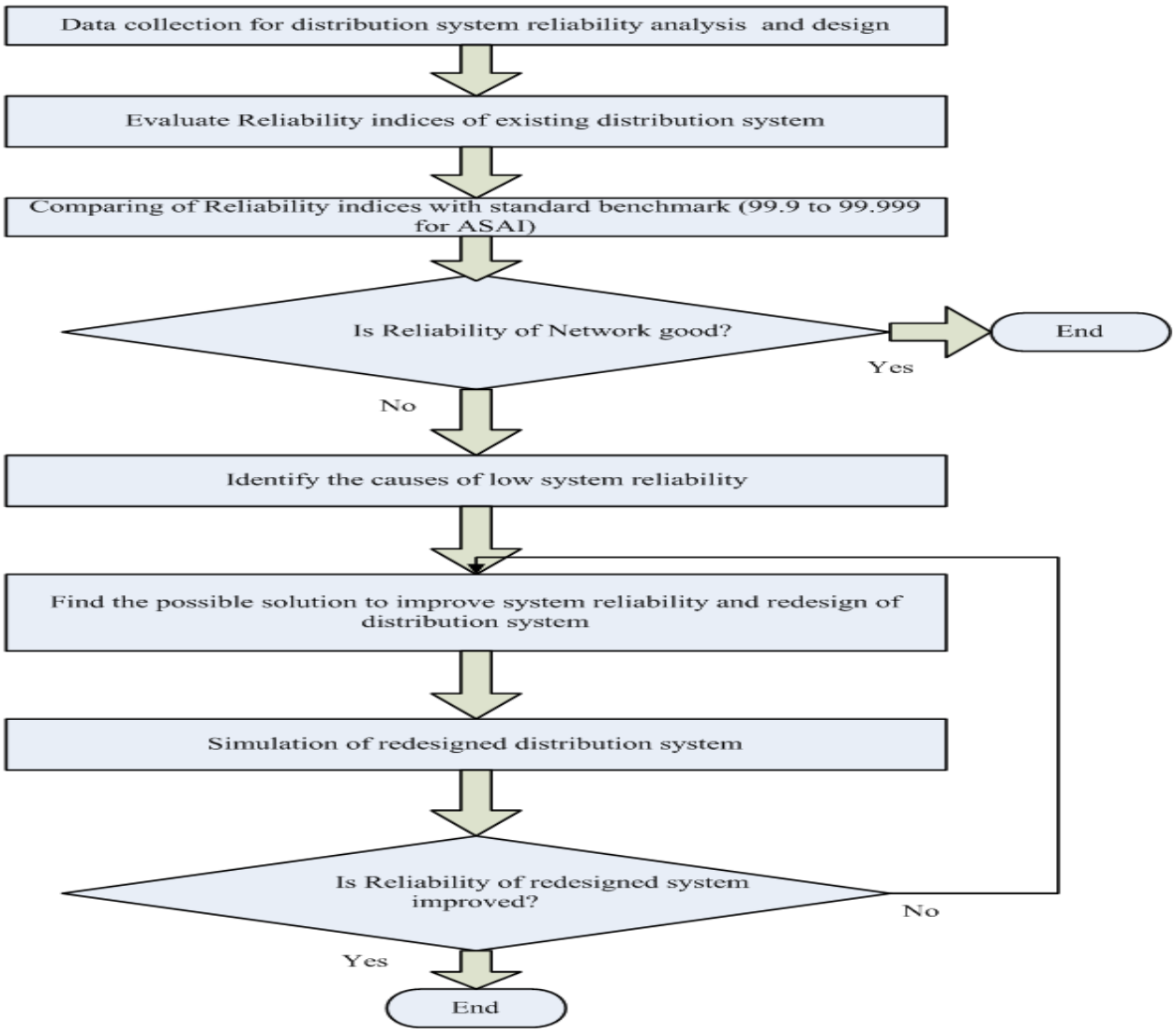

Fig. 3-1 Distribution feeder design flow

Due to the nature of case study, it is started by reviewing literatures related to the investigation of quality and reliability problems of power distribution systems. Recent and unpublished important information and data have been collected from Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) of Nazareth sectors. Interviews with respective professionals at Nazareth substation, utility service center and distribution system maintenance and design sector have been considered. Previous recorded data of one year like interruption frequency, interruption duration, rating of power transformer, number of feeders, distribution transformer number and

capacity, number of customers have been gathered for detail assessment and investigation to come up with a clear solution of the problem. The collected data used to analyze and model power distribution system.

The data collected from distribution system and utility service will be summarized as follows and used for reliability analysis in next chapter and for design purpose in chapter five of this thesis work.

3.1.1 Data Collected From Nazareth distribution substation

The data collected from Nazareth distribution substation are includes capacity of substation, number of incoming line, number of outgoing lines or feeders, number of substation transformer, rating of substation transformer, date of interruption, time of interruption, duration of interruption, frequency of interruption, reconnecting time, interrupted load and causes of interruption on the respective outgoing feeder . These data are expressed in the following tables.

Table 3.1 Distribution Substation Voltage Level and Rating of Substation Transformer [44].

Substation Name	Voltage Level (KV)	Number of substation transformer	Rating of Substation transformer (MVA)
Nazareth	132/15	2	25

Annual interruption frequency, duration of interruptions and interruption load of distribution systems of each feeder shown in table 3.2.

The Data indicates the number of customers on the feeder is not available, but using [14] as reference, number of distribution transformers on the feeder and its ratings the number of customers on the feeder shared and indicted in table 3.2.

The data in table 3.2 is the sum of respective feeder interruptions means that interruption frequency and duration of interruptions. Frequency interruption per year of respective feeder is counted in number, in similar way the duration interruption is also added by taking the difference of disconnecting time and reconnecting time of the feeder to the system in hours and interrupted load also added up and summarized as shown in table 3.2.

Table 3. 2 Interruption Frequencies, Duration of Interruption and Load Interrupted from 01/01/2008 to 30/12/2008 E.C [44].

Feeder	Total number of distribution transformer	Number of customer on feeders (N_i)	Interruption frequency λ_i in ($N_{o)}$	Duration of interruption r_i in hours	Load interrupted in (MW) per year
1	34	9104	562	418.95	2806.3
2	69	11588	390	475.95	2296.7
3	84	13056	434	451.60	2679.4
4	73	11713	378	364.80	2214.5
5	5	1	68	35.53	230
6	12	3745	319	248.37	464.8
7	17	4797	406	476.97	2223.9

3.1.1.1. Types of faults in Nazareth Outgoing Feeders

The main causes of interruption that occurs on the Nazareth distribution system feeders are earth fault, short circuit, over load, request of emergency office and order of load dispatch center to disconnect the feeder from the system. The summery of those causes of interruptions are explained in the table 3.3.

Table 3.3 Summary of Causes of Interruptions in Nazareth Distribution Substation

Type of faults or cause of interruption	Feeders						
	1	2	3	4	5	6	7
Earth fault	96	51	54	60	23	51	91
Short circuit fault	86	76	69	59	9	68	90
Over loads	23	25	28	15	0	12	0
Request (Load Dispatch Centre or Request of Emergency Office)	348	238	288	244	36	188	217
Under frequency	9	0	0	6	0	0	0
Total	562	390	434	378	68	319	406

For simplicity the above causes of interruptions can be categorized as a distribution faults (earth fault, short circuit, over loads and under frequency) and others (request). The total distribution faults and others are1001 and 1556 respectively during the feeder is faulted. As the one of the objective of this thesis work, the distribution faults would be focused in this paper during design. The fault type that mostly occurs in (Nazareth) distribution systems are short circuit faults, Earth faults and overload.

3.1.2 Data collected from Nazareth utility service center

Based on data collected from Nazareth utility service center Nazareth distribution has one substation, seven outgoing feeders, around 54004 customers (i.e. industrial, commercial , residential and others).There are no feeders dedicated for industrial, commercial and residential customers separately except feeder 5 which feeds industrial customer named Turkey.

Table 3.4 load types and total number of customers on the load type [43].

Load type	Total number of customer per load
Domestic or residential	43184
Commercial	9062
Industrial	734
Others	1024
Total	54004

The percent of domestic customer accounts 79.964%, commercial accounts 16.780%, industrial accounts 1.359% and others 1.896%. In addition to those customers; there are customers not registered but using power from meter of registered customers. This causes the disturbance to the distribution system and customers making a system over voltage.

As the data gathered from Nazareth utility service sector name of substation, voltage ratio, power capacity, name of feeder s, feeder colour, total number of distribution transformer, total capacity of distribution transformer in kva, total length of feeder in Km and conductor size are shown in table 3.5.

Table 3.5 Nazareth 15kv feeder data [43]

Nazareth 15KV feeder data								
$S.N_O$	Name of substation	Voltage ratio	Power capacity $N_o \times MVA$	Name of feeder	Total number of DT feeder	Total capacity of DT KVA	Total length of feeder in KM	Conductor size
1	Nazareth	132/15	2×25	Line1	34	7880	13.51	AAC $50mm^2$
2	>>	>>	>>	Line2	69	26457	39.23	>>
3	>>	>>	>>	Line3	84	25515	23.52	>>
4	>>	>>	>>	Line4	73	17510	30.85	>>
5	>>	>>	>>	Line5	5		5.2	>>
6	>>	>>	>>	Line6	12	3915	25	>>
7	>>	>>	>>	Line7	17	5930	12.47	>>

The interruption occurred at the some point through the feeder are more or less similar with the interruption that happen on the total feeder. The interruption considered here are the interruptions that occurred on some part of the feeders. Those interruptions are not causes disconnection of the total feeder from the system but it causes an interruption to the customer beyond the fault point. The data collected for analysis of reliability and design of distribution feeder are interruption frequency and interruption duration or reconnecting time. Number of customer interrupted during the fault, Frequency interruption per year of respective feeder is counted in number, in similar way the duration interruption per year is also added by taking the difference of disconnecting time and reconnecting time of the faulted equipment to the system in hours and summarized as shown in table 3.6. As the data collected from distribution substation the fault occurred on the feeder causes an interruption to the total customers on the feeder that means the feeder is disconnected from the system. But the fault occurred at some point on the feeder saves

a few customers on the feeder that means the feeder is not disconnected from the system but the customers beyond the fault point are interrupted.

Table 3.6 Duration of interruption and interruption frequency

Feeder	Number of customer interrupted (N_{iu})	Interruption frequency λ_{iu} in (N_o)	Duration of interruption r_{iu} in hours
1	8194	1069	796.005
2	10430	741	904.305
3	11750	825	858.04
4	10542	718	693.12
5	1	129	67.507
6	3371	606	471.903
7	4317	771	906.243

The total interruption frequency and interruption duration of each feeder is the sum of interruption data gained from Nazareth substation and utility service as shown in table 3.7.

Table 3.7 Total frequency of interruption and duration of interruption

Feeder	Interruption frequency in λ_t (N_o)	Duration of interruption r_t in hours
1	1631	1214.955
2	1131	1380.255
3	1259	1309.64
4	1096	1057.92
5	197	103.37
6	925	720.273
7	1177	1383.213

3.2 Causes of Faults in Nazareth Distribution System

3.2.1 Earth Fault

The causes of Earth Faults are:-

- Transformer burnout
- Treeming
- Contacting of two or more phase with ground
- Contacting of line with wet objects near the transmission line due to wind force this may be temporary fault.

- Aging

3.2.2 Short circuit fault

The causes of short circuit Faults are:-

- Contacting of two or three line due to wind (this may temporary fault)
- Falling of line on other line
- Opening of the transformer (due to low transformer oil)
- Disconnection of the section
- Drop down of transmission line from its design position and contact with other objects
- Falling of the tower
- Cutting of the line due to aging

3.2.3 Over loads

- Cutting of the line
- Starting of large machineries
- Operation of an industries on full load during peak load time

3.3 Methodology of design and plan of distribution system

The sizing of the components in a power distribution system is a very complex and highly constrained problem primarily driven by the design of the feeder system. The design of the feeder system is also constrained by practical considerations, and is heavily dependent on the nature of the service area for that feeder, such as the amount of load (kVA), its classification (residential, commercial, industrial), its load factor, its power factor, and many other technical characteristics (Willis, 1997, P. 285) [11].

Under the section of data collected to analyze the reliability, it will be identified that the reliability of power distribution system is low or not, it needs upgrading or not and if so the system will be designed to reduce the number of interruption and duration of interruption for the customer satisfaction. In addition to the low system reliability to design and plan from the current status, the data like present peak load of power distribution system, growing load demand of customers per annum, power factor currently used by utility sector, design and plan criteria of EEP and this are shown in table 3.8.

To cope with the demand for electricity caused by the country's economic growth, the Government's future outlook for the power market sector has been divided into short, medium and long term plans of 5,10 and 25 year periods respectively.

Table 3.8 data used for forecasting, design and planning of distribution system and components [14].

Current peak load (MW)	Annual load growth in % (EEP) data		Design and planning of future load demand in period (year)			Annual load growth in % (world bank) data
	Growing area	Saturated area	Short term	Medium term	Long term	
44	5	2	5	10	25	6

Using data mentioned above and other the future load demand forecasted (in this thesis long term forecast of 25 years), distribution system components are designed and components are selected by their appropriate ratings in chapter five sections 5.5.2.

3.4 Software

The software used in this thesis work to design and improve the power distribution system is Electrical Transient and Analysis Program (ETAP) software. ETAP is fully graphical enterprise package that runs on Microsoft ®, Windows® 2003, 2008, 2012, XP, Vista, 7, and 8 Operating systems. ETAP is the most comprehensive analysis tools for the design and testing of power system available [13].

3.5 RELIABILITY ANALYSIS OF POWER DISTRIBUTION SYSTEM

3.5.1 Introduction

Electric power is a vital element in any modern economy. The availability of a reliable power supply at a reasonable cost is crucial for the economic growth and development of a country. Electric power utilities throughout the world therefore endeavor to meet customer demands as economically as possible at a reasonable service of reliability. To meet customer demands, the power utility has to evolve and the distribution system have to be upgraded, operated and maintained accordingly. An analysis throughout the world shows that around 90% of all customer reliability problems are due to the problem in distribution system, hence, improving distribution reliability is the key to improving customer reliability [1].

The majority of customer reliability problems stem from distribution systems. This is largely due to radial nature of most distribution systems, the large number of components involved, the sparsity of protection devices and sectionalizing switches, and the proximity of the distribution system to end-use customers. Since reliability means different things to different people, it is necessary to address the definition of ‘‘distribution system reliability’’ in more detail. In distribution systems, reliability primarily relates to equipment outages and customer interruptions. Thus reliability evaluation of a distribution system is associated with the continuity of supply of energy from the supply points to the individual customer load points [10].

The basic parameters used to evaluate the reliability of a distribution system can be categorized as load point indices and system indices. The load point failure rate, the average outage time and the average annual outage time are the basic load point indices. The system indices can be obtained from these three load point indices and information on the number of customers and load connected at each load point in the system. The set of system reliability indices can be further classified into customer-oriented indices and load-oriented indices. Customer-oriented indices include the System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Index of Reliability (IOR), Customers Experiencing Multiple Interruptions (CEMI), and Customers Experiencing Longest Interruption Duration (CELID). Load-oriented indices include Average System Interruption Frequency Index (ASIFI) and Average System Interruption Duration Index (ASIDI) [14].

Distribution system reliability evaluation is important to ensure appropriate system reliability levels and to provide effective information for regulatory bodies to set proper benchmarks. Analysis of past performance and prediction of future performance are two crucial factors of distribution system reliability evaluation [3].

3.5.2 Reliability Evaluation

Reliability is the probability that the system will perform its intended function under specified working condition for a specified period of time. Reliability is the analysis of failures, their causes and consequences. It is the most important characteristic of product quality as things have to be working satisfactorily before considering other quality attributes. Distribution system

reliability is not dependent solely upon component failure characteristics. It is also dependent upon how the system responds to component failures [14].

3.5.3 Distribution Reliability Indices

Typical distribution system accounts for 40% of the cost to deliver the power and 80% of customer reliability problems distribution system design and operation critical for financial success of the utility company and customer satisfaction.

Interruptions and outages can be studied through the use of predictive reliability assessment tools that can predict customer reliability based on system topology and component reliability data. In order to achieve this distribution reliability indices are calculated. Such reliability indices should concern both duration and frequency of outage. The reliability of a distribution system can be described using two sets of reliability parameters. These are the system reliability indices and the load point reliability indices [3].

3.5.4 Frequency and duration of Interruption of Nazareth Power Distribution System

The reliability analysis of power distribution system would be analyzed by the data collected from the following sectors:

- Nazareth Distribution substation
- Utility service sectors

Based on the data collected and summarized in table 3.7 the interruption frequency and duration of interruption of each feeder respectively shown graphically in the figure 3.2 and 3.3 respectively

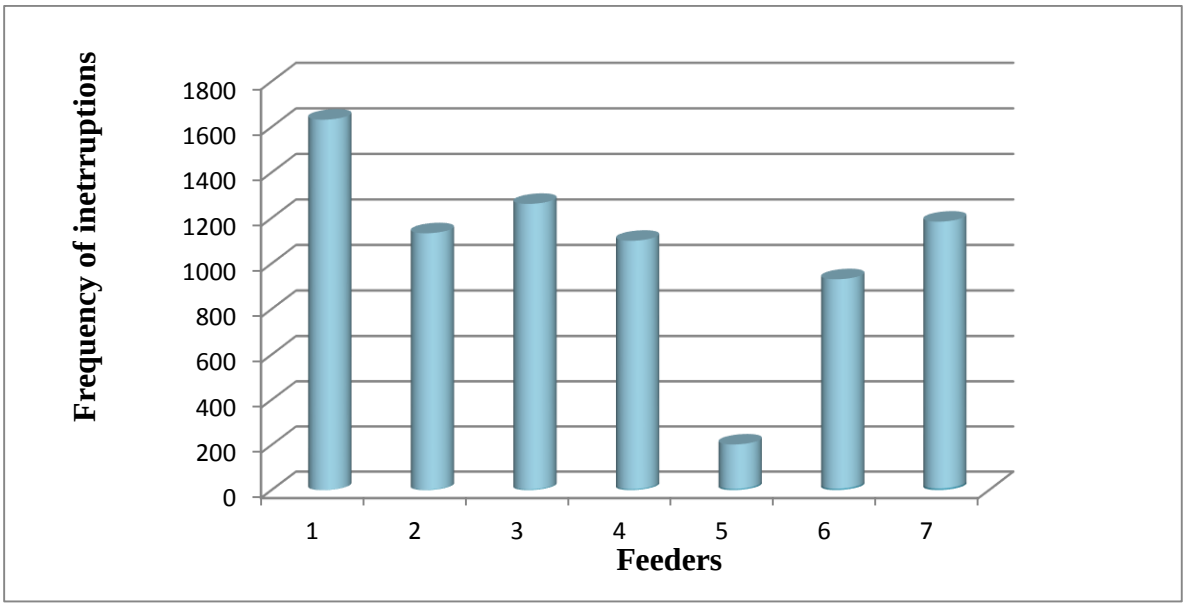

Fig. 3-2 Interruption frequency of distribution system from 01/01/2008 to 30/12/2008

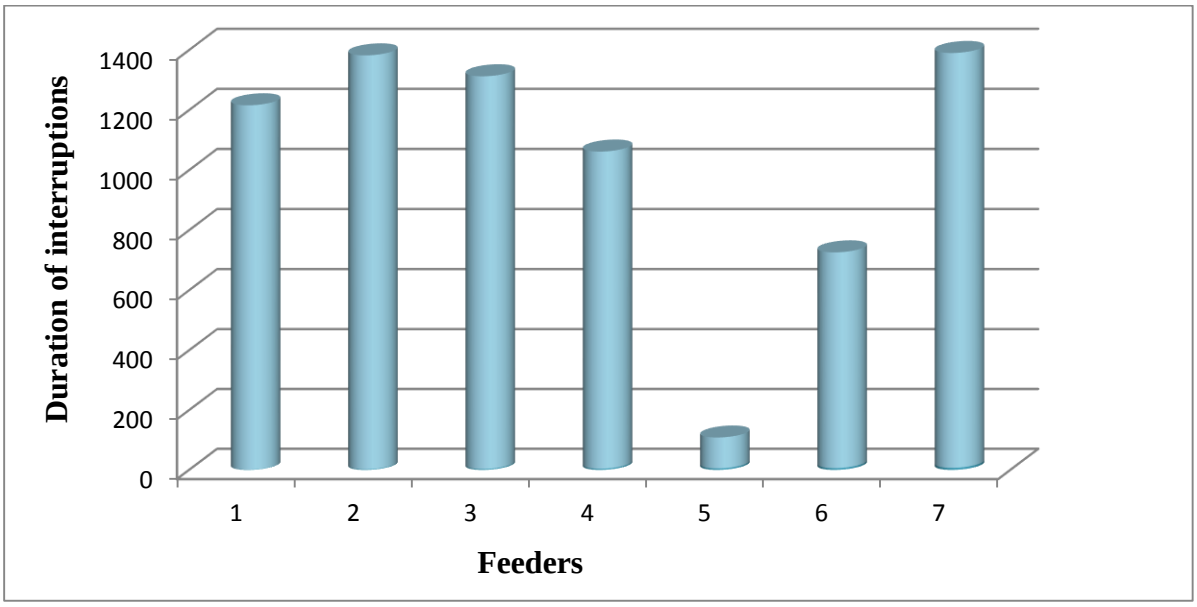

Fig.3-3 Duration of Interruption from 01/01/2008 to 30/12/2008 E.C

3.5.5 Reliability Indices Evaluation of Nazareth Distribution System

Systems reliability indices indicate the annual average performance of the network in terms of interruption frequency and duration. They are weighted by the number of customers or energy supplied. Some of the basic indices that have been used to assess the past performance are discussed below [14]. Evaluating of system average interruption frequency index (SAIFI),

system average interruption duration index (SAIDI) and Average Service Availability Index (ASAI) are one of the objectives of this thesis work. In this paper system reliability indices (SAIFI, SAIDI and ASAI) evaluated and calculated on the period of one year. But reliability indices can be calculated on monthly, daily or for any other time period [3].

The method used to find reliability indices in this paper is Statistical analysis method. Statistical analysis allows monitoring system performance from a reliability point of view; it also provides information that can help validate predictive analysis as well as identify areas where reliability needs to be improved. Statistical approaches require historical data of all service interruptions experienced by customers over a defined evaluation period. System reliability will be quantified by means of the customer interruption indices [15].

3.5.5.1 System Average Interruption Frequency Index (SAIFI)

Reliability indices are normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period. In this thesis work reliability indices are calculated by considering yearly basis.

SAIFI indicates how often an average customer is subjected to sustained interruption over a period of time interval. This index is average number of interruptions per customer served. It is determined by dividing the accumulated number of customer interruptions in a period of time by the number of customers served. This can be achieved by adding the number of interruption occurred when the respective feeder is disconnected from the system as shown in table 3.2 and interruption occurred at some point of feeder with the presence of feeder with system as indicated in table 3.6. SAIFI is calculated by the following formula and are tabulated in table 3.9 and graphed in figure 3.4 respectively [14].

$$\text{SAIFI} = \frac{\text{Total number of customer interruption}}{\text{Total number of customer served}} = \frac{\sum \text{Ni} * \lambda\text{t}}{\sum \text{Nif}} \qquad (3.1)$$

Where N_i is number of customer interrupted

N_{if} is total number of customer served and

λt is frequency of interruption

Table 3.9 System Average Interruption Frequency Index

Feeders	Number of customers (N_{if}) per feeder	Number of interrupted customer (N_i)	Interruption frequency in year (λ_t)	SAIFI=$\frac{\sum Ni*\lambda t}{\sum Nif}$
1	9104	8194	1631	1467.972
2	11588	10430	1131	1017.978
3	13056	11750	1259	1133.061
4	11713	10542	1096	986.4281
5	1	1	197	197
6	3745	3371	925	832.6235
7	4797	4317	1177	1059.226
				Average =956.33

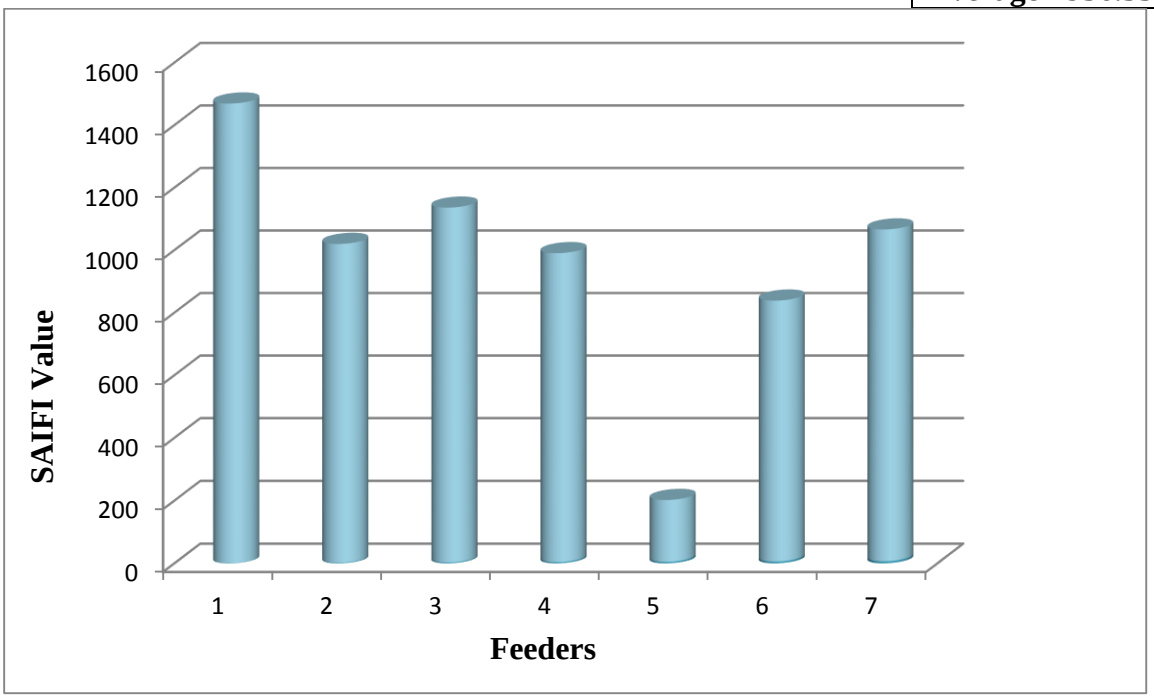

Fig.3-4 SAIFI Value from 01/01/2008 to 30/12/2008 E.C for each distribution feeder.

3.5.5.2 System Average Interruption Duration Index (SAIDI)

This index measures the total duration of an interruption for the average customer during a given period of time. SAIDI is normally calculated on either monthly or yearly basis; however, it can also be calculated daily, or for any other time period. In this thesis work reliability indices are calculated by considering monthly basis. To calculate SAIDI, each interruption during the time period is multiplied by the duration of the interruption to find the customer-minutes of interruption. The customer-minutes of all interruptions are then summed to determine the total

customer-minutes. To find the SAIDI the data of interruption duration at substation indicated in table 3.2 and utility sector indicated in table 3.6 is summed up and is calculated by Eq. (3.2) and the results are shown in table 4.10 and graphed in figure 3.5 respectively [14].

$$\text{SAIDI} = \frac{\text{Total number of customer interruption duration}}{\text{Total number of customer served}} = \frac{\sum \text{Ni} * \text{rt}}{\text{Nif}} \qquad (3.2)$$

Where r_t is total interruption duration

Table3.10 System Average Interruption Duration Index

Feeders	Number of customers on the feeder (N_{if})	Number of customer (N_i) interrupted	Duration of interruption r_{is} in hours at substation	Duration of interruption r_{iu} in hours some place on feeder	Total interruption duration r_t in hr	SAIDI=$\frac{\sum \mathbf{Ni*rt}}{\mathbf{Nif}}$ (hr./year)
1	9104	8194	418.95	796.005	1214.955	1093.513
2	11588	10430	475.95	904.305	1380.255	1242.325
3	13056	11750	451.60	858.04	1309.64	1178.6
4	11713	10542	364.80	693.12	1058.307	952.5034
5	1	1	35.53	67.507	103.037	103.037
6	3745	3371	248.37	471.903	720.273	648.3419
7	4797	4317	476.97	906.243	1383.213	1244.805
						Average =923.3

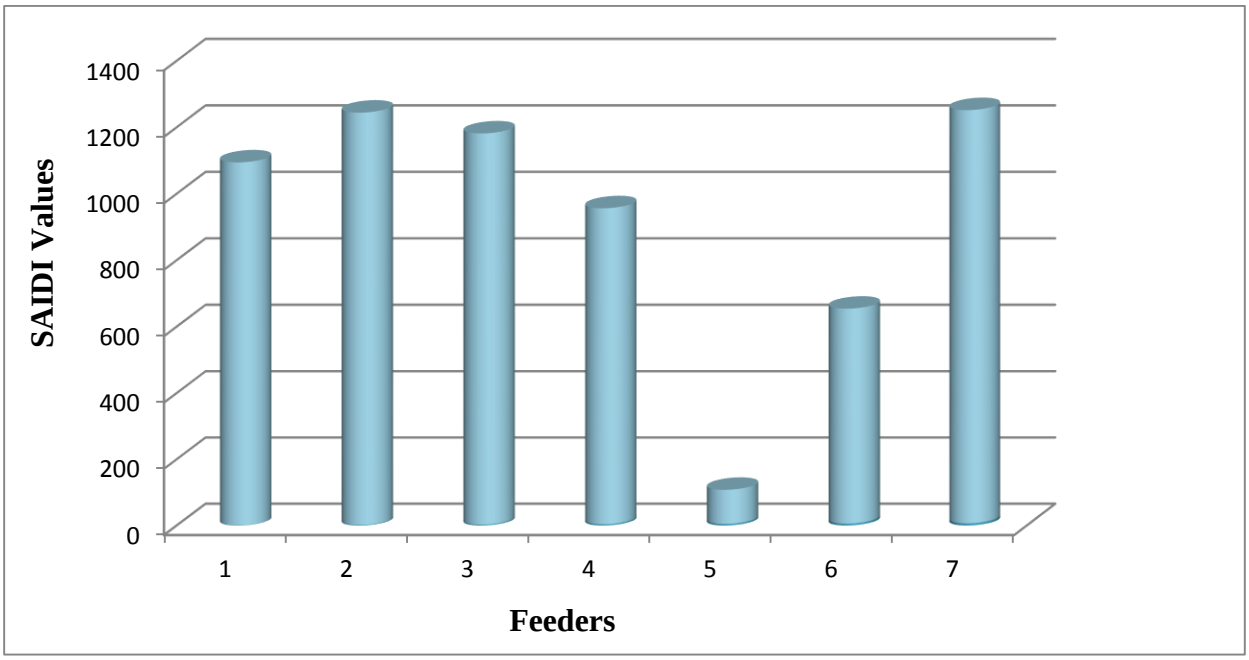

Fig. 3-5 SAIDI Value from 01/01/2008 to 30/12/2008 E.C for each distribution feeder**.**

3.5.5.3 The Average Service Availability Index (ASAI)

ASAI specifies the fraction of time that a customer has received the power during a predefined interval of time. This is the ratio of the total number of customer hours that service was available during a given time period to the total customer hours demanded. This is sometimes known as the "Service Reliability Index". ASAI is usually calculated on either a monthly basis (730 hours) or a yearly basis (8,760 hours), but can be calculated for any time period. ASAI is calculated on yearly basis in this thesis and evaluated by equation (3.4), tabulated in table 3.11 and graphed in figure 3.6 [14].

$$\text{ASAI} = \frac{\text{customer hours of availaible service}}{\text{customers hour demanded}} = \left(1 - \frac{\sum \text{rt} * \text{Ni}}{\text{Nif} * \text{T}}\right) * 100 \qquad (3.3)$$

Where r_t= interruption duration, hours

N_i= Total number of customers interrupted

N_{if}= Total number of customers served

T = Time period under study, hours

Table 3.11 Average Service Availability Index.

Feeders	Number of customers (N_{if})	Number of interrupted customer (N_i)	Duration of interruption r_t in hours	$ASAI = \left(1 - \frac{\sum rt * Ni}{Nif * T}\right) * 100$
1	9104	8194	1214.955	87.517
2	11588	10430	1380.255	85.818
3	13056	11750	1309.64	86.545
4	11713	10542	1057.92	89.131
5	1	1	103.37	98.820
6	3745	3371	720.273	92.599
7	4797	4317	1383.213	85.790
				Average =89.46

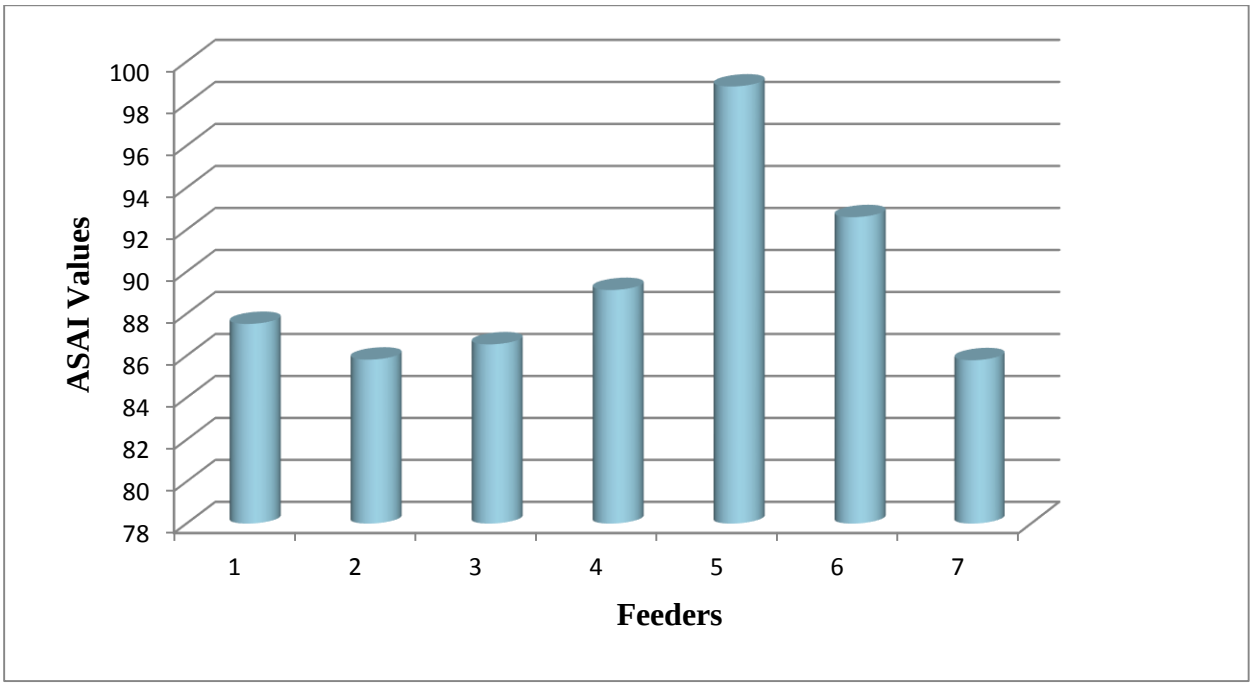

Fig. 3-6 ASAI Value from 01/01/2008 to 30/12/2008 E.C for each distribution feeder.

3.6 Comparison of Reliability Indices with Benchmarks

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

A benchmark of SAIFI, SAIDI, and ASAI for nine countries is shown in Table 3.12. A lower number for SAIDI and SAIFI index indicates better reliability performance, which means lower frequency of outages or shorter outage duration and higher value of the ASAI indicates higher reliability performance. A higher SAIDI and SAIFI index number indicates worse performance. Comparing the average SAIDI, SAIFI and ASAI value of Nazareth distribution with the benchmarks shows that has worse performance [14].

Table 3.12 Benchmarks for Reliability Indices

No	Country	SAIDI (hours/year)	SAIFI (Interruptions/Customer year)	ASAI (%)
1	United States	4	1.5	99.91
2	Austria	1.2	0.9	99.97
3	Denmark	0.4	0.5	99.981
4	France	1.033	1	99.91
5	Germany	0.383	0.5	99.9999
6	Italy	0.967	2.2	99.9991
7	Netherlands	0.55	0.3	99.97
8	Spain	1.733	2.2	99.968
9	UK	1.5	0.8	99.964
10	Ethiopia (Nazareth)	923.3	956.33	89.46

A typical customer expects to have a power at all times. In reality a utility will be able to make power available between 99.9 and 99.999 percent of the time. To put it in another way, the

average customer may be dissatisfied if there is no electricity for more than 53 minutes a year. (Source: APPA distribution system reliability and operations survey report, by Alex Hofmann, Nov 2012, published by American Public power association) [14].

As it can be seen from evaluated data the value of SAIFI, SAIDI and ASAI of Nazareth distribution system needs an improvement to supply the customers within the acceptable range. One of the specific objectives of this thesis work is to identify the cause of low system reliability. This system improvement can be achieved by proper maintenance strategy and redesign of power distribution system which is discussed in the following section of this chapter. The redesign of power distribution is necessitated for improving capacity of power distribution system and supply the customer demand by avoiding the interruption caused by overload.

3.7 Types of Faults Occurred in Distribution System

Electrical networks, machines and equipments are often subjected to various types of faults while they are in operation. When a fault occurs, the characteristic values (such as impedance) of the machines may change from existing values to different values till the fault is cleared. There may be lot of probabilities of faults to appear in the power system network, including lighting, wind, tree falling on lines, apparatus failure, etc. Electrical faults in three-phase power system mainly classified into two types namely open and short circuit faults. Further, these faults can be symmetrical or unsymmetrical faults [3].

Open Circuit Faults: - These faults occur due to the failure of one or more conductors. The most common causes of these faults include joint failures of cables and overhead lines, and failure of one or more phase of circuit breaker and also due to melting of a fuse or conductor in one or more phases.

Short Circuit Faults:-A short circuit can be defined as an abnormal connection of very low impedance between two points of different potential, whether made intentionally or accidentally. These are the most common and severe kind of faults, resulting in the flow of abnormal high currents through the equipment or transmission lines. If these faults are allowed to persist even for a short period, it leads to the extensive damage to the equipment. Short circuit faults are also called as shunt faults. These faults are caused due to the insulation failure between phase

conductors or between earth and phase conductors or both. The various possible short circuit fault conditions include three phases to earth, phase to phase, single phase to earth, two phase to earth and phase to phase plus single phase to earth [3].

These may be due to internal or external effects

- Internal effects include breakdown of transmission lines or equipment, aging of insulation, deterioration of insulation in generator, transformer and other electrical equipments, improper installations and inadequate design.
- External effects include overloading of equipments, insulation failure due to lighting surges and mechanical damage by public.

3.8 Maintenance and Operation Strategy of Nazareth Distribution System

At Nazareth distribution system the maintenance schedule are preventive maintenance and corrective maintenance. Preventive maintenance is to reduce failure probabilities by maintenance before failure or significant degradation has occurred.

However at Nazareth distribution system preventive maintenance is not be done by its scheduled time because of the workers are being busy to do the preventive maintenance activity. Thus preventive maintenance will be on only during summer season and the time when the interruption occurs most frequently.

Corrective maintenance is performed after fault recognition and is intended to put the component in a state it can perform a required function. Corrective maintenance is done continuously depending on the condition whether the interruption is immediate or deferred [3].

3.9 The Possible Solutions for improving the Reliability of Distribution System.

Electrical equipment failures account for millions of dollars in damage and lost business every year. As this country's electrical infrastructure continues to age, this problem is only going to worsen unless active steps are taken to counter the trend. More than two-thirds of electrical system failures can be prevented by a routine preventive maintenance program. The failure rate of electrical equipment is three times higher for components that are not

part of a scheduled preventive maintenance program as compared with those that are scheduled. In addition, a planned EPM program allows the equipment owner to schedule the system outage at a time of their choosing rather than having to correct major problems resulting from an always untimely failure [16].

The purpose of this standard is to provide the insured with recommended practices and frequencies that would form the core of a regularly scheduled electrical preventive maintenance program. All work associated with electric power systems and equipment should be performed in accordance with accepted industry safety standards and work practices [17].

The reliability of a power distribution system is important for making the system more economic and efficient. In turn, consumers will receive a more reliable electric supply by the utility company. In order to ensure that the changing utility environment does not adversely affect the reliability of the customer's power supply, regulatory authorities have begun to specify minimum reliability standards that must be maintained by distribution companies [14]. Maintenance of aging distribution systems is an important part of ensuring that the system is performing well and is reliable [14].

As this thesis work concentrates to conduct a study on reliability and design of power distribution system. So the proposed solution for improving the reliability of distribution system concentrates on giving solution to three major aspects of the distribution system:

- Reliability improvement strategy
- Operation and Maintenance improvement strategy
- Redesign of power distribution system

3.9.1 Reliability Improvement Strategy

Reliability improvement Strategy has to be developed for each utilities depending upon their requirements. Also with strategies, Outage mitigation technique in distribution system is to be used and this can be classified in two categories namely; Electric and Non-electric. Electric mitigation techniques have a direct impact on the distribution system and affect the distribution system analysis and these techniques includes addition of protective devices (reclosers and fuses) and switching devices (manual and automated switches) and system reconfiguration [8].

Due to increase in dependence on electricity and the growth of sensitive loads in all customer sectors (residential, commercial and industrial), the utilities must strive to maximize reliability to ensure that customer requirements are satisfied while incurring the lowest possible cost. By knowing the root causes of faults, it is possible to take actions that will prevent faults from occurring, such as performing tree trimming and installing animal guards and surge arresters. Improving component performances by replacing existing components with comparable components that are less prone to failure, e.g., by replacing overhead networks with underground networks or by replacing aged components with new components. Keeping existing components and instead improve component performance by taking preventative maintenance actions, such as introducing and executing inspection and maintenance plans. Employing network structures that are less sensitive to component outages, e.g., meshed networks. Introducing permanent network solutions incorporating such options as automatic reclosing, manual and automatic feeder sectionalizing, automatic feeder fault locating, remote monitoring and control capabilities and emergency supplies from adjacent feeders. Generally there are two possible strategies for reducing frequency and duration of interruption [3].

3.9.1.1 Reduction of the Number of Faults

The reduction of the interruption frequency is possible by decreasing failure rates of the network component. For example, the reduction of the number of faults in an overhead line can be reached by a tree trimming program, which ensures the clearance distance. This will reduce the failure rate, and increase the system reliability and reduce interruption. A reduction of the number of interruptions leads to lower interruption indices. In summary, the reduction of the number of faults causes a decrease of the frequency of interruptions and unavailability. In the following list, we can find the most important measures for reducing failure rates [14].

- Preventive maintenance
- Monitoring critical components
- Preventive replacement of components which have reached the end of their useful life
- Isolated or tree wires in overhead lines to prevent tree contact with the conductor
- Protection against animals contact with conductors

3.9.1.2 Reduction of Time of Interruption

The time of interruption is the time required to restore the power supply. A fault affected zone in the distribution network can be isolated from the healthy part of the network by disconnecting the affected sector. It is important that the switching actions of the restoring process are optimized in order to isolate the smallest possible section of network affected by the fault. This process does not reduce the time interruption in the fault affected zone, but it will provide a substantial improvement in the sector of the network that is not affected by the fault. Furthermore automated sectioning points will provide a more timely restoration of the power supply. If the restoration of the supply takes place in less than three minutes, the interruption is not considered as long interruption. Time reduction of the time processes lead to a reduction in the unavailability indices, but do not show effects on interruption frequency. The following list shows some of the most important measures for reducing the time of interruption [3]:-

- Distribution network atomization
- System reconfiguration after the fault
- Fault current detection in order to localize the fault in the network
- Faster crew response due to the implementation of an outage management system, travel time coordination and an increased number of crews and dispatch centers

3.9.2 Operation and Maintenance Improvement Strategy

Maintenance is an activity involved in maintaining a system or equipment to be in a proper working order, to improve the reliability and sustainability of the system or equipment and to extend its life expectancy. Certain legislations, manufacturer guidelines, maintenance strategies and philosophies are compelled to conduct maintenance in distribution systems. Maintenance activities in Nazareth distribution system in most instances are not carried out as planned due to unplanned and unforeseen circumstances within the distribution system and most of the time only corrective maintenance is embarked, and this result not to meet the scheduled activities of preventive maintenance. The eventual aging of the electrical network, the extent of damage experienced, conduction of repeatable repairs in the same areas and lack of maintenance leads to deterioration of the distribution network [3].

Types of electrical maintenance practices

a) Preventive maintenance

- Time based (periodic)
- Condition based

b) Corrective maintenance

- Immediate
- Deferred

3.9.2.1 Preventive Maintenance

The concept of preventive maintenance is to reduce failure probabilities by maintenance before failure or significant degradation has occurred. This often translates into trying to avoid costs of corrective maintenance and other costs that belong to unexpected failures. But in Nazareth distribution system preventive maintenance is seldom performed; in site visit it was found that most of equipment needs preventive maintenance in order to improve unexpected power interruption and failure of equipment. This preventive maintenance is highly required on transformer and related switch gears. Equipment like surge arrestors, drop out fuses and High Rupture Capacity (HRC) fuses are seemed to be uninspected. It is categorized by time-based and condition-based maintenance. Periodic (time-based) maintenance as the name implies is performed at regular intervals. This is a proper strategy in the case of a well identified aging process for the component. The time intervals between maintenance should be based on failure with shorter intervals for the maintenance than for the expected time to failure. Condition based maintenance is performed based on an estimate of the components condition. One of the simplest forms of condition based maintenance is to prolong the first service interval of a periodical maintenance routine; this is based on the assumption that new equipment is in better condition compared to the older. Condition based maintenance is based on the knowledge of the condition of the equipment from routine or continuous monitoring (systematic inspections, measurements) [16].

3.9.2.2 Corrective Maintenance

Corrective maintenance is performed after fault recognition and is intended to put the component in a state it can perform a required function. The component is used until it fails. Corrective maintenance might be considered as the last resort and may be considered as the failure of the

maintaining organization performing it. Corrective maintenance might be the right approach for a component group given that resources are focused on other, possibly more important assets. For equipment's with random occurring instant failures corrective maintenance might be the only option. One might consider redesign of the system for these kinds of failures. But it is quite likely these failures might be worth (living with) while focusing on other areas with better goals. It is also categorized by immediate and deferred maintenance [14].

In addition to maintaining of power distribution equipments, replacing of old equipments by new one and using new technologies for improvement of system reliability the updated system design can also improve system reliability. The redesigning work in this thesis necessitated not only for improving system reliability it is also necessitated for upgrading of distribution system capacity to meet the customer demand because the present system is over loaded. This is second part of this thesis work which examines different distribution system equipment redesigns and selection.

3.10 REDESIGN OF POWER DISTRIBUTION SYSTEM

3.10.1 Introduction

Electric power distribution is the portion of the power delivery infrastructure that takes the electricity from the highly meshed, high-voltage trans-mission circuits and delivers it to customers. Primary distribution lines are "medium-voltage" circuits, normally thought of as 600 V to 35 kV. At a distribution substation, a substation transformer takes the incoming trans-mission-level voltage (35 to 230 kV) and steps it down to several distribution primary circuits, which fan out from the substation. Close to each end user, a distribution transformer takes the primary-distribution voltage and steps it down to a low-voltage secondary circuit (commonly 120/240 V; other utilization voltages are used as well). From the distribution transformer, the secondary distribution circuits connect to the end user where the connection is made at the service entrance [19]. The part of power system which distributes electric power for local use is known as distribution system. In general, the distribution system is the electrical system between the sub-station fed by the transmission system and the consumer's meters. It generally consists of

- Feeders
- Distributors and

- Service mains.

In design of power distribution system all materials and workmanship shall be of the best Standard and shall comply with the relevant legislation and Ethiopian Standards, or if such do not exist, with the relevant IEC or International Standard Organization (ISO) Standards. For better distribution reliability, low voltages feeders should be undergrounded. Loads or customers should be separated by specifying industrial, commercial and residential consumers.

The aim of a well-designed electricity system is to provide voltage to customers that is stable, stays within limits and is free from random momentary variations and other disturbing waveforms [20]. The electrical design of distribution facilities is based on the loads they are to carry safely and the permissible voltage variations; the final design, however, cannot be divorced from mechanical, economic, and other considerations. Several different designs may serve the same electrical requirements adequately; each, in turn, may be modified by mechanical considerations. The design ultimately selected must reflect economic considerations: specifically, the design that results in the least annual expense in supplying the load or loads in question. This necessarily involves the evaluation of losses, as well as capital, maintenance, and operation expenses. Often, other considerations must also be taken into account including government regulations (at all levels), national and local industry construction and safety codes, taxes, public relations, and some other, intangible requirements [21].

3.10.2 Standards and Design Guidelines of Power Distribution System

Power distribution system standards and design guidelines are the minimums acceptable criteria's for the design of efficient, economical, durable, maintainable, and reliable electrical power supply and distribution systems. Clarifications of baseline design criteria, standards, policy, and guidelines are provided by Institute of Electrical and Electronics Engineers (IEEE), International Electro-technical Commission (IEC), National Electrical Code (NEC), American National Standards Institute (ANSI), National Electrical Manufacturers Association (NEMA), or International Standard Organization (ISO) [14].

The most suitable solution for any single design of power distribution system will depend on the particular requirements of the facility. In addition to the standards and guide lines designers would use their judgment, experience, knowledge and local conditions as a guide during design to suit the particular installation requirements.

When designing and developing the distribution system for a particular area the following main points should be considered [39]:

a) Service conditions

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

b) Electrical Design

- Transformers and accessories
- Protection of electrical systems
- Operation of the system

c) Mechanical design

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

d) The economics of the design

e) The availability of proven technology

f) The integration and compatibility with existing equipment, and

g) Equipment and installation compliance.

3.10.3 Single Line Diagram of Nazareth Distribution System

Nazareth distribution system has seven outgoing feeders each having 15kv voltage level, distribution transformers with its accessory and two substation transformers each having rate of 25MVA. Single line diagram is shown in figure 3.7.

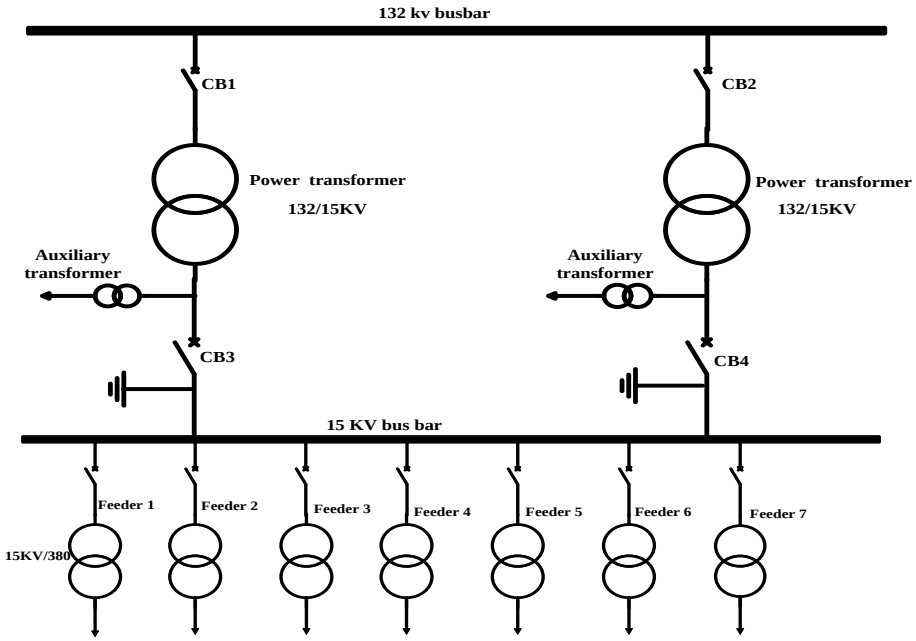

Fig. 3-7 Single Line Diagram of Nazareth Distribution System

3.10.3.1Reliability Analysis of existing distribution system by ETAP

Reliability Analysis of existing power distribution system has been done by ETAP software using interruption duration, frequency of interruption and rating of distribution equipments as input in addition to this default value of parameters has been used. Partial of power distribution system network taken from ETAP work page by snap shoot tool as shown in figure 3.8.

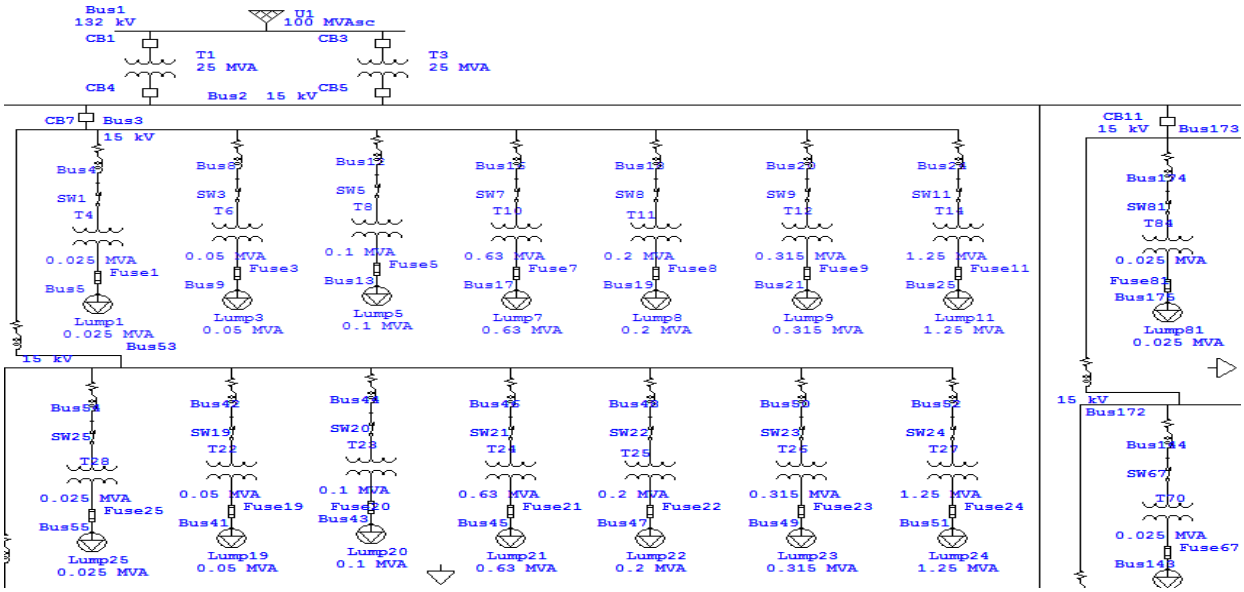

Fig. 3.8 Nazareth distribution systems (existing)

The simulation result of existing distribution system is shown in table 3.13.

Table 3.13 simulation result of existing Nazareth distribution system

Indexes	SAIFI (N_o)	SAIDI (hours)	ASAI (%)
Values	956.3372	923.314	89.46%

3.11 Load modeling

Power distribution networks differ from each other in both characteristics and configuration, depending on location. This will determine important factors such as network strength, fault levels and source impedances, transformer ratings and feeder types/lengths, as well as the level of dedicated public/street lighting. In addition, geographic location, as well as time of the day and season of the year, has a strong influence on the electrical characteristics of the load/demand sectors, so these variations must be taken into account for the correct modeling of loads at the different voltage levels (HV, MV and LV). This information is required for the analysis of the network loading/operating conditions and assessment of network reliability performance in power system studies [11].

The main purpose of a load model is to correctly represent the changes in active and reactive power demands of the modeled load as a function of variations of certain supply system parameters Accordingly, the most frequently used load models can be described as a mathematical or analytical description of the changes in active and reactive power flows to a device, or group of devices connected to the power system, typically with respect to voltage and/or frequency [11].

The load demand to be served is the most important to design the system and to select the appropriate equipment. The objective of this thesis is to design the power distribution system. The Nazareth distribution system has least reliability when it is compared to the benchmark. From the data collected the total customers on the distribution system is around 54004. Most of the customers of distribution systems are domestic customers; it accounts around 79.9% of total customers.

The current peak load on Nazareth distribution substation as the data obtained from load dispatch center is 44MW. This show that the system is overloaded; even it is overloaded all the customers

connected to the system cannot be served unless some lines or sections are disconnected from the system to serve the rest during peak load because of the capacity of distribution system is less than the demand required by the customers. In order to meet customers demand with greater capacity and reliability, it is necessary to upgrade the distribution system by redesigning the distribution system with proper rating of distribution system equipments [14].

The LV design and planning of the Ethiopian Electric Power is carried out by the help of annual load growth of 2% per annum of saturated area and annual load growth of 5% per annum of growing area [24]. In order to be more realistic and general, the World Bank's annual average growth rate of 6% of a power demand forecast have been used to estimate the capacity of the distribution substation.

To cope with the demand for electricity caused by the country's economic growth, the Government's future outlook for the power market sector has been divided into short, medium and long term plans of 5,10 and 25 year periods respectively [22].
Depending on the above concept the Nazareth distribution system load demand for the next 25 years would be 200.2MW (222.44MVA) by considering 0.9 power factor. The current peak load of distribution system is 44MW and load demand after 25 years will be 200.2MW. Thus the distribution equipment would be redesigned based on this future load demand of 200.2 MW.

The maximum feeder service length allows no contingency backup capacity. This limitation renders a feeder incapable of serving any load other than its own at the time of peak loading. While it can be argued that the annual peak loading of a feeder lasts a relatively short time, typical load duration curves show that feeder loadings can remain close to their peak values for hundreds of hours per year. Due to these high exposure periods of not being able to serve load from adjacent feeders, some contingency capacity must be allowed. The amount of contingency capacity to be allowed is a topic of considerable interest, since reserving contingency capacity represents a stranded financial cost, but also allows more versatile operation of the system [11].

The largest amount of contingency capacity that would ever need to be reserved is 50% (Gönen 1986, P. 235). At a 50% contingency capacity reserve, any feeder would be able to backup another entire feeder at any loading level without thermal overload [20].

To reserve 50% contingency capacity for a feeder, its length must be limited to 70.7% of its maximum service length [23].

The Single Contingency Policy (SCP), which is also sometimes called N-1 criterion, is commonly used for sizing equipments' capacities in a distribution system. Under SCP, the substation must meet its load, if failure occurs to either the largest transformer of its own or the largest transformer among all its adjacent substations. The latter case is evaluated when reconfiguration is allowed and load can be transferred between substations during an emergency. The substation planning analyst reviews the load profiles periodically to see if additional feeders, transformers or new substations are needed. Such assessment primarily involves the comparison of substation capacity and forecasted demand. In the event that a substation's forecasted load exceeds the maximum load of the substation, the planner maybe able to permanently reallocate the transformers or the excess load, depending on the available network topology and its reconfiguration possibilities, without necessitating new capital investments such as reinforcing/building feeders, purchasing transformers, or constructing new substations [24].

A distribution feeder main line typically begins at the feeder breaker and radially feeds segments of overhead wire or underground cable with switch connections to adjacent feeder circuit main lines. The main line feeder circuit is typically comprised of electrical equipment including overhead wire, underground cable, voltage regulation equipment, and overhead and underground switching devices. The typical feeder circuit main line is capable of delivering all of the electric energy from the feeder breaker to an average of 1,000 distribution customers [11].

Each distribution main feeder is generally composed of three equal sections that should serve no more than 25% of the total capacity of the main feeder. As a result, during system intact conditions, a feeder circuit with three sections must be loaded to no more than 75% of capacity (also known as utilization rate) , which reserves 25% of the capacity to be used to meet the load of an adjacent feeder circuit in the event of a failure [25].

The 50% contingency capacity is better for adequacy and security of power distribution system, but it is costly because of it requires half of original circuit cost. In this thesis work 10% contingency capacity will be used during design of distribution feeder.

Considering 10% contingency capacity of feeder having similar size the load over 25 years horizon will be 244.684MVA.

3.12 Redesign of Nazareth Power Distribution System

3.12.1 Introduction

The existing structure of most distribution networks is radial, as depicted in Fig 3.9. In this topology, power is transferred in only one direction from a particular source to various delivery points. Although this is the cheapest and simplest topology, its disadvantage is that a disruption or failure at any location in the network affects all downstream customers [26].

Another characteristic of the existing grid is that the generation and consumption of electricity must be balanced, because electricity is consumed nearly instantly after it is generated. The drawback of this is that, in the event of a large uncompensated failure in the grid, the power delivered from generators are rerouted over transmission lines that do not have the capacity to maintain the excess electricity, resulting in further failures. An additional disadvantage of the generation-consumption interdependency is that any surplus energy would be wasted if it were not consumed almost immediately [26].

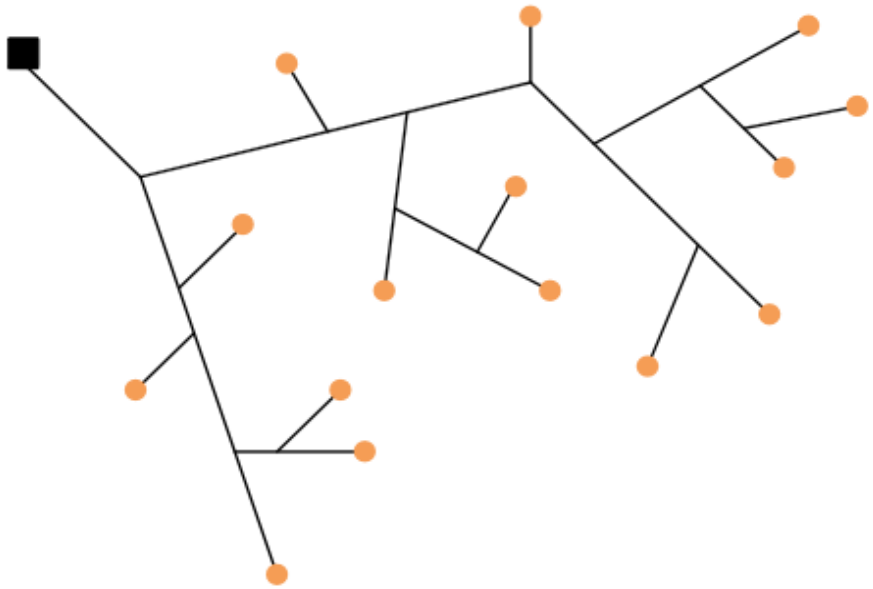

Fig. 3.9 Radial distribution grid topology (black square represents point of generation; orange dots represent points of consumption).

3.12.2 Equipment Redesign and Selection

The main objective of redesign and selection is at the present distribution system cannot meet the customer demand, it is also growing area in which new industries put their footstone for

construction and commercial sectors increases from time to time that is why improving the capacity of power distribution system is necessitated. As alternative way of power distribution capacity improvement construction of additional new power distribution system may suggested which may be restricted from the point view of construction area because it requires new area for construction, but redesign is upgrading of power distribution substation equipments and power distribution system equipments on existing area with small expansion because of some additional equipments.

The planning and design of LV distribution system works for Ethiopian Electric Power is carried out by the help of the following Tables.

In the LV design and planning the following factors are considered:

- Saturated areas will have an annual load growth of 2% per annum [14]
- Growing areas will have an annual load growth of 5% per annum [14]

The engineers are still performing planning and design of distribution network in accordance with the guideline. The guide line has a number of tables giving the necessary information for the engineers to make a quick selection of equipment and material for the distribution system. Though the engineers are using the guideline during the planning and design, but this is not seen on the ground most distribution transformers are loaded [3].

1. Selection of Transformer

Selection of transformer/s size/s must be selected based on the maximum expected load demand and increasing of the load demand at the future. The size of transformer is selected from power ratings given by manufactures list to supply present and future loads [14].

However, the distribution system planners partitions the total distribution system planning problem in to a set of problems which can be handled by using available, usually adhoc method and techniques. The planner in the absence of accepted planning techniques may restate the problem as an attempt to minimize the cost of sub transmission, substations, feeders, laterals, etc. and the cost of losses. In this process, however, the planner is usually restricted by permissible voltage levels, voltage dips, flickers etc., as well as service continuity and reliability. In pursuing these objectives, the planner ultimately has a significant influence on addition to and /or modifications of the sub transmission network, locations and sizes of substation, service areas of

substations, locations of breakers and switch, sizes of feeders and laterals, voltage levels, voltage drops in the system, the location of capacitors and voltage regulators and the loading of transformers and feeder [27].

According to Ethiopian Electric Power the 33 kV and 15 kV primary voltages are used for electric power distribution system [28]. Thus the selection of distribution voltage levels will be based on [27] and [28].

In this thesis work forecasted load is 244.684MVA in addition to this current demand of the customers is greater than the current peak load. This can be clearly known from that all customers cannot be served during peak load demand unless one feeder or section at some place would be disconnected. Thus as the power demand is large it is better to use a substation power transformer with 132/33kV and 50MVA capacity. By taking under consideration of forecasted demand and current overloaded of the system it better to select five power transformers of voltage level of 132/33kV and each transformer ratings of 50MVA. Thus the total capacity of power distribution system would be 250MVA.

After selection of distribution substation power transformers, the distribution transformers are selected based on the following tables (table 3.14-3.16).

The Tables below helps the engineers in planning and design office of EEP and EEU to make a quick decision of what size of transformer of the planned network should have. The selection should be made based on Tables 3.14, 3.15 and 3.16, meaning that the size of the transformer need to be upgraded as soon as one of the criteria's in Tables 3.14, 3.15 and 3.16 have not fulfilled [14] (i.e. by the load criteria, by the number of customers connected to a transformer, maximum distance to customer).

Table 3.14 Selection of Transformer by Load Criteria [14]

Transformer capacity in (KVA)	Present Peak load	
	Saturated areas (KW)	Growing areas (KW)
100	0-63	0-41
200	64-126	42-82
315	127-198	83-129

Table 3.15 Selection of Transformer by Number of Customers Connected to the Transformer [3]

Transformer capacity in (KVA)	Present Peak load	
	Saturated areas (N_o)	Growing areas (N_o)
100	120	80
200	250	160
315	390	260

Table 3.16 Selections of Transformers by Maximum Distance to Customer from Transformer [3]

Transformer capacity in (KVA)	Maximum Distance from the transformer (m)
100	200
200	290
315	360

2. Sizing of bus bars

An electrical bus bar is defined as a conductor or a group of conductor used for collecting electrical energy from the incoming feeders and distributes them to the outgoing feeders. In other words, it is a type of electrical junction in which all the incoming and outgoing electrical current meets. Thus, the electrical bus bar collects the electrical energy at one location. The bus-bars used in electrical substations usually have rectangular cross section bars, but they can be in another shape also, as round tubes, solid round bars, or shape tubes. The bus-bar is usually made up of aluminum. [29].

There are several types of bus bar arrangements, and the choice of particular arrangement depend on different factors such as system voltage, the position of a substation in the system, reliability of supply, flexibility and cost. The following are the electrical considerations governing the selection of any one particular arrangement.

- The bus bar arrangement is simple and easy in maintenance.
- It must have the provision of extension with the load growth.
- The installation should be as economical as possible, keeping in views the needs and continuity of supply [29].

The busbar constitutes the real "backbone" of any distribution assembly. The main busbar and branch bus bars supply and distribute the energy. Busbars can be created using copper or aluminium bars. Flat copper bars are used for busbars up to 4000A with Legrand supports. They provide great flexibility of use, but require machining on request [30].

Bus bar design must ensure easy and uninterrupted maintenance, avoiding any danger to the operating of operating personnel. It must be simple in design and must possess provision for future extension [14].

The design of the busbars should be depends on future load forecasted and the busbar capacity is determined by using equation 5.1a and 5.1b for 132KV incoming feeder and 33KV outgoing feeder respectively.

$$I_{132KV} = \frac{MVA}{KV_{feeder}*\sqrt{3}} = \frac{250MVA}{132KV*\sqrt{3}} = 1.093KA \qquad (3.4a)$$

$$I_{33KV} = \frac{MVA}{KV_{feeder}*\sqrt{3}} = \frac{250MVA}{33KV*\sqrt{3}} = 4.374KA \qquad (3.4b)$$

From data sheet the busbar with the current rating capacity greater or equal with 4.374KA for 33KV side and 1.09KA for 132KV size will be selected as shown in table 3.17

Table 3.17 Busbars ratings for 132KV and 33KV [14]

Description	Minimum Requirements	
	132KV class	33KV class
Type of Bus-bar	Copper	Copper
Rated Current	1.25 kA	5KA
Rated Short Time Withstand Current	65 kA	100KA
Conductors a) Bar Dimensions b) Cross Sectional Area	 90 mm * 6 mm^2 540 mm^2	2 * 200 mm * 6mm^2 2400 mm^2
Resistance	0.036 m Ω/m	0.0091 mΩ/m
Reactance	0.01 m Ω/m	0.0025 mΩ/m
Impedance	0.038 m Ω/m	0.0094 mΩ/m
Voltage Drop (line to line at Power factor of 0.9)	0.08/m)	0.09/m

3. Determination of power transformer Cables and Feeder Conductors current ratings

Engineers in planning and design office of EEP are using Table 3.18 for selecting feeder cables and conductor sizes for the distribution systems by considering transformer size and maximum distance from transformer to customers [14].

Current calculations

For the better selection of appropriate cable or feeder size the current conditions should be considered. For selection of feeder size it necessary to know the voltage and load current in amperes. The rated current of primary cable is calculated [5] using equation 3.5a.

$$I_P = \frac{S}{\sqrt{3}*V_P} = \frac{50MVA}{\sqrt{3}*132KV} = 218.693A \quad (3.5a)$$

Where I_p is primary current in Ampere

S is rating of the transformer in MVA

V_P is primary voltages in KV

The ANSI/IEEE derating method is very useful when it is necessary to calculate the allowable maximum currents when the harmonic makeup of the load is known [31]. The recommended derating factors of transformers which will ensure a sufficient design margin in most application is 85% [32]. In this thesis work also 85% derating factors of transformer is used and standard current calculated [14] as shown blow in equation 5.1b.

$$I_{standard} = \frac{I_P}{\text{derating factor}} = \frac{218.693A}{0.85} = 257.3A \quad (3.5b)$$

This show that the transformer can reliable up to a maximum current of 257.3 A

The rated current of secondary cable is calculated using equation 3.6a as follows.

$$I_S = \frac{MVA}{\sqrt{3}*V_S} = \frac{50MVA}{\sqrt{3}*33KV} = 874.773A \quad (3.6a)$$

Where I_S is secondary current in Ampere

V_S is secondary voltages in KV

By considering the derating factors

$$I_{standard} = \frac{I_S}{\text{derating factor}} = \frac{874.773A}{0.85} = 1029A \quad (3.6b)$$

Choosing of appropriate cable size for load of 1029A is from table 3.18 which shows that the cable size of 1000mm^2 single core unarmored XLPE insulated PVC sheathed 600/1000V stranded copper conductors cable would be capable of carrying a load current [14].

Table 3.18 Single core unarmoured XLPE insulated PVC sheathed 600/1000V stranded copper conductors [14]

Cable size (mm^2)	Electrical Properties								Physical properties		
	1φ cable AC or DC			3φ Trefoil formation				Impedance (Ω/KM)	Nominal Diameters		Nominal mass (Kg/KM)
	Current rating		Voltage drop per Amp per mV (mV)	Current Rating			Voltage drop per Amp per (mV)				
	Ground (A)	Air		Ground (A)	Duct (A)	Air (A)			D1 (mm)	D2 (mm)	
25	118	126	1.75	127	111	112	1.52	0.8767	5.95	11.91	366
35	156	156	1.27	153	132	141	1.1	0.6356	7	12.96	469
50	186	191	0.95	180	155	172	0.82	0.4745	8.15	15.15	632
70	232	246	0.67	221	190	223	0.58	0.3356	9.79	16.57	880
95	281	300	0.5	265	226	273	0.43	0.25	11.54	19.04	1160
120	324	349	0.41	301	256	318	0.36	0.2054	12.96	20.24	1413
150	370	404	0.35	338	287	369	0.3	0.1734	14.39	22.07	1734
185	424	463	0.3	381	323	424	0.26	0.1499	16.1	24.08	2145
240	498	549	0.25	442	372	504	0.22	0.1268	18.71	27.81	2725
300	566	635	0.23	499	419	584	0.2	0.1131	21.45	30.75	3375
400	651	742	0.21	565	472	679	0.18	0.1028	24.3	34.1	4395
500	740	835	0.19	634	532	778	0.17	0.0963	26.51	37.17	5299
630	836	953	0.18	718	603	892	0.15	0.089	33.15	43.62	6965
800	931	1086	0.17	792	689	1020	0.15	0.0852	37.7	49	9118
1000	1041	1216	0.16	856	741	1149	0.14	0.0819	42.25	53.45	11050

4. Selection of Circuit breakers

Electrical circuit breaker is a switching device which can be operated manually as well as automatically for controlling and protection of electrical power system respectively. As the modern power system deals with huge currents, the special attention should be given during designing of circuit breaker to safe interruption of arc produced during the operation of circuit breaker**.** Circuit breakers are installed and used for safety purposes in residential as well as commercial and industrial areas. In power distribution, we need circuit breakers at different

levels. Depending on the current carrying capacity, breaking capacity and other functions, we select a suitable circuit breaker according to our needs [25].

The ratings of 132KV and 33KV circuit breakers are shown in table 3.19[14].

Table3.19 Ratings of 132KV and 33KV circuit breakers [14]

Description	Minimum Requirements	
	132KV	33KV
Type of Circuit Breaker	Outdoor Type	Outdoor Type
Rated Service Voltage	132 kV	33KV
Rated Maximum Voltage	145 kV	36KV
Type of Quenching Medium	SF_6	SF_6
Rated Current	400A	1250A
Rated Short Circuit Current	31.5 kA	25KA
Number of Poles	3	3
Rated Frequency	50 Hz	50HZ
Rated Short Circuit Making Current	63 kA	100KA
Short Circuit withstand current duration	0.5 Sec	0.5Sec
Insulation level a) Power Frequency Withstand (kV RMS for 1 min) b) Impulse Withstand (1.2/50 μsec) kV Peak	 170KV 650KV	 70KV 170KV

5. Reclosers

Reclosers are a kind of sectionalizer which operates like a circuit breaker equipped with a mechanism that can automatically close the breaker after it has been opened due to a fault. Reclosers are used on overhead distribution systems to detect and interrupt momentary faults. Reclosers provide automatic fault detection, fault interrupting and restoration capability including communication protocols for remote control Smart reclosers open when a fault occurs on that part of the main in which they are connected; a timing device, however, enables them to reclose a predetermined number of times for short durations. If a fault is of a temporary nature, the reclosers will remain closed and service will be restored; should the fault persist, the reclosers will remain open and disconnect that part of the section from the circuit [29].

Table 3.20 Ratings of 33KV Reclosers [38].

Rated maximum voltage Ur	38KV
Rated continuous current Ir	630, 800A
Rated lightning impulse withstand voltage Up	170KV
Power frequency insulation level withstand test voltage (one minute dry) Ud	70KV
Rated symmetrical interrupting current Isc	12.5, 16KA
Rated asymmetrical making current (rms)	20, 25KA
Rated peak making current	32.5, 41KA
Mechanical life (operating cycles)	10,000OPS
Permissible short-circuit operations	up to 250OPS
Ambient temperature range	-40 to +55OC

6. Isolators

Isolators are a mechanical switch which isolates a part of circuit from system as when required. Electrical isolators separate a part of the system from rest for safe maintenance works. So definition of isolator can be rewritten as Isolator is a manually operated mechanical switch which separates a part of the electrical power. Isolators are used to open a circuit under no load. Its main purpose is to isolate one portion of the circuit from the other and is not intended to be opened while current is flowing in the line. Isolators are generally used on both ends of the breaker in order that repair or replacement of circuit breaker can be done without danger [12].

Isolator shall be designed such that in fully open position, it shall provide adequate electrical isolation between the contacts on all the three switches. Isolator shall be horizontal side opening, double side break rotating post type for use on a 132kV, 50 Hz, 3 - phase system. The isolator shall be motorized and also fitted with manual operation facility [3]. The ratings of the isolators with respect to voltage levels and current carrying characteristics indicated in table 3.21.

Table 3.21 Ratings of 33KV and 132KV Isolators [3]

Description	Minimum Requirements	
	Rated Service Voltage	
	132 kV	33KV
Rated Maximum Voltage	145 kV	36
Rated Current	400A	1250A
Rated Short-time Current	25 kA	31.5KA
Number of Poles	3	3
Rated Frequency	50 Hz	50Hz
Rated Maximum Withstand current	100 kA	100KA
Closing or Opening Time	≤ 30 Sec	≤ 30 Sec
Insulation level a) Power Frequency Withstand Voltage (kV RMS for 1 min) b) Impulse Withstand Voltage (1.2/50 μsec) kV Peak	170KV 650KV	70KV 170KV

7. Selection of Service Drops Conductor

The selection of service drop conductor is depending on type of the load to be served that is single phase or three phase load, thus after the load to be served is identified the appropriate conductor size will be selected from table 3.22.

The conductor sizes of the service drops in the planning and design office of EEP and EEU are selected in accordance of Table 3.22 [14].

Table 3.22 Selection of the ABC cables for service Drops [14]

Transformer capacity	Selection of service drop conductor	
	ABC cable for service drops (cross section in mm^2)	Remarks
Single phase loads	10 16	Selection is depending on the load
Three phase loads	10 16 25	Selection is depending on the load

8. Selection of Fuse Ratings

Fuses are switching devices those capable of interrupting all currents from the rated maximum interrupting current down to the current that causes melting of the fusible element [40].

Fuses are over current devices designed to protect electrical circuit components. If a circuit develops too much amperes, they are designed to interrupt the flow of current in the circuit. Fuses self-destruct when they sense an overload in the circuit [3].

The criteria required to select a fuse rating in order to select a suitable fuse for use on the distribution system are:

i. Voltage and insulation level.
ii. Type of system.
iii. Maximum short circuit level.
iv. Load current.

The above four factors determine the fuse nominal current, voltage and short circuit capability characteristics [3].

The fuse ratings for distribution system are selected by the planning and design office of EEP in accordance Table 3.23.

Table 3.23 Selections of Fuse Ratings, Depending on Transformer Size & Number of Feeders [14]

Transformer capacity in (KVA)	Selection of Fuse Ratings		
	One Feeder (A)	Two Feeder (A)	Three Feeder (A)
100	160	63-100	-
200	-	100-200	100-160
315	-	160-300	100-300

The planning and design office of Ethiopian Electric Power follows the guidelines to prepare plans, designs, specifications, and cost estimates for the installation, maintenance, repair and expansion of distribution system [3].

In general the distribution equipments are not only those mentioned above there are others equipments rather than mentioned above and their accessories which needed during implementations.

3.13 Power distribution system Redesign summary

- The present 50MVA power distribution system capacity replaced by 250MVA by forecasting of future load demand of customers over 25 years horizon
- The total customers on the present power distribution system including domestic, commercial, industrial and others is 54004
- Customers on redesigned power distribution system increases from this figure in the future as the load demand increases 6% per annum and it is also for growing area which indicates that the number of customers increases from year to year.
- Power distribution substation equipments and power distribution system equipments (equipments after substation) are redesigned and selected based on future load demand of 250MVA

CHAPTER FOUR

SIMULATION RESULT AND DISCUSSION

The reliability indices of existing power distribution system analyzed using mathematical model and simulated using software in chapter three shows that the reliability of the system is low when compared with benchmark as shown in table 3.12. The causes of low system reliability are failure of distribution equipments due to short circuit, earth fault, over load, ending operations of distribution equipments and similar problems.

For improvement of system reliability from present status; good maintenance strategy especially preventive maintenance schedule which reduces about two-third of electrical system failures and redesign of power distribution system equipments as designed and selected in chapter five is needed. Under this section power transformer, distribution transformer, busbars, circuit breakers, fuses, isolators, reclosers, service drop conductors those are redesigned and selected in section 3.12.2 used with their rating capacity as input for simulation. In addition to rating capacity of power distribution equipments some default value are used during simulation.

The simulation result of designed power distribution system would be evaluated using reliability analysis software namely Electrical Transient and Analysis Program (ETAP) which is used in this thesis work. The diagram shown in figure 4.1 is taken from the ETAP work page using snap shoot and it is a partial of designed power distribution system and the arrow shows that the network continued towards right hand side and down on ETAP work page. The result of redesigned system is shown in table 4.1.

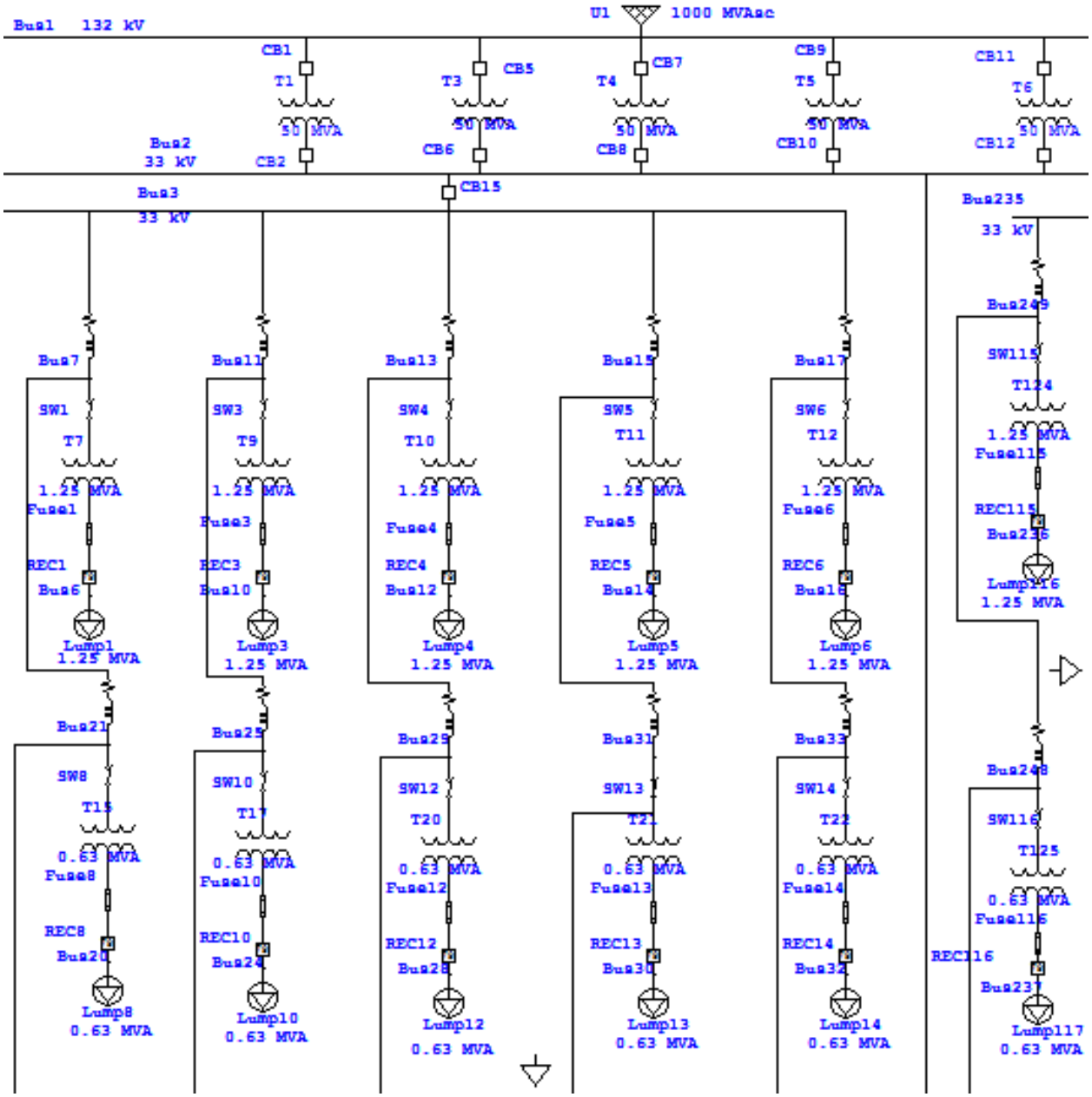

Fig. 4-1 Partial of redesigned power distribution system

The simulation result of redesigned power distribution system shown in table 4.1.

Table 4.1 simulation result of redesigned power distribution system

Indexes	SAIFI (f/customer year)	SAIDI (hr/customer year)	ASAI (%)
Values	2.75	38.72	99.56%

As it can be seen from the simulation result of existing power distribution system shown in table 3.12 is improved by redesign of distribution system as shown in table 4.1. Comparing of existing and redesigned power distribution system reliability indices is shown in table 4.2.

Table 4.2 comparison of existing and redesigned power distribution system reliability

Indexes	SAIFI (f/customer year)	SAIDI (hr/customer year)	ASAI (%)
Existing Network	956.33	923.31	89.46%
Designed Network	2.75	38.72	99.56%

Comparing of reliability indices, of existing and redesigned of power distribution system show that redesigned power distribution system indices has been improved.

Comparing of redesigned power distribution system reliability indices with benchmarks shown in table 3.12 shows the marginal difference of reliability indices reduced significantly and system reliability indices improved.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this thesis, the data collected from power distribution substation and utility service center has been used to evaluate the reliability indices of existing distribution system using analytical and simulation methods and redesign of power distribution system to improve system reliability.

The type of faults and their causes in Nazareth power distribution has been investigated and also its reliability index analyzed and verified against standard benchmark. Comparing of reliability index of existing power distribution system with benchmark shows that reliability of the system is not up to the level or standard demanded by customers. Reliability improvement techniques are identified to reduce frequency and duration of an interruption and to increase the average system availability index.

Low system reliability index of existing Nazareth power distribution system has been improved by redesigned of existing 15KV/2×25MVA to 33KV/5×50MVA by considering overloaded of present distribution system and future load forecast over 25 years horizon. The reliability index of redesigned power distribution system has been analyzed using ETAP software and the result of SAIFI interruption per customer year, SAIDI hours per customer year and ASAI in % after redesign changes from 956.33, 923.3 and 89.46 to 2.75, 38.72 and 99.56 respectively. The reliability index of redesigned power distribution system compared with existing one and standard benchmark. The results obtained reveal that by using proper maintenance strategy especially preventive one and redesign of power distribution system has improve system reliability indices.

5.2 Recommendation

- The maintenance types like preventive and corrective maintenance should apply as per its scheduled to reduce the customer interruptions and increase the system availability. In Nazareth distribution system the preventive maintenance is not applied most of the time ;

preventive maintenance should carry on its regular time to repair and replacement the distribution equipments before it fails

- The Ethiopian Electric Power (EEP) and Ethiopian Electric Utility (EEU) should use computerized way of recording data in order to have more accurate data from distribution substation and utility service center that used for future research.
- The distribution feeders should be dedicated for industrial, commercial and residential to simplify for data collection, distribution equipment selection, controlling the demand during peak load hours.
- The equipments of distribution system should not be overloaded; because most of distribution equipments are overloaded which leads the equipments failures that takes a time to repair and replacements, the customer interruption, loss of income to Ethiopian Electric power and etc.
- Distribution system reliability evaluation is important to ensure appropriate system reliability levels. The reliability indices used to evaluate the reliability of the distribution system are not only those mentioned in this thesis work, further analysis of reliability indices like Customer Average Interruption Duration Index (CAIDI), Index of Reliability (IOR), Customers Experiencing Multiple Interruptions (CEMI), and Customers Experiencing Longest Interruption Duration (CELID),Average System Interruption Frequency Index (ASIFI) and Average System Interruption Duration Index (ASIDI) helps to know performance of the power distribution system.
- Underground power distribution system has more power reliability than overhead one because of its less affected by interruption.
- The majority of customer reliability problems stem from distribution systems. This is largely due to radial nature of most distribution systems thus upgrading of the distribution system from radial to loop or mesh network which improve system reliability.

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