CHAPTER ONE
INTRODUCTION

1.1 Overview

The basic function of an electrical power system is to meet its customers while maintaining acceptable levels of quality and continuity of supply. It is important to note that the distribution system is a vital link between the bulk power system and its customers. In many cases, these links are radial in nature that makes them vulnerable to customer interruptions due to a single outage event. A radial distribution circuit generally uses main feeders and lateral distributors to supply customer energy requirements. In the past, the distribution segment of a power system received considerably less attention in terms of reliability planning compared to generation and transmission segments. The basic reason behind this is the fact that generation and transmission segments are very capital intensive, and outages in these segments can cause widespread catastrophic economic consequences for society [1].

An electric power system comprises generation, transmission and distribution. It is necessary to ensure a reasonable balance in the reliability of these various constituent parts. Electric power distribution systems constitute the greatest risk to the interruption of power supply. It has been reported in the literature that more than 90% of all customer interruptions occur due to failures in the distribution system. The distribution segment has been the weakest link between the source of supply and the customer load points. Though a single distribution system reinforcement scheme is relatively inexpensive compared to a generation or a transmission improvement scheme, an electric utility normally spends a large sum of capital and maintenance budget collectively on a huge number of distribution improvement projects [1].

At present, in many electric utilities, acceptable levels of service continuity are determined by comparing the actual interruption frequency and duration indices with arbitrary targets. For example, monthly reports on service continuity statistics produced by many utilities contain the arbitrary targets of system reliability indices for performance comparison purposes. It has long been recognized especially in the deregulated market environment that rules of thumb and implicit criteria cannot be applied in a consistent manner to the very large number of capital and maintenance investment and operating decisions that are routinely made. Though some reliability programs with limited capabilities are available, virtually no utilities perform distribution system expansion studies using probabilistic models.

Distribution utilities are required only to furnish historical distribution system performance indices to regulatory agencies. Reliability evaluation and maintenance planning techniques have separately been well developed. However, few techniques relate system reliability to component maintenance. Furthermore, the available techniques are not generally put into practice. The reason for this, according with the authors, is the lack of suitable input data and a reluctance to use theoretical tools to address the practical problem of maintenance planning. A great problem encountered in the area of distribution systems is how to reduce the number of interruptions experienced by customers. At first, these reductions can be obtained with the substitution of the equipment with the high failure rates and by increasing the maintenance staff. Usually, these are very expensive solutions. The automation of the protection has proven to be a feasible and efficient alternative to solve this problem. A reliability evaluation can be used to evaluate past performance and predict future performance of the distribution system. A reliability evaluation study can also identify the problematic components in the system that can impact reliability. The reliability study can also help to predict the reliability performance of the system after any expansion and quantify the impact of adding new components to the system. The number and locations of new components needed to improve the reliability indices to certain limits can be identified and studied [1].

The power system basically consists of generation, transmission and distribution, regulated either by a single entity or by the number of entities. Hence, the responsibility of maintaining reliability at different levels falls with different entities and should be the common goals of the custodians of the various systems at different levels. Also Regulators require most of investor owned utilities to report their reliability indices and the regulator trend is moving towards performance based rates where performance is rewarded and penalized based as quantified by regulator indices [2].

The failure of a component in a radial distribution system always leads to customer interruptions. Reliable distribution systems minimize this impact by allowing faults to clear themselves, by minimizing the number of customers affected with protection device operations and by quickly restoring customers through system reconfiguration. For this purpose, the radial systems basically consist of main feeders and lateral with protective equipment and are normally operated in a radial configuration for effective coordination of their protective system, as shown in figure 1.1.

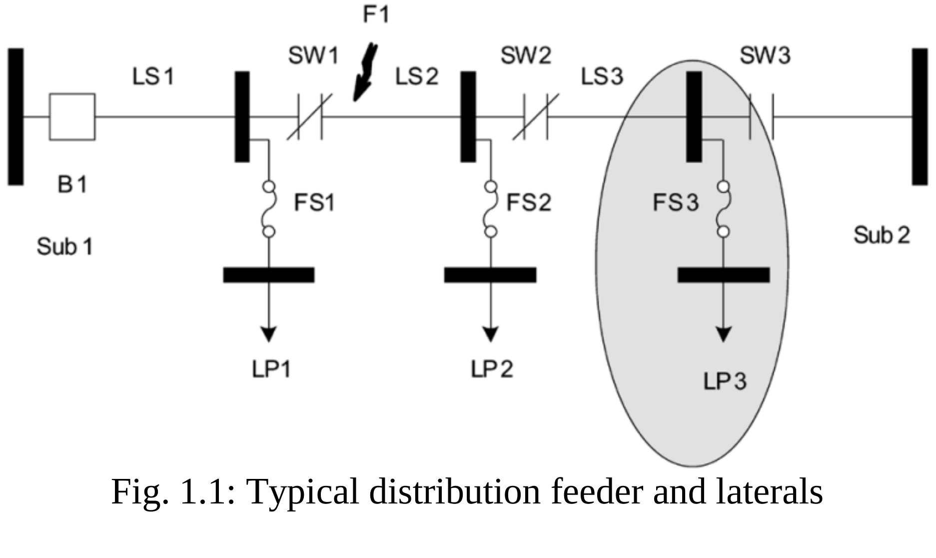

Fig. 1.1: Typical distribution feeder and laterals

Moreover, supply can be restored from alternative sources (Sub2) through interconnections using switching operations. Protective equipment is normally installed at the beginning of line sections in the main feeder or lateral line section [3]. When a fault F1 (e.g., an overhead line fault or a fault at isolating switch) occurs in the system shown in figure 1.1, the circuit breaker B1 is tripped and leads to customer interruption of all load points—LP1, LP2, and LP3. After the fault is located, the operators or crews will open the normally closed isolating switch SW2 and close the circuit breaker B1 automatically or manually, so that the load point LP1 can be fed from the main source (Sub1). In addition, the load point LP3 can be fed from alternative sources (Sub2) by closing the normally open switch SW3. When a three-phase protection device such as a recloser is installed in line section LS2 and a fault F1 occurs, there will be customer interruption at load points LP2 and LP3 but not at load point LP1. Thus, the additional installation of three-phase protection devices or switches on the main feeder will increase the reliability of radial distribution systems.

1.2 Power System Hierarchical levels

In reliability analysis, power systems are often divided into three parts to define the boundaries of the reliability assessment. These parts are referred to as hierarchical levels, and can be described as shown in figure 1.2, [2].

Hierarchical level I (HL I) includes only generation and load of the system. A reliability study of HL I is an evaluation of the total system generating capacity necessary in order to satisfy the expected system demand. Hierarchical level II (HL II) is in the power system reliability field often referred to as the “bulk power system”, including generation and transmission. Hence, a reliability study of HL II evaluates the generation and transmission capacity to supply the system load (distributed in bulk load points).

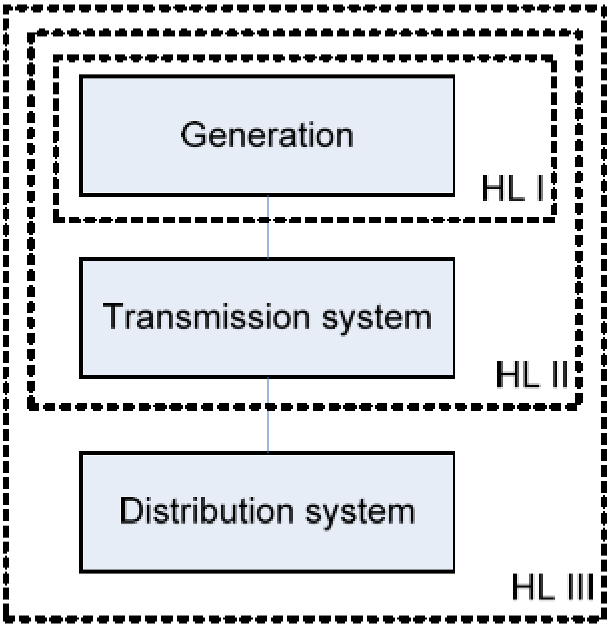

Fig. 1.2: Hierarchical levels

Hierarchical level III (HL III) includes the whole power systems (generation, transmission and distribution). Due to the size and complexity of the power system, a reliability study of HL III is typically only practical for small systems. A common solution is to utilize the results from a HL II evaluation as input for a separate evaluation of a specific distribution system. In such procedure the effects that the distribution system may have on the reliability of the transmission and generation systems are neglected [4].

1.3 Problem Statement

After corporatization and forming as utility company, SEDC's mission is to distribute and supply adequate electricity in a safe, reliable and efficient manner and this has to be accomplished. The process of network development should be directed towards a long term vision aligned with the expectations of the present and future customers.

The main problem facing by electric power utilities in developing countries today is that the power demand is increasingly rapidly where supply growth is constrained by scarce resources, environmental problems and other social concerns. This has resulted in a need for more extensive justifications of the new system facilities, and improvements in production and use of electricity. System planning and operation based on reliability cost/worth evaluation approach provides an opportunity to justify one of the scrutinized and vulnerable economic sectors in Sudan. It is with this objective to conduct customer surveys to find out the outage cost of interruptions**.**

Most of the interruption has been caused due to the failure in the distribution systems in Khartoum. Hence it is felt necessary to improve the reliability of the system in order to improve the utility's performance and to keep the customers satisfied. The reliability improvement should be based most probably upon the consideration of reliability worth and to find the reliability worth.

1.4 Motivation

The rapid and dramatically increase in electrical consumption in Khartoum state and the extension of the network to cover the whole state. In addition to the diversity in the customers required robust and reliable network to reduce system outages and reduce the financial losses.

1.5 Objectives

The main objective of this thesis is to evaluate and develop a framework for reliability analysis of distribution system in Khartoum. Its main aim is to determine system reliability and customer satisfaction. The following issues shall be discussed;

- Carry-out reliability analysis within the framework of Khartoum distribution system.
- Assessment of the reliability indices of the existing Khartoum distribution system
- Analyze major cause of interruptions and suggest the suitable way to improvement the reliability.

This study will carry-out on 11KV feeders fed from distribution substation.

1.6 Thesis Lay-out

The thesis is organized as follow:

Chapter one gives brief introduction and summarized the thesis objectives and problems.

Chapter two gives brief background about the literature review and previous studies with several methods used.

Chapter three discusses reliability analysis including the main two types of indices, relation between availability, reliability and power quality. And also represents the outage cost evaluation.

Chapter four contains of the analysis of Khartoum distribution system and several ways to improve the reliability of the existing system (Alebour 11KV line).

Chapter five explains brief conclusion and recommendations for future studies to enhance the reliability of Khartoum distribution system.

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Power systems have evolved over decades. Their primary emphasis has been on providing a reliable and economic supply of electrical energy to their customers. Spare or redundant capacities in generation and network facilities have been inbuilt in order to ensure adequate and acceptable continuity of supply in the event of failures and forced outages of plant, and the removal of facilities for regular scheduled maintenance. The degree of redundancy has had to be commensurate with the requirement that the supply should be as economic as possible.

The probability of consumers being disconnected for any reason can be reduced by increased investment during the planning phase, operating phase, or both. Overinvestment can lead to excessive operating costs which must be reflected in the tariff structure. Consequently, the economic constraint can be violated although the system may be very reliable. On the other hand, underinvestment leads to the opposite situation. It is evident therefore that the economic and reliability constraints can be competitive, and this can lead to difficult managerial decisions at both the planning and operating phases [5].

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

The Value Based Reliability Planning directly takes account of the value of reliability and power quality to customers in assessing the cost effective of the proposed investment alternatives. In general, VBRP follows the process as shown in the figure 2.1. The probability of consumers being disconnected for any reasons can be reduced by increased investment during planning phase, operating phase or both and is vice versa. It is evident therefore that the economic and reliability constraints can be competitive, and this can lead to difficult managerial decisions at both planning and operating phase [2].

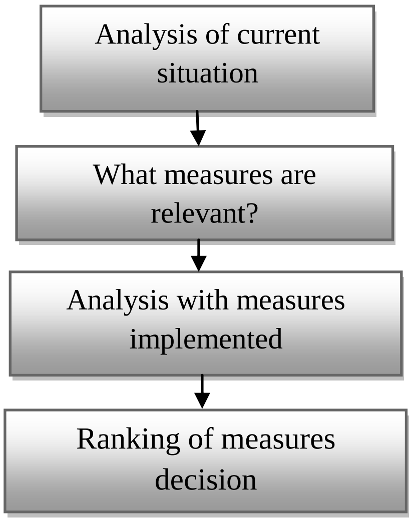

Fig. 2.1: Identification of problems and analysis of measures

The Mitigation techniques like electric or non-electric methods could be used to improve the reliability in the system. Modern automation technologies can reduce contingency margins, improve utilization and economy of operation and even provide improved scheduling and effectiveness of maintenance and service [5]. However, they must be applied well, with the technologies selected to be compatible with systems need and targeted effectively. On the other hand, non-electric method such as vegetation management, system improvements, crew placement and management, maintenance practices plays an important role in improving reliability in the system.

As seen from [8], this paper presents basic reliability evaluation techniques needed to evaluate the reliability of distribution systems which are applied in distribution system planning and operation. In this paper it is considered seven different alternatives and examined on distribution system. Basically the reliability study can also help to predict the reliability performance of the system after quantifying the impact of adding new components to the system. The number and locations of new components needed to improve the reliability indices to certain limits can be identified and studied. In this paper introduced partial automation this automation has proven to be a feasible and efficient alternative in these studies.

Other thesis [4] gives an overview of the state of the art of analytical power system reliability assessment techniques. The paper is addressed to readers with interest in the possibilities and limitations by these models.

The motivation behind this paper is to establish a comprehensive overview of the field of analytical power system reliability assessment techniques and to serve as input for further research and development in the area of applicability.

A new method for composite system state evaluation using real numbers encoded Generic Algorithm (GA) is developed [12]. The objective of GA is to minimize load curtailment for each sampled state. Minimization is based on the dc load flow model. System constraints are represented by fuzzy membership functions. The GA fitness function is a combination of these membership values. The proposed method has the advantage of allowing sophisticated load curtailment strategies, which lead to more realistic load point indices.

2.2 Reliability Evaluation

The two main approaches applied to reliability evaluation of distribution systems are;

- Simulation methods based on drawings from statistical distributions (Monte Carlo).
- Analytical methods based on solution of mathematical models

The vast majority of techniques have been analytically based and simulation techniques have taken a minor role in specialized applications.

The main reason for this is because simulation generally requires large amounts of computing time, and analytical models and techniques have been sufficient to provide planners and designers with the results needed to make objective decisions [2].

2.3 Concepts of adequacy and security

Whenever a discussion of power system reliability occurs, it invariably involves a consideration of system states and whether they are adequate, secure, and can be ascribed an alert, emergency, or some other designated status [5], this is particularly the case for transmission systems. It is therefore useful to discuss the significance and meaning of such states.

- *The concept of adequacy* is generally considered to be the existence of sufficient facilities within the system to satisfy the consumer demand. These facilities include those necessary to generate sufficient energy and the associated transmission and distribution networks required to transport the energy to the actual consumer load points. Adequacy is therefore considered to be associated with static conditions which do not include system disturbances.
- *Security*, on the other hand, is considered to relate to the ability of the system to respond to disturbances arising within that system. Security is therefore associated with the response of the system to whatever disturbances they are subjected. These are considered to include conditions causing local and widespread effects and the loss of major generation and transmission facilities.

2.4 Reliability Indices

Reliability indices are statistical aggregations of reliability data for a well-defined set of customers or loads. Most reliability indices are average values of a particular reliability characteristic for an entire system, operating region, substation service territory, or feeder.

2.4.1 Customer-based indices

The most widely used reliability indices are averages that weight each customer equally. Customer-based indices are popular with regulating authorities since a small residential customer has just as much importance as a large industrial customer [6].

They have limitations, but are generally considered good aggregate measures of reliability and are often used as reliability benchmarks and improvement targets. Formulae for customer-based indices include (unless otherwise specified, interruptions refer to sustained interruptions):

(i) System Average Interruption Frequency Index:

$$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ Number\ of\ Customers\ Served} \quad Int/yr \qquad (2-1)$$

SAIFI is a measure of how many sustained interruptions an average customer will experience over the course of a year. For a fixed number of customers, the only way to improve SAIFI is to reduce the number of sustained interruptions experienced by customers.

(ii) System Average Interruption Duration Index:

$$SAIDI = \frac{Total\ Number\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customers\ Served} \quad hr/Int \qquad (2-2)$$

SAIDI is a measure of how many interruption hours an average customer will experience over the course of a year. For a fixed number of customers, SAIDI can be improved by reducing the number of interruptions or by reducing the duration of these interruptions. Since both of these reflect reliability improvements, a reduction in SAIDI indicates an improvement in reliability.

(iii) Customer Average Interruption Duration Index:

$$CAIDI = \frac{Total\ Number\ of\ Customer\ Interruption\ Durations}{Total\ Number\ of\ Customer\ Interruptions} = \frac{SAIDI}{SAIFI} \quad hr/yr \qquad (2-3)$$

CAIDI is a measure of how long an average interruption lasts, and is used as a measure of utility response time to system contingencies. CAIDI can be improved by reducing the length of interruptions, but can also be reduced by increasing the number of short interruptions. Consequently, a reduction in CAIDI does not necessarily reflect an improvement in reliability.

(iv) Average Service Availability Index:

$$ASAI = \frac{Customer\ Hours\ Service\ Availability}{Customer\ Hours\ Service\ Demand} = \frac{8760 - SAIDI}{8760} \quad pu. \qquad (2-4)$$

ASAI is the customer-weighted availability of the system and provides the same information as SAIDI. Higher ASAI values reflect higher levels of system reliability, with most US utilities having ASAI greater than 0.999.

2.4.2 Load-Based Reliability Indices

Two of the oldest distribution reliability indices weight customers based on connected kVA instead of weighting each customer equally. Because of this, the following are referred to as load-based indices:

(i) Average System Interruption Frequency Index:

$$ASIFI = \frac{Connected\ KVA\ Interrupted}{Total\ Connected\ KVA\ Served} \quad hr/yr \qquad (2-5)$$

(ii) Average System Interruption Duration Index:

$$ASIDI = \frac{Connected\ KVA\ Hours\ Interrupted}{Total\ Connected\ KVA\ Served} \quad hr/yr \qquad (2-6)$$

From a utility perspective, ASIFI and ASIDI probably represent better measures of reliability than SAIFI and SAIDI. Larger kVA corresponds to higher revenue and should be considered when making investment decisions.

2.5 System Performance

The customer and load based indices described in sections 2.4.1 and 2.4.2 are useful for assessing the severity of system failures in future reliability prediction analysis. They can be used, however, as a means of assessing the past performance of a system. The assessment of system performance is a valuable procedure for three important reasons [2];

- It establishes the chronological changes in system performance and therefore helps to identify weak areas and the need for the reinforcement.
- It establishes existing indices which serves as a guide for acceptable values in future reliability assessments.
- It enables previous predictions to be compared with actual operating experience.

2.6 Reliability Cost and Worth

Reliability worth is a useful tool in value based system operation and investment planning, to optimize the reliability level versus the total cost of providing the electricity. In investment planning, reliability worth can be used to relate the value of possible investments to the worth of the reliability improvement that the investment would have. In operation planning, reliability worth can be used to identify optimum operational reserves versus the interruption cost.

The Cost of Energy Not Supplied (CENS) can provide additional information on the level of reliability worth. An example where this is necessary is when telecommunication equipment is involved. Such equipment is sensitive toward power outages, and even a short interruption of supply can cause serious malfunction. Since the CENS can often be neglected for short interruptions, the CENS is a superior reliability index in this case.

An important aspect is that reliability levels are interdependent with economics since increased investment is necessary to achieve increased reliability or even to maintain its current and acceptable levels [2]. This concept as illustrated in figure 2.3 which shows the change in incremental cost of reliability ΔR with investment cost ΔC needed to achieve it or alternatively a given increase in investment produces a decreasing increment in reliability as the reliability is increased.

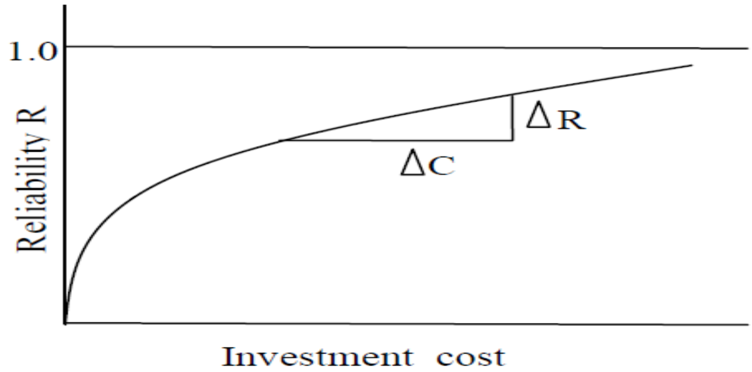

Fig. 2.2: Incremental cost for reliability

It is one way of deciding whether an investment in the system is worth. In either case a high reliability is expensive to achieve. It is therefore, important to recognize that reliability and economics must be treated together in-order to perform objective cost benefit studies. The relation between cost and reliability can be described as shown in figure 2.4, where the optimal reliability level can be identified as the point where the marginal increase in operating and investment costs equals the marginal decrease in interruption cost. The reliability worth varies with several parameters, such as time of day, type of customer, and duration of interruption.

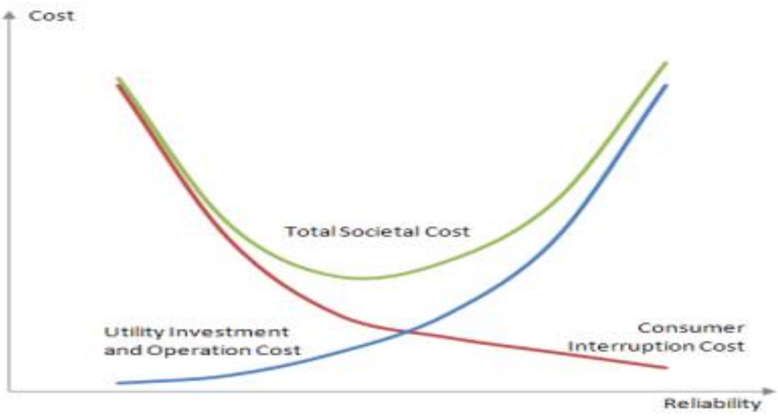

Fig. 2.3: Reliability cost and reliability worth

This total cost exhibits a minimum, and so an “Optimum” or target level of reliability is said to be deduced. Although the concept of optimum reliability may be worthy an ultimate goal, it can only be achieved best in this way.

2.7 Effects of Mitigation techniques and Protection System on Reliability

A properly co-ordinate protection system is vital to ensure that an electricity distribution network can operate within preset requirements for safety for individual items of equipment, staff and public, and the network overall. Suitable and reliable equipment should be installed on all circuits and electrical equipment and to do this, protective relays are used to initiate the isolation of faulted sections of a network in order to maintain supplies elsewhere on the system. This then leads to an improved electricity service with better continuity and quality of supply. This can reduce the permanent outages and its durations. Nowadays, with the increase of the sensitive load with the end user; to improve power quality and to mitigate the momentary interruptions is also equally important. The first step is to find out the root cause of the problem and apply mitigation solutions to a circuit that affects the largest number of customers. A better over-current protection scheme can reduce number of customers affected by temporary and permanent faults. The reliability of the system depends on the mitigation techniques being used by the utility namely, electric and non-electric mitigation techniques. So, historical data can be used to quantify improvements and predict the best locations for sectionalizing devices for reliability improvements. Adding numbers of recloser at optimal locations can reduce SAIFI, SAIDI but it should be economically viable. The location and installation of number of Auto-recloser, Switches, Load Break Switches(LBS) and Sectionalizers either manual or automated helps to reduce fault rate, repair time and sectioning time which directly reduces the impacts on the system when fault occurs. The Mitigation Techniques applied shall depend on the need of utility whether it wants to reduce fault rate, repair time or both or outage duration.

CHAPTER THREE

RELIABILITY ANALYSIS AND OUTAGE COST EVALUATION

3.1 Overview

The two main approaches can apply to reliability evaluation of distribution systems are; Simulation methods based on drawings from statistical distributions (Monte Carlo) and Analytical methods based on solution of mathematical models.

The main aim of this study is to see how reliability could be improved in the distribution system by incorporating reliability analysis in the systematic planning approach so that “Optimum Reliability” is achieved.

The reliability indices of the present system shall be evaluated, assessed and compared with the international standards and see how risk of failure could be mitigated.

Rigorous analytical treatment of distribution reliability requires well-defined units of measurements, referred to as metrics. Unfortunately, reliability vocabulary has not been used consistently across the industry, and standard definitions are just beginning to be adopted. This chapter begins by providing definitions for terms and indices commonly used in the areas of power quality and reliability. It continues by comparing engineering measures of reliability with economic measures, and concludes with a discussion on reliability targets [6].

The general process flow chart is being developed based upon the systematic planning approach of distribution network design as shown in figure 3.1. It consists of nine modules. However, in this research, It will be only concentrated on the reliability analysis of the case study area and the choice of alternatives shall be based on cost benefit.

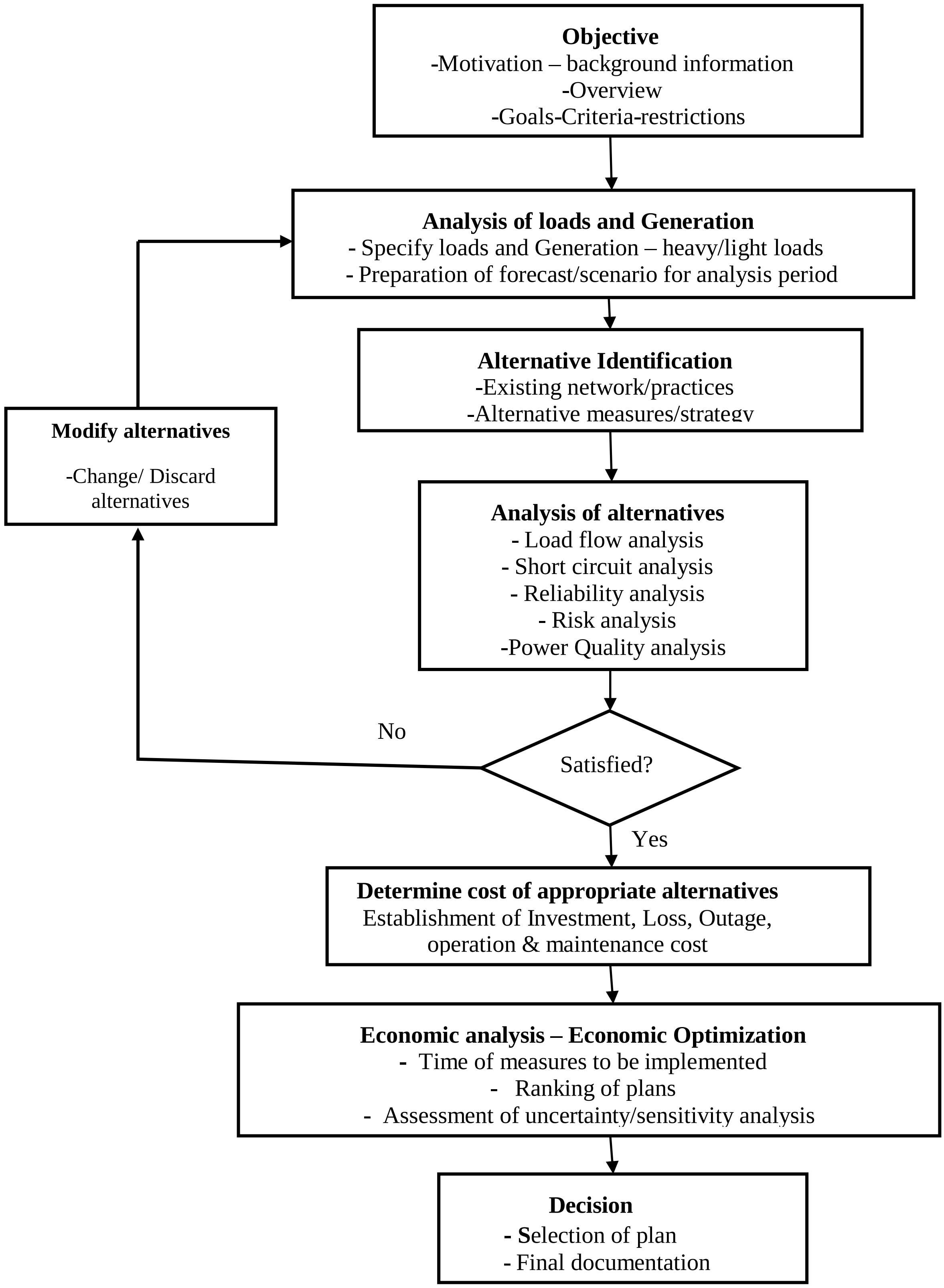

Fig. 3.1: System planning approach of distribution network

The failure in the system cannot be prevented; however, the impacts of the failure could be reduced with proper analysis and planning.

3.2 Identification of Alternatives

Actually, it is assumed to have number of alternatives in any plan. Based upon experience and knowledge, the alternatives which are technically feasible and economically viable shall be considered. The existing networks solution will be taken as reference solution. As seen from the flow chart, the alternative which does not meet the objective or criteria shall be discarded. In this project, the Predictive Reliability Analysis shall be carried out in 11kV feeder fed from Kilo-17 substation and number of alternatives shall be evaluated.

The following alternatives which may improve reliability in the system shall be considered as mentioned below:

- Assessment of the existing system
- Change in network configuration such as Interconnection of 11kV network feeders fed from Kilo-17 Substation
- Use of additional sectionalizing switches
- System Automation (Auto Reclosing devices)
- Placement of Distributed Generation
- Evaluation by applying Mitigation Techniques.

In the existing system, most of the customers are rural based which is away from the in-feed substation. Therefore, reliability still could be improved by placing auto-reclosers. The Placement of distribution generators could play a Vitol role in improvement of the reliability in the system.

3.3 Analysis of system alternatives

The following analysis shall be carried out on the alternatives chosen which available to improve system reliability.

- *Load Flow Analysis*

Load flow studies determine if system voltages remain within the specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded. It is also used to identify the need of additional generation, capacitive, or inductive VAR support, or the placements of capacitors/or reactors to maintain system voltages within the specified limits.

- *Short Circuit Analysis*

The optimal design of switch gear and network protection requires knowledge of short circuit currents and levels, In case of restricted short circuit levels, this type of analysis may have an impact when selecting system solutions.

- *Reliability Analysis*

Frequency and duration of outages are relevant measures for reliability in electricity supply systems. If reliability is regarded as a technical restriction, adequate outage indices have to be evaluated. If outages are associated with costs, reliability shall be included within operating costs. The estimation of outage cost mostly used around is the customer survey approach. When comparing among alternatives of approximately equal total costs, the outage indices will be helpful in selection of the best solution.

- *Risk Analysis*

It helps us to set the management priorities, such as which of several alternatives/activities should be considered for the future plan. A detailed overview of the risk in this context will be important to give decision makers a most complete picture of the all risk factors that are relevant. These risks can be categorized as Economic risk, Quality, Personal safety, Environment and Reputation.

In network planning context, we have to weigh the probability of failures of the system (outage/interruption) and the consequences of the failure (cost of energy not supplied) in the system.

3.4 Costs-Benefit Analysis

Before a project is considered, it is to be proved that the project is worthwhile and is not a waste of money; or when there are several alternatives to be chosen from, it is necessary to determine the alternative that is most beneficial, and in both situations, the conclusion is made from a cost–benefit analysis.

Cost–benefit assessment is an economic approach where all the economic principles apply. It is also applicable to all economic activities, from financial investment decisions to the making of public policy. In the case of investment problems, the costs are the capital and the benefits are the profits. The applications to other projects can be more complicated. In many situations, there are a lot of intangibles. If those intangibles can be quantified and measured, they need to be included in the analysis. Otherwise, the analysis will include only the economic factors and the decision makers will have to include other noneconomic factors in their considerations [7].

3.5 Power Quality, Reliability and Availability

A power quality problem might be defined as any electric supply condition that causes appliances to malfunction or prevents their use. From a utility perspective, a power quality problem might be perceived as noncompliance with various standards such as RMS voltage or harmonics. In fact, power is equal to the instantaneous product of current and voltage, and formulating a meaningful definition of power quality is difficult. The best a utility can do is to supply customers a perfect sinusoidal voltage source. Utilities have no control over the current drawn by end uses and should be generally unconcerned with current waveforms. Load current can affect voltage as it interacts with system impedances, but voltage is the ultimate measure of power quality [6].

Perfect power quality is a perfect sinusoid with constant frequency and amplitude. Less than perfect power quality occurs when a voltage waveform is distorted by transients or harmonics, changes its amplitude, or deviates in frequency.

According to this definition, customer interruptions are power quality concerns since they are a reduction in voltage magnitude to zero. Reliability is primarily concerned with customer interruptions and is, therefore, a subset of power quality. Although there is general agreement that power quality includes reliability, the boundary that separates the two is not well defined. Sustained interruptions (more than a few minutes) have always been categorized as a reliability issue, but many utilities have classified momentary interruptions (less than a few minutes) as a power quality issue. The reasons are

1. Momentary interruptions are the result of intentional operating practices,

2. They did not generate a large number of customer complaints, and

3. They are difficult to measure. Today, momentary interruptions are an important customer issue and most distribution engineers consider them a reliability issue. Therefore, this thesis defines reliability as all aspects of customer interruptions, including momentary interruptions.

Availability is defined as the percentage of time a voltage source is uninterrupted. Its complement, unavailability, is the percentage of time a voltage source in interrupted. Unavailability can be computed directly from interruption duration information. If a customer experiences 9 hours of interrupted power in a year, unavailability is equal to 9 ÷ 8760 = 0.1% (there are 8760 hours in a year). Availability is equal to 100% - 0.1% = 99.9%. Since availability and unavailability deal strictly with interruptions, they are classified as a subset of reliability. The hierarchy of power quality, reliability, and availability is shown in figure 3.2.

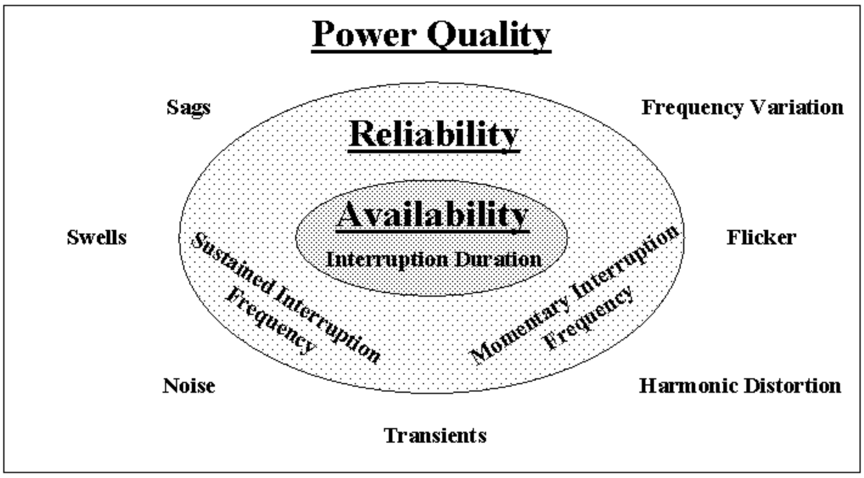

Fig. 3.2: Hierarchy of power quality, reliability and availability

It can be seen from above figure:

- Availability is a subset of reliability and reliability is a subset of power quality.
- Power quality deals with any deviation from a perfect sinusoidal voltage source. Reliability deals with interruptions.
- Availability deals with the probability of being in an interrupted state.

3.6 Reliability Analysis

Reliability analysis of electrical distribution system is considered as a tool for the planning engineer to ensure a reasonable quality of service and to choose between different system expansion plans that cost wise were comparable considering system investment and cost of losses [2]. The basic theories for reliability analysis are discussed below.

3.6.1 Series and Parallel System Model Equations

The key load point reliability indices used to define the reliability of the distribution power delivery system to a single load point are

1. λ, the frequency of load point interruptions per year
2. ***r***, the average interruption duration expressed in hours per interruptions
3. ***U***, the total annual interruption duration (i.e., hours per year).

The basic equations used in IEEE Standard 493-2007 (IEEE Gold Book) for a two-component system whose component failure rates are λ_1 and λ_2 and whose individual component average repair times are r_1 and r_2, respectively [7], are summarized in Tables 3.1 and 3.2.

Table 3.1: Failure rate equations for series and parallel systems

Equivalent Failure rate of a series system	Equivalent Failure rate of a parallel system
$\boldsymbol{\lambda_s = \lambda_1 + \lambda_2}$	$\lambda_P = \frac{\lambda_1\lambda_2[r_1 + r_2]}{1 + r_1\lambda_1 + r_2\lambda_2} \approx \lambda_1\lambda_2[r_1 + r_2]$

Table 3.2: Average repair time equations for series and parallel systems

Equivalent Average repair time of a series system	Equivalent Average repair time of a parallel system
$\boldsymbol{r_s = \frac{r_1\lambda_1 + r_2\lambda_2 + \lambda_1\lambda_2 r_1 r_2}{\lambda_1 + \lambda_2}}$	$r_P = \frac{r_1 r_2}{r_1 + r_2}$

Figures below illustrate structures of series and parallel systems.

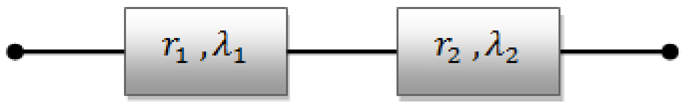

Fig. 3.3: Series system

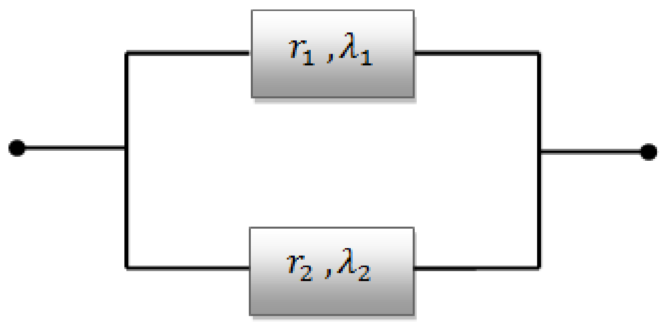

Fig. 3.4: Parallel system

These are adequate for simple radial systems and more extended indices have to be used for general distribution systems (mixed radial and meshed systems).

3.6.2 State Enumeration Methodologies

These methods involve defining all possible mutually exclusive states of a system based on the states of its components. A state is defined by listing the successful and failed elements in a system. For a system with *n* elements or components, there are 2^n possible states, so that a system of 5 components would have 32 states. The number of possible states quickly becomes computationally unfeasible for systems with a large number of components [7].

The states that result in successful network system operation are identified, and the probability of occurrence of each successful state is calculated. The reliability of the system is the sum of all the successful state probabilities. The event tree technique is a typical method that uses the state enumeration methodology and is computationally efficient for systems containing a small number of components (e.g., five or fewer).

3.6.3 Markov Chain model

Markov model is a powerful method based on system states and transition between these states. Though computationally intensive, Markov techniques are well suited to a variety of modeling problems and have been successfully applied to many areas related to reliability analysis [6].

Markov models make two basic assumptions regarding system behavior which are:

1. The system is memory less. This means that the future probability of events is solely a function of the existing state of the system and not what has occurred prior to the system entering the present state.
2. The system is stationary, which means that transition probabilities between states are constant and do not vary with time.

It is assumed for example that a component-wise reliability can only be in one of the following conditions;

- Condition 1: Component is in the function (in);
- Condition 2: Component is in repair (out).

This is illustrated in two state model diagram in figure 3.5 represented by **0**(component in failed state) and **1**(component is in a normal state).

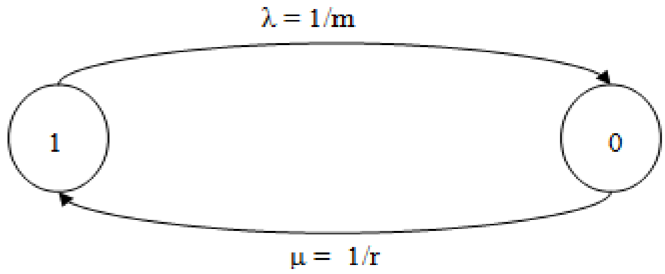

Fig. 3.5: Transition diagram of component states

Where;

λ: fault frequency

r: mean time to repair(MTTR)

μ: repair frequency

m: mean time to failure(MTTF)

$$\lambda = \frac{Number\ of\ outages\ on\ component\ in\ a\ given\ period}{Total\ time\ component\ is\ in\ operation} \qquad (3-1)$$

The figure 3.6 illustrates expected functional and outage time for a component (so called state cycle).The system can be represented by Markov process and equations developed for the probabilities of residing in each state in terms of state transition rates are as follows[2];

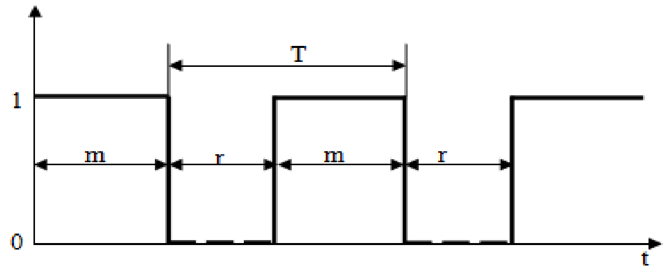

Fig. 3.6: Average state cycle

The average function time, m, is given by; m = 1/ λ

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

r = MTTR, mean time to repair = 1/ μ

m+r = MTBR, mean time between failures = T = 1/f

f = cycle frequency = 1/T

T = cycle time = 1/f

The probability of component to be in either one of the two states is as shown in the figure;

$$P_0 = \frac{r}{r+m} = \frac{\lambda}{\lambda+\mu} = \frac{r}{T} = \frac{f}{\mu} = \frac{\sum(Down\,Time)}{\sum(Down\,Time)+\sum(Up\,Time)} \qquad Where,\ f = \mu \times P_0$$

$$P_0 = \frac{m}{r+m} = \frac{\mu}{\lambda+\mu} = \frac{m}{T} = \frac{f}{\lambda} = \frac{\sum(Up\,Time)}{\sum(Down\,Time)+\sum(Up\,Time)} \qquad Where,\ f = \lambda \times P_1$$

$$f = \lambda \times P_0 = \mu \times P_1$$

Where, P_0 = probability for a component to be in state 0 (down)

P_1 = probability of a component to be in state 1 (up)

f = cycle frequency (frequency to be in or out)

3.6.4 The RELRAD Model

Reliability evaluation of **Rad**ial distribution network (RELRAD) model is developed on Norway [2] and is considered as analytical approach, based on the fault contribution from all network components and their consequences to the load point outages. This differs from failure mode or minimum cut set analysis which assesses the individual load point reliability directly by the minimum cut set. In short the minimum cut set analysis the individual load points, while the analytical simulation approach analysis the individual network components as shown.

Figure 3.7 shows which component give outage at the load point L1 and figure 3.8 shows a RELRAD approach which load points will have outage caused by the component.

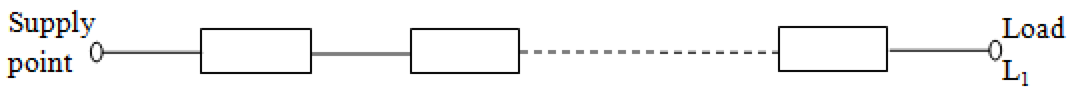

Fig. 3.7: Minimum cut set for load point L_1

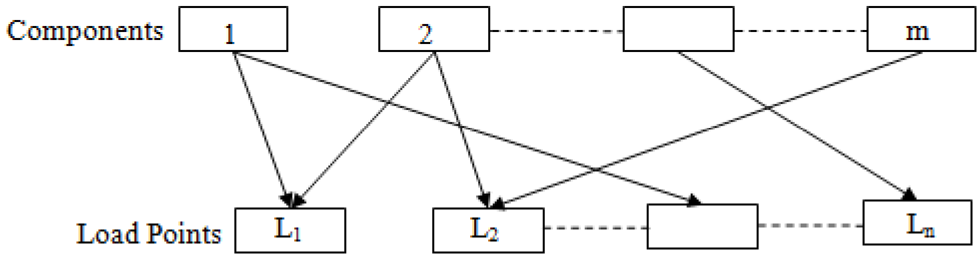

Fig. 3.8: Analytical techniques (RELRAD approach)

This approach is considered as a complimentary to minimum cut set approach.

3.6.5 Sequential Monte Carlo Simulation Method

A sequential Monte Carlo simulation is implemented by dividing the simulation time period into small slices. Starting at the first, each time slice is simulated in sequence to identify new contingencies (such as faults) and respond to prior unresolved contingencies (see figure 3.9). Simulation accuracy increases as time slices become smaller, but at the expense of increasing computation time.

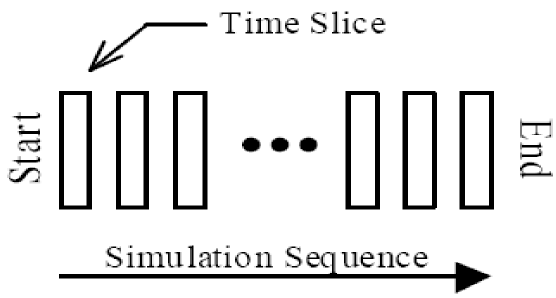

Fig. 3.9: Monte Carlo divides the simulation into small time slices.

To model a year with a one-hour time resolution requires 8760 time slices. To model a year with a one-minute time resolution requires more than half a million time slices. Computational efficiency can be improved by utilizing variable time slice resolution, which utilizes long time slices during normal conditions and switches to shorter time slices while the system is responding to a contingency.

3.7 Basic Interruption Evaluation Approaches

A variety of methods has been utilized to evaluate customer impacts due to interruption. These methods can be grouped, based on methodological approach used, into three broad categories [9];

1. Indirect analytical methods: These approaches infer interruption cost values from associated indices or variables.

2. Case study of a particular outage: This approach has been limited to major, large-scale blackouts.

3. Customer Surveys: With this method, customers are asked to estimate their costs or losses due to supply outages of varying duration and frequency at different times of the day and year.

3.8 Customer Survey Methods:

The three basic Customer Survey Methods to conducting a customer survey are explained as follows:

(a) Contingent Valuation Method

The contingent valuation method establishes a momentary value of outage cost for incremental changes in levels of service. This quantified either through the customer’s willingness to pay (WTP) to avoid having an interruption, or the willingness to accept (WTA) Compensation. The WTP values should nearly equal to WTA values, but actual customer valuations reveal that WTP values are significantly less than WTA values, this is due to customer s normally do not have a choice of suppliers and therefore their responses may be governed largely by their concern for potential rate changes. They may react against providing further money for a service they considered already paid for. Valuations based on WTP and WTA are valuable measures and may serve as upper and lower bounds, respectively, in cost-of-outage assessment.

(b) Direct Costing Method

This method is the most approach for determining customer interruption costs for given outage conditions. The respondent is given a “worksheet” and asked to identify the impacts and evaluate the costs associated with particular outages. This approach provides consistent results in those situations where most losses and tangible, directly identifiable, and quantifiable. Thus it is most applicable for the industrial sector and for most large electrical users. It can also be effective in the commercial markets but must be used with care.

(c) Indirect Costing Method

This method is based on the economic principles of substitution in which the valuation of a replacement good is used as a measure of worth of the original good. It is extremely useful when social considerations and inconvenience effects are expected (or known) to comprise a significant part the overall interruption costs, such as in the residential sector. This approach attempts to provide a mean to lessen the perceptions associated with rate related to antagonism and customer’s lack of experience in rating the worth of reliability.

3.9 Questionnaire Content and Data Treatment

3.9.1 Questionnaire Content

It is obviously desirable to investigate all possible factors which might affect interruption costs. The length of a questionnaire, however, is limited by the amount of effort that respondents are prepared to put into fill it out. This limitation is particularly relevant in the residential sector, where a significant portion of outage cost is related to somewhat intangible impacts.

A questionnaire must therefore, be developed with considerable care. In general, the following factors should be included:

(a) Cost Factors used in residential Cost Estimates

1. Interruption Costs - interruption duration, time of day & week, season of year, frequency
2. User Characteristics such as number, age &education, heat usage, activity interruption, income business at home, user experience with interruption, Discomfort, Fear of accident, Fear of drive.
3. Average Costs and they are; Average cost/interruption and annual energy consumption (SDG/kWh).

(b) Cost Factors used in Small Industrial Cost Estimates

To summarize the kinds of data collected and the considerations for evaluation and survey of interruption costs are follows:

i) Interruption characteristics

- Interruption duration, frequency, occurrence time
- Worst, the greatest damage resulted, interruption season/ week / day.
- Interruption area (partial or complete)

ii) Customer characteristics

- Characteristics of manufacturing activity
- Customer size by the monthly consumption of electricity
- Type of works stopped by interruption etc.,

iii) Cost factors **-** Damage on manufacturing facilities, Loss of raw materials and finished Product damage, Stat up costs, Production loss, over time cost to take make up lost production etc.,

iv) Mitigating or standby facility for interruption

To reduce the impact and economic loss from interruption customers install various facilities such as DVR (dynamic voltage regulator), UPS, SSTS (solid state transfer switch), battery energy storage systems, engine driven system etc., but these are not included in the calculating cost in this time.

(c) Cost Factors Used in Commercial Cost Estimates

Paid staff to unable work, Loss of sales, starts up costs, Spoilage of food, Damage to equipment/supplies and other costs or effects. The main objectives of the survey were to understand losses to commercial consumers resulting from service interruptions and to identify variables that contribute to these losses.

3.9.2 Data treatment

Customer surveys can generate a considerable amount of data including some" bad" information, and it is necessary to conduct appropriate statistical analysis before utilizing the data. This includes calculation of mean values, standard deviations, and correlations coefficients and filtering the bad data. Such analysis should be conducted for each customer category, for each service area, and for the regions with in service areas [9].

CHAPTER FOUR

RELIABILITY ANALYSIS OF KHARTOUM DISTRIBUTION SYSTEM

4.1 Overview on Khartoum Distribution Area

SEDC categorized Khartoum state distribution network for three zones; Khartoum, Khartoum North and Omdurman. The overall load consumed by Khartoum state is about 60% of national grid load comparing with the other states (Figures 4.1 & 4.2) leading to the importance of its availability, reliability and power quality.

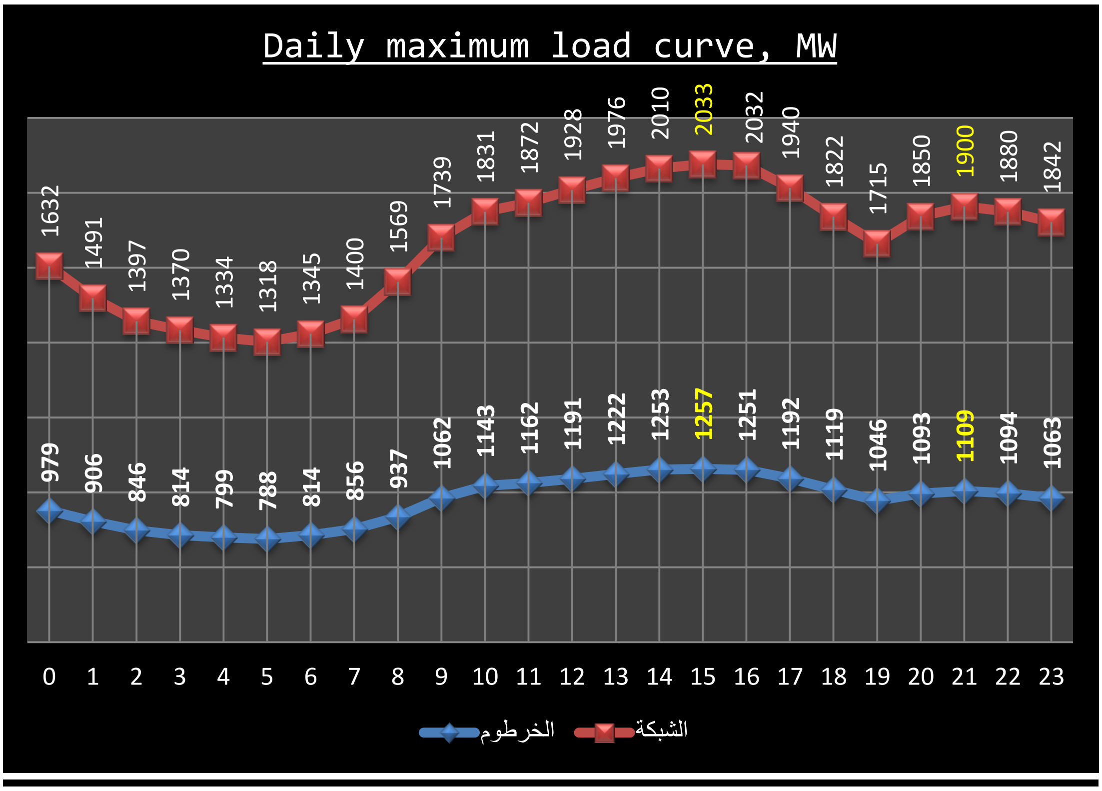

Fig. 4.1: Daily maximum load curve (MW) during summer for distribution network, 2014

As seen from figure 4.1, it is observed that the maximum load will be at 15:00 and 21:00 for day and night load cycle.

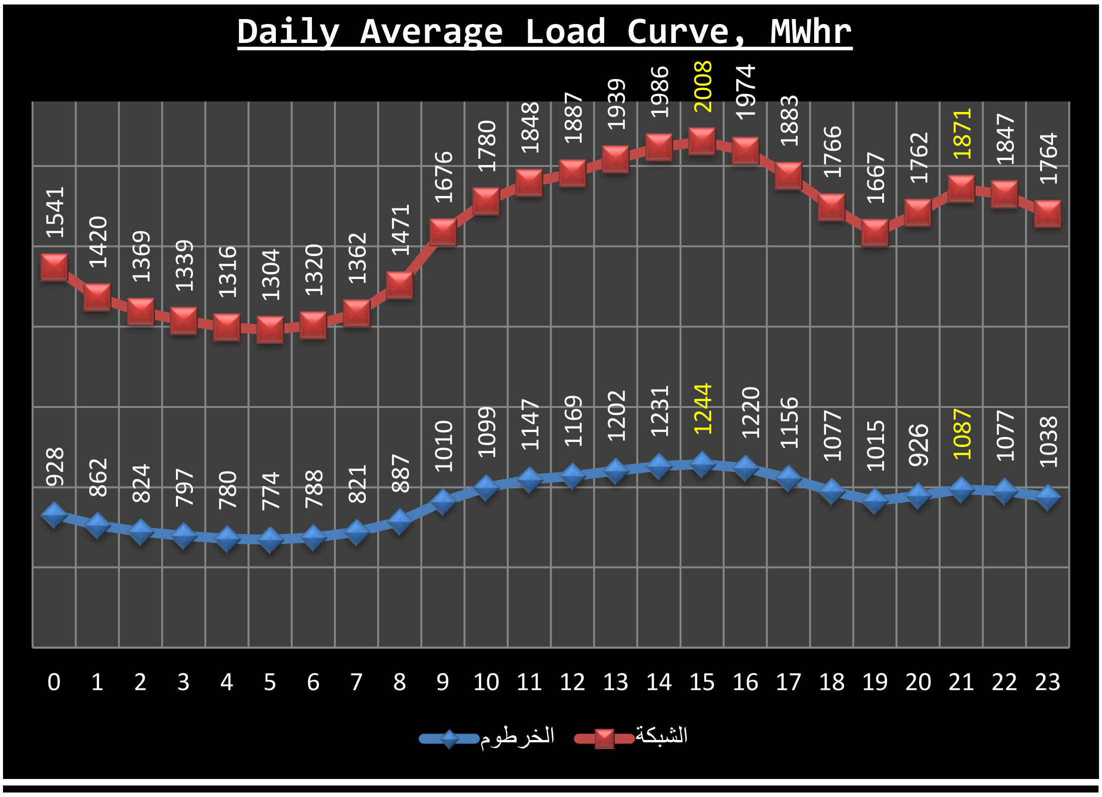

Fig. 4.2: Daily average load curve (MWhr) during summer for distribution network, 2014

This study deal with an important sector of Khartoum distribution system which is contains of three departments Khartoum middle, east and south. These departments have number of distribution (33/11) KV and transmission (110/33/11) KV substations which are presented in table 4.1;

Table 4.1: Transmission and Distribution Substations at Khartoum Sector

No.	*Kh. Middle dept.*	*Kh. East dept.*	*Kh. South dept.*
Distribution Sub.	17	12	4
Transmission Sub.	3	3	2
33KV feeders	47	34	11
11KV feeders	112	68	21
(33/11)KV transformer	34	23	8

Also there are eleven special distribution substations distributed along Khartoum sector.

Electricity is distributed at 33kV for high voltage customers and 11kV-0.415kV for industries, commercial institutions and bulk consumers.

Table 4.2 illustrates the number of customers in national grid, 2013

Sector	Khartoum	Khartoum North	Omdurman	General management	National grid
No.	315,557	242,441	314,577	872,575	2,028,452

The sector wise energy consumption for the year 2013 is shown in figure 4.3. The consumption by the domestic consumer is the highest whereas the consumption by the industry and public lighting is the lowest.

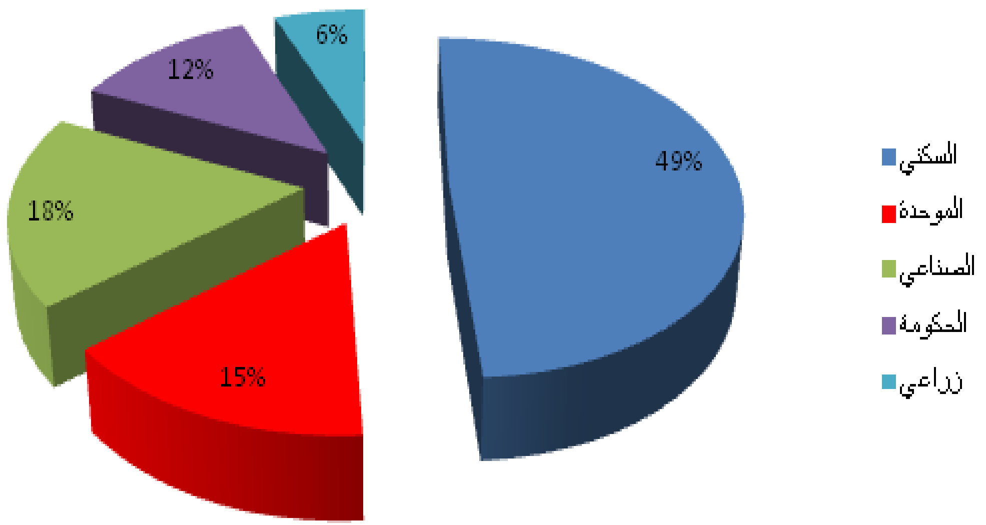

Fig. 4.3: Energy consumption for several sectors, 2013

4.2 Background on the existing system (Al Ebour line)

Al Ebour feeder is fed from Kilo-17 distribution substation and supplied residential heavy and light loads certainly Soba area figures 4.4 & 4.5 and table 4.3.

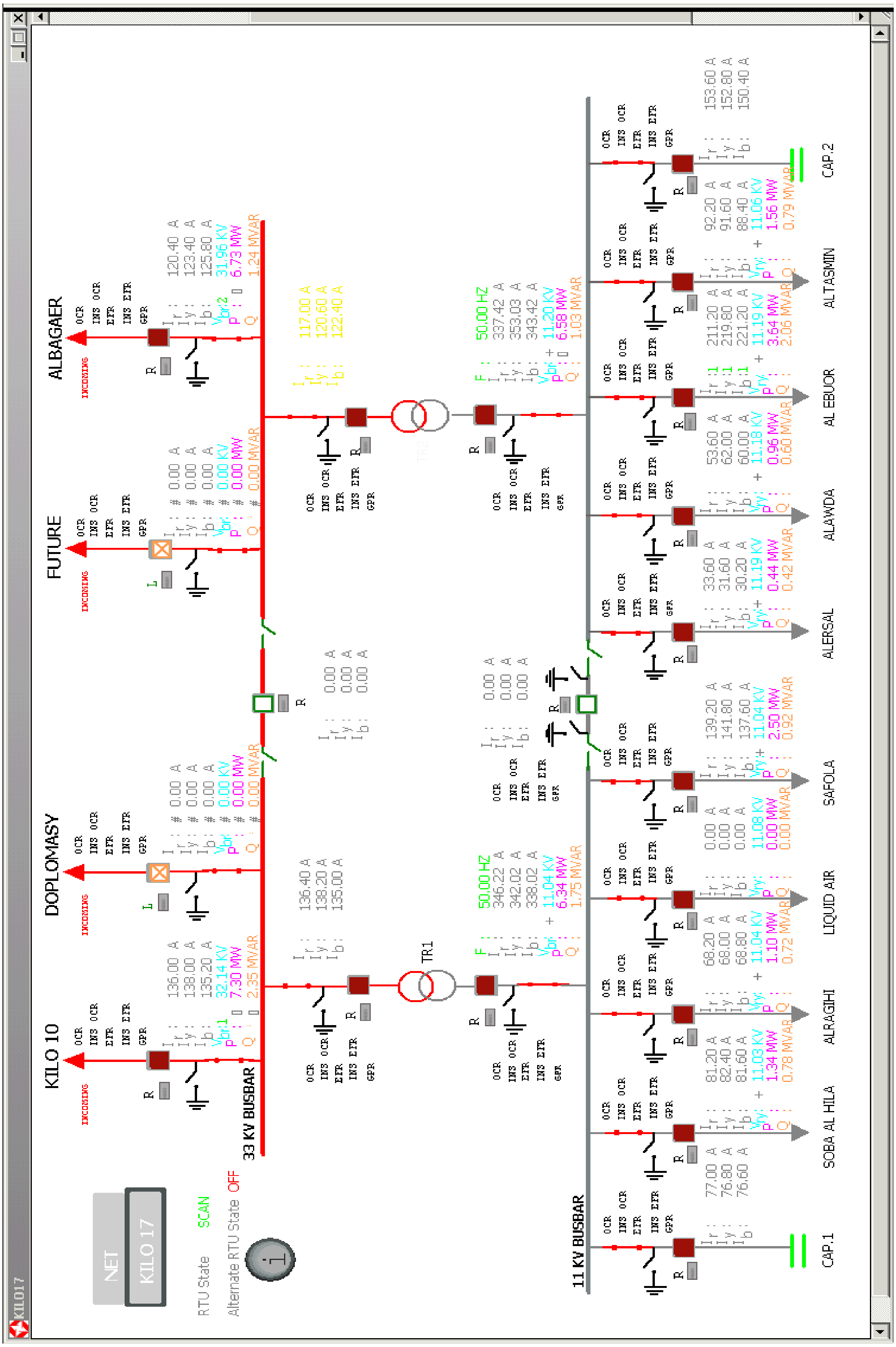

Fig. 4.4: Schematic single line configuration of Kilo-17 substation.

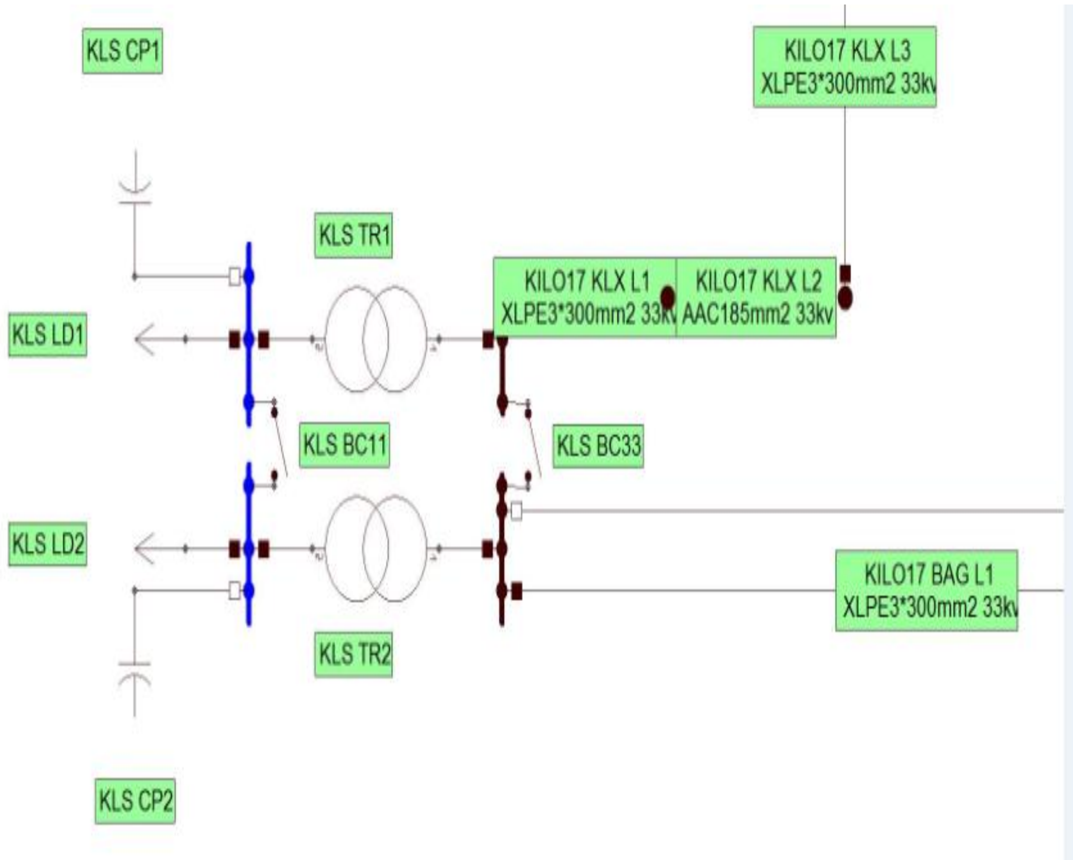

Fig. 4.5: Simplified single line diagram of Kilo-17 substation.

Table 4.3: Overview on Kilo-17 substation system

Voltage level(KV)	Number & Transformer rating(MVA)	No. of outgoing feeders	Incoming feeders
33/11	2*20	8	Kilo-10, Diplomacy and Albagaer feeders

Reliability indices based on fault only for Khartoum distribution system are calculated and tabulated in table 4.4 below 2013.

Table 4.4: Reliability indices based on fault only for Khartoum sector.

Sector	No. of customers	No. of customers interrupted	%age of customer interrupted	*SAIFI*	*SAIDI*	*CAIDI*
Khartoum	315,557	276,374	87.6	5.17	9.21	1.78
Omdurman	314,577	233,910	74.4	4.23	8.36	1.98
Kh. North	242,441	230,533	95.1	4.89	10.23	2.09
General Management	872,575	740,817	84.9	4.76	9.19	1.93

As seen from above table, Khartoum sector has higher values of SAIDI and SAIFI comparing with other sectors and also has great number of customer so, it is desirable to assess and enhance the reliability of Khartoum sector leading to improve the overall distribution reliability.

Reliability and performance indices based on fault only for 11KV overhead lines in Khartoum distribution system are calculated and tabulated in table 4.5;

Table 4.5: Reliability indices based on fault only for11KV lines, 2013

Sector	Outage Duration	Outage Frequency	Total no. of Lines	*SAIDI*	*SAIFI*
Khartoum	1548.36	908	250	6.19	3.63
Omdurman	949.00	484	115	8.25	4.21
Kh. North	1146.50	531	121	9.48	4.39
General Management	3643.86	1923	486	9.19	3.96

According to annual interruption and fault report of SEDC, 2013 shown in table 4.6, Alebour 11KV line has been ranked as second line which has higher interruption frequency and outage duration 193 times and 14.92hrs respectively comparing with the other lines. For this reason it is assumed to assess and improve its reliability.

Table 4.6: Interruption frequency for Kio-17 feeders, 2013.

		المجموع	عمل	عطل	أهوية	تشييد	النقل	عوامل خار
كيلو 17	الإرسال	245	25	198	11	0	9	2
	العبور	193	30	143	16	1	1	2
	سوبا الحلة	152	38	103	9	0	1	1
	التسمين	109	28	53	12	1	15	0
	الراجحى	77	9	48	1	2	15	2
	صافولا	64	18	18	2	0	24	2
	العودة	46	17	24	2	1	1	1
	الهواء السائل	11	6	2	0	0	1	2
	المجموع	897	171	589	53	5	67	12

It is observed that from above table, Alersal 11kV line is classified as totally agricultural nature and subdivided into two suctions fed from Kilo-17 and Soba new industries distribution substations and ringed at close point and the total number of customers served are 96 comparing with Alebour line which classified as residential feeder and has a higher number of customers served so, this study focuses with the reliability of Alebour line.

A summarized reliability data 2013 for ALebour feeder collected from SEDC-Khartoum is presented in table 4.7, which will be used for further analysis.

Table 4.7: Summarized reliability data of Alebour 11KV line

Outage frequency (No./yr)	Outage duration (hrs/yr)	Customer served (No.)	Feeder length (km)	Transformers (No.)
193	14:55	3884	20.732	45

The detailed layout of Alebour line showing all location of customers and their transformer is shown in figure 4.6.

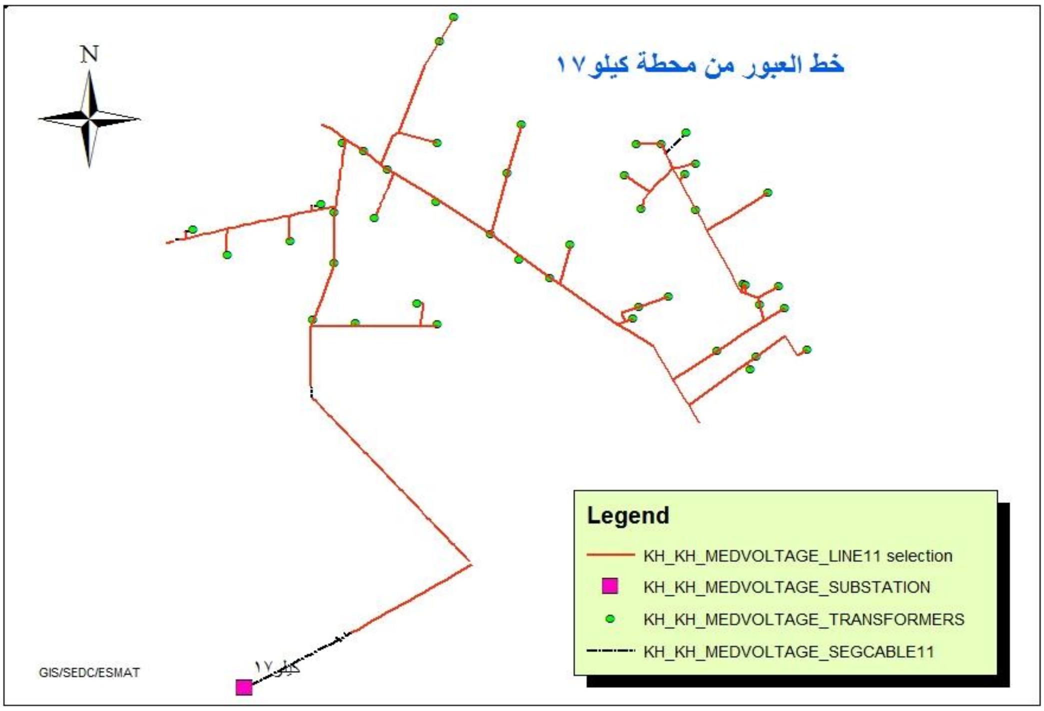

Fig.4.6: Schematic single line diagram of ALebour 11kV OHTL

4.3 Current Situation Reliability Indices:

It is desirable to calculate the reliability indices of the existing system with respect to the normal condition using above reliability data. Popular Customer-based indices such as SAIFI, SAIDI, CAIDI and ASAI are calculated and tabulated in table 4.8.

Table 4.8: Reliability results of the old system for year 2013

Indices	Unit	Reference Values
SAIFI	*Int./yr*	193
SAIDI	*Hr/Int*	14.92
CAIDI	*Hr/yr*	0.0773
ASAI	*%*	99.83

It is noted that, for Alebour feeder, SAIFI and SAIDI values are the same as reported values as well as high values indicating that the line circuit breaker tripped the line completely. These indices help us to establish the chronological changes in the line performance and therefore help us to identify the weak points and the need of improvement its reliability. This data will also help us to make predictive analysis for the future system.

4.4 Load Break Switch

A load break switch is a disconnect switch that has been designed to provide making or breaking of specified currents.

This is accomplished by addition of equipment that increases the operating speed of the disconnect switch blade and the addition of some type of equipment to alter the arcing phenomena and allow the safe interruption of the arc resulting when switching load currents. Disconnect switches can be supplied with equipment to provide a limited load switching capability. Arcing horns, whips, and spring actuators are typical at lower voltages.

These switches are used to de-energize or energize a circuit that possesses some limited amount of magnetic or capacitive current, such as transformer exciting current or line charging currents [11].

An air switch can be modified to include a series interrupter (typically vacuum or SF_6) for higher voltage and current interrupting levels.

These interrupters increase the load break capability of the disconnect switch and can be applied for switching load or fault currents of the associated equipment.

Fig. 4.7: SF_6 Insulated Load Break Switch for the use in medium voltage switchboards for secondary distribution networks.

4.5 Reliability Enhancement

There are several methods to improve the reliability of line from technical perspective and they include:

4.5.1 Sectionalizing Switches

Sectionalizing switches have the potential to improve reliability by allowing faults to be isolated and customer service to be restored before the fault is repaired.

The effectiveness of this process depends upon how much of the feeder must be switched out to isolate the fault, and the capability of the system to reroute power to interrupted customers via normally open tie points. Generally more manual normally closed and normally-open switches will result in reduced duration-oriented indices like SAIDI and will not impact frequency-oriented indices like SAIFI. However, since each switch has a probability of failure, placing more and more switches on a feeder will eventually result in a degradation of system reliability.

The location of the Load break switch in the existing system are as shown in figure 4.8 which plays Vitol role in restoration of system back to normal after interruption and for maintenance, thus providing the opportunity to make an step restoration which reduces SAIDI of the system though it may not help in SAIFI. It also helps to reduce Non Delivered Energy NDE to the customer and the total cost of customer interruption is therefore reduced.

Using above data, reliability indices were calculated and tabulated at the following table 4.9.

The alternatives chosen for the line is placement a number of load break switches at different locations.

1. Alt.1 - Installation of LBS-1
2. Alt.2 - Installation of LBS-2
3. Alt.3 - Installation of LBS-3

Table 4.9: Reliability results of the existing system for year 2013

Indices	**Unit**	**Alt. 1**	**Alt. 2**	**Alt. 3**
SAIFI	*Int./yr*	130.737	66.09	11.081
SAIDI	*Hr/Int*	10.106	5.109	0.8566
CAIDI	*Hr/yr*	0.0773	0.0773	0.0773
ASAI	*%*	99.885	99.94	99.99

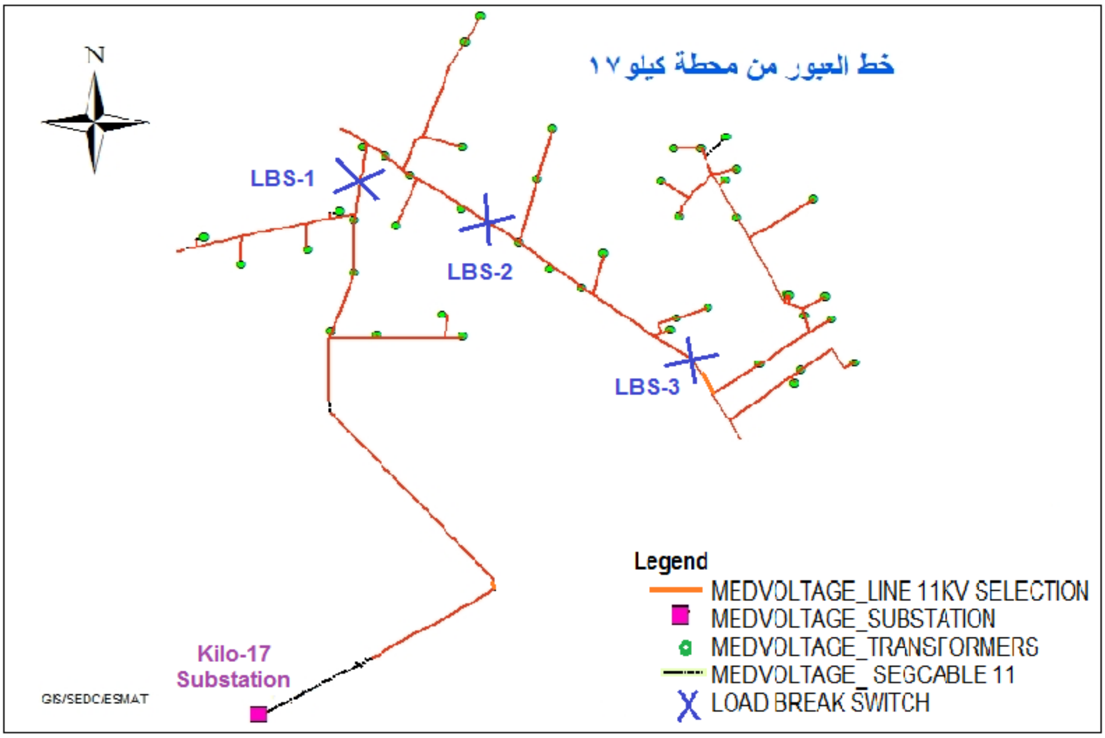

Fig. 4.8: Schematic single line diagram of ALebour 11KV OHTL with LBS

From table 4.9, it is being observed that alternative 3 gives the better results in terms of improvement of SAIDI and SAIFI, which in turn gives the minimum interrupted energy.

It is very important to place the sectionalizing switches at strategic locations to enhance the customer-based indices however; it may not be practically true since the location of such switches should be near the availability of communication facilities. If it is located at such points, it will facilitate to sectionalize the faulty sections faster and to make the supply available to the un-faulty ones. The reliability indices like SAIFI and SAIDI with reference values and different alternatives are illustrated in the figure 4.9.

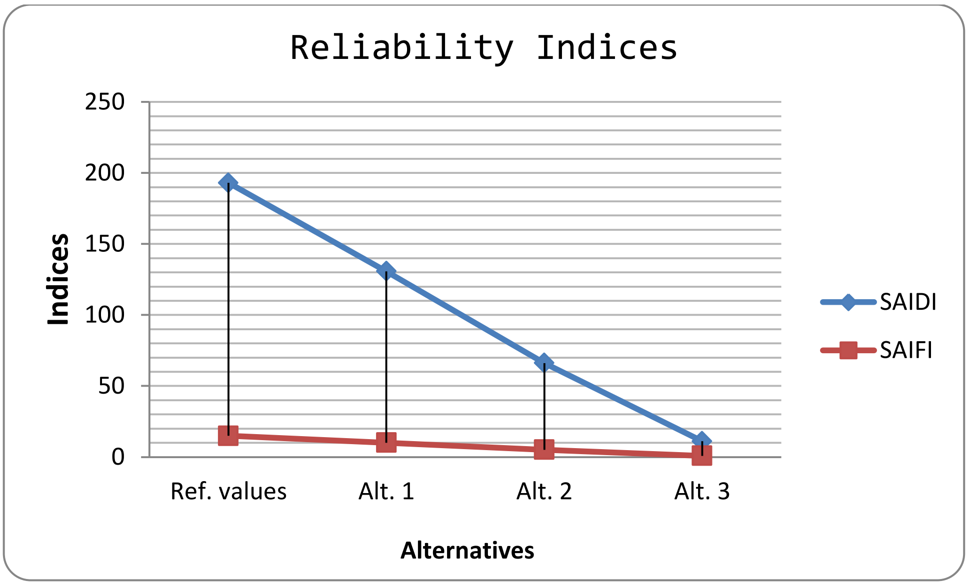

Fig. 4.9: Reliability Indices

It was found that from figure 4.9, an Alt. 3 gives the minimum SAIDI and SAIFI comparing with the other alternatives and reference values.

4.5.2 Reliability Enhancement by Redundant Line:

Reliability indices can also be improved by assuming redundant line connects between K-1 and K-2 nodes as shown in figure 4.10.

The main advantage of the installation of this line is to provide additional track to flow the current incase of occurrence any fault in the line.

In this case, the alternatives chosen for the line is placement a number of Load break switch at different locations as explained previously.

1. Alt.1 - Installation of LBS-1 and LBS-2
2. Alt.2 - Installation of LBS-2 and LBS-3
3. Alt.3 - Installation of LBS-3 and redundant line between K-1 and K-2 nodes.

Then, reliability indices for three different alternatives were calculated and tabulated in table 4.10.

Table 4.10: Reliability results of the existing system for year 2013

Indices	Unit	Alt. 1	Alt. 2	Alt. 3
SAIFI	*Int./yr*	64.64	55.008	9.938
SAIDI	*Hr/Int*	4.997	4.2524	0.768
CAIDI	*Hr/yr*	0.07729	0.0773	0.0773
ASAI	*%*	99.885	99.94	99.99

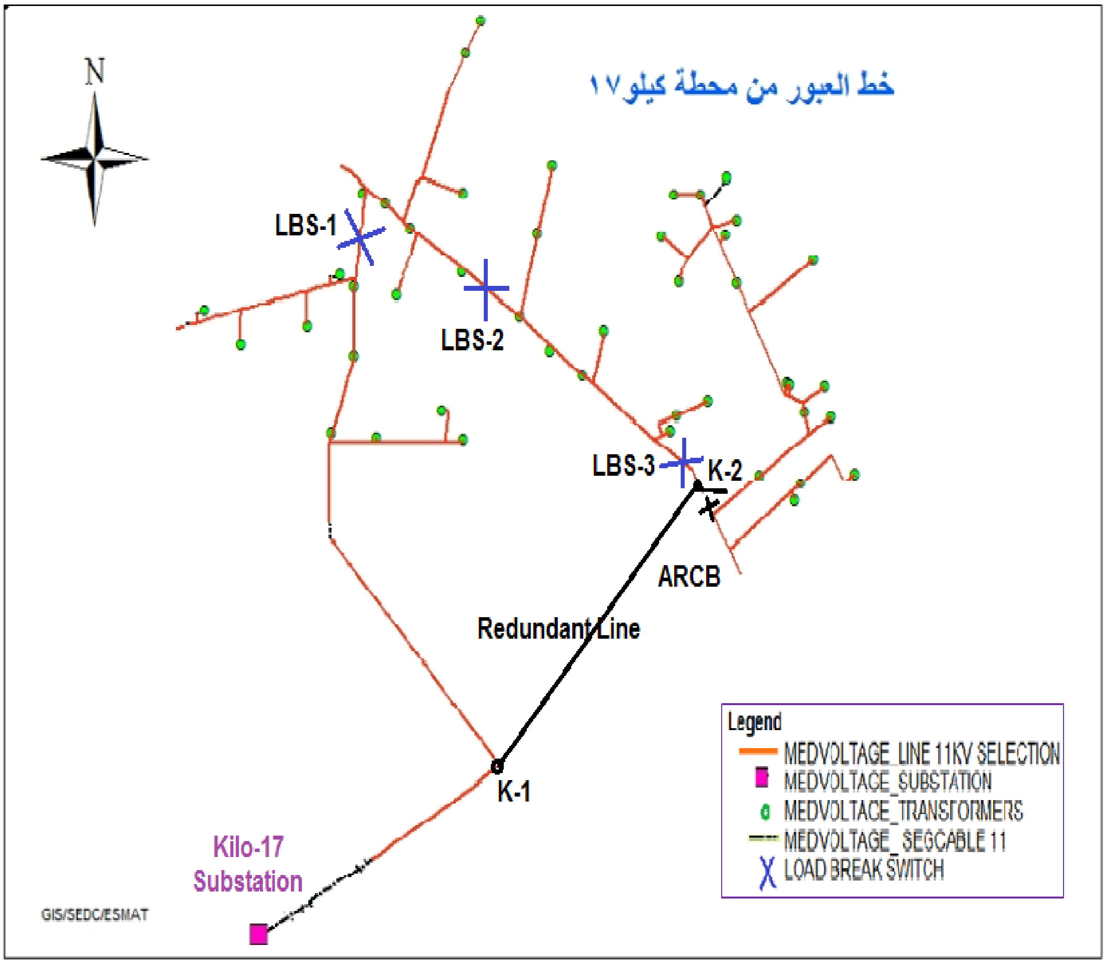

Fig. 4.10: Schematic single line diagram of ALebour 11KV OHTL with LBS and redundant line

The reliability indices like SAIFI and SAIDI with reference values and different alternatives are simulated and illustrated in the figure 4.11 below.

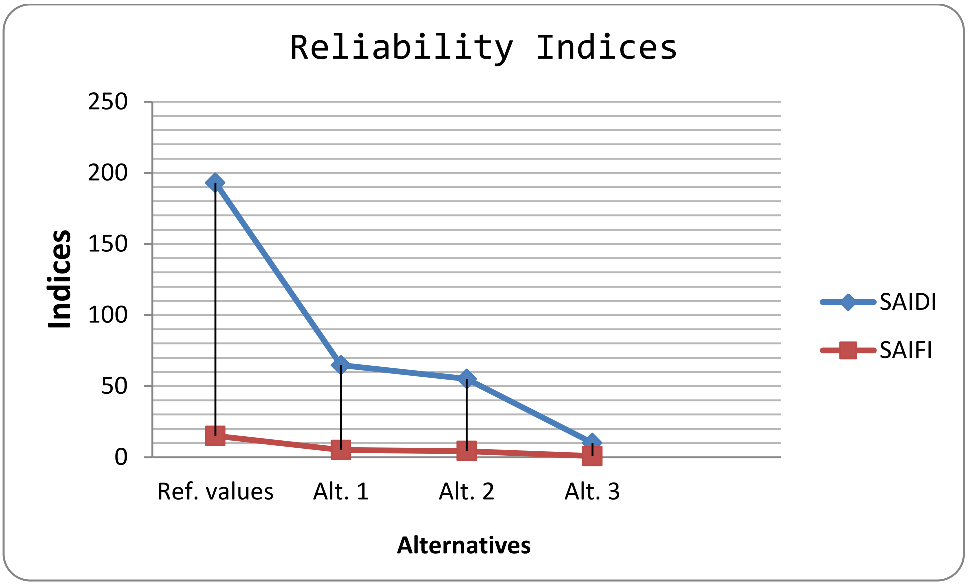

Fig. 4.11: Reliability Indices with reference values and different Alternatives

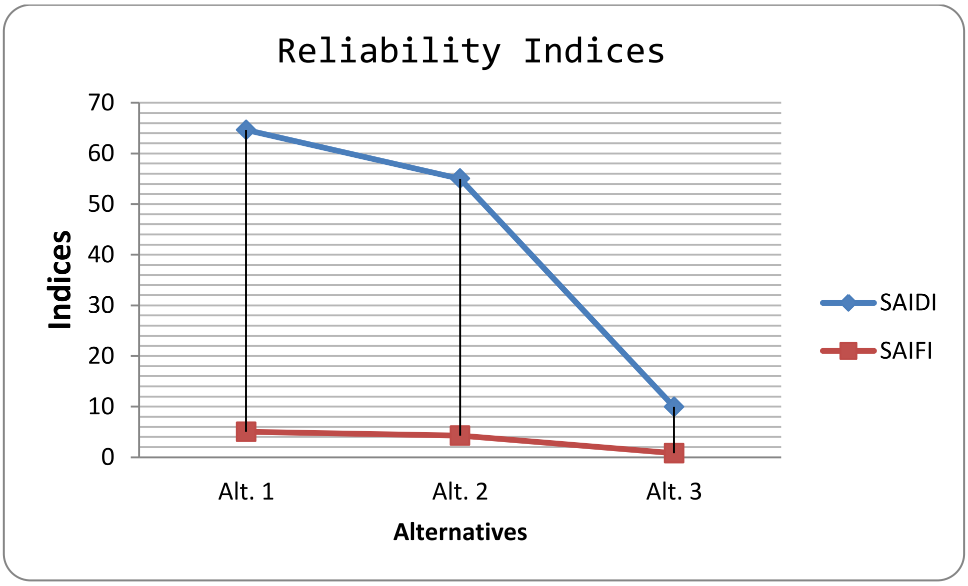

Fig. 4.12: Reliability Indices with different alternatives

It is noted that, Alt.3 gives the better reliability indices for each SAIDI and SAIFI indicates small amount of power has been interrupted and ASAI is 99.99% referring to enhancement of system reliability.

Although this line improves the reliability indices but at the same time the utility must carry the installation cost and this lead to reduce the cost of customer interruption.

4.5.3 Protection Devices

Adding protection devices is one of the most straightforward and effective methods for improving distribution system reliability. Assuming proper coordination, increasing the number of protection devices reduces the number of customers that experience interruptions after a fault occurs. Stated differently, increasing the number of protection devices increases the selectivity of the protection system.

4.5.4 Faster Crew Response

An obvious way to improve duration related reliability indices such as SAIDI is to speed up service restoration and speed up repair times. Though easily accounted for in reliability models by reducing the mean time to switch (MTTS) of switches and the mean time to repair (MTTR) of equipment, these reductions should be justified by actual projects that improve operational performance.

Several reliability improvement projects that have the potential to improve crew response time are:

(a) Outage Management System

In their most basic form, outage management systems contain system connectivity information, switch position information and customer location information. When an interrupted customer calls the utility, the outage management system automatically identifies the geographic location of the customer as well as the location of the upstream protection device that has likely tripped. If many interrupted customer calls are received, the outage management system infers which upstream device has likely tripped based on predefined rules. In any case, trouble calls are immediately brought to the operator’s attention and can immediately be acted upon by sending crews to the expected fault location. Subsequent switching can also be performed faster due to the possibilities of visual representation of switch positions, superimposition of crew locations on electronic maps, and automatically generated switching sequences. When modeling the impact of outage management systems, it is appropriate to reflect decreases in both MTTR and MTTS.

(b) Faulted Circuit Indicators

Faulted circuit indicators set a visible flag when they detect fault current. When placed regularly along a distribution circuit, they allow crews to follow the activated flags directly to the fault. These devices are effective for both overhead and underground systems, and can be modeled by reducing the MTTR and MTTS of feeder devices by the expected reduction in time from the crew being dispatched to the fault being located.

(c) Automatic Fault Location Devices

These devices measure fault magnitudes and infer fault location based on system topology and line impedances. Though uncertainties in pre-fault current, fault impedance and circuit impedance make precise fault location impossible, advanced techniques using protection device, and reclosing characteristics (location and time-overcurrent characteristics) can often reduce likely fault locations to a few possibilities.

(d) Increased Number of Crews and Dispatch Centers

In this method, Improvement can be obtained by hiring more crews, utilizing more service centers, optimally siting service centers, tracking crews with global positioning systems, incentivizing crews based on response time, and a variety of other methods.

The difficulty is in quantifying the expected improvements associated with various strategies so that their reliability impact can be modeled and quantified. Typically, improvements in response time are associated with reductions in travel time from the initial crew location to the fault location.

4.5.5 Fewer Equipment Failures

There are a virtually unlimited number of ways to reduce equipment failure rates, and it is impossible to provide a comprehensive treatment in this section. Regardless, each is similar in that it will mitigate one or more physical root causes of failure rates and can be modeled by a reduction in aggregate component failure rate. Some of the more common failure reduction programs include:

- *Increased Inspection and Monitoring*, SEDC perform regular inspection and maintenance on their transformer fleet in an effort to minimize failures.
- *Substation Transformer failures*, they are a function of many factors including age, manufacturer, loading history, number of through faults, maintenance history, the presence of on-load tap changers, etc.
- *Use of Covered Wire*, SEDC improve and replace bare overhead conductor with covered conductor.
- *Cable Replacement Programs*
- *Increased Lightning Protection*
- *Distribution transformer load management programs*, SEDC should apply optimum loading percentage for transformers.

Many old feeder systems have been extended and reconfigured many times and, consequently, have sections containing old and small wire that has a lower than desired capacity. The failure rate of old wire tends to be higher than that of new wire due to oxidation, cumulative annealing, and fatigue. In addition, the failure rate of small wire tends to be higher due to burn-down during short circuits.

Replacing these sections of old and small wire will reduce associated failure rates, and will have the additional reliability advantage associated with increased capacity.

4.6 Analysis of Major Causes of Interruption

When attempting to improve reliability, it is important to know the greatest contributing factors to these indices. However, predictive root cause analysis is different than historical root cause analysis which typically identifies the physical cause of faults [2] where predictive root cause analysis computes each components contribution to reliability indices. The cause of outages depends on geographical locations of the area. From historical data of the past year 2013, major cause of outages in the system is being recorded as explained in table 4.11 and illustrated in figure 4.14 as shown below.

Table 4.11: causes of outages and their frequencies

Cause	Fault	Work	Wind	Structure	Transmission	Other Fact.
Frequency	143	30	16	1	1	2

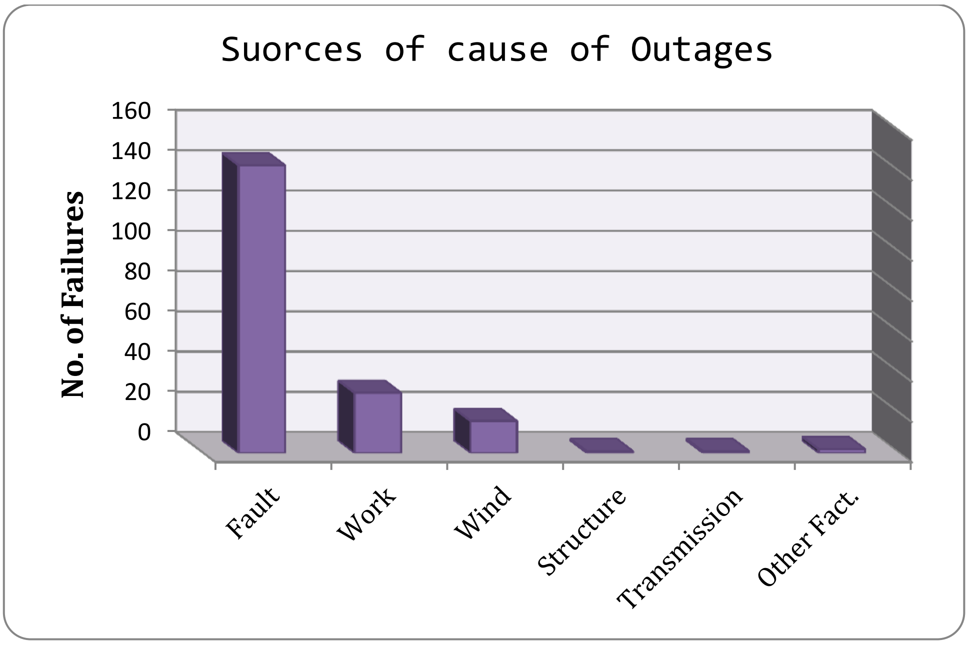

Fig. 4.13: Sources of cause of outages

Faults are not evenly distributed along lines. Not all faults are inevitable “acts of nature.” Most of them are from specific deficiencies at specific structures. On overhead circuits, most faults result from inadequate clearances, inadequate insulation, old equipment, or from trees or branches falling onto a line [2].

A first step in eliminating faults is to identify what is causing them. Keeping in mind that most faults result from specific structural deficiencies, field identification of fault sources is a key part of construction-improvement programs. Field personnel can be trained to spot pole structures where faults have occurred or might likely occur. Common structural deficiencies include poor jumper clearances; old equipment (such as expulsion arresters); bushings or other equipment unprotected against animals, ground leads or grounded guys near phase conductors; poor clearances with polymer arresters; damaged insulators; damaged covered wire (replace bare overhead conductor with covered conductor).; and dangerous trees or branches present.

It is noted that the greatest value of outage along 2013 year is due to fault which decrease the reliability of line and also there are number of outages which could have been easily mitigated by creating awareness among the public regarding safety precautions and the importance of electricity to various consumers, so they could take preventive measure to avoid damage to electric lines and equipment, thus avoiding interruptions.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The foremost aim of this study is to see how reliability could be improved in Khartoum distribution system by incorporating reliability analysis in the systematic planning approach so that Optimum Reliability is achieved, meaning that the Utility cost is equal to the customer cost.

The fault rates and reliability indices for the year 2013, is being considered as base year for the case study. The general process flow chart is being developed based upon the systematic planning approach of distribution network.

This thesis has reviewed some aspects of reliability research in distribution systems in the following three main topics:

- Introduction of concepts of reliability in distribution system
- Reliability indices system (customer-based and load-based indices)
- Reliability Assessment of Khartoum distribution system (Alebour 11kV overhead line).

Techniques for reliability evaluation are important in the planning and operation of distribution system. Operation and maintenance costs due to low reliability can be reduced by adequate planning, monitoring system behavior and taking proper control actions.

Reliability indices has been calculated and assessed for Khartoum distribution system due to high consumption of total network load, certainly, Khartoum sector for Alebour 11KV overhead line which fed from Kilo-17 distribution substation. The performance of the present system could be enhanced and improved by installation of LBS at several locations along the line. Alternative 3 gives minimum energy interrupted and low SAIDI.

Most of the interruption has been caused due to temporary faults and this may be mainly due to low clearance maintained between lines and trees than the required standards.

Reliability of Alebour line enhanced by several ways, it was found that, the better approach is to reconfigure by installation of redundant line and sectionalize it using LBS which consists of fault passage indicator (FPI) to reduce the time of finding the fault location leading to get minimum SAIDI and SAIFI.

Maintaining fault resistance should be an on-going process and SEDC must maintain consistency in it

5.2 Recommendations

Having gone through the study of reliability assessment of distribution network, the future work has been identified as;

- ♦ Availability and power quality of distribution system from the fact that availability is a subset of reliability and reliability is a subset of power quality.
- ♦ Develop a suitable way to calculate the actual investment and operation costs of the several methods of reliability enhancement (sectionalizing switches and redundant line) and how to return the cost.
- ♦ Study other distribution lines such as Alersal, Soba Alhilla and Soba Almazarie which have a higher interruption frequency and outage duration in annual report.
- ♦ Provide a simple way to connect Alebour line with other line from Kilo-10 substation to be ring system in order to enhance reliability of line.
- ♦ SEDC should care with regular inspection and maintenance on their transformer fleet in an effort to minimize failure.
- ♦ SEDC should continue improvement issue by replacing bare overhead conductor with covered conductor in order to avoid fault occurrence.

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