RELIABILITY ANALYSIS OF DISTRIBUTION NETWORK

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Abstract

The knowledge of the reliability of distribution networks and systems is important consideration in the system planning and operations for development and improvements of power distribution systems. To achieve the target as minimum interruptions as possible to customers, utilities must strive to improve the reliability but at the same time reduce cost. It is a known fact that most of customer interruptions are caused by the failure in distribution system. However, valid data are not easy to collect and the reliability performance statistic not easy to obtain. There is always uncertainty associated with the distribution network reliability. For evaluation and analysis of reliability, it is necessary to have data on the number and range of the examined piece of equipment. It’s important to have database for failure rates, repair time and unavailability for each component in distribution network. These studies present the analysis of distribution networks and systems by using analytical methods in SESB’s distribution substations and network systems. These studies use analytical methods to determine the reliability indices and effect of distribution substation configuration and network to the reliability indices performance. Then the result obtained will be compare with the actual data from SESB to determine the area of improvement required for mutual benefit and also for improvement in the future studies.
Abstrak

Pengetahuan tentang reliability terhadap sistem dan rangkaian pengagihan adalah sangat penting dalam perancangan and operasi untuk tujuan peningkatan mutu pengagihan kuasa. Untuk mencapai objektif bagi meminimumkan gangguan bekalan keatas pengguna-pengguna di kawasan pengagihan, syarikat utility perlu berusaha untuk meningkatkan mutu kebolehpercayaan sistem tetapi dalam masa yang sama mengurangkan kos. Menurut fakta, kebanyakan gangguan bekalan yang dihadapi pengguna adalah disebabkan oleh kegagalan system pengagihan itu sendiri. Walaubagaimanapun, data yang sah serta statistik prestasi kebolehpercayaan tidak mudah untuk dikumpul dan diperolehi. Ketidakpastian dan ketepatan data menjadi masalah utama dalam sistem pengagihan. Sebagai tujuan menilai dan menganalisis sistem pengagihan, adalah menjadi keperluan untuk mempunyai data yang sah bagi semua peralatan yang terlibat dalam sistem pengagihan. Data – data tersebut adalah merujuk kepada kadar kegagalan dalam satu tempoh tertentu dan maklumat berkaitan yang dapat membantu dalam analisis kebolehpercayaan sistem. Pembelajaran dan penyelidikan dalam tajuk ini adalah menurus kepada analisis sistem dan rangkaian pengagihan menggunakan kaedah analitikal terhadap pencawang pengagihan di SESB. Kaedah analitikal digunakan secara terperinci untuk mendapatkan indeks kebolehpercayaan dan kesan konfigurasi pencawang terhadap prestasi indeks kebolehpercayaan pengagihan tersebut. Keputusan yang diperolehi akan dibandingkan dengan indeks sebenar yang diperoleh daripada SESB. Berdasarkan perbandingan tersebut, penambahbaikan akan diambil kira untuk kegunaan dan aplikasi pada masa akan datang.
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<td>System Average Interruption Duration Index</td>
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<td>SAIFI</td>
<td>System Average Interruption Duration Index</td>
</tr>
<tr>
<td>CAIDI</td>
<td>Customer Average Interruption Duration Index</td>
</tr>
<tr>
<td>ASAI</td>
<td>Average Service Availability Index</td>
</tr>
<tr>
<td>ASUI</td>
<td>Average Service Unavailability Index</td>
</tr>
<tr>
<td>ENS</td>
<td>load- and energy-orientated indices such as Energy Not Supplied</td>
</tr>
<tr>
<td>AENS</td>
<td>Average Energy Not Supplied</td>
</tr>
<tr>
<td>ACCI</td>
<td>Average Customer Curtailment Index</td>
</tr>
<tr>
<td>SESB</td>
<td>Sabah Electricity Sendirian Berhad</td>
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<tr>
<td>kV</td>
<td>kilo volt</td>
</tr>
<tr>
<td>U</td>
<td>Average unavailability</td>
</tr>
<tr>
<td>r</td>
<td>Average repair rate</td>
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<td>λ</td>
<td>Average failure rate</td>
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CHAPTER 1

INTRODUCTION

1.1 Project Background

Power distribution network system established mainly to provide adequate electricity supply to customers as economically as possible with reasonable assurance of reliability. Nowadays, the power distribution networks have grown exponentially in term of size and technology over the past few years. As a result, utility company must strive to ensure that the customer’s reliability requirements are met with optimum strategic planning and lowest possible cost. The ability of the system to provide adequate supply of electricity energy determine by the term reliability. Reliability analysis of distribution network is not a new topic in electric power industries, a lot of studies and research have been carried out due to the increasing cost of blackouts and fault outages.

Over the past, distribution network system have received less attention devoted to reliability studies compared to generation and transmission system [1]. The reasons being is the generation and transmission systems are capital intensive and the inadequacy can have widespread consequences for both society and environment. However, a distribution system is slightly cheaper compare to the other two because its effects are localized. Analysis of the customer failure statistics of most utilities shows that distribution system makes the greatest individual contribution to the unavailability of electrical supply to customer.

It is very important to assess and evaluate the reliability of power system networks in order to obtain the most accurate and effective way in decision making especially in planning, operation, and maintenance. Historical assessment and
predictive methods are normally used to evaluate the reliability of a distribution network. Most utilities focus more on historical assessment rather than predictive methods. Predictive methods are categorized into analytical and simulation methods. Reliability assessment method for distribution system fall into two classes: simulation and analytical [2]. Simulation is the most flexible method but require extensive time in computational and also uncertainty in precision. Analytical method can be further divided into network modeling and Markov modeling. Network modeling has been the most popular technique for distribution system reliability analysis due to the simplicity of the method and natural similarities between network model and the distribution topology. The difference between simulation and analytical method is the way in which the system reliability indices are evaluated. By applying both analytical and simulation method, the reliability indices for distribution systems will be determined such as System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). The probability distribution of SAIFI and SAIDI which give information about the variability of the indices also need to obtain in order to improve in decision making.

1.2 Problem Statements

There are many factors that contribute to the failure of distribution network system. Reliability is very important issue in dealing with planning and operation of the networks. In distribution system planning, reliability aspects are an important part of the decision base. Thus, to be able to assess and evaluate, reliability is needed in the planning process. The data obtained from Sabah Electricity Sdn Bhd (SESB) showed that the distribution network contribute the highest SAIDI and SAIFI for three years from 2011 to 2013.

The main problem facing is the power demand is rapidly increased whilst supply growth is constrained by limited sources, environmental problem and other social concerns. According to statistic, about 80% of power interruptions result from power distribution system failure [2]. Historical assessment and predictive methods are normally used to evaluate the reliability of a distribution network. Most utilities focus more on historical assessment rather than predictive methods. Hence, it is vital in design and development of distribution network to study and analyze the reliability. Enhance knowledge in reliability analysis of distribution network will
contribute to the measurement of how far the system meet the performance criteria, to help quantify comparison between various options, and to help in term of economic decision [3]. Besides that, reliability analysis result will determine the failure rate and mean failure duration for particular equipment or group of equipments, thus with more detail in databases, the information gained may be important for utilities operators, such as the most frequent cause of failures, areas of greatest amount of undelivered energy [4] or the most weakness area of protection system which contribute to interruptions and fault.

In this project, the most challenging and difficult aspect will be on the analytical part where details concentration are required to acquire input data from utilities and industries and calculation to obtained useful reliability indices which will be used for comparison with the historical assessment. Incorrect input data will of course lead to false result [6]. Furthermore, the difficulties for completing this project are to apply the analytical methods for analysis of the existing distribution network and systems. The advantages and disadvantages associates with both analytical and simulation techniques are as follows:

(a) The analytical model always gives the same numerical result for the same system, same model and same set of input data, whereas the result from a simulation method is dependent on the random number generator used and the number of simulations.

(b) The model used in the analytical approach is usually a simplification of the system. The simulation approach, however, can incorporate and simulate any system characteristic that can be recognized. Thus it gives a better description of practical system behavior.

(c) The solution time for analytical techniques is relatively short, as compared to that for simulation techniques which is usually extensive. This disadvantage has been partially overcome by the development of modern computational facilities. However, the solution time still remains high in applications that demand several reliability assessments.

(d) Simulation techniques can provide a wide range of output parameters, including, probability density functions and their respective moments, whereas the output of the analytical techniques is usually limited only to expected values.
1.3 Project Objectives

The major objective of this project is to evaluate the reliability of distribution networks in Sector 2 of Sabah Grid network and to determine the system reliability indices by using analytical method. The reliability indices are System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI). Result from these approaches and some changes in philosophy study are analyze and compared. The following issues shall be discussed:

a) To assess and evaluate the existing reliability indices of distribution network system of Sector 2 area in Sabah grid network.
b) To determine the reliability indices System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) using predictive (analytical) methods.
c) To compare the results for further recommendation and improvement in decision making of planning and design based on predictive methods and some changes in the operating philosophy.

1.4 Project Scopes

This study will focus on the analysis of 33kV and 11kV distribution network in Sector 2 of Sabah Grid network. The parameter used to determine the reliability indices are failure rate, repair rate and unavailability. The scopes of this project are:

a) Implementation of predictive analysis methods for the existing distribution network 33kV and 11kV system.
b) Analysis of SAIDI and SAIFI for distribution level. Compare both method and further evaluate to obtain optimum reliability indices.
c) The operating philosophy and system configuration which includes protection, control, monitoring and equipment used.

This project will concentrate on analytical methods since historical assessment has been used by the utilities over the past few years. Moreover, analytical methods are more enhance to provide more useful and higher accuracy of results. By comparing both methods, further evaluation will be discussed and result obtained can be used as reference for decision making in planning and operation. The actual source of
databases such as SAIDI and SAIFI acquired from Sabah Electricity Sendirian Berhad (SESB), from System Operation Division.

The past or historical data will be used as benchmarking and reference for comparison with predictive analysis results. Two methods in analytical technique which has been used extensively by researchers and as a benchmark system: Network Modelling Markov chain modelling.

The result of analytical methods depends on the quality of input data or the data available with the company and user. Therefore, it is very important for the utilities to maintain and update the data recording systems for future use. This would enhance to improve the system studies in future and the overall reliability in the system.

1.5 Project Outline

This project is organized in 5 chapters. An overview of the research along with features and aim are outline in Chapter 1. A literature review is carried out in Chapter 2. This chapter consist of the previous research by other students and it’s illustrated a comprehensive technique and method used for reliability analysis. Chapter 3 is the methodologies elaborate further on how the project will be carried out, the technique used and its present the historical data for the past three years from SESB operation division. Besides that, the interruption causes which contribute to the performance of reliability indices also present in this chapter. The calculation and determination of reliability analysis was performed in Chapter 4. An analytical technique was applied to determine the reliability indices by using different configurations and operational concept. Further discussion and justification was explained in this chapter, the comparison of the result obtained and its advantages and disadvantages. A bar chart representation was constructed to illustrate the comparison. Chapter 5 presents the conclusions as well as recommendations for future works. The list of references and list of publications resulted from this project are present after this chapter.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Electrical power are vital important to our modern society nowadays in line with the challenges to provide the most efficient and cost effective way of supplying electricity from industrial area up until residential consumers. The availability of a reliable power supply at reasonable cost is crucial for the economic growth and development of a country [5]. Power Utilities Company nowadays try to enhance and develop their own strategies based on experience, trending, research and studies to meet customer demands as economically as possible at reasonable service of reliability. An analysis throughout the word shows that around 90% of all customer reliability problems are due to the problem in distribution system. Thus, improving distribution reliability is the key to improving customer reliability [6]. The concept of power-reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. There is a reasonable subdivision of the concern designated as system reliability which is shown in Figure 2.1.

![System Reliability Subdivision](image)

Figure 2.1: System Reliability Subdivision.
Figure 2.1 represents two basic aspects of a power system: system adequacy and security. Adequacy relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. These include the facilities necessary to generate sufficient energy and the associated transmission and distribution facilities required to transport the energy to the actual consumer load points. Security relates 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 perturbations it is subject to [3].

2.2 Reliability

2.2.1 Reliability Evaluation

The ultimate goal of reliability analysis is to help answer questions like “is the system reliable enough?”, “which scheme will fail less?” and “where can the next dollar be best spent to improve the system?”. As discuss before, reliability in power system can be divided into two basic aspects which is System Adequacy and System Security. Since distribution system are seldom loaded near their limits, reliability emphasis in system security compared to system adequacy. Reliability evaluation of distribution systems consist of two main approaches Simulation and Analytical methods.

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

The Monte Carlo techniques are normally very time consuming due to large number of drawing necessary in order to obtain accurate results. The fault distribution from each component is given by a statistical distribution of failure rates and outage times. The analytical approach is based upon assumptions concerning statistical distribution of failure rate and repair times. The most common evaluation techniques are using a set of approximate equation of failure mode analysis or minimum cut analysis. This method is less time consuming than the simulation method, but suffers from problem representing repair times adequately.
2.2.2 Reliability Indices

The basic load-point reliability indices used to predict the reliability of a distribution system are the average load point failure rate \( (\lambda_s) \), the average load point outage duration \( (r_s) \), and the average annual load point time or unavailability \( (U_s) \) \[7\]. A wide range of system indices can be calculated with these three parameters. The system reliability indices may be customer-orientated such as SAIFI, SAIDI, Customer Average Interruption Frequency Index (CAIFI), Customer Average Interruption Duration Index (CAIDI), Average Service Availability Index (ASAI), Average Service Unavailability Index (ASUI) or load- and energy-orientated indices such as Energy Not Supplied (ENS), Average Energy Not Supplied (AENS) and (ACCI).

Quantitative reliability evaluation of a distribution system can be divided into two basic segments; measuring of the past performance and predicting the future performance \[8\]. Below are some of the basic indices that have been used to assess the past performance:

- **System Average Interruption Frequency Index (SAIFI).** It is designed to give information about the average frequency of sustained interruption per customer over predefined area.

\[
SAIFI = \frac{\text{Total Number of Customer Interruptions}}{\text{Total Number of Customer Served}} = \frac{\sum \lambda_i N_i}{\sum N_i}
\]

- **System Average Interruption Duration Index (SAIDI).** It is commonly referred to as customer minutes of interruption or customer hours, and is designed to provide information about the average time that the customers are interrupted.

\[
SAIDI = \frac{\text{Sum of Customer Interruption Durations}}{\text{Total Number of Customer Served}} = \frac{\sum U_i N_i}{\sum N_i}
\]

Past performance statistics provide valuable reliability profile of the existing system. However, distribution planning involves the analysis of future systems and evaluation of system reliability when there are changes in; configuration, operation conditions or in protection schemes. This estimates the future performance of the system.
system based on system topology and failure data of the components. Due to stochastic nature of failure occurrence and outage duration, it is generally based on probabilistic models. The basic indices associated with system load points are: failure rate, average outage duration and annual unavailability.

2.3 Power Quality and Availability

Perfect power quality is characterized by a perfect sinusoidal voltage source without waveform distortion, variation in amplitude or variation in frequency. To attain near perfect quality, a utility could spend vast amounts of money and accommodate equipment with higher power quality needs. On the other hand a utility could spend little and require customers to compensate for the resulting power quality problems. Neither of extreme is desirable, utilities must find a balance between cost and power quality provided to the customer. Power quality concerns are becoming more frequent with the proliferation of sensitive electronic equipment and automated process. Power quality problems are basically divided into many categories such as interruptions, sags, swells, transients, noise, flicker, harmonic distortion and frequency variations [9].

Availability is defined as the percentage of time a voltage source is uninterrupted. 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. Availability is the probability of something being energized and Unavailability is the probability of not being energized. It is most basic aspect of reliability and is typically measure in percent or per unit. Unavailability can be computed directly from interruption duration information. If a customer experiences 9 hours of interrupted power in a year, unavailability is equal to $\frac{9}{8760} = 0.10\%$ (8760 hours in a year). Then availability is equal to $100\% - 0.1\% = 99.90\%$. With the growth of ultrasensitive loads, it has become common to describe high levels of reliability.
2.4 Network Equivalent Technique

The analytical techniques required for distribution system reliability evaluation are highly developed. Many of the published concepts and techniques are presented and summarized in [1]. Conventional techniques for distribution system reliability evaluation are generally based on failure mode and effect analysis (FMEA) [10]. This is an inductive approach that systematically details, on a component-by-component basis, all possible failure modes and identifies their resulting effects on the system. Possible failure events or malfunctions of each component in the distribution system are identified and analysed to determine the effect on surrounding load points. A final list of failure events is formed to evaluate the basic load point indices. The FMEA technique has been used to evaluate a wide range of radial distribution systems. In systems with complicated configurations and a wide variety of components and element operating modes, the list of basic failure events can become quite lengthy and can include thousands of basic failure events. This requires considerable analysis when the FMEA technique is used. It is therefore difficult to directly use FMEA to evaluate a complex radial distribution system. A reliability network equivalent approach is used to simplify the analytical process. The main principle in this approach is using an equivalent element to replace a portion of the distribution network and therefore decompose a large distribution system into a series of simpler distribution systems. This approach provides a repetitive and sequential process to evaluate the individual load point reliability indices.

2.5 Description of Previous Methods

2.5.1 Reliability Evaluation of Distribution Networks Using Fuzzy Logic

The fuzzy logic concept is used to evaluate the reliability distribution network. The basic concept underlying fuzzy logic is that of a linguistic variable whose values are words rather than numbers. The use of fuzzy logic as an evaluation tool has distinguish characteristic, this technique aims at exploiting the tolerance for imprecision and uncertainty to achieve tractability, robustness and low solution cost [11].
The fuzzy logic method was used to predict the reliability as there was no mathematic function describing the relationship between subsystems and the network reliability. The advantage of fuzzy logic method is its enabling the possibility of adding new fuzzy systems to the existing model, in order to account for factors that were not included in the model. These new fuzzy level can be added into fuzzy level 1 or 2. The reason is that all subsystems are assumed to be independent to each other. Furthermore, fuzzy logic is more flexible thus it allow for its application to simplify complex models. Due the simplification, the computation time is reduced and larger model could be easily evaluated with minimal computation time.

2.5.2 The Reliability Analysis of Distribution System Based on Dynamic Bayesian Network

Dynamic Bayesian network is a time extension of the static Bayesian network, which consists of the initial network and transfer network. Based on Dynamic Bayesian networks, the actual value of the component failure rates and repair rates can be accurately reflected and failure frequency and duration of distribution system can be calculated. Bayesian network method permits not only computing the reliability indices of a distribution system but also presenting the effect of each component or some components on the system reliability.

This method can't calculate the situation with time, which not only can't calculate outage frequency index and outage time index, but also can't exactly reflect the actual value of the failure rate and repair rate of components. In order to solve these problems, an approximate Bayesian network inference algorithm for time-sequence simulation is presented [12]. But this method is similar to the Monte Carlo simulation method, which simulate the events using the sampling, and suffer in computation time and uncertainty of precision. Dynamic Bayesian Network inherits the advantages of static Bayesian Networks, and it can be able to describe the dynamic evolution process of the distribution system due to the disconnect switches and protection devices.
2.5.3 Case Study of Distribution Network Reliability Analysis Based on Probabilistic Method.

This study is based on probabilistic method where the reliability of a large distribution network is calculated. Some solutions were introduced to improve the weaknesses of the network system. A probabilistic distribution model is proposed by using radial basis function neural network with orthogonal least square learning method [13]. Monte-Carlo time sequential simulation technique also applied for worth assessment. Probabilistic reliability assessment flowchart is illustrated in Figure 2.3.
The failure model describes that the system component will fail, how it fail and how long the repair time required. The load models may consist of only a few possible load demands, or based on precise load forecast and growth scenarios. The combination of one or more simultaneous faults and a specific load condition is called a system state. The system state production module will use failure and load models to build a list of relevant system states. Each of this system states may have one or more faults.

This case study also using the Stochastic models where it describes how and how frequent a certain object changes. A line, for example, may suffer an outage due to a short circuit and it will be back to service after an outage repair completed. This study used Markov model to define stochastic model by using two states constant failure rate and constant repair rate. These two parameters will be used to calculate and obtained other parameter such as mean time to repair (MTTR), mean time to failure (MTTF), availability (P) and unavailability (Q). The availability gives the fraction of time during which the component is in service and the unavailability gives the fraction of time it is in repair. The total of P and Q therefore equal to 1. The
reliability assessment functions are based on “Weibull-Markov” model (W-M model). This model illustrated in Figure 2.4.

![Figure 2.4: A Weibull Markov model.](image)

Refer to above Figure 2.4, each behaviour represent different state which is: S0 states with 100% capacity, S1 describe a state with limited capacity and S2 describe the repair state. It can be concludes that positive effects on final results and initial capital before implementation and construction of network [14].

### 2.5.4 Summary of Previous Methods

The summary of the previous research and study on reliability analysis for distribution network is shown in Table 2.1.

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Model</th>
<th>Advantages</th>
</tr>
</thead>
</table>
| 2010 | M.R Emjedi, K.Awodele, S.Chowdhury, S.P Chowdhury | Fuzzy Logic | - Fuzzy logic used to examine the influence of the various sub-system that comprise in distribution network in term of reliability.  
- Enabling the possibility of adding new fuzzy systems to the existing model, to |
<table>
<thead>
<tr>
<th>Year</th>
<th>Authors</th>
<th>Methodology</th>
<th>Advantages</th>
</tr>
</thead>
</table>
| 2012 | Aoxue Su, Mingtian Fan, Zhonglai Li | Dynamic Bayesian Network | • Construct the topological relationship of distribution system on influence of each component on the systems.  
• This method not considers the impact of time factor to the variables, but reflect the probabilistic dependencies between variables and time varying of variables.  
• Able to describe the dynamic evolution process of distribution system due to disconnect switches and protection devices. |
| 2011 | Yong Tang | Artificial Neural Network | • Used Radial Basic Function (RBF) Neural network classifier to distinguish the high reliability and low reliability of load point.  
• This method not applicable to ring distribution network and network classification error may occur due to complexity. Need further improvements. |
CHAPTER 3

METHODOLOGY

3.1 Project Methodology

3.1.1 Overview

This research is adopting methods involving analysis and evaluation of reliability of the distribution network in sector 2 of Sabah grid network 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 and sees how risk of failure could be mitigated. The reliability indices for the year 2011 to 2013 are being considered as base year for the case study.

Reliability indices such as SAIFI, SAIDI and CAIDI can be calculated using equation given in 2.2.2 [3]. These indices provide a relative measure for a group of load points or for the entire system. Analysis will be carried out at distribution network substation Tuaran 66/11kV system. But the selection of distribution substation depends on the availability of data and information required for calculation and analysis. Result from these approaches will be compare with the actual value of reliability indices obtain from year 2011 to 2013. In this project, we will apply two analytical methods to determine the reliability indices which are Markov model and Network modelling. The project’s Gantt chart is given in Appendix A. The research is conducting in phase’s basis as shown in flowchart in Figure 3.1:
Figure 3.1: The planning approach for the Reliability Analysis of Distribution network.
3.1.2 Feasible Study on Reliability Analysis

The feasible study on reliability analysis concentrates on the previous methods used for reliability evaluation and assessment. The existing system network will be benchmark and compare with the previous study and research so that the methods that need to be apply is suitable with the current systems. In order to achieve this, details study and research is required to be conduct by referring to SESB distribution system operation and design.

The technique required to analyze a distribution system depend on the type of system being considered and depth of analysis needed. Firstly, we need to know the basic evaluation technique then extend to more complex system inclusive of more refined modeling aspects. This project will be base on two methods which are Network modeling including basic evaluation technique for distribution system and Markov chain model. More concentration on the basic evaluation technique as the existing distribution network system is more compatible with this technique.

3.1.3 Markov Modelling

In this project, the technique term Hierarchical Markov Modelling (HMM) will be used to determine the reliability indices. The HMM decompose the reliability problem into three levels according to system topology, integrated protection system behaviour and individual protection devices behaviour [13]. To illustrate HMM, the example distribution system in Figure 3.2 will be used.

![Figure 3.2: Example of simple distribution system.](image)

This system is characterized two normally closed switches (S1, S2), one normally open switch (S3), a breaker (B1), three fuses (F1, F2 and F3) and three customers.
This system is normally fed from a substation and can be back fed from a second substation if needed. HMM begins by creating primary model based on system topology. Primary model has a normal operating state (S0) and additional states corresponding to various switching actions. Parameter such as repair rates and switching rates will be required. In the primary model, states are determined exclusively by sectionalizing switch positions and not by the status of protection devices. The sectionalizing switches determine the system topology while the protection system determines how the system will respond to contingencies while in a certain topology.

Secondary Markov models will be created to model the protection system behavior of each primary model state. These model have a base state of all protective devices in a close position. The secondary model protection devices can either be open or closed, and are characterized by a failure rate and repair rate.

Tertiary Markov models accommodate the complex behavior of individual protection devices. This model has a base state for when the device is closed, and an additional states corresponding to specific causes of tripping for examples primary tripping, backup tripping, maintenance and false tripping. After the tertiary models have been solved, the behavior of each protection device is known. This protective device behavior is used by secondary models to determine the overall protective system behavior of each configuration. After the protective system is known, HMM is completed by finding the primary model state durations. After the primary model is solved, the total expected interruption frequency and duration for each customer can be found.
Figure 3.3 illustrate the three models in HMM. In Figure 3.3 (a), $\mu$ represent repair rates, and $\sigma$ represent switching rates, in (b) $\lambda$ represent failure rates and $\mu$ represent repair rates. To implement HMM, a software application is required and further study and research will be conduct to find suitable software for HMM.

### 3.1.4 Network Modelling

Network modelling is the use of series-parallel combinations to reduce the network. It determines the load point indices and aggregates them to get the system wide indices. A radial system basically consists of set of series components like; breakers, lines, switches, transformers and at the end a “Customers”. In the series structure
both components must be intact for the system to function, "a chain is no stronger
than its part" while in the parallel structure both must fail for the system to stop
functioning. In this case, all the components are connected in series as shown in
Figure 3.4 and the equations needed to evaluate the basic indices are as follows;

\[
\lambda_s = \lambda_1 + \lambda_2 = \sum_{i=1}^{2} \lambda_i
\] (3.1)

(b) Average outage time of the system:

\[
r_i = \frac{\lambda_1 r_1 + \lambda_2 r_2 + \lambda_1 \lambda_2 r_1 r_2}{\lambda_1 + \lambda_2} = \sum_{i=1}^{2} \frac{\lambda_i r_i}{\lambda_i} = \frac{U_s}{\lambda_s}
\] (3.2)

If \( \lambda_1 \lambda_2 r_1 r_2 \ll \lambda_1 r_1 \) or \( \lambda_2 r_1 r_2 \)

(c) Average Annual Outage time of the system:

\[
U_s = f_s \cdot r_i = \lambda_s \cdot r_s
\] (3.3)

Where \( \lambda_i \) the failure rate at node i, \( r_i \) is the outage time at node i. In parallel
system, the failure modes of the load point involve overlapping outages, i.e. two or
more components must be on outage at the same time in order to interrupt a load
point as shown in Figure 3.5. It is assumed that the failures are independent and that
restoration involves repair or replacement, the equations used to evaluate the indices
of the overlapping outage are as shown below.

Figure 3.5: Parallel Structure
(d) Average Failure rate of the system:

\[ \lambda_p = \frac{\lambda_1 \lambda_2 (r_1 + r_2)}{1 + \lambda_1 r_1 + \lambda_2 r_2} = \lambda_1 \lambda_2 (r_1 + r_2) \]  

(3.4)

Where \( \lambda_1 \) \( r_1 \) and \( \lambda_2 \) \( r_2 \) usually \( \ll 1 \)

(e) Average outage time of the system:

\[ r_p = \frac{r_1 r_2}{r_1 + r_2} \]  

(3.5)

(f) Average Annual Outage time of the system:

\[ U_p = \lambda_p r_p \]  

(3.6)

These are adequate for simple radial systems and more extended indices have to be used for general distribution systems (mixed radial and meshed systems). In this master project, the following alternatives which may improves reliability in the system shall be considered:

i) Assessment of the existing network
ii) Change in the network configuration
iii) Use of additional sectionalizing switches
iv) Automation and control facilities via control centre monitoring and supervision.

In this project, we will assume that the distribution system are design and construct as single radial and parallel systems:

i) Single radial system
   - 11kV feeder supply direct to customer
   - 33kV feeder for interconnection between substation

ii) Parallel System
   - 33kV transformer (incomer) connected to two bus bar system (reserve and main) to supply 11kV feeder connected to customer.

Three basic reliability parameters requires for analysis:

Average failure rate : \( \lambda_s = \sum_i \lambda_i \)  

(3.7)

Average annual outage time : \( U_s = \sum_i \lambda_i r_i \)  

(3.8)

Average outage time : \( r_i = \frac{U_s}{\lambda_i} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \)  

(3.9)
A radial system consists of a set of series components, including lines, cables, disconnects (or isolator), bus bar, breaker, earth switch and etc [15]. A customer or substation connected to any load point of such a system requires all components between himself and the supply point to be operating. A simple radial system is shown in Figure 3.6. The assumed failure rates and repair times of each line A, B and C are shown in Table 3.1 and the load point reliability indices are shown in Table 3.2. Data shown is the typical and general feature of radial system. The assumption made is perfect isolation of faults on line element A, B and C by the circuit breaker.

![Figure 3.6: Simple 3-load point radial system](image)

Table 3.1 Component data for system in Figure 3.6

<table>
<thead>
<tr>
<th>Line</th>
<th>λ (f/yr)</th>
<th>r (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.2</td>
<td>6.0</td>
</tr>
<tr>
<td>B</td>
<td>0.10</td>
<td>5.0</td>
</tr>
<tr>
<td>C</td>
<td>0.15</td>
<td>8.0</td>
</tr>
</tbody>
</table>

Table 3.2 Load Point reliability indices for the system of Figure 3.6

<table>
<thead>
<tr>
<th>Load Point</th>
<th>λ (f/yr)</th>
<th>r (hours)</th>
<th>U_L (hours/yr)</th>
<th>Number of customer</th>
<th>Average Load Demand (kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>0.2</td>
<td>6.0</td>
<td>1.2</td>
<td>200</td>
<td>1000kW</td>
</tr>
<tr>
<td>F2</td>
<td>0.10</td>
<td>5.0</td>
<td>1.7</td>
<td>150</td>
<td>700kW</td>
</tr>
<tr>
<td>F3</td>
<td>0.15</td>
<td>8.0</td>
<td>2.9</td>
<td>100</td>
<td>400kW</td>
</tr>
</tbody>
</table>

The customer and load oriented indices can now be evaluated as follows:
SAIFI = \frac{(0.2 \times 200) + (0.3 \times 150) + (0.45 \times 100)}{200 + 150 + 100} = 0.289\text{ interruption/year}
SAIDI = \frac{(1.2 \times 200) + (1.7 \times 150) + (2.9 \times 100)}{450} = 1.74\text{ hours/customer year}
CAIDI = \frac{SAIDI}{SAIFI} = 6.02\text{ hours/customer interruption}

The above illustration is the basic evaluation technique for basic radial system. For the purpose of this study, further operating philosophy will be apply such as additional of isolation (disconnects), additional protection and automation, transferrable load and others system configuration that might affect the reliability indices. It shall be observe that, when the additional features applied on the evaluation, there will be changes and improvement in the reliability indices.

3.2 Overview and Analysis of the Existing Distribution Network.

Appendix D1 shows the detail single line diagram of Tuaran 66/11kV and 66/33 kV system. For the purposed of the study, we will consider the distribution feeder for supply direct to customer or feeder that interconnect between substation such as Tuaran 11kV, Mengaris 132/33kV interconnect to Kota Marudu 33/11kV. Here we will also look at the future performance of the distribution system reliability when there are changes in the configuration, operation condition and or protection schemes, and expansion in the network. In this project, the predictive reliability analysis shall be carried out in 33kV and 11kV feeder and a number of alternatives shall be evaluated. Further evaluation and study on the existing network will be conducted to determined type of network configuration either radial, parallel or mesh.

3.3 Reliability Indices of the Existing Distribution Network

Data was obtained from Sabah Electricity Sdn Bhd (SESB), from System Operation division. In this project, it will concentrate on the reliability analysis of the case study area at Tuaran within Sector 2 where the total number of customer among the highest compared to other distribution area. The total number of customer serves 25,376 in 2011, 26,655 in 2012 and 26,941 in 2013. Detail data is shown in
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