YANGON TECHNOLOGICAL UNIVERSITY
DEPARTMENT OF ELECTRICAL POWER ENGINEERING

IMPACT OF VOLTAGE DIP ON SYSTEM RELIABILITY IN YANGON DISTRIBUTION NETWORK

BY

NYI NYI AUNG
EP-9 (MARCH, 2018)

(B.E. THESIS)

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We certify that we have examined, and recommend to the University Steering Committee for Undergraduate Studies for acceptance of the thesis entitled **"IMPACT OF VOLTAGE DIP ON SYSTEM RELIABILITY IN YANGON DISTRIBUTION NETWORK"** submitted by **Mg Nyi Nyi Aung, Roll No. EP-9 (MARCH, 2018)** in partial fulfilment of the requirements for the degree of Bachelor of Engineering.

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ABSTRACT

This thesis presents the impact of voltage dip on distribution system and evaluation of system reliability. There are two main parts of analysis in this thesis, and the first part concerns with the fault calculation, where it includes calculation of current and voltage during fault. When a fault occurs on lateral line or feeder sections, the protection devices can protect other areas by disconnecting the faulted part. However, some sensitive loads are disconnected or cannot run for a short period of time because of voltage dip caused by fault occurred in other areas, if the dip violates the customer satisfactory voltage level. It is important to consider the impact of voltage dip for sensitive loads and system reliability's point of view. In this thesis, the voltage dip levels of each load point during faults is evaluated and analyze its impact of system. Bahan township's distribution network is used as the test system in this paper.

Generally, impact of voltage dip is not considered when reliability calculation is conducted. In the second part, evaluation of system reliability is taken into account and, Therefore, in this thesis, based on first part analysis and the data obtained, new reliability indices will be calculated. Then, the current condition of system reliability and the reliability with consideration of impact of voltage dip are compared with tables, charts and graphs.

In conclusion, this thesis is trying to point out the impact of voltage dip on system and how it worsens the reliability. Therefore, by considering the voltage dip impact, the system operator can forecast system conditions more appropriately.

TABLE OF CONTENTS

LIST OF FIGURES

Figure **Page**

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Motivation

Current research topics are relating to distribution system and finding the factors to improve reliability. Voltage dip and its impact on system are what usually neglected in trying to improve system reliability. So this thesis is going to analyze the impact of voltage dip on system reliability and a substation in Yangon is selected as test system. In this thesis, there are generally two parts; the first one is fault calculation and evaluation of voltage dip on system and the next one is reliability calculation. As for the first part, these days system is assumed that voltage dip due to fault is not violated the voltage envelope of the customer and its impact is ignored to take account in calculation. But in practice, there are lots of impacts of voltage dip on the customers, and some customers cannot tolerant the dip level and cut off from the supply. Then, when impact of voltage dip is considered, how the system reliability changed will be analyzed as second part of this thesis.

A key function of a power system is to supply customers with electrical energy as economically and reliably as possible. An electrical service interruption can have a profound economic impact on certain customers. Not only sustained interruption results in lost production, but momentary interruptions may also cause damages to the consumers.

In general, customers will be reluctant to increase their service reliability locally, exerting in higher pressure for utilities to improve. Apart from replacing high failure rate components, e.g. replacing a bare conductor by an insulated conductor, it is widely known that the utility can improve its reliability by improving its protection system. Better coordination or putting more appropriate protective devices into the system, e.g. recloser, fuse and disconnecting switch, can help improve its reliability.

The coordination of protective devices aims to maintain the selectivity among the devices involved in several fault possibilities, in order to assure safe operation and reliability of the system. In an efficient and coordinated protection system, faults are eliminated in the smallest possible time, isolating the smallest part of the system containing the cause of the fault. Whenever a fault occurs, the voltage level of each load point will be decreased and it is generally known as voltage dip or voltage sag. The voltage dips have to be compared with customer voltage envelope curve and if the customer cannot tolerant the dip or the dip violates the envelope, it will be cut off from the supply permanently. Actually, the customer means some loads that are used in residence or industrial zones, and that loads are sensitive and when the voltage level is under their standard point, that loads are cut off from the supply and they are generally known as sensitive loads. In addition, in our country, Myanmar, safe guards are usually used to protect the electrical equipment from decreasing voltage level or burning the devices, so after the devices are disconnected, the safe guard maintains the equipment for five minutes to reconnect to the supply. Then, the system reliability needs to take account that duration in calculation and how the reliability changed can be seen.

In this thesis, even though protective devices are installed, how the voltage dip impacts on system when a fault occurs will be evaluated and this event will be considered in reliability calculation.

1.2 Objective of Thesis

The specific objectives of this thesis are devoted

1. To choose fault locations and calculate the fault currents and voltages
2. To evaluate voltage dip and its impacts on system reliability
3. To calculate system reliability with consideration of voltage dip

1.3 Scope of Thesis

The scope of this research is limited to

1. Choosing fault conditions (single line to ground fault) with two different fault locations and neglect fault duration
2. Analyzing voltage dip and its impact on system even though protection devices (only fuse is taken into account) are installed on distribution system
3. Focusing on reliability indices (SAIFI, SAIDI, ENS) of distribution system
4. Calculating system reliability indices with consideration of voltage dip and consider one load point to check how these indices changed

1.4 Outlines of Thesis

These outlines will be included in this thesis;

- Chapter 1 generally introduces about scope, aims and objectives of this thesis.
- Chapter 2 is about what voltage dip does mean and what its impact on system is.
- Chapter 3 contribute methods and ideas how to calculate voltage and current during fault and how to figure out voltage dip impact.
- Chapter 4 uses test system and results to point out the calculation and evaluation.
- Chapter 5 finally concludes and discusses about voltage dip and recommend the idea to overcome its impact.

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In this chapter, a detailed and thorough review of the literature in the area of effects of voltage sags on power system operation is presented. Although there are many sections in the view of project, this literature is going to discuss general overview of voltage dips on power system (means sensitive loads).

2.2 General Review on Voltage Dips

Voltage sags are a common power quality problem. Despite being a short duration (10ms to 1s) event during which a reduction in the RMS voltage magnitude takes place, a small reduction in the system voltage can cause serious consequences.

2.2.1 Voltage Dips

The definition of voltage sags is often set based on two parameters: magnitude/depth and duration. However, these parameters are interpreted differently by various sources. Other important parameters that describe a voltage sag are the point-on-wave where the voltage sag occurs, and how the phase angle changes during the voltage sag. A phase angle jump during a fault is due to the change of the X/R-ratio. The phase angle jump is a problem especially for power electronics using phase or zero-crossing switching.

A sag or sag is “a decrease in RMS voltage or current at the power frequency for durations from 0.5 cycles to 1 minute, reported as the remaining voltage”. Typical values are between 0.1 p.u. and 0.9 p.u. Typical fault clearing times range from three to thirty cycles depending on the fault current magnitude and the type of overcurrent detection and interruption.

Terminology used to describe the magnitude of a voltage sag is often confusing. Throughout the course of the project work, a usage of sag ‘of’ a certain value has been used and has been represented as ΔV. Thus, a sag of 20 % means a voltage drop, ΔV, of 20 % from its initial voltage level.

2.2.2 Characterization of Voltage Dip

The voltage during a voltage sag is assumed to be a constant RMS value, usually the lowest phase voltage. However, in reality, the RMS value varies during a sag. Hence, various methods have been proposed to characterize voltage sags.

The most common approach to define a voltage level during a sag is to consider the lowest phase voltage and ignore the rest. However, this method reports only one sag per fault and does not distinguish between single-phase and multi-phase voltage sags.

Another method is to consider the voltage in each phase. A voltage sag in each phase will be counted as a separate event. With this method. a three-phase-voltage sag will be counted as three voltage sags. The third representation is to use the average voltage of all phases. This method only reports one voltage sag per fault, and usually none of the phases has the same voltage as the average.

2.3 Causes and Effects of Voltage Dips on Power Systems

There are various causes of voltage sags in a power system. They are as follows:

1. Voltage dips due to faults
2. Voltage dips due to induction motor starting
3. Voltage dips due to transformer energizing
4. Multistage voltage sags due to faults

Among these causes, this paper is going to focus and discuss on voltage dip due to faults.

2.3.1 Voltage Dips due to Faults

Voltage sags due to faults can be critical to the operation of a power plant, and hence, are of major concern. Depending on the nature of the fault (e.g., symmetrical or unsymmetrical), the magnitudes of voltage sags can be equal in each phase or unequal respectively. For a fault in the transmission system, customers do not experience interruption, since transmission systems are looped/networked.

Factors affecting the sag magnitude due to faults at a certain point in the system are:

- Distance to the fault

- Fault impedance
- Type of fault
- Pre-sag voltage level
- System configuration
  - System impedance
  - Transformer connections

The type of protective device used determines sag duration.

2.3.2 Effect of Voltage Dips on Sensitive Loads

Voltage sags in power systems produce an important effect on the behavior of sensitive loads. Tripping of power adjustable speed drives (ASD) is one of the greatest voltage sag problems, causing critical loads to stop with the resultant interruption of the manufacturing process several times a year. The resulting loss of time and production, or damaged equipment may cause significant economic losses. Voltage sags are due to short duration increases of current originated in remote locations of the power system. These increases in the current are mainly caused by faults, overloads, starting of large motors and transformer energizing. Voltage sags in the terminals of a load affect the equipment's normal operation. The equipment may fail due to several causes, such as insufficient voltage for regulators, under voltage circuit trips, unbalanced relay trips, reset circuits may incorrectly trip at the end of the voltage sag etc.

For examples; these days air conditioning compressor, refrigerators, digital computers, microwave ovens, programmable logic controllers and others are considered as sensitive loads. When the sag depth has typically varied from 0 – 60% and sag duration varied from 0 – 120 cycles, safe guard make these devices disconnected from the supply and it needs to wait at least for 5 minutes, what's more, it increases SAIFI and SAIDI and decline the reliability curve.

2.4 General Review on System Reliability

The basic aim of every electric power utility is to meet its energy and load demand at the acceptable levels of quality and continuity of supply. The ability of an electric power network to provide an adequate supply of electrical energy is usually designated by the term 'power system reliability'. Power system reliability assessment, both deterministic and probabilistic, can be divided into the two basic aspects of system adequacy and system security. System adequacy relates to the availability of sufficient generation, transmission and distribution facilities within the system to provide the required electrical energy to the customer load points. Adequacy therefore relates to static system conditions. System security, on the other hand, is associated with the ability of the system to respond to disturbances arising within the system and is therefore linked with system dynamics. It is important to recognize that most of the probabilistic techniques presently available for power system reliability evaluation are in the domain of adequacy assessment. Most of the indices are adequacy indices.

There are two main categories of reliability evaluation techniques: analytical and simulation. Analytical techniques represent the system by a mathematical model and evaluate the reliability indices from this model using mathematical solution. Monte Carlo simulation methods, however, estimate the reliability indices by simulation the actual process and random behavior of the system. Generally, Monte Carlo simulation requires a large amount of time and is not used extensively if alternative analytical methods are available. In this thesis, analytical technique is used to find the reliability indices.

2.4.1 Functional Zones and Hierarchical Levels

An electrical power can be broadly divided into the three segments of generation, transmission, and distribution. These segments are commonly referred to as functional zones. While this division of the power system may seem somewhat simplistic, it is very appropriate, as most electric power utilities are either divided into such zones for the purposes of organization, planning, and operation which are responsible for individually in each of these zones. The functional zones of an electric power system can be combined to form hierarchical levels. This categorization is depicted in levels(HL). Adequacy assessment techniques can also be grouped under this hierarchical generation to meet the system load requirement and this area of activity is usually termed as generation capacity reliability evaluation. Both generation and the associated transmission facilities are considered at HLII adequacy assessment and is sometimes referred to as composite system or bulk system adequacy. HLIII adequacy assessment involves the consideration of all the three functional zones in an attempt to evaluate customer load point adequacies. Figure 2.1 shows hierarchical levels in power system.

2.4.2 Typical Customer Unavailability Statistics

Over the past few decades, distribution systems have not received much attention on reliability modeling and evaluation as generating systems. The main reason is that generation systems are individually very capital intensive. A distribution system is relatively cheap and outages have very localized effect. Therefore, less effort has been

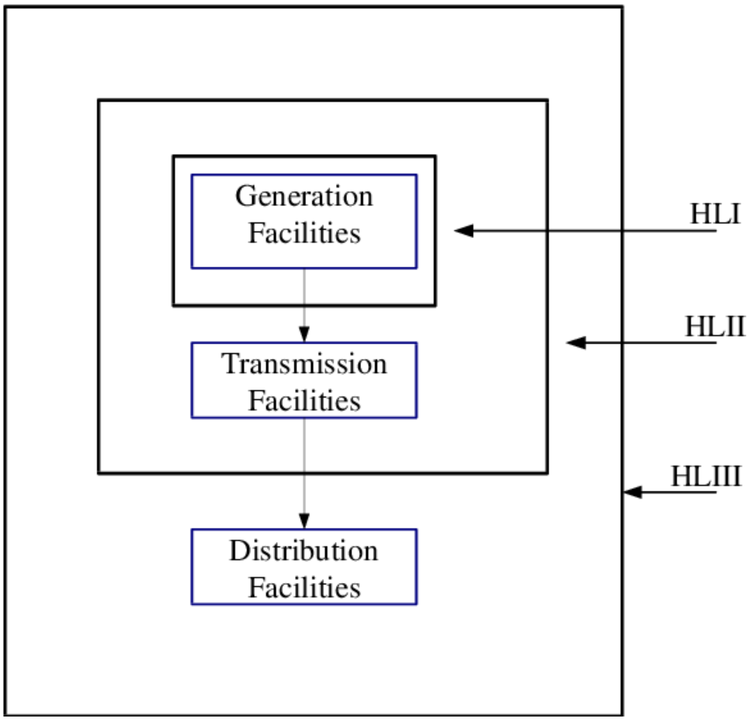

Figure 2.1: Hierarchical Levels in Electrical Power System

devoted to quantitative assessment of the adequacy of various alternative designs and reinforcements. On the other hand, analysis of customer failure statistics of most utilities shows that the distribution system makes the greatest individual contribution to the unavailability of supply to a customer. Therefore, it is clear that we have to pay attention to distribution system reliability.

Reliability evaluation is an essential aspect of distribution system planning. Distribution system reliability assessment can be divided into the two basic segments of measuring past system performance and prediction future performance. Most electric power utilities collect data on past system performances and evaluate appropriate indices. Predictive reliability evaluation is an attempt to estimate future performance at the actual customer load points. These predictions can also be aggregated to provide system performance indices. Two sets of reliability indices which are important for individual customer load points and for the overall distribution system reliability.

2.5 Basic Distribution Systems

Electric power distribution is the portion of the power delivery infrastructure that takes the electricity from the highly meshed, high-voltage transmission circuits and delivers it to customers. Primary distribution lines are "medium-voltage" circuits, normally thought of as 600 V to 35 kV. At a distribution substation, a substation transformer takes the incoming transmission- level voltage (35 to 230 kV) and steps it down to several distribution primary circuits, which fan out from the substation. Close to each end user, a distribution transformer takes the primary-distribution voltage and steps it down to a low-voltage secondary circuit.

Sub-transmission circuit, distribution substations, primary feeders, distributed transformers, secondary circuits and load points are parts of an electric distribution system. Therefore, reliability evaluation in a distribution system deals with how adequately these combined elements perform their intended function. The distribution system is an important part of the total electric system as it provides the final link between the bulk system and customer. In many cases, these links are radial in nature and therefore susceptible to outage due to a single event. Outages in distribution systems tend to have localized effects and there is the perception that these outages do not contribute significantly to overall customer supply inadequacy.

CHAPTER 3
RESEARCH METHODOLOGY

3.1 Fault Calculation

3.1.1 Introduction

Faults are usually caused by dielectric breakdown of insulation systems and can be categorized as self-clearing, temporary and permanent. A self-clearing fault will extinguish itself without any external intervention (e.g., a fault occurring on a secondary network that persists until it burns clear). A temporary fault is a short circuit that will clear if deenergized and then re-energized (e.g., an insulator flashover due to a lightning strike — after the circuit is de-energized, the fault path will de-ionize, restoring the insulator to full dielectric strength). A permanent fault is a short circuit that will persist until repaired by human intervention.

When a fault occurs on the line, the voltage level of all load points is affected by decreasing voltage level. In this thesis, the voltage of each load points during fault is calculated. By using some protective devices, the voltage level will be back to satisfactory after those devices have disconnected the faulted points or lines. But sometimes, even though protective devices are used in the system, the customer may still cut off from the system if the dip violates the customer satisfactory voltage level.

3.1.2 Characteristics of Power System Fault

A fault on a power system is an abnormal condition that involves an electrical failure of power system equipment operating at one of the primary voltage within the system. Generally, two types of failure can occur. The first is an insulating failure that results in a short circuit fault and can occur as a result of overstressing and degradation of the insulation over time or due to a sudden overvoltage condition. The second is a failure that results in a cessation of current flow or an open-circuit fault.

3.1.3 Types of Fault

Short-circuit faults can occur between phase, or between phases and earth, or both. Short circuits may be one-phase to earth, phase to phase, tow-phase to earth, three-phase clear of earth and three-phase to earth. The three-phase fault that symmetrically affects the three phases of a three-phase circuit is the only balanced fault whereas all the other faults are unbalanced. Simultaneous faults are a combination of two or more faults that occur at the same time. They may be of the same of different types and may occur at the same or at different locations. A broken overhead line conductor that falls to earth is a simultaneous one-phase open-circuit and one-phase short-circuit fault at one location.

A short-circuit fault occurring at the same time on each circuit of a double-circuit overhead line, where the two circuits are strung on the same tower, is a simultaneous fault condition. A one-phase to earth short-circuit fault in a high impedance earthed distribution system may cause a sufficient voltage rise on a healthy phase elsewhere in the system that a flashover and short-circuit fault occurs. This is known as a cross-country fault. Most faults do not change in type during the fault period but some faults do change and evolve from say a one-phase to earth short circuit to engulf a second phase where it changes to a two-phase to earth short circuit fault. This can occur on overhead lines or in substations where the flashover arc of the faulted phase spreads to other healthy phases. Internal short circuits to earth and open-circuit faults can also occur on windings of transformers, reactors and machines as well as faults between a number of winding turns of the same phase. In this paper, among short-circuit faults, single line-to-ground fault is focused to calculate and evaluate the voltage dip impacts.

3.1.4 Causes of Fault

Open-circuit faults may be caused by the failure of joints on cables or overhead lines or the failure of all the three phases of a circuit-breaker or disconnect or to open or close. For example, two phases of a circuit-breaker may close and latch but not the third phase or two phases may properly open but the third remains stuck in the closed position. Except on mainly underground systems, the vast majority of short-circuit faults are weather related followed by equipment failure. The weather factors that usually cause short-circuit faults are: lightning strikes, accumulation of snow or ice, heavy rain, strong winds or gales, salt pollution depositing on insulators on overhead lines and in substations, floods and fires adjacent to electrical equipment, e.g. beneath overhead lines. Vandalism may also be a cause of short-circuit faults as well as contact with or breach of minimum clearances between overhead lines and trees due to current overload.

Equipment failure, e.g. machines, transformers, reactors, cables, etc., cause many short-circuit faults. These may be caused by failure of internal insulation due to ageing and degradation, breakdown due to high switching or lightning over voltages, by mechanical incidents or by inappropriate installation. An example is a breakdown of a cable's polymer insulation due to ageing or to the creation of voids within the insulation caused by an external mechanical force being accidentally applied on the cable. Short-circuit faults may also be caused by human error. A classic example is one where maintenance staffs inadvertently leave isolated equipment connected through safety earth clamps when maintenance work is completed. A three-phase to earth short-circuit fault occurs when the equipment is reenergized to return it to service.

3.1.5 Fault Calculation

The fault currents and voltages are calculated for any types of faults using bus impedance matrix, Z_{bus} which is based on the principle of superposition. The detail calculation and the equation can be seen in. In this theses, unbalanced fault (single line-to-ground fault) will be considered. This type of fault is defined as the simultaneous short circuit across all three phase. It occurs infrequently, but it is the most serve type of fault encountered. Because the network is balanced, it is solved on a per-phase basis. The other two phases carry identical current except for the phase shift.

A fault represents a structural network change equivalent with that caused by the addition of an impedance at the place of fault. If the fault impedance is zero, the fault is referred as the bolted fault or the solid fault.

3.1.6 Unsymmetrical Fault Analysis Using Bus Impedance Matrix

The network reduction also can use for fault calculation. But it is not efficient and is not applicable to large networks. By utilizing the elements of the bus impedance matrix, the fault current as well as the bus voltages during fault are readily and easily calculated.

Consider a typical bus of an n-bus power system network as shown in figure 4.1. The system is assumed to be operating under balanced condition and a per phase circuit model is used. Each machine is represented by a constant voltage source behind proper reactance which may be X_d'', X_d' or X_d. Transmission lines are represented by their equivalent pi model and all impedances are expressed in per unit on a common MVA base. A balanced three-phase fault is to be applied at bus k through a fault impedance. The prefault bus voltages, are obtained from the power flow solution and are represented by the column vector.

$$V_{bus} = \begin{bmatrix} V_1(0) \\ - \\ - \\ V_k(0) \\ - \\ - \\ V_n(0) \end{bmatrix} \tag{3.1}$$

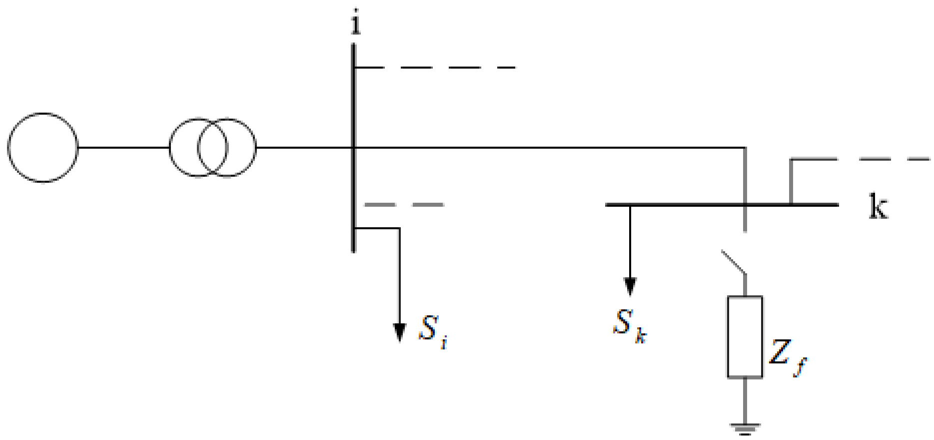

Figure 3.1: A Typical Bus of a Power System

The changes in the network voltage caused by the fault with impedance, which is equivalent to those caused by the added voltage with all other sources short circuit. Zeroing all voltage sources and representing all components and loads by their appropriate impedances, we obtain in Thevenin's circuit shown in figure 3.2. the bus voltage change caused by the fault in this circuit are represented by equation 3.2.

$$\Delta V_{bus} = \begin{bmatrix} \Delta V_1(0) \\ - \\ - \\ \Delta V_k(0) \\ - \\ - \\ \Delta V_n(0) \end{bmatrix} \tag{3.2}$$

From the Thevenin's theorem, bus voltage during fault are obtained by superposition of the prefault bus voltages and the changes in the bus voltages given by equation 3.3. The injected bus currents, I_{bus} are expressed in terms of the bus voltages with bus 0 as reference. Where Y_{bus} is the bus admittance matrix. The diagonal element of each bus is the sum of admittances connected to it.

$$V_{bus}(F) = V_{bus}(0) + \Delta V_{bus}$$

$$I_{bus} = Y_{bus} V_{bus} \tag{3.3}$$

In the Thevenin's circuit of figure 3.2, current entering every bus is zero except at the faulted bus. Since the current at faulted bus is leaving the bus, it is taken as a negative current entering bus k. Thus, the node equation applied to this circuit becomes as shown in equation (4.5).

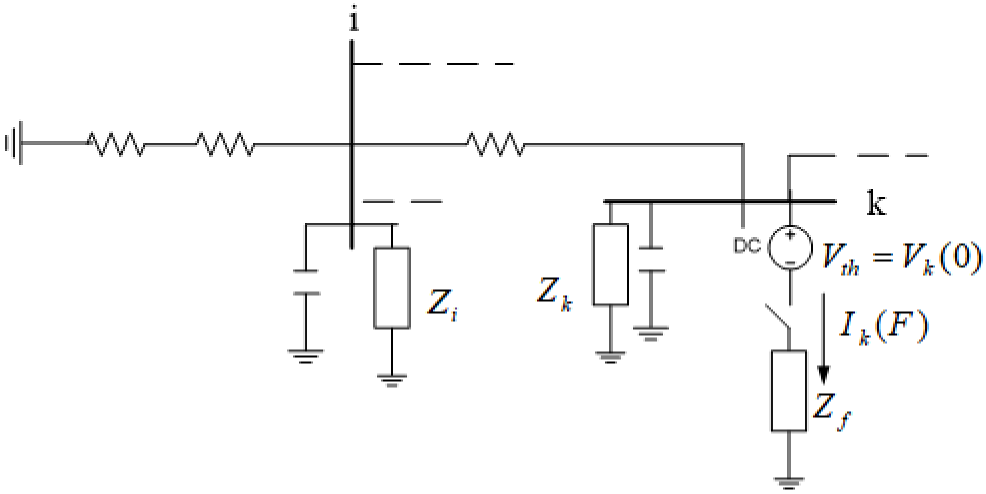

Figure 3.2: Thevenin's Circuit of Figure 3.1

$$\begin{bmatrix} 0 \\ . \\ . \\ . \\ -I_k(F) \\ . \\ . \\ . \\ 0 \end{bmatrix} = \begin{bmatrix} Y_{11} & . & . & . & Y_{1k} & . & . & . & Y_{1n} \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ Y_{k1} & . & . & . & Y_{kk} & . & . & . & Y_{kn} \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ Y_{n1} & . & . & . & Y_{nk} & . & . & . & Y_{nn} \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ . \\ . \\ . \\ \Delta V_k \\ . \\ . \\ . \\ \Delta V_n \end{bmatrix} \tag{3.4}$$

Or

$$I_{bus}(F) = Y_{bus}\Delta V_{bus} \tag{3.5}$$

The changes in the bus voltage is

$$\Delta V_{bus} = Z_{bus} I_{bus}(F) \tag{3.6}$$

Where Z_{bus} is inversed of Y_{bus}. Substituting equation 3.6 to equation 3.3, the bus voltage vector during fault becomes equation 3.7 and equation in terms of its element is in equation 3.8.

$$V_{bus}(F) = V_{bus}(0) + Z_{bus} I_{bus}(F) \tag{3.7}$$

$$\begin{bmatrix} V_1(F) \\ . \\ . \\ . \\ V_k(F) \\ . \\ . \\ . \\ V_n(F) \end{bmatrix} = \begin{bmatrix} V_1(0) \\ . \\ . \\ . \\ V_k(0) \\ . \\ . \\ . \\ V_n(0) \end{bmatrix} \begin{bmatrix} Z_{11} & . & . & . & Z_{1k} & . & . & . & Z_{1n} \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ Z_{k1} & . & . & . & Z_{kk} & . & . & . & Z_{kn} \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ Z_{n1} & . & . & . & Z_{nk} & . & . & . & Z_{nn} \end{bmatrix} \begin{bmatrix} 0 \\ . \\ . \\ . \\ -I_k(F) \\ . \\ . \\ . \\ 0 \end{bmatrix} \tag{3.8}$$

Since there is only single nonzero element in the current vector, the kth equation of equation 3.8 becomes to equation 3.9.

$$V_k(F) = V_k(0) - Z_{kk} I_k(F) \tag{3.9}$$

Also from the Thevenin's circuit shown in figure 3.2, the following equation is obtained,

$$V_k(F) = Z_f I_k(F) \tag{3.10}$$

For bolted fault, Z_f =0 and $V_k(F)$=0. Substituting these values into equation 3.9, the fault current becomes

$$I_k(F) = \frac{V_k(0)}{Z_{kk} + Z_f} \tag{3.11}$$

$I_k$is fault current at fault bus k. Z_{kk} is element of the bus impedance matrix. This element is needed the Thevenin's impedance as viewed from the faulted bus.

$$V_i(F) = V_i(0) - \frac{Z_{ik}}{Z_{kk} + Z_f} V_k(0) \tag{3.12}$$

Where $V_i(F)$ is bus voltage at bus i during fault, $V_i(0)$ is pre-fault bus voltage, $V_k(0)$ is bus voltage at fault bus k and Z is impedance from Z_{bus}. With the knowledge of bus voltage during the fault, the fault current in all the lines can also be calculated.

3.1.7 Symmetrical Components and Unbalanced Fault

3.1.8 Fundamentals of Symmetrical Components

Symmetrical components allow unbalanced phase quantities such as currents and voltages to be replaced by three separate balanced symmetrical components.

In three-phase system the phase sequence is defined as the order in which they pass through a positive maximum. Consider the phasor representation of a three-phase balanced current shown in figures.

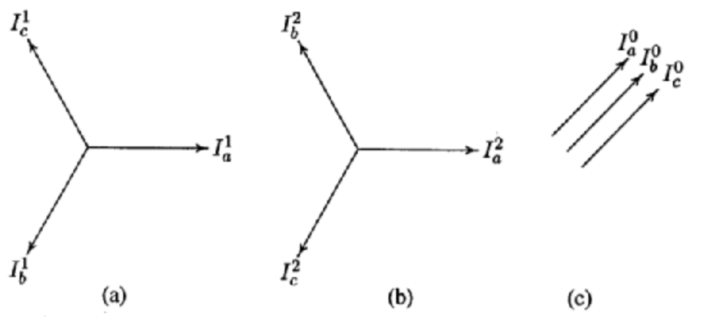

Figure 3.3: Representation of Symmetrical Components

By convention, the direction of rotation of the phasors is taken to be counterclockwise. The three phasors are written as

$$
\begin{aligned}
I_a^1 &= I_a^1 \angle 0^\circ = I_a^1 \\
I_b^1 &= I_a^1 \angle 240^\circ = a^2 I_a^1 \\
I_c^1 &= I_a^1 \angle 120^\circ = a I_a^1
\end{aligned} \tag{3.13}
$$

Where, a defined operator a causes a counterclockwise rotation of 120^o, such that

$$
\begin{aligned}
a &= 1\angle 120^\circ = -0.5 + j0.866 \\
a^2 &= 1\angle 240^\circ = -0.5 - j0.866 \\
a^3 &= 1\angle 360^\circ = 1 + j0
\end{aligned} \tag{3.14}
$$

From above, it is clear that;

$$1 + a + a^2 = 0$$

The order of the phasor is *abc*. This is designated the positive phase sequence. When the order is *acb* as in figure (3.1). it is designated the negative phase sequence, the *negative phase sequence* quantities are represented as

$$
\begin{aligned}
I_a^2 &= I_a^2 \angle 0^\circ = I_a^2 \\
I_b^2 &= I_a^2 \angle 120^\circ = a I_a^2 \\
I_c^2 &= I_a^2 \angle 240^\circ = a^2 I_a^2
\end{aligned} \tag{3.15}
$$

When analyzing certain types of unbalanced faults, it will be found that a third set of balanced phasors must be introduced. These phasors, known as the *zero phase sequence*, are found to be in phase with each other. Zero phase sequence currents, as in figure c would be designated.

$$I_a^0 = I_b^0 = I_c^0 \tag{3.16}$$

The superscripts 1,2 and 0 are being used to represent positive, negative and zero-sequence quantities, respectively.

1. Positive-sequence components consisting of a set of balanced three-phase components with a phase sequence *abc*.
2. Negative-sequence components consisting of a set of balanced three-phase components with a phase sequence *acb*.
3. Zero-sequence components consisting of three single-phase components, all equal in magnitude but with the same phase angles.

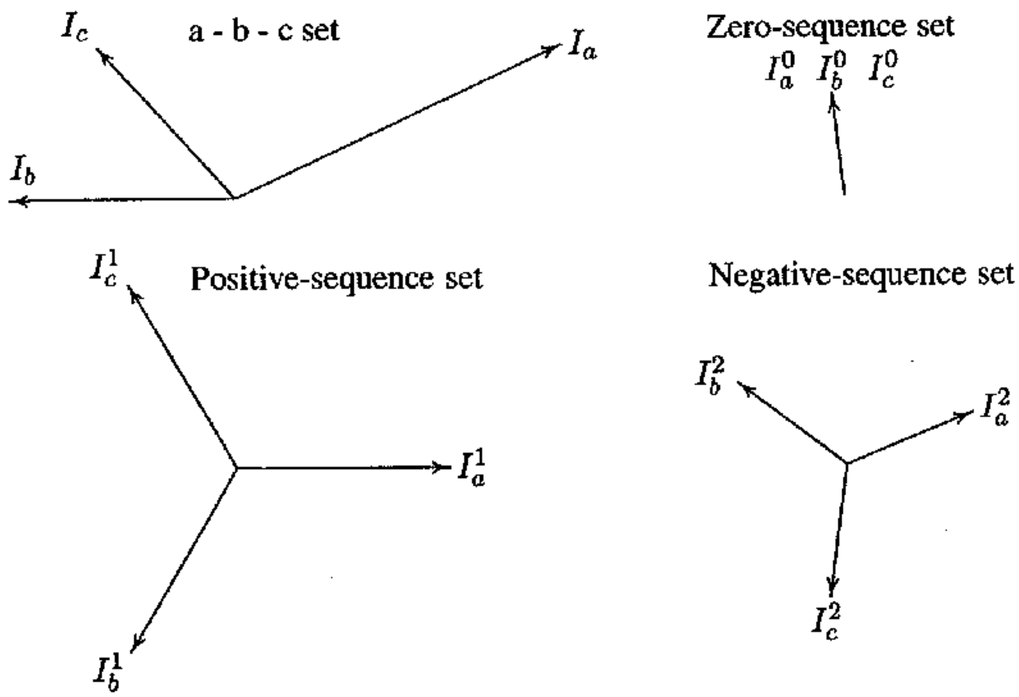

Figure 3.4: Resolution of Unbalanced Phasors in Symmetrical Components

The three symmetrical components of the current of the above figure are as followed;

$$I_a = I_a^0 + I_a^1 + I_a^2$$
$$I_b = I_b^0 + I_b^1 + I_b^2$$
$$I_c = I_c^0 + I_c^1 + I_c^2 \tag{3.17}$$

According to the definition of the symmetrical components as given by eq 1, 3, and 4, eq 5 is rewritten all in terms of phase *a* components.

$$I_a = I_a^0 + I_a^1 + I_a^2$$
$$I_b = I_a^0 + a^2 I_a^1 + a I_a^2$$
$$I_c = I_a^0 + a I_a^1 + a^2 I_a^2 \tag{3.18}$$

The above equations in matrix form is;

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \begin{bmatrix} I_a^0 \\ I_a^1 \\ I_a^2 \end{bmatrix} \tag{3.19}$$

Rewrite that equation 3.19 in matrix equation,

$$I^{abc} = A I_a^{012} \tag{3.20}$$

where A is known as *symmetrical components transformation matrix* (SCTM) which transforms phasor currents I^{abc} into component currents I_a^{012}, and is

$$A = \begin{bmatrix} 1 & 1 & 1 \\ 1 & a^2 & a \\ 1 & a & a^2 \end{bmatrix} \tag{3.21}$$

Solving equation 3.20 for the symmetrical components of currents,

$$I_a^{012} = A^{-1} I^{abc} \tag{3.22}$$

The A inverse is given by,

$$A^{-1} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \tag{3.23}$$

From equation 3.21 and 3.23,

$$A^{-1} = \frac{1}{3} A^*$$

Substituting for A^{-1} in eq 3.22,

$$\begin{bmatrix} I_a^0 \\ I_a^1 \\ I_a^2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & a & a^2 \\ 1 & a^2 & a \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{3.24}$$

or in component form, the symmetrical components are,

$$\begin{aligned} I_a^0 &= \frac{1}{3}(I_a + I_b + I_c) \\ I_a^1 &= \frac{1}{3}(I_a + aI_b + a^2 I_c) \\ I_a^2 &= \frac{1}{3}(I_a + a^2 I_b + aI_c) \end{aligned} \tag{3.25}$$

Noted that zero-sequence component of current is equal to one-third of the sum of the phase currents. Therefore, when the phase currents sum to zero, e.g., in a three-phase system with ungrounded neutral, the zero-sequence current cannot exist. If the neutral of the power system is grounded, zero-sequence current flows between the neutral and the ground.

Similar expressions exist for voltages Thus the unbalanced phase voltages in terms of the symmetrical components voltages are

$$\begin{aligned} V_a &= V_a^0 + V_a^1 + V_a^2 \\ V_b &= V_a^0 + a^2 V_a^1 + aV_a^2 \\ V_c &= V_a^0 + aV_a^1 + a^2 V_a^2 \end{aligned} \tag{3.26}$$

or in matrix notation,

$$V^{abc} = AV_a^{012} \tag{3.27}$$

The symmetrical components in terms of the unbalanced voltages are

$$\begin{aligned} V_a^0 &= \frac{1}{3}(V_a + V_b + V_c) \\ V_a^1 &= \frac{1}{3}(V_a + aV_b + a^2 V_c) \\ V_a^2 &= \frac{1}{3}(V_a + a^2 V_b + aV_c) \end{aligned} \tag{3.28}$$

or in matrix notation,

$$V_a^{012} = A^{-1} V^{abc} \tag{3.29}$$

Finally, by using these equations and methods, fault currents and voltages can be calculated whenever an unsymmetrical fault (single line-to-ground fault) occurs.

3.2 Voltage Dip Analysis

Voltage sags or voltage dips cause some of the most common and hard-to-solve power quality problems. Sags can be caused by faults some distance from a customer's location. The same voltage sag affects different customers and different equipment differently. Solutions include improving the ride-through capability of equipment, adding additional protective equipment (such as an uninterruptible power supply), or making improvements or changes in the power system.

Voltage sags are temporary RMS reductions in voltage typically lasting from a half cycle to several seconds. They are a major power quality concern since they can cause sensitive electronic equipment to fail and motor contacts to drop out. "IEC documents use the term dip rather than sag". Sags result from high currents, typically due to faults or starting motors, interacting with system impedances. The magnitude of a sag is described by either (1) the resulting per unit voltage, or (2) the per unit voltage decrease below nominal. An event that results in a voltage of 0.7 pu can be described as either a "sag to 0.7 pu" or a "sag of 0.3 pu". An example of voltage dip characteristic is shown in figure.

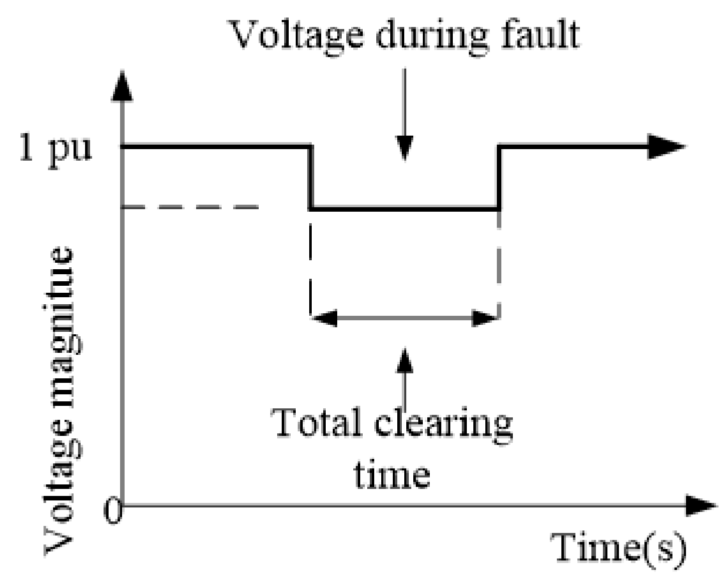

Figure 3.5: Example of Voltage Dip Curve

Voltage sags caused by severe weather conditions, car pole accidents, utility equipment operations or failures, and adjacent customers are beyond your control. However, voltage sags caused internally in facility can be resolved using different mitigation techniques before implementing the following standards. To help improve the robustness or voltage sag ride-through capabilities in the procurement of new equipment and improvements in equipment system design, the industry association for the semiconductor industry known as Semiconductor Equipment and Materials International (SEMI). Figure 3.5 shows the voltage envelope curve and the dips of each load points have to be compared with this curve. If the dips violate the envelope, the customer will be cut off from the system.

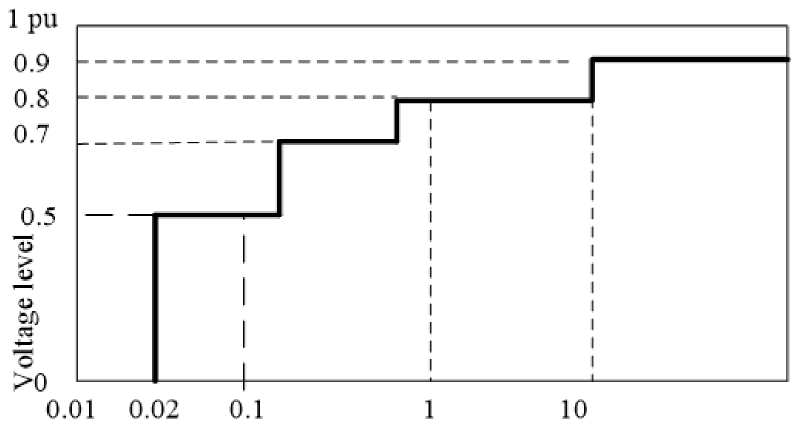

Figure 3.6: Voltage Envelope Curve of SEMI F47

Duration of dips is mainly determined by the fault clearing time. Generally sparking faults in transmission systems are cleared faster than the faults in the distribution system, which effects the duration of faults depending on its location in the system. Voltage dip is much more of a “global” problem than interruption. Reducing the number of interruption typically requires improvement on one feeder, but reducing number of voltage sags requires improvement on several feeders, and often even at transmission lines far away. Most of the current interest in voltage sag is directed to voltage sag due to short circuit faults. These voltage sags are the ones which causes the majority of equipment trip.

3.3 Reliability Evaluation

3.3.1 Evaluation Techniques

A radial distribution system consists of a set of series components, including lines,sections, transformers, fuses, bus-bars, etc. A customer connected to any load point of such a system requires all components between himself and the supply point to be operating.

Generally, there are three basic reliability parameters of average failure rate, λ_s, average outage time, r_s, and average annual outage time, U_s, are given by

$$\lambda_s = \sum_i \lambda_i \tag{3.30}$$

$$U_s = \sum_i \lambda_i r_i \tag{3.31}$$

$$r_s = \frac{U_s}{\lambda_s} = \frac{\sum_i \lambda_i r_i}{\sum_i \lambda_i} \tag{3.32}$$

These indices are basic reliability parameters and based on them, customer-orientated indices and load- and energy-orientated indices can be calculated.

3.3.2 Additional Interruption Indices

The reliability indices that have been evaluated using classical concepts are the three primary ones of average failure rate, average outage duration and average annual unavailability or average annual outage time. It should be noted, however, that they are not deterministic values but are the expected or average values of an underlying probability distribution and hence only represent the long-run average values. Similarly the word 'average' or 'expected' will be generally omitted from all other indices to be described, but again it should be noted that this adjective is always implicit in the use of these terms.

Although the three primary indices are fundamentally important, they do not always give a complete representation of the system behavior and response. For instance, the same indices would be evaluated irrespective of whether one customer or 1 00 customers were connected to the load point or whether the average load at a load point was 10 kW or 100 MW. In order to reflect the severity or significance of a system outage, additional reliability indices can be and frequently are evaluated. The additional indices that are most commonly used are defined in the following section.

3.3.3 Customer-Orientated Indices

1. System average interruption frequency index, SAIFI

$$SAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers served}} = \frac{\sum \lambda_i N_i}{IN_i} \tag{3.33}$$

   where λ_i, is the failure rate and N_i, is the number of customers of load point i.

2. Customer average interruption frequency index, CAIFI

$$CAIFI = \frac{\text{total number of customer interruptions}}{\text{total number of customers affected}} \quad (3.34)$$

This index differs from SAIFI only in the value of the denominator. It is particularly useful when a given calendar year is compared with other calendar years since, in any given calendar year, not all customers will be affected and many will experience complete continuity of supply. The value of CAIFI therefore is very useful in recognizing chronological trends in the reliability of a particular distribution system. In the application of this index, the customers affected should be counted only once, regardless of the number of interruptions they may have experienced in the year.

3. System average interruption duration index, SAIDI

$$SAIDI = \frac{\text{sum of customer interruption durations}}{\text{total number of customers}} = \frac{\sum U_i N_i}{\sum N_i} \quad (3.35)$$

where U_i, is the annual outage time and N_i, is the number of customers of load point i.

4. Customer average interruption duration index, CAIDI

$$CAIDI = \frac{\text{sum of customer interruption durations}}{\text{total number of customer interruptions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \quad (3.36)$$

where λ_i, is the failure rate, U_i, is the annual outage time and N_i is the number of customers of load point i.

3.3.4 Load- and Energy-Orientated Indices

One of the important parameters required in the evaluation of load- and energy-orientated indices is the average load at each load-point bus-bar.

1. The average load L_a is given by

$$L_a = L_p f \quad (3.37)$$

where

$$L_p = \text{peak load demand}$$

$$f = \text{load factor}$$

another way to evaluate L_a is

$$L_a = \frac{\text{total energy demanded in period of interest}}{\text{period of interest}} = \frac{E_d}{t} \tag{3.38}$$

2. Energy not supplied index, ENS

$$ENS = \text{total energy not supplied by the system} = ZL_{a(i)}U_i \tag{3.39}$$

where $L_{a(i)}$ is the average load connected to load point i.

Even though there are many reliability indices, in this thesis, only SAIFI, SAIDI and ENS will be focused and evaluated.

CHAPTER 4
TEST SYSTEM AND RESULTS

This chapter is mainly being divided into two sections; evaluation of the impact of voltage dip on distribution system and calculation of system reliability. Using the evaluation techniques from chapter 3 and knowledge of chapter 2, the impact of voltage dip on system reliability can be focused. According to the methods from chapter 3, voltage and current during fault can be obtained using fault calculation. Then, by using these fault voltages and currents, voltage dip can be evaluated and how the system reliability indices changed can be checked, and in this thesis, the figure 4.5 shows the example test system to study fault calculation. Base MVA is 10 and base voltage is 11 kV. Base current is 909.09 kA. Impedance of transformer and line are assumed j22.1 and 0.472 + j0.366 Ω/m.

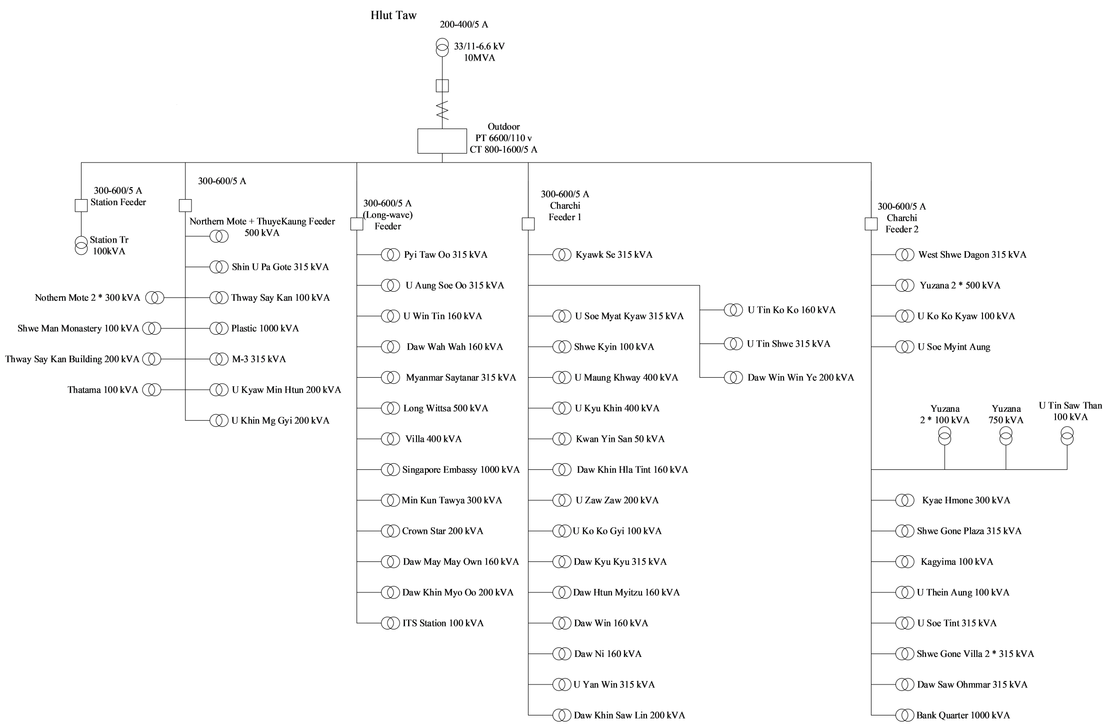

Figure 4.1: Single Line Diagram of Thuye Kaung Substation

Although there are many feeders in that substation, Northern Mote + Thuye Kaung feeder is chosen to calculate fault current and fault voltage, and figure 4.6 shows the single line diagram of that feeder

4.1 Impact of Voltage Dip on System Reliability

There are generally two kinds of impact on system reliability due to voltage dip.

1. Impact of voltage dip on the reliability of system with fuse
2. Impact of voltage dip on the reliability of the system with recloser-fuse coordination.

In this thesis, only the impact of voltage dip on system reliability with fuse will be focused. To focus impact of voltage dip, voltage and current during fault have to be calculated firstly.

4.1.1 Impact of Voltage dip on Test System with Fuse

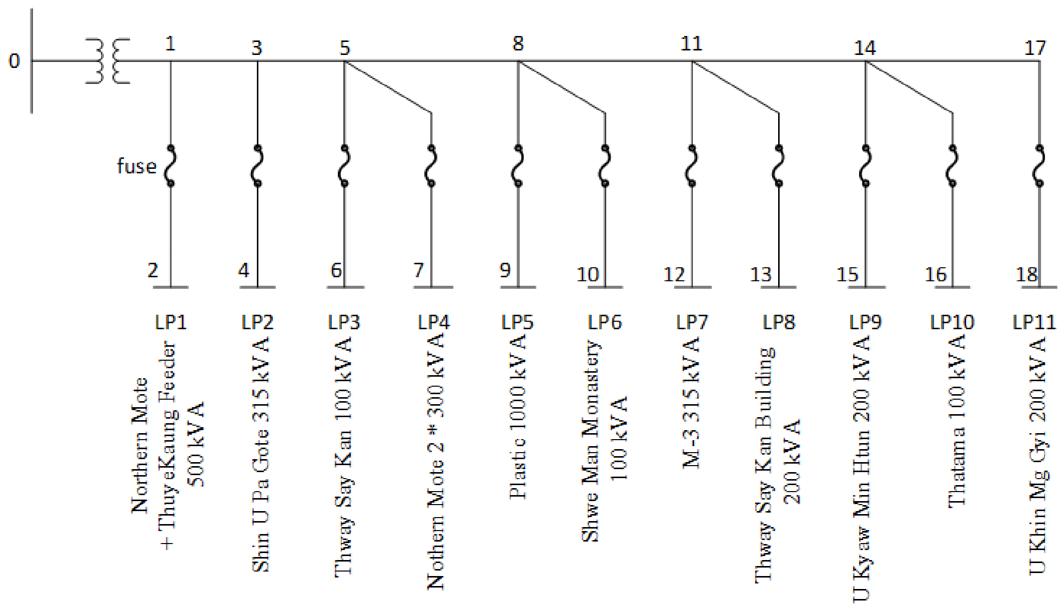

Figure 4.2: Single Line Diagram of Myout Mote + Thuye Kaung Feeder

In general, suppose a fault occurs on laterals, the fuse will be trip out themselves from the system. Therefore, the fault will only trip out the faulted load from the system. But in this case, it should be considered whether the voltage level at other load points is satisfactory or not for customer. If the customer cannot tolerant the voltage dip, they will be cut off from the supply. Suppose that a fault occurs on lateral 12 or LP 8 and the fuse will trip out only load LP 8 from the system. In this case, impact of voltage dip is not considered and it is generally assumed that other load points can stand the voltage dip caused by fault. Actually, every load point cannot stand the voltage dip and some of them may trip out from the system even though fuse is used in laterals. In this thesis, this impact will be taken into account for reliability calculation. Example test system with fuse is shown in the above figure.

Suppose when a fault occurs at lateral 12, let's focus on the impact of voltage on load point 5. The voltage dip level at this load point is 0.5153 pu and fault current is 337.82 A. When sensitive loads in that load points cannot withstand that voltage level, protective devices (safe guard) will disconnect that load point from the supply and it needs to wait for a few minutes. That results in decreasing system reliability, by inclining SAIDI, and SAIFI, so when voltage dip is not taken into account in consideration, there is no impact on other load points but voltage dip at others violated the voltage envelope curve. However, when reliability of load point 5 is considered, the interruption of lateral 12 also need to be considered.

4.1.2 System Data of Myout Mote + Thuye Kaung Feeder

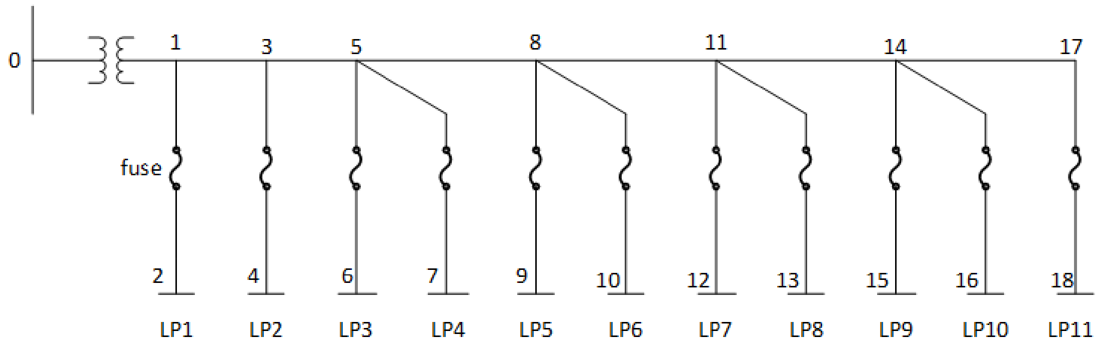

Figure 4.3: Single Line Diagram of Myout Mote + Thuye Kaung Feeder with LPs

4.1.3 Basic System Data

In that distribution system, one generator, one transformer, seven sections and eleven lines are included in table 4.1. The generator's voltage rating is 33kV and the transformer (step-down) drops that voltage to 11kV and other lines and sections' voltage rating is 11kV as well. Then basic MVA is 10 for all devices, and positive, negative and zero sequences of all components are expressed in per units.

4.1.4 Effect of Lateral Distribution Protection

Whenever a fault occurs, that fault will trip out all lines and sections but these days transmission and distribution system use protection devices. In this thesis, fuse will only be considered as protective device in test system. When fuses are installed, only

Item	Voltage rating	Base MVA	X^1	X^2	X^0
G	33kV	10	0.15	0.15	0.05
T	33/11kV	10	0.10	0.10	0.10
$L_{1,2}$	11kV	10	0.125	0.125	0.30
$L_{1,3}$	11kV	10	0.15	0.15	0.30
$L_{1,4}$	11kV	10	0.25	0.25	0.7125
$L_{4,5}$	11kV	10	0.30	0.30	0.60
$L_{4,6}$	11kV	10	0.15	0.15	0.30
$L_{4,7}$	11kV	10	0.45	0.45	0.90
$L_{7,8}$	11kV	10	0.40	0.40	0.80
$L_{7,9}$	11kV	10	0.40	0.40	0.80
$L_{7,10}$	11kV	10	0.60	0.60	1.00
$L_{10,11}$	11kV	10	0.70	0.70	1.10
$L_{10,12}$	11kV	10	0.43	0.43	0.80
$L_{10,13}$	11kV	10	0.48	0.48	0.95
$L_{13,14}$	11kV	10	0.35	0.35	0.70
$L_{13,15}$	11kV	10	0.48	0.48	0.90
$L_{13,16}$	11kV	10	0.30	0.30	0.50
$L_{16,17}$	11kV	10	0.15	0.15	0.30
$L_{17,18}$	11kV	10	0.30	0.30	0.50

Table 4.1: Sequence Data of Test System

the faulted part will be trip out and there is no effect on other load points. But this is the condition without consideration of voltage dip and when the impact of voltage dip is taken into consideration, other lines and sections are affected by decreasing voltage level even though fuses are installed. Therefore, voltage dip is considered in this thesis and this impact on system will be evaluated by using test system.

4.1.5 Fault Allocation

Suppose a fault occurs at bus 13 or LP8, fault current and voltage are calculated below.

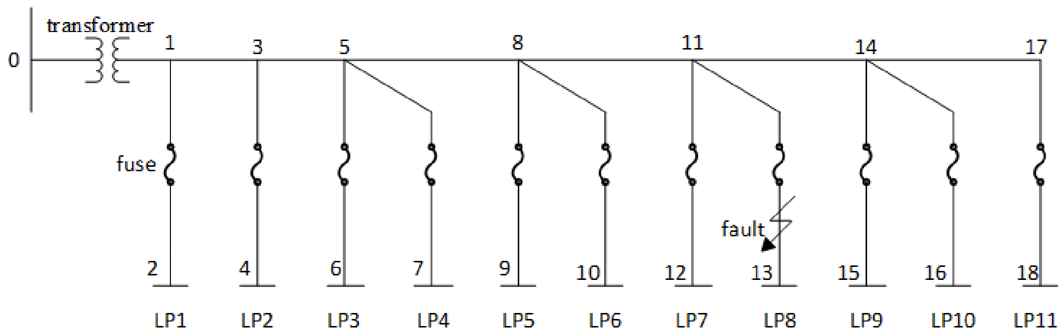

Figure 4.4: Test System with Fault at Bus 13

4.1.6 Fault Voltage and Fault Current when Fault Occur at Branch 13

Load point	Voltage during fault	Without consideration of voltage dip impact	With consideration of voltage dip impact
1	0.9007	in service	no effect
2	0.8289	in service	no effect
3	0.6965	in service	no effect
4	0.6965	in service	no effect
5	0.5199	in service	effect
6	0.5199	in service	effect
7	0.2439	in service	effect
8	0.0331	disconnected	effect
9	0.2439	in service	effect
10	0.2439	in service	effect
11	0.2439	in service	effect

Table 4.2: Different Voltage Level at Load Points when Fault Occurs at LP8

In this case, if voltage dip is not considered in calculation, fuse will trip out the faulted part and no impact on other load points. But, there is a time gap of short duration which is between the period of fault occurs and before the fuse trip out that fault. Therefore, when voltage level drops for that moment, half cycle to several seconds (called voltage dip) is taken into calculation, some load points cannot withstand that voltage level even for a short period and need to be disconnected from a supply.

The line chart 4.5 is the condition where voltage dip is considered, show the voltage level of each load point. When voltage dip is ignored, other load points are in service and no impacts but when it is considered, fault current is 0.3311pu and some load points have been effected by impact of voltage dip. What's more, in this case, fault occurs at load point 8, and all of the other load points also impacted by voltage level decreasing. In this thesis, voltage "sag to 0.6pu" is considered as reference voltage dip level and sensitive loads will not tolerant the voltage that is below 0.6pu. Therefore, when it is studied this case in details, only four load points (from LP1 to LP4) are above the reference voltage level and other load points are under that level, then in that load points, all of the sensitive loads will be disconnected from a supply by protective devices (safe guard). According to the standard of protective devices, loads disconnected from the supply need to wait for five minutes to reconnect to the supply. Therefore, even when the load points are not disconnected from the supply, sensitive loads will be trip out and cannot connect instantly. That results in unreliable estimation and inaccurate reliability, and reliability indices (SAIDI & SAIFI) keep growing upward trend, which outcomes in unreliable system. Then, another fault location is selected as well and current and voltage during fault are calculated and compared below.

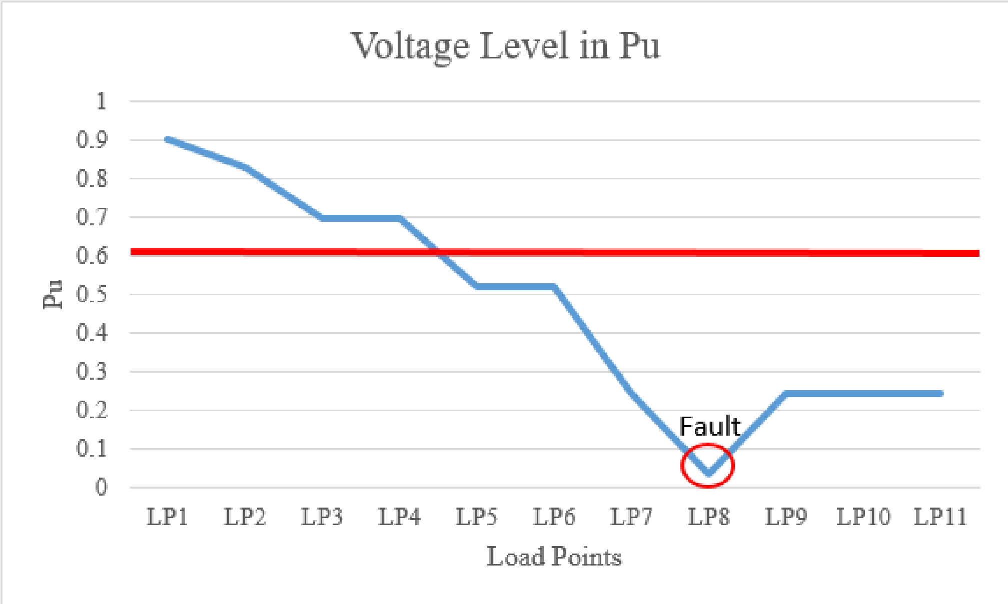

Figure 4.5: Voltage Level during Fault Occurs at LP8 in Line Chart

4.1.7 Another Fault Allocation

Suppose a fault occurs at bus 18 or LP11, and fault current and voltage are calculated as follow;

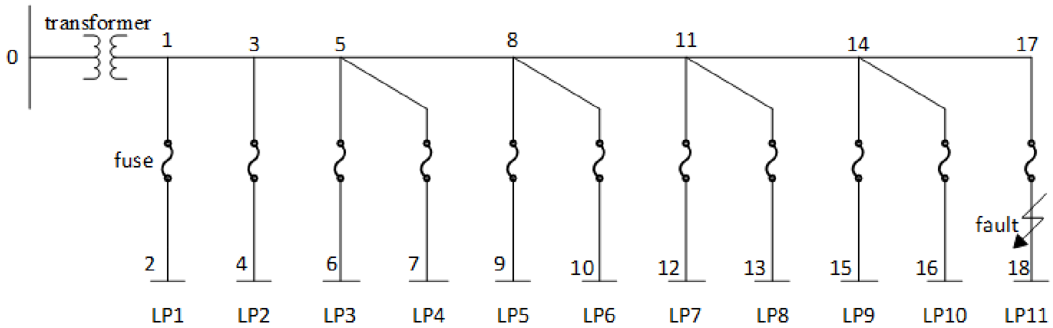

Figure 4.6: Test System with Fault at Bus 18

4.1.8 Fault Voltage and Fault Current when Fault Occur at Branch 18

Load point	Voltage during fault	Without consideration of voltage dip impact	With consideration of voltage dip impact
1	0.9122	in service	no effect
2	0.8488	in service	no effect
3	0.7317	in service	no effect
4	0.7317	in service	no effect
5	0.5756	in service	effect
6	0.5756	in service	effect
7	0.3317	in service	effect
8	0.3317	in service	effect
9	0.1951	in service	effect
10	0.1951	in service	effect
11	0.0293	disconnected	effect

Table 4.3: Different Voltage Level at Load Points when Fault Occurs at LP11

This is another case with new fault location but effects of that fault and impact of voltage dip on other load points are similar with previous one. In this case, fault occurs at load point 11, and when voltage dip is not considered, all load points except faulted point are in service then fuse cut down that faulted part, and no impact on other points. But when decreasing voltage level for a short period is taken into calculation, fault current is 0.2927 pu and some load points cannot be in service and need to be disconnected from supply because sensitive loads cannot withstand that voltage level and if it is not cut down, these devices will burn or be over or under voltage fault.

The line chart 4.7 represents the voltage drop level of each load point and it is a downward trend. In this case, "sag to 0.6pu" is a satisfactory voltage level and only four load points (from LP1 to LP4) are above that level and other load points are below 0.6pu. However, that is similar with previous test system and the only difference is line in chart 1 is downward trend with little fluctuation while line in chart 2 is a dramatic downward trend. Moreover, wherever a fault occurs, at the middle of the branch or at the end of the system, when voltage dip is taken into consideration, it impacts on other load points and on sensitive loads. Furthermore, the system need to consider these conditions in reliability calculation in order to gain high reliability and accurate estimation. Therefore, the impact of voltage dip on system is considered in calculation and estimated as follow.

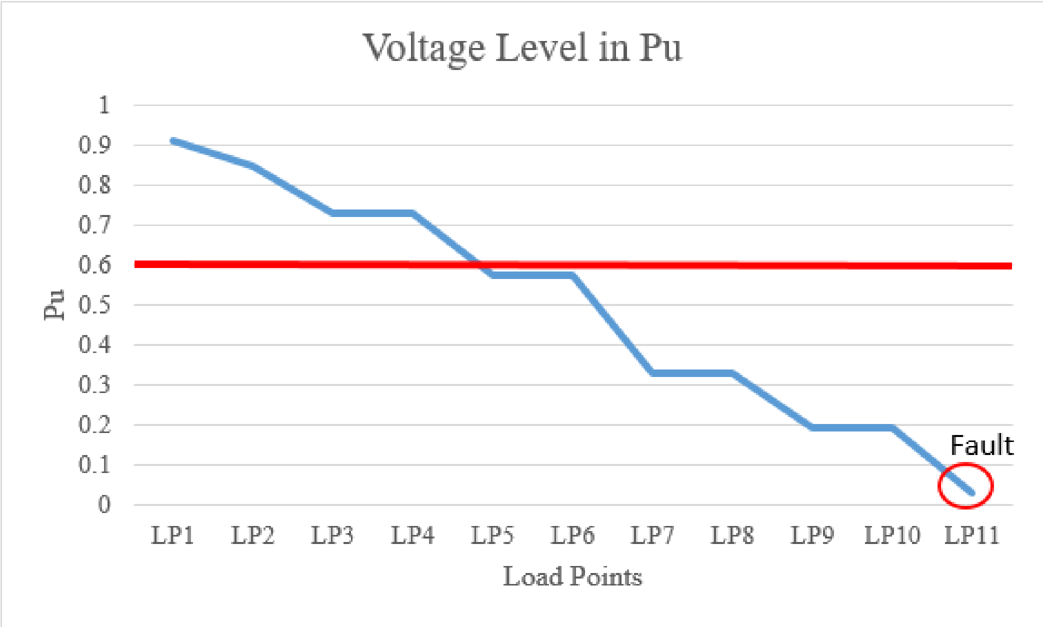

Figure 4.7: Voltage Level during Fault Occurs at LP11 in Line Chart

4.2 Reliability Evaluation

In this section, there are generally two parts, one is evaluation of current reliability condition and the next one is calculation and comparison of reliability of current condition and voltage dip considered condition. The figure 4.8 shows the test system with numbers of lines, sections and transformer.

4.2.1 Current Reliability Condition

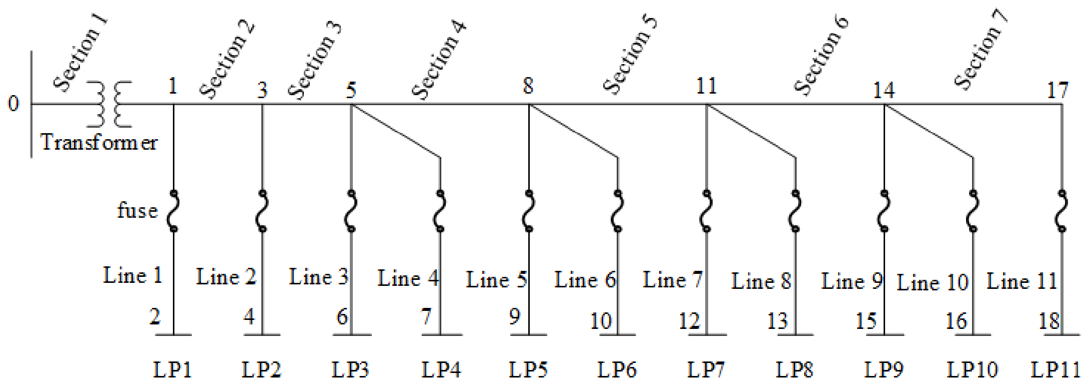

Figure 4.8: Test System with Lines, Sections and Transformer

When reliability indices are considered, there are three main basic reliability parameters of average failure rate, λ_s, average outage time, r_s, and average annual outage time, U_s, these basic reliability parameters of test system are as followed;

System Components	Failure rate (λ)	Outage time (r)	Annual outage time (r)
Transformer	0.7	0.5	0.35
Section 1	0.3	3	0.9
Section 2	0.1	3	0.3
Section 3	0.3	3	0.9
Section 4	0.2	3	0.6
Section 5	0.2	3	0.6
Section 6	0.2	3	0.6
Section 7	0.2	3	0.6
Line 1	0.2	2	0.4
Line 2	0.3	1	0.3
Line 3	0.2	2	0.4
Line 4	0.4	2	0.8
Line 5	0.3	1	0.3
Line 6	0.1	3	0.3
Line 7	0.3	2	0.6
Line 8	0.2	1	0.2
Line 9	0.3	2	0.6
Line 10	0.3	2	0.6
Line 11	0.2	1	0.2
Total	5	1.91	9.55

Table 4.4: Basic Reliability Parameters for System Components

The total failure of this this test system is 5 f/yr and different components have different failure rate, like a transformer has 0.7 f/yr while sections and lines have around 0.4 f/yr. As for outage time, the transformer is quite low because there is always an extra transformer in substation and when a current transformer is in failure, the another one will be used and it does not take so long. But for sections, it need around 3 hours to repair one because it has to find where it is damaged and how far from substation as well. Moreover, having being connected many lines in a branch also raise outage time and even though it does not need quite long to fix one, it has lots of line and higher rate of failure, and results in increasing outage time. Finally, annual outage time, being the outcome of failure rate and outage time, it depends on these two factors and total annual outage time for this test system is nearly 10 hour/yr. Based on these basic reliability data and used equations in methodology, current reliability conditions are calculated below;

Number of Loads	SAIFI	SAIDI	ENS	Average Load
LP1	2.4	5.25	1575	300
LP2	2.5	5.15	927	180
LP3	2.4	5.25	945	180
LP4	2.6	5.65	395.5	70
LP5	2.5	5.15	360.5	70
LP6	2.3	5.15	2832.5	550
LP7	2.5	5.45	654	120
LP8	2.4	5.05	909	180
LP9	2.5	5.45	381.5	70
LP10	2.5	5.45	654	120
LP11	2.4	5.05	606	120

Table 4.5: Current Reliability Condition of Test System

The table 4.5 shows the current condition of reliability indices (SAIFI, SAIDI, & ENS) of test system. Then, current SAIFI is around 2.3 and SAIDI is 5 but this is the condition where impact of voltage dip is not considered and it needs to check when voltage dip is taken into account in calculation, how these indices changed and how voltage dip impacts on this test system. To check so, all load points need to calculate again with consideration of impact of voltage dip on system and for e.g., when fault occurs at LP1 and how it impacts on other load points and it needs to repeat calculation for all load points. But in this thesis, only one load point will be focused and whether sensitive loads in other load points can tolerate or not, will be checked. Therefore, LP6 is chosen as sample load point and reliability at LP6 will be evaluated again with the impact of voltage dip considered.

Firstly, to calculate reliability indices changed at LP6, it needs to monitor voltage during fault at LP6 when faults occur at different load points. Therefore, different voltage level at LP6 with different fault location is tabulated below.

4.2.2 Reliability with Consideration of Voltage Dip Condition

Different Fault Locations	Voltage Level at LP6
Line 1	0.8686
Line 2	0.7737
Line 3	0.5985
Line 4	0.5985
Line 5	0.3650
Line 6	0.0438
Line 7	0.3650
Line 8	0.3650
Line 9	0.3650
Line 10	0.3650
Line 11	0.3650

Table 4.6: Voltage Level at LP6 with Different Fault Location

The above table represents different voltage level at LP6 with different fault locations and in that condition, when fault occurs at line1, 2, 3 & 4, voltage level at LP6 is above satisfactory point with around 0.6pu. But when fault occurs at other lines, voltage during fault at LP6 is below reference voltage level and, so it need to consider in calculation. Then, these voltage level at LP6 is shown in line chart 4.9.

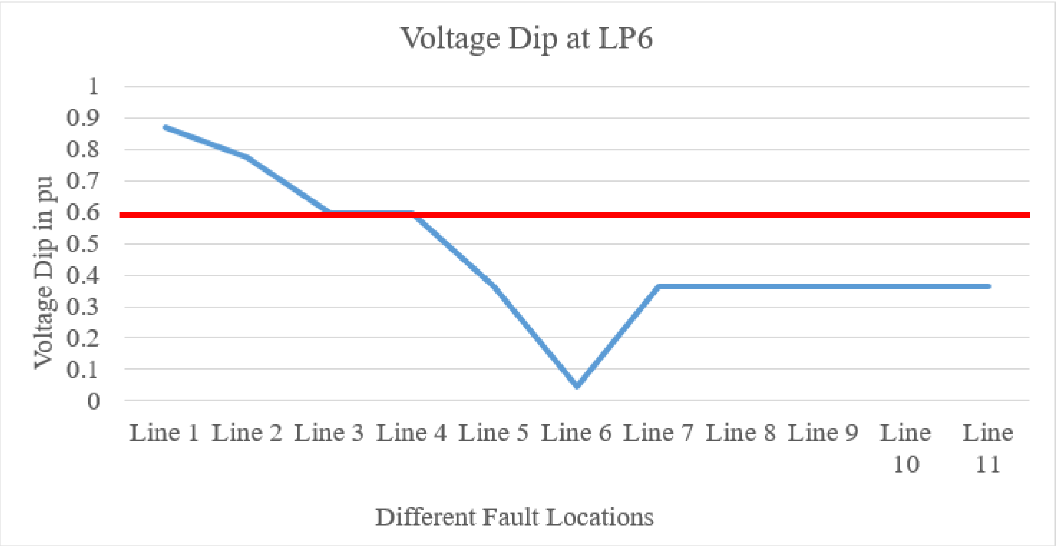

Figure 4.9: Voltage Level at LP6

4.2.3 Analysis on Reliability Indices at LP6

When impact of voltage dip is taken into account in calculation, current reliability indices at LP6 will be changed and by using equation and concept mentioned in Chapter

3, new reliability indices are obtained as follow and compared below.

Load Point	SAIFI	SAIDI	ENS	Average Load
LP6	2.3	5.15	2832.5	550

Table 4.7: Current Condition at LP6

Different Fault Locations	SAIFI	SAIDI	ENS	Average Load
Fault at Line5	2.6	5.158	2836.9	550
Fault at Line7	2.6	5.158	2836.9	550
Fault at Line8	2.5	5.158	2836.9	550
Fault at Line9	2.6	5.158	2836.9	550
Fault at Line10	2.6	5.158	2836.9	550
Fault at Line11	2.5	5.158	2836.9	550

Table 4.8: Changed Condition at LP6

Load Point	SAIFI	SAIDI	ENS	Average Load
LP 6	2.445	5.154	2834.9	550

Table 4.9: New Reliability Indicies at LP6

In condition where voltage dip is not considered, SAIFI at LP6 is about 2.3 interruptions/customer and SAIDI is 5.15 hours/customer. Then, ENS is around 2830 kWh and average load will not be changed whether voltage dip is ignored or not. However, SAIFI, SAIDI & ENS changed when voltage dip is considered, and SAIFI become around 2.6 interruptions/customer and increased by 0.3 in average, meanwhile SAIDI inclines gradually to 5.158 from 5.15 hours/customer. In addition, ENS would not change too much because it depends on SAIDI and when SAIDI changed a little, it also rises just around 7 kWh and become 2837 kWh. To check this comparison clearly, each comparison is figured in line chart as follow;

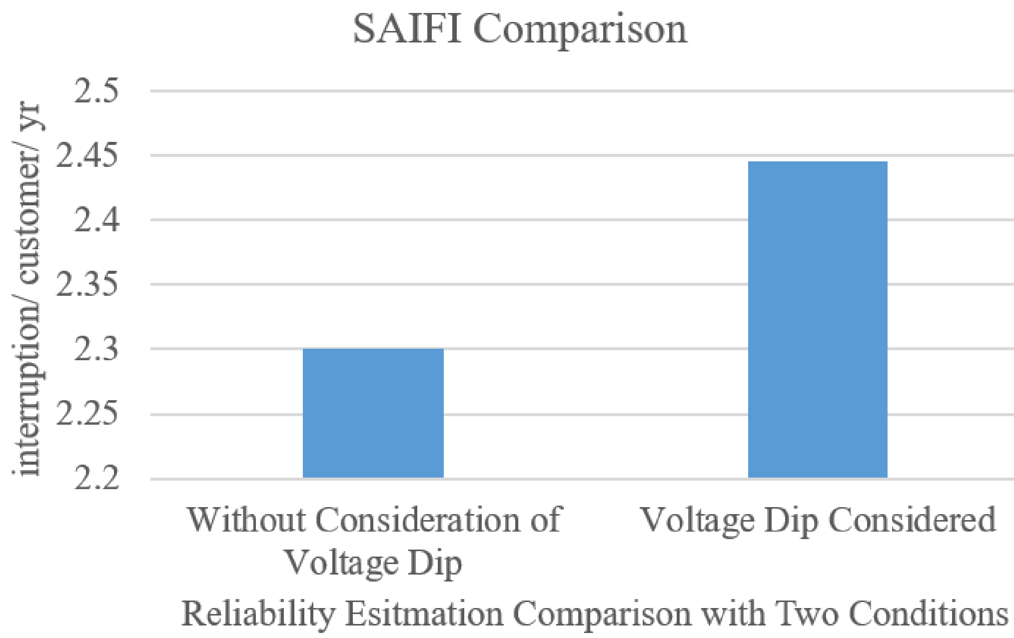

Figure 4.10: SAIFI Comparison with Two Conditions

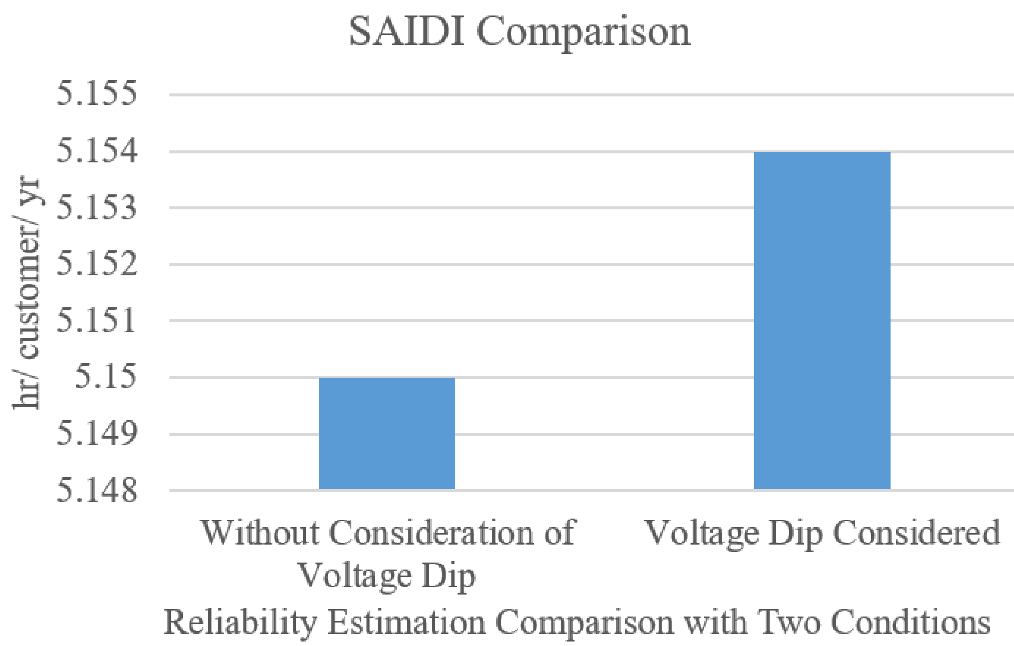

Figure 4.11: SAIDI Comparison with Two Conditions

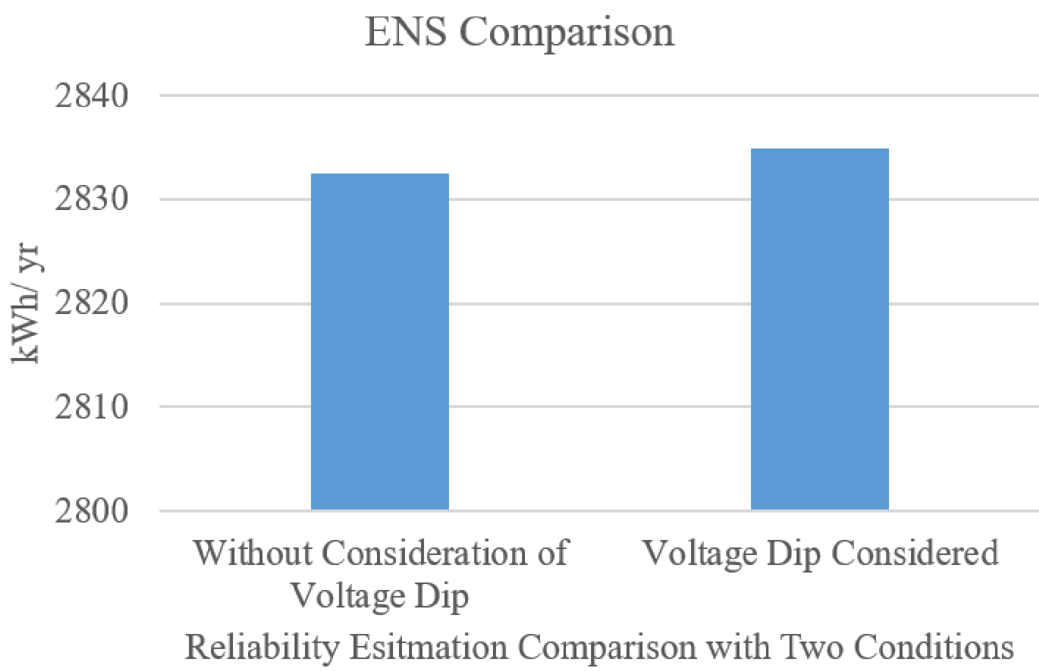

Figure 4.12: ENS Comparison with Two Conditions

In these comparisons, SAIFI change dramatically although SAIDI and ENS do not change significantly and however less and less amount in these factors results in more reliable system. Therefore, by considering the impact of voltage dip in reliability calculation, more accurate reliability estimation can be gained.

CHAPTER 5
DISCUSSION AND CONCLUSION

The study on impact of voltage dip and reliability evaluation on electrical distribution system has been conducted in this thesis. Firstly, fault calculation on system is figured out with different fault locations. Moreover, voltage dip and its impact are aimed and evaluated as well. Then, based on this impact of voltage dip, current reliability indices of the existing system are focused and calculated how these indices changed when voltage dip is taken into account.

When it is studied in details, it is obvious that when a fault occurs at load point, it effects on sensitive loads and other load points. Even though fuses or other protective devices are installed, it impacts on other load points because there is a time gap when the fuses disconnect the faulted part. At that moment, it drains voltage level of the system for a short duration like from few seconds to several seconds and it is generally called voltage dip or voltage sag. It mainly effects on sensitive loads and as the nature of these loads, they cannot tolerate the low voltage level and it needs to be disconnected from the supply when voltage level is below its limit. If not, they will be or damaged. Furthermore, this results in increasing accurate reliability estimation and declining the reliability curve of the system and so this is one main reason why this thesis focused on its impact. Moreover, although everyone knows the impacts of voltage dip on system, it is still ignored in reliability calculation and consideration because it lasts only for few seconds and does not have large impact on system. But to get more accurate reliability estimation, the impact is also needed to take account, and so this thesis is focused on this effect and evaluated by using fault calculation. To analyze the impact of voltage dip, fault allocation is firstly considered in this thesis and after that started calculation of voltage and current during fault.

After fault calculation, it is clearly seen that how much this impacts on system and how it drains the system reliability. As a second part of this thesis, reliability calculation is focused and compared with current one and changed one. The current condition means what voltage dip is not included in reliability calculation and the next one is calculated the reliability with consideration of the impact of voltage dip and these two conditions are compared with line charts and tables. Therefore, by implementing this method in reliability evaluation, more accurate estimation of reliability can be obtained and system will become highly reliable. Finally, these all steps are conducted in thesis and impact of voltage dip is mainly analyzed.

As a future work or recommendation, all loads are considered as sensitive loads in this thesis but actually all loads cannot be sensitive, then some loads will only be considered as sensitive loads and partially evaluated as the future work. Moreover, to overcome this impact on system and mainly on sensitive loads, some countermeasures need to be considered. For example, analyzing and utilizing of dynamic voltage restorer, super conducting magnetic storage, dynamic sag corrector and others. In addition, how the reliability estimation improves and how they overcome the voltage dip impact can be evaluated as future work by using these devices.

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