ผลกระทบของแรงดันตกชั่วครู่และของระบบป้องกันที่มีต่อความน่าเชื่อถือได้ของระบบจำหน่ายไฟฟ้า

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IMPACT OF VOLTAGE DIP AND PROTECTION SYSTEM OPERATON ON ELECTRICAL DISTRIBUTION SYSTEM RELIABILITY

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A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Engineering Program in Electrical Engineering
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นายออนซินลิน:ผลกระทบของแรงดันตกชั่วครู่และของระบบป้องกันที่มีต่อความน่าเชื่อถือได้ของระบบจำหน่ายไฟฟ้า. (IMPACT OF VOLTAGE DIP AND PROTECTION SYSTEM OPERATION ON ELECTRICAL DISTRIBUTION SYSTEM RELIABILITY) อ.ที่ปรึกษาวิทยานิพนธ์หลัก : ศ.ดร.บัณฑิต เอื้ออาภรณ์, 80 หน้า.

วิทยานิพนธ์ฉบับนี้นำเสนอการวิเคราะห์ผลกระทบจากการทำงานของอุปกรณ์ป้องกันและแรงดันตกชั่วครู่ที่มีต่อความเชื่อถือได้ของระบบจำหน่ายไฟฟ้ากำลัง แนวทางการวิเคราะห์ในวิทยานิพนธ์แบ่งออกเป็น 2 ส่วน ส่วนแรกเกี่ยวข้องกับการวิเคราะห์ผลกระทบของอุปกรณ์ป้องกันที่มีต่อความเชื่อถือได้โดยทั่วไปแล้วการติดตั้งอุปกรณ์ป้องกัน เช่น ฟิวส์ อุปกรณ์ตัดวงจร และรีโคลสเซอร์ สามารถช่วยปรับปรุงระดับความเชื่อถือได้ให้ดีขึ้น การวิเคราะห์ผลจะมุ่งให้ความสนใจต่อระบบป้องกัน 3 ลักษณะคือ ฟิวส์ที่ป้องกันสายแยกย่อย ฟิวส์ที่ทำงานร่วมกับอุปกรณ์ตัดวงจร และฟิวส์ที่ทำงานร่วมกับรีโคลสเซอร์ ผลจากการวิเคราะห์ได้แสดงให้เห็นว่าการป้องกันในแต่ละลักษณะช่วยให้ความเชื่อถือได้ดีขึ้น อีกทั้งลดผลกระทบของพลังงานที่เกิดจากไฟฟ้าดับและลดจำนวนครั้งของไฟฟ้าดับได้

สำหรับส่วนที่สองนั้น เกี่ยวข้องกับการวิเคราะห์ผลกระทบของแรงดันตกชั่วครู่ที่มีต่อความเชื่อถือได้ของระบบไฟฟ้า ทั้งนี้ผลจากการวิเคราะห์ในส่วนแรกนั้นได้แสดงให้เห็นว่าระบบป้องกันสามารถช่วยให้ความเชื่อถือได้ของระบบดีขึ้น อย่างไรก็ตา มผลดังกล่าวอยู่บนสมมติฐานว่าลูกค้าทั้งหมดสามารถทนรับผลกระทบจากแรงดันตกชั่วครู่ที่มีผลจากความผิดพร่องที่อาจเกิดขึ้นในระบบจำหน่ายไฟฟ้าได้ซึ่งอาจไม่เป็นความจริงในทางปฏิบัติ ผลดังกล่าวอาจทำ ให้ลูกค้าบางรายต้องประสบกับปัญหา ไฟฟ้าดับอันเนื่องมาจากการทำงานของอุปกรณ์ป้องกันของตนเอง ดังนั้นการคำนึงถึงผลจากแรงดันตกชั่วครู่ที่มีต่อความเชื่อถือได้ จึงจะได้รับการนำมาวิเคราะห์ในส่วนนี้

วิธีการวิเคราะห์ผลที่พัฒนาขึ้นนี้ได้นำไปทดสอบกับระบบทดสอบ RBTS ซึ่งผลการทดสอบที่น่าพอใจ ได้นำแสดง ในวิทยานิพนธ์ฉบับนี้

ภาควิชา วิศวกรรมไฟฟ้า ลายมือชื่อนิสิต
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OHN ZIN LIN: IMPACT OF VOLTAGE DIP AND PROTECTION SYSTEM OPERATION ON ELECTRICAL DISTRIBUTION SYSTEM RELIABILITY THESIS ADVISOR: PROF. BUNDHIT EUA-ARPORN, PH.D, 80 PP.

This thesis presents the impact of voltage dip and protection system operation on electrical distribution system reliability. There are two parts of analysis in this thesis. The first part concerns the impact analysis of protective devices on system reliability. In general, using protective devices on the system e.g. Fuses, disconnecting switches, and recloser can help the system its reliability improves. The analysis will be done based on three cases of protection scheme, i.e. fuses as lateral protection, fuses and disconnecting switches, and fuse-recloser coordination. It will be shown in this thesis that all of these schemes have great impact on system reliability, a large amount of energy can be saved, and a number of interruptions can be avoided.

The second part concerns the analysis of the impact of voltage dip on system reliability. In the first analysis, it can be known that using protective devices can system reliability improve. In that case, it is just assumed that all the remaining customers can with stand the voltage dip. However, in practice, some customers can not tolerate the voltage dip, and they will be cut off from the supply. Therefore, the impact of voltage dip on customer interruptions should not be neglected and have to be taken into account. This thesis shows that the impact of the voltage dip worsen system reliability.

In this thesis, the developed methods based on an analytical method will be test with the Reliability Test System (RBTS). Satisfactory results are obtained.

Department: Electrical Engineering Student's Signature:
Field of Study: Electrical Engineering Advisor's Signature: B. Eua-arporn
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CHAPTER I

INTRODUCTION

1.1 Motivation

Current research topics relating to distribution system reliability have gained increasing attention. In this thesis, there are two parts of analysis. The first one is impact of protection system on distribution system reliability and the later is that impact of voltage dip on system reliability. Using protective device, it can make system reliability help improve. But in the first analysis, it is assumed that voltage dip due to fault is not violated the voltage envelope of the customer. In practice, there have impacts of voltage dip on the customer, and some customer can not tolearant the dip level and cut off from the supply.

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.

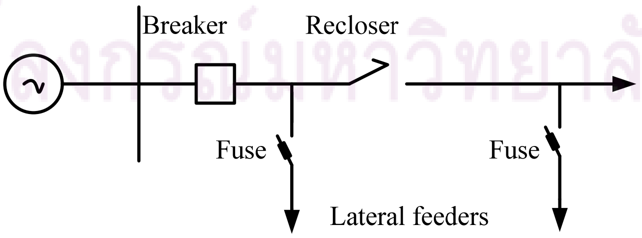

Figure 1-1 Typical radial distribution feeder

The disconnected switches, reclosers or fuses can be properly placed on radial systems resulting in better system reliability. This thesis will analyse the impact of protective devices on distribution system reliability. The analysis will focus on permanent outage events. Results of system and load point reliability indices will be presented. In addition the impact on voltage dip due to protective device operation and fault locations will also be analyzed. Bus 2 of Reliability Test System (RBTS) will be used in this analysis.

The main aspect of the protection coordination is that the primary device, closer to the fault point, should act before the backup devices . Additional protection is frequently used in practical distribution systems. One possibility in the case of the system shown in Figure 1.1 is that a short circuit on a lateral distributor causes its appropriate fuse to blow. The event causes disconnection of its load point until the failure is repaired. However, it does not affect or cause the disconnection of any other load points.

A second or alternative reinforcement or improvement scheme is the provision of disconnecting switches or isolators at judicious points along the main feeder. These are generally not fault-breaking switches and therefore any short circuit on a feeder still causes the main breaker to operate. After the fault has been detected, however, the relevant disconnect can be opened and the breaker reclosed. This procedure allows restoration of all load points between the supply point and the point of isolation before the repair process has been completed. Whether these devices are used on the system or not have great effect on the system. A lateral fuse is responsible for the permanent fault that occurs in part of the lateral feeder. Reclosers, as they are usually called, are popular circuit interrupting devices for distribution systems in which the magnitudes of fault currents are limited [1].

When a fault occurs, the voltage level of each load point will be decreased. It is known as voltage dip or voltage sag. The voltage dips have to be compared with customer voltage envelope. If the customer cannot tolerant the dip or the dip violates the envelope, it will be cut off from the supply permanently. Therefore, this event will impact on reliability of the system.

In the thesis, impact of protective devices installation, e.g. disconnecting switch, recloser and fuse on distribution system reliability will be analyzed. In addition, impact of voltage dip on each load point will also be calculated and presented. The developed method has been tested with the Reliability Test System (RBTS) [2].

1.2 Objective of Thesis

The specific objectives of this thesis are devoted to

(1) Calculate the reliability indices of existing distribution system
(2) Analyse customer's reliability impacts from protection system and its coordination.
(3) Develop computer program to calculate reliability indices taking into account voltage impacts

1.3 Scope of Research

The scope of this research is limited to

(1) Focusing on reliability indices, e.g. SAIFI, SAIDI, CAIDI, ENS and AENS of distribution system.
(2) Neglect fault impedance to allow fault current as much as possible.
(3) Analyse the impacts of protection system on distribution system reliability indices.
(4) Consider only radial configuration.

(5) Consider only permanent fault and neglect fault duration

1.4 Expected Contribution

The contribution of this thesis includes:

1. Useful information and resources for distribution system reliability.
2. Suggestion on improving distribution system reliability, and
3. Long-term customer's satisfactory indices by using the analytical results.

In this thesis, chapter II describes literature review of distribution system and system reliability. Evaluation techniques to calculate basic reliability indices and additional indices are also mentioned. According to basic knowledge of reliability, it can be known that reliability of distribution system need to emphasize because most of load interruptions are due to distribution system. In chapter III, literature review of protection system is described firstly. And, how to find the impact of lateral protection on system reliability is mentioned. Moreover, the way to find impact of disconnection switches and lateral protection on system reliability is presented. In chapter IV, characteristic of fault and techniques to find voltage and current during fault are presented. In the main chapter, chapter V, there are three main parts. The first one is calculation of reliability indices, the second one is impact of protection system on system reliability and the last is impact of voltage dip. Using the evaluation techniques and knowledge given in chapter 2, 3 and 4, the impact of protection system operation and voltage dip on electrical distribution system reliability can be analysed. Analytical calculation is described in chapter 5 with as test system.

The evaluation techniques in this thesis can also be used for any Test system. The test results show that it is important to take into account of using protective devices in the distribution system. And voltage dips caused by faults are also necessary to consider for reliability analysis.

CHAPTER II

DISTRIBUTION SYSTEM RELIABILITY ASSESSMENT

2.1 Introduction

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 [3].

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 [1].

2.2 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 .

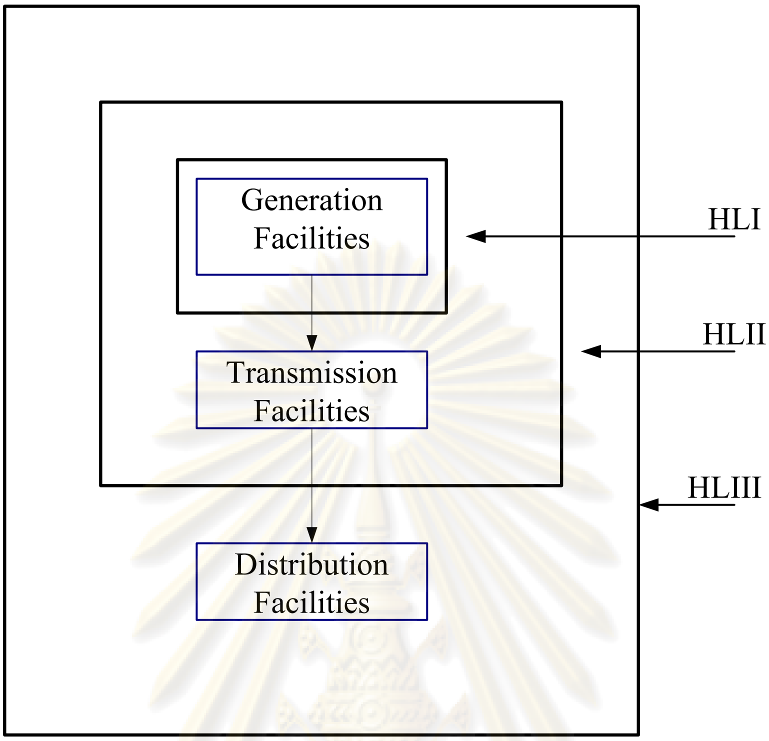

Figure 2-1 Hierarchical Levels in Electrical Power system [3]

2.3 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 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. Figure 2.2 shows the typical customer unavailability statistics depended on the types of contributor [1, 3].

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 [3].

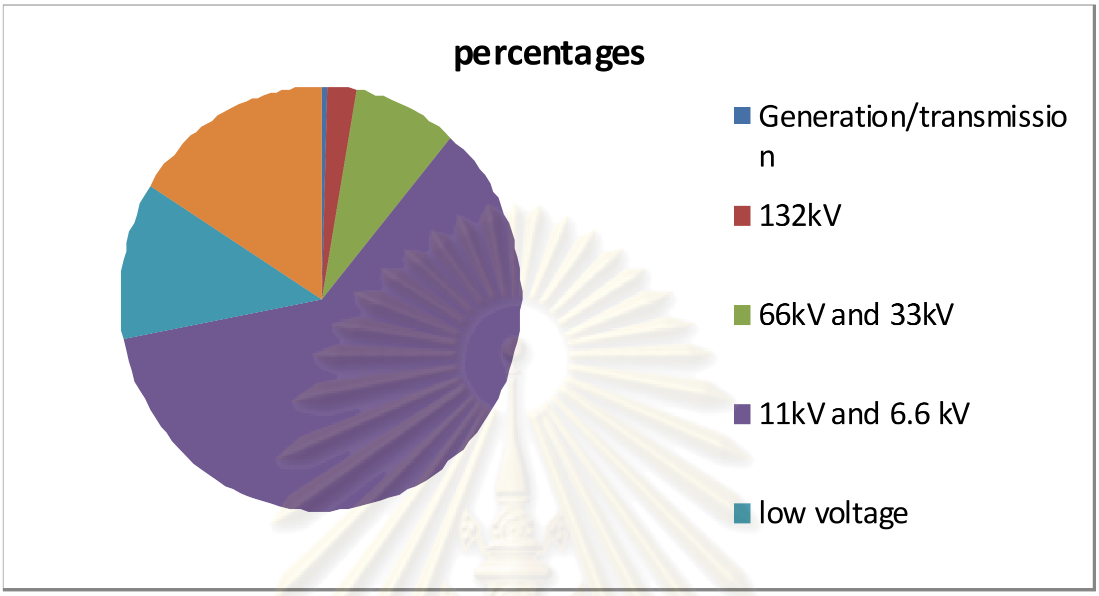

Figure 2-2 Typical customer unavailability statistics[1]

2.4 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 [4]. Figure 2.3 shows the overview of electricity infrastructure.

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 [3].

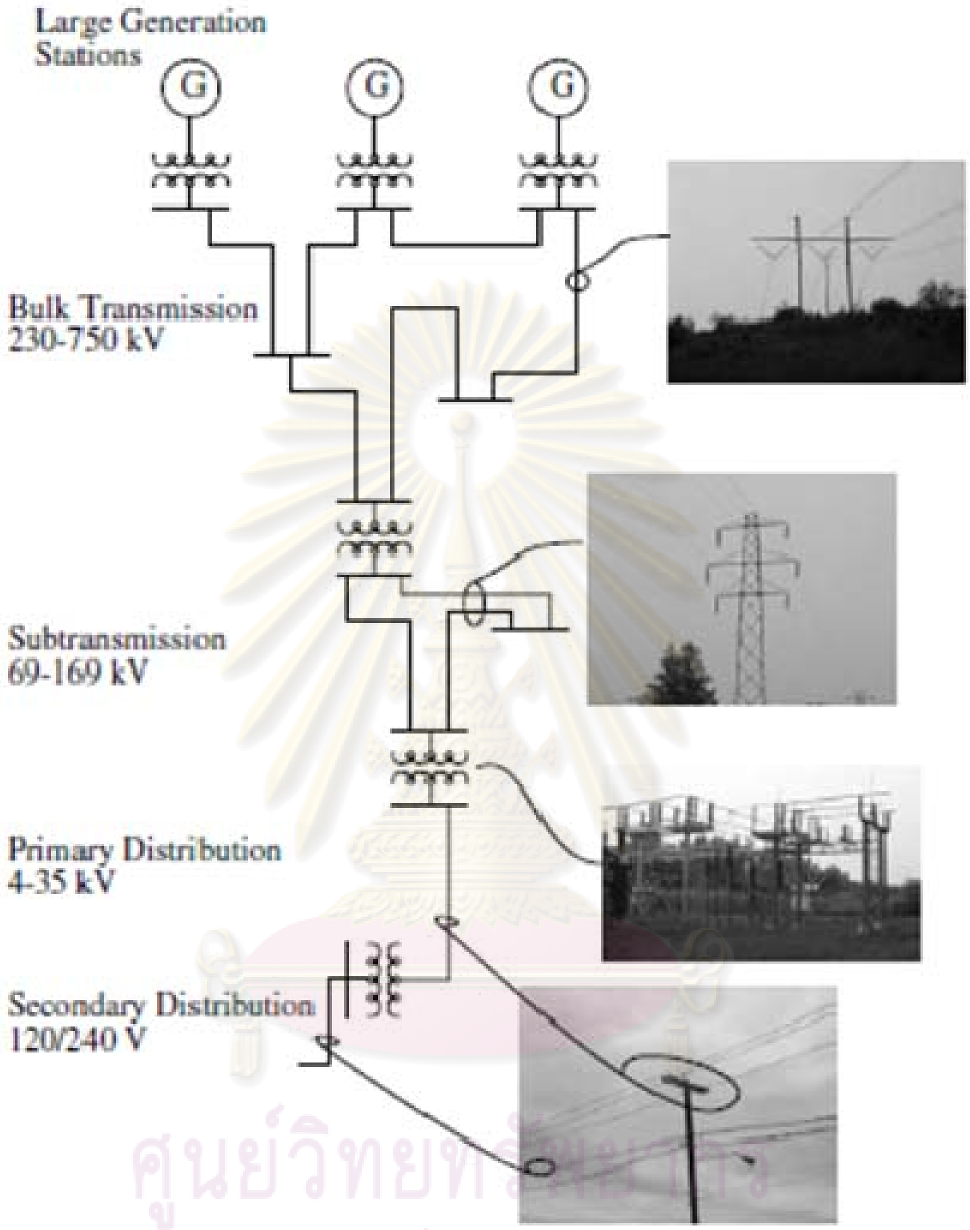

Figure 2-3 Overview of electricity infrastructure [4]

2.4.1 Radial Distribution System

A distribution circuit normally uses a primary or main feeder and lateral distributors. The main feeder originates from the sub-transmission substation and passes through the major load points and is constructed using single, parallel or meshed circuits. Many distribution systems used in practical have a single circuit main feeder, and these are referred to as radial systems. Other systems, although connected as meshed circuits, are normally operated as radial systems using normally open points. Radial systems are popular due to their simple design and generally low cost. The outage duration due to component failures are reduced by protection and sectionalizing schemes. The time taken to isolate a faulted component by isolation and switching action is termed as switching or restoration time. In some systems, there is provision for an alternate supply in the case of a failure or due to a component maintenance outage.

2.5 Evaluation Techniques

There are two sets of indices, namely the basic load point indices and the system performance indices for distribution systems [1]. The basis indices are important with respect to a particular load point, but they do not give an overall appreciation of the area or system performance. The system indices are calculated as weighted averages of the basic load point indices and are basically identical to those that have been used for many years to assess past system performance. Load and energy orientated indices can also be considered.

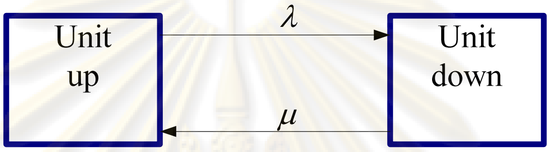

Figure 2-4 Two-state model for a base load unit[1,3]

The basic component model used in these applications is the two-state representation shown in figure 2.4. The rate of departure from the component up state to its down state is the component failure rate λ. The restoration of the component to its operating state is denoted by another transition rate termed the component repair rate μ.

2.5.1 Basic Load Point Indices

The approach used in this paper to conduct radial distribution system reliability assessment is to perform a failure modes and effects analysis utilizing the following basic equations [1] at each load point. There are three basic reliability parameters of average failure rate (λ_p), average outage time (r_p), and average annual outage time (U_p), where N denotes the number of outage events affecting load point i [5].

$$\lambda_p = \Sigma_{i=1}^{N} \lambda_i \quad \text{fail/yr} \tag{2.1}$$

$$U_p = \sum_{i=1}^{N} \lambda_i r_i \quad \text{hr/yr} \tag{2.2}$$

$$r_p = \frac{U_p}{\lambda_p} \quad \text{hr/yr} \tag{2.3}$$

2.5.2 System Indices or Customer-orientated Indices

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 100 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 indices can be and frequently are evaluated. In this thesis, system average interruption frequency index (SAIFI), system average interruption duration index (SAIDI), customer average interruption duration index (CAIDI) and energy not supplied index (ENS) will be considered to analyze the impact of protection system on reliability indices. The equations of additional indices which used in this paper are as follow [1]:

$$\mathrm{SAIFI} = \frac{\text{total number of customer interruptions}}{\text{total number of customer sserved}}$$

$$= \frac{\sum \lambda_i N_i}{\sum N_i} \text{ fail/customer/yr} \qquad (2.4)$$

$$\mathrm{SAIDI} = \frac{\text{sum of customer interruption duration}}{\text{total number of customer}}$$

$$= \frac{\sum U_i N_i}{\sum N_i} \text{ hr/customer/yr} \qquad (2.5)$$

$$\mathrm{CAIDI} = \frac{\text{sum of customer interruption duration}}{\text{total number of customer interruptions}}$$

$$= \frac{\sum U_i N_i}{\lambda_i N_i} \text{ hr/interruption /yr} \qquad (2.6)$$

2.5.3 Load- and Energy-oriented Indices

One of the most important parameters in the evaluation of this indices is the average load at each load-point bus bar.

$$L_a = \frac{\text{total energy demand inperiod of interest}}{\text{period of interest}} = \frac{E_d}{t} \qquad (2.7)$$

Where L_a is average load.

$$\mathrm{ENS} = \sum L_{a(i)} U_i \qquad (2.8)$$

where ENS is energy not supply, $L_{a(i)}$ is the average load connected to load point i and U_i is outage time at load point i.

$$\mathrm{AENS} = \sum \frac{L_{a(i)} U_i}{N_i} \tag{2.9}$$

where AENS is average energy not supply and N_i is total number of customers served.

2.6 Application to Radial System

Reliability indices are useful for determining what a customer can expect in terms of interruption frequencies and durations [6]. Reliability indices are typically computed by utilities at the end of each year by using historical outage data recorded in distribution outage reports. This is important so that utilities know how their systems are performing, but is less useful when the specific impact of various design improvement options wish to be quantified and compared. To make such comparisons, a model must be developed which is capable of predicting reliability measures based on system topology, component reliability data, and operational data [6]. Now, the evaluation techniques will be applied using an example of radial system and the data is from [1].

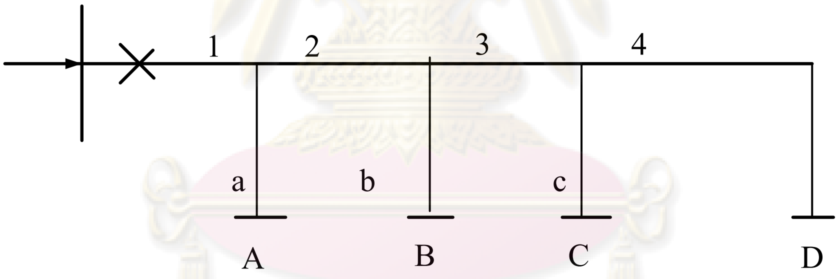

Figure 2-5 Typical radial distribution network

Table 2-1 reliability and Load data of example system

Component	λ (f/yr)	r(hours)	Load point	No of customers	Average Load connected(kW)
Section			A	1000	5000
1	0.2	4			
2	0.1	4			
3	0.3	4	B	800	4000
4	0.2	4			
Distributor					
a	0.2	2	C	700	3000
b	0.6	2			
c	0.4	2			
d	0.2	2	D	500	2000

Table 2-2 Basic load point indices for example system

	Load point A			Load point B			Load point C			Load point D		
C	λ	r	U	λ	r	U	λ	r	U	λ	r	μ
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
3	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2
4	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
a	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4
b	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**
c	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**
d	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**
Total	2.2	2.73	6.0	2.2	2.73	6.0	1.0	2.73	6.0	2.2	2.73	6.0

In this section, reliability indices will be calculated using evaluation techniques. Typical radial distribution network is as shown in figure 2.3. This system will be used as example system. Reliability and load data are shown in table 2.1. Firstly, basic indices for each laod point can be calculated. The result are shown in table 2.2. In this case, no protective device is used in the sytem. After that using the basic load point indices, system indices and energy-oriented indices can be calculated below.

Based on eqations (2.4), (2.5) and (2.6), we can obtain SAIFI, SAIDI and CAIDI. To calculate ENS and AENS, equations (2.8) and (2.9) are employed.

SAIFI = (2.2+2.2+2.2+2.2)/4
= 2.2 interruptons/customer yr

SAIDI = (6.0+6.0+6.0+6.0)/4
= 6.0 hours/customer yr

CAIDI = (2.73+2.73+2.73+2.73)/4
=2.73 hours/customer interruption

$\mathrm{ENS} = \mathrm{SAIDI} \times \mathrm{Total\,load}$
=6 x 14MW
=84 MWh/yr
AENS=84/3000
=28 kWh/yr-customers

Using this analysis, reliability indices of existing system can be calculated. And the reliability of future system can be focused.

CHAPTER III

PROTECTION SYSTEM

With the increasing dependence on electricity supplies, in both developing and developed countries, the need to achieve an acceptable level of reliability, quality and safety at an economic price become even more important to customers. A further requirement is the safety of the electricity supply. A priority of any supply system is that it has been well designed and properly maintained in order to limit the number of faults that might occur.

Associated with the distribution networks themselves are a number of ancillary systems to assist in meeting the requirements for safety, reliability and quality of supply. The most important of these are the protection systems which are installed to clear faults and limit any damage to distribution equipment. Amongst the principal causes of faults are lightning discharges, the deterioration of insulation, vandalism, and tree branches and animals contacting the electricity circuit. The majorities of faults are of a transient nature and can often be cleared with no loss of supply, or just the shortest of interruptions, whereas permanent faults can result in longer outages. In order to avoid damage, suitable and reliable protection should be installed on all circuits and electrical equipment. Protective relays initiate the isolation of faulted sections of the network in order to maintain supplies elsewhere on the system. This then leads to an improved electricity service with better continuity and quality of supply [7].

A properly coordinated protection system is vital to ensure that an electricity distribution network can operate within preset requirements for safety for individual items of equipment, staff and public, and the network overall. Automatic operation is necessary to isolate faults on the networks as quickly as possible in order to minimize damage. The economic costs and the benefits of a protection system must be considered in order to arrive at a suitable balance between the requirements of the scheme and the available financial resources.

When providing protective devices on any supply network the following basic principles must be apply. On the occurrence of a fault or abnormal condition, the protection system must be capable of detecting it immediately in order to isolate the affected section, thus permitting the rest of the power system to remain in service and limiting the possibility of damage to other equipment. Disconnection of equipment must be restricted to the minimum amount necessary to isolate the fault from the system.

The protection must be sensitive enough to operate when a fault occurs under minimum fault conditions, yet be stable enough not to operate when its associated equipment is carrying the maximum rated current, which may be a short-time value. It must also be fast enough to operate in order to clear the fault from the system quickly to minimize damage to system components and be reliable in operation. Back-up protection to cover the possible failure of the main protection is provided in order to improve the reliability of the protection system. While electromechanical relays can still be found in some utilities, the tendency is to replace these by microprocessor and numerical relays, particularly in the more complex protection arrangements [7]. In this thesis, a conventional protection system will be considered on simple radial distribution system. Then the impact on reliability indices will be analysed taking into account the protection coordination and its operating time.

3.1 Protective devices used in distribution systems

The devices mostly used for distribution system protection are:

1. Overcurrent relays;
2. Reclosers ;
3. Sectionalisers;
4. Fuse.

To analyze the impact on system reliability, reclosers and fuse will be considered in this thesis. Therefore, overcurrent relays and sectionalisers will not be mentioned in details.

3.1.1 Overcurrent Relays

Overcurrent relays are the most common form of protection used to deal with excessive currents on power systems. They should not be installed purely as a means of protection systems againt overloads-which are associated with the thermal capacity of machines or lines-since overcurrent protection is primarily intended to operate only under fault conditions. However, the relay settings that are selected are often a compromise in order to cope with both overload and overcurrent conditions. Based on the relay operating characteristics, overcurrent relays can be classified into three groups such as definite current or instantaneous, definite time and inverse time.

Define-current relays operates instantaneously when the current reaches a predetermined value. The setting is chosen so that, at the substation furthest away from the source, the relay will operate for a low current value and the relay operating currents are progressively increased at each substation, moving towards the source. Thus, the relay with the lower setting operates first and disconnects load at the point nearest to the fault. This type of protection has the drawback of having little selectivity at high values of short-circuit current. Another disadvantage is the difficulty of distinguishing between the fault current at one point or another when the impedance between these points is small in comparison to the impedance back to the source, leading to the possibility of poor discrimination. Definite current relays are not used as the only overcurrent protection, but their use as an instantaneous unit is common where other types of protection are in use.

Definite-time relay enables the setting to be varied to cope with different levels of current by using different operating times. The setting can be adjusted in such a way that the breaker nearest to the fault is tripped in the shortest time, and then the remaining breakers are tripped n succession using longer time delays, moving back towards the source. The difference between the tripping times for the same current is called the discrimination margin. Since the operating time for definite-time relays can be adjusted in fixed steps, the protection is more selective. The big disadvantage with this method of discrimination is that faults near to the source, which result in bigger currents, may be cleared in a relatively long time. This type of relay has a current or pick-up setting – also known as the plug or tap setting - to select the value at which the relay will start, plus a time dial setting to obtain the exact timing of the relay operation. It should be noted that the time-delay setting is independent of the value of the overcurrent required to operate the relay. These relays are used a great deal when the source impedance is large compared to that of the power system element being protected when fault levels at the relay position are similar to those at the end of the protected element.

The fundamental property of these relays is that they operate in a time that is inversely proportional to the fault current, as illustrated by the characteristic curves shown later. Their advantage over definite-time relays is that, for very high currents, much shorter tripping times can be obtained without risk to the protection selectivity. Inversetime relays are generally classified in accordance with their characteristic curve that indicates the speed of operation; based on this they are commonly defined as being inverse, very inverse, or extremely inverse. Inverse-time relays are also referred to as inverse definite minimum time or IDMT overcurrent relays.

3.1.2 Reclosers

A recloser is a device with the ability to detect phase-to-each overcurrent conditions, to interrupt the circuit if the overcurrent persists after a predetermined time and then to reclose automatically re-energize the line. If the fault that originated the operation still exists, then the recloser will stay open after a reset number of operations, thus isolating the faulted section from the rest of the system. In an overhead distribution system between 80 to 95 percent of the faults are of a temporary nature and last, at the most, for a few cycles or seconds. Thus, the recloser, with its opening/closing characteristic, prevents a distribution circuit being left out of service for temporary faults. Typically, reclosers are designed to have up to three open-close operations and, after these, a final open operation to lock out the sequence.

Co-ordination with other protection devices is important in order to ensure that, when a fault occurs, the smallest section of the circuit is disconnected to minimize disruption of supplies to customers. Generally, the time characteristic and the sequence of operation of the recloser are selected to co-ordinate with mechanisms upstream towards the source. After selecting the seize and sequence of operation of the recloser, the devices downstream are adjusted in order to achieve correct co-ordination. If the fault is permanent, the time-delay operation allows other protective devices nearer to the fault to open, limiting the amount of the network being disconnected.

Reclosers are used at the following points on a distribution network:

1. to provide primary protection for a circuit in substations.
2. In order to permit the sectioning of long lines and thus prevent the loss of a complete circuit due to a fault towards the end of the circuit in main feeder circuits.
3. To prevent the tripping of the main circuit due to faults on the spurs in branches or spurs.

When installing reclosers, it is necessary to take into account system voltage, short-circuit level, maximum load current, minimum short-circuit current within the zone to be protected by the recloser, co-ordination with other mechanisms located upstream towards the source, and downstream towards the load. The voltage rating and the short-circuit capacity of the recloser should be equal to, or greater than the values that exist at the point of installation [7].

3.1.3 Fuses

A fuse is an overcurrent protection device. It possesses and element that is directly heated by the passage of current and is destroyed when the current exceeds a predetermined value. A suitably selected fuse should open the circuit by the destruction of the fuse element, eliminate the arc established during the destruction of the element and then maintain circuit conditions open with nominal voltage applied to its terminals.

The majority of fuses used in distribution systems are to operate on the expulsion principle, i.e. they have a tube to confine the arc, with the interior covered with de-ionizing fiber, and fusible element. In the presence of a fault, the interior fiber is heated up when the fusible element melts and produces de-ionizing gases which accumulate in the tube. The zone of operation is limited by two factors; the lower limit based on the minimum time required for the fusing of the element (minimum melting time) and the maximum total clearing time that the fuse takes to clear the fault.

In distribution systems, the use of fuse links designated K and T for fast and slow types, respectively, depending on the speed ration, is very popular. The speed ration is the ration of minimum melting current that causes fuse operation at 0.1 s to the minimum melting current for 300s operation. [7].

3.1.4 Sectionalisers

A sectionaliser is a device that automatically isolates faulted sections of a distribution circuit once an upstream breaker or recloser has interrupted the fault current and is usually installed downstream of a recloser. Since sectionalisers have no capacity to break fault current, they must be used with a back-up device that has fault current breaking capacity. Sectionalisers count the number of operations of the recloser during fault conditions. After a preselected number of recloser openings, and while the recloser is open, the sectionaliser opens and isolates the faulty section of line. This permits the recloser to close and re-establish supplies to those areas free of faults. If the fault is temporary, the operating mechanism of the sectionaliser is reset.

Sectionalisers are constructed in single- or three-phase arrangements with hydraulic or electronic operating mechanisms. A sectionaliser does not have a current/time operating characteristic, and can be used between two protective devices whose operating curves are very close and where an additional step in co-ordination is not practicable. Sectionalisers with hydraulic operating mechanisms have an operating coil in series with the line. Each time an overcurrent occurs the coil drives a piston that activates a counting mechanism when the circuit is opened and the current is zero by the displacement of oil across the chambers of the sectionaliser. After a prearranged number of circuit openings, the sectionaliser contacts are opened by means of pretensioned springs. This type ofsectionaliser can be closed manually. Sectionalisers with electronic operating mechanisms are more flexible in operation and easier to set. The load current is measured by means of CTs and the secondary current is fed to a control circuit which counts the number of operations of the recloser or the associated interrupter and then sends a tripping signal to the opening mechanism. This type of sectionaliser is constructed with manual or motor closing.

3.2 Time-Current characteristic of recloser and fuse used in Test System

The operating time of fuses and reclosers can also be calculated using Time-Current characteristic curve. The types and rating of fuses can be chosen according to fault current of lateral feeders and main sections. Minimum melting time and total clearing time of fuse are shown for type 200k in figure 3.1.

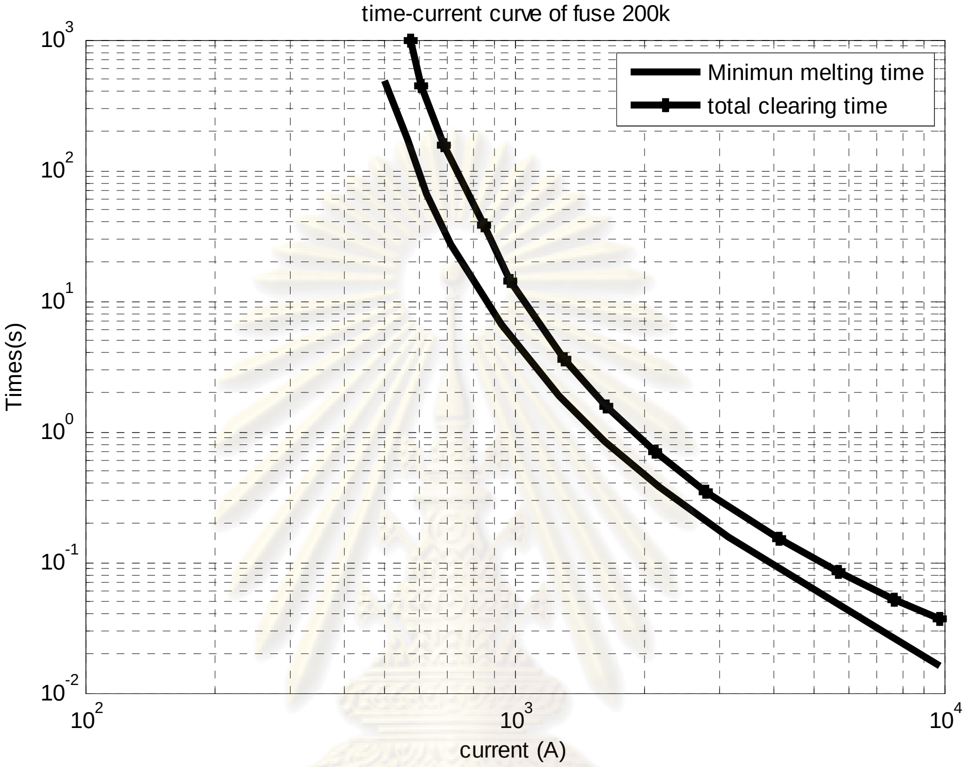

Figure 3-1 Time-current curve of fuse (type 200k)

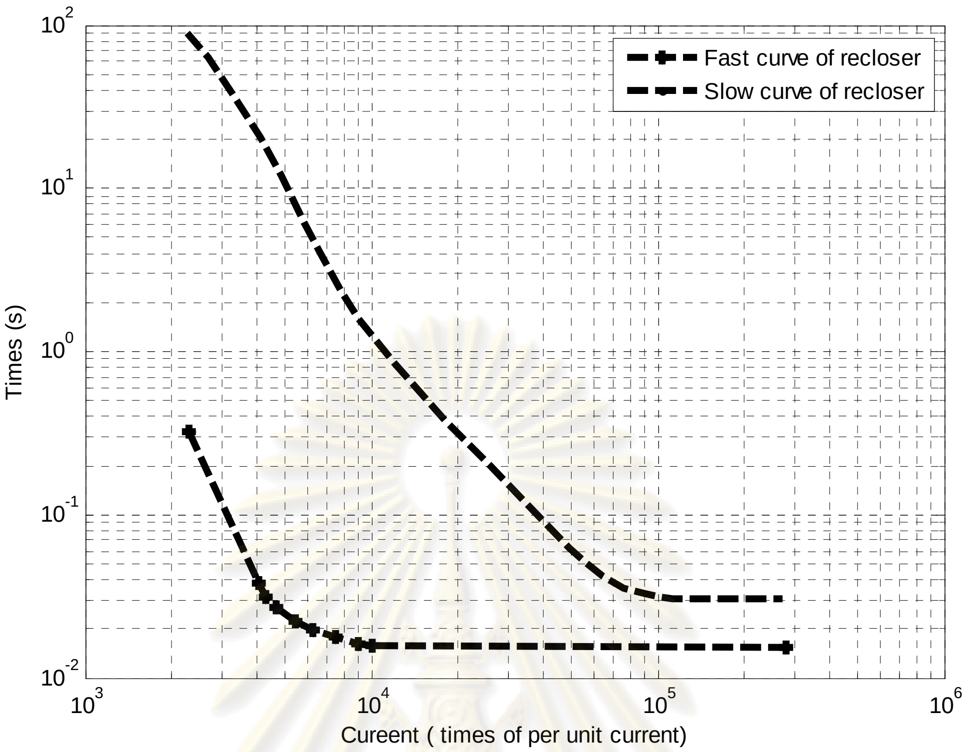

Figure 3-2 Time-current curve of recloser(102 and 165 type)

Figure 3.2 shows the time-current characteristic of recloser (type 102 and 165). There are two curves of slow switching and fast switching. According to the amount of fault current, the operating time of fuse and recloser can be focused.

3.3 Co-ordination of fuse and recloser

The following basic criteria should be employed when co-ordinating time/current devices in distribution system:

1. The main protection should clear a permanent or temporary fault before the backup protection operates, or continue to operate until the circuit is disconnected. However, if the main protection is a fuse and the backup protection is a recloser, it is normally acceptable to co-ordinate the fast operating curve or curves of the recloser to operate first.
2. Loss of supply caused by permanent faults should be restricted to the smallest part of the system for the shortest time possible.

In this thesis, the impact of recloser-fuse co-ordination on system reliability will be analyzed. The criteria for determining recloser-fuse co-ordination depend on the relative locations of these devices, i.e. whether the fuse is at the source side and then backs up the operation of the recloser that is at the load side, or vice versa. These possibilities are treated in the following paragraphs. Figure 3.4 shows time-current curve of fuse-recloser coordianation.

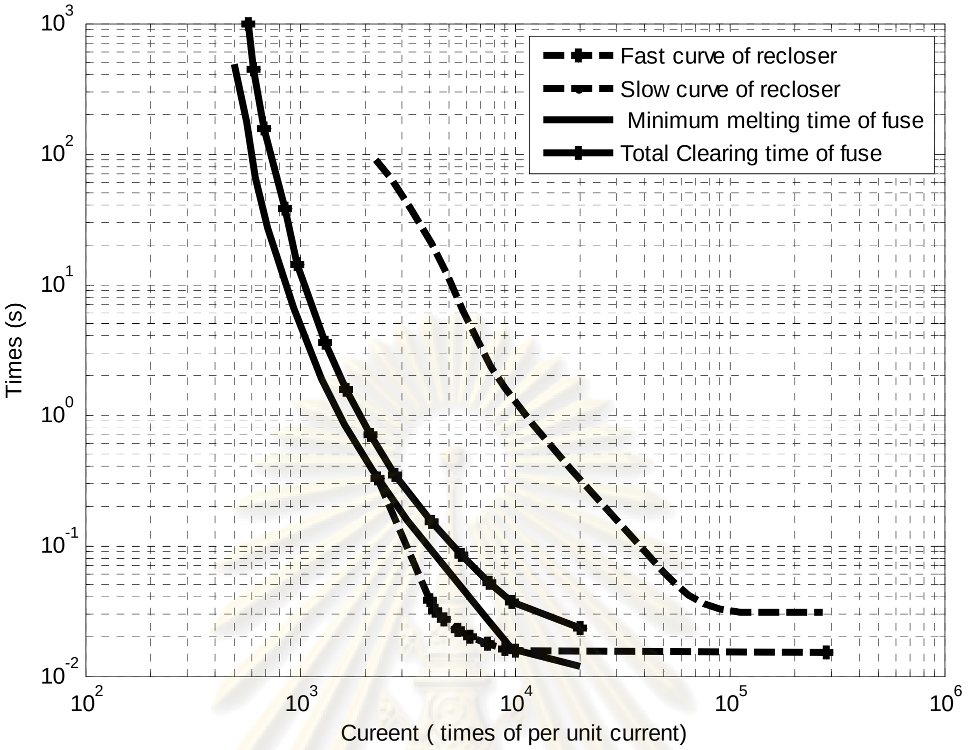

Figure 3-3 Characteristic curve of fuse and recloser coordination

3.4 Protection system response on radial system

The protection system response of a radial distribution system is straightforward since fault energy can be assumed to flow downstream from the source of power to the fault location. If the protection system is properly coordinated and operates correctly, the protection device nearest to the fault will operate before other upstream devices. Slight modifications of this rule occur when reclosing devices are utilized in an attempt to allow temporary faults to clear. The two basic reclosing schemes are fuse saving and fuse clearing. Fuse saving allows all temporary faults a chance to automatically clear and results in fewer sustained interruptions but more momentary interruptions. Fuse clearing allows lateral fuses to clear all downstream faults and results in fewer momentary interruptions but more sustained interruptions [8]. Figure 3.4 shows a simple radial system with fuse-recloser coordination.

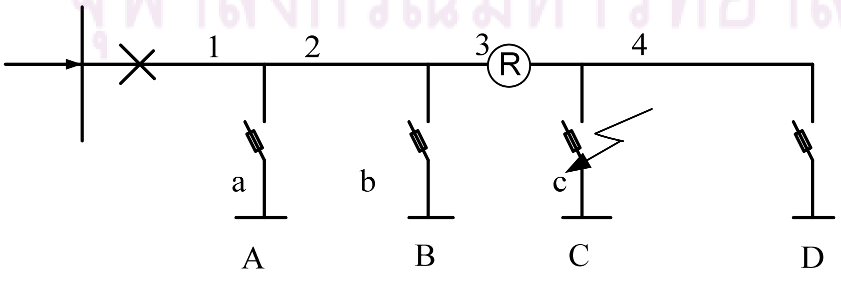

Figure 3-4 a simple radial system

3.4.1 Reclosing with Fuse Saving

After a fault occurs, the nearest upstream reclosing device opens without any intentional delay (initiated by an instantaneous relay). After a brief delay, the device recloses. If the fault persists, the device may operate several more times with increasing delays. If the fault still persists, the reclosing device will lock out. If a temporary fault occurs on a fused lateral with a reclosing device upstream of the fuse, the reclosing device will operate first and "save" the fuse. Fuse-saving schemes are also referred to as feeder selective relaying [8]. Suppose a fault occurs at lateral C as shown in figure 3.5, the recloser will operate first and save the fuses at lateral. In this thesis, this scheme will be considered.

3.4.2 Reclosing (Fuse Clearing)

In this scheme, reclosing devices have their instantaneous relays disabled. If a temporary fault occurs on a fused lateral with a reclosing device upstream of the fuse, the fuse will blow before the recloser's time overcurrent relay operates. Fuse-clearing schemes are also referred to as instantaneous relay blocking. Reclosing schemes have a substantial impact on customer reliability. As such, it is critical to model them accurately when simulating a contingency. Rarely does such a simple and inexpensive act (i.e., enabling or blocking an instantaneous relay) have such a large impact on system performance, with some customers experiencing improved reliability and other customers experiencing degraded reliability[8]. Figure 3.6 shows a simple radial system. Suppose a fault is located as shown in figure 3.5, the fuse will blow before the recloser operates.

3.5 Improving Reliability

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

The first step towards improving reliability is to place a protective device, typically a fuse, on all radial branches. Both field experience and reliability studies show conclusively that laterals should be fused. The only compelling reasons not to fuse a lateral are nuisance fuse blowing (which can generally be avoided by specifying larger fuses) and the inability to coordinate. Three-phase laterals may require devices with 3 phase lockout capability if they serve large motors which may be damaged by unbalanced voltages, or transformers with primary delta-connected windings, which may create safety problems due to the possibility of backfeeding. The effectiveness of lateral fusing increases as total lateral exposure increases and as average lateral length decreases. Assuming perfect fuse operation, a fault on an unfused lateral will interrupt the entire feeder while a fault on a fused lateral will only interrupt customers on the lateral.

Main trunk protection, typically in the form of a recloser, can also be an effective method of improving feeder reliability. Reclosing devices are most commonly used to allow temporary faults on over head systems to self-clear. Placing a line recloser on a feeder will improve the reliability of all upstream customers by protecting them from downstream faults. As such, an effective method of improving reliability for a specific customer is to place a recloser just downstream of its service connection [8]. The analysis of reliability improvement will be conducted for the following cases.

(1) Effect of lateral protection
(2) Effect of disconnection switches , and
(3) Effect of fuse-recloser coordination

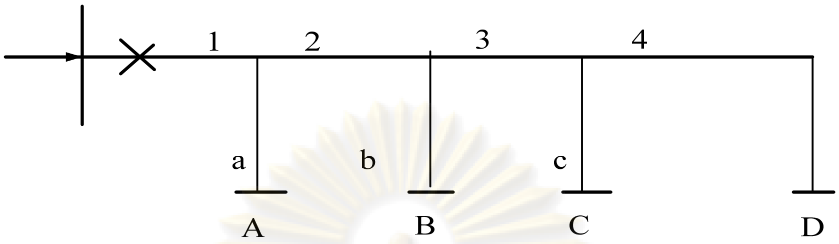

Figure 3-5 Typical radial distribution network

Table 3-1 Basic System data of figure 3-5

Component	λ (f/yr)	r(hours)	Load point	No of customers	Average Load connected(kW)
Section			A	1000	5000
1	0.2	4			
2	0.1	4			
3	0.3	4	B	800	4000
4	0.2	4			
Distributor					
a	0.2	2	C	700	3000
b	0.6	2			
c	0.4	2			
d	0.2	2	D	500	2000

Using protective device on radial system has a great effect on reliability of the system. In this thesis the protection failure is not considered and only permanent fault is taken into account. Typical radial distribution network is shown in figure 3.5. This system will be used as an example system. Reliability and load data are shown in table 3.1 [1].

Table 3-2 Basic load point indices for example system

	Load point A			Load point B			Load point C			Load point D		
C	λ	r	U	λ	r	U	λ	r	U	λ	r	μ
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
3	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2
4	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
a	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4	0.2	2	0.4
b	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**	**0.6**	**2**	**1.2**
c	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**	**0.4**	**2**	**0.8**

d	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**	**0.2**	**2**	**0.4**
Total	2.2	2.73	6.0	2.2	2.73	6.0	1.0	2.73	6.0	2.2	2.73	6.0

Firstly, basic indices for each laod point can be calculated using equations (2.1), (2,2) and (2.3). The results are shown in table 3.2. In this case, no protective device is used in the sytem. With the obtained the basic load point indices, system indices and energy-oriented indices can be calculated according to on equations (2.4), (2.5), (2.6) , (2.8) and (2.9).

SAIFI = (2.2+2.2+2.2+2.2)/4
= 2.2 interruptons/customer yr

SAIDI = (6.0+6.0+6.0+6.0)/4
= 6.0 hours/customer yr

CAIDI = (2.73+2.73+2.73+2.73)/4
=2.73 hours/customer interruption

$$\mathrm{ENS} = \mathrm{SAIDI} \times \text{Total load}$$
=6 x 14MW
=84 MWh/yr

$$\mathrm{AENS} = \frac{\mathrm{ENS}}{\text{numbe s of customer}}$$

=28 kWh/customer yr

3.5.1 Effect of Lateral Distributor Protection

Additional protection is frequently used in practical distribution systems. One possibility in the case of the system shown in figure 3.5 is to install Fusegear at the tee-point in each lateral distributor as shown in figure 3.6. In this case a short circuit on a lateral distributor causes its appropriate fuse to blow; this causes disconnection of its load point until the failure is repaired but does not affect or cause the disconnection of any other load point. They system reliability indices are therefore modified to those shown in table 3.3.

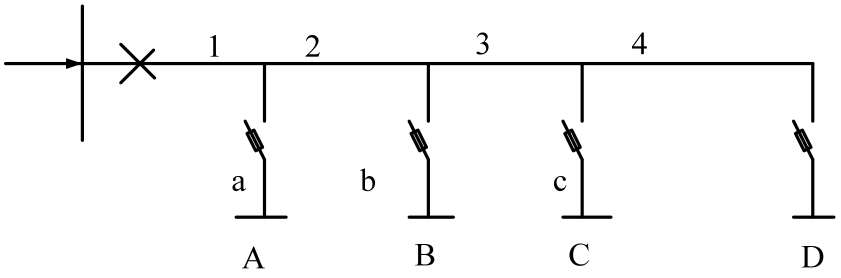

Figure 3-6 Network of figure 3.6 reinforced with Fusegear

Table 3-3 Impact of fuse on system reliability indices

	Load point A			Load point B			Load point C			Load point D		
C	λ	r	U	λ	r	U	λ	r	U	λ	r	μ
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
3	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2	0.3	4	1.2
4	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
a	0.2	2	0.4									
b				**0.6**	**2**	**1.2**						
c							**0.4**	**2**	**0.8**			
d										**0.2**	**2**	**0.4**
Total	1.0	3.6	3.6	1.4	3.14	4.4	1.2	3.33	4.0	1.0	3.6	3.6

In this case, the reliability indices are improved for all load points although the amount of improvement is different for each one. The most unreliable load point is B because of the dominant effect of the failures on its lateral distributor 0.6 f/yr compared with 0.4 and 0.2 f/yr on other laterals. The additional indices for this system can be calculated as shown belows.

$$SAIFI = \frac{(1.0+1.4+1.2+1.0)}{4}$$

=1.15 interruption/customer yr

$$\text{SAIDI} = \frac{\text{sum of } \mu}{\text{total number of loadpoints}}$$

$$\text{SAIDI} = \frac{(3.6+4.4+4.0+3.6)}{4}$$

= 3.91 hours/customer yr

$$\text{CAIDI} = \frac{\text{sum of } r}{\text{total number of loadpoints}}$$

$$\text{CAIDI} = \frac{(3.6+3.14+3.33+3.6)}{4}$$

= 3.39 hours/customer interruption

$$\text{ENS} = \text{SAIDI} \times \text{Total Load}$$

$$\text{ENS} = 3.91 \times 14 = 54.8 \text{ MWh/yr}$$

$$\text{AENS} = \frac{\text{ENS}}{\text{numbe s of customer}}$$

=18.3 kWh/customer yr

Comparing the results of the system between the case of without using protective device and the case of using fuse, the energy not suppy of the system, ENS is reduced from 84 MWh/yr to 54.8 MWh/yr.

3.5.2 Effect of Lateral Protection and Disconnecting Switches

A second of alternative reinforcement of improvement scheme is the provision of disconnects or isolators at judicious points along the main feeder. These are generally not fault-breaking switches and therefore any short circuit on a feeder still causes the main breaker to operate. After the fault has been detected, however, the relevant disconnecting switch can be opened and the breaker reclosed. This procedure allows restoration of all load points between the supply point and the point of isolation be installed in the previous system as shown in figure 3.7 and let the total isolation and switching time be 0.5 hours.

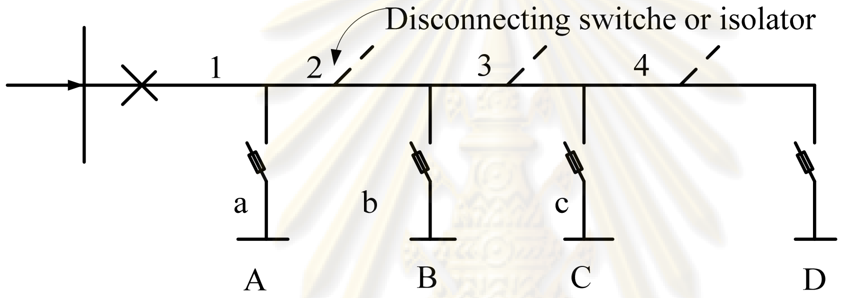

Figure 3-7 Network of figure 3.6 reinforced with Fusegears and disconnecting swtiches

The reliability indices for the four load points are now modified to those shown in table 3.4. In this case, the reliability of load points A,B,C are improved, the amount of improvement being greater for those near to the supply points and less for those further from it. The indices of load point D remain unchanged because isolation cannot remove the effect of any failure on this load point.

Table 3-4 Impact of fuse and disconnecting switches on system reliability

	Load point A			Load point B			Load point C			Load point D		
C	λ	r	U	λ	r	U	λ	r	U	λ	r	μ
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0.1	0.5	0.05	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
3	0.3	0.5	0.15	0.3	0.5	0.15	0.1	4	1.2	0.3	4	1.2
4	0.2	0.5	0.1	0.2	0.5	0.1	0.2	0.5	0.1	0.2	4	0.8
a	0.2	2	0.4									
b				**0.6**	**2**	**1.2**						
c							**0.4**	**2**	**0.8**			
d										**0.2**	**2**	**0.4**
Total	1.0	1.5	1.5	1.4	1.89	2.65	1.2	2.75	3.3	1.0	3.6	3.6

Based on the obtained basic indices and evaluation techniques described in chapter 2, the additional indices can be calculated as shown below.

$$\mathrm{SAIFI} = \frac{\text{sum of } \lambda}{\text{total number of loadpoints}}$$

$$SAIFI = \frac{(1.0 + 1.4 + 1.2 + 1.0)}{4}$$

$$=1.15 \text{ interruption/customer yr}$$

$$\mathrm{SAIDI} = \frac{\text{sum of } \mu}{\text{total number of loadpoints}}$$

$$\mathrm{SAIDI} = \frac{(1.5 + 2.65 + 3.3 + 3.6)}{4}$$

$$= 2.58 \text{ hours/customer yr}$$

$$\mathrm{CAIDI} = \frac{SAIDI}{\mathrm{SAIFI}}$$

$$\mathrm{CAIDI} = \frac{2.58}{1.15}$$

$$= 2.24 \text{ hours/customer interruption}$$

$$\mathrm{ENS} = \mathrm{SAIDI} \times \text{Total Load}$$

$$\mathrm{ENS} = 2.58 \times 14 = 35.2 \text{ MWh/yr}$$

$$\mathrm{AENS} = \frac{\mathrm{ENS}}{\text{numbe s of customer}}$$

$$=11.7 \text{ kWh/customer yr.}$$

3.5.3 Effect of Fuse-recloser Coordination

Using fuse-relcoser coordination on system can help reliability improve. If a fault occurs on sections beyond recloser, it will be tripped out and can not affect on other section before recloser. As well, recloser can also be used as fuse saving scheme. Figure 3.8 shows the radial system with fuse-recloser coordination.Suppose a fault at section 4, the recloser will cut off it from the system and the load points A and B will not be interrupted.

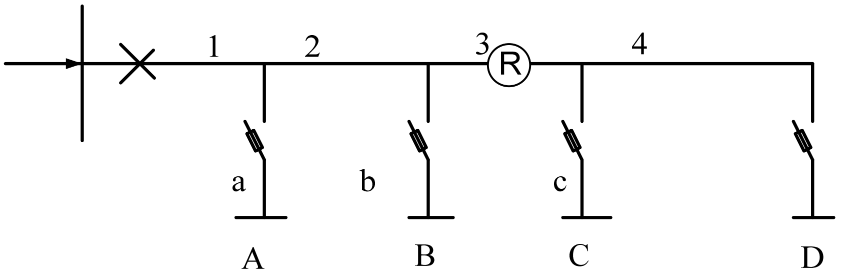

Figure 3-8 Network of figure 3.6 reinforced with fuse-recloser coordination

Table 3-5 Impact of fuse-recloser coordination on system reliability

	Load point A			Load point B			Load point C			Load point D		
C	λ	r	U	λ	r	U	λ	r	U	λ	r	μ
1	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8	0.2	4	0.8
2	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4	0.1	4	0.4
3	-	-	-	-	-	-	0.3	4	1.2	0.3	4	1.2
4	-	-	-	-	-	-	0.2	4	0.8	0.2	4	0.8
a	0.2	2	0.4									
b				**0.6**	**2**	**1.2**						
c							**0.4**	**2**	**0.8**			
d										**0.2**	**2**	**0.4**
Total	0.5	3.2	1.6	0.9	2.67	2.4	1.2	3.33	4.0	1.0	3.6	3.6

Based on obtained basic indices and the evaluation techniques described in chapter 2, additional indices can be calculated as shown below.

$$\text{SAIFI} = \frac{\text{sum of } \lambda}{\text{total number of loadpoints}}$$

$$SAIFI = \frac{(0.5 + 0.9 + 1.2 + 1.0)}{4}$$

$$= 0.9 \text{ interruption/customer yr}$$

$$\text{SAIDI} = \frac{\text{sum of } \mu}{\text{total number of loadpoints}}$$

$$\text{SAIDI} = \frac{(1.6 + 2.4 + 3.3 + 3.6)}{4}$$

$$= 2.725 \text{ hours/customer yr}$$

$$\text{CAIDI} = \frac{SAIDI}{\text{SAIFI}}$$

$$\text{CAIDI} = \frac{2.58}{1.15}$$

$$= 3.028 \text{ hours/customer interruption}$$

$$\text{ENS} = \text{SAIDI} \times \text{Total Load}$$

$$\text{ENS} = 2.58 \times 14 = 38.15 \text{ MWh/yr}$$

$$\text{AENS} = \frac{\text{ENS}}{\text{numbe s of customer}}$$

$$=12.72 \text{ kWh/customer yr.}$$

3.5.4 Comparison of System Reliability

The system reliability level can be compared according to four cases, i.e.

Case A: no protective device is used,
Case B: fuse is used as lateral protection.,
Case C: fuse and disconnecting switches are used and
Case D: fuse-recloser coordination, with no disconnecting switche.

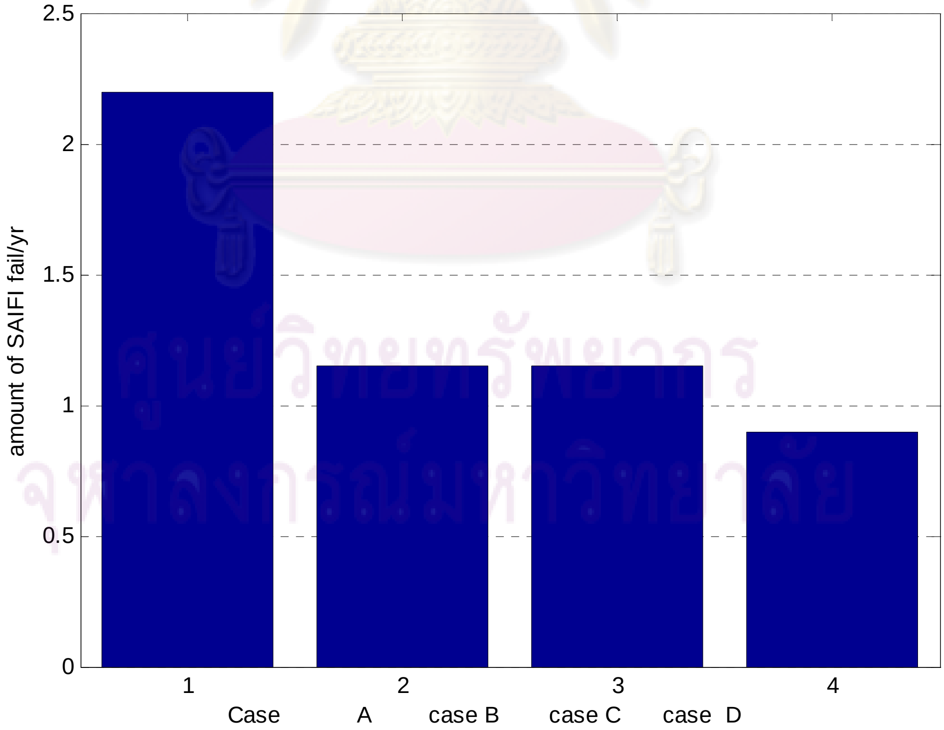

Figure 3-9 Comparison of SAIFI

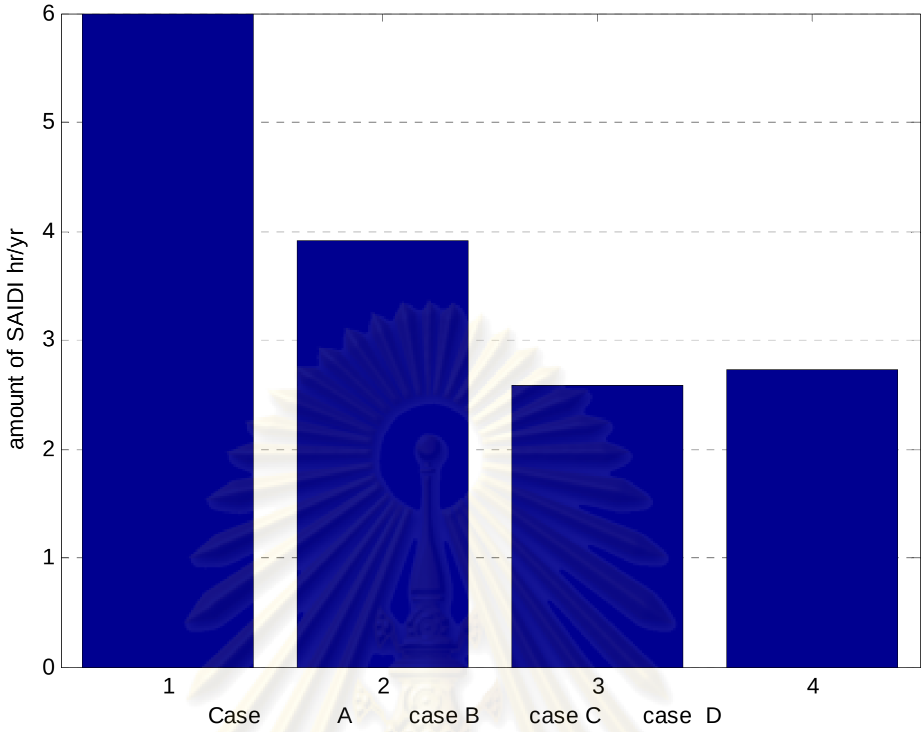

Figure 3-10 Comparison of SAIDI

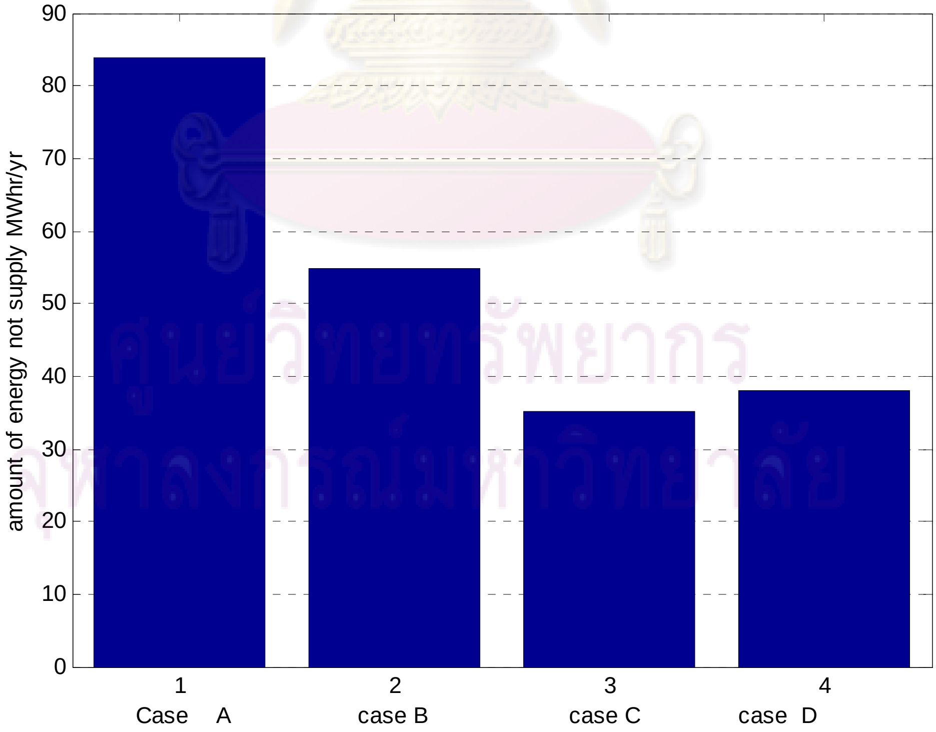

Figure 3-11 Comparison of Energy not supply for each case

Figure 3.9 shows the comparison of SAIFI. In Case A, the SAIFI is 2.2 fail/yr. With fuse, the SAIFI increases to 1.15 fail/yr in cases B and case C. There is no effect of disconnecting switches on SAIFI. In case D, with fuse-recloser coordination, SAIFI is increased to 0.9 fail/yr. Therefore, we can conclude that fuse-recloser coordination is the best protection scheme to improve SAIFI of system according the results.

Figure 3.10 shows the comparison of SAIDI. The SAIDI in Case A, with no protective device, is 6 hr/yr. In case B, with fuse, it decreases 6 to 3.91 hr/yr.
In case C, with fuse and disconnecting switches, SAIDI is decreased from 6 to 2.58 hr/yr. In case D, fuse-recloser coordination results in the value of SAIDI of 2.725 if compared with case A.

Figure 3.11 shows the comparison of ENS. Case A with no protective device has amount of ENS 84 MWhr/yr. with fuse, it can improve to 54.8 MWhr/yr. Using fuse and disconnecting switches, it can improve ENS to 35.2 MWhr/yr which is the best case for this system reliability. Fuse-recloser coordination has also great impact on ENS compared with case A. It can make the system ENS improve to 38.15 MWhr/yr.

It is clearly seen that protective devices help improve system reliability.

CHAPTER IV

FAULT CALCULATION AND VOLTAGE DIP

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 [7].

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.

4.1 Characteristic 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 [9].

4.1.1 Types of faults

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 [9].

4.1.2 Causes of faults

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 classical 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 [9].

4.2 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 [10]. In this theses, balanced three-phase 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.

4.2.1 Systematic 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 respresent by a constant voltage source behind proper reactance which may be $X''_d, X'_d, \text{or} X_d$. 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 Z_f. The perfault bus voltages , V_{bus} are obtained from the power flow solution and are represented by the column vector.

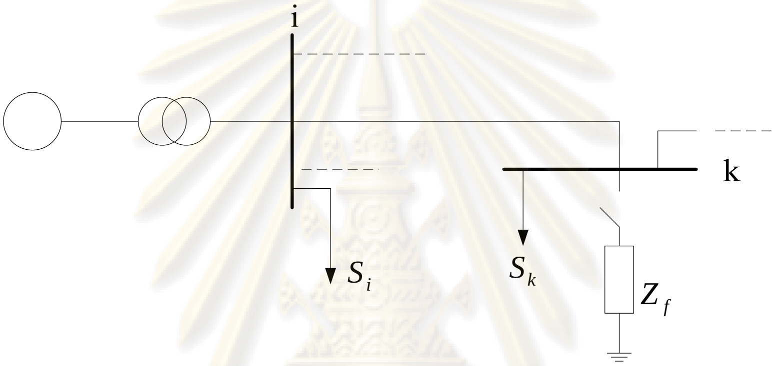

Figure 4-1 A typical bus of a powr system

$$V_{bus} = \begin{bmatrix} V_1(0) \\ - \\ - \\ V_k(0) \\ - \\ - \\ V_n(0) \end{bmatrix} \tag{4.1}$$

The changes in the network voltage caused by the fault with impedance Z_f is equivalent to those caused by the added voltage $V_k(0)$ 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 4.2. the bus voltage change caused by the fault in this circuit are represented by equation (4.2).

$$\Delta V_{bus} = \begin{bmatrix} \Delta V_1(0) \\ - \\ - \\ \Delta V_k(0) \\ - \\ - \\ \Delta V_n(0) \end{bmatrix} \tag{4.2}$$

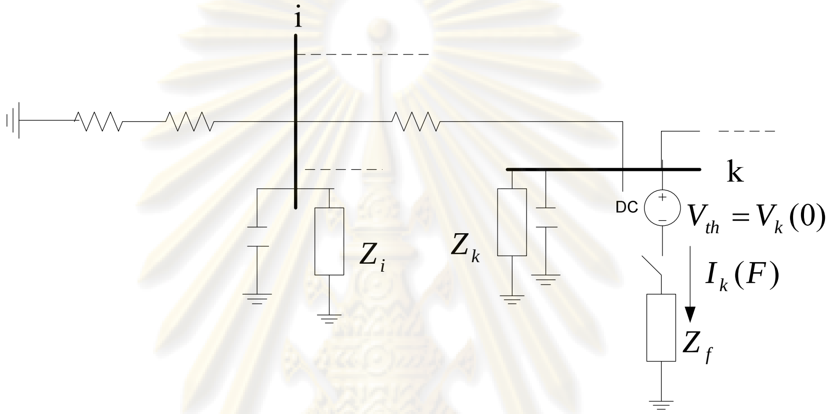

Figure 4-2 Thevenin's circuit of figure 4.1

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 (4.3). The injected bus currents, I_{bus} are expressed in terms o 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.

$$V_{bus}(F) = V_{bus}(0) + \Delta V_{bus} \tag{4.3}$$

$$I_{bus} = Y_{bus} V_{bus}$$
(4.4)

In the thevenin's circuit of figure 4.2, current entering every bus is zero except at the faulted bus. Since the current at aulted 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).

$$\begin{bmatrix}0\\ \cdot\\ \cdot\\ \cdot\\ -I_k(F)\\ \cdot\\ \cdot\\ \cdot\\ 0\end{bmatrix} = \begin{bmatrix} Y_{11} & \cdot & \cdot & .Y_{1k} & \cdot & \cdot & .Y_{11}\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ Y_{k1} & \cdot & \cdot & .Y_{kk} & \cdot & \cdot & .Y_{kn}\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ Y_{n1} & \cdot & \cdot & .Y_{nk} & \cdot & \cdot & .Y_{nn}\end{bmatrix} \begin{bmatrix}\Delta V_1\\ \cdot\\ \cdot\\ \cdot\\ \Delta V_k\\ \cdot\\ \cdot\\ \cdot\\ \Delta V_n\end{bmatrix} \qquad (4.5)$$

Or $I_{bus}(F) = Y_{bus}\, \Delta V_{bus}$ (4.6)

The changes in the bus voltage is

$$\Delta V_{bus} = Z_{bus} I_{bus}(F) \qquad (4.7)$$

Where Z_{bus} is inversed of Y_{bus}. Substituting (4.7) to (4.3), the bus voltage vector during fault becomes (4.8) and equation in terms of its element is in (4.9).

$$V_{bus}(F) = V_{bus}(0) + Z_{bus} I_{bus}(F) \qquad (4.8)$$

$$\begin{bmatrix}V_1(F)\\ \cdot\\ \cdot\\ \cdot\\ V_k(F)\\ \cdot\\ \cdot\\ \cdot\\ V_n(F)\end{bmatrix} = \begin{bmatrix}V_1(0)\\ \cdot\\ \cdot\\ \cdot\\ V_k(0)\\ \cdot\\ \cdot\\ \cdot\\ V_n(0)\end{bmatrix} \begin{bmatrix} Z_{11} & \cdot & \cdot & .Z_{1k} & \cdot & \cdot & .Z_{1n}\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ Z_{k1} & \cdot & \cdot & .Z_{kk} & \cdot & \cdot & .Z_{kn}\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ \cdot & & \cdot & \cdot & & \cdot & \cdot\\ Z_{n1} & \cdot & \cdot & .Z_{nk} & \cdot & \cdot & .Z_{nn}\end{bmatrix} \begin{bmatrix}0\\ \cdot\\ \cdot\\ \cdot\\ -I_k(F)\\ \cdot\\ \cdot\\ \cdot\\ 0\end{bmatrix} \qquad (4.9)$$

Since we have only single nonzero element in the current vector, the kth equation of (4.9) becomes to (4.10).

$$V_k(F) = V_k(0) - Z_{kk} I_k(F) \qquad (4.10)$$

Also from the Thevenin's circuit shown in figure 4.2, we have

$$V_k(F) = Z_f I_k(F) \qquad (4.11)$$

For bolted fault, $Z_f = 0$ and $V_k(F) = 0$. Substituting these values into (4.10), the fault current becomes

$$I_k(F) = \frac{V_k(0)}{Z_{kk} + Z_f} \tag{4.12}$$

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.

$$V_i(F) = V_i(0) - \frac{Z_{ik}}{Z_{kk} + Z_f} V_k(0) \tag{4.13}$$

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.

4.3 Voltage dip

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 [4].

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" [8]. An example of voltage dip characteristic is shown in figure 4.3.

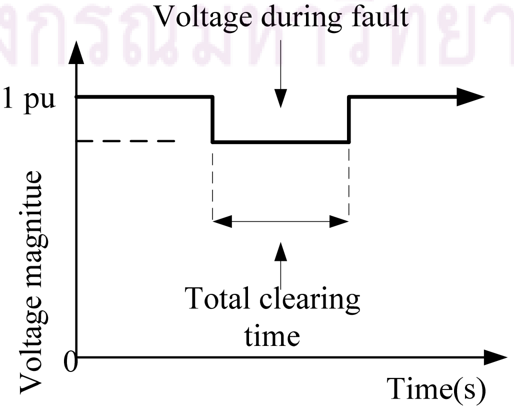

Figure 4-3 Example of voltage dip curve

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 your 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 4.1 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 [11].

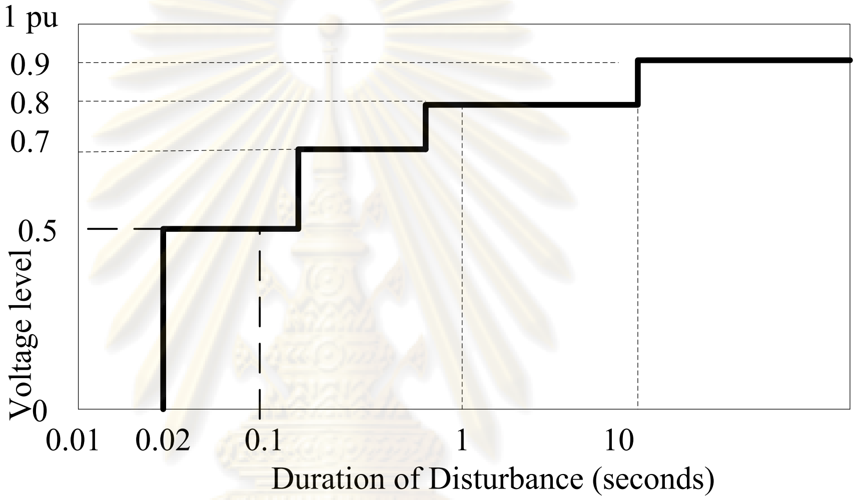

Figure 4-4 Voltage Envelope curve of SEMI F47[11]

Duration of dips is mainly determined by the fault clearing time. Generally speaking 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 [12].

4.4 Impact of voltage dip on system reliability

There are two kinds of impact on system reliability due to voltage dip in my thesis.

(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.

To focus impact of voltage dip, voltage and current during fault have to be calculated firstly.

Figure 4.5 shows the example test system to study fault calculation. Base MVA is 25 and base voltage is 11 kV. Base current is 2272 kA. Impedance data of system is shown in table 4.1. Using the evaluation techniques shown in section 4.2, voltage and current during fault can be calculated as shown in table 4.2.

Table 4-1 Impedance data of example test system

branch	From bust	To bus	R	X
1	0	1	0.0731	0.0567
2	1	2	0.0731	0.0567
3	2	3	0.0731	0.0567
4	3	4	0.0585	0.0454
5	1	5	0.0585	0.0454
6	1	6	0.0780	0.0605
7	2	7	0.0780	0.0605
8	2	8	0.0585	0.0454
9	3	9	0.0780	0.0605
10	3	10	0.0731	0.0567
11	4	11	0.0780	0.0605

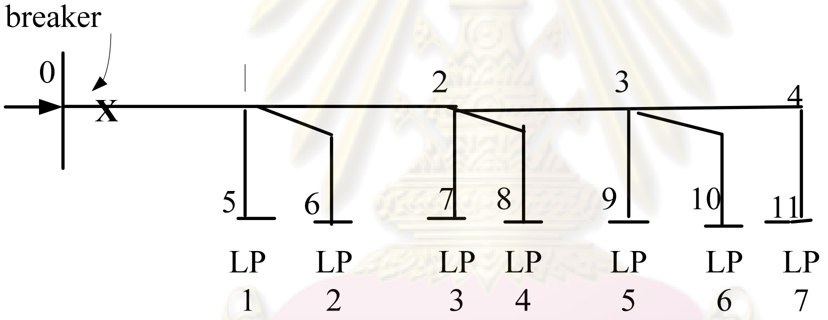

Figure 4-5 Sample test system

Table 4-2 Voltage during fault and fault current when fault occur at branch 10

Load point	Voltage during fault	Total fault current
1	0.7500	2.7011 per unit or 6138 kA.
2	0.7500	
3	0.5000	
4	0.5000	
5	0.2500	
6	0.0000	
7	0.2500	

Table 4-3 Voltage and current during fault when fault occur at branch 4

Load points	Voltage during fault	Total fault current
1	0.7368	2.8433 per uint or 6460 kA
2	0.7368	
3	0.4737	
4	0.4737	
5	0.2105	
6	0.2105	
7	0.0000	

4.4.1 Impact of voltage dip on the reliability of system with fuse

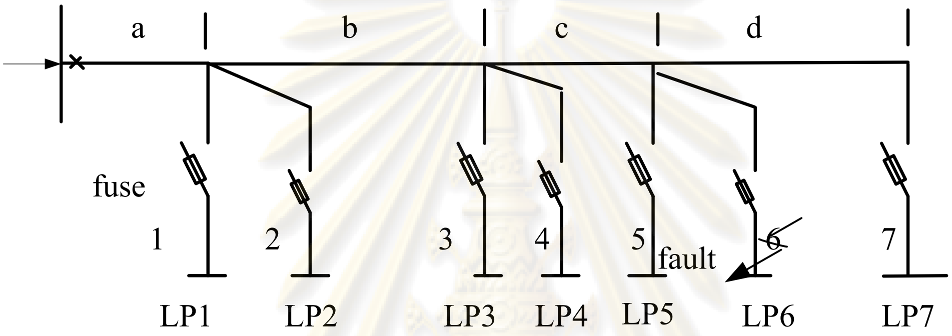

Figure 4-6 Example test system with fuse

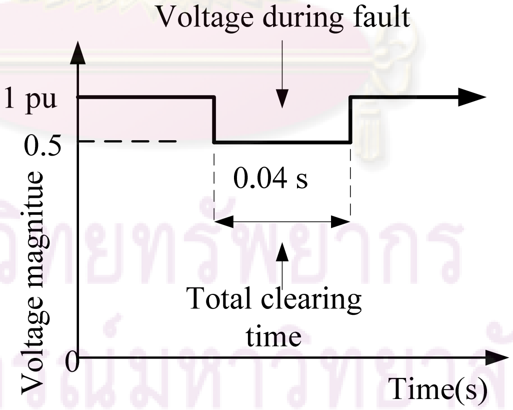

Figure 4-7 Characteristic curve of voltage dip at loat point 4

In general, suppose a fault occurs on laterals, the fuse will be trip out theirself 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 6 and the fuse will trip out only load LP 6 from the system. In this case, impact of voltage dip is not considered and we assumed that other load points can stand the voltage dip caused by fault. Actually, every load point can not 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 using fuse is shown in figure 4.6.

Suppose when a fault occurs at lateral 6 we will focus the impact of voltage on load point 4. The voltage dip level at this load point is 0.5 pu and fault current is 6138 kA. According to the time-current characteristic curve of fuse shown in figure 3.1, the total clearing time of fuse is 0.04 seconds. Therefore, the characteristic curve of the voltage dip at load point 4 becomes figure 4.7.

The curve of voltage dip has to be compared with the voltage envelope curve of figure 4.4. According the comparison of two curves, the customer can stand only 0.02 seconds at voltage level of 0.5 pu. So there has an impact of voltage dip on load point 4 . Generally to evaluate the reliability indices at load point 4, we don’t need to consider the interruptions of branch 10 as fuse is used. However, if we take into account impact of voltage dip, the voltage dip at load point 4 is violated the envelope curve. Therefore, to consider reliability of load point 4, we also need to take into account the interruption of lateral 6.

4.4.2 Impact of Voltage Dip on the Reliability of System with Fuse-recloser Coordination

Figure 4.8 shows example test system with fuse-recloser coordination protection. In general, suppose a fault occurs on sections 4 and 3, the recloser will be trip out theirself 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 levels at load points are satisfactory or not for customer. If the customer cannot tolerant the voltage dip, they will be cut off from the supply.

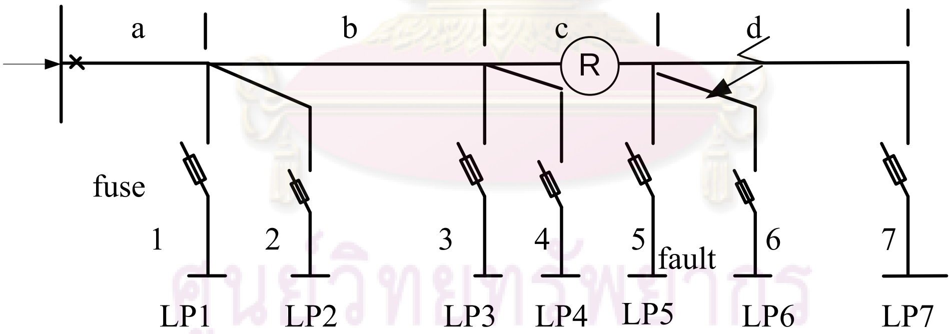

Figure 4-8 Example test system with fuse-recloser coordination

Suppose a fault occurs at section d, the recloser will be trip out the faulted location and load point 7 will be cut off. There is no effect on other load points. If we focus on load point 1, the voltage during fault is 0.7368 pu and fault current is 6460 kA. Using time-current characteristic curve of figure 3.3, the voltage dip characteristic curve become as shown in figure 4.9.

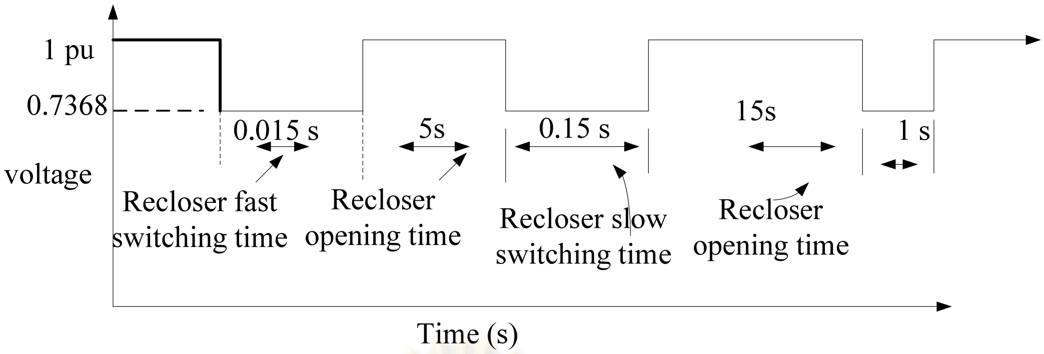

Figure 4-9 Characteristic curve of voltage dip at load point 1

The voltage dip curve of load point 1 has to be compared with voltage envelope cure of figure 4.4. The customer can stand only 0.8 seconds at voltage level of 0.7368 pu. So the dip violates the envelope curve. Generally, the interruption at section d is not considered to focus on load point 1 because of using recloser. However, there is an impact of voltage dip and it become to take into account interruption of section d .

CHAPTER V

TEST RESULTS AND DISCUSSION

In this chapter, there are mainly two parts to study impact of protection system operation and impact of voltage dip on system reliability. Using the evaluation techniques from chapter 2 and knowledge of chapter 3, the impact of protection system operation on system reliability can be focused. According to the methods from chapter 4, voltage and current during fault can be obtained using fault calculation. To find the voltage dip characteristic curve, the time-current curves from chapter 3 and the results from fault calculation have to be used. In this thesis, Reliability Test System of RBTS bus 2 is used as a test system.

5.1 Data for RBTS bus 2

The Reliability Test System of RBTS bus 2 is shown in figure 5. There is a single 11 kV supply point for with 20 MW load on this network. The feeders are operated as radial feeders although they are connected as a mesh through normally open sectionalizing points. Component reliability data for the RBTS distribution system are shown in Table 5.1. Table 5.2 shows types of feeder and their lengths as well customer data and load data are shown in Table 5.3. All the data are from brought [2] and [5]. In this test, only the 11kV feeders are taken into account while any failure in the 33kV system, the 33/11kV substation ,and the 11kV breakers are ignored.

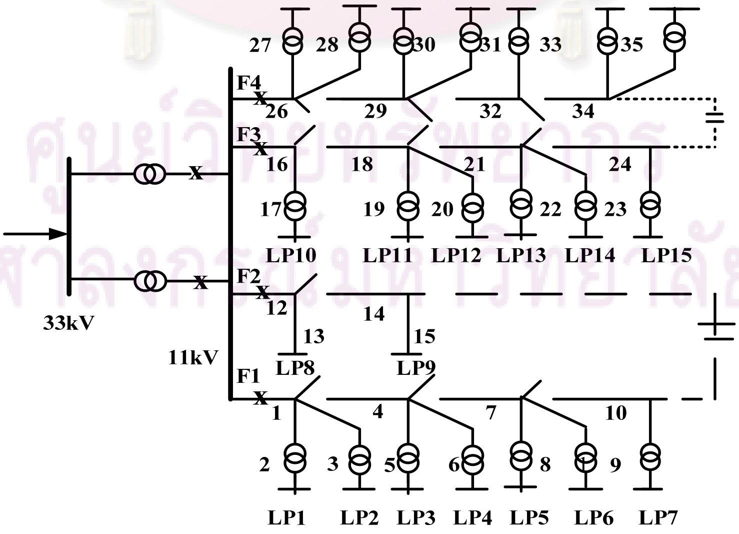

Figure 5-1 One line diagram of RBTS bus2

Table 5-1 Component reliability data for RBTS distribution system

Type	λ_m	λ_a	r	r_p	S
Transformer					
33/11kV	0.05	0.015	--	15.0	1.0
LT	-----	0.015	200.0	10.0	1 .0
Breakers					
33kV	0.002	0.0015	4.0	---	1.0
11kV	0.006	0.0040	4.0	---	1 .0
Bus bars					
33kV	0.001	0.001	2.0	---	1.0
11lkV	0.001	0.001	2.0	---	1 .0
Lines					
33kV	0.060	0.046	8.0	---	2.0
11kV	-----	0.065	5.0	---	1.0
Cables					
11kV	-----	0.040	30.0	---	3.0

Note: Lines and Cables failure rates are in f/yr-km. Where LT is lateral transformer, λ_m is momentary failure rate (f/yr), λ_a is active failure rate (f/yr) , r is repair time(hr) , r_p is replacement time of transformer and s is switching time (hr).

Table 5-2 Feeder type and length

Type	Length(km)	feeder section numbers
1	0.6	2 , 6 , 10 , 14 , 17, 21, 25, 28 , 30 , 34
2	0.75	1 , 4, 7, 9, 12, 16 , 19 , 22 , 24 , 27, , 29 , 32 , 35
3	0.8	3 , 5 , 8 ,11 , 13, 15 ,18 , 20 , 23, 26, 31 , 33, 36

Table 5-3 Customer number and load data

Loads Points	Peak Load	Average Load /Load pt (MW)	No of Customer/load pt
1-7	5.934	3.645	652
8-9	3.500	2.15	2
10-15	5.057	3.106	632
16-22	5.509	3.390	622

5.2 Reliability Improvement

To improve reliability, appropriate coordination of protective devices have to be used in the system. In this thesis, three cases will be analysed, i.e.

(1) Effect of lateral protection or fuse.

(2) Effect of fuses and disconnecting switches.

(3) Effect of fuse-recloser coordination in which case disconnecting switches are not considered.

Using the given data in table 5.1, Base case load point reliability indices for RBTS bus 2 system can be calculated as in Table 5.4.

Table 5-4 Basic indices of test system

Feeder	Load Point	Failure Rate	Repair Rate	Outage Time
1	1.0000	0.6260	37.7029	23.6020
	2.0000	0.6260	37.7029	23.6020
	3.0000	0.6260	37.7029	23.6020
	4.0000	0.6260	37.7029	23.6020
	5.0000	0.6260	37.7029	23.6020
	6.0000	0.6260	37.7029	23.6020
	7.0000	0.6260	37.7029	23.6020
2	8.0000	0.1917	5.0104	0.9607
	9.0000	0.1917	5.0104	0.9607
3	10.000	0.5590	36.3900	20.3420
	11.000	0.5590	36.3900	20.3420
	12.000	0.5590	36.3900	20.3420
	13.000	0.5590	36.3900	20.3420
	14.000	0.5590	36.3900	20.3420
	15.000	0.5590	36.3900	20.3420
4	16.000	0.6260	37.7029	23.6020
	17.000	0.6260	37.7029	23.6020
	18.000	0.6260	37.7029	23.6020
	19.000	0.6260	37.7029	23.6020
	20.000	0.6260	37.7029	23.6020
	21.000	0.6260	37.7029	23.6020
	22.000	0.6260	37.7029	23.6020

Table 5-5 customer indices and energy-oriented indices

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
1	0.6260	23.6020	37.7029	86.0293	0.1319
2	0.1917	0.96070	5.0104	2.0656	1.0328
3	0.5590	20.3420	36.3900	63.1823	0.1000
4	0.6260	23.6020	37.7029	80.0108	0.1286

Based on evaluation techniques described in chapter 2, the system indices and energy indices can be calculated. Table 5.5 shows system indices and energy indices. For the base case , no protective device is used in the system.

5.2.1 Effect of lateral distributor protection

In this case, using protective devices, the reliability indices will be calculated. The fusegears will be used as protective devices of lateral. Table 5.6 shows Basic indices , whereas System and energy oriented indices are shown in table 5.7.

Table 5-6 Basic indices of the system with lateral protection

Feeder	Load Point	Failure Rate	Repair Rate	Outage Time
1	1.0000	0.2393	17.2257	4.1212
	2.0000	0.2523	16.5956	4.1863
	3.0000	0.2523	16.5956	4.1863
	4.0000	0.2393	17.2257	4.1212
	5.0000	0.2523	16.5956	4.1863
	6.0000	0.2490	16.7470	4.1700
	7.0000	0.2523	16.5956	4.1863
2	8.0000	0.1397	5.0000	0.6987
	9.0000	0.1397	5.0000	0.6987
3	10.000	0.2425	17.0619	4.1375
	11.000	0.2523	16.5956	4.1863
	12.000	0.2555	16.4481	4.2025
	13.000	0.2523	16.5956	4.1863
	14.000	0.2555	16.4481	4.2025
	15.000	0.2425	17.0619	4.1375
4	16.000	0.2523	16.5956	4.1863
	17.000	0.2425	17.0619	4.1375
	18.000	0.2425	17.0619	4.1375
	19.000	0.2555	16.4481	4.2025
	20.000	0.2555	16.4481	4.2025
	21.000	0.2523	15.0496	3.7963
	22.000	0.2555	16.4481	4.2025

Table 5-7 Customer indices and energy-oriented indices

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
1	0.2481	4.1654	16.7973	15.1827	0.0233
2	0.1397	0.6987	5.0000	1.5023	0.7512
3	0.2501	4.1754	16.7019	12.9688	0.0205
4	0.2509	4.1236	16.4448	13.9789	0.0225

Table According to the results from tables 5.5 and 5. 7 With fuse, the SAIFI of feeder 1 is decreased from 0.626 to 0.2481 fail/yr and SAIDI is decreased from 23. 602 to 3.6138 to 4.1654 hr/yr. Other indices can also be compared.

5.2.2 Effect of fuses and disconnecting switches

In this case, the disconnecting switches or isolators will be used on the main feeders in addition to lateral protection. The modified system reliability can be seen in table 5.8 and table 5.9.

Table 5-8 Basic load point indices of test system

Feeder	Load Point	Failure Rate	Repair Rate	Outage Time
1	1.0000	0.2393	14.9436	3.5753
	2.0000	0.2523	14.4311	3.6403
	3.0000	0.2523	14.4311	3.6403
	4.0000	0.2393	14.9436	3.5753
	5.0000	0.2523	14.4311	3.6403
	6.0000	0.2490	14.5542	3.6240
	7.0000	0.2523	14.2765	3.6013
2	8.0000	0.1397	3.8837	0.5428
	9.0000	0.1397	3.6047	0.5038
3	10.000	0.2425	14.7567	3.5785
	11.000	0.2523	14.3796	3.6273
	12.000	0.2555	14.2603	3.6435
	13.000	0.2523	14.3796	3.6273
	14.000	0.2555	14.2603	3.6435
	15.000	0.2425	14.7567	3.5785
4	16.000	0.2523	14.4311	3.6403
	17.000	0.2425	14.8103	3.5915
	18.000	0.2425	14.7567	3.5785
	19.000	0.2555	14.2603	3.6435
	20.000	0.2555	14.2603	3.6435
	21.000	0.2523	14.2250	3.5882
	22.000	0.2555	14.1076	3.6045

Table According to the results from tables 5.5 and 5.9, it can be known that fuse can improve SAIFI, and disconnecting switches can reduce repair time. With fuse, the SAIFI of feeder 1 is decreased from 0.626 to 0.2481 fail/yr and SAIDI is decreased from 23. 602 to 3.6138 hr/yr. It can be known that fuse can improve SAIFI whereas disconnecting switches can improve SAIDI.

Table 5-9 Energy-oriented of Test system with fuse and disconnecting switches

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
1	0.2481	3.6138	14.5730	13.1722	0.0202
2	0.1397	0.5232	3.7442	1.1250	0.5625
3	0.2501	3.6164	14.4655	11.2326	0.0178
4	0.2509	3.6129	14.4073	12.2476	0.0197

5.2.3 Effect of fuse-recloser coordinatin on system reliability

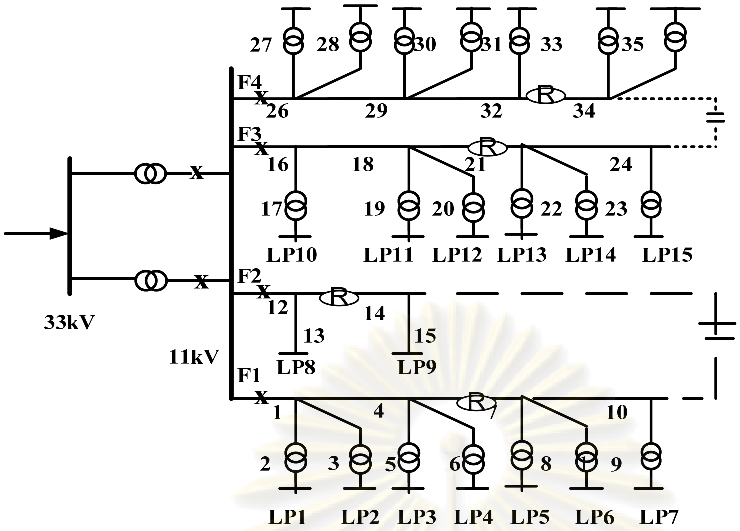

Figure 5-2 Test system with fuse-recloser coordination

Table 5-10 Basic reliability indices

Feeder	Load points	Failure rate	Repair rate	Outage time
1	1	0.1515	24.3069	3.6825
	2	0.1645	22.7812	3.7475
	3	0.1645	22.7812	3.7475
	4	0.1515	24.3069	3.6825
	5	0.2523	16.5956	4.1863
	6	0.2490	16.7470	4.1700
	7	0.2523	16.5956	4.1863
2	8	0.1008	5.0000	0.5038
	9	0.1397	5.0000	0.6987
3	10	0.1548	23.9015	3.6988
	11	0.1645	22.7812	3.7475
	12	0.1678	22.4367	3.7637
	13	0.2523	16.5956	4.1863
	14	0.2555	16.4481	4.2025
	15	0.2425	23.9015	4.1375
4	16	0.1645	22.7812	3.7475
	17	0.1548	23.9015	3.6988
	18	0.2425	17.0619	4.1375
	19	0.1678	22.4367	3.7637
	20	0.2555	16.4481	4.2025
	21	0.2523	15.0496	3 .7963
	22	0.2555	16.4481	4.2025

Table 5-11 System and Energy oriented indices

Feeder	SAIFI	SAIDI	CAIDI	ENS	AENS
1	0.1979	3.9146	20.5878	14.2689	0.0219
2	0.1203	0.6013	5.0000	1.2927	0.6463
3	0.2062	3.9560	21.0108	12.2875	0.0194
4	0.2133	3.9355	19.1610	13.3415	0.0214

In this case, the effect of fuse-recloser coordinaton on system reliability will be focused. Fuses are used at all lateral and recloser is used as shown in figure 5.2. Table 5.10 and 5.11 shows basic reliability, system and energy oriented indices of this case. According to table 5.5 and 5.11, the reliability improvement can be seen clearly. For feeder 1, SAIFI is decreased from 0.626 to 0.1979 fail/yr. SAIDI is decreased from 23.602 to 3.9146 hr/yr. Other indices can also be compared.

5.2.4 Comparison of reliability levels

Reliability level can be compared for four base as shown below:
Case A: no protective device is used.
Case B: fuse is used as lateral protection.
Case C: fuse and disconnecting switches are used.
Case D: fuse-recloser coordination is used and in this case disconnecting switches are not used in the system.

Table 5-12 Comparison of customer indices and energy-oriented indices

	SAIFI	SAIDI	CAIDI	ENS	AENS
Feeder No.	Case (A) :no protective device				
1	0.6260	23.6020	37.7029	86.0293	0.1319
2	0.1917	0.96070	5.0104	2.0656	1.0328
3	0.5590	20.3420	36.3900	63.1823	0.1000
4	0.6260	23.6020	37.7029	80.0108	0.1286
System Total	0.6034	22.4984	37.2891	231.2879	0.1212
Feeder No.	Case (B) : with fuses				
1	0.2481	4.1654	16.7973	15.1827	0.0233
2	0.1397	0.6987	5.0000	1.5023	0.7512
3	0.2501	4.1754	16.7019	12.9688	0.0205
4	0.2509	4.1236	16.4448	13.9789	0.0225
System Total	0.2495	4.1514	16.6368	43.6328	0.0229
Feeder No.	Case (C) : disconnecting switches- fuses-				
1	0.2481	3.6138	14.5730	13.1722	0.0202
2	0.1397	0.5232	3.7442	1.1250	0.5625
3	0.2501	3.6164	14.4655	11.2326	0.0178
4	0.2509	3.6129	14.4073	12.2476	0.0197
System Total	0.2495	3.6111	14.4715	37.7774	0.0198

Feeder	Case (D) : fuse-recloser coordination				
1	0.1979	3.9146	20.5878	14.2689	0.0219
2	0.1203	0.6013	5.0000	1.2927	0.6463
3	0.2062	3.9560	21.0108	12.2875	0.0194
4	0.2133	3.9355	19.1610	13.3415	0.0214
Total	0.2056	3.9317	19.1245	41.1905	0.0216

Customer and Energy-oriented indices or SAIFI, SAIDI, CAIDI, ENS and AENS can be compared in detail as shown in table 5.12. Figure 5.3 shows the comparison of SAIFI. In case B, according to the results, using fuses on the laterals, system total SAIFI is reduced from 0.6034 to 0.2495 fail/yr. Furthermore in case C, if disconnection switches is used on all sections, the index will reduced to the same values as case B. It can be known that there is no impact of disconnecting switches on SAIF. In case D, using fuse-recloser coordination can make SAIFI improve to 0.2056 fail/yr.

Figure 5.4 compares SAIDI results. Case A, with no protective device has SAIDI 22.4984 fail/yr. In case B, it decreases from 22.4984 to 34.1514 hr/yr using of fuse. In case C, with fuse and disconnecting switches, SAIDI is decreased to 14.4715 hr/yr. In case D, fuse-recloser coordination results in the value of SAIDI from 22.4984 to 3.9317 hr/yr if compared with case A.

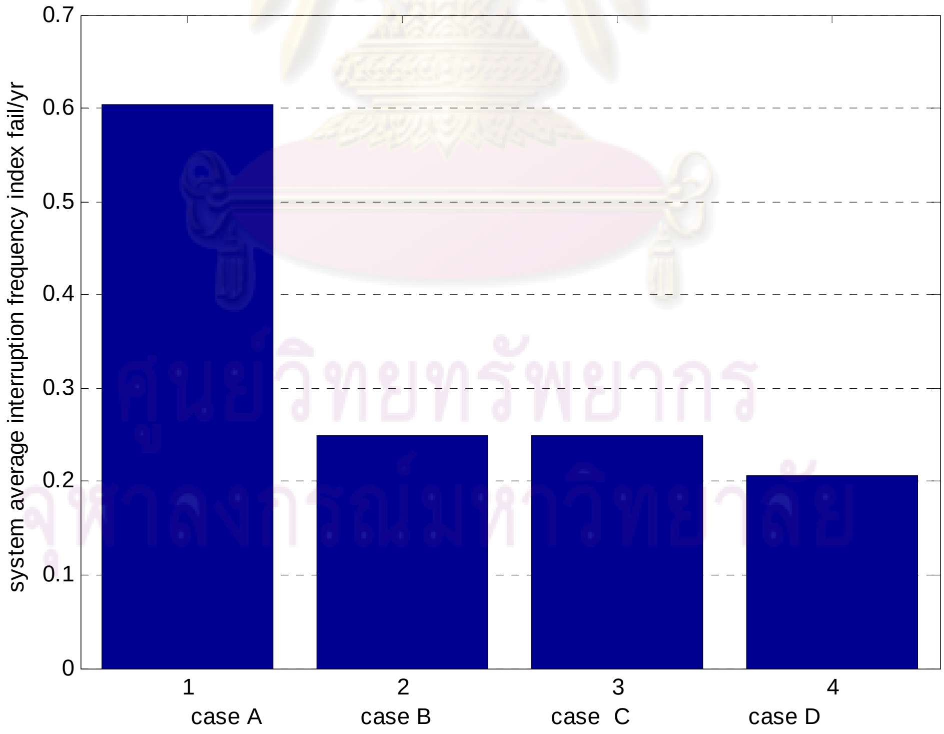

Figure 5-3 Comparison of SAIFI

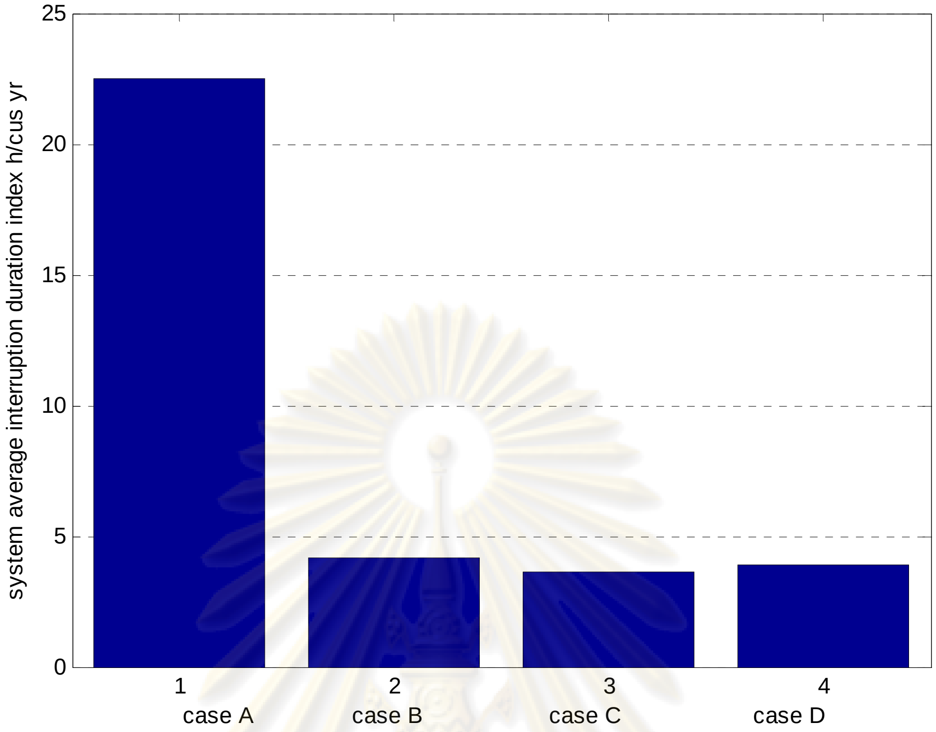

Figure 5-4 Comparison of SAIDI

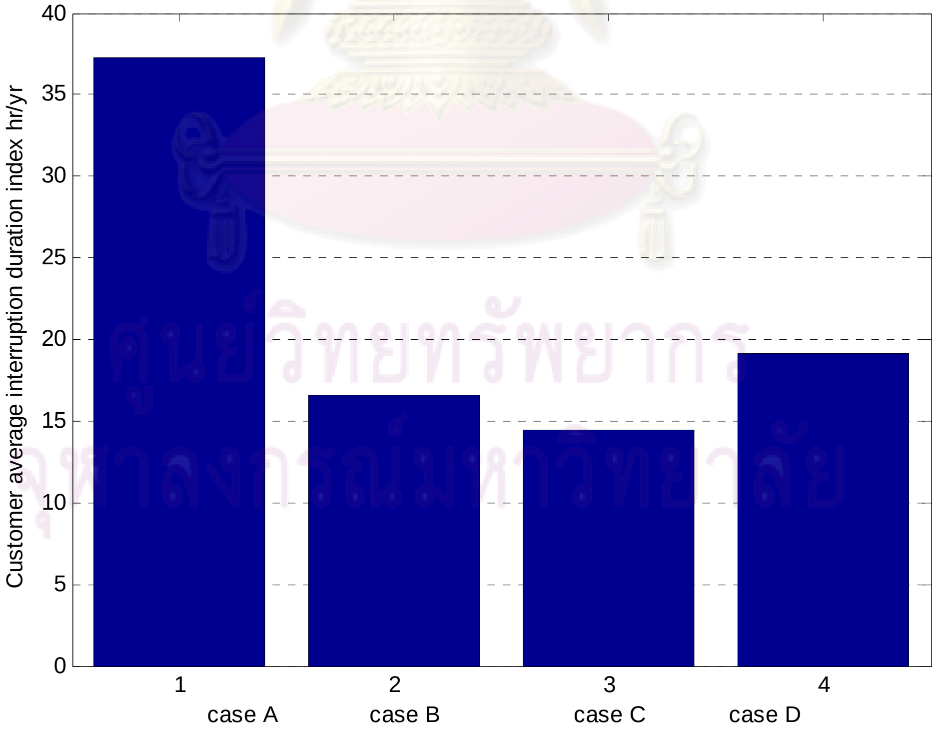

Figure 5-5 Comparison of CAIDI

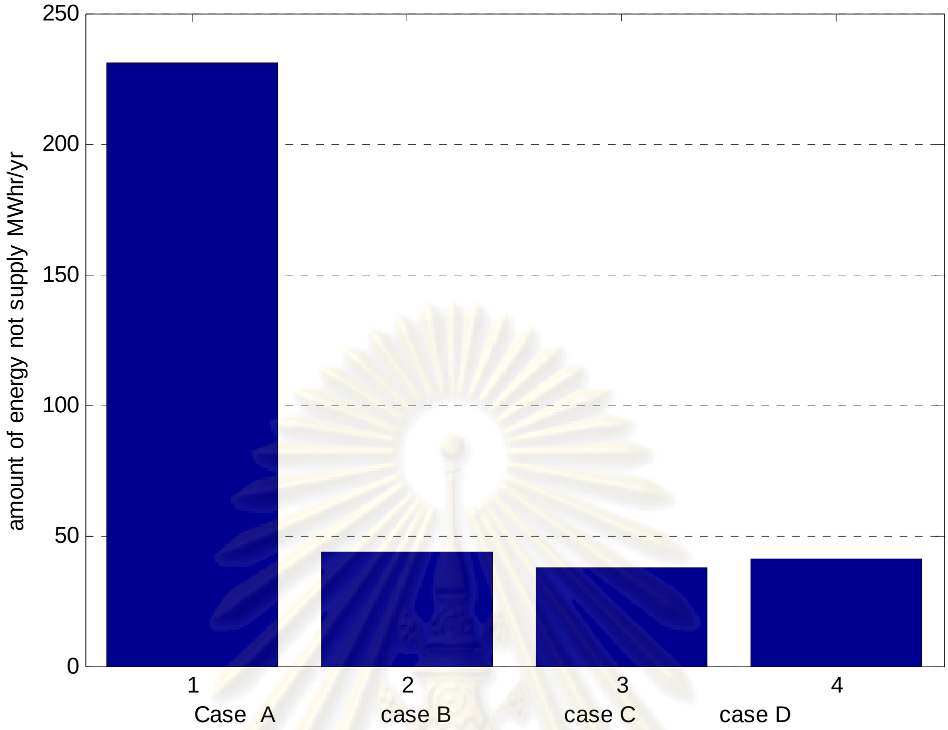

Figure 5-6 Comparison of ENS

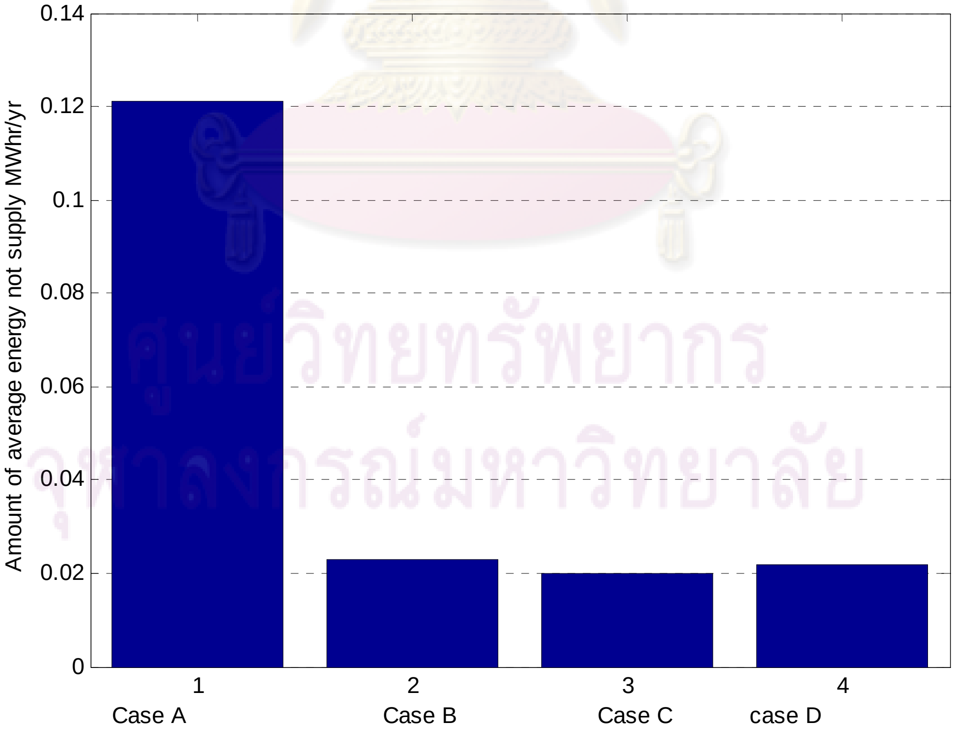

Figure 5-7 Comparison of AENS

Figure 5.5 shows the comparison of CAIDI. The value of CAIDI is 37.2891 hr/yr in case A. In case B, it is decreased to 16.6368 and reliability is better. Using fuses and disconnecting switches, CAIDI further decreases to 14.4715 hr/yr while fuse-recloser coordination results in the CAIDI decrease to 19.1245.

Figure 5.6 shows the comparison of ENS. Case A ENS 84 MWhr/yr. Using fuse in case B, it can improve to 54.8 MWhr/yr. Using fuse and disconnecting switches, it can improve ENS to 35.2 MWhr/yr which is the best result. Fuse-recloser coordination has also great effect on ENS compared with case A, since ENS 38.15 MWhr/yr.

Figure 5.7 shows the comparison of AENS. Using fuse can be reduced amount of AENS 0.1212 to 0.0229 MWhr/yr for each customer by comparing case A and case B. If fuse and disconnecting switches are used as in case C, AENS can be reduced to 0.0198 MWhr/yr. For consideration of fuse-recloser coordination, the amount of AENS can be reduced to 0.0216 MWhr/yr.

Using some protective devices such as fuse , disconnecting switchs or isolators and recloser ,the customer indices and energy-oriented indices can be improved. It can be known that using protective device on distribution system is an important role to improve its reliability.

5.3 Impact of voltage dip on power system reliability

In figure 5.8, Feeder 1 of RBTS bus 2 comprises a number of buses and load points. In this case we consider only Feeder 1 of RBTS bus2 for calculation of voltage during fault. Disconnecting switches are not considered since it takes long time to operate itself, which is beyond the time frame of voltage dip. Voltages levels of each load point when bolted fault occurs at lateral feeder 5 are shown for example in figure 5.9. Regarding fault calculation, the base power and the base voltage for this test system are assumed as 25MVA and 11kV respectively. The base current is calculated to be 2272.7 A. Assume that impedance of transformer is 22.1j and impedance of line is 0.472+0.366j per kilo meter [13].

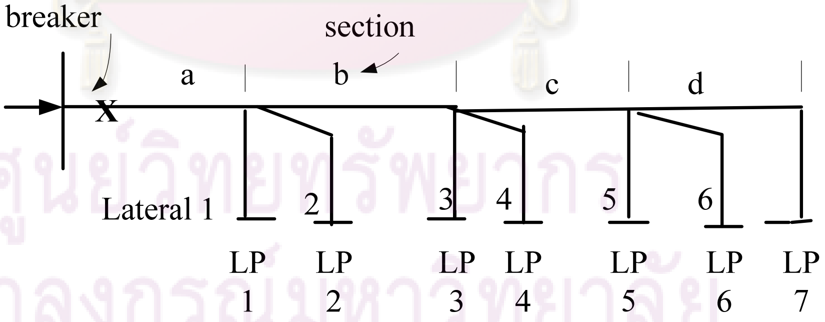

Figure 5-8 Feeder 1 of RBTS bus 2 system

To analyse the impact of voltage on system reliability, it can be divided into two cases. The first one is focused on system with using fuses and the last is to focus on system with fuse-recloser coordination.

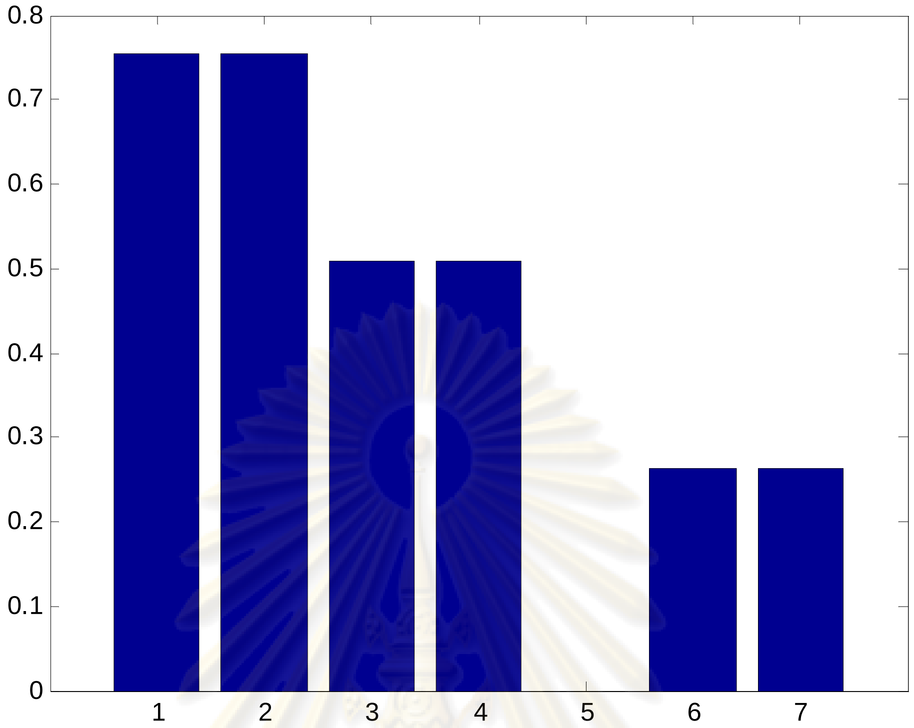

Figure 5-9 Comparison Voltage levels of each load point when fault occurs at lateral 5

5.3.1 Voltage dip impact on system using fuses

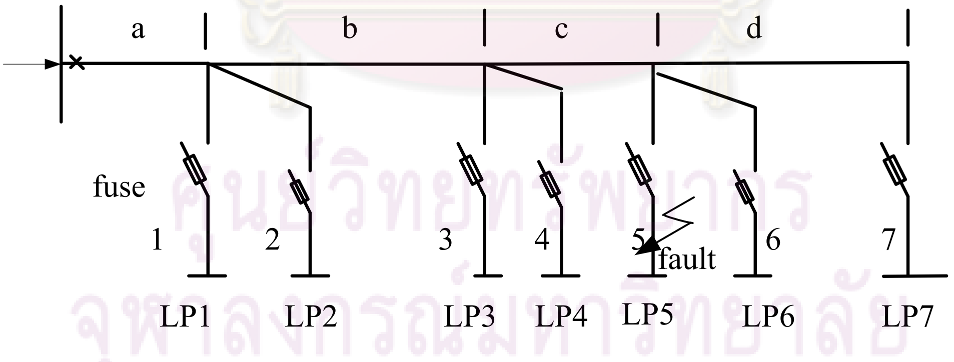

Figure 5-10 Test system with only fuses

Figure 5.10 shows the test system with considering only a fuse on each lateral. For an example analysis, it is assumed that a fault occurs at the middle of lateral 5. During fault, the voltage level of each load point will drop to an individual value. Figure 5.11 shows the characteristic curve of voltage dip on LP 1. In this case, the fault current of 2.6569 pu, and the voltage level at LP1 will decrease to 0.7541 pu. For base current is 2272.7 A, the total fault current will be 6.03 kA. According to the fault current and current-time characteristic shown in figure 3.1, the total clearing time is 0.08 s. After the fuse has tripped out the fault, the voltage will be back to 1 pu. It can be known clearly that fuses play an important role on voltage dip of the system. The characteristic of voltage dip cure is similar for all other load points. However, the amount of dip and total clearing of fuses is different.

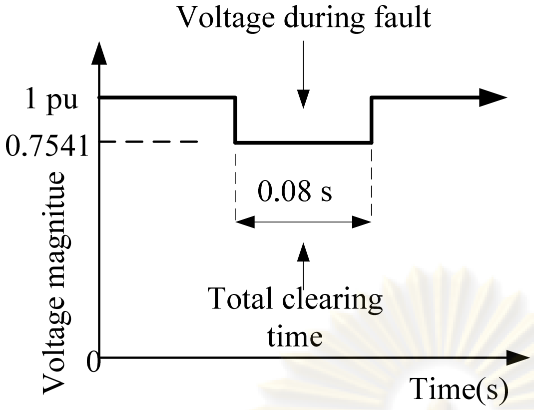

Figure 5-11 Characteristic curve of voltage dip on Load point 1 when fault occurs on lateral 5

According to Table 5.13 to5.19, the voltage dip and it's duraton of each load point can be seen. After that, the impact of voltage dip on system reliability can be obtained.

Table 5-13 Impact of voltage dip on load point 1

	Without voltage dip impact						With voltage dip impact		
Faulted location	λ (failure/ Yr)	r(hr/yr)	μ Hr/failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip time (s)	Vtg dip (yes/no)	λ (failure/ Yr)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	The old indices is the same with new ones.
section b	0.0488	5	0.2440	0.5000	5.4023	12278	-	-	
section c	0.0488	5	0.2440	0.6667	3.6015	8185.2	-	-	
section d	0.0390	5	0.1950	0.7368	2.8433	6462	-	-	
						13642			
lateral 1	0.0390	5	0.195	0.0000	6.0025	486.59	0.03	-	
LT	0.015	200	3	0.0000	0.2141	11882	-	-	
						485			
lateral 2	0			0.5161	5.2280	8007.3	0.035	No	
LT	0			0.9875	0.2134	478.86		No	
						8770			
lateral 3	0			0.6739	3.5232	480.45	0.05	No	
LT	0			0.9874	0.2107	6038.4		No	
						472.95			
lateral 4	0			0.6429	3.8588	6138.9	0.04	No	
LT	0			0.9875	0.2114	473.41	0	No	
						5045.7			
lateral 5	0			0.7541	2.6569	468.18	0.08	No	
LT	0			0.9874	0.2081		0	No	
lateral 6	0			0.7500	2.7011		0.075	No	
LT	0			0.9874	0.2083		0	No	
lateral 7	0			0.9873	2.2201		0.1	No	
LT	0			0.9873	0.2060		0	N o	
Total	0.2394	17.218	4.122						

Table 5-14 Impact of voltage dip on load point 2

	Without voltage dip impact							With voltage dip impact		
Faulted location	λ (failure/yr)	r (hr/yr)	μ (hr/failure)	Voltage Level(pu)	Total Fault Current (pu)	Total Fault Current (A)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.5000	5.4023	12278	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.6667	3.6015	8185.2	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.7368	2.8433	6462	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	No	0	-	-
						11882				
lateral 2	0.0520	5	0.2600	0.0000	5.2280	485	-	0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2134	8007.3	-	0.0150	200	3
						478.86				
lateral 3	0			0.6739	3.5232	8770	No	0	-	-
LT	0			0.9874	0.2107	480.45	No	0	-	-
						6038.4				
lateral 4	0			0.6429	3.8588	472.95	No	0	-	-
LT	0			0.9875	0.2114	6138.9	No	0	-	-
						473.41				
lateral 5	0			0.7541	2.6569	5045.7	No	0	-	-
LT	0			0.9874	0.2081	468.18	No	0	-	-
lateral 6	0			0.7500	2.7011		No	0		
LT	0			0.9874	0.2083		No	0		
lateral 7	0			0.7945	2.2201		No	0		
LT	0			0.9873	0.2060		No	0		
Total	0.2524	16.5888	4.1870					0.2914	15.0378	4.382

Table 5-15 Impact of voltage dip on load point 3

	Without voltage dip impact							With voltage dip impact			
Faulted location	λ (failure/yr)	r (hr/yr)	μ (hr/ Failure)	Voltage Level(pu)	Total Fault Current(pu)	Total Fault Crt(A)	Dip time (s)	Vtg dip (yes/no)	λ (failure/yr)	r (hr/yr)	μ (hr/yr)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.3333	3.6015	8185.2	-	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.4737	2.8433	6462.0	-	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No		0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0.0520	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.260
LT	0.015	0	0	0.9751	0.2107	478.86		No	0.015	0	0
lateral 4	0	5	0.195	0.0000	3.8588	8770	0.04	-	0.0390	5	0.1950
LT	0	200	3	0.0000	0.2114	480.45	0	-	0	200	3
lateral 5	0		0	0.5082	2.6569	6038.4	0.08	No	0	0	0
LT			0	0.9750	0.2081	472.95	0	No	0	0	0
lateral 6	0		0	0.5000	2.7011	6138.9	0.075	No	0	0	0
LT	0		0	0.9750	0.2083	473.41	0	No	0	0	0
lateral 7	0		0	0.5890	2.2201	5045.7	0.1	No	0	0	0
LT			0	0.9749	0.2060	468.18	0	No	0	0	0
Total	0.2394	17.218	4.122						0.3304	13.8529	4.577

Table 5-16 Impact of voltage dip on load point 4

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure/yr)	r (hr/yr)	μ (hr/failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip time (s)	Vtg dip (yes/no)	λ	r (hr/yr)	μ (hr/yr)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.3333	3.6015	8185.2	-	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.4737	2.8433	6462	-	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.260
	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0.0390	5	0.195	0.0000	3.8588	8770	0.04	-	0.0390	5	0.1950
	0.015	200	3	0.0000	0.2114	480.45	0	-	0.015	200	3
lateral 5	0		0	0.5082	2.6569	6038.4	0.08	No	0	0	0
	0		0	0.9750	0.2081	472.95	0	No	0	0	0
lateral 6	0		0	0.5000	2.7011	6138.9	0.075	No	0	0	0
	0		0	0.9750	0.2083	473.41	0	No	0	0	0
lateral 7	0		0	0.5890	2.2201	5045.7	0.1	No	0	0	0
			0	0.9749	0.2060	468.18	0	No	0	0	0
Total	0.2394	17.218	4.122						0.3304	13.8529	4.577

Table 5-17 Impact of voltage dip on Load Point 5

	Without Voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt(A)	Dip time(s)	Vtg dip (yes/no)	λ New	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.0000	3.6015	8185.2	-	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.2105	2.8433	6462	-	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.2600
	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0	0	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
	0	0	0	0.9752	0.2114	480.45	0	No	0	0	0
lateral 5	0.0520	5	0.2600	0.0000	2.6569	6038.4	0.08	-	0.0520	5	0.2600
	0.0150	200	3	0.0000	0.2081	472.95	0	-	0.0150	200	3
	0										
lateral 6	0			0.2500	2.7011	6138.9	0.075	Yes	0.0488	5	0.2440
LT				0.9628	0.2083	473.41	0	No	0	0	0
	0										
lateral 7	0			0.3836	2.2201	5045.7	0.1	Yes	0.0390	5	0.1950
LT				0.9627	0.2060	468.18	0	No	0	0	0
Total	0.2524	16.5888	4.1870						0.4702	11.221	5.276

Table 5-18 Impact of voltage dip on load point 6

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ Failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt(A)	Dip time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ Failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.0000	3.6015	8185.2	-	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.2105	2.8433	6462	-	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.26
LT	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0	0	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0	0	0	0.9752	0.2114	480.45	0	No	0	0	0
lateral 5	0	0	0	0.2623	2.6569	6038.4	0.08	Yes	0.0520	5	0.26
LT	0	0		0.9628	0.2081	472.95	0	No	0	0	0
lateral 6	0.0488	5	0.244	0.0000	2.7011	6138.9	0.075	-	0.0488	5	0.244
LT	0.015	200	3	0.0000	0.2083	473.41	0	-	0.015	200	3
lateral 7	0			0.3836	2.2201	5045.7	0.1	Yes	0.0390	5	0.1950
LT	0			0.9627	0.2060	468.18	0	No	0	0	0
Total	0.2492	16.74	4.171						0.5612	9.4	5.276

Table 5-19 Impact of voltage dip on Load point 7

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure/yr)	r (hr)	μ (hr/failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip time (s)	Vtg dip (yes/no)	λ (failure/yr)	r (hr/yr)	μ (hr/failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0.0488	5	0.2440	0.0000	3.6015	8185.2	-	-	0.0488	5	0.2440
section d	0.0390	5	0.1950	0.0000	2.8433	6462	-	-	0.0390	5	0.1950
lateral 1	0	-	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	-	0	0.9875	0.2141	486.59	-	No	0	-	-
lateral 2	0	-	0	0.5161	5.2280	11882	0.035	No	0	-	-
LT	0	-	0	0.9875	0.2134	485		No	0	-	-
lateral 3	0	-	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.2600
LT	0	-	0	0.9751	0.2107	478.86		No	0	-	-
lateral 4	0	-	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0	-	0	0.9752	0.2114	480.45	0	No	0	-	-
lateral 5	0	-	0	0.2623	2.6569	6038.4	0.08	Yes	0.0520	5	0.2600
LT	0	-	0	0.9628	0.2081	472.95	0	No	0	-	-
lateral 6	0	-	0	0.2500	2.7011	6138.9	0.075	Yes	0.0488	5	0.2440
LT	0	-	0	0.9628	0.2083	473.41	0	No	0	-	-
lateral 7	0.0520	5	0.2600	0.0000	2.2201	5045.7	0.1		0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2060	468.18	0		0.0150	200	3
Total	0.2524	16.589	4.1870						0.4832	11.0534	5.341

Table 5-20 New basic load point indices due to voltage dip impact

Load point	Failure rate	Repair rate	Outage time
1	0.2394	17.218	4.122
2	0.2914	15.0378	4.382
3	0.3304	13.8529	4.577
4	0.3304	13.8529	4.577
5	0.4702	11.221	5.276
6	0.5612	9.4	5.276
7	0.4832	11.0534	5.341

Table 5.20 shows new basic load point indices of test system dude to voltage dip impact. Using these indices and evaluation techniques, the followings indices can be calculated. And then, system indices and energy oriented indices can compare for three cases as follows.

Case A : system without using protective devices.

Case B : system with fuses on laterals .

Case C: system with fuses on laterals with consideration of voltage dip impact. The comparison of reliability indices for these three cases is shown in Table 5.21.

Table 5-21 Comparison of reliability indices

Indices	Case A	Case B	Case C
SAIFI (failure/yr)	0.6260	0.2481	0.3866
SAIDI (hr/yr)	23.6020	4.1654	4.793
CAIDI (hr/yr)	37.7029	16.7973	12.398
ENS (MWh/yr)	86.0293	15.1827	17.47
AENS (kWh/yr)	131.9	23.3	26.8

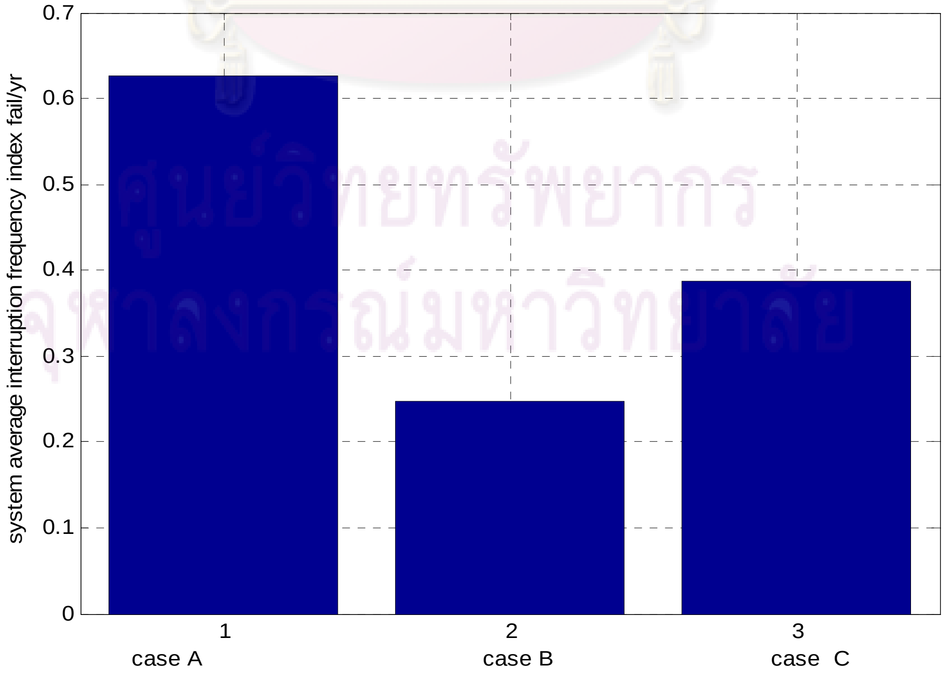

Figure 5-12 Comparison of SAIFI

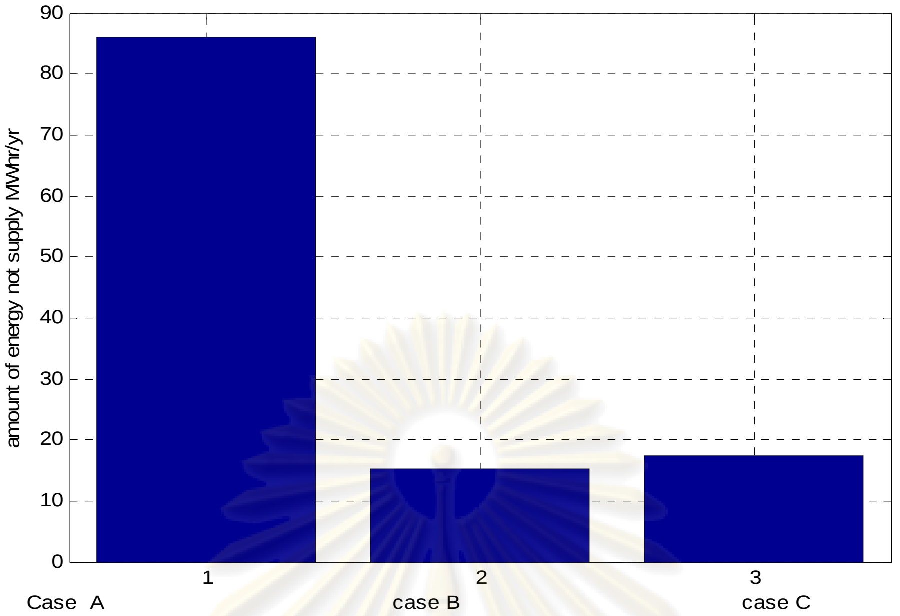

Figure 5-13 Comparison of ENS

According to the results of case B, the system reliability is improved if fuses are applied to lateral. In case B, we did not consider impact of voltage dip, and it is assumed the fuses will immediately trip out the fault. In case C, the impat of voltage dip is also considered. According to figure 5.10, if the fuse is used in the system, system average interruption frequency index will decrease 0.626 to 0.2481 fail/yr. But if the impact of voltage dip is considered, the index will increase from 0.2487 to 0.3866 fail/yr . Figure 5.11 shows the comparison of ENS. Using fuse on laterals, the value of ENS will reduce 86.0293 to 15.1827 MWhr/yr. However, when the impact of voltage dip is considered, ENS will increases from 15.1827 to 17.47MWh/yr.

5.3.2 Impact of voltage dip on system reliability with fuse-recloser coordination

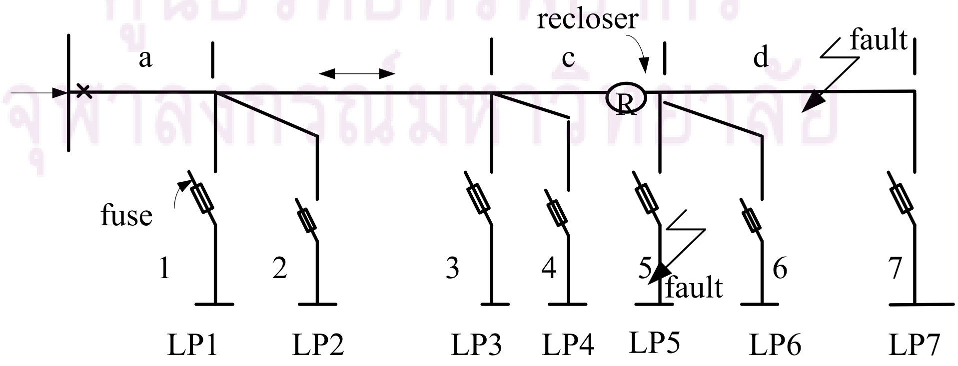

Figure 5-14 Test system with consideration of fuse and recloser

Figure 5.14 shows Test system with consideration of fuse and recloser. Suppose that a permanent fault occurs at lateral 5 with the current 6.03 kA, impact of recloser and fuse on voltage dip can be seen in figure 15. The result shows that the recloser will firstly operate with its fast curve having operating time of 0.015 sec. However, he fault still remains, and the fuse will trip out the fault. After that, the voltage will be back to 1 per unit.

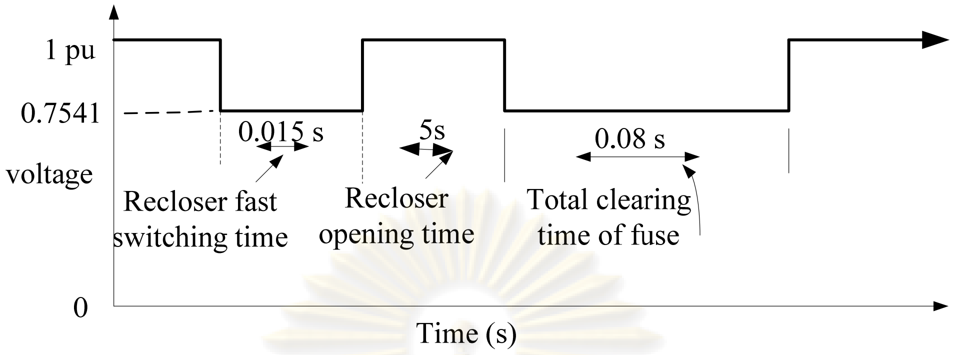

Figure 5-15 Characteristic of voltage dip on LP1 when fault occurs at lateral 5

In another case, a fault occurs at section d with the current 6.46 kA, the characteristic of voltage dip can be seen in figure 5.16. The recloser will finally trip out clearly the fault after 21.165 seconds. Then the voltage will come back to 1 per unit. If recloser is not used, the breaker will have to disconnect the fault line. It will take long time to get back the normal conditions and it can make other load points cut off from the system. With this kind of analysis, we will be able to prepare and set up proper coordination between the customer's protection system and the utility's to avoid permanent trip from the voltage dip. Whether the voltage dip has impact or not on the system can be decided using voltage dip level and dip time as shown in figure A-1 to A-7. According to Table 5.22 to 5.28, the detail calculation can be seen.

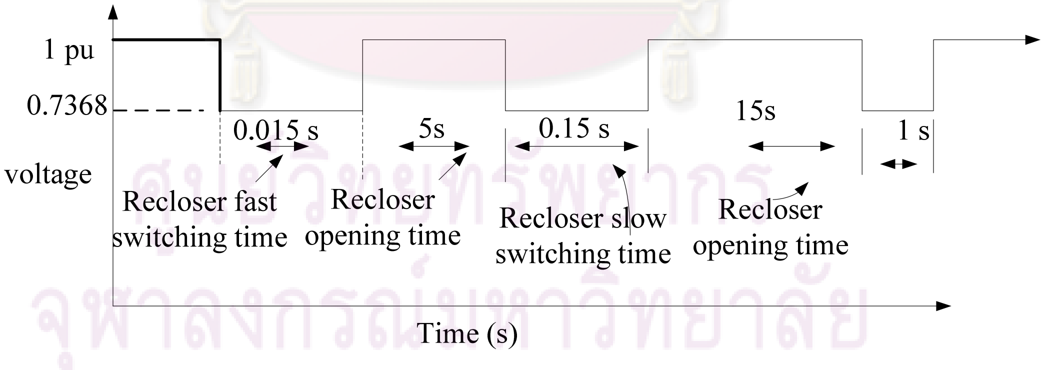

Figure 5-16 Characteristic of voltage dip on LP1 when fault occurs at section d

Table 5-22 Impact of voltage on load pont 1(fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.5000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	-	-	0.6667	3.6015	8185.2	1	yes	0.0488	5	0.2440
section d	0	-	-	0.7368	2.8433	6462	1	yes	0.0390	5	0.1950
lateral 1	0.0390	5	0.195	0.0000	6.0025	13642	0.03	-	0.0390	5	0.195
LT	0.015	200	3	0.0000	0.2141	486.59	-	-	0.015	200	3
lateral 2	0			0.5161	5.2280	11882	0.035	No	0	-	
	0			0.9875	0.2134	485		No	0	-	
lateral 3	0			0.6739	3.5232	8007.3	0.05	No			
	0			0.9874	0.2107	478.86		No			
lateral 4	0			0.6429	3.8588	8770	0.04	No			
	0			0.9875	0.2114	480.45	0	No			
lateral 5	0			0.7541	2.6569	6038.4	0.08	No			
	0			0.9874	0.2081	472.95	0	No			
lateral 6	0			0.7500	2.7011	6138.9	0.075	No			
	0			0.9874	0.2083	473.41	0	No			
lateral 7	0			0.7945	2.2201	5045.7	0.1	No			
				0.9873	0.2060	468.18	0	no			
Total	0.1516	25.61	3.883						0.2394	17.218	4.122

Table 5-23 Impact of voltage on load point 2 (fuse-recloser coordination)

	Without voltage dip impact							With voltage dip impact			
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.5000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.6667	3.6015	8185.2	1	yes	0.0488	5	0.2440
section d	0	0	0	0.7368	2.8433	6462	1	yes	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	-	-
lateral 2	0.0520	5	0.2600	0.0000	5.2280	11882	0.035	-	0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2134	485		-	0.0150	200	3
lateral 3	0			0.6739	3.5232	8007.3	0.05	No	0	-	-
LT	0			0.9874	0.2107	478.86		No	0	-	-
lateral 4	0			0.6429	3.8588	8770	0.04	No	0	-	-
LT	0			0.9875	0.2114	480.45	0	No	0	-	-
lateral 5	0			0.7541	2.6569	6038.4	0.08	No	0	-	-
LT	0			0.9874	0.2081	472.95	0	No	0	-	-
lateral 6	0			0.7500	2.7011	6138.9	0.075	No	0		
LT	0			0.9874	0.2083	473.41	0	No	0		
lateral 7	0			0.7945	2.2201	5045.7	0.1	No	0		
LT	0			0.9873	0.2060	468.18	0	No	0		
Total	0.165	22.72	3.748						0.2914	15.0378	4.382

Table 5-24 Impact of voltage on load pont 3 (fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
ection a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.3333	3.6015	8185.2	1	yes	0.0488	5	0.2440
section d	0	0	0	0.4737	2.8433	6462	1	yes	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0.0520	5	0.2600	0.0000	3.5232	8007.3	0.05	-	0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2107	478.86	-	-	0.0150	200	3
lateral 4	0			0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0			0.9752	0.2114	480.45	0	No	0	0	0
lateral 5	0			0.5082	2.6569	6038.4	0.08	No	0		0
LT	0			0.9750	0.2081	472.95	0	No	0		0
lateral 6	0			0.5000	2.7011	6138.9	0.075	No	0		0
LT	0			0.9750	0.2083	473.41	0	No	0		0
lateral 7	0			0.5890	2.2201	5045.7	0.1	No	0		0
LT	0			0.9749	0.2060	468.18	0	No	0		0
Total	0.1646	22.77	3.748						0.3304	13.8529	4.577

Table 5-25 Impact of voltage on load point 4 (fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.3333	3.6015	8185.2	1	-	0.0488	5	0.2440
section d	0	0	0	0.4737	2.8433	6462	1	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.260
LT	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0.0390	5	0.195	0.0000	3.8588	8770	0.04	-	0.0390	5	0.1950
LT	0.015	200	3	0.0000	0.2114	480.45	0	-	0.015	200	3
lateral 5	0		0	0.5082	2.6569	6038.4	0.08	No	0	0	0
LT	0		0	0.9750	0.2081	472.95	0	No	0	0	0
lateral 6	0		0	0.5000	2.7011	6138.9	0.075	No	0	0	0
LT	0		0	0.9750	0.2083	473.41	0	No	0	0	0
lateral 7	0		0	0.5890	2.2201	5045.7	0.1	No	0	0	0
LT			0	0.9749	0.2060	468.18	0	No	0	0	0
Total	0.1516	24.29	3.683						0.3304	13.8529	4.577

Table 5-26 Impact of voltage on load point 5 (fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.0000	3.6015	8185.2	1	-	0.0488	5	0.2440
section d	0	0	0	0.2105	2.8433	6462	1	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.2600
LT	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0	0	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0	0	0	0.9752	0.2114	480.45	0	No	0	0	0
lateral 5	0.0520	5	0.2600	0.0000	2.6569	6038.4	0.08	-	0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2081	472.95	0	-	0.0150	200	3
lateral 6	0	0	0	0.2500	2.7011	6138.9	0.075	Yes	0.0488	5	0.2440
LT	0	0	0	0.9628	0.2083	473.41	0	No	0	0	0
lateral 7	0	0	0	0.3836	2.2201	5045.7	0.1	Yes	0.0390	5	0.1950
LT	0	0	0	0.9627	0.2060	468.18	0	No	0	0	0
Total	0.1646	22.77	3.748						0.4702	11.221	5.276

Table 5-27 Impact of voltage on load point 6 (fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	0	0	0.0000	3.6015	8185.2	1	-	0.0488	5	0.2440
section d	0	0	0	0.2105	2.8433	6462	1	-	0.0390	5	0.1950
lateral 1	0	0	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	0	0	0.9875	0.2141	486.59	-	No	0	0	0
lateral 2	0	0	0	0.5161	5.2280	11882	0.035	No	0	0	0
LT	0	0	0	0.9875	0.2134	485		No	0	0	0
lateral 3	0	0	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.26
LT	0	0	0	0.9751	0.2107	478.86		No	0	0	0
lateral 4	0	0	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0	0	0	0.9752	0.2114	480.45	0	No	0	0	0
lateral 5	0	0	0	0.2623	2.6569	6038.4	0.08	Yes	0.0520	5	0.26
LT	0	0		0.9628	0.2081	472.95	0	No	0	0	0
lateral 6	0.0488	5	0.244	0.0000	2.7011	6138.9	0.075	-	0.0488	5	0.244
LT	0.015	200	3	0.0000	0.2083	473.41	0	-	0.015	200	3
lateral 7	0			0.3836	2.2201	5045.7	0.1	Yes	0.0390	5	0.1950
LT	0			0.9627	0.2060	468.18	0	No	0	0	0
Total	0.1614	23.12	3.732						0.5612		

Table 5-28 Impact of voltage on load point 7 (fuse-recloser coordination)

	Without voltage dip impact								With voltage dip impact		
Faulted location	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)	Voltage Level (pu)	Total Fault Current (pu)	Total Fault Crt (A)	Dip Time (s)	Vtg dip (yes/no)	λ (failure /yr)	r (hr/yr)	μ (hr/ failure)
section a	0.0488	5	0.2440	0.0000	10.8046	24556	-	-	0.0488	5	0.2440
section b	0.0488	5	0.2440	0.0000	5.4023	12278	-	-	0.0488	5	0.2440
section c	0	-	0	0.0000	3.6015	8185.2	1	-	0.0488	5	0.2440
section d	0	-	0	0.0000	2.8433	6462	1	-	0.0390	5	0.1950
lateral 1	0	-	0	0.4444	6.0025	13642	0.03	Yes	0.0390	5	0.1950
LT	0	-	0	0.9875	0.2141	486.59	-	No	0	-	-
lateral 2	0	-	0	0.5161	5.2280	11882	0.035	No	0	-	-
LT	0	-	0	0.9875	0.2134	485		No	0	-	-
lateral 3	0	-	0	0.3478	3.5232	8007.3	0.05	Yes	0.0520	5	0.2600
LT	0	-	0	0.9751	0.2107	478.86		No	0	-	-
lateral 4	0	-	0	0.2857	3.8588	8770	0.04	Yes	0.0390	5	0.1950
LT	0	-	0	0.9752	0.2114	480.45	0	No	0	-	-
lateral 5	0	-	0	0.2623	2.6569	6038.4	0.08	Yes	0.0520	5	0.2600
LT	0	-	0	0.9628	0.2081	472.95	0	No	0	-	-
lateral 6	0	-	0	0.2500	2.7011	6138.9	0.075	Yes	0.0488	5	0.2440
LT	0	-	0	0.9628	0.2083	473.41	0	No	0	-	-
lateral 7	0.0520	5	0.2600	0.0000	2.2201	5045.7	0.1		0.0520	5	0.2600
LT	0.0150	200	3	0.0000	0.2060	468.18	0		0.0150	200	3
Total	0.1646	22.77	3.748						0.4832	11.0534	5.341

Table 5-29 Reliability indices of they system with fuse-recloser coordination

	Without voltage impact			With voltage impact		
Load point	Failure rate	Repair rate	Outage time	Failure rate	Repair rate	Outage time
1	0.1516	25.61	3.883	0.2394	17.218	4.122
2	0.165	22.72	3.748	0.2914	15.0378	4.382
3	0.1646	22.77	3.748	0.3304	13.8529	4.577
4	0.1516	24.29	3.683	0.3304	13.8529	4.577
5	0.1646	22.77	3.748	0.4702	11.221	5.276
6	0.1614	23.12	3.732	0.47	11.225	5.276
7	0.1646	22.77	3.748	0.4832	11.0534	5.341

5.3.3 Comparison of System Reliability Level

Table 5-30 Comparison of System and energy-oriented indices

Indices	No protective device	Using fuse-recloser coordination	Using fuse-recloser with voltage dip impact
SAIFI (failure/yr)	0.6260	0.1605	0.3736
SAIDI (hr/yr)	23.6020	4.2911	4.7930
CAIDI (hr/yr)	37.7029	26.738	12.83
ENS (MWh/yr)	86.0293	15.64	17.47
AENS (kWh/yr)	131.9	24	26.8

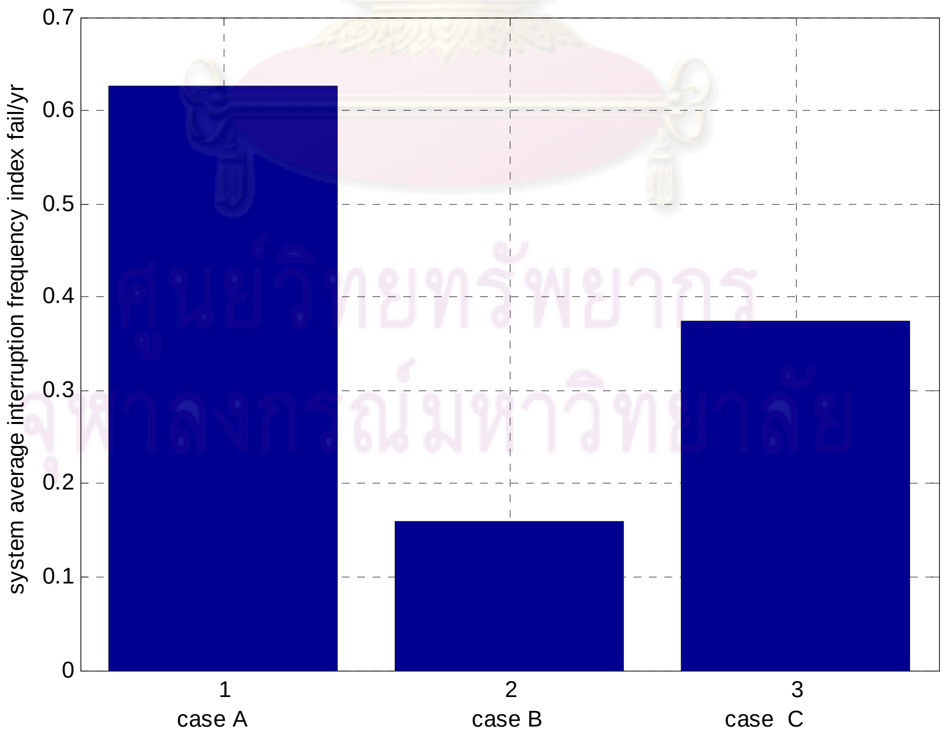

Figure 5-17 Comparison of SAIFI

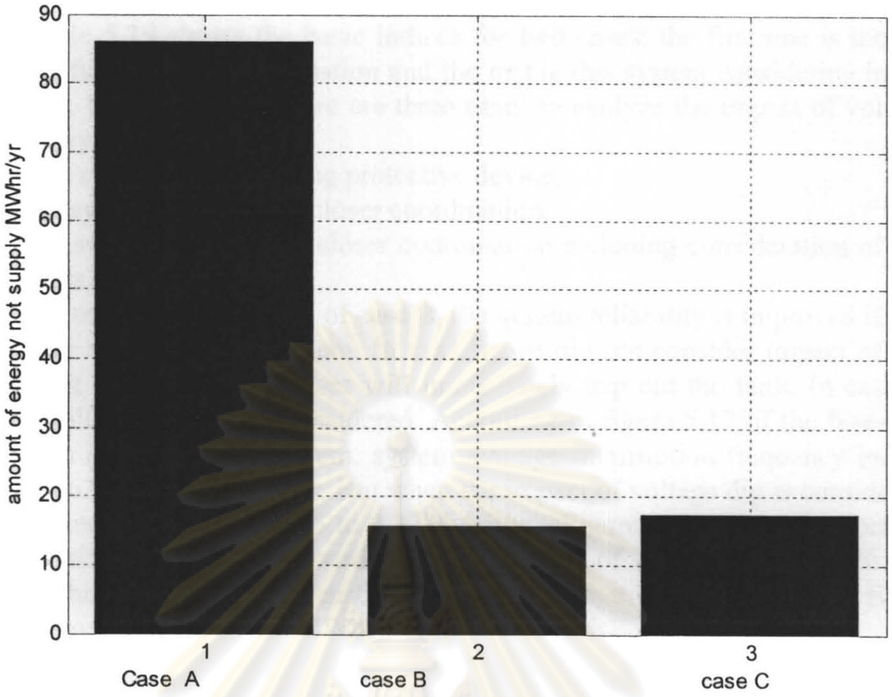

Figure 5-18 Comparison of ENS

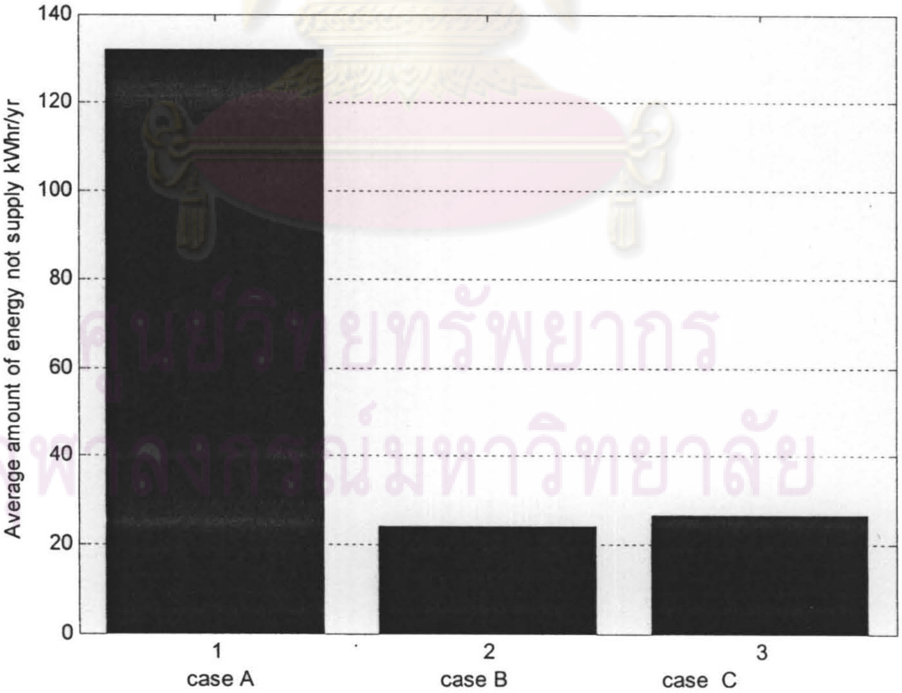

Figure 5-19 Comparison of AENS

Table 5.29 shows the basic indices for two cases: the first one is the system with using fue-recloser coordination and the rest is this system considering impact of voltage dip. In this section, there are three cases to analyze the impact of voltage dip clearly. They are

(a) Case A: system without using protective device.
(b)Case B: system with fuse-recloser coordination.
(c)Case C: system with fuse recloser coordination including consideration of voltage dips impacts.

According to the results of case B, the system reliability is improved if fuses – recloser are applied to the system. In case B, we did not consider impact of voltage dip, and it is assumed the fuses will immediately trip out the fault. In case C, the impat of voltage dip is also considered. According to figure 5.17, if the fuse-recloser coodination is used in the system, system average interruption frequency index will decrease 0.626 to 0.1605 fail/yr. But when the impact of voltage dip is considered, the index will increase from 0.1605 to 0.3736 fail/yr . Figure 5.18 shows the comparison of ENS. Using fuse-recloser coordination, the value of ENS will reduce 86.0293 to 15.64 MWhr/yr. However, when the impact of voltage dip is considered, ENS will increases from 15.64 to 17.47MWh/yr.

According test results, it can be known clearly that the system reliability can be improved using appropriate protective devices. However, the voltage dip impact on system reliability worsens the system reliability again. If we do not taken into account voltage dip impact, the system will not obtained its satisfactory reliability as expected. It can be known that voltage dip impact is also important for the system reliability, and it is need to protect the unsatisfactory voltage dips as a future work.

CHAPTER VI

CONCLUSION

The study on impact of voltage dip and protection system operation on electrical distribution system has been conducted in this thesis. Firstly the reliability indices of the existing system are focused. Moreover, it is clearly known that with the proper use of protective devices, the system reliability can be improved. Generally, the impact of voltage dip on system reliability is not considered. It is clearly shown that the voltage dip caused by fault at one point has impact on another. The impact of voltage dip on system reliability has been analyzed in this thesis.

The application of the most common types of devices, including line reclosers, automatic sectionalisers and manual switches are applied and their impact on system reliability is analysed. Secondly, an analysis to quantify the reliability improvements with protection coordination is conducted. This thesis focus on three cases to evaluate the impact of protection system on system reliability. First, the impact of fuse is analysed if it is used as lateral protection. It can be seen clearly that there is a great impact of using fuses on reliability indices. Second, the effect of fuse and disconnecting switches on system reliability are also analysed. According to the test results, this case provides the best result for system reliability. Amount of energy not supply to customers is the largest. In the last case, fuse-recloser coordination is considered on the system and it has also great impact on reliability improvement. This case provides the best result of System average interruption frequency index. In this case, disconnecting switches is not considered. Suppose it disconnecting switches is considered in this case, it is surely that it will be the best for system reliability. This thesis describes and compared the system reliability for different conditions.

Generally, protective devices will trip out the fault. When a fault occurs, the voltage level of all customers is decreased. It is called as voltage dip. And if the customers can't not tolerate, the voltage dip will cause interruption. It is considered that instantaneous power shortage has little effect on they system, equipment and users in terms of power reliability. So voltage sags are generally ignored when considering the continuity and dependability of the power supply. But with the change of the load structure in the contemporary procedure require higher quality for power supply. Voltage sag has made severe influence for a lot of equipment, and is considered to cause the most badly dynamic power quality problem. It is important to correctly evaluate the effect of voltage dips should be taken into consideration [14].

In this thesis, the impact of voltage dip on system reliability is also analysed. The protection scheme of fuse-recloser coordination is used to focus the impact of voltage dip. After that, the thesis shows the comparison of the reliability indices for the system with no protective device, system with fuse-recloser coordination, and system with fuse-recloser coordination with consideration of voltage dip impact. According to the results, the reliability level of the system is increased by using fuse-recloser coordination. And then it becomes to decrease when the impact of voltage dip is considered. Therefore, it can be known that the voltage dip worsens the system reliability.

As a future work, how to protect the impact of voltage dip can be considered. Moreover , the impact of more protective device can also be considered such as breaker, sectionalizer.

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APPENDIX

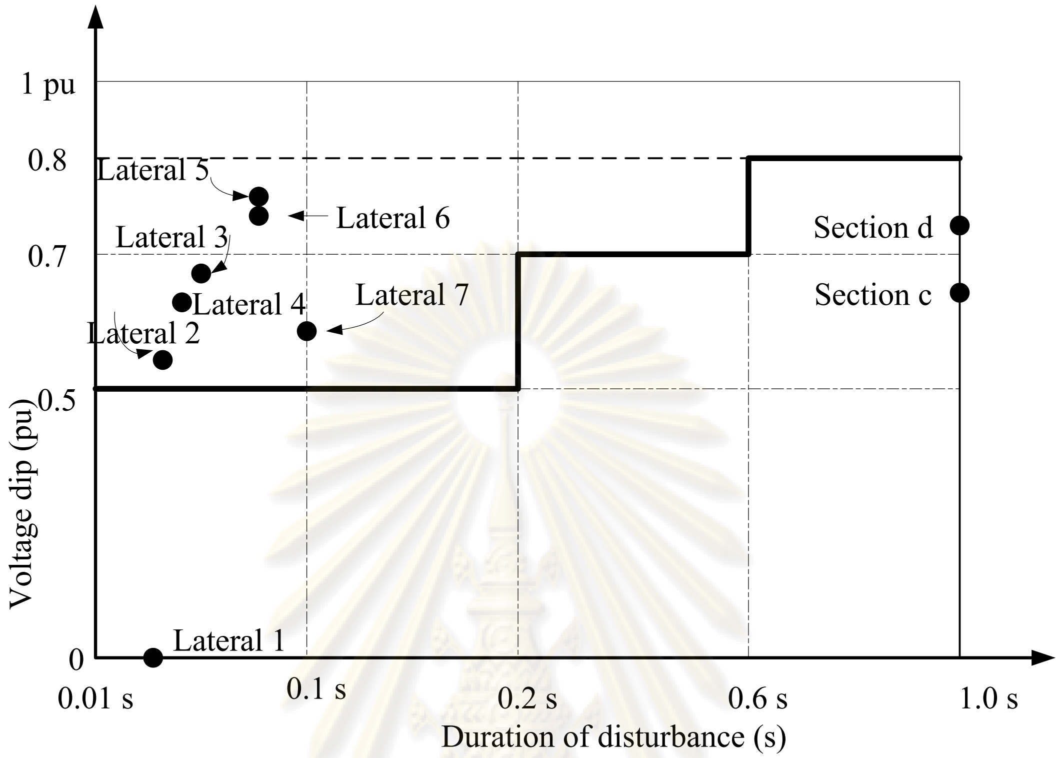

Figure A-1 Comparison of voltage dip and voltage envelope curve for LP 1

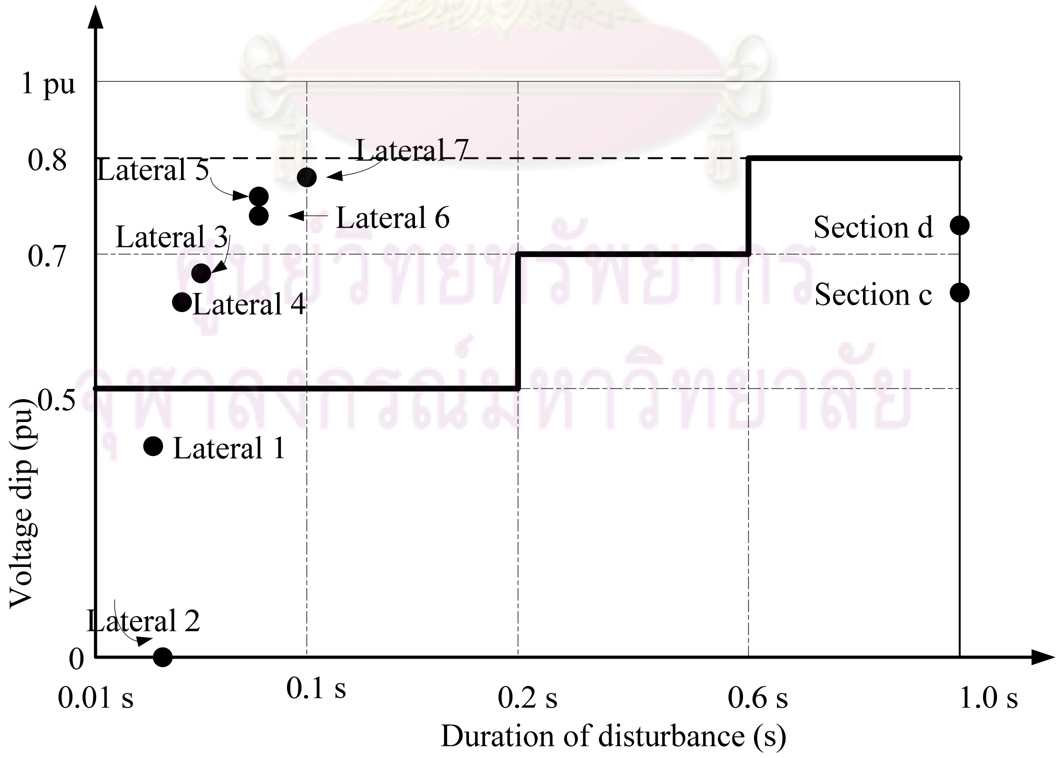

Figure A-2 Comparison of voltage dips and envelope curve for LP 2

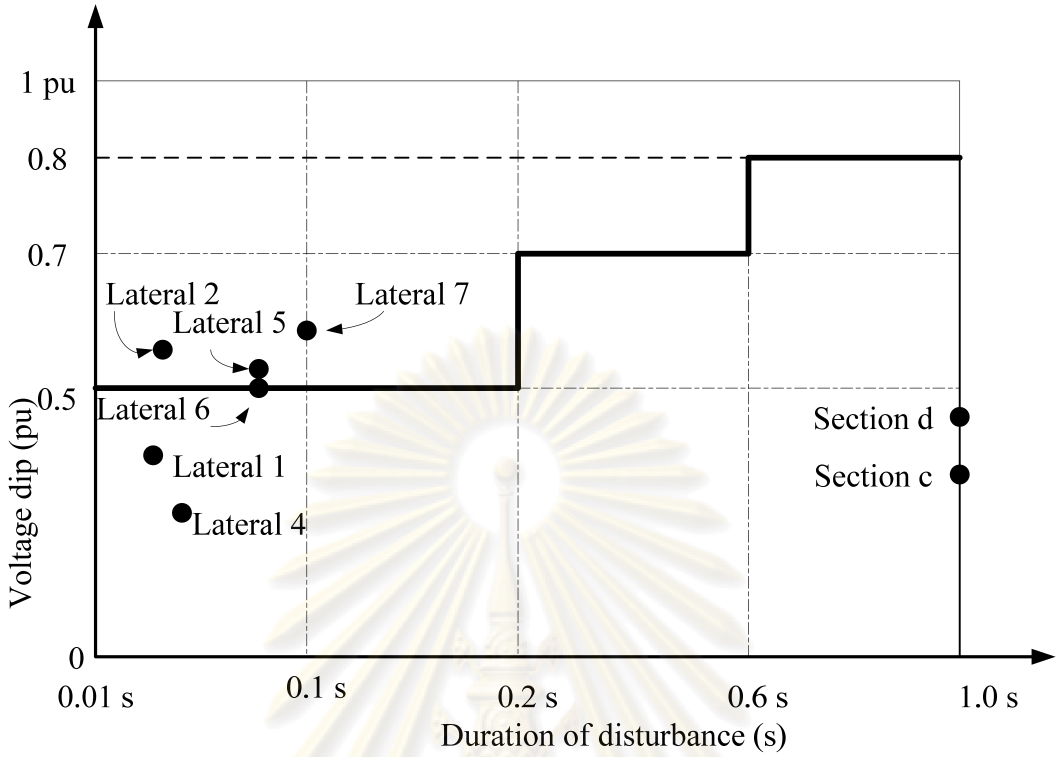

Figure A-3 Comparison of voltage dip and voltage envelope curve for LP 3

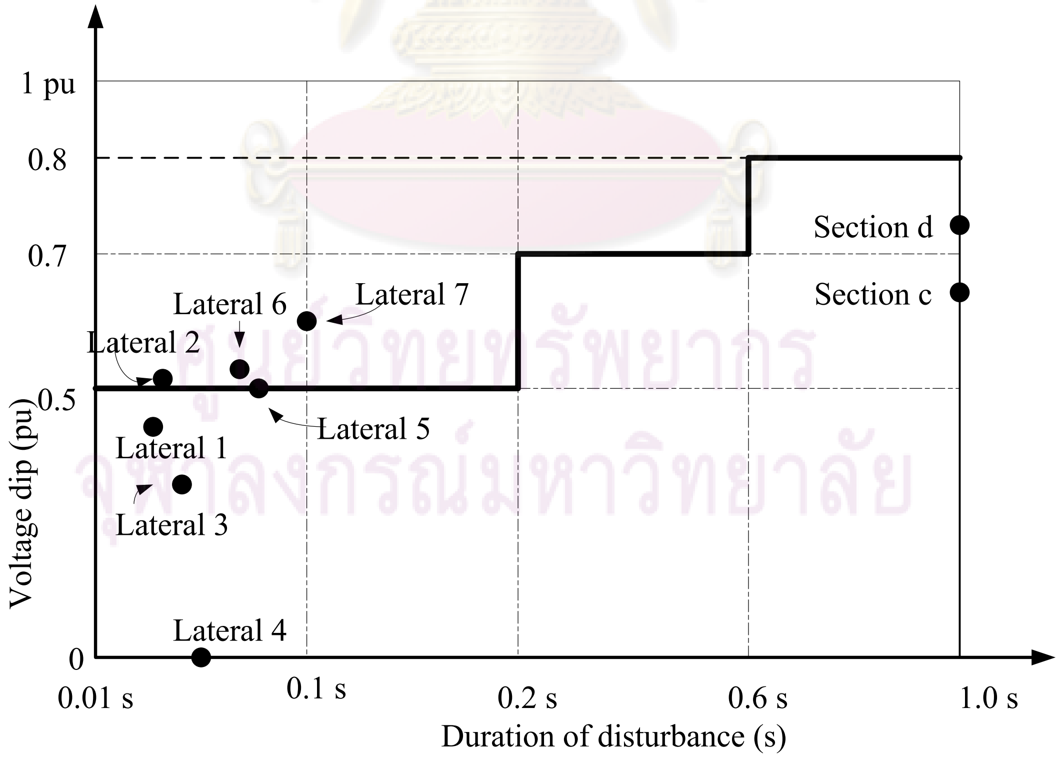

Figure A-4 Comparison of voltage dips and voltage envelope curve for LP4

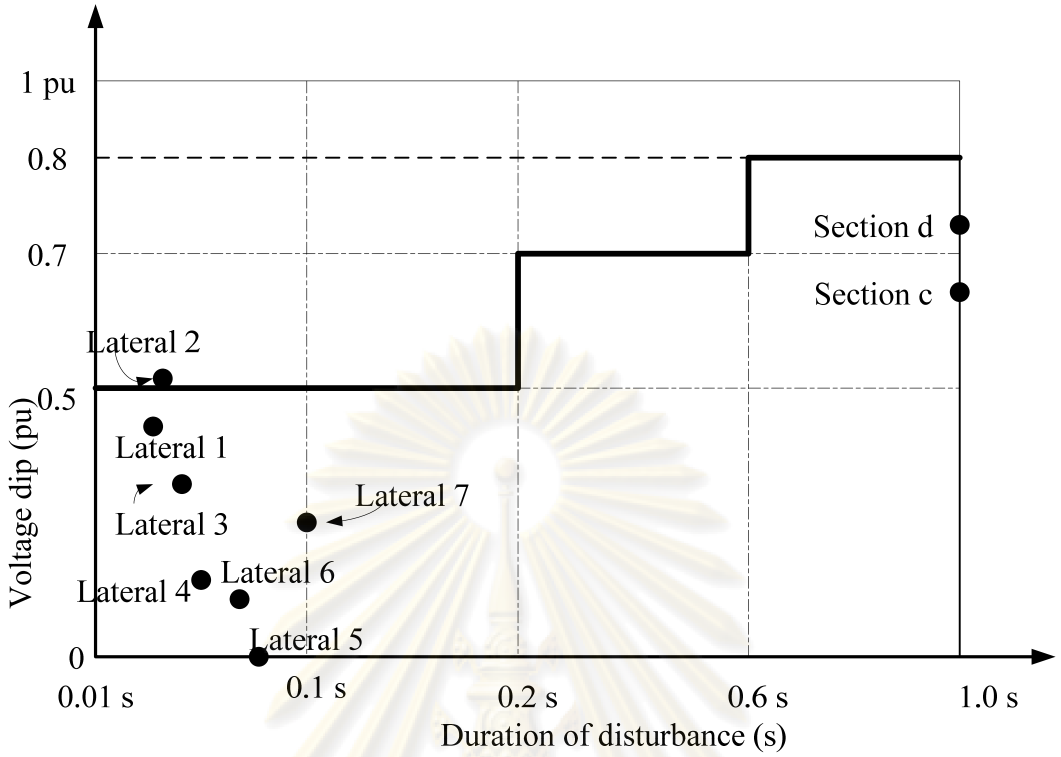

Figure A-5 Comparison of voltage dips and voltage envelope curve for LP5

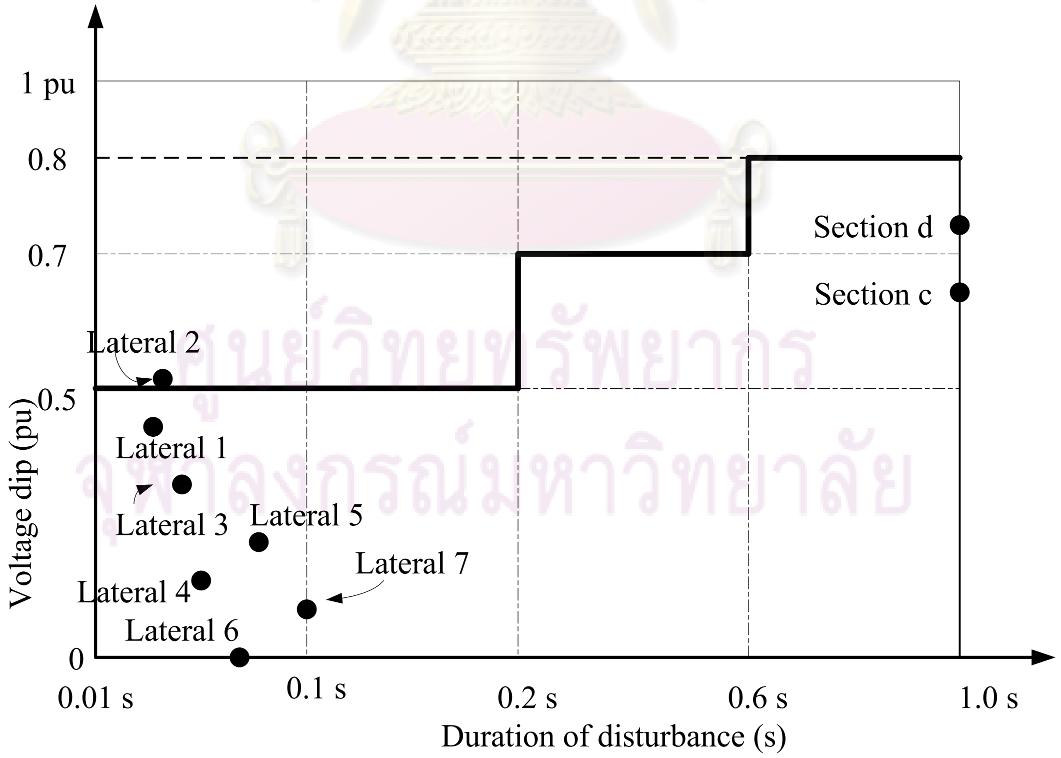

Figure A-6 Comparison of voltage dips and voltage envelope curve for LP6

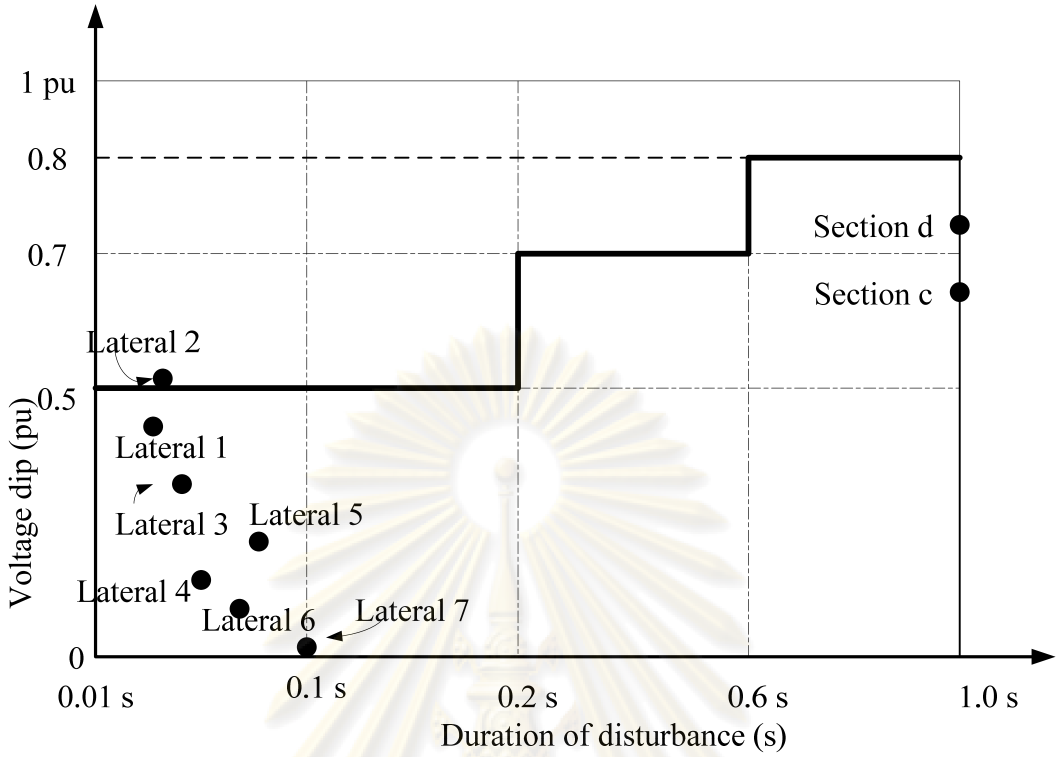

Figure A-7 Comparison of voltage dip and envelope curve for LP7

BIOGRAPHY

Ohn Zin Lin was born on February, 21 1984 in Nay Pyi Daw , the new capital city of Myanmar. He spent most of his time in Mandalay for his undergraduate study. He studied in Department of Electrical Engineering, major of Electrical Engineering, Mandalay Technological University, Mandalay , Myanmar. He earned his Bachelor of Engineering degree in 2006. He was awarded AUN/SEED-Net scholarship to continue his study in Department of Electrical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok, Thailand in November 2007. His current research interests are in the power system reliability.