ANALYSIS OF OVERCURRENT PROTECTION RELAY SETTINGS OF A COMMERCIAL BUILDING

NURUL SYAQIRAH BINTI MOHD SUFI

UNIVERSITI MALAYSIA PAHANG

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NURUL SYAQIRAH BINTI MOHD SUFI

This thesis is submitted as partial fulfilment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Power Systems)

Faculty of Electrical & Electronics Engineering
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ABSTRACT

This paper presents analysis of overcurrent relay settings for the selected commercial building using radial system, Library of Universiti Malaysia Pahang, Pekan Campus. The main software used is Electrical Transient and Analysis Program (ETAP) software. The analysis been done based on the real data collected from the selected commercial building which is modelled into ETAP and compared using theoretical study of manual calculation specifically for overcurrent relay settings. All the rules for the theoretical manual calculation is considered. Load flow analysis and fault analysis includes calculation of Single Line-to-Ground fault, Double Line-to-Ground fault, Line-to-Line fault and Three-Phase fault is performed using the software based on the setting obtained from the real data. The analysis is necessary as to compare the normal condition and other eleven possible conditions of circuit breakers and to ensure the stability of system. Besides, it is essential to coordinate the overcurrent relay settings by determining the main and backup protection devices for the line of fault occurs and provide correct discrimination to protect system from further damage or breakdown. Based on the analysis, it proves that the standard discrimination time between two successive relays of 0.25 seconds is practical to be used. The result shows manual calculation results are more sensitive compared to the settings made in the real commercial building. Thus, this paper is successful in determining proper and practical method on the overcurrent relay setting for power distribution network. In addition, the efficiency and reliability of the overcurrent relay coordination is validated and verified.

ABSTRAK

Kertas kerja ini membentangkan analisis tetapan geganti arus untuk bangunan komersial yang dipilih dengan menggunakan sistem jejarian, Perpustakaan Universiti Malaysia Pahang, Kampus Pekan. Perisian utama yang digunakan adalah perisian ETAP. Analisis ini dilakukan berdasarkan data sebenar yang dikumpul daripada bangunan komersial yang dipilih yang dimodelkan ke dalam ETAP dan dibandingkan menggunakan kajian teori pengiraan manual khusus untuk tetapan geganti arus lampau. Semua peraturan untuk pengiraan manual diambilkira. Analisis aliran beban dan analisis kesalahan termasuk pengiraan kesalahan 'Single Line-to-Ground', kesalahan 'Line-to-Ground Double', kesalahan 'Line-to-Line' dan kesalahan tiga fasa dilakukan dengan menggunakan perisian berdasarkan tetapan yang diperolehi daripada data sebenar . Analisis ini adalah perlu untuk membandingkan keadaan biasa dan sebelas lagi keadaan pemutus litar lain dan untuk memastikan kestabilan sistem. Selain itu, ia adalah penting untuk menyelaraskan tetapan geganti arus dengan menentukan peranti perlindungan utama dan sandaran untuk garis kesalahan berlaku dan menyediakan diskriminasi yang betul untuk melindungi sistem daripada kerosakan yang lebih atau kerosakan sistem. Berdasarkan analisis, ia membuktikan bahawa masa diskriminasi umum antara dua geganti berturut iaitu 0.25 saat adalah praktikal untuk digunakan. Hasil kajian menunjukkan keputusan pengiraan manual adalah lebih sensitif berbanding tetapan dibuat dalam bangunan komersial sebenar. Oleh itu, kertas kerja ini berjaya dalam menentukan kaedah yang betul dan praktikal pada geganti arus lebih untuk menetapkan rangkaian pengagihan kuasa. Di samping itu, kecekapan dan kebolehpercayaan koordinasi geganti arus lebih telah disahkan dan berjaya.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

An electrical power system consists of generators, transformers, and transmission and distribution lines [1]. The power system is subject to continual interruption initiated by random load changes, by faults produced by natural causes and at times as a result of operator or equipment breakdown. Relaying is the division of electric power engineering concerned with the fundamentals of design and operation of equipment that are called protective relays that identifies abnormal power system conditions and set up corrective operations as fast as possible in order to restore the power system to its normal state [12]. The speed of response is a fundamental element for protective relaying systems which includes transducers such as voltage transformer and current transformer and also circuit breakers. Protection is essential not only against short circuits but also against any other abnormal conditions which may arise on a power system such as overvoltage, under-frequency and many more [1].

This overview contains about information on overcurrent protection relay that will be discussed and analysed throughout this thesis. Overcurrent relay is one of a protective relay that functions when the load current surpass a pre-set rate. As for the analysis, the thesis focuses on the Inverse Definite Minimum Type (IDMT) type of IEC 60255 that are used widely for the protection of distribution lines. It been used to find out the proper settings of the overcurrent relay as a primary and backup protection, then provides a full protection coordination of the entire project. IDMT relay provides an inverse-time current characteristics at minimum values of the fault current and with definite-time characteristics. It is obtained if the value of plug setting multiplier is below 10 [1]. Whereas if the values of plug setting multiplier between 10 and 20, the characteristics tend to become a straight line; towards the definite time characteristics [1]. A radial feeder has its own proper selectivity of the relays for overcurrent protective schemes. The relay current setting is set based on the fault current level at the chosen particular section that is to be protected. The time setting is done in a more increasing value towards the source.

The load flow analysis is required to find and investigate the characteristic of electrical power system under normal condition and evaluate the various operating states of an existing system for the commercial building based on its power factor, voltage drop and its power losses. Fault analysis also will be executed to check the fault current of the system for each busses. There are four types of fault that will be considered for short circuit analysis that are symmetrical faults or 3-phase faults, single-line to ground faults, line-to-line fault and double-line-to-ground fault. The theoretical analysis will be considered and compared with the actual result from ETAP summary report. The fault analysis is essential for the project as to determine the value of fault current at chosen protected zone.

This project presents the analysing of the load flow and fault analysis based on the actual circuit, parameter and rating of electrical equipment used from the specific chosen commercial building. The analysis include overcurrent relay and earth fault setting of the existing system and will be analysed under four types of fault situation. The manual calculation will be used to compare its result with the practical setting used for the system. The actual data use is from building of Library Universiti Malaysia Pahang, Pekan Campus. Electrical Transient Analyser Program (ETAP) software will be used as main software to simulate the load flow analysis, short circuit analysis, overcurrent relay settings and star-view feature for relay coordination.

1.2 PROBLEM STATEMENT

In this modern era, using traditional hand computational work can consume a lot of time. Thus, the complex and time consuming calculation for relay setting using conventional tool can be at highly disadvantage in electrical power system industry. Besides, especially for a large system, it is harder to identify causes for overlapping or short circuit issues in industry's conventional method of distribution system.

1.3 OBJECTIVE

The two (2) main objectives of the project are:

i. To study and apply the practical setting method for overcurrent relay; specifically for a real commercial building system.

ii. To determine the optimum relay coordination by improving its reliability and efficiency.

1.4 SCOPES OF THE PROJECT

Several scopes for the project which are:

i. Collect real data from targeted commercial building for its system's drawing and practical overcurrent relay settings.

ii. Do modelling of one-line diagram in ETAP software based on parameters collected and summarised from the real data.

iii. Perform load flow analysis based on system's normal condition and estimated several conditions of switchgears.

iv. Perform fault analysis; include calculation of three phase fault, single-line to ground fault, line-to-line fault and double-line-to-ground fault.

v. Do overcurrent relay calculation using theoretical method and apply the setting in ETAP software specifically for overcurrent relay coordination. Compare the result of manual calculation, ETAP software and setting from the selected commercial building.

1.5 THESIS OUTLINE

An overview for each chapter is as follow:

i. **Chapter 1** contains the background of the study, problem statement, objectives, scope of work of the project are stated.

ii. **Chapter 2** presents the focus on literature review that exposed studies and researches of the related previous case study on the load flow, fault analysis, overcurrent relay settings and star-view feature of ETAP software.

iii. **Chapter 3** deliberates on the methodology of works; the flow of the overall project and steps in modeling distribution networks using ETAP software, deduce the load flow and then the short circuit analysis, formula for manual calculation of relay settings and steps for simulation of overcurrent relay coordination by ETAP.

iv. **Chapter 4** reports and discusses on the project's results that provided by load flow and short circuit simulations through ETAP summary report. The manual calculations of relay settings will be presented and results on simulation of overcurrent relay coordination using star-view feature of ETAP.

v. **Chapter 5** concludes the overall project. The project achieved objectives and results are concluded and suggestions for future improvement are discussed in this section.

1.6 SUMMARY

This thesis is on theoretical and practical research of the distribution system for a commercial building by using power analysis tool, ETAP software to perform and analyse load flow and short-circuit calculation. The results are then considered for relay settings and analysis on overcurrent relay coordination using theoretical and practical method.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter begins on literature reviews of the previous case studies on the procedure scheme setting for the project. To have deep understanding on aforementioned researches are essential as a guideline to proceed on this study. The background researches that related to the project are explained and presented in this chapter.

2.2 Faults Occurrences

In electrical power system, a fault is defined as abnormal condition of a system that include failures in electrical equipment such as generators, busbars, transformers, rotating machines and many more. The characteristic ratings of the equipment may altered or changed compared to its existing values till the fault is cleared when a fault occurs. When the fault takes place in a device or circuit, current and voltage ratings vary from their normal ranges. The causes of electrical fault may happened due to environmental conditions, equipment failures and human errors. The occurrence of fault leads to distraction of electric flows of the system such as undervoltage, overcurrent, reversed power and unbalance of phases, equipment damages and also death of animals and humans.

2.3 Type of Faults

Faults in power system are mainly two types; symmetrical faults and unsymmetrical faults. The least occurring type of fault is the symmetrical or balanced three-phase fault. In a three-phase fault, all the three-phases are short circuited [1]. It is broadly used as a standard fault to determine the fault level of the system. As for the unsymmetrical type, the highest occurring type of fault is a Single Line-to-Ground (SLG) fault. It may be due to the failure of the insulation between a phase conductor and the earth, or due to phase conductor breaking and falling to the ground [1]. The second highest occurring type is the Line-to-Line fault (LL). It happened when a short circuit between any two phases [1]; such as heavy winds that causes the overhead conductors may in touch together. As for the least among the unsymmetrical fault is the Double Line-to-Ground (DLG) fault. It is a severe fault where it happens between any two phases and the earth. This may due to the natural occurrence of a falling tree falls on two of the power lines. Figure 2.1 illustrates the mentioned types of unsymmetrical faults.

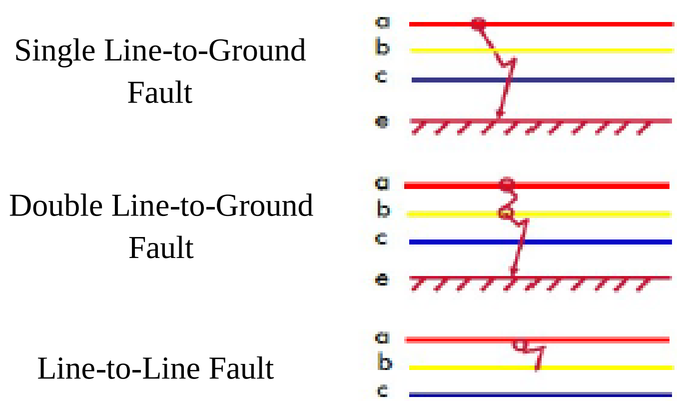

Figure 2.1: Types of transmission line faults [2]

2.4 Power System Protection

Power system protection is essential in electrical power system as it is needed to isolate the faulty element as quickly as possible to keep the healthy section of the system in normal operation [1]. It is needed not only against short circuit but also against any other abnormal condition which may arise on a power system [1]; such as overvoltage, over-speed of motors and generators, loss of excitation, under-frequency etc. The fault must be cleared away within of a specified second. Therefore, the system is important in protecting humans or any equipment from any damages. The fundamental principle of a protection is that the protection only can prevent short-circuit current continuity by abruptly disengage the short-circuit path from the system.

There are some abnormal conditions which are usually happen in an interconnected system. For that reason, the disturbance in the supply and the damage of equipment associated to the power system could be developed.

2.5 Protection System Components

A protective system consists of three essential equipment that includes transducers; Current Transformers (CTs) and Voltage Transformers (VTs), protection devices (overcurrent relay) and circuit breakers. The power system protection components are as shown in Figure 2.2.

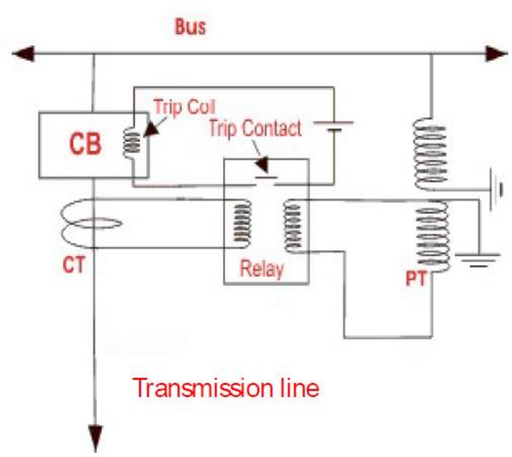

Figure 2.2: Power system protection components [3]

2.5.1 Current Transformers (CTs)

The CTs are used to achieve current signal reduction from the power system as for the objective of protection, control and measurement. The high currents from the power system are reduced to the lower ratings which are applicable for relays and any other instruments connected to their secondary windings to operate. CTs also isolate the relays and instruments circuits from the primary circuit which is a high voltage power circuit and allow the use of standardized current ratings for relays and meters [1]. The current ratings of protective relays are the same as the standardized secondary current rating of CTs that are 5A and 1A.

The CTs are constructed to endure the fault current that may be 50 times higher than the full load current for a few seconds [1]. Current transformers used in relaying are required to give a correct ratio up to several times the rated primary current [1]. The knee point voltage of CTs should not be less than the maximum voltage induced in the secondary with the highest fault current [8]. CTs that connected to relays should be faithfully transformed up to the highest possible fault current as the IDMT overcurrent and earth fault relays only provide accurate performance when they receive correct data of the fault current.

2.5.2 Voltage Transformers (VTs)

VTs also called as Potential Transformers (PTs). VTs are functioned in reducing the voltage of power system to the lower ratings and to cater isolation between the power network with high voltage and the relays and any other equipment connected to its secondaries [1]. The secondary windings has standardized rating of voltages and it is desired to give voltage signals to the relays which are reliable in reproductions of the primary voltages [1].

2.5.3 Protection Devices (Overcurrent Relay)

Relays are one of essential element in the power system protection. The relays are mainly function in sensing the fault and to perform the correct circuit breakers and disconnect the faulty equipment from the system as fast as possible, thus to minimize damage and trouble caused by faults when they occur [8]. It is also important as to clear the fault before the system becomes unstable and identify distinctly as to where the fault has occurred [8].

There are many types of relay can be used in protect transmission lines systems according to their characteristic, logic, actuating parameter and operation mechanism such as magnitude relay, instantaneous relay, differential relay, directional relay, and distance schemes [5].

In this project, we are specifically use overcurrent relay for the analysis. Overcurrent relay is a relay which operates when the actuating current exceed preset value or its pick-up value [1]. It is classified into four classes that are very inverse time relays, extremely inverse time relays, inverse definite minimum time relay and definite time relays. The Inverse Definite Minimum Time (IDMT) relay is used for the protection of overcurrent. The characteristic of the IEC 60255 for the four classes comparing with time as shown in Figure 2.3 [6]

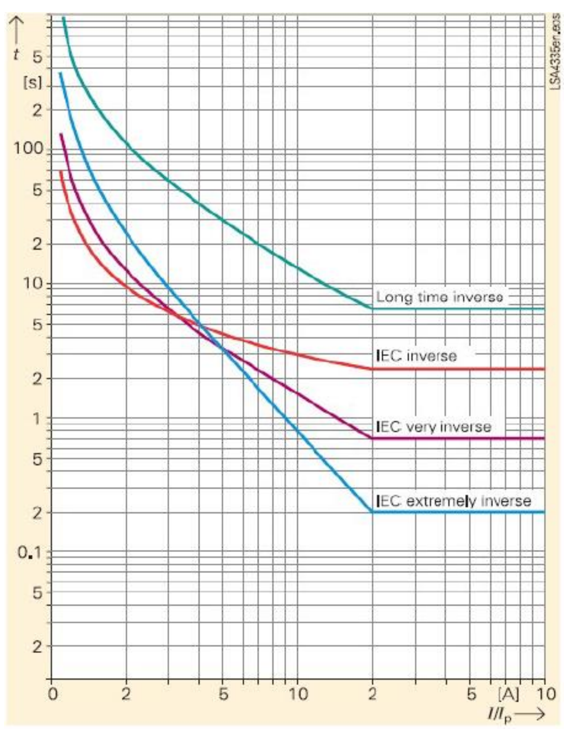

Figure 2.3: IDMT relay of IEC 60255 Characteristic with TMS = 1

There are six important requirements to be fulfilled by a protective system;

2.5.3.1 Discrimination

A protective system should be able to discriminate between fault and load conditions even when the minimum fault current is less than the maximum load current [8]. The fault and an overload are sometimes identical to the protective scheme, thus relay has to be sharp to distinguish between the two conditions [8].

2.5.3.2 Selectivity

Selection has to be done by the relays in isolating the section that is faulty entirely from the rest of the healthy system [8]. The coordinate settings of relays for different zones are made based on regulation made. The current-time overcurrent protection are one of example of relative selectivity [8].

2.5.3.3 Reliability

The protective device must operate reliably when a fault occurs in its zone of protection [1]. The protective system may failed to operate if any one or more elements of protective devices are not function; such as the relays, transducers, circuit breakers etc.

2.5.3.4 Sensitivity

The device is said to be sensitive enough to act when the current magnitudes exceed the pick-up or preset value. The required cause of operation is expressed as the apparent power in VA; thus a 1 VA relay is more sensitive than a 3 VA relay [8].

2.5.3.5 Stability

The protective device is required to remain stable even when high current flows in the protective zone that may because of external fault that is not lies in the zone. The circuit breaker will trip or open only after the preset value of delay in relay to clear the fault.

2.5.3.6 Speed

It is important for a protective device to react as fast as possible in minimizing damage and maintain the stability of the system by isolating the faulty zones on time. For distribution system the operating time of protective relay may be more than one cycle [1].

2.5.4 Circuit Breaker

The circuit breakers are one of the electrical switchgear that is important in power system protection. The circuit breaker are widely used in protection industry as one of its function is required to be efficient in conducting short-circuit current magnitudes until the fault is cleaned by another fuse or breaker closest to the fault point. The protective relays sense and evaluate fault and identify the time for the breaker to trip or open; or in other words the relay controls the circuit breaker to trip when needed. The tripping time of high speed circuit breakers are from three to eight cycles.

In this project, the types of circuit breakers used are the air-break circuit breakers (ACB) and Vacuum Circuit Breakers (VCB). The ACB has in-built thermal overload release and high speed operation on short circuits [8]. The ACB is recorded having breaking capacity up to 80kA and usually use for applications up to 415 volts and with rating currents around 100 to 4000 A. While the VCB is the latest and modern technology of circuit breakers that are now widely used in substation of rating up to 33kV.

2.6 Zones of Protection

The zones of protection are associated with relays and circuit breakers for each zone. The protection zones are overlapped so that there is no unprotected spot [8]. The location of current transformers will be used to decide the zone of protection. In each zones, the line defence are contains with main or primary and back up protective schemes. The back up at the second line of defence will react when the main protection at the first line of defence failed to operate for some reason to clear the fault. Figure 2.4 shows the zone of protection system that consists of generator, transformer, busses, transmission lines and motor [2].

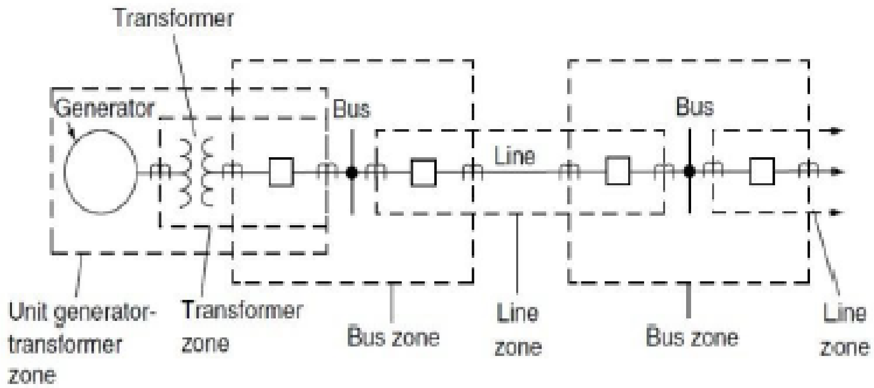

Figure 2.4: The zones of protection system (Primary and Back up protection) [2]

2.7 Distribution System Network

The distribution system network is functioned as a power distribution to the individual loads or consumers. Loads are categorized as industrial loads, commercial loads and the residential loads. The distribution system has three different types of designs that are loop, radial or network. As in the analysis, it is from the radial distribution system where it is used widely in industry and consume cheapest construction cost. The radial system has only one power source connected to the users. Thus, if failure or interruption in power occur, it will interrupt the entire system line. Therefore, proper protective device and coordination has to be installed and made to protect the upper stream of the system.

The distribution substation are mainly functioned as to step down voltage rating to the voltage level of distribution that are commonly rated as 11kV and 33kV. The transformers are responsible in stepping down the voltage rating. The high voltage bus are installed with high voltage circuit breakers while the relay-controlled circuit breakers are used for switching of low voltage. The voltage drops are varied from substation to user when there changes on load of the feeder. Besides, the substation must installed with protection devices to protect against the occurrence of short circuit. The system are also protected with fuses. Substations are functioned as an idea of monitoring. The process of distributing will be monitored using the digital recording meters that are placed in substation. It will display various parameters such as average, minimum or maximum values of power factors, current, voltages etc. The simple single line for distribution substation that consists of switches, voltage regulator, transformers, protection devices, and meters that can be found in a substation is as shown in Figure 2.5 [7].

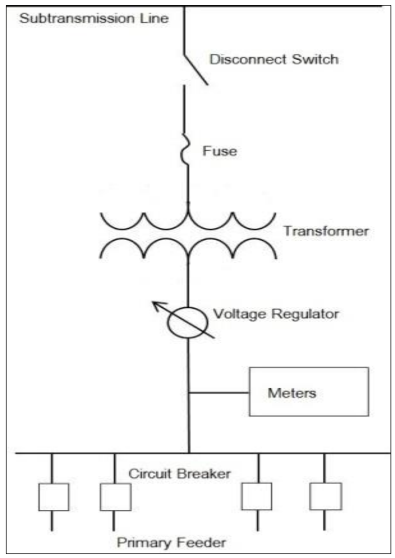

Figure 2.5: The single line diagram of a simple distribution substation[7]

2.7.1 Distribution Feeder Analysis

The analysis of distribution feeder will be conducted under normal steady-state operating conditions and short circuit conditions [7].

2.7.1.1 Load Flow Analysis

Load flow analysis or power flow analysis is important as it helps in ensuring the power is connecting correctly, to show the stability of an equipment if it's reliable and working to our utmost advantage. The analysis are specialized for economic scheduling, power interchange between utilizes and for network planning and operation. This analysis able to determine and display voltage magnitudes and angles at all nodes of the bus bar, current and real and reactive power. The voltage drop, voltage at each bus, the power flow and losses, and also power factor in all branches and feeders can be calculated using this analysis. There are three types of buses that are loaded bus, regulated bus and slack or swing bus. The loaded bus known as P-Q bus as it specified in the active and reactive power while the regulated bus is called as P-V bus for it has specified the voltage magnitude and real power. Swing or slack bus used as reference and has specified phase angle and magnitude of voltage. Power flow analysis can be done in several methods such as Gauss-Seidel, Newton-Raphson method and also Fast-Decoupled method [9]. The result from this analysis will be used in determining the relay plug setting for this project.

2.7.1.2 Short Circuit Analysis

Short circuit or also known as fault is the abnormal conditions that affect one or more phases which by accident in touch with each other or with ground. Short circuit protection is essential as it able to defend the equipment from damage or failure which due to the resulting excessive current flow through. Besides, it needed to be considered in designing the proper ratings of protective devices; for instance fuse and circuit breaker. However for large system, it is necessary to determine both switchgear ratings and relay settings [10]. The short circuit analysis is also necessary in this project to determine the value of fault current at buses which is one of important element in calculating settings of overcurrent relays. Furthermore, the result from this analysis will be used in determining the plug setting multiplier (PSM) of relay which then can be used to find time multiplier setting (TMS) of backup relay [4].

2.8 Relay Setting and Coordination

As for the overcurrent relay settings, there are consideration that has to be made in terms of it rules and regulation, which then will be used in coordinating the relays based on primary and back up protection schemes. For this project, the coordination are made using star view; the unique feature of ETAP software. The relays in the system has to be coordinated so as to avoid mal-operation and hence to avoid unnecessary outage of healthy part of the system [4]. The rules of setting the overcurrent relay for a radial system are as follows [4];

a) Plug setting: Plug setting are to be decide considering three rules [8]:
    I. The relays shall reach up to the end of the next protected zone. This is required to ensure the backup protection [8].
    II. The plug setting must not be less than the maximum normal load including permissible continuous overload unless monitor by undervoltage relay, otherwise the relay will not allow the normal load to be delivered [8].
    III. In estimating the plug setting, an allowance must be made for the fact that the relay pickup varies from 1.05 to 1.3 times plug settings, as per standards [8].

b) Time setting:
    I. The time multiplier setting must be chosen to give lowest possible time for the relay at the end of the radial feeder. In the preceding sections toward the source, the time multiplier should be chosen to give desire selective interval from the down-stream relay at maximum fault conditions [8].
    II. The time multiplier setting should allow not only for the time of the breaker but also for the overshoot of the relay and allowable time-errors in the time of operation of successive relays [8].
    III. It is a common practice to use a fixed selective interval of 0.25 second (considering two cycle breakers) between the successive relays [8].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will briefly explain the system modelling and analysis approach for this project. All the processes associate in this project is important in ensuring the flow of the project smoothly run. The software that had been used in this project is Electrical Transient Analyzer Program (ETAP) in performing load flow calculation, short-circuit calculation, overcurrent relay setting, and overcurrent relay coordination using ETAP star view feature.

3.2 FLOW CHART FOR PROJECT DEVELOPMENT

Based on the flow chart, the project are firstly begin with the study on literature review. Secondly, the real data are collected from the selected commercial building; Library of Universiti Malaysia Pahang, Pekan Campus which then is summarized and modelled in ETAP software based on its real parameter and rating of electrical equipment. The connectivity of the one-line diagram is verified by performing load flow analysis which then proceeds for short circuit analysis. The next step are performing overcurrent relay setting using manual calculation which then the relay coordination will be tested using ETAP star view feature. Lastly, analysis on the results are made and proceed for thesis writing. Figure 3.1 shows the flow chart for this project.

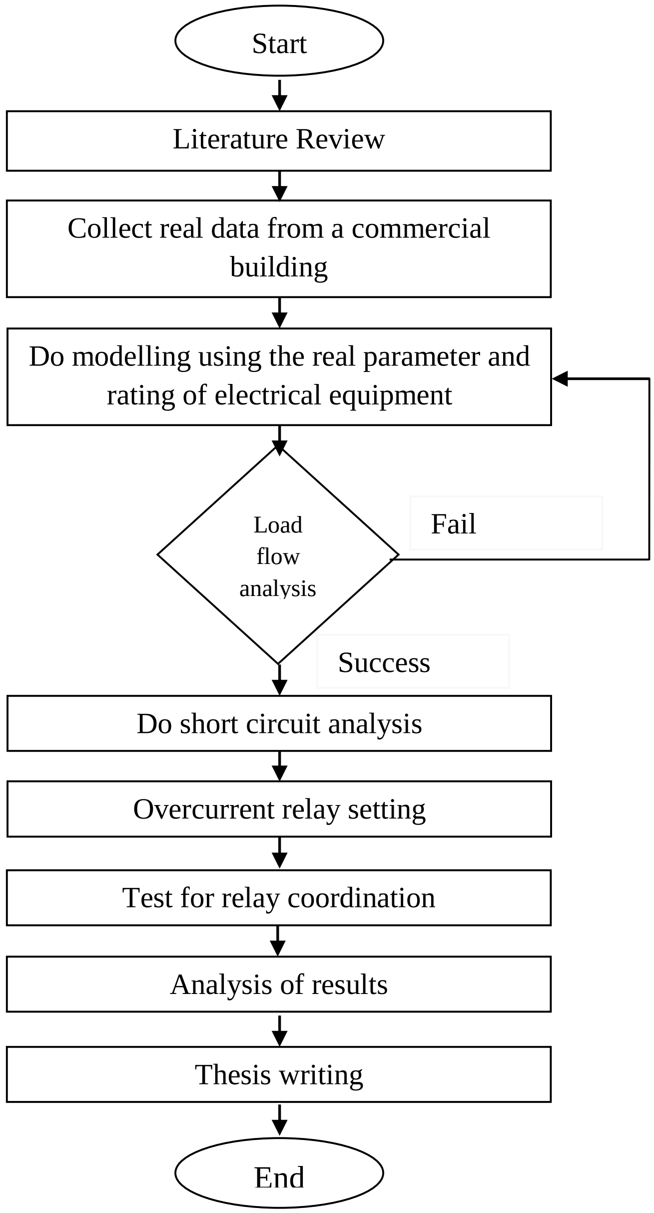

Figure 3.1: Flow chart of the project

3.3 COLLECTING DATA

Based on the flow chart as illustrates in Figure 3.1, the data is collected from the selected commercial building, Library of Universiti Malaysia Pahang, Pekan Campus. The data collected is the real operating circuit diagram of the substation and its overcurrent relay and earth fault setting.

3.3.1 CIRCUIT DESIGN OF COMMERCIAL BUILDING

The circuit been used to do load flow and short circuit analysis is the real summarized circuit from Library Universiti Malaysia Pahang, Pekan Campus. All parameter and rating of electrical equipment needed has been recorded during site visit at the substation. There is several electrical equipment must be considered for simulation and calculation such as Power Grid, Bus, Circuit Breaker, Current Transformer, Overcurrent Relay and Earth Fault and Load. From the data collected, circuit has been created referred to the real diagram from the substation and the circuit design is shown at Figure 3.2.

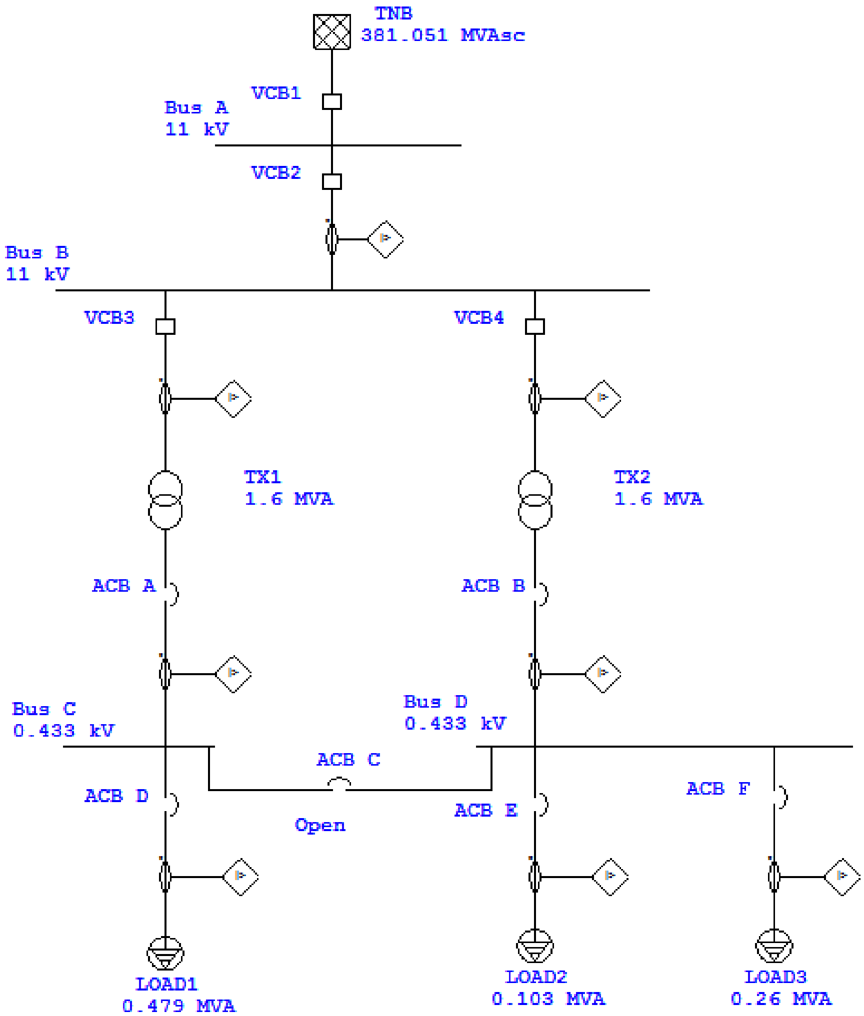

Figure 3.2: The summarized circuit design from the substation

3.3.2 OVERCURRENT RELAY AND EARTH FAULT SETTING FROM THE COMMERCIAL BUILDING

Table 3.1, Table 3.2 and Table 3.3 shows the overcurrent (OC) relay and earth fault (EF) setting made for the library of Universiti Malaysia Pahang from the Incoming TNB, Feeeder to Library and the Incomer of Library.

Table 3.1: OC and EF setting for Incoming TNB

CT 300 / 5A (Incoming TNB)												
Setting	Primary				Secondary				Percentage			
OC	252	A	tms;	0.1	4.2	A	tms;	0.1	84.0%	A	tms;	0.1
EF	30	A	tms;	0.1	0.5	A	tms;	0.1	10.0%	A	tms;	0.1

Table 3.2: OC and EF setting for Feeder to Library

CT 300 / 5A (Incoming TNB)												
Setting	Primary				Secondary				Percentage			
OC	225	A	tms;	0.1	3.75	A	tms;	0.1	75.0%	A	tms;	0.1
EF	30	A	tms;	0.1	0.5	A	tms;	0.1	10.0%	A	tms;	0.1

Table 3.3: OC and EF setting for Incoming Library

CT 300 / 5A (Incoming TNB)												
Setting	Primary				Secondary				Percentage			
OC	225	A	tms;	0.1	3.75	A	tms;	0.1	75.0%	A	tms;	0.1
EF	30	A	tms;	0.1	0.5	A	tms;	0.1	10.0%	A	tms;	0.1

3.4 MODELLING DESIGN USING ETAP SOFTWARE

Electrical Transient Analyser Program (ETAP) is a software tool for power system studies that deals with large power distribution network to create various analysis such as load flow analysis, short circuit analysis, relay coordination and many more. There are several steps to design the simulation using ETAP software.

Step 1: Open the ETAP software; open file > New Project and enter the name of project as shown in Figure 3.3 and Figure 3.4.

Figure 3.3: ETAP Software Version 12.6

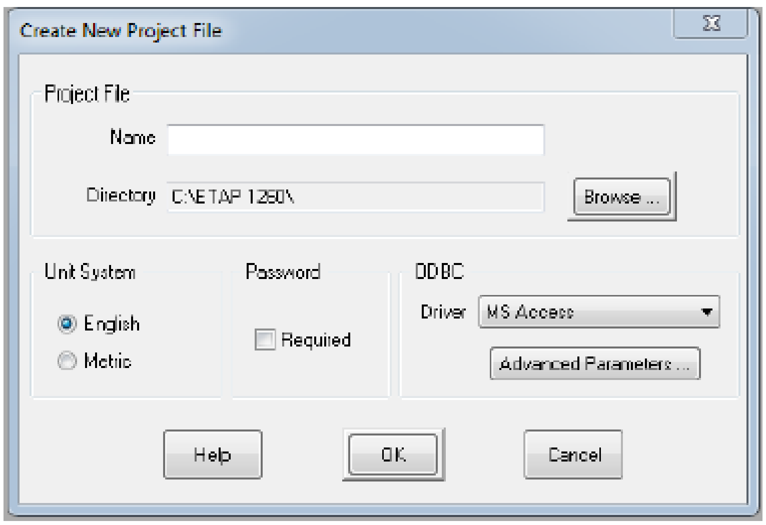

Figure 3.4: Step 1 Create New Project

Step 2: One Line Diagram (Edit Mode) will appear and the electrical equipment can be chosen at the right side of the software to start the modelling. All electrical equipment can be edited its value, name and many more by clicking them twice. Figure 3.5 shows the second step and the complete modelling design as shown in Figure 3.6.

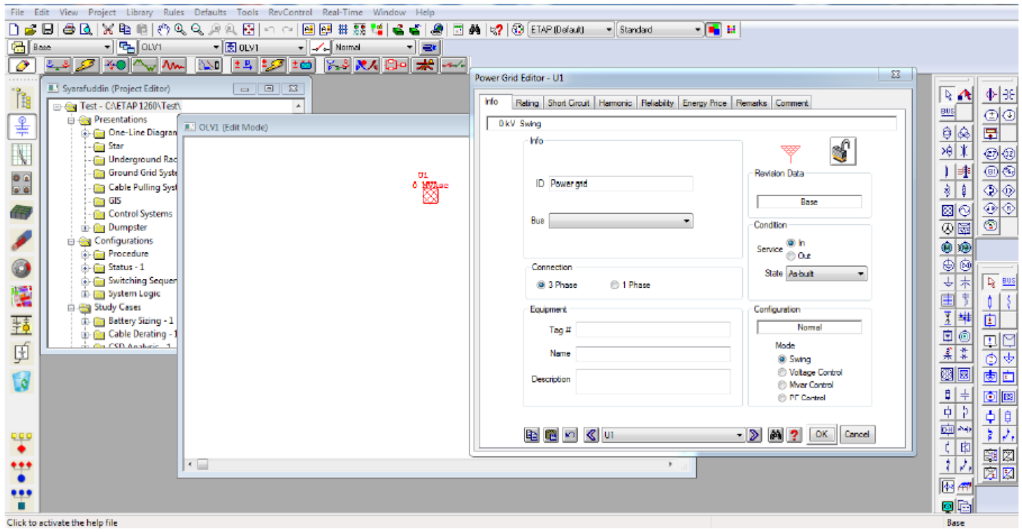

Figure 3.5: One-Line Diagram (Edit Mode)

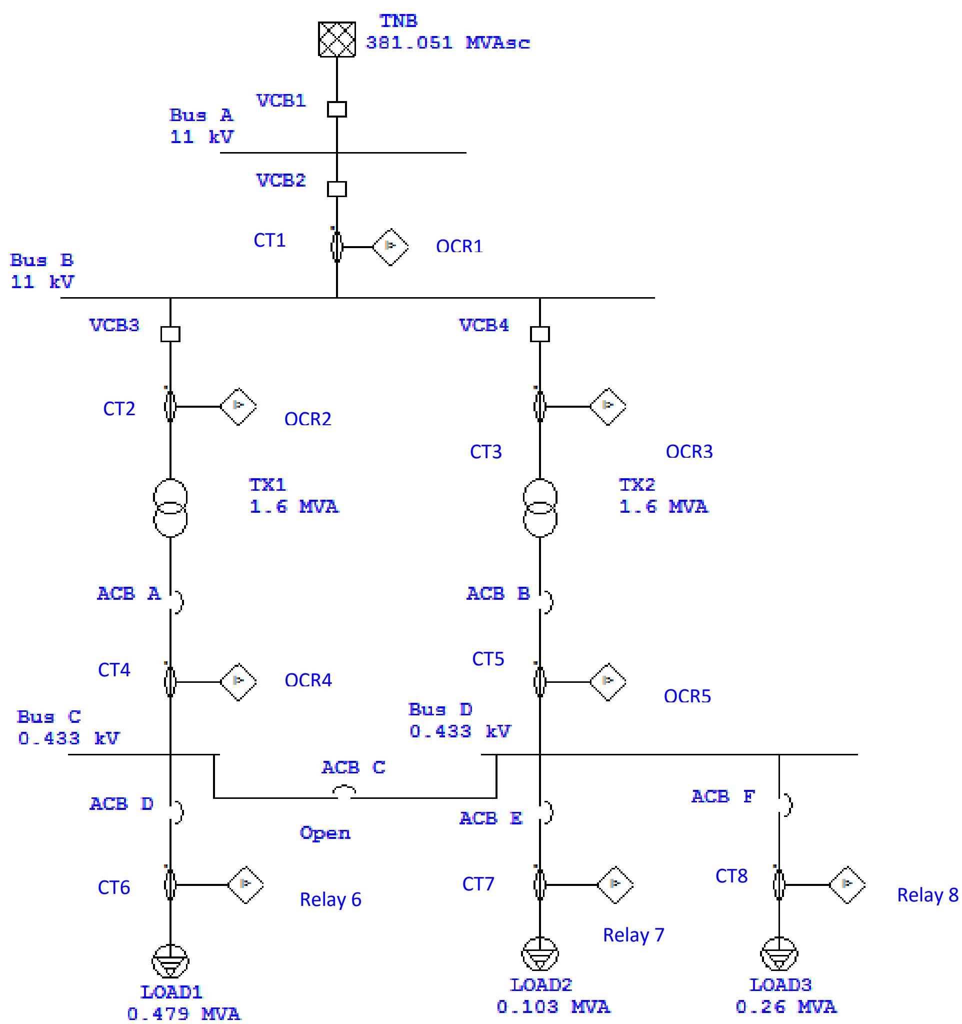

Figure 3.6: Complete One-Line Diagram Modelling Design

After the modelling phase is completed, the actual rating or parameter of Power Grid, Transformer, Circuit Breaker, Bus, and Lump Load are modelled into each of the electrical equipment used in ETAP. All rating can be set by clicking twice at the equipment modelled as shown in Figure 3.7.

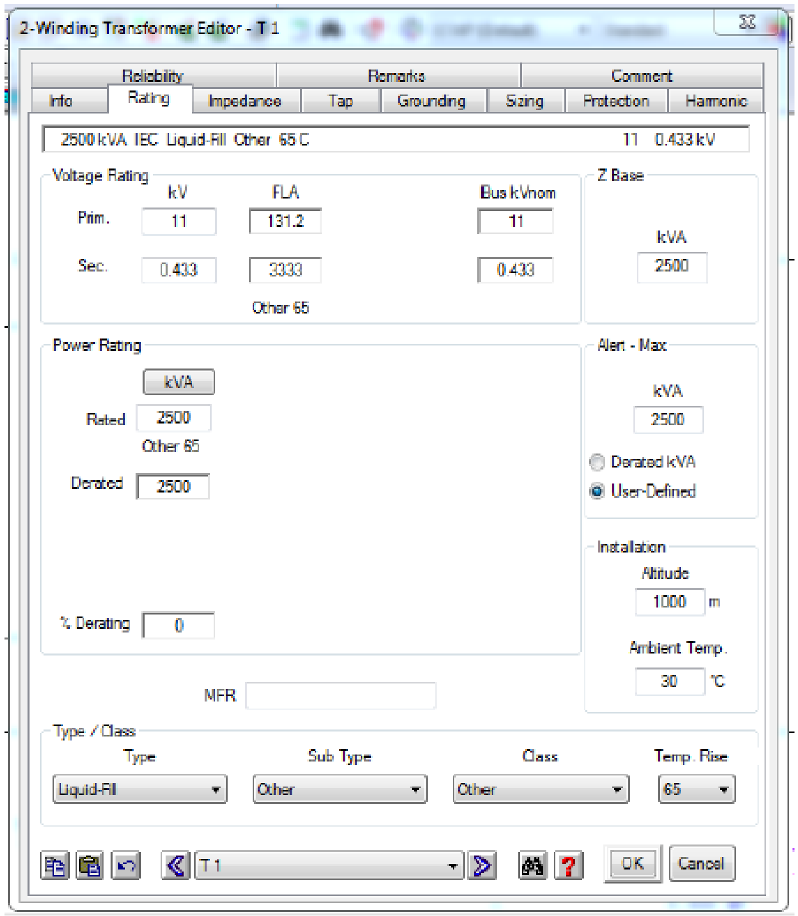

Figure 3.7: Set up rating of equipment

The circuit shown in Figure 3.2 is a complete one-line diagram of 11kV feeder line circuit for Library of Universiti Malaysia Pahang, located in Pekan Campus, Pahang. This circuit is a radial system, which is meaning the power is transferred only in one direction, and in this case, from the uppermost portion of the circuit to the lower portion.

Power is distributed to this circuit is from one TNB source that is 381 MVA located in the substation of Library Universiti Malaysia Pahang. The source provides power to the system under normal conditions. This source is fed into 'Bus A' (11kV) and connected with 1250A 'VCB1'; a 1250A medium voltage vacuum circuit breaker which in turn distributes the power to 'Bus B' (11kV). At Bus A, it is connected with two protection devices labelled as 'VCB2' with rating 630A and 'OCR1'. OCR1 is an ABB SPAJ140C overcurrent and earth fault protective relay. The purpose of installing overcurrent protective relay is to monitor the feeder and protect when an overcurrent situation happened by signaling the circuit breaker to trip or turn into open state.

Whereas at Bus B, the bus have feeders coming off from it that connect to two transformers; 'TX1' and 'TX2' that transform the voltage from 11kV on the primary side to 433V on the secondary side. The feeder that connected to 'TX1' is 'VCB3' with rating 630A and 'OCR2'. The feeder that connected to 'TX2' is 'VCB4' and 'OCR4'. Every each overcurrent protective relay (OCR) are connected to a current transformer (CT). It scales the current down to a level that an OCR can monitor. These three devices; current transformer (CT1, CT2, CT3), overcurrent protective relay (OCR1, OCR2, OCR3) and circuit breaker (VCB 1, VCB 2, VCB 3, VCB 4) are for protections of any devices upstream, in the case of fault. While for the downstream in the case of fault happened at Bus C and Bus D; Relay6, Relay7, and Relay8 will react and give signal to ACB D, ACB E and ACB F to trip and if it fails to do so, ACB A and ACB B will see the fault and trip, protecting the upstream especially the power source. Therefore, in order to effectively protect upstream devices, all protective devices must be coordinated with each other.

Table 3.4: Modelling's Equipment

Equipment	Abbreviations
TNB Source 381MVAsc	TNB
Medium Voltage Circuit Breaker	VCB1, VCB2, VCB3, VCB4
Busbar	BUS A, BUS B, BUS C, BUS D
Overcurrent and Earth Fault Relay (ABB SPAJ140C)	OCR1, OCR2, OCR3, OCR4, OCR5, Relay6, Relay7, Relay8
Voltage Transformer 1.6 MVA, 11/0.433kV	TX1, TX2
Low Voltage Air Circuit Breaker	ACB A, ACB B, ACB C, ACB D, ACB E, ACB F
Current Transformer 3x300/5A	CT1, CT2, CT3

Current Transformer 4x2000/5A	CT4, CT5
Current Transformer 4x800/5A	CT6
Current Transformer 4x1600/5A	CT7
Current Transformer 4x600/5A	CT8
Load	LOAD1, LOAD2, LOAD3

3.5 Simulation of Load Flow Analysis

Figure 3.8 shows step how to do setting for categories. Loading categories and generation categories must be set by clicking Project > Settings… > Loading Categories… as shown in Figure 3.9 and Generation Categories as shown at Figure 3.10. First category set for maximum value, second category set for normal value and the third category is for minimum.

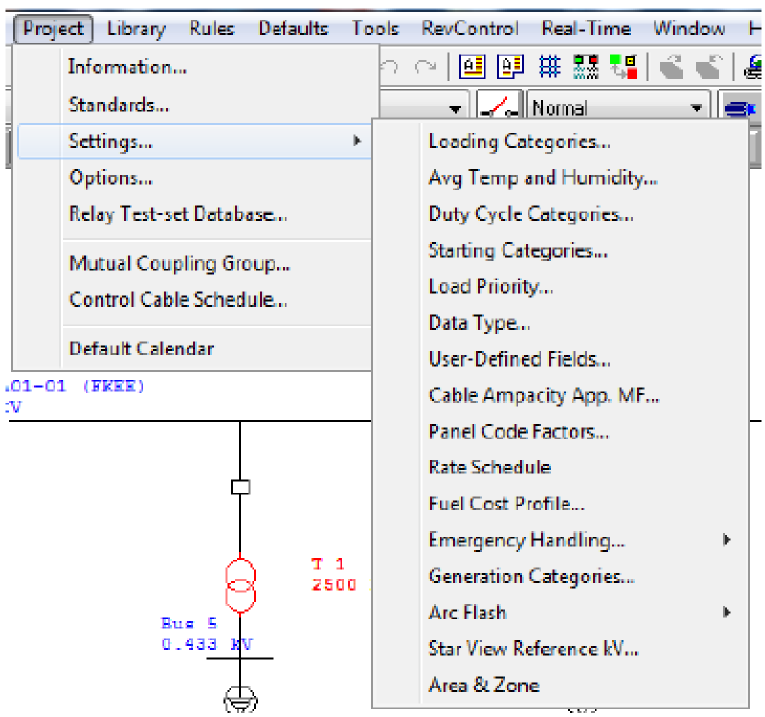

Figure 3.8: Setting for categories

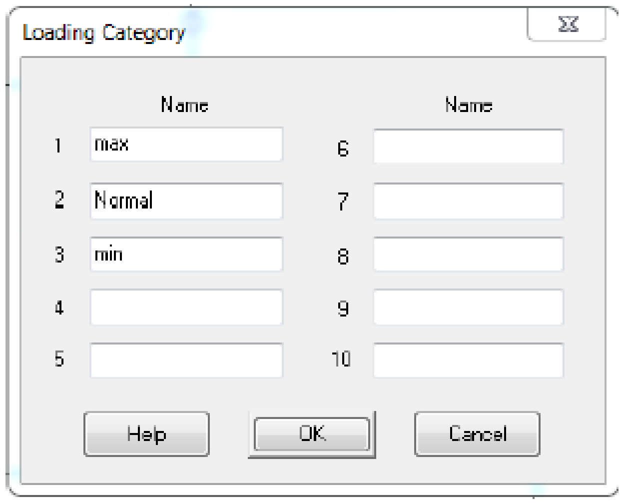

Figure 3.9: Loading categories

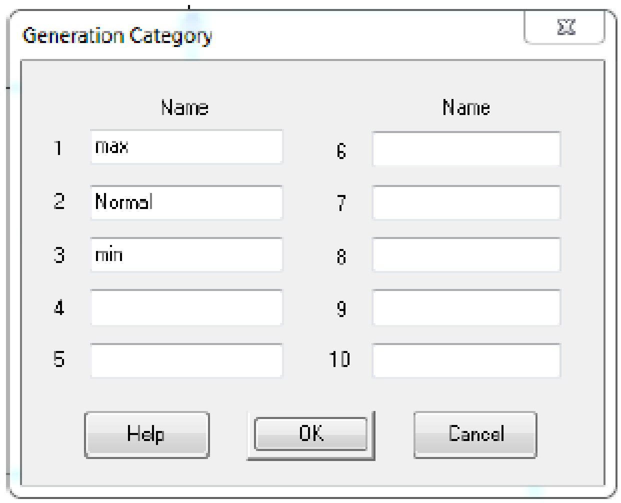

Figure 3.10: Generation categories

The condition of categories must be set in voltage percentage by clicking twice power grid and all lump loads. The setting for Power Grid and Lump Load is shown in Figure 3.11 and Figure 3.12 respectively.

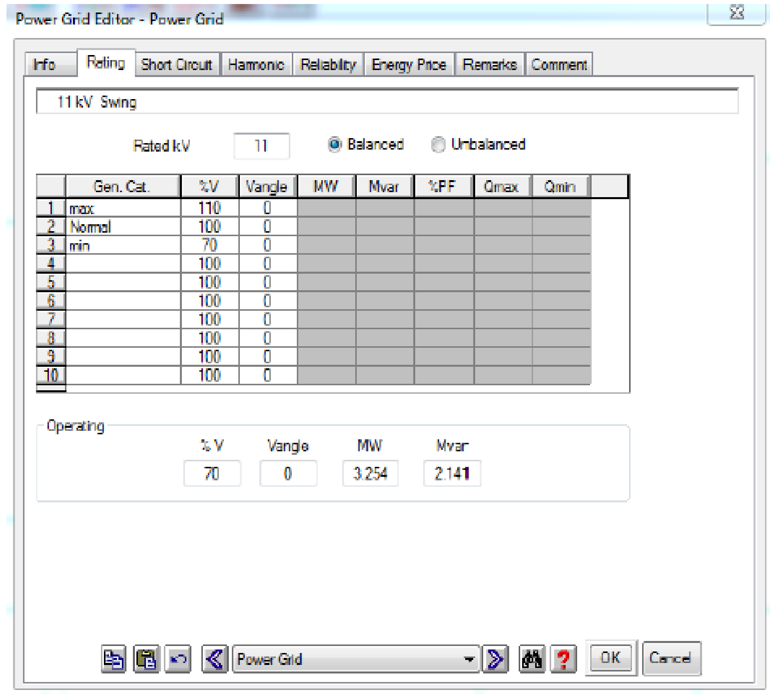

Figure 3.11: Voltage percentage of Power Grid

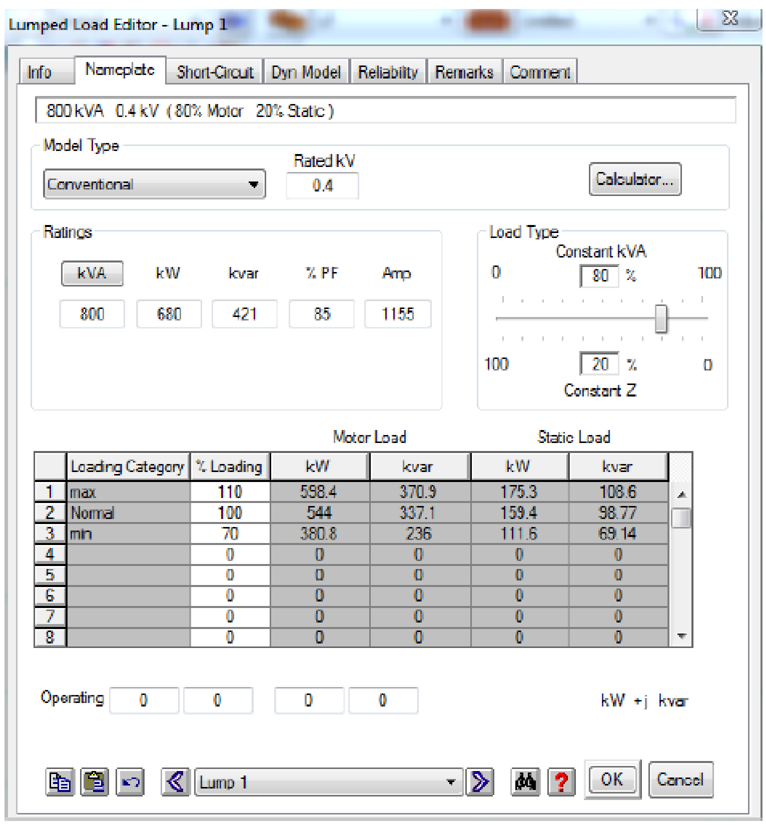

Figure 3.12: Voltage percentage for Lump Load

After all the setting has done, run the load flow analysis by clicking the icon as shown in Figure 3.13.

Figure 3.13: Load flow icon

The voltage magnitude, phase angle at each bus, real and reactive power flowing in each element will be shown under three categories; overvoltage, under voltage and normal condition. Our desire result categories can be chose as shown in Figure 3.13.

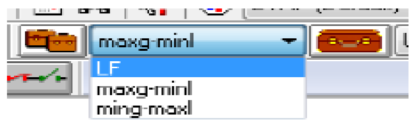

Figure 3.14: Selection of categories

After clicking the 'Run Load Flow' icon and categories are selected, the result is shown and the load flow calculation can be determined as displayed on the one-line diagram as shown in Figure 3.15. Summary of the result will be displayed in the PDF form as shown in Figure 3.16.

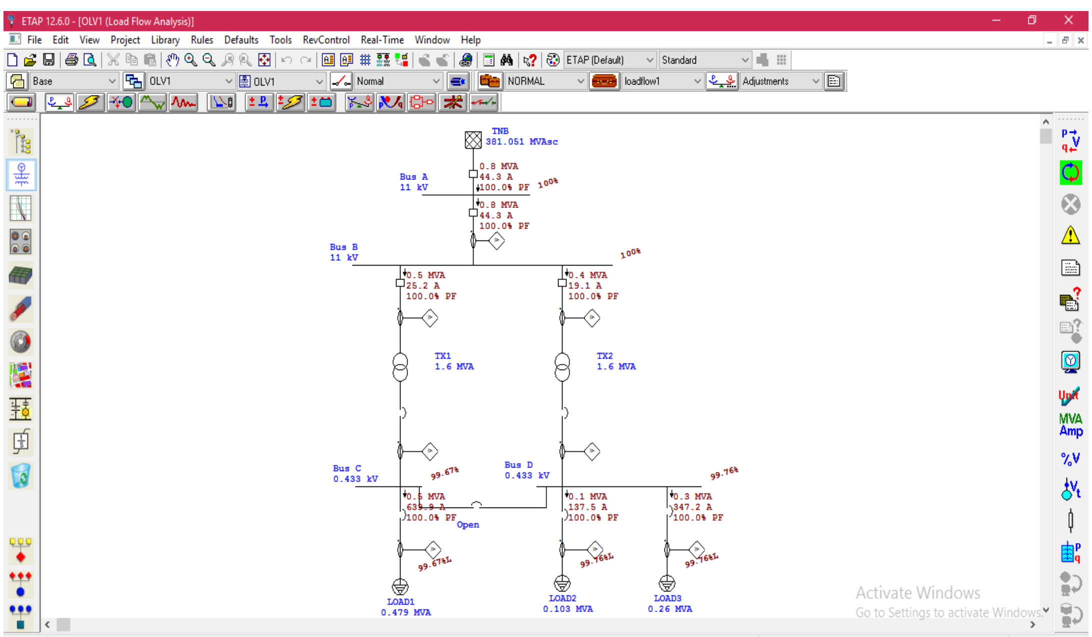

Figure 3.15: Load Flow Analysis

LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus A	11.000	100.000	0.0	0.843	0.014	0	0	Bus B	0.843	0.014	44.3	100.0	
Bus B	11.000	100.000	0.0	0	0	0	0	Bus C	0.480	0.009	25.2	100.0	
								Bus D	0.363	0.005	19.1	100.0	
								Bus A	-0.843	-0.014	44.3	100.0	
Bus C	0.433	99.675	-1.1	0	0	0.478	0.000	Bus B	-0.478	0.000	639.9	100.0	
Bus D	0.433	99.757	-0.8	0	0	0.363	0.000	Bus B	-0.363	0.000	484.7	100.0	

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

# Indicates a bus with a load mismatch of more than 0.1 MVA

Figure 3.16: Summary of Load Flow Report

3.6 Simulation of Short-Circuit Analysis

From the ETAP software, there are four types of fault that can be calculated such as three phase fault, single-line-to-ground fault, line-to-line fault and double line to ground fault. Firstly, run the short circuit analysis by clicking the icon shown at Figure 3.17 and all the current and voltage of each fault type will be shown.

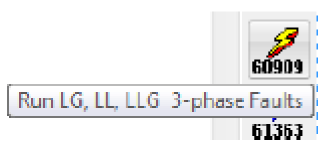

Figure 3.17: Short circuit icon

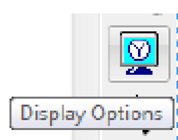

Figure 3.18: Display option icon

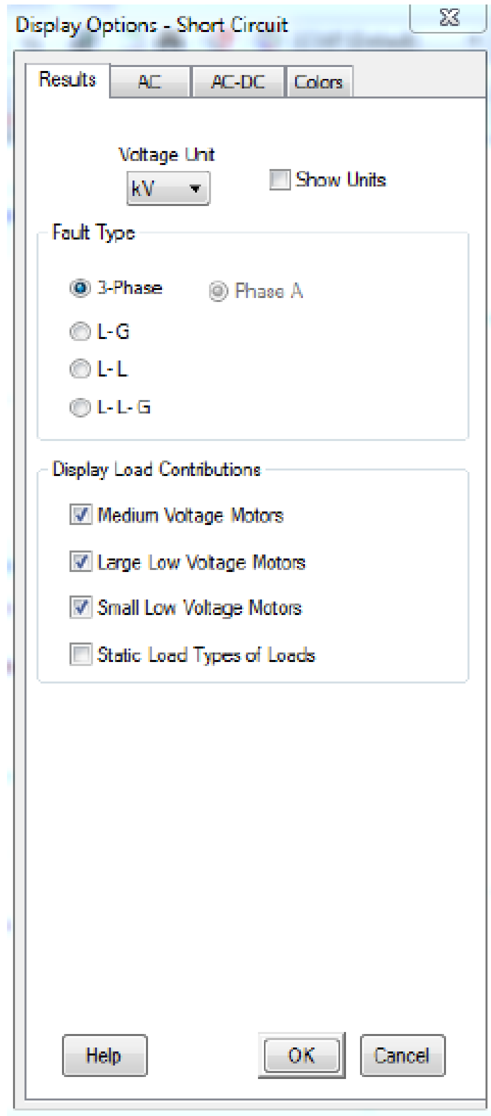

Figure 3.19: Fault type

The result is shown at the short circuit report manager and also on the one line diagram as shown in Figure 3.20 and Figure 3.21 respectively.

SHORT- CIRCUIT REPORT

Fault at bus: Bus A
Nominal kV = 11.000
Voltage c Factor = 1.10 (User-Defined)

Contribution		3-Phase Fault		Line-To-Ground Fault					Positive & Zero Sequence Impedances Looking into "From Bus"			
From Bus ID	To Bus ID	% V From Bus	kA Symm. rms	% Voltage at From Bus Va	Vb	Vc	kA Symm. rms Ia	3I0	% Impedance on 100 MVA base R1	X1	R0	X0
Bus A	Total	0.00	20.217	0.00	100.25	100.11	20.144	20.144	4.69E+000	2.82E+001	4.67E+000	2.85E+001
TNB	Bus A	100.00	20.000	100.00	100.00	100.00	20.000	20.144	4.67E+000	2.85E+001	4.67E+000	2.85E+001
Bus C	Bus B	7.97	0.122	59.37	61.06	100.00	0.081	0.000	1.75E+003	4.38E+003		
Bus D	Bus B	6.50	0.100	59.05	60.47	100.00	0.066	0.000	2.16E+003	5.36E+003		
LOAD1	Bus C	100.00	3.110	100.00	100.00	100.00	1.789	0.000	1.68E+003	4.01E+003		
LOAD2	Bus D	100.00	0.679	100.00	100.00	100.00	0.391	0.000	7.84E+003	1.86E+004		
LOAD3	Bus D	100.00	1.857	100.00	100.00	100.00	1.068	0.000	2.87E+003	6.82E+003		
Bus B	Bus A	0.00	0.222	0.00	100.25	100.11	0.148	0.000				

	3-Phase	L-G	L-L	L-L-G
Initial Symmetrical Current (kA, rms) :	20.217	20.144	17.508	20.195
Peak Current (kA), Method C :	46.215	46.048	40.023	46.164
Breaking Current (kA, rms, symm) :		20.144	17.508	20.195
Steady State Current (kA, rms) :	20.000	20.144	17.508	20.195

\# Indicates a fault current contribution from a three-winding transformer
* Indicates a zero sequence fault current contribution (3I0) from a grounded Delta- Y transformer

Figure 3.20: Short circuit report manager

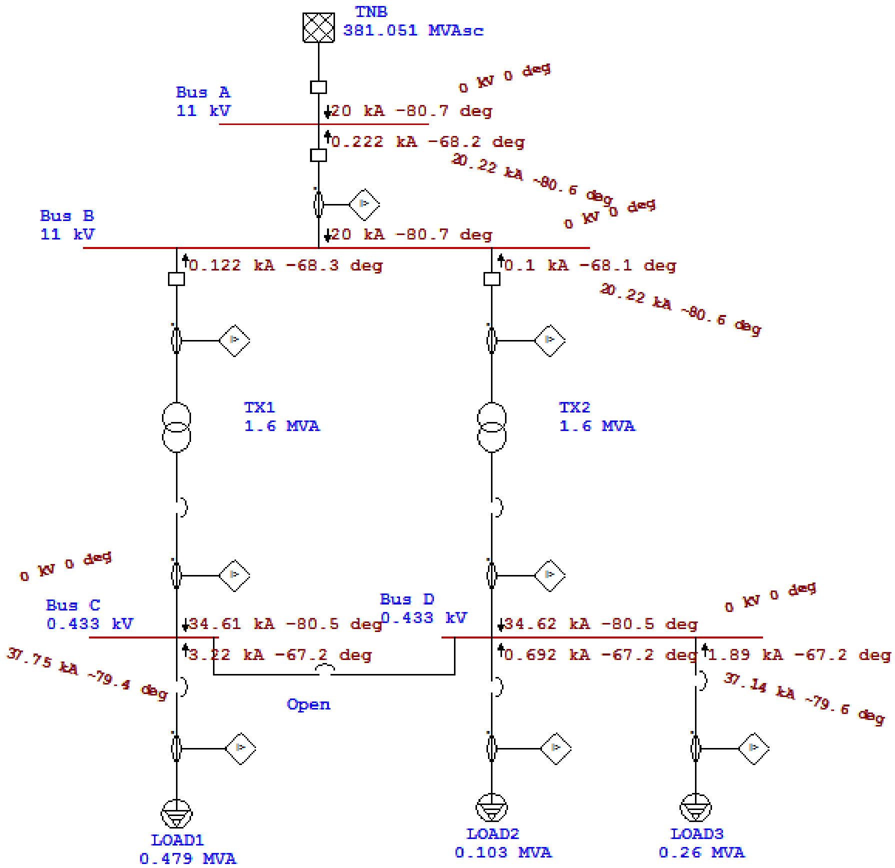

Figure 3.21: Short circuit analysis

3.7 OVERCURRENT RELAY SETTING

For the overcurrent relay setting, study and comparison has been made in selecting correct formula to be used for the manual calculation of overcurrent relay settings. The setting of overcurrent relay setting must obey the rules made for plug setting and time setting.

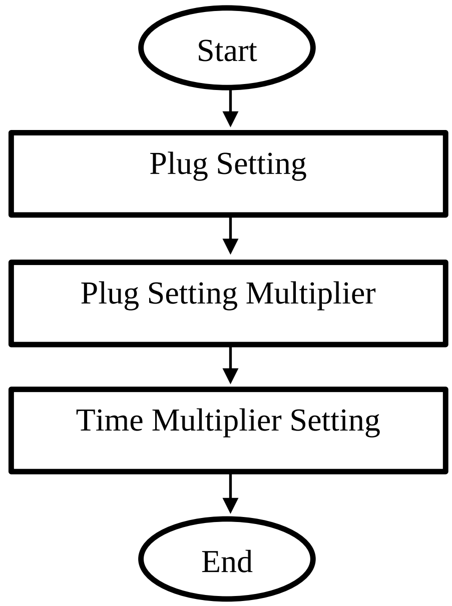

Figure 3.22: The steps of determining overcurrent relay setting

3.7.1 Plug Setting

Based on the third rule of plug setting, in estimating the plug setting, an allowance must be made for the fact that the relay pickup varies from 1.05 to 1.3 times plug settings, as per standards [8]. Thus, the formula used in calculating the plug setting as follows;

Plug setting of OCR 4 & OCR 5:

$$\text{PS of OCR 4} = \frac{kVA\ x\ 1000}{\sqrt{3}\ x\ Secondary\ Rated\ Voltage\ of\ TX1}$$

Plug Setting of OCR 2 & OCR 3:

$$\text{PS of OCR 2} > \left(\frac{1.3}{1.05}\right) \text{ x } \left(\frac{Secondary\ Rated\ Voltage\ of\ TX1}{Primary\ Rated\ Voltage\ of\ TX1}\right) \text{ x PS of OCR 4}$$

Plug Setting of OCR 1:

$$\text{PS of OCR 1} > \left(\frac{1.3}{1.05}\right) \text{ x PS of OCR 2}$$

The IDMT relays are normally available with the plug setting in the range 50-200% of the relay setting in seven equal steps, 50-75-100-125-150-175-200 per cent of the relay rating [8].

3.7.2 Plug Setting Multiplier (PSM)

An inverse-time characteristic is obtained if the value of the plug setting multiplier is below 10 [1]. For values of plug setting multiplier between 10 and 20, the characteristics tends to become a straight line [1]. The value of fault current for the specific faulted bus are obtained from the result of short circuit analysis.

$$\text{PSM of OCR} = \frac{Fault\ Current}{Relay\ Current\ Setting\ x\ CT\ Ratio}$$

3.7.3 Time Setting Multiplier (TMS)

As for the manual calculation of TMS, it is a common practice to use a fixed selective interval or discrimination time of 0.25 second between the successive relays [8]. Based on the result of PSM calculated, the formula used are as follows;

- For PSM more than 20, Time of operation = $\frac{3}{\log 20}$ x TMS
- For PSM less than or equal to 20,Time of operation = $\frac{3}{\log PSM}$ x TMS

Therefore, the value of TMS of the successive relay;

TMS = Time of Operation + 0.25 second

3.8 RELAY COORDINATION METHOD

For the relay coordination, the ETAP star view feature will be used in coordinating the relay. The flow begins with deciding the primary and back up relay of the line. Secondly, the manual calculation result is transferred into ETAP for each of the overcurrent relay setting. The result are then viewed on ETAP star view; the time – current curve will be displayed. The next step are to get its pickup current and delay time from the graph and comparison will be made compared to the manual calculation and the practical setting from the commercial building. Figure 3.23 shows the flow of coordinating relays for this project.

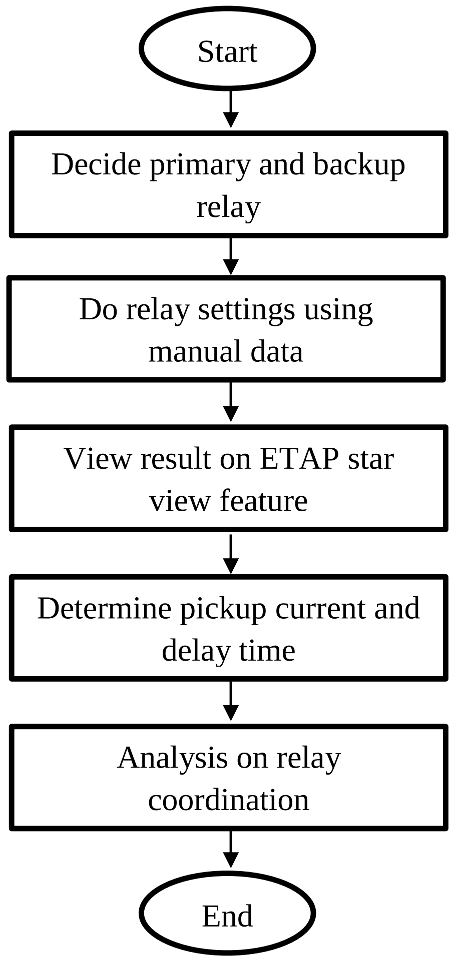

Figure 3.23: Method for Relay Coordination

In deciding the primary and backup relay, Figure 3.24 shows the selection of the protection schemes when specified bus are faulted. Figure 3.25 shows the setting been made for the overcurrent relay in ETAP based on manual calculation result.

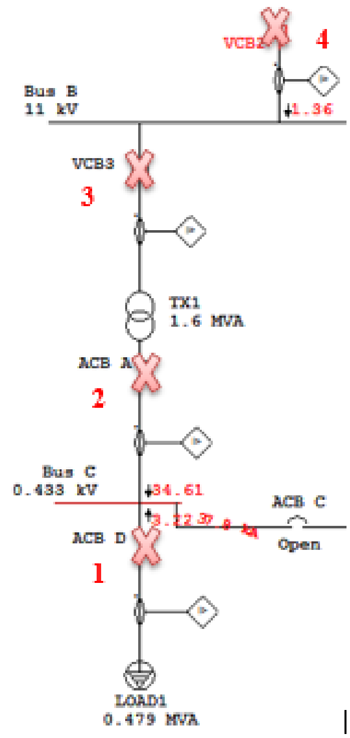

Figure 3.24: The selection of primary and backup relay

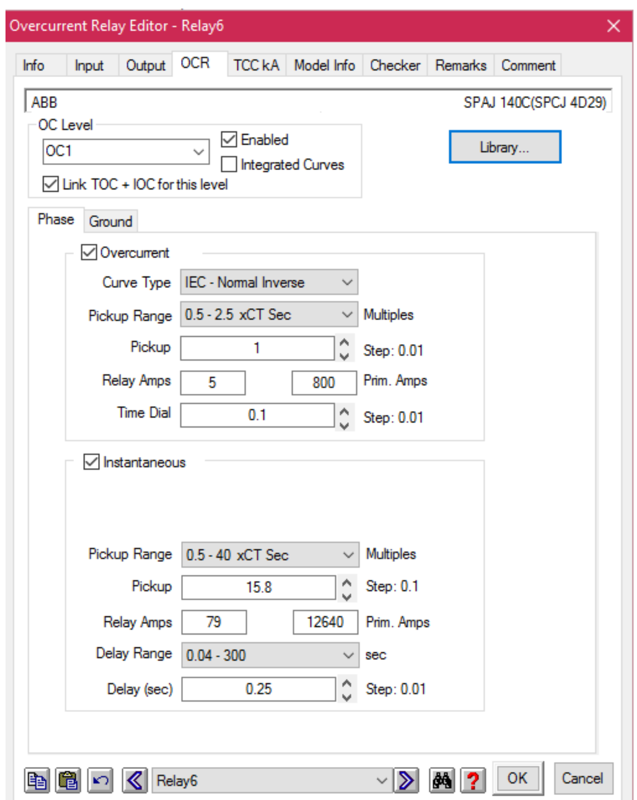

Figure 3.25: Setting of Overcurrent Relay on ETAP

Figure 3.26 shows the TCC graph of the relay. The graph appeared when any overcurrent relay from the one-line diagram are selected and dragged into the graph.

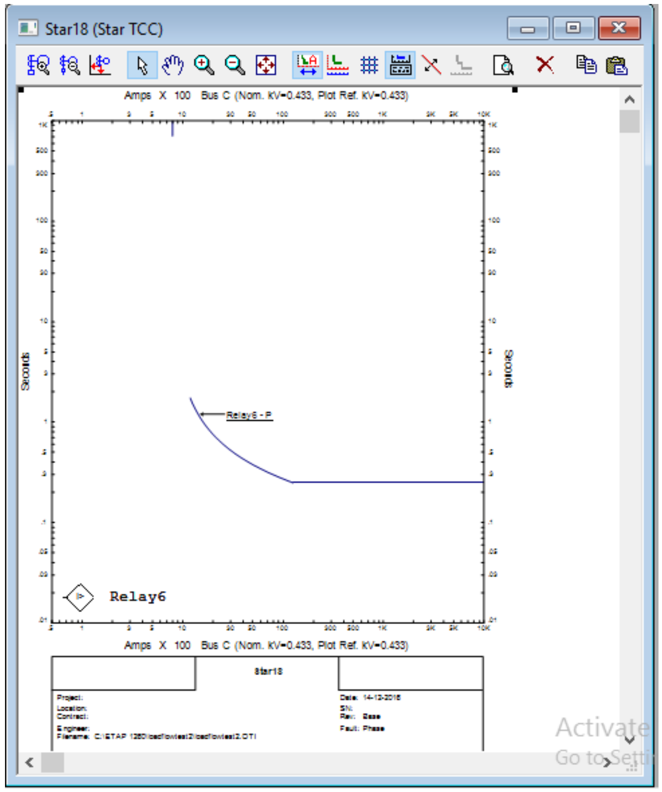

Figure 3.26: ETAP Star View

Figure 3.25 and Figure 3.26 has shown the setting of the pickup current and delay setting. Based on the result, the analysis on the setting and curve will be analysed and discussed in comparison of manual calculation, practical setting and the result obtained from ETAP.

3.9 SUMMARY

The summary of the project scope in details include the flowchart of the project, the steps involved in collecting data, modelling in the ETAP software, load flow analysis, short circuit analysis, manual calculation for relay settings and finally on relay coordination.

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

This chapter will be clarification of project's result that obtained from the simulation and its discussion. Improper coordination of relays may worsen the system condition, which can cause further equipment failure, thus, it is necessary to give proper and comprehensive considerations on coordinating the relays. The single-line diagram of 11kV feeder with 4 bus transmission system network of Library Universiti Malaysia Pahang, Pekan Campus had been constructed in ETAP. Both load flow and short-circuit analysis had been performed. Load flow analysis will be observed under normal condition and other eleven possible conditions whereas short-circuit analysis will be analysed for the effect of changing fault location and fault type and its effect on changing the breaker control. Thus, load flow and fault analysis must be required in relay coordination [4]. The overcurrent relay and earth fault will be analysed under application of practical setting method for overcurrent relay and its optimum relay coordination to improve its reliability and efficiency is determined.

4.2 LOAD FLOW ANALYSIS

Load Flow analysis had been run for the one-line diagram of circuit in order to check its power flow for each busses and components. Figure 4.1 shows result of the load flow analysis for a normal condition. As for normal condition in real situation, ACB C is in open state. That is because, ACB C is an ACB coupler that used as a prevention to the circuit, to protect the upstream that are transformers and the source. At ACB A and ACB B are installed with castell key lock each where only two ACB can operate in one time; both ACB A and ACB B or both ACB A and ACB C or both ACB B and ACB C while ACB C, ACB B and ACB A is in open state respectively. From the real data, all the power factor stated are at unity or 1.0 p.u. The load flow analysis gives the current, voltage and power flow of line, transformer, bus, circuit breakers and other equipment [4]. Using the load flow study, the plug setting of relay can be decided for coordinating relays [4]. Load flow is performed on the system to check its load to source balance [11].

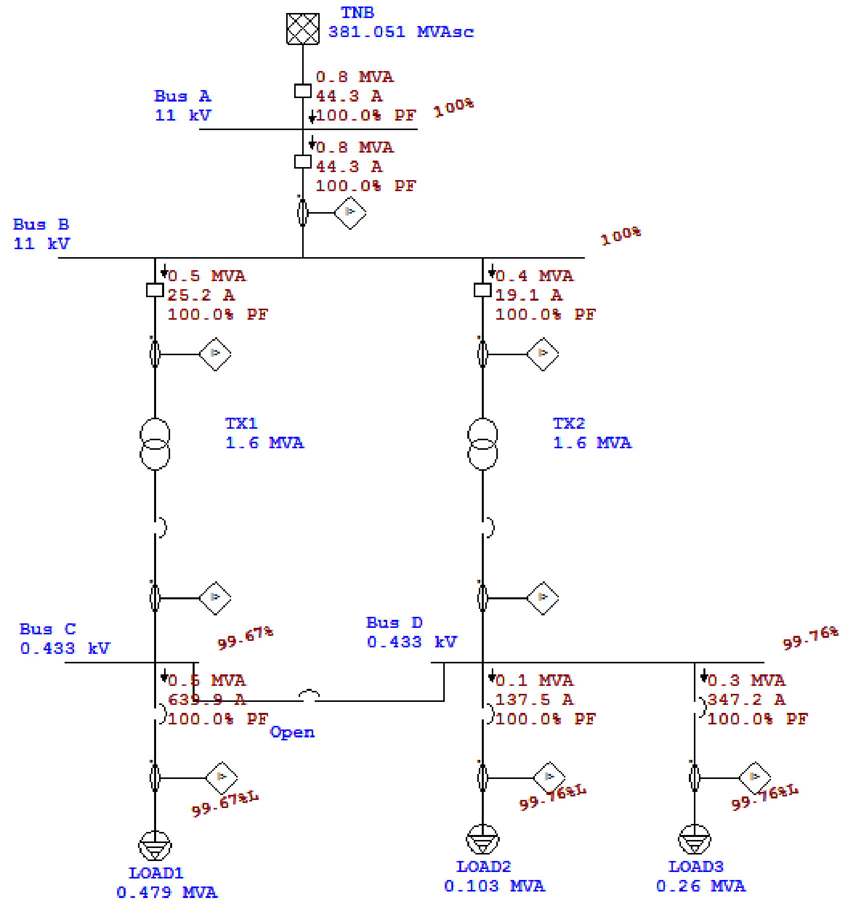

Figure 4.1: Load flow result for a normal condition (ACB C open)

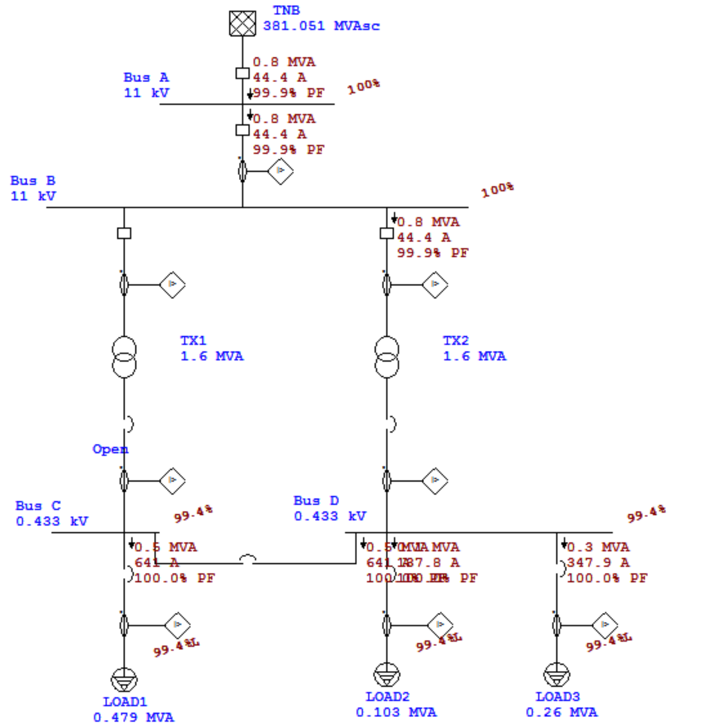

Figure 4.2: Load Flow Analysis Case 1 (ACB A open)

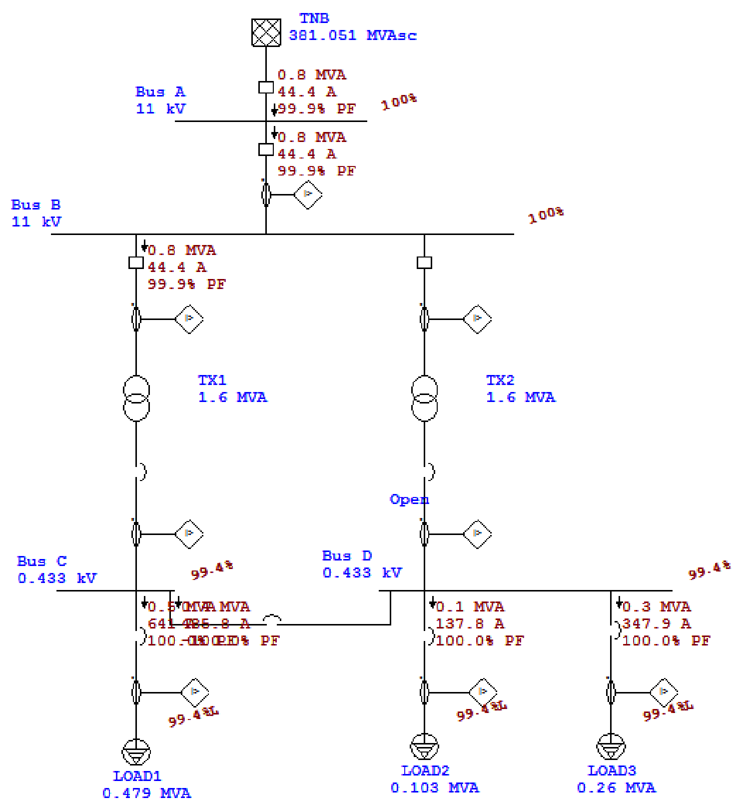

Figure 4.3: Load Flow Analysis Case 2 (ACB B open)

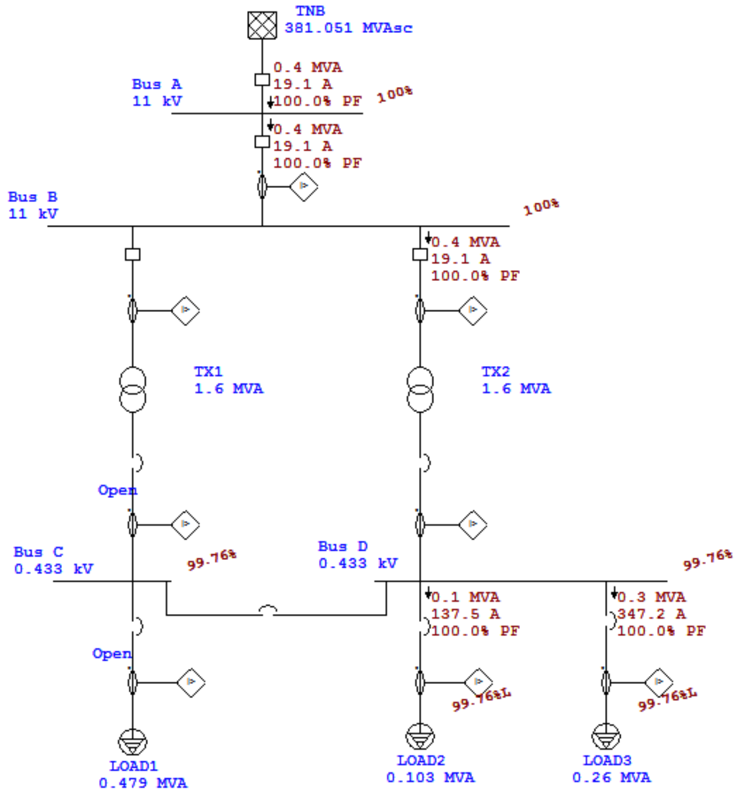

Figure 4.4: Load Flow Analysis Case 4 (ACB A and ACB D open)

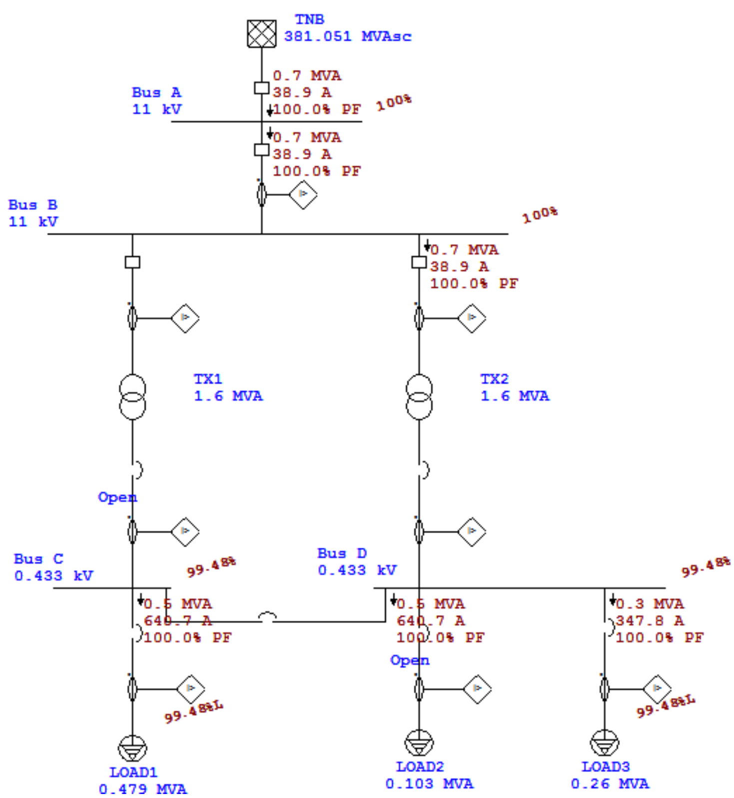

Figure 4.5: Load Flow Analysis Case 4 (ACB A and ACB E open)

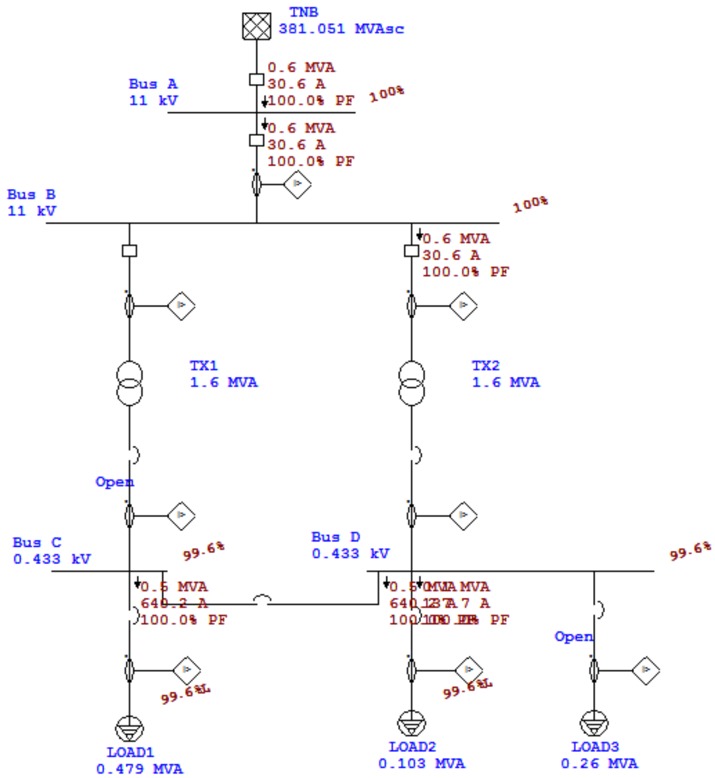

Figure 4.6: Load Flow Analysis Case 5 (ACB A and ACB F open)

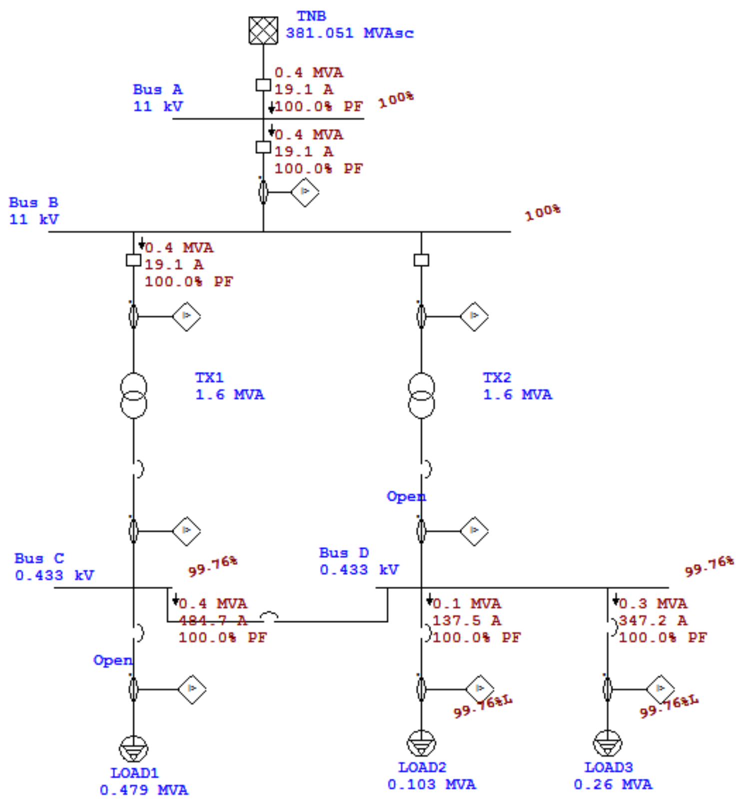

Figure 4.7: Load Flow Analysis Case 6 (ACB B and ACB D open)

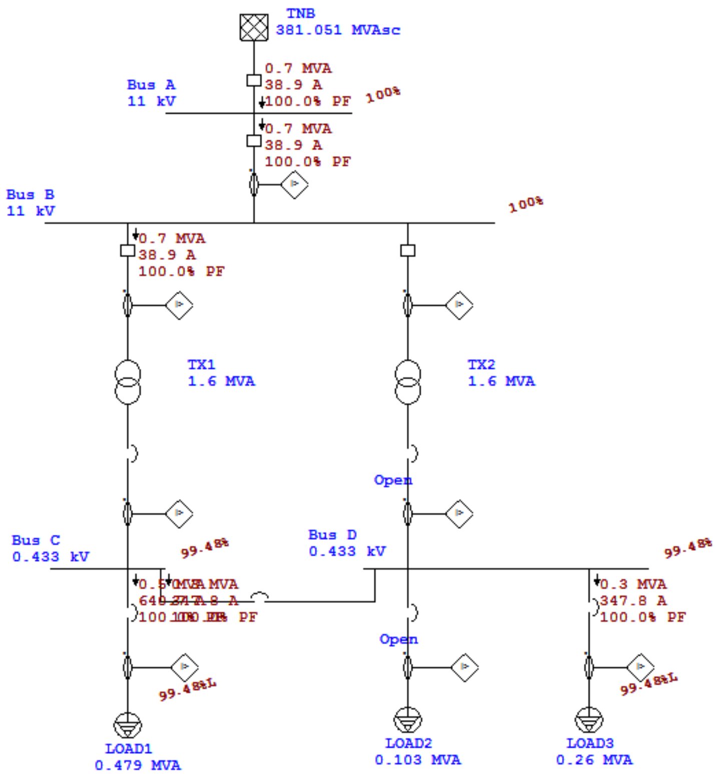

Figure 4.8: Load Flow Analysis Case 7 (ACB B and ACB E open)

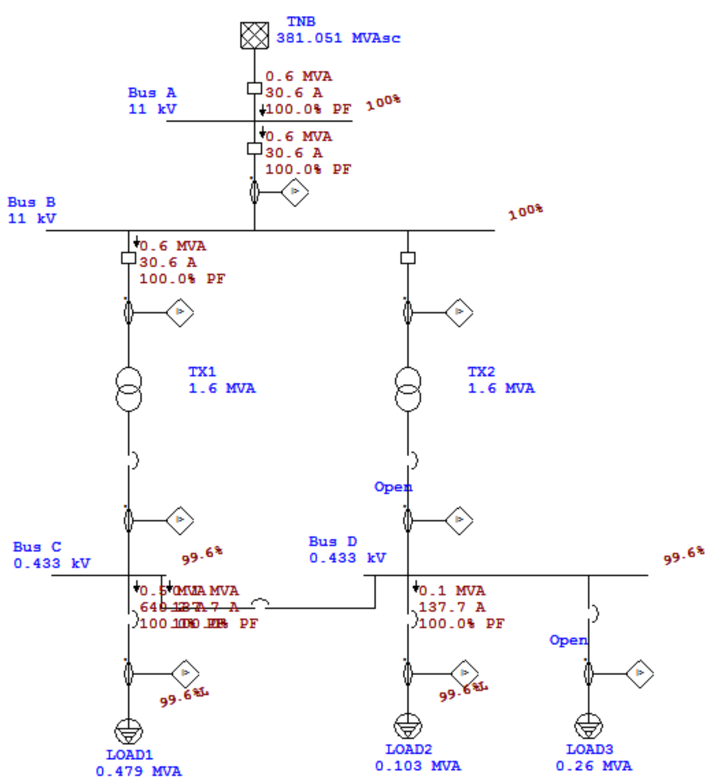

Figure 4.9: Load Flow Analysis Case 8 (ACB B and ACB F open)

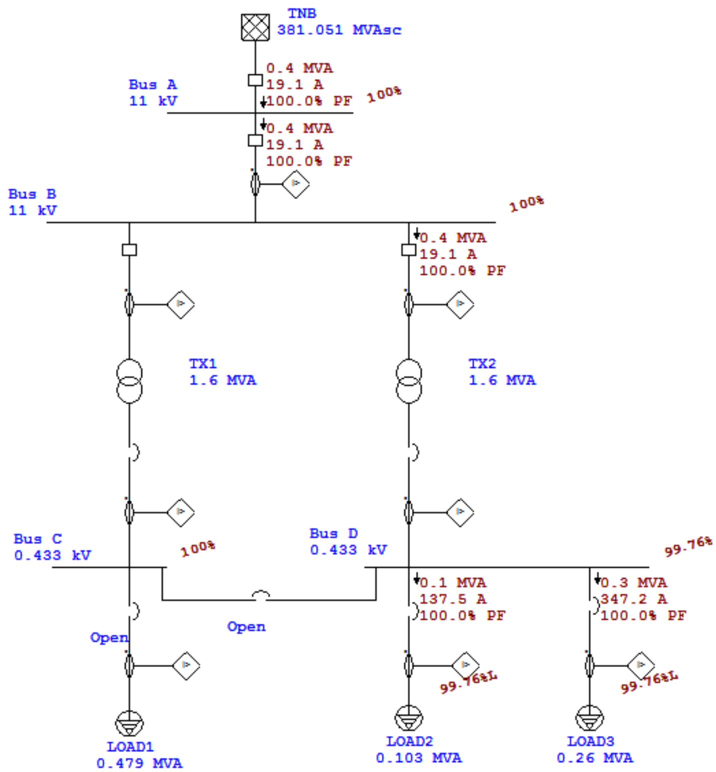

Figure 4.10: Load Flow Analysis Case 9 (ACB C and ACB D open)

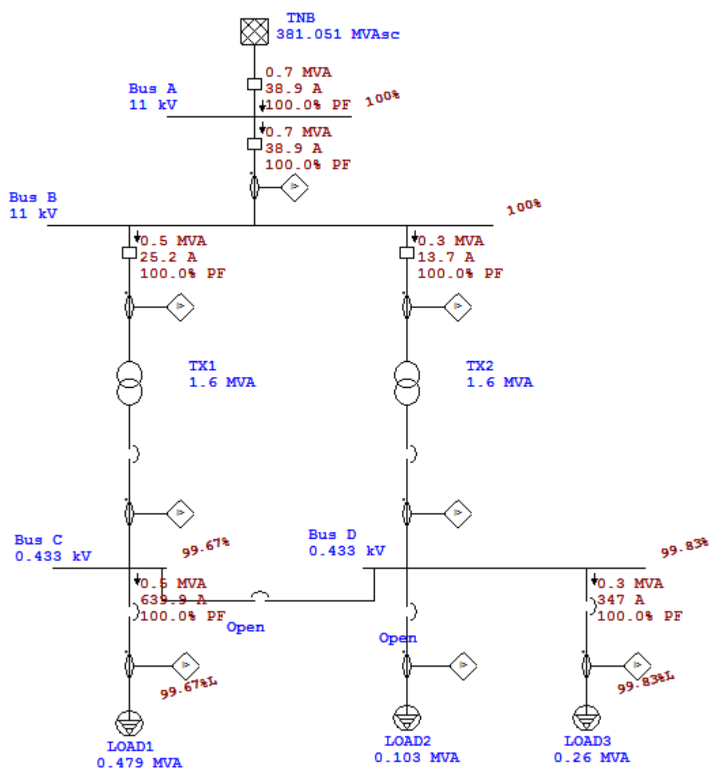

Figure 4.11: Load Flow Analysis Case 10 (ACB C and ACB E open)

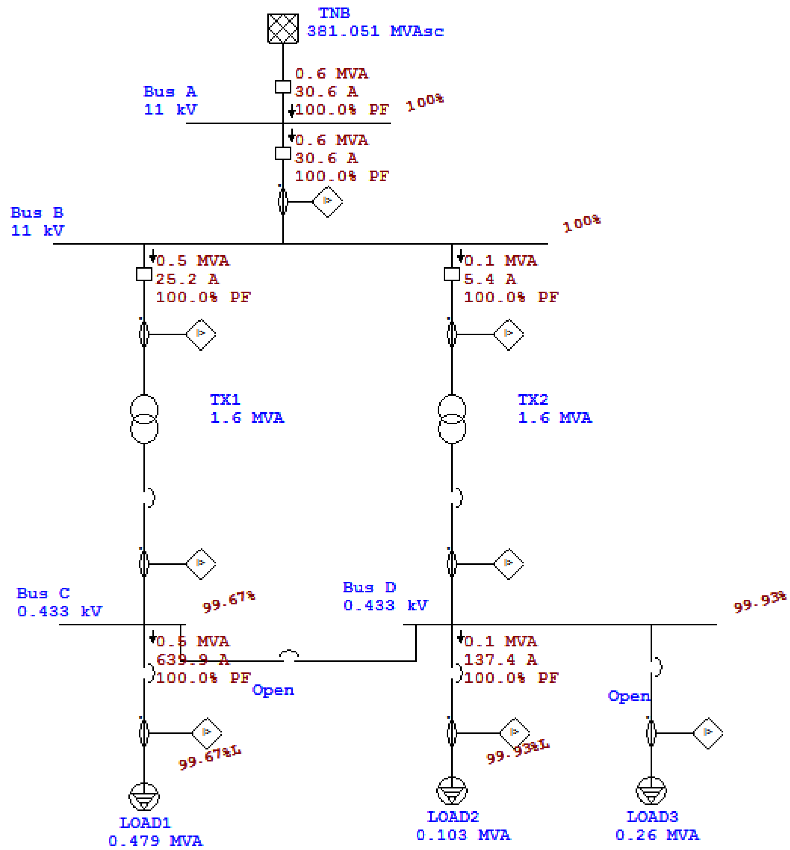

Figure 4.12: Load Flow Analysis Case 11 (ACB C and ACB F open)

4.2.1 Results and Discussion of Load Flow Analysis

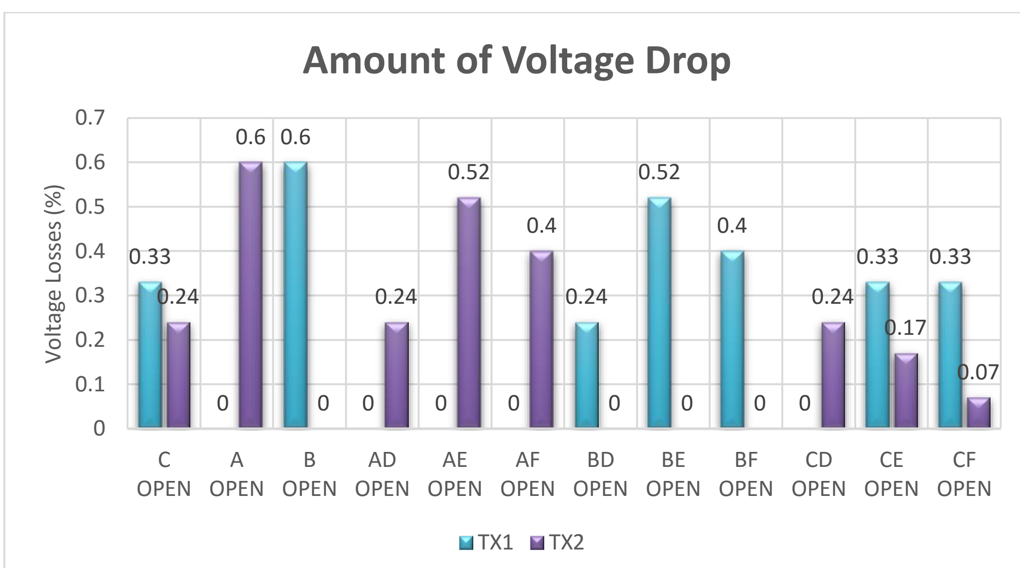

Figure 4.13: Graph of amount voltage drop of normal condition (C open) versus the 11 cases of condition of the circuit breakers

Table 4.1: ETAP Branch Losses Summary Report

Cases	Branch	Real Power Losses (kW)	Reactive Power Losses (kVar)
ACB C open (normal)	TX1 TX2	1.5 0.8	8.9 5.1
ACB A open	TX2	4.6	27.5
ACB B open	TX1	4.6	27.5
ACB AD open	TX2	0.8	5.1
ACB AE open	TX2	3.5	21.2
ACB AF open	TX2	2.2	13.1
ACB BD open	TX1	0.8	5.1
ACB BE open	TX1	3.5	21.2
ACB BF open	TX1	2.2	13.1
ACB CD open	TX2	0.8	5.1
ACB CE open	TX1 TX2	1.5 0.4	8.9 2.6
ACB CF open	TX1 TX2	1.5 0.1	8.9 0.4

Based on the tabulated graph, comparison have been made. Overall, the total amount of voltage drop of normal condition (circuit breaker C open) is 0.57. The graph shown that there is no significant changes in the busbar voltage drop from upper busbar to the load. The voltage are still within the range of 99% to 101%. Thus, this shows that the system are stable and able to cater power in any state of possible conditions of circuit breakers efficiently; and most importantly able to protect the circuit when trip happen due to overvoltages and so on. Equipment exposed to undervoltage or overvoltage can be severely damaged and can prevent the operation of machinery [4].

Furthermore, the table 4.1 shows the summary report of branch losses from ETAP. It presents the value of losses from transformer; TX1 and TX2. The highest power losses can be seen from the results are when ACB A or ACB B open which is

4.6kW + 27.5kVar. There are no major losses happened which may due to the transformers itself. The transformers in the feeder system can greatly reduce the I^2R losses [12]. However, the transformer does carry some additional elements into the loss equations [12]. Every system operation has objectives in managing reactive power and voltages [8]. The first objective is it necessary to keep adequate voltages throughout the transmission and distribution system for both contingency and current condition [8]. Then, second objective is it seeks to lessen the congestion of real power flows and lastly to reduce real power losses.

On other hand, power factor of the entire system for the normal condition and the cases been tested are within the limit of 0.95 p.u to 1.0 p.u (unity). The unity power factor are obtained when voltage and current are in phase, the circuit is in a reactive circuit at resonance and only contain resistance. Power factor are essential in electrical power system as high power factor draws low current than a load with low power factor for the equal amount of useful power distributed or transferred. The low power factor tends increasing the energy lost in distribution system thus higher cost of charges will be charged to industrial or commercial customers. Furthermore, all the switchgear equipment has to be maintained and serviced in every two years of operation to ensure all equipment are functioning when fault happen.

4.3 FAULT ANALYSIS

Short circuit analysis had been done for the one-line diagram of the circuit to check the system short circuit current level; besides it must be performed in order to be able to determine device coordination. A power system is changing during operation and planning; it is not static. Faults normally happen due to flashover, insulation failure, human error or physical damage. This analysis is essential to find PMS of relay which then can be used to find the TMS of back up relay [4]. The fault analysis been done under normal condition of circuit. For any kind of fault whether it is unsymmetrical or symmetrical, the overcurrent relay needs to provide correct discrimination and operate efficiently [11]. In the results, value of I"k, Ip, Ib and Ik are included. I"k is the initial symmetrical short circuit current value, Ip is the peak short circuit current, Ib is the breaking current where the value of highest short circuit current that circuit breaker shall be capable of breaking is determined as described in IEC 60909-02001, and lastly Ik is the steady state current. If the current is higher than Ip, system may not be functioning or even explode.

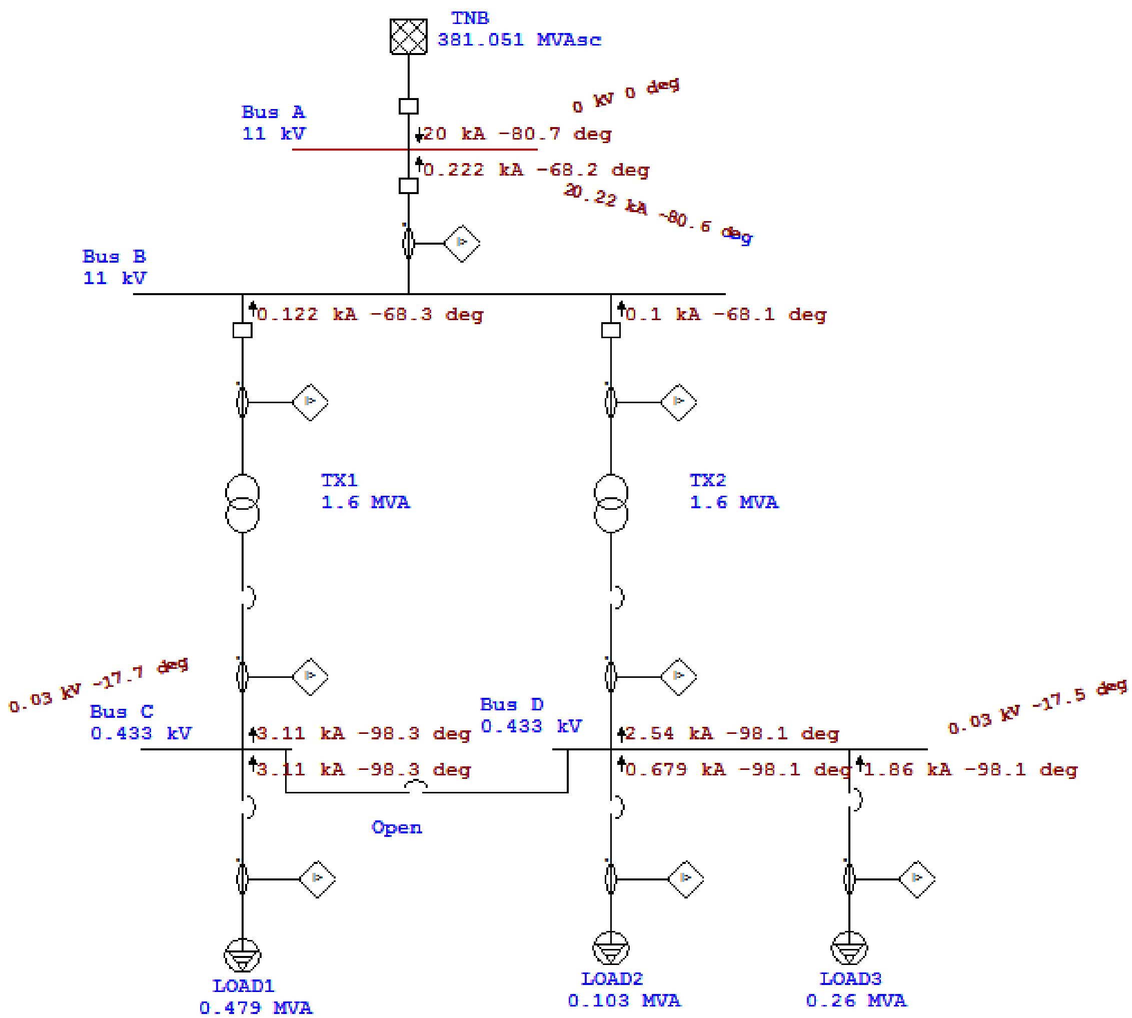

Figure 4.14: Short-circuit Current at Bus A

3-Phase fault at bus: **Bus A**

Nominal kV	=	11.000	
Voltage c Factor	=	1.10	(User-Defined)
Peak Value	=	46.080	kA Method C
Steady State	=	20.000	kA rms

Contribution		Voltage & Initial Symmetrical Current (rms)				
From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	X/R Ratio	kA Magnitude
Bus A	Total	0.00	3.292	-19.876	6.0	20.147
TNB	Bus A	100.00	3.236	-19.737	6.1	20.000
Bus C	Bus B	7.97	0.045	-0.114	2.5	0.122
Bus D	Bus B	1.82	0.011	-0.026	2.4	0.028
LOAD1	Bus C	100.00	1.152	-2.889	2.5	3.110
LOAD2	Bus D	100.00	0.273	-0.658	2.4	0.712
Bus B	Bus A	0.00	0.056	-0.140	2.5	0.150

Breaking and DC Fault Current (kA)

Based on Total Bus Fault Current

TD (S)	Ib sym	Ib asym	Idc
0.01	20.132	26.324	16.960
0.02	20.118	22.517	10.114
0.03	20.104	20.991	6.038
0.04	20.091	20.412	3.606
0.05	20.078	20.193	2.154
0.06	20.072	20.113	1.287
0.07	20.065	20.080	0.769
0.08	20.059	20.065	0.459
0.09	20.053	20.055	0.274
0.10	20.048	20.048	0.164
0.15	20.036	20.036	0.012
0.20	20.025	20.025	0.001
0.25	20.014	20.014	0.000

Figure 4.15: Short circuit report at Bus A

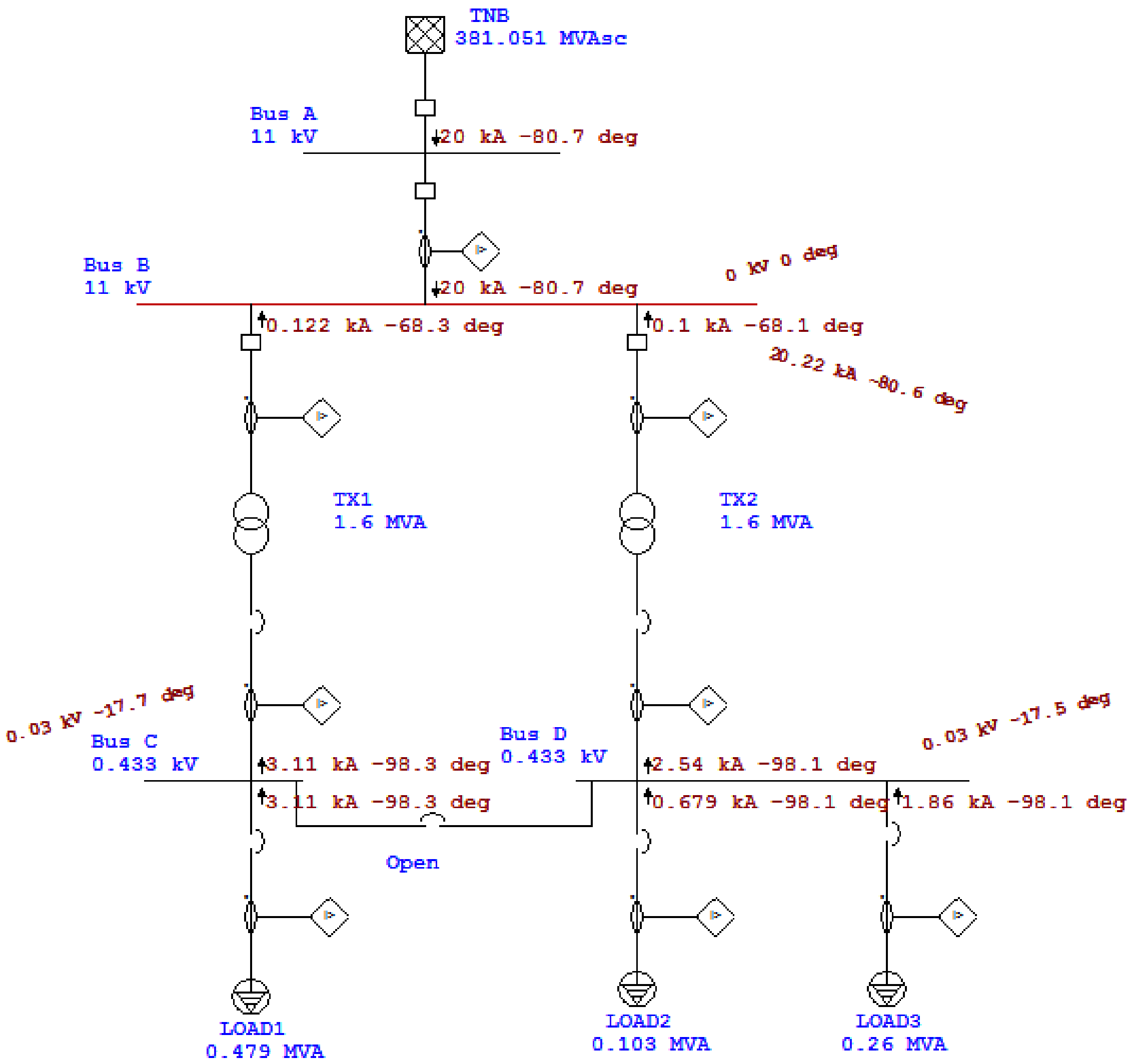

Figure 4.16: Short-circuit Current at Bus B

3-Phase fault at bus: Bus B

Nominal kV	= 11.000		
Voltage c Factor	= 1.10	(User-Defined)	
Peak Value	= 46.080	kA	Method C
Steady State	= 20.000	kA rms	

Contribution		Voltage & Initial Symmetrical Current (rms)				
From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	X/R Ratio	kA Magnitude
Bus B	Total	0.00	3.292	-19.876	6.0	20.147
Bus C	Bus B	7.97	0.045	-0.114	2.5	0.122
Bus D	Bus B	1.82	0.011	-0.026	2.4	0.028
TNB	Bus A	100.00	3.236	-19.737	6.1	20.000
LOAD1	Bus C	100.00	1.152	-2.889	2.5	3.110
LOAD2	Bus D	100.00	0.273	-0.658	2.4	0.712
Bus A	Bus B	0.00	3.236	-19.737	6.1	20.000

Breaking and DC Fault Current (kA)

Based on Total Bus Fault Current

TD (S)	Ib sym	Ib asym	Idc
0.01	20.132	26.324	16.960
0.02	20.118	22.517	10.114
0.03	20.104	20.991	6.038
0.04	20.091	20.412	3.606
0.05	20.078	20.193	2.154
0.06	20.072	20.113	1.287
0.07	20.065	20.080	0.769
0.08	20.059	20.065	0.459
0.09	20.053	20.055	0.274
0.10	20.048	20.048	0.164
0.15	20.036	20.036	0.012
0.20	20.025	20.025	0.001
0.25	20.014	20.014	0.000
0.30	20.014	20.014	0.000

Figure 4.17: Short circuit report at Bus B

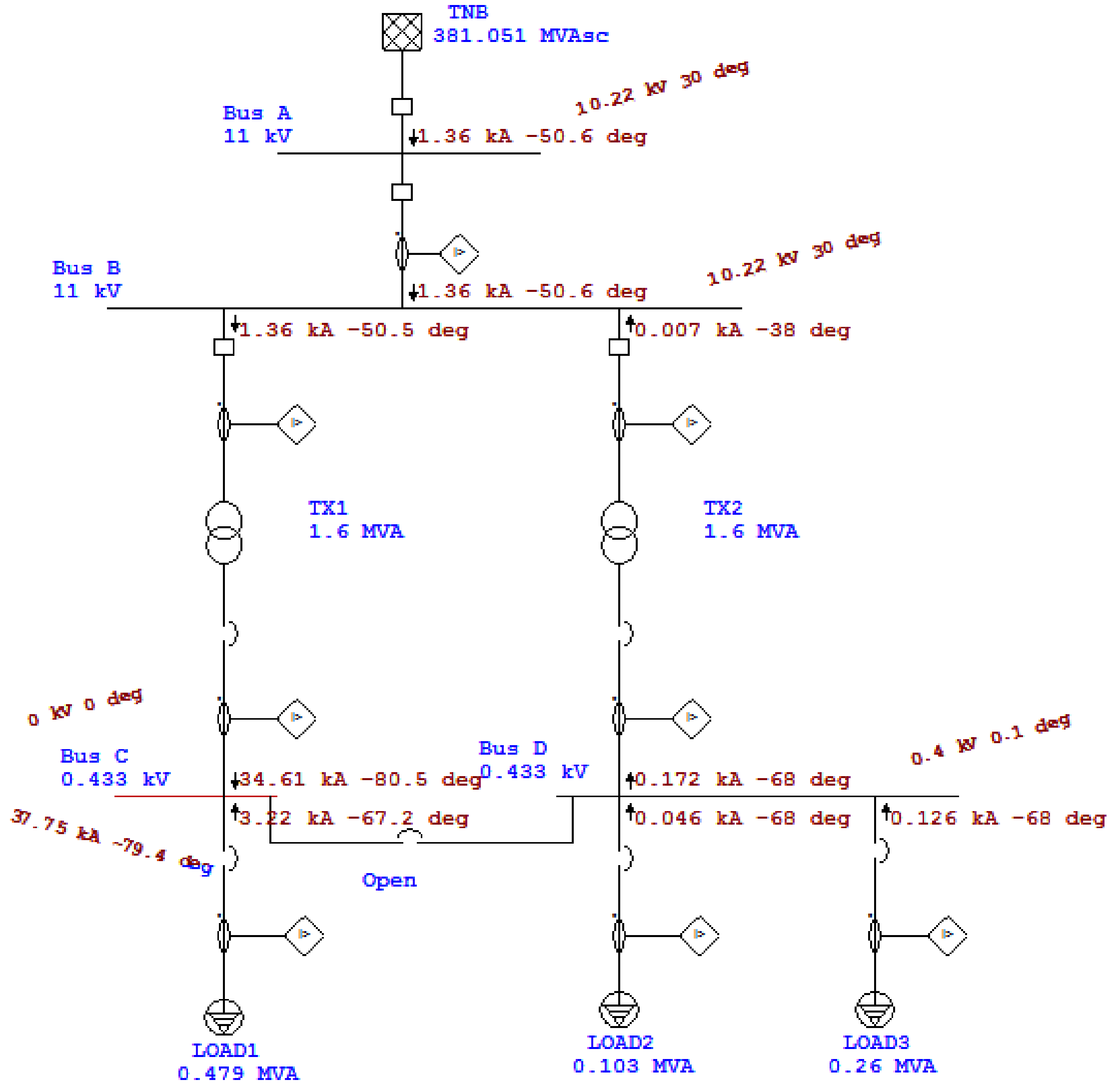

Figure 4.18: Short-circuit Current at Bus C

3-Phase fault at bus: **Bus C**

Nominal kV	=	0.433	
Voltage c Factor	=	1.05	(User-Defined)
Peak Value	=	84.946	kA Method C
Steady State	=	34.602	kA rms

Contribution		Voltage & Initial Symmetrical Current (rms)				
From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	X/R Ratio	kA Magnitude
Bus C	Total	0.00	6.930	-37.103	5.4	37.744
Bus B	Bus C	92.87	5.683	-34.135	6.0	34.605
LOAD1	Bus C	100.00	1.247	-2.968	2.4	3.219
Bus D	Bus B	93.00	0.001	-0.002	2.4	0.002
TNB	Bus A	100.00	0.223	-1.342	6.0	1.360

Breaking and DC Fault Current (kA)

Based on Total Bus Fault Current

TD (S)	Ib sym	Ib asym	Idc
0.01	37.573	48.508	30.681
0.02	37.339	41.466	18.036
0.03	37.109	38.561	10.484
0.04	36.886	37.386	6.094
0.05	36.671	36.849	3.619
0.06	36.567	36.628	2.113
0.07	36.466	36.487	1.234
0.08	36.367	36.374	0.720
0.09	36.270	36.272	0.420
0.10	36.175	36.176	0.250
0.15	35.982	35.982	0.017
0.20	35.798	35.798	0.001
0.25	35.624	35.624	0.000
0.30	35.615	35.615	0.000

Figure 4.19: Short circuit report at Bus C

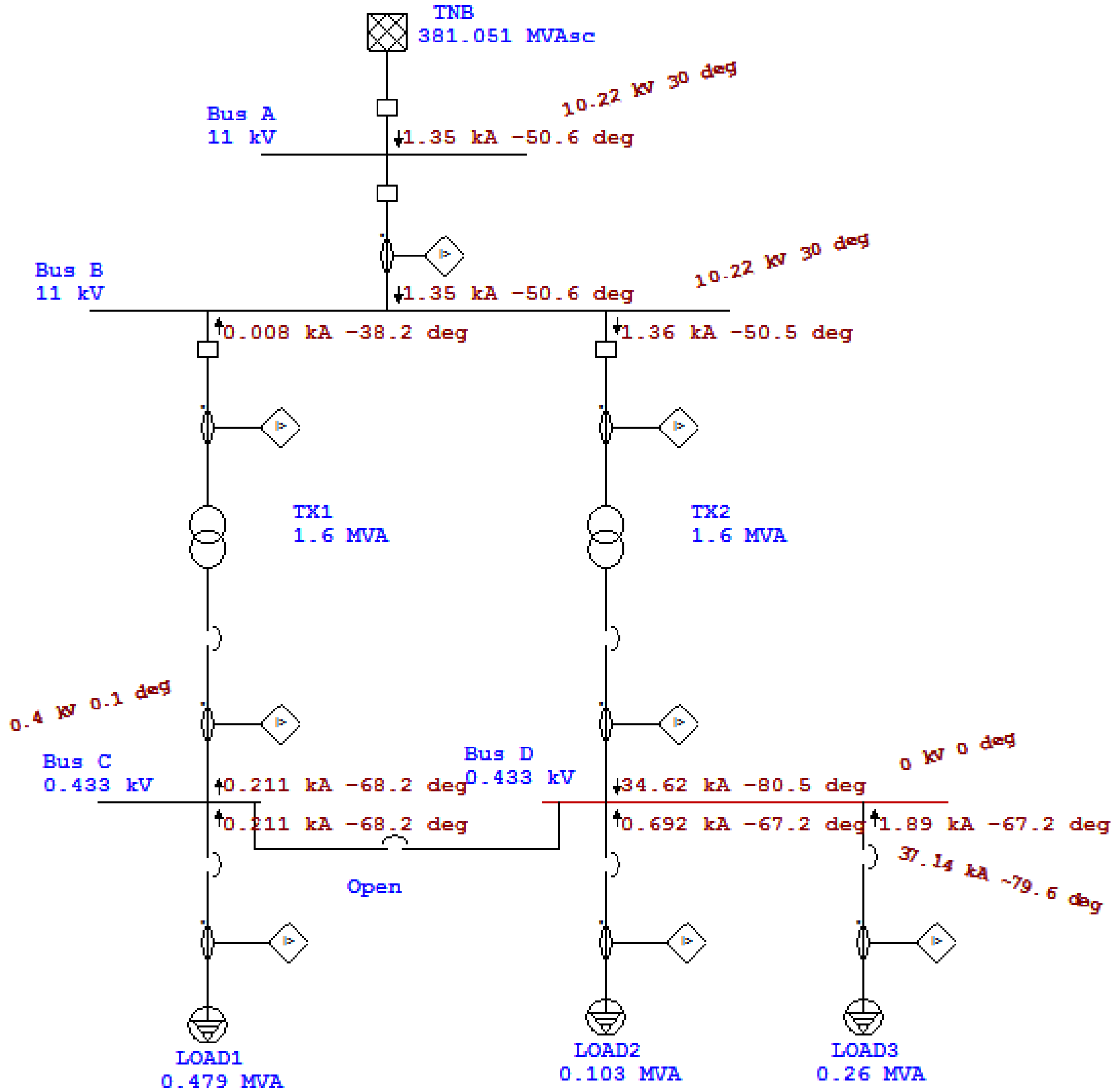

Figure 4.20: Short-circuit Current at Bus D

3-Phase fault at bus: **Bus D**

Nominal kV	= 0.433		
Voltage c Factor	= 1.05	(User-Defined)	
Peak Value	= 80.318	kA	Method C
Steady State	= 34.602	kA rms	

Contribution		Voltage & Initial Symmetrical Current (rms)				
From Bus ID	To Bus ID	% V From Bus	kA Real	kA Imaginary	X/R Ratio	kA Magnitude
Bus D	Total	0.00	5.956	-34.784	5.8	35.290
Bus B	Bus D	92.90	5.688	-34.146	6.0	34.616
LOAD2	Bus D	100.00	0.268	-0.638	2.4	0.692
Bus C	Bus B	93.46	0.003	-0.008	2.5	0.008
TNB	Bus A	100.00	0.221	-1.336	6.1	1.355

Breaking and DC Fault Current (kA)

Based on Total Bus Fault Current

TD (S)	Ib sym	Ib asym	Idc
0.01	35.165	45.821	29.377
0.02	35.117	39.184	17.382
0.03	35.071	36.540	10.258
0.04	35.025	35.545	6.054
0.05	34.982	35.166	3.590
0.06	34.961	35.025	2.121
0.07	34.940	34.963	1.253
0.08	34.920	34.928	0.740
0.09	34.900	34.903	0.437
0.10	34.881	34.882	0.259
0.15	34.845	34.845	0.019
0.20	34.811	34.811	0.001
0.25	34.779	34.779	0.000
0.30	34.779	34.779	0.000

Figure 4.21: Short circuit report at Bus D

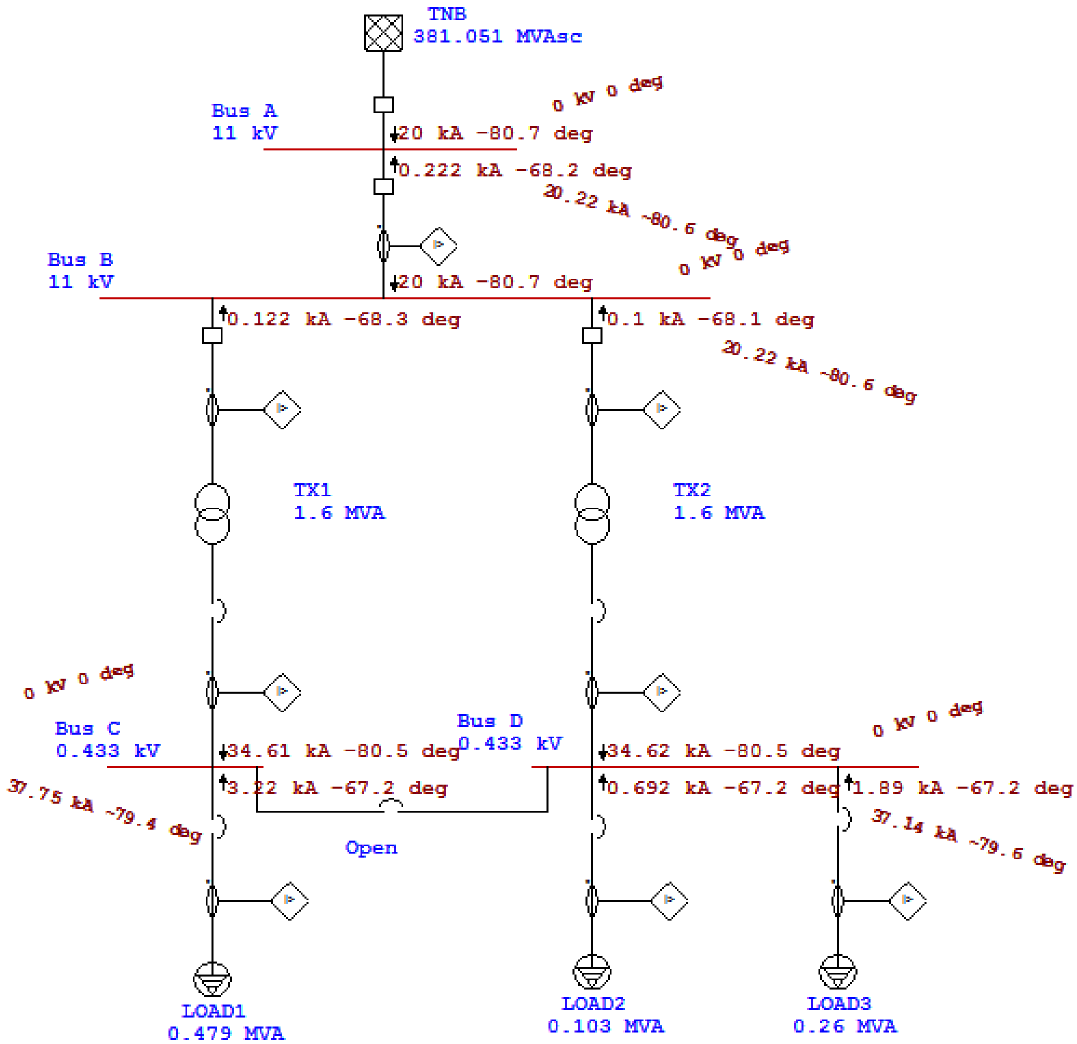

Figure 4.22: Short-Circuit Current at Bus A, Bus B, Bus C and Bus D

4.3.1 Effect of Changing Fault Location and Fault Type

In this section, the effect of changing fault type will be analysed when faulted any bus of the system. The fault type involved are the three-phase (3ϕ) fault, line-to-ground (LG) fault, line-to-line (LL) fault and line-to-line-to-ground (LLG) fault. 3ϕ fault is the symmetrical fault while the LG fault, LL fault and LLG fault are the types of unsymmetrical fault or also called as unbalanced fault.

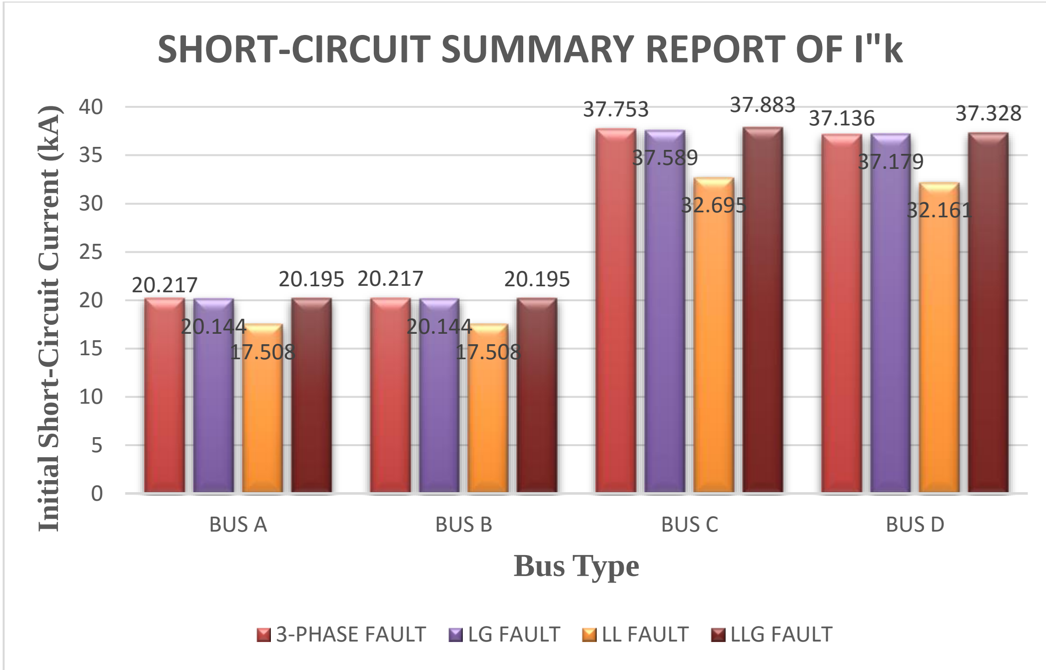

Figure 4.23: Short-Circuit Summary Report of I''k for Bus A, Bus B, Bus C and Bus D for four different types of fault; 3-PHASE, LG, LL and LLG

Based on the result of simulations for the short-circuit current system, it shows that Bus A and Bus B with rating of 11kV have same amount of initial symmetrical current. Bus C and Bus D were rated 0.433kV. This analysis is essential to be carried out as the unsymmetrical or unbalanced faults are used to determine size of a circuit breaker for largest short-circuit current while the symmetrical faults are used as a requirement in selecting the rupturing capacity of the circuit breakers, determining set-phase relays and other protective devices or switchgears. In this case, for Bus C and Bus D, L-L-G fault has the highest value of I"k compared to other faults that is 37.883kA and 37.328kA respectively. However, for the whole system, the three-phase faults results will be considered in determining relay coordination.

4.3.2 Effect of Changing the Breaker Control

This analysis has been carried out to analyse the comparison in short-circuit current of normal condition versus the eleven cases that had been done in load flow. It is essential to carry out this analysis to ensure all of the possible cases will not exceed the value of Ip, the peak short-circuit current; to avoid system from malfunction or even exploded.

Table 4.2: Summary Report Data of Short-Circuit Current of Normal Condition (ACB C OPEN) VS Eleven Cases of ACB

ACB OPEN	BUS TYPE	FAULT TYPE / I'K (kA)			
		3ϕ	LG	LL	LLG
C (Normal Condition)	**A**	**20.217**	**20.144**	**17.508**	**20.195**
	B	**20.217**	**20.144**	**17.508**	**20.195**
	C	**37.753**	**37.589**	**32.695**	**37.883**
	D	**37.136**	**37.179**	**32.161**	**37.328**
A/B	A	20.203	20.135	14.497	20.182
	B	20.203	20.135	14.497	20.182
	C	**40.271**	**39.220**	**34.876**	**40.145**
	D	**40.271**	**39.220**	**34.876**	**40.145**
AD/BD	A	20.097	20.065	17.405	20.087
	B	20.097	20.065	17.405	20.087
	C	37.122	37.169	32.148	37.315
	D	37.122	37.169	32.148	37.315
AE/BE	A	20.182	20.121	17.478	20.163
	B	20.182	20.121	17.478	20.163
	C	39.593	38.787	34.289	39.537
	D	39.593	38.787	34.289	39.537
AF/BF	A	20.143	20.095	17.444	20.128
	B	20.143	20.095	17.444	20.128
	C	38.418	38.026	33.271	38.481
	D	38.418	38.026	33.271	38.481

CD	A	20.097	20.065	17.405	20.087
	B	20.097	20.065	17.405	20.087
	C	**34.614**	**35.453**	**29.976**	**35.053**
	D	**37.122**	**37.169**	**32.148**	**37.315**
CE	A	20.192	20.128	17.487	20.172
	B	20.192	20.128	17.487	20.172
	C	**37.75**	**37.587**	**32.692**	**37.881**
	D	**36.461**	**36.724**	**31.575**	**36.719**
CF	A	20.147	20.098	17.448	20.132
	B	20.147	20.098	17.448	20.132
	C	**37.744**	**37.583**	**32.688**	**37.876**
	D	**35.29**	**35.923**	**30.562**	**35.662**

Based on the result tabulated in the table, it shows that the value of when ACB A or ACB B open at Bus C and Bus D shows slightly higher values of short-circuit current compared to the normal condition. For the results of ACB CD open at Bus C and results of ACB CE and CF open at Bus D show that the value is slightly lower compared to the normal conditions at Bus C and Bus D. The summary table also did not show any significant difference at Bus A and Bus B for all cases compared to the normal condition, as the location is at the high voltage side. Only at the load voltage side shows variation of difference in the short-circuit current result. However, all of the values stated still do not presented huge significant difference; where none of the results exceed normal condition of Ip value. Thus, the system are in stable condition and all the rating been used for the protective devices and switchgears of the circuit are practical and safe.

Thus, from the result obtained from short-circuit analysis for normal condition, the value of short-circuit current for each relays are as follows;

Table 4.3: Fault current of relays

Relay	Fault Current (kA)
OCR 1	20.22
OCR 2	20.22
OCR 3	20.22
OCR 4	37.75
OCR 5	37.14
Relay 6	37.75
Relay 7	37.14
Relay 8	37.14

4.4 RELAY COORDINATION

The load flow and short circuit analysis has been done using ETAP for the one-line diagram of the transmission line for Library Universiti Malaysia Pahang, Pekan Campus. All the result has been tabulated in previous section. All the parameters been used are calculated using theoretical method and compared with the real data parameters; which then will be transferred into ETAP settings for relay coordination [4]. ETAP's STAR module is used for this analysis that is to coordinate the time-current curves.

Protections system are used to detect and isolates the faulty system automatically [1]. The protective scheme requisite to operate quick and selectively sooner to avoid power system from becoming unstable. There must be adequate time for the relay to sense the fault, transmit to the breaker, and to trip or open the nearest breaker for isolation. The upstream device must perform it if it does not occur in the downstream device to protect components or equipment from gain any damages and interruption of the supply connected to the power system could be happen [1].

4.4.1 Overcurrent Relay Data of the Commercial Building (Bus A and Bus B)

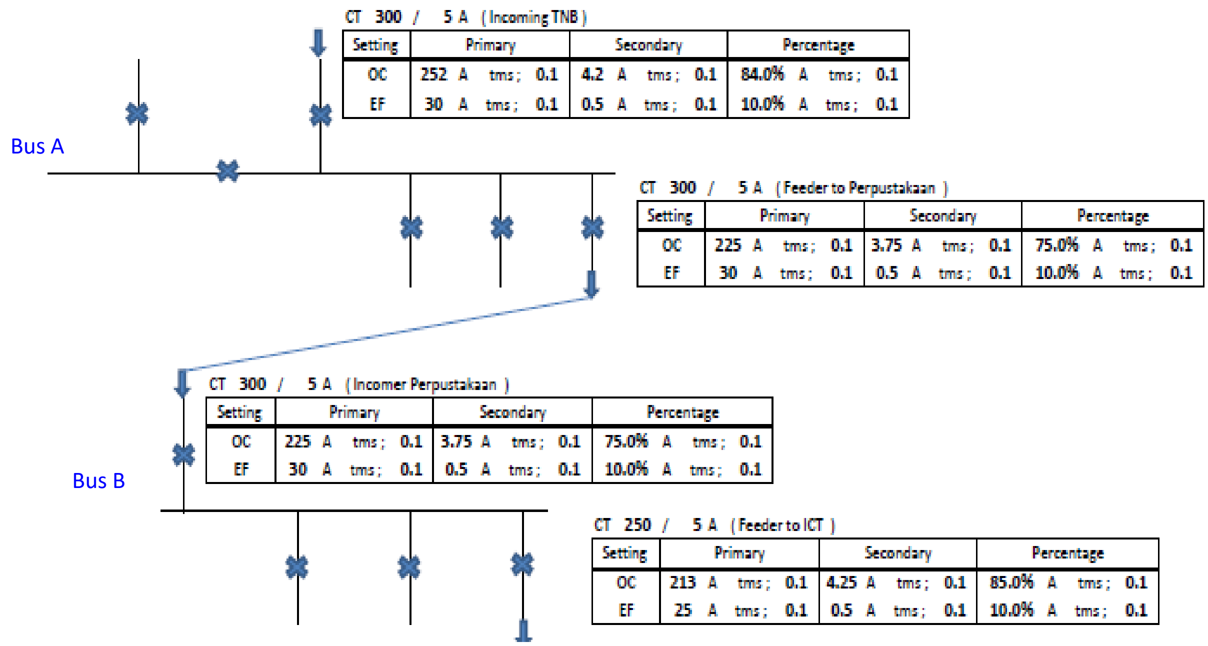

Figure 4.24: Overcurrent Relay Setting of Real Data for Bus A and Bus B

Normal Inverse (Type A) t= $\frac{0.14}{(I/I_s)^{0.02}-1} \times T_p$ (sec)

Calculation				ICT		Perpustakaan ICT	Perpustakaan Incomer	Main Station Library	Main Station Incomer
				CT 200/5		CT 250/5	CT 300/5	CT 300/5	CT 300/5
			Tms.; 0.16	200	Tms.; 0.1	250	250	250	252
1.002	0.002	1.1	11.740	220	7.337	275	275	275	277.2
1.004	0.004	1.2	6.132	240	3.832	300	300	300	302.4
1.005	0.005	1.3	4.258	260	2.661	325	325	325	327.6
1.007	0.007	1.4	3.317	280	2.073	350	350	350	352.8
1.008	0.008	1.5	2.751	300	1.719	375	375	375	378
1.009	0.009	1.6	2.372	320	1.482	400	400	400	403.2
1.011	0.011	1.7	2.100	340	1.312	425	425	425	428.4
1.012	0.012	1.8	1.894	360	1.184	450	450	450	453.6
1.013	0.013	1.9	1.734	380	1.084	475	475	475	478.8
1.014	0.014	2.0	1.605	400	1.003	500	500	500	504

Figure 4.25: Calculated real data for Normal Inverse (Type A) at TMS 0.1

4.4.2 Manual Calculation

4.4.2.1 Plug Setting (PS)

Current Transformers ratio are as follow:

CT6 ratio is 800:5 A, CT7 ratio is 1600:5 A, CT8 ratio is 600:5 A, CT4 & CT5 ratio is 2000:5 A, CT1, CT2 & CT3 ratio is 300:5 A.

As per standard in estimating the plug setting, Relay 6 picks up at 1.3 times its plug setting and OCR 4 at 1.05 times its plug setting. The pickup current of Relay 6 and OCR 4 are thus, 1040A and 2100A, respectively.

Plug setting of OCR 4 & OCR 5:

PS of OCR4 $= \frac{1600\ x\ 1000}{\sqrt{3}\ x\ 433}$

= 2133.39 A ~ 106.67 % of 2000A (125%)

Plug Setting of OCR 2 & OCR 3:

PS of OCR2 > $(\frac{1.3}{1.05})$ x $(\frac{433}{11000})$ x 1.25 x 2000

PS of OCR2 > 121.8398 A ~ 40.61% of 300A (50%)

Plug Setting of OCR 1:

PS of OCR2 > $(\frac{1.3}{1.05})$ x 121.8398

PS of OCR2 > 150.8493 A ~ 50.28% of 300A (75%)

Thus, plug setting of Relay 6, Relay 7 and Relay 8 is obviously 100% of 800 A, 1600A, and 600A, respectively, while plug setting of OCR 4 and OCR 5 is 125%. On the other hand, the plug setting of OCR 2 and OCR 3 is 50% not the same as been set at the real situation of Library Universiti Malaysia Pahang Pekan Campus. This may due to the calculation been made here are considered from the downstream of the library circuit. Based on theoretical method, the plug setting for OCR 1 at Bus 1 is calculated as 75%

compared to that been set in real data that is 84%. As the IDMT relays are normally available with the plug setting in the range 50-200% of the relay setting in seven equal steps, 50-75-100-125-150-175-200 per cent of the relay rating [8].

4.4.2.2 Plug-setting Multiplier (PSM)

PSM of Relay 6 $= \frac{Fault\ Current}{CT\ Ratio}$

$= \frac{37750}{800}$

= 47.1875

PSM of Relay 7 $= \frac{Fault\ Current}{CT\ Ratio}$

$= \frac{37140}{1600}$

= 23.2125

PSM of Relay 8 $= \frac{Fault\ Current}{CT\ Ratio}$

$= \frac{37140}{600}$

= 61.9000

PSM of OCR 4 $= \frac{Fault\ Current}{Relay\ Current\ Setting\ x\ CT\ Ratio}$

$= \frac{37750}{6.25\ x\ (\frac{2000}{5})}$

= 15.1000

PSM of OCR 5 $= \frac{37140}{6.25\ x\ (\frac{2000}{5})}$

= 14.8560

PSM of OCR 2 & OCR 3 $= \frac{20220}{2.5\ x \left(\frac{300}{5}\right)}$

$= 134.8000$

PSM of OCR 1 $= \frac{20220}{3.75\ x \left(\frac{300}{5}\right)}$

$= 89.8667$

Based on the result of PSM calculated, there are results that is more than 20, thus in next step, the formula used to calculate the time of operation of an IEC 60255 standard inverse IDMT relay curve is constant and equal to $\frac{3}{\log 20}$ x TMS [8]. However, for the PSM calculated less than or equal to 20, formula of $\frac{3}{\log PSM}$ x TMS will be used to find its time of operation [8].

4.4.2.3 Time Multiplier Setting (TMS)

As for the manual calculation of TMS, it is a common practice to use a fixed selective interval or discrimination time of 0.25 second between the successive relays [8].

Initially, the TMS of Relay 6, Relay 7 and Relay 8 is selected 0.1. Thus, time of operation (TOP) or also called as tripping time of Relay 6, Relay 7 and Relay 8 is,

$= \frac{3}{\log 20}$ x 0.1

= 0.2306 sec ~ 0.23 sec

The time of operation of OCR4 & OCR 5 is = 0.23 sec + 0.25 sec

= 0.48 sec

To determine the TMS of OCR 4 & OCR 5;

Time of operation OCR 4 $= \frac{3}{\log(PSM)}$ x TMS OCR 4

TMS OCR 4 $= \frac{0.48\ X \log(15.1)}{3}$

$= 0.1886$ sec ~ 0.19 sec

Time of operation OCR 5 $= \frac{3}{\log(PSM)}$ x TMS OCR 5

TMS OCR 5 $= \frac{0.48\ X \log(14.83)}{3}$

$= 0.1874$ sec ~ 0.19 sec

The time operation of OCR 2 & OCR 3 = 0.48 sec + 0.25 sec

= 0.73 sec

Time of operation OCR 2 $= \frac{3}{\log(20)}$ x TMS OCR 2

TMS OCR 2 $= \frac{0.73\ X \log(20)}{3}$

$= 0.3166$ sec ~ 0.32 sec

The time operation of OCR 1 = 0.73 sec + 0.25 sec

= 0.98 sec

Time of operation OCR 1 $= \frac{3}{\log(20)}$ x TMS OCR 1

TMS OCR 1 $= \frac{0.98\ X \log(20)}{3}$

$= 0.4250$ sec ~ 0.43 sec

Table 4.4: Parameter of Overcurrent Relays

Relay	OCR 1	OCR 2	OCR 3	OCR 4	OCR 5	Relay 6	Relay 7	Relay 8
PS (%)	75	50	50	125	125	100	100	100
PSM	89.87	134.80	134.80	15.10	14.86	47.19	23.21	61.90

TOP at TMS 0.1sec	0.98	0.73	0.73	0.48	0.48	0.23	0.23	0.23
TMS	0.43	0.32	0.32	0.19	0.19	0.1	0.1	0.1
TOP at TMS set(sec)	0.421	0.234	0.234	0.101	0.101	0.023	0.023	0.023

4.4.3 Relay Setting in ETAP

The first calculation considering the fault occurred at Bus 3. Therefore, near the faulted bus, overcurrent relay of Relay 6 must first be operated as shown in Figure 4.26.

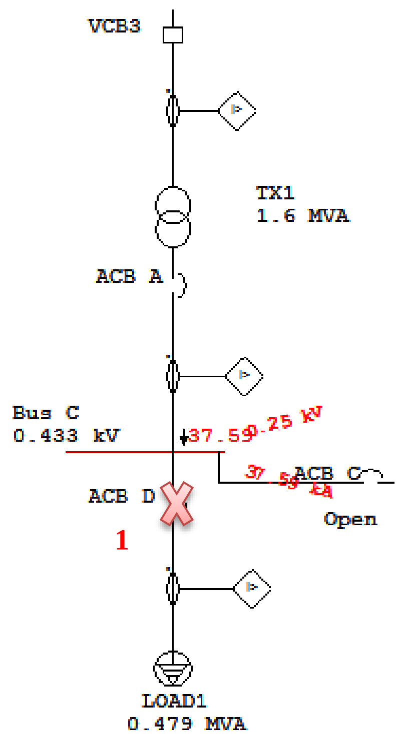

Figure 4.26: Relay 6 operated as primary protection

OCR 4 must then operate as for the backup of Relay 6. In another word, Relay 6 will act as the primary protection when fault happen at Bus 3 and OCR 4 act as a backup protection. Figure 4.27 present the above description.

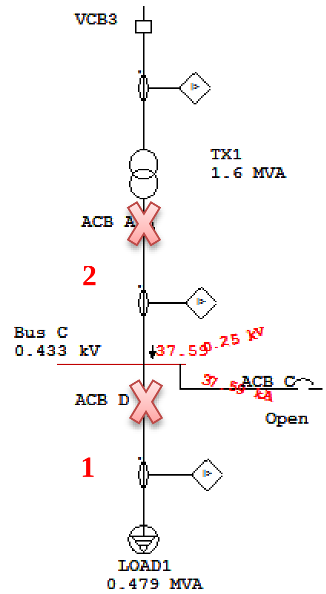

Figure 4.27: OCR 4 is operated as backup protection

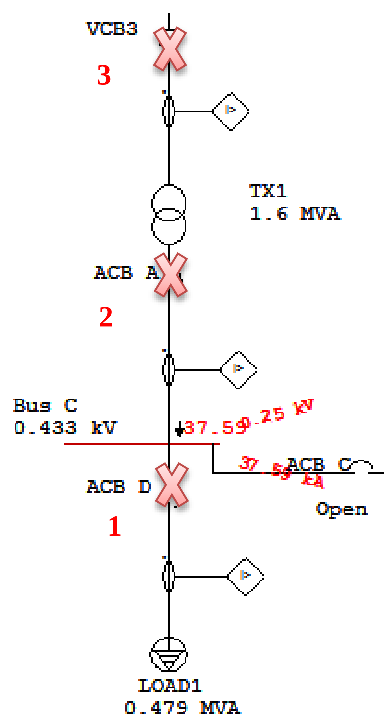

Figure 4.28: OCR 2 operated as back up of OCR 4 and Relay 6

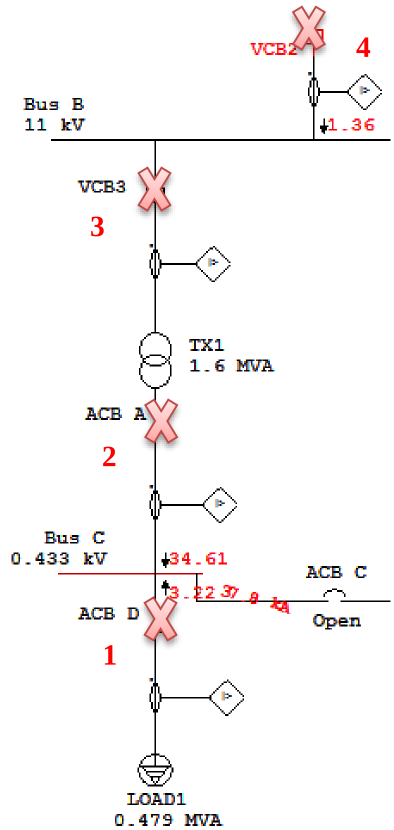

Figure 4.29: OCR 1 operated as backup of Relay 6, OCR 4 and OCR 2 for source protection

Thus Figure 4.28 shows the coordination of relay Relay 6, OCR 4 and OCR 2. Same way, if the relay OCR 4 is failed, the relay OCR 2 must be operated as backup relay, then lastly OCR 1 will be operate as backup to the source as shown in Figure 4.29. In the ETAP software, the exact coordination of relays can be shown through the star view feature. Figure 4.30 represents the star view result of the primary relay Relay 6 and back up relay of OCR 4, OCR 2 and OCR 1.

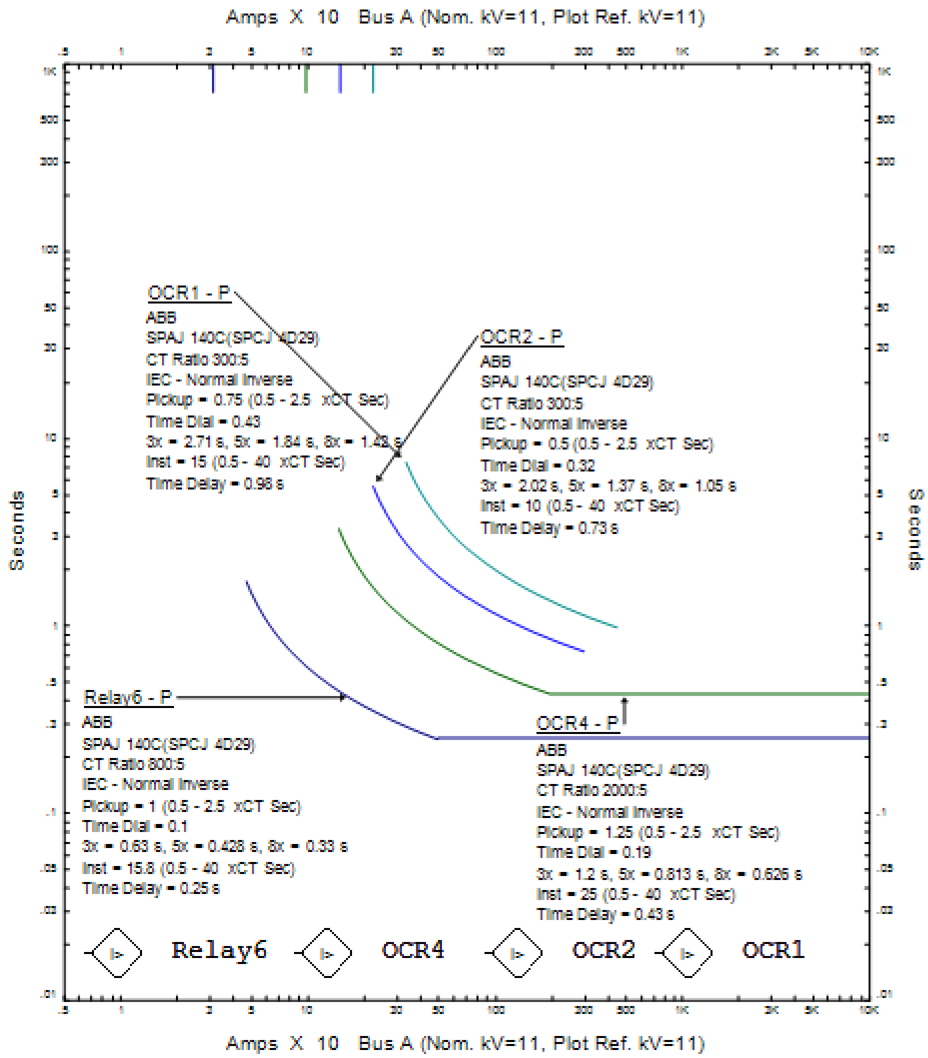

Figure 4.30: Star View of primary protection Relay 6, and backup protection OCR 4, OCR 2 and OCR 1

For another case, if the fault happen at Bus D, then Relay 7 or Relay 8 will act as primary protection and relays OCR 5, OCR 3 and OCR 1 are in backup protection as shown in Figure 4.31.

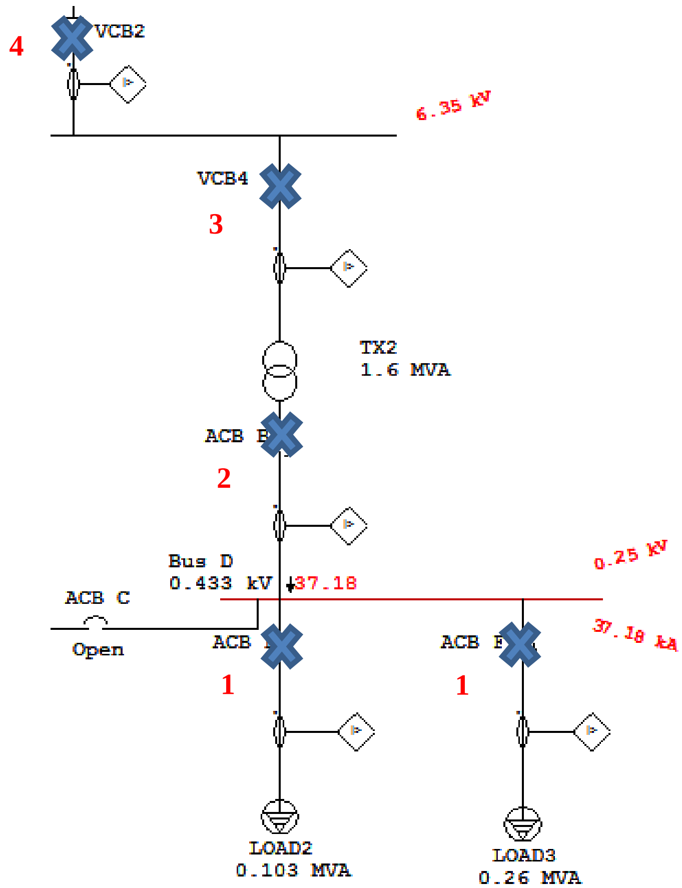

Figure 4.31: Fault on Bus D

The star view of relay coordination for protection scheme when fault happen at Bus D are displayed as shown in Figure 4.32.

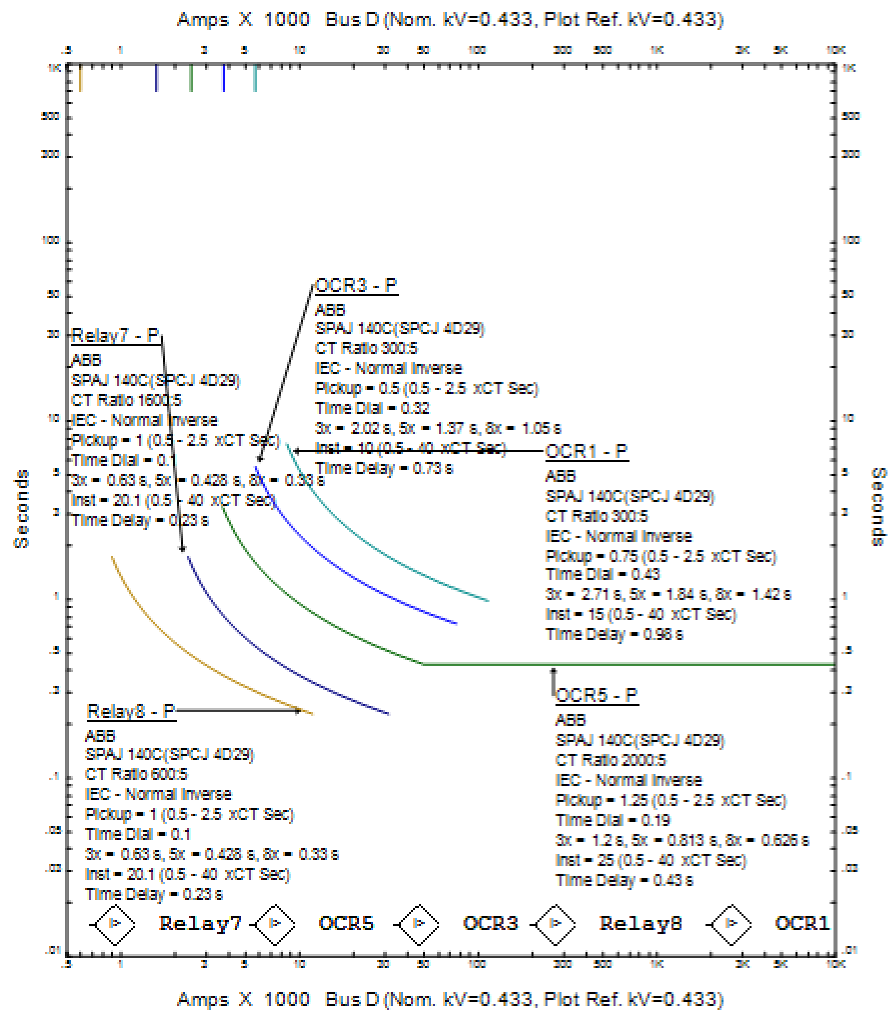

Figure 4.32: Star View of Relay Coordination when Fault at Bus D

Therefore, relay coordination for all relays has been done using the star view feature of ETAP software. The graphical view of all relays are as shown in Figure 4.33. The figure shows its relays function of primary or backup of bus fault accordingly. The downstream relay is served as primary and next relay in the direction towards the upstream is working as secondary as shown in Figure 4.30, Figure 4.32 and Figure 4.33 [4]. All the relay works as primary and secondary according to the faulted bus.

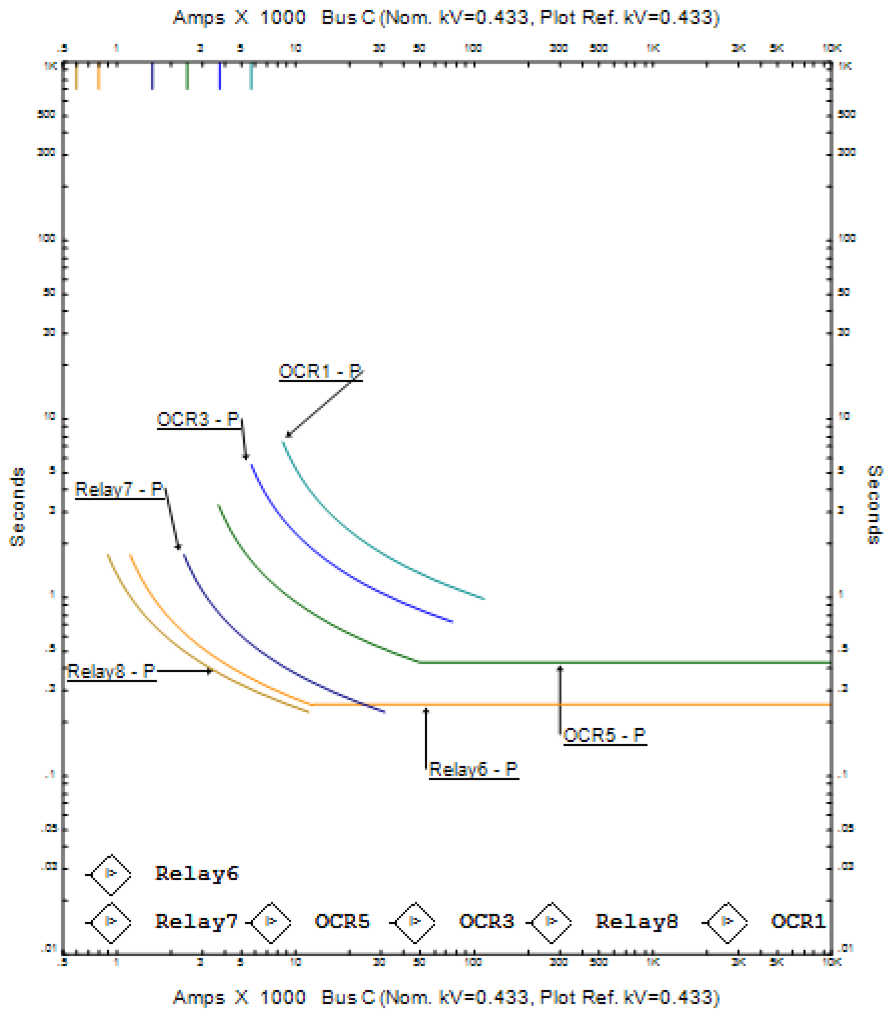

Figure 4.33: Star View of all Relays

Based on the manual calculation and practical results shown through ETAP's star view, the comparison been made as shows in Table 4.5.

Table 4.5: Comparison Result of Manual Calculation and Star View Result

Relay	OCR 1	OCR 2	OCR 3	OCR 4	OCR 5	Relay 6	Relay 7	Relay 8
PS (%)	75	50	50	125	125	100	100	100
PSM	67.4	89.87	89.87	15.10	14.86	47.19	23.21	61.90
TOP at TMS 0.1sec (manual)	0.98	0.73	0.73	0.48	0.48	0.23	0.23	0.23

TOP at TMS 0.1sec (ETAP)	0.98	0.73	0.73	**0.43**	**0.43**	**0.25**	0.23	0.23
TMS	0.43	0.32	0.32	0.19	0.19	0.1	0.1	0.1
TOP at TMS set(sec) (manual)	0.421	0.234	0.234	0.101	0.101	0.023	0.023	0.023
TOP at TMS set(sec) (new)	0.421	0.234	0.234	**0.082**	**0.082**	**0.025**	0.023	0.023

Based on the result tabulated in Table 4.5, the standard theoretical discrimination time of 0.25 is practical to be used as the results achieved through the ETAP's star view are mostly the same as been calculated. Thus, this shows that the value are reliable to be used even though there are a bit difference in result of Relay 6, OCR 4 and OCR 5, however there were no major difference.

At real situation, fault happen at Bus 3 and Bus 4 will be majorly happen due to load; overvoltage, under voltage, and many more. On the other hand, it may happen due to busbar itself, for instance for the occurrence of phase-to-phase short, the relay nearest to the fault will detect and send signal to circuit breakers to trip. Thus it is necessary for Relay 6, Relay 7 and Relay 8 to be the primary protection of the circuit, to avoid from further damage towards the upstream especially the power source. However, if the circuit breakers ACB D, ACB E and ACB F do not react, therefore the relay OCR 4 and OCR 5 will react as the backup protection of the feeder. These shows clearly the importance of coordination in power system. The protection scheme has to be coordinated properly and function at the specific time of fault. At substation, all relays are been tested once in two years to check its reliability.

The difference in plug setting of Bus A and Bus B of theoretical and real setting data from the commercial building are clearly shown. The real plug setting at OCR 1 and OCR 2 is 84% and 75% respectively, whereas the calculated one is 50% and 75% respectively. The difference may due to method of analysis been used. For the calculation method, the plug setting is been set from the downstream towards the upstream of the circuit. Thus, from the real setting shown, shows that the setting been made are all for the upstream feeders from TNB to Library and PBMSK building of Universiti Malaysia Pahang. Furthermore, in theoretical, the plug setting is increased 25% in 7 steps at the range of 25-50-75-100-125-150-200. Therefore, this shows that the manual calculation method compared to the result from star view represents the reliability and practicality of the formula been used in this analysis. The manual calculation and overcurrent relay setting made in ETAP are more sensitive compared to the practical setting from the chosen commercial building.

For proper selectivity of relays, overcurrent protective schemes has three different types of graded depending on the system condition; that are time-graded system, current-graded system and combination of time and current grading. For the time-graded, the faults near the power source will involve higher time of operation [1]. This scheme is suitable to be used when the impedance or distance between substations is low. For the current-graded system, the operating time kept the same for all relays used to protect different sections of the feeder. It will be used when the impedance between substations is capable to create a margin of difference in fault currents [1]. However, this scheme's operating time is less near to the power source compared to time-grading. As for the one been used widely for the protection of distribution system is the IDMT relays which employed throughout this analysis. The IDMT relays are the combination of current and time. The difference in operating time or time delay of two successive relays are kept 0.25s.

4.5 SUMMARY

Throughout the analysis been made, it is necessary and important in ensuring the reliability of one distribution network that able to run smooth in normal load or peak load before any technology been implemented to the system. Load flow analysis and short circuit analysis been carried out before coordinating relays. The process are important to check the real system into ETAP software and ensuring that the parameters are all correct and precise before further analysis been made. Based on the load flow analysis, the normal load and all eleven cases been made and analysed are reliable and able to cater variety of condition. The results do not represents any major voltage drop and power losses throughout the analysis. In addition, the power factors are maintained within 0.95 pu to 1.0 pu for the whole cases. As for the short circuit analysis, fault current relays are obtained through this analysis. Besides, the normal load condition and the eleven cases are compared in this analysis to ensure that there are no short circuit current exceed the peak short circuit current in any situations. Finally, the relay coordination are presents in this chapter. The manual calculation is showed clearly and the value are transferred for relay setting of the system and results are compared using the star view result from ETAP software. The results shows the capability of the formula been used for deciding the relay setting of the real system.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In short, all objectives of this project were successfully achieved. The proper and practical method on the overcurrent relay setting in power distribution network is determined. Secondly, the efficiency and reliability of the relay coordination is validated and verified. The analysis of overcurrent relay setting of the selected commercial building has been successfully modeled and tested using ETAP software.

Coordination of relays are essential in power system, to protect the distribution network or feeder line from malfunction and to avoid the unnecessary outage of healthy part of the system [4]. The overcurrent relay coordination in radial network is highly constrained optimization problem. The analysis includes load flow analysis, short circuit analysis, manual calculation of plug setting, plug setting multiplier (PSM), time multiplier setting (TMS), and time of operation, and finally relay setting on ETAP. The plug setting and time setting for overcurrent relays are followed in analyzing and setting the relay coordination. The standard discrimination time between two successive relays of 0.25 seconds are used in the analysis. The overcurrent relay need to be set properly so that they provide correct discrimination and act as primary as well as back up protection devices [11]. The results are presented in star view.

Using the ETAP software, it proves its efficiency and capability of the software as a power system tool to solve the coordination problem of overcurrent relays in radial system.

5.2 FUTURE RECOMMENDATION

The analysis of overcurrent relay setting of 4 bus system network for Library Universiti Malaysia Pahang Pekan Campus has been done successfully. For future recommendation, there might be additional research that can be considered; and that may include:-

- Comparison between overcurrent relay setting of distribution network for UMP Pekan Campus and Gambang Campus.
- Testing for multi-layers of busbar of big industry using ETAP software.

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ANALYSIS OF OVERCURRENT PROTECTION RELAY SETTINGS OF A COMMERCIAL BUILDING

NURUL SYAQIRAH BINTI MOHD SUFI

UNIVERSITI MALAYSIA PAHANG