CHAPTER 1
INTRODUCTION

1.1 Background of Study

This study is purposed to improve existing power system protection coordination of Universiti Teknologi PETRONAS (UTP) which the power is supplied by in-plant generator which is Gas District Cooling (GDC) and Tenaga Nasional Berhad (TNB) as supply. The protection is needed in order to safeguard the entire system to maintain continuity of supply, to minimize damage and repairing costs, and to ensure safety of personnel [2]. The Power system protection is achieved by isolating the faulted parts within the electrical network so that it will not bring any interruption to operation of the system. The importance to clear all faults; some of them are to avoid damages to the equipment which can cause destruction, fire or explosion, reduction instability margins as well as to avoid the system become unbalanced which will cause improper operation of the equipment [3]. Through this study, there are elements of a power system that covers generation, transmission, distribution and utilization that require to be protected which are generators, transformers, bus bars, capacitors, reactors and also motors [1].

This study will involve basically on the characteristics of all protective devices and finally the suitable coordination is determined to be applied in UTP electrical network system.

1.2 Problem Statement

Power system protection miscoordination had been observed to occur at Universiti Teknologi PETRONAS (UTP) during the tripping of the upstream protection when there was a fault at the downstream. A well coordinated protection system would allow the downstream protection to clear the fault discriminatively, hence reducing the load loss.

1.3 Significance of Study

Upon completion of this study, student is expected to fully utilize the knowledge of power system protection as well as the knowledge in SKM Power*Tools Electrical Engineering software. Also, the final outcome of the study will be used to improve the protection system at Universiti Teknologi PETRONAS (UTP).

1.4 Objective of Study

1. To study the power system protection at Universiti Teknologi PETRONAS (UTP).
2. To study on characteristics of each power system protection devices.
3. To improve existing power system protection coordination at Universiti Teknologi PETRONAS (UTP).

1.5 Scope of Study

The studies are based on the electrical power system protection, characteristics of protection devices such as fuses, relays and circuit breaker, overcurrent and earthfault relay coordination and setting. Also the studies will cover on coordination of overcurrent relays, differential relaying, and restricted earth fault protection.

Besides, this studies deals with SKM Power*Tools Electrical Engineering software to get the prospective fault current from short circuit simulation. Consequently, by using Microsoft Excel spreadsheet, the best coordination of overcurrent setting and earthfault setting for power system protection in Universiti Teknologi PETRONAS (UTP) is determined. Student will be exposed to the usage of other feature in SKM through out this study.

CHAPTER 2
LITERATURE REVIEW

2.1 Distribution Protection Principles

Main purpose of distribution protection and electrical protective devices is to isolate the faulted component from the healthy parts as fast as possible. In doing so, the equipment will be safeguarded from further damage and more importantly from endangering human life. There is no compromise on the safety of the operators and customers. Having this criteria set and adhered to then one can look at the second important objective, that is, to minimize interruptions [3].

2.2 Basic Requirements of Distribution Protection

A protection system must satisfy the following requirements:-

a) Selective – Disconnection of equipment is restricted to the minimum necessary to isolate the fault.
b) Sensitive – Sensitive enough to operate under minimum fault condition.
c) Stable – Stable and remain inoperative under certain specified condition such as transmission system disturbance, through faults, transients, etc.
d) Fast – Fast operation in order to clear the fault from the system thus to minimize damage to the effected components.
e) Reliable – The protective equipment should not fail to operate in the events of fault in the protected zone. In may be necessary to provide backup protection to cover the failure of the main protection [3].

2.3 Common Types of Distribution Protection

2.3.1 Overcurrent and Earthfault Protection

Overcurrent and earthfault protection is the most common type of protection employed in the distribution system. It is used to protect feeders, transformer, motors, capacitors and other equipment. The protection devices used are either fuses or relays.

2.3.2 Directional Overcurrent and Earthfault Protection

Directional overcurrent and earthfault protection is used in a closed ring or parallel system. In case of any fault on any section of the distribution system, it is required that the circuit breaker on both side of the fault to operate thus isolating the faulty section from all sources of supply and leaving other in normal operation.

2.3.3 Pilot Wire Unit Protection

A unit protection system responds only to fault inside the protected zone. Unit protection using pilot wire is based on the differential principle in which current flowing into one end of the feeder is compared with that flowing out of the other end of the feeder. Under normal or through fault conditions, the currents at the two ends should be identical and the protection should not operate. When an internal fault occurs, the currents at the two ends would be different and the protection should detect and operate to isolate the faulty section of the feeder.

2.3.4 Autoreclosing Schemes

An autoreclosing facility can be provided such that the reclosing is performed automatically. There are two types of autoreclosing schemes, autoreclose relaying and autorecloser. Autoreclose relaying uses autoreclose relay to reclose the breaker after the initial trip out. Autorecloser is special pole mounted single units to perform the duty of both the breaker as well as the autoreclose relay [3].

2.3.5 Sensing Devices

When the quantities – current and voltage – to be measured are too high to facilitate direct connection to the power circuit, measuring transformers are required. Current and voltage transformers are the common devices used in protective system.

i) Current Transformers

A current transformer as shown in figure 1 comprises of two windings. The primary winding is connected in series with the main circuit. In most cases, the primary winding is part of the main circuit. The secondary winding comprises of several turns of wire wrap around the iron core.

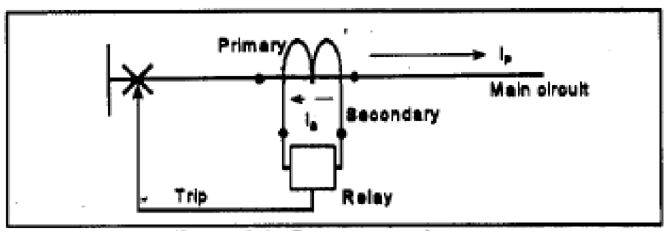

Figure 1: Current Transformer

ii) Voltage Transformers

In distribution protection, voltage transformers (VT) are used for measurement, directional protection – conventional or reverse power relays – and undervoltage/overvoltage protection. The primary of the VT is connected directly to the power circuit between phase and ground as illustrated in figure 2.

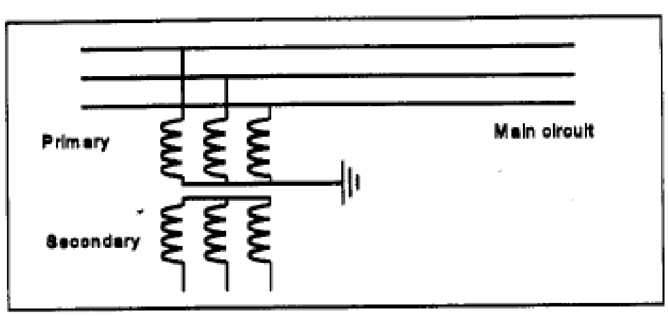

Figure 2: Voltage Transformer connection

2.4 Types of Protection

There are various types of protection that can be considered in any distribution network. However, from the readings, in the TNB distribution network, the following protection systems are generally considered [4].

2.4.1 Non-unit protection

When a fault occurs, a number of relays will respond and only those closest to the fault complete the tripping operation leaving the remaining relays reset.

2.4.2 Unit Protection

A unit protection is a protection system in which the protected zone can be clearly identified by means of CT boundaries. It responds to only internal faults (faults inside the protected zone).

i) Circulating Current

The relay is connected at the summation node and under normal and through fault conditions, the two currents cancel each other and thus no operating current flows in the relay.

ii) Voltage Balance

In voltage balance system, two voltages across the secondaries of the current transformers at the two ends will be identical in phase and magnitude under normal and through fault conditions hence no current flows in the pilot wire and the relay.

2.4.3 Overcurrent and Earthfault Protection

Overcurrent and earthfault protection is used to protect feeders, transformers, motors, capacitors and other equipment. The protection devices used are either fuses or relays [4].

i) Fuses

Fuses act as fault current protective sensing as well as an isolation device. It is connected in series with the circuit or equipment to be protected. With the flow of fault current, metallic element of the fuse will melt and disconnect the circuit from the supply source.

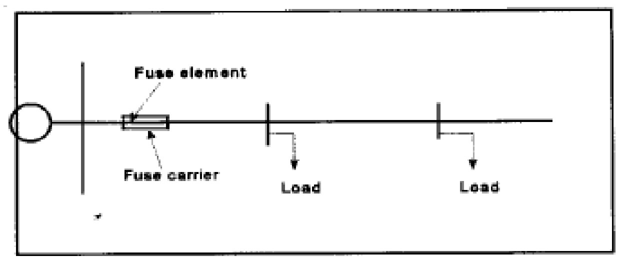

Figure 3: Fuse application

ii) Relay

The basic function of the relay is thus to sense the presence of signal (circuit current) and activate an action that normally actuates the operation of switchgear if such a signal surpassed a certain set value.

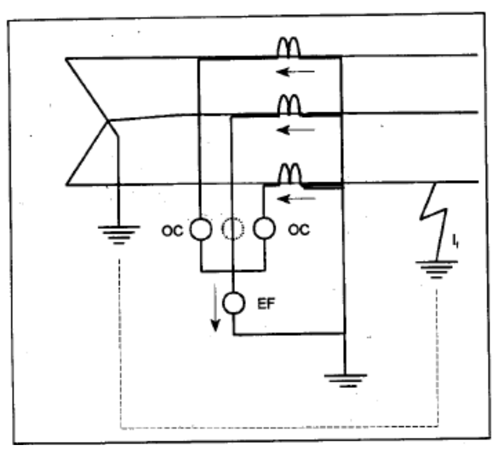

Figure 4: Combined overcurrent and earthfault calculation

2.4.4 Transformer Protection

Transformer is one of the most important links in power transmission and distribution system. For smaller rating such as below 1.5MVA, the typical type of protection that applied to protect the transformer are fuses. In case of any damaged to the transformer, the fuses will blow as the fault current passing it.

However for higher rating transformer, more protection scheme is needed in order to protect or to minimise the damaged that could be experienced by the transformer. Therefore, a few numbers of relays will be installed to perform the duty. The typical protection scheme that requires for power transformers are:

i) Differential Protection
ii) Restricted Earth Fault
iii) Standby Earth Fault

2.4.5 Transformer Guard

The purpose of transformer guard is to detect any mechanical fault of the transformer. For example, if there is a winding fault, some degree of arcing will take place and the resulting decomposition of the oil will release gases. For minor fault, gas is released slowly but for major fault, rapid release of large volume of gases and vapour will build up pressure and cause explosion as well as displacement of oil. Therefore the duty of transformer guard is to detect these phenomena as soon as possible so that damage to the transormer could be avoided or minimised. Typical transformer guards are:

i) Buchholz
ii) Pressure Relief Device
iii) Oil Temperature
iv) Winding Temperature
v) Low Oil Level

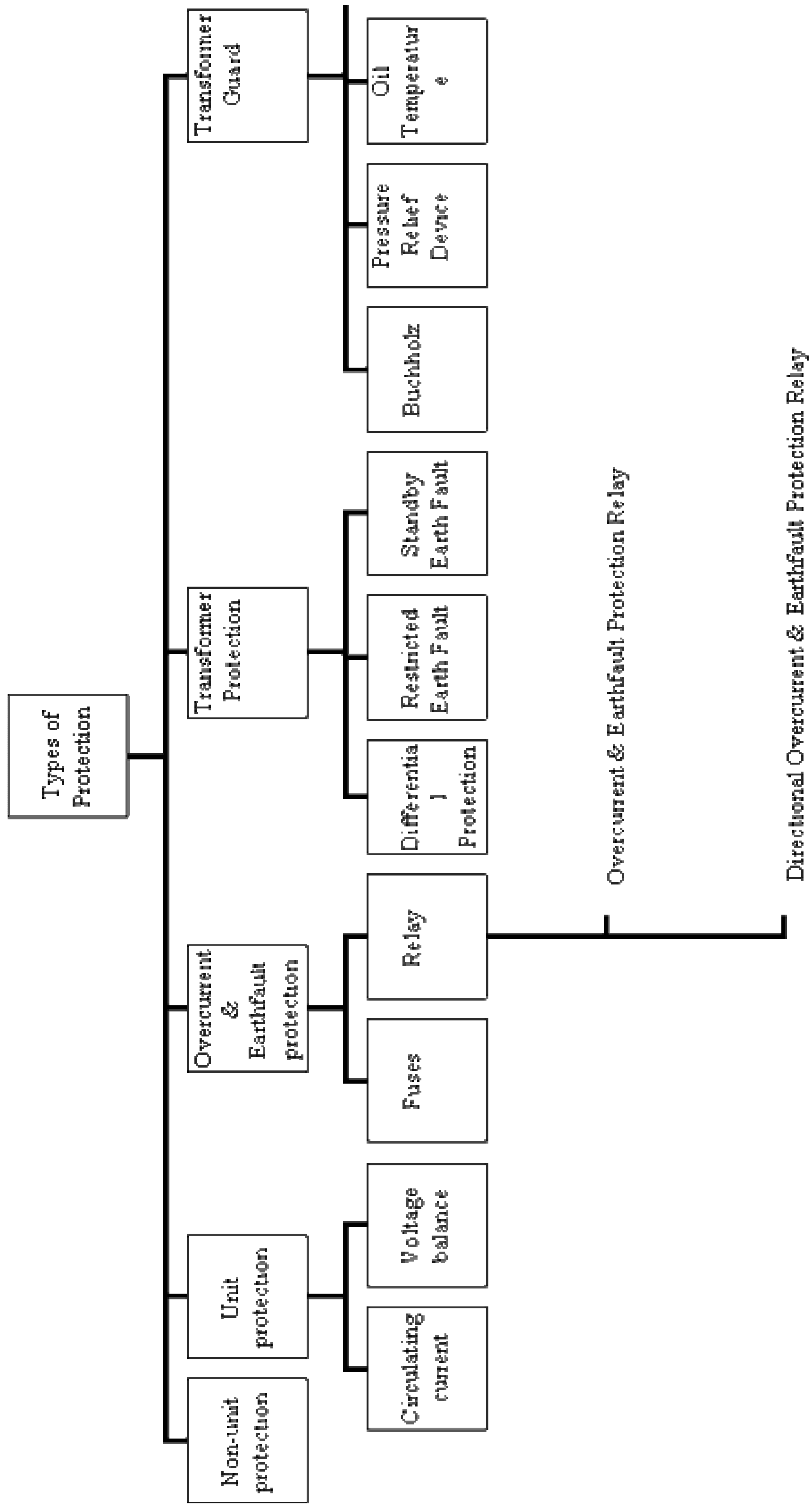

Figure 5: Types of Protection Chart

2.5 Circuit-Breaker Current Rating

A circuit-breaker is expected to perform the following for duties [5]:

i. To continuously carry the normal rated current.
ii. To be able to open during occurrence of fault and isolate it – breaking capacity.
iii. To be able to close on fault – making capacity.
iv. To be able to carry fault current for a short time – short-time capacity

These duties are specified under the following terms:

Normal Current Rating (A): The rated normal rms current that the circuit-breaker must be able to carry continuously at its rated frequency.

Breaking Capacity (MVA): The capacity that a circuit-breaker is capable of breaking at a stated recovery voltage and restriking voltage. Recovery voltage is the normal frequency voltage that appears across the breaker poles after final arc extinction and restriking voltage is the voltage that appears across the contacts at the instant of arc extinction.

Making Capacity (MVA): The capacity that the circuit-breaker has upon closing on dead fault.

Short-Time Rating (kA, *rated time*): The capability of the circuit-breaker to carry the specified maximum current without breaking for a given time.

2.6 Fault in Electrical Power Distribution

2.6.1 General

A fault in electrical system can be short circuit or open type. A short circuit fault is more common than open circuit fault. The short circuit can either be between two conductors or short circuit between a conductor and an object at earth potential. An open circuit fault can lead to a short circuit and vice versa. Examples of short circuit faults are as follows [6]:

i) Accidental damage to an underground cable while digging
ii) A cable cutting in a sharp edge inside a switchboard or on a tray or any other sharp object on which it is resting
iii) Tracking on terminations due to dust, pollution or moisture
iv) Failure of insulation (generally for motors, cables and transformers) due to overheating or age
v) Failure of cable insulation due to friction (cable sitting tight against a surface)
vi) Failure of insulation due to heat from other sources, such as fire
vii) Presence of moisture, such as water leak in to an equipment

Examples of open circuit faults are snapping of a conductor at the termination, breakage of overhead conductor, breakage of a joint and burning of a conductor.

Current does not flow in an open circuit fault and therefore, fault level calculations are not required for open circuit fault. Fault level calculations are performed to determine the expected fault current through a device, in the event of a short circuit ahead of the device. This information is used to:

i) Select fault withstand capacity of the device
ii) Determine the protection setting for the protective device protecting the device

2.6.2 Types of fault

Faults can be classified onto following types:

i) Three-phase (all the three-phases shorted together)
ii) Three phase and earth
iii) Two-phase (two-phases shorted together)
iv) Two-phase and earth
v) Single-phase to earth

Two-phase and two-phase to earth faults are rare in underground or indoor systems and occur mostly in an overhead system. Some of the examples of three-phase and three-phase to earth fault are as follows:

i) The earth switch at one end of a high-voltage line is in a closed state and the breaker at the other end is closed
ii) Terminals of a transformer are shorted for testing and some one may have forgotten to remove the short before energizing the transformer
iii) A cable is cut by accident, across all conductors

In a three-phase, and three-phase to earth fault, the current is the same because the fault current flows through the phase conductors only and cancels out. No current flows through the earth return path.

Single-phase to earth fault is the most common fault and examples are:

i) A terminal of a cable/transformer is earthed for testing and cable/transformer is energized without removing the short
ii) Damage to a cable or an equipment due to accident
iii) Loose termination
iv) Moisture leakage

For three-phase circuits the highest fault current of all the above types of faults, is used to select the fault capacity of a device. In the vicinity of a generating station or generator, a single-phase to earth fault can be higher than a three-phase fault. For a single-phase circuit, a single-phase to earth fault current is used to decide the fault capacity of an equipment or device. For residential, commercial and industrial systems only three-phase and single-phase to earth fault are considered because generally these produce the highest fault current and are the most likely faults.

2.7 Overcurrent Relay

An overcurrent (OC) relay has a single input in the form of ac current. The output of the relay is a normally-open contact, which changes over to closed state whent the relay trips. The relay has two settings. These are the time setting and the plug setting. The time setting decides the operating time of the relay while the plug setting decides the current required for the relay to pick up. The name plug setting comes from the electromechanical overcurrent relay. In these relays, we have to insert a shorting plug in a plug-setting bridge, so as to change the number of turns of the operating coil to get a particular pick-up value [6]. The same terminology continues to be used in the modern relays. The block diagram of an OC relay is shown in figure 6.

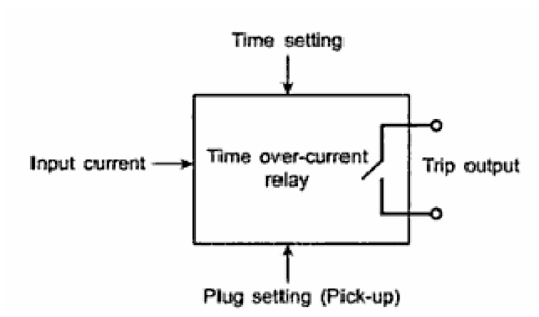

Figure 6: Block Diagram of an overcurrent relay

The plug-setting multiplier, PSM, is defined as follows:

$$PSM = \frac{Irelay}{PS}$$

where *Irelay* is the current through the relay operating coil and PS is the plug-setting of the relay. The value of PSM tells us about the severity of the current as seen by the relay. A PSM less than 1 means that normal load current is flowing. At PSM > 1, the relay is supposed to pick up. Higher values of PSM indicate how serius the fault is. For example, let us consider a 1.0 relay (i.e a relay with current coil designed to carry 1.0 A on a continous basis) whose plug has been set at 0.5A, i.e at 50%. Assume that, for a certain fault, the relay current is 5.0 A. the relay, therefore, is said to be operating at a PSM of (5.0/0.5) = 10.

2.7.1 Instantaneous OC Relay

It is being noted that the word instantaneous has a different connotation in the field of power system protection. Instantaneous actually means no intentional time delay. Howsoever fast we want the relay to operate; it needs a certain minimum amount of time. The operating time of an instantaneous relay is of the order of a few milliseconds. Such a relay has only the pick-up setting and does not have any time setting. The construction and the characteristics of an instantaneous attracted armature type relay is shown in figure 7.

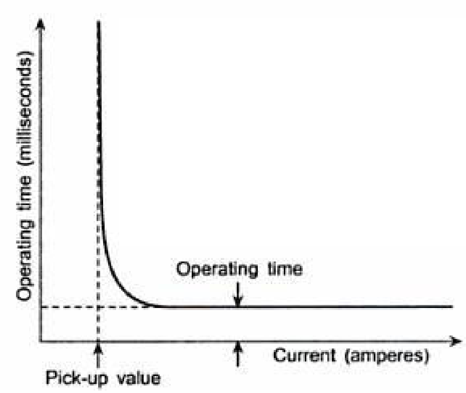

Figure 7: Instantaneous overcurrent relay characteristic

2.7.2 *Definite Time Overcurrent Relay*

A definite time overcurrent relay can be adjusted to issue a trip output at a definite (and adjustable) amount of time, after it picks up. Thus, it has a time-setting adjustment and a pick-up adjustment. The characteristic and the block diagram are shown in figure 8.

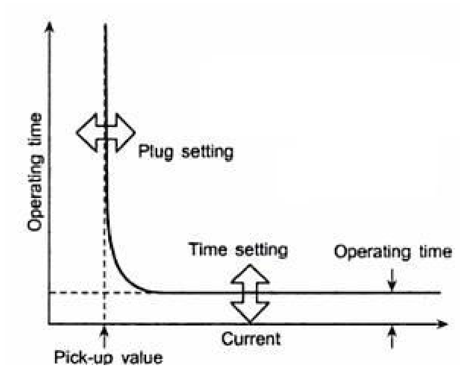

Figure 8: Definite time overcurrent relay characteristic

2.7.3 *Inverse Time Overcurrent Relay*

Inverse time characteristic fits in very well, with the requirement that the more severe a fault is, the faster it should be cleared to avoid damage to the apparatus. This type of characteristic is naturally obtained from an electromechanical relay, which has led to its widespread use and standardization. With the advent of microprocessor-based relays, it is now possible to generate any imaginable time-current characteristic. However, in order to maintain compatibility with the very large number of electromechanical relays, still in service, certain inverse time characteristics, described in the next section, have been standardized.

i. Inverse definite minimum time (IDMT) overcurrent relay

This is possibly the most widely used characteristic. The characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high. The reason for the operating time becoming definite minimum, at high values of current, is that in the electromechanical relays the flux saturates at high values of current and the relay operating torque, which is proportional to the square of the flux, does not increase substantially after the saturation sets in. such a characteristic came about because of the limitation of the electromechanical technology. Ideally, we may demand that the operating time be inverse in nature throughout the operating range.

The mathematical relation between the current and the operating time of IDMT characteristic can be written as

$$t = \frac{0.14\,(TMS)}{(PSM)^{0.02} - 1}$$

where PSM is the plug-setting multiplier and TMS is the time-multiplier setting of the relay. Thus, the operating time is directly proportional to the TMS and inversely proportional to the PSM. The characteristic of the IDMT relay are shown in figure 9.

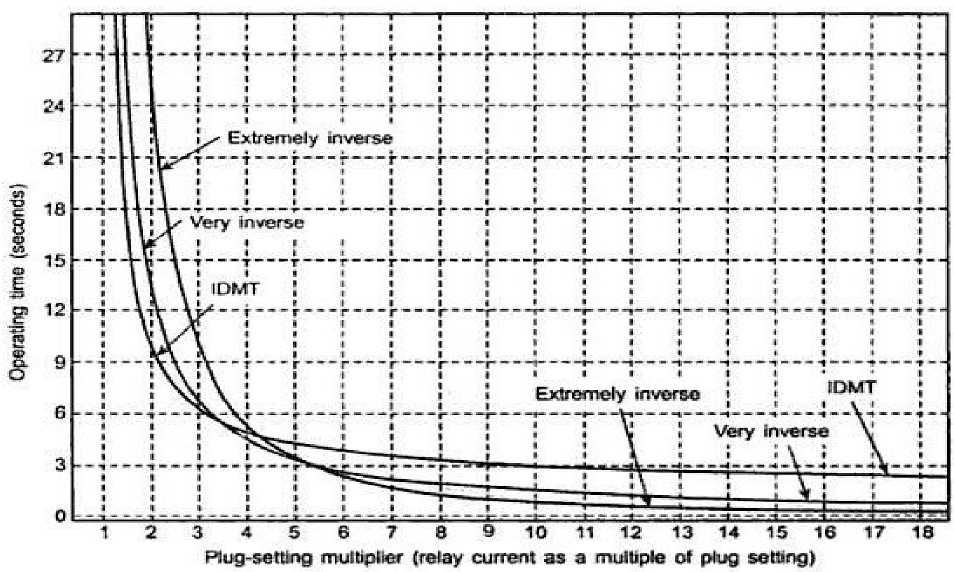

Figure 9: Inverse definite minimum time relay characteristics (TMS = 1.0)

ii. Very inverse time overcurrent relay

The inverseness of this characteristic is higher than that of the IDMT characteristic. The mathematical relation between the current and the operating time of such characteristic can be written as

$$t = \frac{13.5(TMS)}{(PSM) - 1}$$

The characteristic of the relay is shown in figure 9.

iii. Extremely inverse time overcurrent relay

The inverseness of this characteristic is higher than that of the very inverse characteristic. The mathematical relation between the current and the operating time of such characteristic can be written as

$$t = \frac{80.0(TMS)}{(PSM)^2 - 1}$$

The characteristic of the relay is shown in figure 9.

2.8 Application of Inverse Definite Minimum Time Relay on a Distribution Feeder

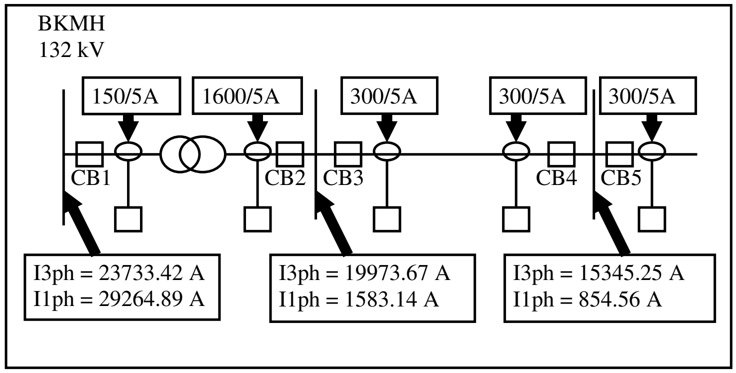

Figure 10: Example on distribution feeder

Table 1: Details of CTs and Relays

Circuit Breaker	CT Ratio	Relay Type
CB1	150/5	Standard Inverse
CB2	1600/5	Standard Inverse
CB3	300/5	Standard Inverse
CB4	300/5	Standard Inverse
CB5	300/5	Standard Inverse

Start grading from CB2;

Using standard inverse equation to determine operating time;

i. overcurrent setting

With t = 1.6s,

$$1.6 = \frac{0.14\,(TMS)}{\left(\frac{19973.67}{1600}\right)^{0.02} - 1}$$

$$TMS = 0.59$$

ii. earthfault setting

With t = 1.6s,

$$1.6 = \frac{0.14\,(TMS)}{(\frac{1583.14}{0.2 \times 1600})^{0.02} - 1}$$

$$TMS = 0.37$$

Next, grading CB3;

0.4 sec margin is required between CB2 and CB3 due to their location at different feeder.

i. overcurrent setting

t_{CB3} = 1.6 – 0.4 = 1.2 sec

$$1.2 = \frac{0.14\,(TMS)}{(\frac{19973.67}{300})^{0.02} - 1}$$

$$TMS = 0.75$$

ii. earthfault setting

With t = 1.2s,

$$1.2 = \frac{0.14\,(TMS)}{(\frac{1583.14}{0.2 \times 300})^{0.02} - 1}$$

$$TMS = 0.58$$

Next, grading CB4;

Since CB3 and CB4 are located within the same feeder, there is no margin required.

i. overcurrent setting

Use $TMS_{CB4} = TMS_{CB3} = 0.75$,

$$t = \frac{0.14(0.75)}{(\frac{15345.25}{300})^{0.02} - 1}$$

$$t = 1.28 \text{ sec}$$

ii. earthfault setting

With TMS = 0.58,

$$t = \frac{0.14(0.58)}{(\frac{854.56}{0.2 \times 300})^{0.02} - 1}$$

$$t = 1.488 \text{ sec}$$

Next, grading CB5;

0.4 sec margin is required between CB4 and CB5 due to their location at different feeder.

i. overcurrent setting

$t_{CB3} = 1.28 - 0.4 = 0.88$ sec

$$0.88 = \frac{0.14(TMS)}{(\frac{15345.25}{300})^{0.02} - 1}$$

$$TMS = 0.51$$

ii. earthfault setting

t_{CB3} = 1.488– 0.4 = 1.088 sec

$$1.088 = \frac{0.14\,(TMS)}{\left(\frac{854.56}{0.2 \times 300}\right)^{0.02} - 1}$$

$$TMS = 0.42$$

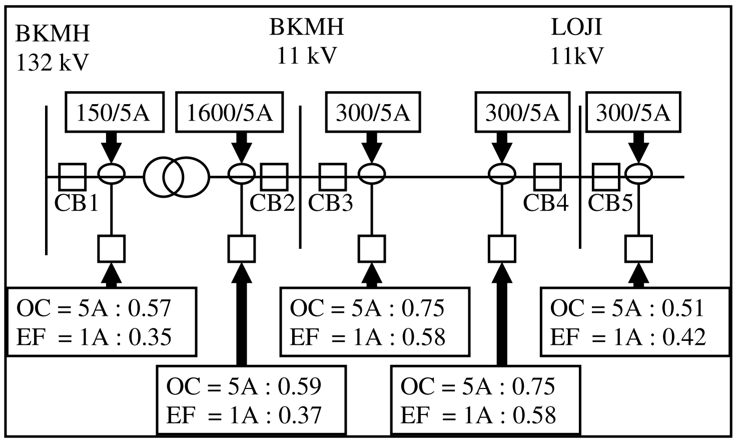

Figure 11: Relay setting calculated

Noted that grading margin is required between adjacent relays which determined by:

i) Circuit breaker time

ii) Relay overshoot

iii) Instrument error

2.9 OCEF Relay

OCEF stands for overcurrent and earthfault relay which used as the protection on medium- and low-voltage networks. OCEF relays are star-connected [7] as shown in the figure 12 below:

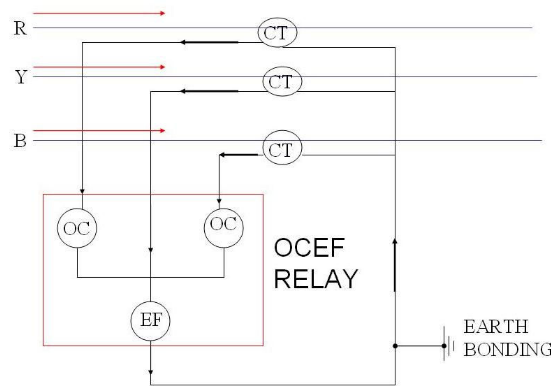

Figure 12: Schematic diagram of OCEF Relay

From the schematic:

$$\sum I_R + I_Y + I_B$$

2.9.1 Example of overcurrent between two phases

The highlighted relay circuit which is OC will be energized to trip.

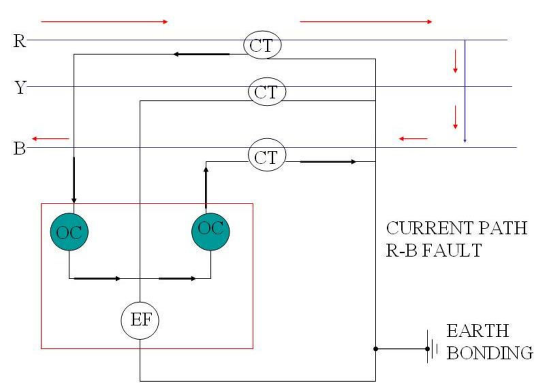

Figure 13: Overcurrent fault (R-B)

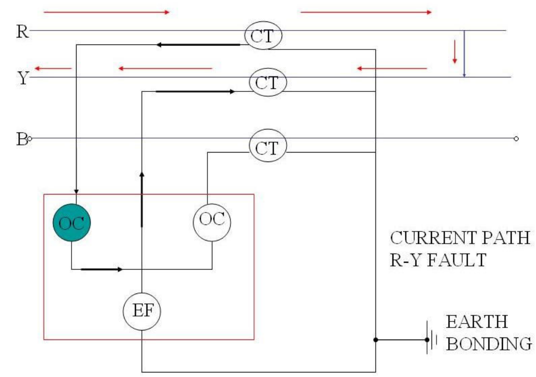

Figure 14: Overcurrent fault (R-Y)

2.9.2 *Example of earthfault.*

The highlighted relay circuit which is EF will be energized to trip.

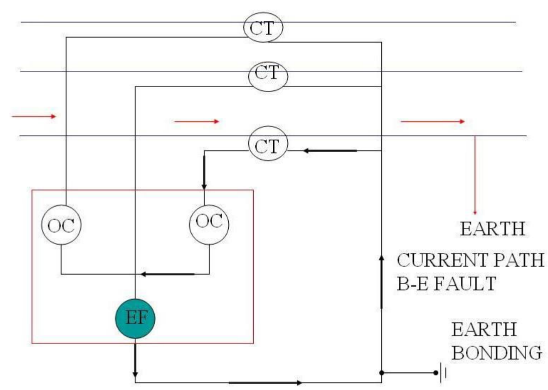

Figure 15: Earthfault (B-E)

OC elements are set based on three-phase fault while EF element is based on earthfault or single-phase fault. Normally coordination is done by using simulator or coordination software available in the market.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

There are some procedures has to be done throughout this study. This is to ensure that the study can be accomplished within the given timeframe.

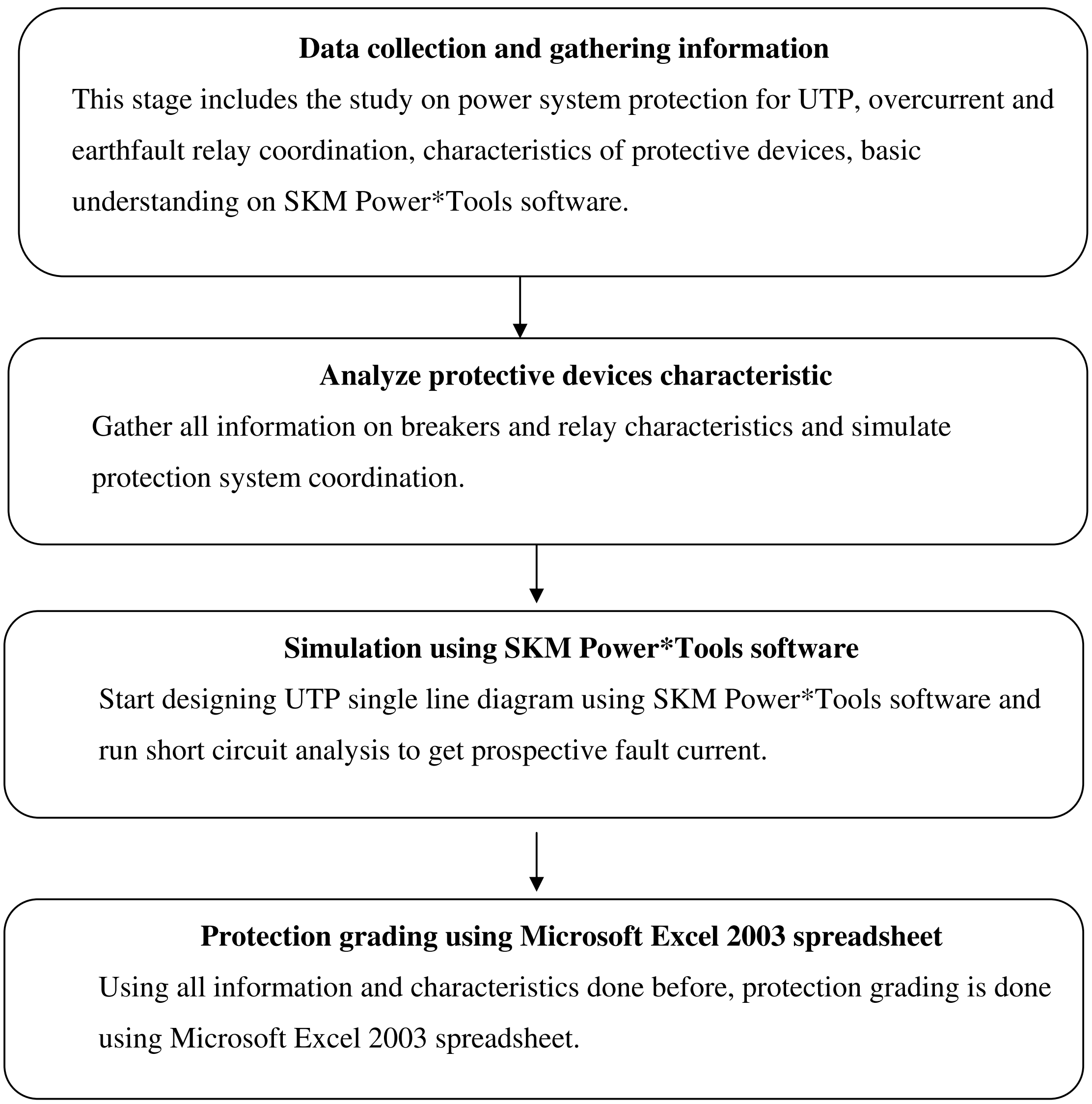

Figure 16: Procedures flowchart

3.2 Tools and Equipment

i. SKM Power*Tools Electrical Engineering software

This electrical engineering analysis software is used to create a power system model and perform short circuit study for this study.

ii. Microsoft Excel 2003 spreadsheet

Formulas are assigned into the spreadsheet to get the best protection grading.

3.3 Project Activities

Throughout this study, up until this point of time there were discussions made by the author with project supervisor in collecting information as well as activities done. They are:

i. Study on HV & LV single line diagram of Universiti Teknologi PETRONAS (UTP) academic complex and old buildings.

The single line diagram shows how power is being distributed within UTP area and study in electrical power system protection, characteristics of protection devices such as fuses, relays and circuit breaker, overcurrent and earthfault relay coordination and setting.

ii. Gas District Cooling (GDC) site visit on 3rd March 2009.

On 3rd March 2009, under guidance of project supervisor, Ir. Mohd Faris Bin Abdullah a site visit to UTP's GDC was made in order to make the author familiarized with the plant and its process in generating and distributing power to UTP area. Besides, some discussions have been made to assist in the studies.

iii. Familiarizing with SKM Power*Tools Electrical Engineering software.

After successfully installation of SKM software, the author is trying to be familiarized with the software in power system design and analysis especially in fault analysis which is basic requirement for this study. The software can assist the author by calculating the voltage drop on each feeder and transformer branch, voltage on each bus, projected power flow, and losses in the power system. It also provides a network solution of three-phase, single-line to ground, line-to line, and double line to ground fault currents; RMS momentary fault currents; asymmetrical fault duties at three, five, and eight cycles; the positive, negative, and zero sequence impedance values between each fault location, and contributions from utilities, generators, and motors.

iv. Construct circuit based on UTP single line diagram by using SKM Power*Tools software.

After collecting data, the author is trying to construct UTP single line diagram in order to get an overview of power protection system in UTP. By using the software the circuit can be constructed and the author hopes after completing this stage, short-circuit analysis can be done to get the respected results.

v. Perform short circuit study on UTP single line diagram.

After completing the drawing of single line diagram, the author has to perform short circuit study on the system and compare the compatibility with the current system. The study is purposed to model the current that flows in the power system under abnormal conditions and determines the prospective fault currents in an electrical power system. These currents must be calculated in order to sufficiently specify electrical apparatus withstand and interrupting ratings. The Study results are also used to selectively coordinate time current characteristics of electrical protective devices.

Procedure for the Short Circuit Study is as shown below:

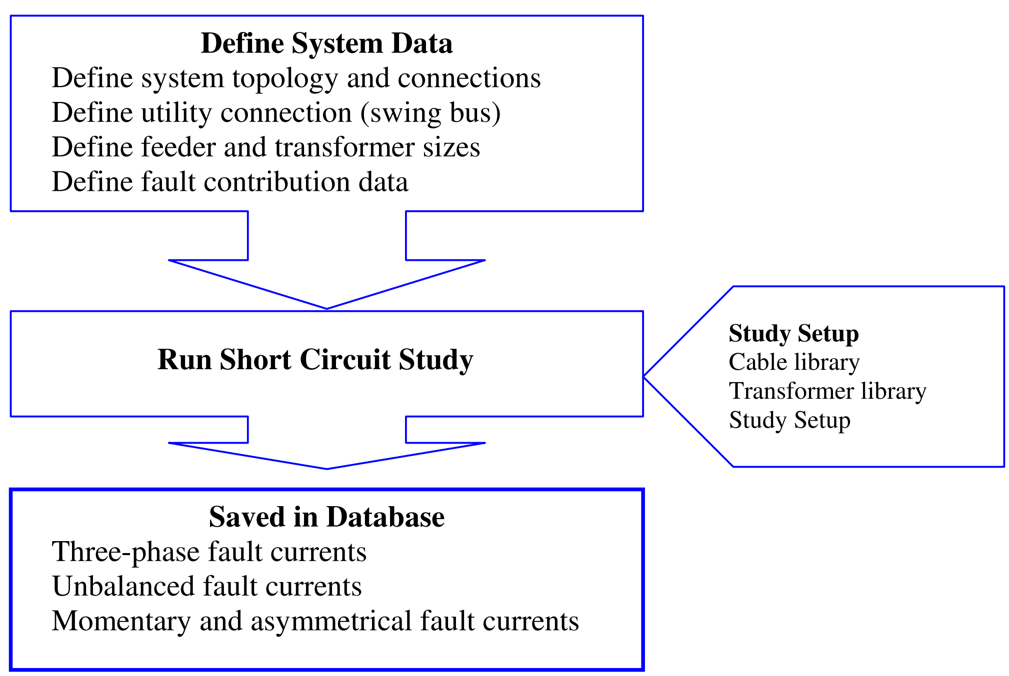

Figure 17: Short circuit study flowchart

vi. Perform protection grading using Microsoft Excel 2003 spreadsheet.

Using protection grading template in the spreadsheet, the author is required to complete protection grading to UTP power system network. From the spreadsheet operating time of all relays, its margin as well as feeder current can be determined.

3.4 Project Ganttchart

Project Gantchart is as being attached in Appendix A.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Universiti Teknologi PETRONAS Single Line Diagram

After gathering all date required, a single line diagram of UTP is constructed using SKM power tools software. The drawing of UTP single line diagram is divided into two parts:

i) UTP old building; which covers substations ETS, sports complex, Multi Purpose Hall (MPH), old library, hostels, old chemical building and old USM building.

ii) New academic complex; which covers substations at Chancellor Hall, Pocket C, Pocket D and all academic buildings.

Below is the drawing of single line diagram that have been constructed:

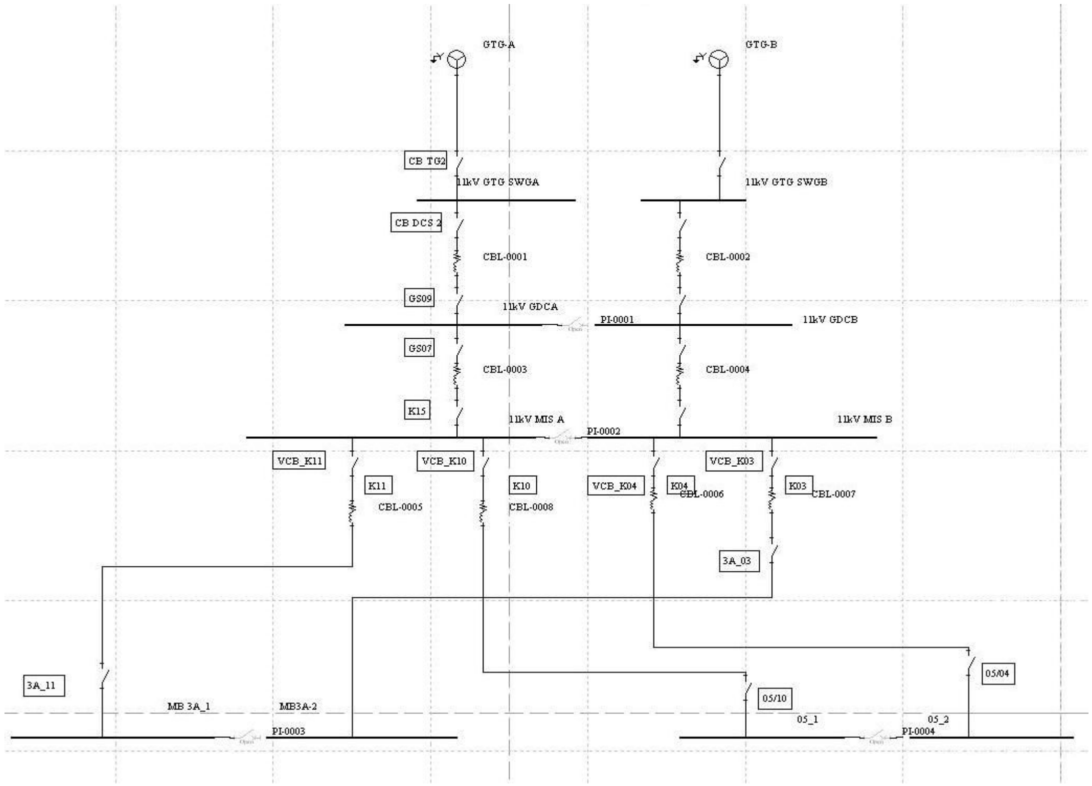

Figure 18: Single line diagram of UTP new academic complex

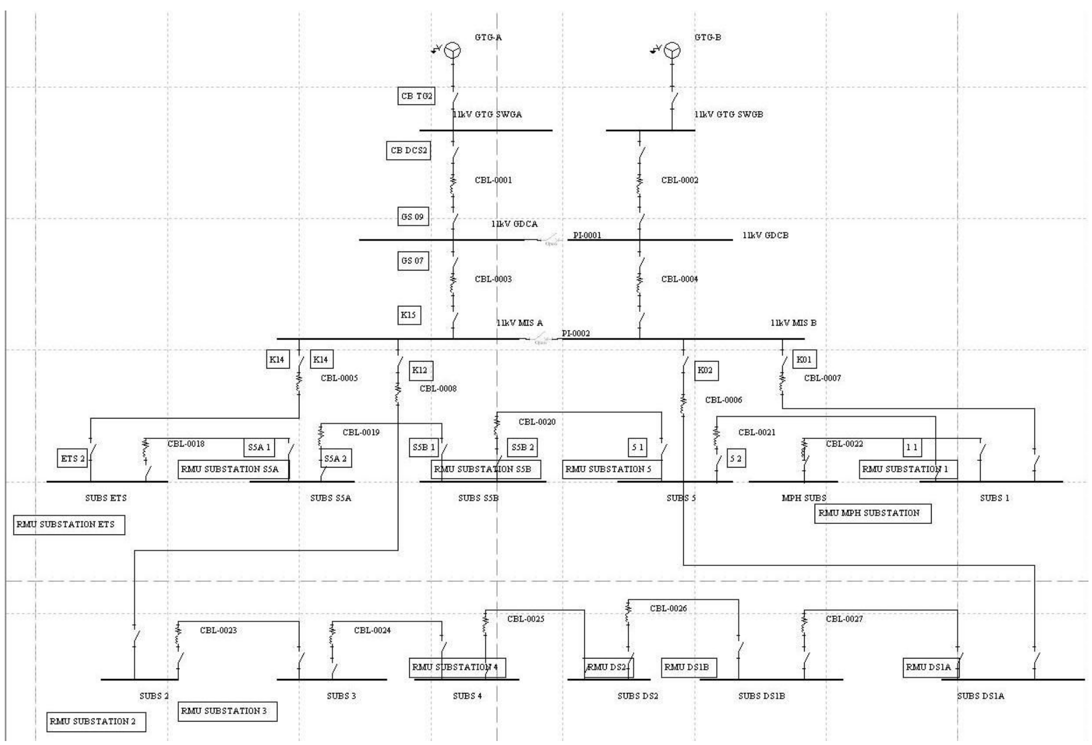

Figure 19: Single line diagram of UTP Old Building

After keying in all data required for each generator, busses, cables, transformers and all protective devices, a short circuit analysis should be run in order to model the current that flows in the power system under abnormal conditions and determines the prospective fault currents in an electrical power system.

4.2 Electrical System

The UTP electrical system that is of interest of this study is the 11kV system. This report is based on two (2) Gas Turbine Generators (GTG) running in parallel in island operation.

Two (2) generators are connected to 11kV GTG Switchgear, which connected to 11kV GDC Switchgear. These GTGs are modeled as 5.3MW (0.8PF) machines respectively with Neutral Earthing Resistance (NER) of 31.75 Ω.

4.3 Short-circuit Analysis Results

Results for short-circuit analysis for New academic complex and old building can be seen in Appendix B.

4.4 Relay Protection Coordination

In this study, protection coordination will start at the generation part which in this study is from UTP turbine generator. As discussed earlier in Chapter 2 Literature Review, relay must be coordinated so that there will be 0.4 margin between each so that protection coordination on the system will be as selective, sensitive, fast, stable and reliable as required. It should be noted that only relay nearest to the fault will operate at time of fault occurs.

4.4.1 Overcurrent Protection Coordination at 11kV GTG SWG bus

Table 2: Existing Protection Coordination at 11kV GTG SWG bus

RELAY	CB TG-2	CB DCS 2
SWITCH	INCOMING	OUTGOING
C.T. RATIO	500 / 5	400 / 5
RELAY FUNCTION	OC/EI	OC/EI
FAULT LEVEL (MVA)	44.070	44.070
PSM (%)	**360**	**110**
TMS	**0.800**	**0.500**
VOLTAGE (KV)	11	11
OP. TIME	98.26	1.50
MARGIN (s)	0.00	96.76
FEEDER CURRENT	1800	440
PSM (HIGH SET)(%)	**380**	**150**
TIME SETTING	**0.50**	**0.20**
OP. TIME	**0.50**	**0.20**
MARGIN (s)	0.00	0.30
FEEDER CURRENT	1900	600
FAULT CURRENT	2313	2313
ACTUAL OP. TIME	0.50	0.20
ACTUAL MARGIN (s)	0.00	0.30

Table 3: Recommended Protection Coordination at 11kV GTG SWG bus

RELAY	CB TG-2	CB DCS 2
SWITCH	INCOMING	OUTGOING
C.T. RATIO	500 / 5	400 / 5
RELAY FUNCTION	OC/EI	OC/EI
FAULT LEVEL (MVA)	44.070	44.070
PSM (%)	**360**	**110**
TMS	**0.800**	**0.500**
VOLTAGE (KV)	11	11
OP. TIME	98.26	1.50
MARGIN (s)	0.00	96.76
FEEDER CURRENT	1800	440
PSM (HIGH SET)(%)	**463**	**578**
TIME SETTING	**0.50**	**0.10**
OP. TIME	**0.50**	**0.10**
MARGIN (s)	0.00	0.40
FEEDER CURRENT	2313	2313
FAULT CURRENT	2313	2313
ACTUAL OP. TIME	0.50	0.10
ACTUAL MARGIN (s)	0.00	0.40

In coordinating overcurrent relay and its margin, only the path that is connected to the source that needs to be coordinated is taken into considerations. While, other path that is not connected to the source and not included in the coordination will be isolated (disconnected). For the first step, Time Multiplier Setting (TMS) of the relay near to the generator is being fixed as reference to do the coordination. Then, TMS value of the next relay will be varied to determine the operating time of the relay so that its margin will be 0.4 seconds. The margin should be 0.4 seconds to avoid higher relay to trip first and result all component in the system to be isolated. Three-phase fault level is used in determining proper setting for overcurrent protection coordination.

From the table, it can be seen that existing protection coordination has 0.3 margin of operating time. To avoid operation overlaps between CB TG-2 relay and CB DCS 2 relay also to avoid CB DCS 2 relay to operate first, it is recommended to change high set for lower relay which CB DCS 2. Also, for maximum fault at 11kV GTG SWG bus, it is recommended to change PSM for high set for both relays.

4.4.2 Overcurrent Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

Table 4: Existing Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

SUBSTATION	CB DCS 2	GS 09
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	OC/EI	OC/SI
FAULT LEVEL (MVA)	43.520	43.520
PSM (%)	**110**	**75**
TMS	**0.500**	**0.250**
VOLTAGE (KV)	11	11
OP. TIME	1.54	0.84
MARGIN (s)	103.31	0.70
SETTING CURRENT	440	300
PSM (HIGH SET)(%)	**150**	**420**
TIME SETTING	**0.20**	**0.00**
OP. TIME	**0.20**	**0.00**
MARGIN (s)	0.30	0.20
SETTING CURRENT	600	1680
FAULT CURRENT	2284	2284
ACTUAL OP. TIME	0.20	0.00
ACTUAL MARGIN (s)	0.30	0.20

Table 5: Recommended Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

SUBSTATION	CB DCS 2	GS 09
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	800 / 5
RELAY FUNCTION	OC/EI	OC/SI
FAULT LEVEL (MVA)	43.520	43.520
PSM (%)	**110**	**50**
TMS	**0.500**	**0.390**
VOLTAGE (KV)	11	11
OP. TIME	1.54	1.54
MARGIN (s)	103.31	0.00
SETTING CURRENT	440	400
PSM (HIGH SET)(%)	**578**	**-**
TIME SETTING	**0.10**	**-**
OP. TIME	**0.10**	**-**
MARGIN (s)	0.40	-
SETTING CURRENT	2313	-
FAULT CURRENT	2284	2284
ACTUAL OP. TIME	1.54	1.54
ACTUAL MARGIN (s)	103.31	0.00

From table 4, there is 0.20 s margin between CB DCS 2 and GS 09. This is not a good practice because these two relays are within the same feeder, thus no margin is required. So, the solution is new TMS value is proposed for GS 09 in order to get 0 margins. In addition, the actual feeder current is set to be 300 A which is not rational for the existing coordination since the lower relay which is GS 07 that will be discussed later is having higher feeder current. To solve this problem, it is suggested to change the CT ratio of GS 09 relay as well as its PSM and TMS value.

Having done the changes, it can be seen that both relays can operate at the same time if fault occur at 11kV GDC bus.

4.4.3 Overcurrent Protection Coordination at 11kV GDC bus

Table 6: Existing Protection Coordination at 11kV GDC bus

SUBSTATION	**GS 09**	**GS 07**
SWITCH	INCOMING	OUTGOING
C.T. RATIO	400 / 5	1000 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	43.520	43.520
PSM (%)	**75**	**40**
TMS	**0.250**	**0.500**
VOLTAGE (KV)	11	11
OP. TIME	0.84	1.97
MARGIN (s)	0.70	-1.13
SETTING CURRENT	300	400
PSM (HIGH SET)(%)	**420**	**-**
TIME SETTING	**0.00**	**-**
OP. TIME	**0.00**	**-**
MARGIN (s)	0.20	-
SETTING CURRENT	1680	-
FAULT CURRENT	2284	2284
ACTUAL OP. TIME	0.00	1.97
ACTUAL MARGIN (s)	0.20	-1.97

Table 7: Recommended Protection Coordination at 11kV GDC bus

SUBSTATION	**GS 09**	**GS 07**
SWITCH	INCOMING	OUTGOING
C.T. RATIO	800 / 5	1000 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	43.520	43.520
PSM (%)	**50**	**40**
TMS	**0.390**	**0.280**
VOLTAGE (KV)	11	11
OP. TIME	1.54	1.11
MARGIN (s)	0.00	0.43
SETTING CURRENT	400	400
PSM (HIGH SET)(%)	**-**	**-**
TIME SETTING	**-**	**-**
OP. TIME	**-**	**-**
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2284	2284
ACTUAL OP. TIME	1.54	1.11
ACTUAL MARGIN (s)	0.00	0.43

From table 6, there is negative margin between GS 09 and GS 07. This is not a good practice because negative margin indicates that upper relay will operates first instead of lower relay. Since negative margin must be eliminated from the system, new TMS value also proposed to be applied at relay GS 07 and there is 0.43 s margin between these relays. In addition, high setting for GS 09 relay is being eliminated because it will cause difficulties in coordination without additional benefits. So, it is suggested just to have high set only for nearest relays to the generator to protect it which are CB TG 2 and CB DCS 2 relay.

4.4.4 Overcurrent Protection Coordination from 11kV GDC bus to 11kV MIS bus

Table 8: Existing Protection Coordination from 11kV GDC bus to 11kV MIS bus

SUBSTATION	**GS 07**	**K15**
SWITCH	OUTGOING	INCOMING
C.T. RATIO	1000 / 5	1000 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	42.880	42.880
PSM (%)	**40**	**40**
TMS	**0.500**	**0.200**
VOLTAGE (KV)	11	11
OP. TIME	1.99	0.80
MARGIN (s)	-1.14	1.19
SETTING CURRENT	400	400
PSM (HIGH SET)(%)	**-**	**-**
TIME SETTING	**-**	**-**
OP. TIME	**-**	**-**
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2251	2251
ACTUAL OP. TIME	1.99	0.80
ACTUAL MARGIN (s)	-1.99	1.19

Table 9: Recommended Protection Coordination from 11kV GDC bus to 11kV MIS bus

SUBSTATION	**GS 07**	**K15**
SWITCH	OUTGOING	INCOMING
C.T. RATIO	1000 / 5	1000 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	42.880	42.880
PSM (%)	**40**	**40**
TMS	**0.280**	**0.280**
VOLTAGE (KV)	11	11
OP. TIME	1.12	1.12
MARGIN (s)	0.44	0.00
SETTING CURRENT	400	400
PSM (HIGH SET)(%)	**-**	**-**
TIME SETTING	**-**	**-**
OP. TIME	**-**	**-**
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2251	2251
ACTUAL OP. TIME	1.12	1.12
ACTUAL MARGIN (s)	0.44	0.00

The existing coordination between relay GS 07 and K15 have 1.19 s margins. This is not a good practice in protection coordination since the relays are within the same feeder. So, new TMS is proposed to get 0 margins between and having the same operating time when fault occurred.

4.4.5 Overcurrent Protection Coordination at 11kV MIS bus

Table 10: Existing Protection Coordination at 11kV MIS bus

SUBSTATION	**K15**	**VCB K11**
SWITCH	INCOMING	OUTGOING
C.T. RATIO	1000 / 5	400 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	42.880	42.880
PSM (%)	**40**	**100**
TMS	**0.200**	**0.150**
VOLTAGE (KV)	11	11
OP. TIME	0.80	0.60
MARGIN (s)	1.19	0.20
SETTING CURRENT	400	400
PSM (HIGH SET)(%)	**-**	**-**
TIME SETTING	**-**	**-**
OP. TIME	**-**	**-**
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2251	2251
ACTUAL OP. TIME	0.80	0.60
ACTUAL MARGIN (s)	1.19	0.20

Table 11: Recommended Protection Coordination at 11kV MIS bus

SUBSTATION	**K15**	**VCB K11**
SWITCH	INCOMING	OUTGOING
C.T. RATIO	1000 / 5	400 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	42.880	42.880
PSM (%)	**40**	**100**
TMS	**0.280**	**0.180**
VOLTAGE (KV)	11	11
OP. TIME	1.12	0.72
MARGIN (s)	0.00	0.40
SETTING CURRENT	400	400
PSM (HIGH SET)(%)	**-**	**-**
TIME SETTING	**-**	**-**
OP. TIME	**-**	**-**
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2251	2251
ACTUAL OP. TIME	1.12	0.72
ACTUAL MARGIN (s)	0.00	0.40

For K15 and VCB K11 relays, there are 0.20 s margins which is to small that can allow overlapping to occur. To get 0.4 differences in margins, new TMS is proposed to relay VCB K11.

4.4.6 Overcurrent Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

Table 12: Existing Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

SUBSTATION	VCB K11	3A 11
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	OC/SI	OC/SI
FAULT LEVEL (MVA)	41.630	41.630
PSM (%)	100	90
TMS	0.150	0.100
VOLTAGE (KV)	11	11
OP. TIME	0.61	0.38
MARGIN (s)	0.20	0.23
SETTING CURRENT	400	360
PSM (HIGH SET)(%)	-	-
TIME SETTING	-	-
OP. TIME	-	-
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2185	2185
ACTUAL OP. TIME	0.61	0.38
ACTUAL MARGIN (s)	0.20	0.23

Table 13: Recommended Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

SUBSTATION	VCB K11	3A 11
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	OC	OC
FAULT LEVEL (MVA)	41.630	41.630
PSM (%)	100	90
TMS	0.180	0.191
VOLTAGE (KV)	11	11
OP. TIME	0.73	0.73
MARGIN (s)	0.41	0.00
SETTING CURRENT	400	360
PSM (HIGH SET)(%)	-	-
TIME SETTING	-	-
OP. TIME	-	-
MARGIN (s)	-	-
SETTING CURRENT	-	-
FAULT CURRENT	2185	2185
ACTUAL OP. TIME	0.73	0.73
ACTUAL MARGIN (s)	0.41	0.00

Next, new TMS is also proposed to 3A 11 relay in order to increase the margin so that there will be 0.4 differences between the margin.

It can be concluded that only the nearest relay to the fault will operates first, then followed by the upstream relay that is in the same fault path. Also, it is required for the relays at different feeder to operate at 0.4 seconds margin. This is to avoid other relay to operate when they are not needed. For coordination that includes transformer, damage curve of the transformer will be main constraint than its margin. For 0 margins, it indicates that the relay will trip at instant during the fault thus it will result minimum interruption.

The coordination is made so that if the relay curve is plotted, they will not overlap into each other and operates the way they should be.

The same coordination is applied for other path in the system. If the load at each feeder and at the same bus is identical, the relay setting also should be identical. The consideration is applied to other relays. The overall overcurrent protection coordination result is attached in Appendix C and Appendix D.

4.4.7 Earthfault Protection Coordination at 11kV GTG SWG bus

Table 14: Existing Protection Coordination at 11kV GTG SWG bus

SUBSTATION	CB TG-2	CB DCS 2
SWITCH	INCOMING	OUTGOING
C.T. RATIO	500 / 5	400 / 5
RELAY FUNCTION	EF/EI	EF/EI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**150**	**10**
TMS	**1.000**	**0.200**
VOLTAGE (KV)	11	11
SETTING CURRENT	150	8
FAULT CURRENT	199	199
OP. TIME (s)	105.26	0.03
MARGIN (s)	0.00	105.23

Table 15: Recommended Protection Coordination at 11kV GTG SWG bus

SUBSTATION	CB TG-2	CB DCS 2
SWITCH	INCOMING	OUTGOING
C.T. RATIO	500 / 5	400 / 5
RELAY FUNCTION	EF/EI	EF/EI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**150**	**70**
TMS	**1.000**	**0.200**
VOLTAGE (KV)	11	11
SETTING CURRENT	150	56
FAULT CURRENT	199	199
OP. TIME (s)	105.26	1.38
MARGIN (s)	0.00	103.88

For earthfault protection coordination, the same procedure is applied where only the path that is connected to the source that needs to be coordinated is taken into considerations. For the first step, Time Multiplier Setting (TMS) of the relay near to the generator is being fixed as reference to do the coordination. Then, TMS value of the next relay will be varied to determine the operating time of the relay so that its margin will be 0.4 seconds. The margin should be 0.4 seconds to avoid higher relay to trip first and result all component in the system to be isolated. Single-phase fault level is used in determining proper setting for earthfault protection coordination.

In addition, to determine proper setting of operating time of the relays, plug setting multiplier (PSM) is set to 20% of CT ratio and time multiplier setting (TMS) will be adjusted accordingly to get required margin.

From Table 14, it can be seen that existing earthfault coordination is set at the very low feeder current value. This is not a good practice in protection coordination since the relay could possibly operate when it is not required. So, to avoid this from happen, new PSM is proposed so that the relay operates as required.

4.4.8 Earthfault Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

Table 16: Existing Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

SUBSTATION	**CB DCS 2**	**GS 09**
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	EF/EI	EF/SI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**10**	**10**
TMS	**0.200**	**0.390**
VOLTAGE (KV)	11	11
SETTING CURRENT	8	8
FAULT CURRENT	199	199
OP. TIME (s)	0.03	0.05
MARGIN (s)	105.23	-0.02

Table 17: Recommended Protection Coordination from 11kV GTG SWG bus to 11kV GDC bus

SUBSTATION	CB DCS 2	GS 09
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	800 / 5
RELAY FUNCTION	EF/EI	EF/SI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**70**	**10**
TMS	**0.200**	**0.510**
VOLTAGE (KV)	11	11
SETTING CURRENT	56	56
FAULT CURRENT	199	199
OP. TIME (s)	1.38	1.38
MARGIN (s)	103.88	0.00

From Table 16, there is negative margin between CB DCS 2 relay and GS 09. This indicates that when fault occurs, upper relay which CB DCS 2 will operates first. This is not good practice in protection coordination where it will cause damages and losses to the whole system. So, it is proposed to change its PSM and TMS value of GS 09 relay is adjusted to get 0 margins since both relays are within the same feeder.

4.4.9 Earthfault Protection Coordination at 11kV GDC bus

Table 18: Existing Protection Coordination at 11kV GDC bus

SUBSTATION	GS 09	GS 07
SWITCH	INCOMING	OUTGOING
C.T. RATIO	400 / 5	1000 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**10**	**10**
TMS	**0.390**	**0.350**
VOLTAGE (KV)	11	11
SETTING CURRENT	8	20
FAULT CURRENT	199	199
OP. TIME 1 (s)	0.05	0.29
MARGIN (s)	-0.02	-0.24

Table 19: Recommended Protection Coordination at 11kV GDC bus

SUBSTATION	GS 09	GS 07
SWITCH	INCOMING	OUTGOING
C.T. RATIO	800 / 5	1000 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.791	3.791
PSM (%)	**10**	**10**
TMS	**0.510**	**0.320**
VOLTAGE (KV)	11	11
SETTING CURRENT	48	20
FAULT CURRENT	199	199
OP. TIME 1 (s)	1.38	0.95
MARGIN (s)	0.00	0.43

The same procedure is applied to coordinate relay GS 09 and GS 07. Since negative margin must be eliminated from the system, new TMS value also proposed to be applied at relay GS 07 and there is 0.43 s margin between these relays.

4.4.10 Earthfault Protection Coordination from 11kV GDC bus to 11kV MIS bus

Table 20: Existing Protection Coordination from 11kV GDC bus to 11kV MIS bus

SUBSTATION	GS 07	K15
SWITCH	OUTGOING	INCOMING
C.T. RATIO	1000 / 5	1000 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.772	3.772
PSM (%)	**10**	**5**
TMS	**0.350**	**0.150**
VOLTAGE (KV)	11	11
SETTING CURRENT	20	10
FAULT CURRENT	198	198
OP. TIME 1 (s)	0.29	0.03
MARGIN (s)	-0.24	0.26

Table 21: Recommended Protection Coordination from 11kV GDC bus to 11kV MIS bus

SUBSTATION	GS 07	K15
SWITCH	OUTGOING	INCOMING
C.T. RATIO	1000 / 5	1000 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.772	3.772
PSM (%)	**10**	**5**
TMS	**0.320**	**0.420**
VOLTAGE (KV)	11	11
FEEDER CURRENT	20	10
FAULT CURRENT	198	198
OP. TIME 1 (s)	0.95	0.95
MARGIN (s)	0.43	0.00

The existing coordination between relay GS 07 and K15 have 0.26 margins for relay within the same feeder. This is not a good practice in protection coordination. So, new TMS is proposed to get 0 margins between.

4.4.11 Earthfault Protection Coordination at 11kV MIS bus

Table 22: Existing Protection Coordination at 11kV MIS bus

SUBSTATION	K15	VCB K11
SWITCH	INCOMING	OUTGOING
C.T. RATIO	1000 / 5	400 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.772	3.772
PSM (%)	**5**	**10**
TMS	**0.150**	**0.100**
VOLTAGE (KV)	11	11
SETTING CURRENT	10	8
FAULT CURRENT	198	198
OP. TIME 1 (s)	0.03	0.01
MARGIN (s)	0.26	0.02

Table 23: Recommended Protection Coordination at 11kV MIS bus

SUBSTATION	K15	VCB K11
SWITCH	INCOMING	OUTGOING
C.T. RATIO	1000 / 5	400 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.772	3.772
PSM (%)	**5**	**10**
TMS	**0.420**	**0.250**
VOLTAGE (KV)	11	11
SETTING CURRENT	10	8
FAULT CURRENT	198	198
OP. TIME 1 (s)	0.96	0.53
MARGIN (s)	0.00	0.43

For K15 and VCB K11 relays, there are 0.02 margins which is to small that can allow overlapping to occur. To get 0.4 differences in margins, new TMS is proposed to relay K15.

4.4.12 Earthfault Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

Table 24: Existing Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

SUBSTATION	VCB K11	3A 11
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.715	3.715
PSM (%)	**10**	**10**
TMS	**0.100**	**0.100**
VOLTAGE (KV)	11	11
SETTING CURRENT	8	8
FAULT CURRENT	195	195
OP. TIME 1 (s)	0.01	0.01
MARGIN (s)	0.02	0.00

Table 25: Recommended Protection Coordination from 11kV MIS bus to 11kV MB 3A/1 bus

SUBSTATION	VCB K11	3A 11
SWITCH	OUTGOING	INCOMING
C.T. RATIO	400 / 5	400 / 5
RELAY FUNCTION	EF/SI	EF/SI
FAULT LEVEL (MVA)	3.715	3.715
PSM (%)	**10**	**10**
TMS	**0.250**	**0.250**
VOLTAGE (KV)	11	11
SETTING CURRENT	8	8
FAULT CURRENT	195	195
OP. TIME 1 (s)	0.53	0.53
MARGIN (s)	0.43	0.00

Next, new TMS is also proposed to 3A 11 relay in order to increase the margin so that there will be 0.4 differences between the margin.

It can be concluded that only the nearest relay to the fault will operates first, then followed by the upstream relay that is in the same fault path. Also, it is required for the relays at different feeder to operate at 0.4 seconds margin. This is to avoid other relay to operate when they are not needed. For coordination that includes transformer, damage curve of the transformer will be main constraint than its margin. For 0 margins, it indicates that the relay will trip at instant during the fault thus it will result minimum interruption.

The coordination is made so that if the relay curve is plotted, they will not overlap into each other and operates the way they should be.

The same coordination is applied for other path in the system. If the load at each feeder and at the same bus is identical, the relay setting also should be identical. The consideration is applied to other relays. The overall earthfault protection coordination result is attached in Appendix C and Appendix D.

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study is about power system protection coordination at Universiti Teknologi PETRONAS (UTP). The whole project had been outlined into two-semester plan. The first semester was concentrating on learning and studying power system protection in electrical systems in which to understand on its working principle and the equipments involved. Besides, some effort has been put in learn and getting familiar with SKM power tools engineering software. The second semester was focusing on modeling the system's network and completing the protection coordination.

Inverse Definite Minimum Time Overcurrent and Earthfault (IDMT OCEF) type of relay had been identified in this paper and the functionality of the protective relay had been tested. This protective relay was modeled based on the static relay characteristics. Some of the relays are based on extremely inverse (EI) and standard inverse (SI) characteristics. As discussed earlier in this paper, the upper relay will operate faster than relays located below. This is to provide protection to the equipment as well as the system. Thus, protection coordination principle as discussed in Chapter 2 can be achieved. Also, short circuit analysis on UTP single line diagram had been performed successfully using SKM power tools engineering software. This software was capable in determining fault current at each bus including three-phase and single line to ground fault current which are required in this study to perform protection coordination. Also, the simulation will give information on bus voltages as well as branch current of the system. Microsoft Office Excel 2003 spreadsheet is determined as useful tools in completing the protection coordination of the relays in UTP power system network.

This can be done by assigning required formulas to the spreadsheet and start grading the relay consecutively. From the spreadsheet, relay operating time, its margin and feeder current can be determined.

From the studies, it can be concluded that the power system protection coordination that has been performed is workable and can be improved into a more detailed coordination. The coordination can be used in analyzing the power system protection and to study the system behaviour. Therefore, the generated coordination can be used as educational tools in overcurrent and earthfault protection coordination.

5.2 Recommendations

Despite the fact that the power system protection coordination has been developed successfully, there are still some weaknesses and improvement can be made to enhance the coordination. Due to intensive study on power system protection and getting familiar with SKM power tools engineering software as well as Microsoft Office 2003 Excel spreadsheet, the next successor to this project or a project which is similar to this can make full advantage of this report. Listed are recommendation based on this project:

5.2.1 Protection Coordination Recommendations

i) Existing protection coordination shows that there are numbers of relays within the same path having high setting in the operation. It is recommended that only relays nearest to the generator will be having high setting in order to protect the generator as the main purpose. This is because by having numbers of high setting relays will cause difficulties in coordination without having any benefits.

ii) Usage of extreme inverse (EI) type of relays should be maintained for two relays nearest to the generator since EI relays will operates faster than standard inverse (SI) type of relays.

iii) Usage of Neutral Earth Resistance for both generator should be maintained in order to control the fault current, prevents the lines being charged to excessive high voltage due to lightning or switching surges and also to maintain sensitivity of protecting equipment work properly [8].

5.2.2 Other Recommendation

i) The basic theories on Power System Protection had been covered; therefore less time is needed to understand on power system protection. The methods of modeling the power system single line diagram and short circuit analysis using SKM Power Tools Engineering Software had been covered in detail; hence this report can be used as the reference for the methodology.

ii) Since SKM Power Tools Engineering Software bought by UTP is not the full version, it is recommended to UTP to buy the full version of the software so that protection coordination can be done by the software instead of doing it manually in the spreadsheet. This will reduce consumed time in preparing the proper coordination for the system.

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APPENDICES

APPENDIX A

Project Ganttchart

APPENDIX B

Short-circuit Analysis

on

New Academic Complex and Old Building

Single Line Diagram

APPENDIX C

Relay Setting

and

Grading

(actual)

APPENDIX D

Relay Setting

and

Grading

(Proposed)