ANALYSIS OF PROTECTION SYSTEM SETTING IN 11KV DISTRIBUTION SYSTEM

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER IN POWER SYSTEM ENGINEERING

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ABSTRACT

One of the fundamental protections used in electrical network power system is Overcurrent and Earth Fault (OCEF) protection. They have to be both sensitive and quick in minimizing the electrodynamic and thermal stress imposed on the equipment during the fault time interval. It is utmost important for the relays to be capable of removing only the faulty section while keep up the flexibly to solid areas in the system. In order to achieve this objective, correct relay coordination setting is important to prevent the system from suffering catastrophic effects. These days, the consumer is enforcing raising performance demands by reducing operational and maintenance costs. At the same moment, improvement of the consistency and quality of supply is required. The cumulative fault current at each bus in the network needs to be determined to achieve the most effective relay coordination. This will be along with the calculation of relay settings to get the Time Setting Multiplier (TMS) value. The differential time graph of the relay grading curves will be plotted based on the value of size of CT, current setting, relay characteristic and TMS. This is due to the small margin inherited from the upper-stream utilities, a thorough analysis needs to be performed to achieve the strongest relay communication to a ring delivery network. This research report includes of reviewing of new ones of OCEF relay coordination setting in a ring distribution system, calculations on fault current, and suggestion on improvement of the relay coordination setting using directional relay and non-directional relay. A software to use for OCEF relay simulation of a distribution system was developed by writer using Microsoft Excel. It consists of fault current calculation, relay setting calculations and graphical plot of the relay grading curves. The proposed improvement of the relay coordination environment using directional relay and non-directional relay would provide a better method of distribution in terms of reliability and maintainability.

Keywords: OCEF, fault current, directional relay, non-directional relay, margin

ANALISIS PENETAPAN SISTEM PERLINDUNGAN DALAM SISTEM PENGAGIHAN 11KV

ABSTRAK

Perlindungan Arus-Lebihan dan Kesalahan-Bumi (OCEF) adalah perlindungan asas yang digunakan dalam rangkaian sistem kuasa elektrik. Ia mesti peka dan cepat dalam meminimumkan tekanan elektrodinamik dan terma yang dikenakan pada peralatan semasa tempoh kerosakan. Sangat penting bagi geganti untuk dapat menghilangkan hanya bahagian yang rosak sementara mengekalkan bekalan ke bahagian yang sihat dalam sistem. Oleh itu, pengaturan koordinasi geganti yang betul adalah mustahak untuk mengelakkan sistem daripada mendatangkan malapetaka. Masa kini, pengguna menumpukan peningkatan permintaan terhadap kecekapan dengan mengurangkan kos operasi dan penyelenggaraan. Pada masa yang sama, penambahbaikan diperlukan dari segi kesinambungan dan kualiti pembekalan tenaga elektrik. Untuk mencapai koordinasi geganti yang optimum, arus kerosakan maksimum pada setiap bas dalam sistem perlu dikira. Seterusnya, tetapan geganti dikira untuk mendapatkan nilai TMS. Graf diskriminasi penggredan masa geganti akan diplotkan berdasarkan nilai ukuran CT, tetapan semasa, ciri geganti dan TMS. Margin yang terhad diwarisi dari syarikat utiliti di aliran atas, kajian komprehensif perlu dilakukan untuk mendapatkan koordinasi geganti yang terbaik dalam sistem pengedaran cincin. Laporan penyelidikan ini merangkumi pengesahan pengaturan koordinasi geganti OCEF yang ada dalam sistem pengagihan cincin, pengiraan arus kerosakan, dan cadangan penambahbaikan pengaturan koordinasi geganti menggunakan geganti arah dan geganti bukan arah. Program yang mesra pengguna untuk simulasi geganti OCEF sistem pengedaran dibangunkan menggunakan Microsoft Excel. Ia terdiri daripada pengiraan arus kerosakan, pengiraan tetapan geganti dan plot graf penggredan geganti. Cadangan penambahbaikan koordinasi geganti menggunakan geganti arah dan geganti bukan arah akan memberikan sistem pengagihan yang lebih baik dari segi keboleh-harapaan dan keboleh-senggaraan.

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My special thanks are extended to University of Malaya and faculty members of the engineering department who advocated and given me with the necessary facilities to complete the project.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

IDMT	:	Inverse Definite Minimum Time
IEC	:	International Electrotechnical Commission
AC	:	Alternating Current
LED	:	Light Emitting Diode
PLC	:	Programmable Logic Controller
ROT	:	Relay Operating Time
ANSI	:	American National Standards Institute
BS	:	British Standard
NI	:	Normal Inverse
TMS	:	Time Setting Multiplier
IEEE	:	Institute of Electrical and Electronics Engineers
OC	:	Over Current
CT	:	Current Transformer
PS	:	Plug Setting
SI	:	Standard Inverse
VI	:	Very Inverse
EI	:	Extremely Inverse
EFR	:	Earth Fault Relay
RCA	:	Relay Characteristics Angle
NOP	:	Normal Off-Point
CB	:	Circuit Breaker
CW	:	Clockwise
ACW	:	Anti-Clockwise
GM	:	Grading Margin

CHAPTER 1: INTRODUCTION

1.1 Overview

Major concern in designing a power system is to avoid any error or faulty to struck which may cause hazard and catastrophic states towards the operators, the equipment and as well as the system. Thus, the major aspect to be considered in designing the power system protection is minimizing the destruction and provide protection to the power supply in a dependable and harmless condition. Due to this, relay is one of the most significant and important components in protection system. Numerous types of relay introduced for this purpose and each has its own unique function.

The Institute of Electrical and Electronic Engineers (IEEE) defines a relay as an electric device that is designed to respond to input conditions in a prescribed manner and, after specified conditions are met, that will cause contact operation or similar abrupt change in associated electric control circuits. A note amplifies: 'Inputs are usually electric, but may be mechanical, thermal or other quantities or a combination of quantities. Limit switches and similar devices are not relays. [1]

Integration of protection relay in power system is mainly to detect flaw in lines and equipment and other possible hazard condition. It can either starts or authorize switching or simply triggers an alarm. Main component of a protection system are circuit breakers and relays. It is important to integrate both component in a protection system to make sure the protection is effectively functional. This is of no use to apply either one of these components in a system as there is less or no significant function.

The basic principle of protection system is to provide safeguard against excess current in power system and it further evolve to suit with more sophisticated power station system. The development of the graded overcurrent system, a discriminative fault protection was conducted by referring to this basic principle. In fact, overcurrent protection can be defined as faults clearance process which take place at the correct location and position to reduce the risk of unnecessary tripping and power supply loss.

In power distribution system, the most common backup protection method is over current and earth fault (OCEF) protection with IDMT relay. The difference in fault type and power distribution system require specific types of OCEF relay to be used to achieve the purpose. Directional relay is one of OCEF relay which reliable for this purpose. Study on existing relay setting system was conducted and setting improvement was proposed using directional and non-directional relay. This will in fact be the focus part of this research report.

1.2 Problem Statement

In normal power system operation, protection system is not obliged to function, but in the presence of abnormalities, protection system is essential to control intolerable system condition and prevent dangerous disruption and damage in power system. Hence, the accuracy when these relays operates is of the utmost important. Normally, relays are continuously connected in the system, but the real operating time can be in the order of a few seconds. In daily operation, the relays are frequently operating during maintenance and testing activities than in feedback to adverse service condition. Note that these relay systems must be able to give feedback on any abnormalities which can possibly happen within the power system [2].

The combination of overcurrent and earth fault relay is connected to the CT and a secondary relay that should protect the CT. OCEF relay will continuously measure the phase current and neutral current of the equipment. To detect the fault, OCEF will trip the circuit breaker by providing alarms, the fault data is recorded and others based on the setting that been configured by the relay functions. As OCEF being practice widely, a simulation must be done to analyze the data.

For grading margin, it must be sufficient or should be provided. If any of these two criteria does not meet, it will cause the relay will operate more that one. This also will affect determining the fault location and unrelated loss of supply to some consumer.

An efficient electrical power supply requires a careful and good planning, design, installation, operation, and maintenance of a complex network of generators, transformers, transmission and distribution lines. The five basic features are:

a) Reliability: assurance that the protection will perform correctly
b) Selectivity: maximum continuity of service with minimum system disconnection.
c) Speed of operation; minimum fault duration and consequent equipment damage.
d) Simplicity: minimum protective equipment and associated circuit to achieve the protection objectives.
e) Economics: maximum protection at minimal total cost.

1.3 Objectives

The following objectives have been pursued throughout the duration of the research:

a) To utilize a program for OCEF relay operation analysis for a ring distribution system

b) To determine minimum grading margin between relays in distribution system.

c) To improve the reliability of power distribution by using directional and non-directional relay coordination.

d) To study the effect of varying the current setting and grading margin towards coordination of relay setting.

1.4 Scope of the project

Specifically, this research aims to focus on relay setting and coordination in a power distribution system. Research in this area has two main phases; firstly, analysis was performed on existing relay setting at site; and secondly was further explained in three stages.

The first stage was focused on analysis on three phase fault current and single phase to ground current. Next stage was concentrated on relay setting calculation. The result from this stage was to obtain the minimum relay operating time (ROT) by analyzing different current setting and grading margin of relay with the developed program. The final stage was to observe the results on relay grading and coordination curves from simulation of calculated result into a discrimination time plot graph. To evaluate this method, the relay setting variables of current setting and grading margin will be verified from the relay curves obtained.

1.5 Research Report Organization

The research report can be broadly divided into six main chapters. The first chapter briefly on introduction which includes the relay protection introduction, the objectives, the scope of research and the research report organization.

Second chapter of the research report, we present an overview of the Literature Review regarding the protection system, fault current analysis, protection relay, over current & earth fault relay, directional relay and coordination procedure.

Details elaboration on methodology used in verification of over current and earth fault relay coordination settings is discussed in Chapter Three of this research report. In short, methodology of data collection up to the simulation on the plotted relay grading curves are covered in this chapter. To conclude this chapter, result of the calculation and relay grading curves graph are further discussed.

In Chapter Four the research paper now turns to the presentation of the results obtained from plotted graph and calculation. Differences for each plotted graph can be seen after the results obtained are segregated between different direction of clockwise and anti-clockwise, and between overcurrent relay and earth fault relay.

Result obtained from calculation and graph was analyzed and further discussed in Chapter Five.

In final chapter of this research paper, conclusions of the study and potential future prospect to be explored was discussed and suggested.

CHAPTER 2: LITERATURE REVIEW

2.1 Background

Literature review related to fault current and protection relay presented in this chapter for further understanding on this research report area of studies. Detail explanation on the concept and theory of fault current and protection relay will be presented in this chapter. For reference purpose, related formula for calculation was also shown. In general, the results are obtained from the formula by varying the input values for its calculation. Solid understanding on the theory behind each variable applied to the formula is crucial to get the best result. Questions on how, why and what the parameters need to be selected for the calculation and selection on fault current calculation and relay settings coordination will be answered in this chapter.

2.2 Fault Current Analysis

In power system protection study, accurate analysis on fault current is critical. It is one of important steps for power system protection analysis. The approach taken for this analysis is to calculate the short circuit on the anticipated electrical fault location. The main purpose of the analysis is to determine the characteristics of the equipment required to withstand or break the fault current. In order to achieve this, short circuit must be calculated at each level in the electrical system.

IEC 60909 (impedance method) standard is applied in this research report. In general, IEC 60909 standards provide concise procedure and method of implementing symmetrical components that can be used by engineers who are not specialized in the field. The method is applicable to electrical networks with a nominal voltage of less than 550 kV and the standard explains the calculation of minimum and maximum short-circuit currents [1].

Application of a separate relay for earth fault current protection is indeed a best practice considering its characteristic which can be adjusted to provide faster and more sensitive protection for single phase to ground fault than the phase relays can provide. However, there is circumstance when the phase relay alone needs to rely on the protection against all type of faults. In contrast, there is also condition that the phase relay need to be inoperative on the zero-sequence component of ground fault to ensure that phase relay operation during ground fault is not performed.

Practically, unique characteristic of overcurrent relay which are straightforward, economical and do not require to be directional and no AC voltage source involve make it very well adaptable for distribution system protection.

2.3 Types of Fault

During equipment installation, assessment on the equipment capability to withstand the energy generated without causing any damage is very crucial. Thus, know-how on fault current in a power system is important. There are five possible modes of fault; single phase to ground, three phase short circuit, phase to phase, two-phase to ground and three phase to ground. Due to the fact that the most common fault is single phase to ground fault and the most severe is the three phase fault, the distribution system is focused on these two faults.

Difference between three phase balanced fault and the single phase to ground for unbalanced fault in terms of positive sequence impedance are illustrated in Figure 2.1 and Figure 2.2, given that Z_1 (Z^+); negative sequence impedance, Z_2 (Z^-); and zero sequence impedance, Z_0.

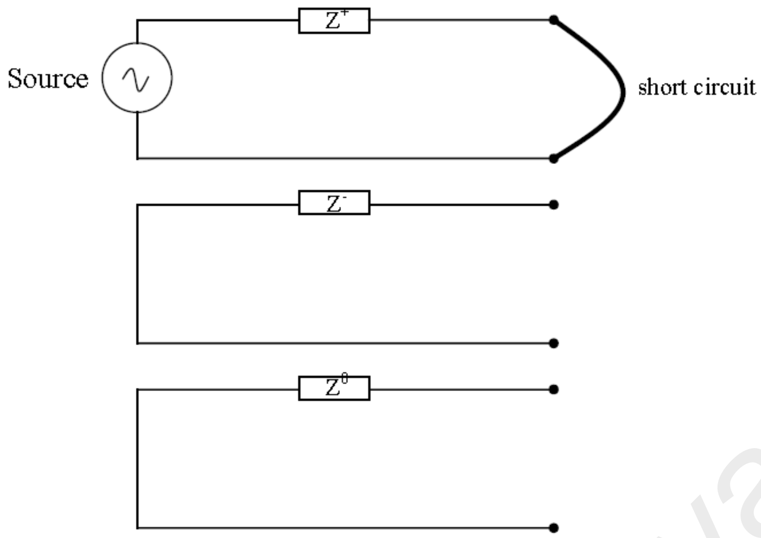


Figure 2. 1 : Three phase fault for balanced fault

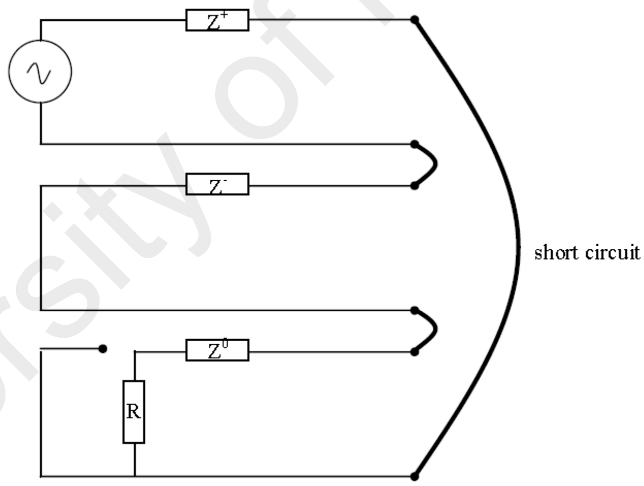


Figure 2. 2 : Single phase to ground fault for unbalanced fault in Delta-Star Transformer

2.3.1 Three Phase Fault

The impedance of the system limits the fault current that flow during short circuit. The magnitude of the current is simply determined by the Ohm's law (I=V/Z).

To calculate the fault current, the following steps are performed:

a) A single line diagram of the circuit containing all element is drawn

b) A single line impedance diagram containing one phase and neutral is drawn

c) The total impedance up to the fault point is calculated

d) The short circuit current is calculated using:

$$\text{Short circuit MVA} = \frac{MVA\ base}{Zpu} \tag{2.1}$$

$$\text{Short circuit current} = \frac{Short\ Circuit\ MVA\ x\ 1000}{\sqrt{3}\ X\ Vline} \tag{2.2}$$

2.3.2 Single Phase to Ground Fault

For single phase to ground fault calculation, two conditions must be fulfilled: the use of symmetrical component and separation of circuits into positive, negative and zero sequence networks. This makes calculation for single phase to ground fault more challenging compared to three phase fault calculation. The sequence impedances of lines contained in each component are considered. For transformers and generator, the zero sequence diagrams are highly depend on ground connections and element type. Transformer impedance is contained in positive and negative sequence networks. On the other hand, the voltage sources are added in the positive sequence network for generators. Figure 2.3 and 2.4 show example of a sequence network for a generator and transformer respectively.

Fault current for a single line to ground can be determined using:

$$\text{If, 1ph} = 3 \text{ x line kV} / (Z_1 + Z_2 + Z_0) \tag{2.3}$$

Where, $Z_0 = Zs + 3Z_n$

Zs is the source impedance and Zn is the neutral to ground impedance of the source. In case of solidly grounded source, Zn is equals to zero. Same equation is used to calculate the earth fault current for a distribution network. Normally, in a distribution system**,** single phase and three phase fault levels at the transmission main intake substation are given. From a transmission planning or utility protection department, we can always obtain the three phase and single phase fault levels which sometimes known as Maximum ROT. More the equivalent Thevenin impedances of the source can be obtained. The positive and zero sequence impedances of the source can be obtained from these fault levels by using below equation:

Z_{S1} = j (Base MVA) / (Three phase fault level) (2.4)

From Equation (2.3),

If ,1ph = 3 x line kV / (Z_1 + Z_2 +Z_0),

Where value of Z_1 and Z_2 are normally to be equal; $Z_1 = Z_2$

Then, Equation (2.3) will be reduced to:

Z_{S0} = j [(3x Base MVA) / (One phase fault level)] – 2 Z_{S1} (2.5)

Where,

Z_{S1} = source positive sequence impedance

Z_{S0} = source zero sequence impedance

The transformer and generator sequence network of equivalent circuits used for the calculation of fault current are schematically shown in Figure 2.3 and Figure 2.4.

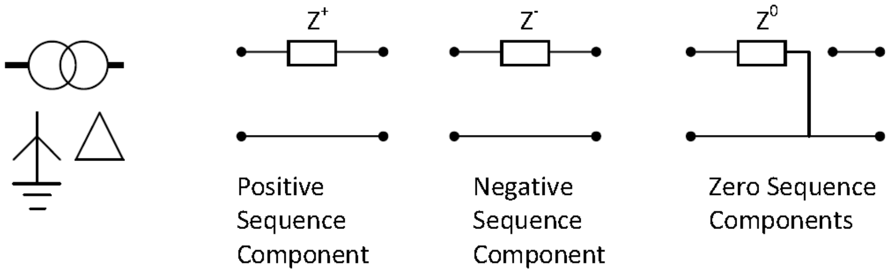


Figure 2. 3 Transformer Sequence Network

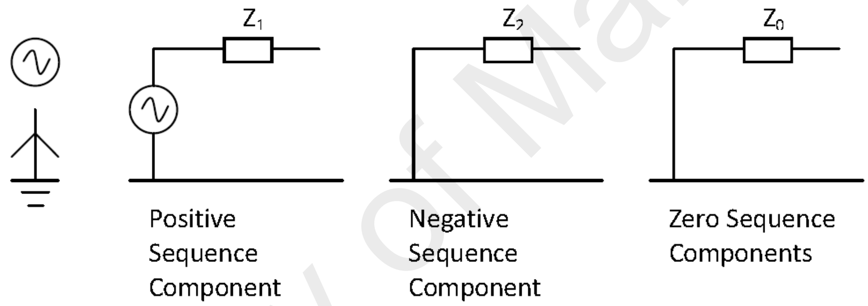


Figure 2. 4: Generator Sequence Network

2.4 Main and backup protections

2.4.1 Main protection

In general, main protection system can be described as a safeguard mechanism to clear a fault from power distribution system by initiating the tripping of appropriate circuit breakers promptly and discriminatively.

In designing main protection system, fast and reliable protection is always the aim. A unit protection; (e.g.: pilot wire protection, line differential protection and transformer differential protection) is commonly used in main protection in order to achieve this. An important thing to bear in mind when applying unit protection is the characteristic of unit protection which will only cover certain zone of protection, limited by two side of current transformers. The downside of this approach is the other nearest main protection will not trigger the fault occurred in the main protection if there is a fault occurs in a faulty main protection, which covers a limited region or zone. Thus, a backup protection scheme is necessary to overcome this problem.

2.4.2 Backup protection

In the event of failure of any main protection to clear the fault, back-up protection is a necessity for protection mechanism as it is designed to operate in such circumstance. In practice, IDMT overcurrent protection is commonly used as a backup protection for feeders, transformers and generators. There is circumstance where fault clearance conceivably non-discriminative with back-up overcurrent protection. It is a bit challenging to obtain sufficient backup overcurrent protection settings on feeder for this type of network. This is because of the fault current may flow in any direction depending on the fault location. Normally, similar nominal setting is given to the relays in case of specific operational requirements not available.

Backup overcurrent relays at the nearest feeder will operate at certain time delay at the moment a failure detected on the main protection feeder. The current setting of a backup overcurrent relay is determined by:

a) The minimum fault current which the relay is required to operate
b) The maximum load current which is required to be carried under emergency conditions

Technical requirement and cost efficiency are always the main factors to be considered to determine the specification and quantity of the main backup system to be installed on the feeder.

2.5 Protection Relay

A protection relay is a smart device that receives inputs, compares them to set points, and provides outputs. Inputs can be current, voltage, resistance, or temperature. Outputs can include visual feedback in the form of indicator lights and/or an alphanumeric display, communications, control warnings, alarms, and turning power off and on. [3] Figure 2.5 shown below shows the function of protection relay.

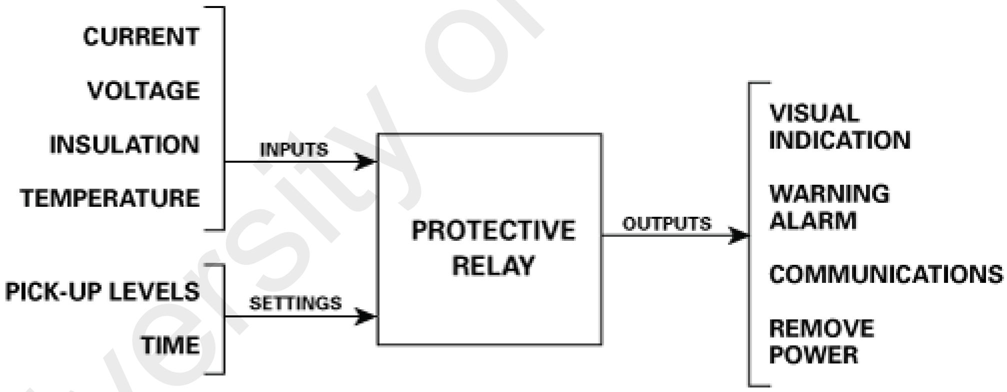


Figure 2. 5 : Function of protection relay

Earth fault relay, overcurrent relay and earth leakage relay are protection relay commonly used in power distribution system. Depend on the technical requirement and purpose, protection relays can be either electromechanical or electronic/microprocessor based. Electromechanical relays is a basic mechanical switching mechanism which apply electromagnetism concept. To maintain the relays within intended tolerance, routine calibration is required on the mechanical parts. It is a major drawback and the main reason why this type of relay slowly obsolete. To overcome this, more reliable and sophisticated device such as microprocessor or electronic relays were invented. Application of unprecedented digital technology, electronic relays are able to provide fast, reliable, accurate and repeatable outputs. Obviously, it is the best option which give us great advantages including improved accuracy, extra functions, smaller space requirement as well as cost effective in term of maintenance and life cycle.

For better understanding on protection relay function, further explanation on the terminology and its functionality is explained below:

a) Inputs

   Information or inputs from the system is crucial for a relay to decide. There are several ways to collect the inputs from the system. In some circumstance, the measured parameters need to be converted to a format that can be processed by relay. To covert the measured parameters, additional devices may be needed for instance current transformers, potential transformers, tension couplers, RTDs or others suitable devices.

b) Settings

   Adjustable settings is one of the main specifications for most type of protection relays. Firstly, protection relay must be allowed to decide. To set this condition, user need to program the setting (pick-up levels). The relay operates by comparing the inputs to these setting and responds accordingly.

c) Processes

   Main process which taken place in protection relay is comparing inputs and program setting. From these values, protection relay is able to make a decision for the system. There are range of relays available in market for different functions and need. In fact, main factors to consider for relay selection are technical requirement and cost efficiency.

d) Outputs

Decision made by the relay is delivered in several ways of communication to the system. In typical relay mechanism, the relay contact will engage to indicate an input that has surpassed a setting. In some advanced relay, faulty signal is transmitted by providing notification via visual feedback such as a meter or LED. Ability to communicate with a network or a PLC give an upper hand to electronic or microprocessor relays which make it best suited with nowadays power system.

In a power system, the protection relays must be able to recognize the fault, perform self-tripping or initiate trip command to relevant switching devices. Proper protection relays setting is very crucial to ensure selective tripping. Absolute selectivity is not always assured.

Selectivity can be defined as the series-connected protection relay nearest the fault first trips the faulted line. Other protection relays (further upstream) recognize the fault but trip only after a delay (backup protection). [4]

By applying the overcurrent protection principle, protection of distribution feeders is accomplished. In this research report, the combination of the OCEF protection principle with the inverse time operating characteristic is considered. The inverse relationship of current magnitude and the relay operating time is shown by the inverse time characteristic. The characteristic shows that the higher fault current magnitude, the shorter the relay operation times.

2.5.1 Overcurrent Relay

Overcurrent is a condition where the current flow in an abnormal way caused by insulation failure. This condition also known as short circuit. Normally, ground over current condition occur from phase to earth failure where the current will flow to earth. This condition is known as earth fault.

Definite Time Relay, Instantaneous or High Set Relay and Inverse Definite Minimum Time (IDMT) Relay are a few types of OCEF relays which are convenient and fit the purpose.

Variation of the current/time tripping characteristics of IDMT relays may be needed. The variation is subjected to the tripping time required and the characteristics of other protection devices used in the network. For these purposes, IEC 60255 defines a number of standard characteristics as follows:

a) Normal Inverse (Standard Inverse)
b) Very Inverse
c) Extremely Inverse
d) Long Time Inverse

2.5.1.1 Mathematical expression

Formula for each characteristics and comparison of IEC/BS142 and ANSI standards is summarized in Table 2.1.

Table 2. 1: IEC/BS and ANSI

	IEC/BS	ANSI
NI	$t = \frac{0.14}{(I / I_p)^{0.02} - 1} \cdot T_p$	$t = \left(\frac{8.9341}{(I / I_p)^{2.0938} - 1} + 0.17966 \right) \cdot D$
VI	$t = \frac{13.5}{(I / I_p) - 1} \cdot T_p$	$t = \left(\frac{3.922}{(I / I_p)^2 - 1} + 0.0982) \right) \cdot D$
EI	$t = \frac{80}{(I / I_p)^2 - 1} \cdot T_p$	$t = \left(\frac{5.64}{(I / I_p)^2 - 1} + 0.02434 \right) \cdot D$
LI	$t = \frac{120}{(I / I_p) - 1} \cdot T_p$	$t = \left(\frac{5.6143}{(I / I_p) - 1} + 2.18592 \right) \cdot D$
	t = Tripping time T_p = Setting value of the time multiplier I = Fault current I_p = Setting value of the current	

Normal Inverse (NI) characteristic is commonly known as the 3/10 characteristic, which means that at ten times of the setting current and TMS of 1, the relay will operate in 3 seconds. In this research report, NI characteristic will be used for the setting. The characteristic curve was defined as [5]:

$$t = \frac{0.14}{(\frac{1}{1S})^{0.02} - 1} \tag{2.6}$$

where,

t = operating time

I = fault current

Is = setting current

General representation of the other characteristic curves given as:

$$t = \frac{k\beta}{(\frac{I}{IS})^{\alpha} - 1} \tag{2.7}$$

Where,

t = relay operating time in seconds

k = time multiplier setting

I = fault current level in secondary amps

Is = pick-up current selected

α, β and L = constant

α, β and L depends on various standard overcurrent relay types manufactured under ANSI/IEEE and IEC Standards.

The slope of the characteristics is determined by the constant α and β. For various standard overcurrent relay types manufactured under IEC Standard, values of α, β and L are given in Table 2.2.

Table 2. 2 : IEC standard for relay characteristics

Curve	Standard	α	β	L
Standard Inverse	IEC	002	0.13	0
Very Intense	IEC	1.0	12.5	0
Extremely Inverse	IEC	2.0	80.0	0
Long-Time Inverse	IEC	1.0	120	0

Difference of sensitivity can be seen clearly from the plotted discrimination time for all the relay characteristics as shown in Figure 2.6.

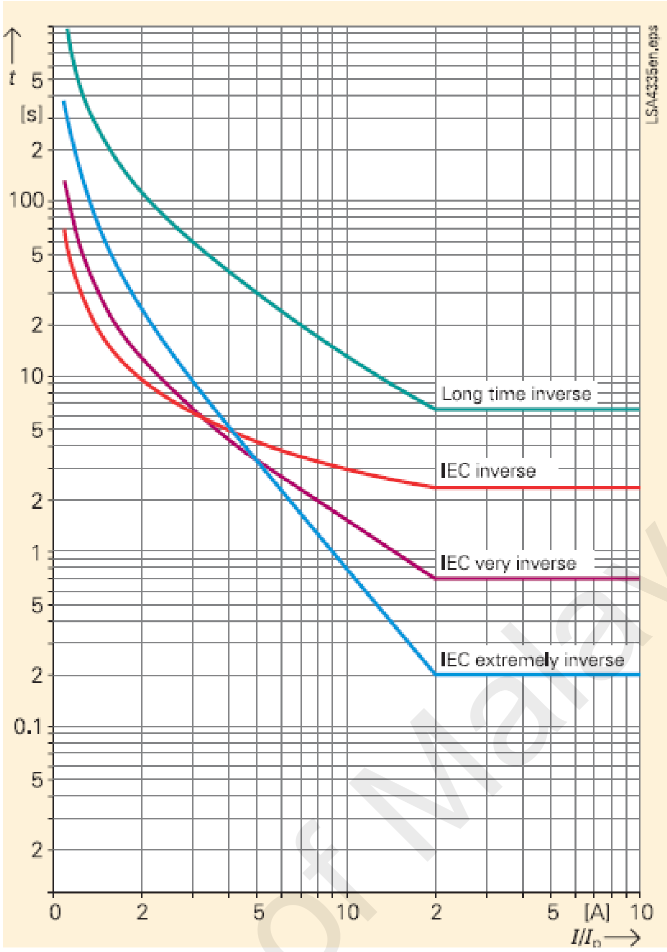


Figure 2. 6 : IEC/BS Relay Characteristic Curves

Isolation of the smallest section of the system in the shortest time possible is viable. This can be achieved by configuring the settings correctly and also by coordinating the operation of the relays. Configuring the correct setting and coordinating the relays operation in such a way minimize the unnecessary disruption to other consumers at the same time preventing damage to equipment at the faulty section.

Coordination between current and time is required for in series OC relays. The arrangement is meant to protect the incoming in the event of fault current at the outgoing. Coordination is made according to the characteristic curve plotted based on log graph.

2.5.1.2 Examples of coordination between OC

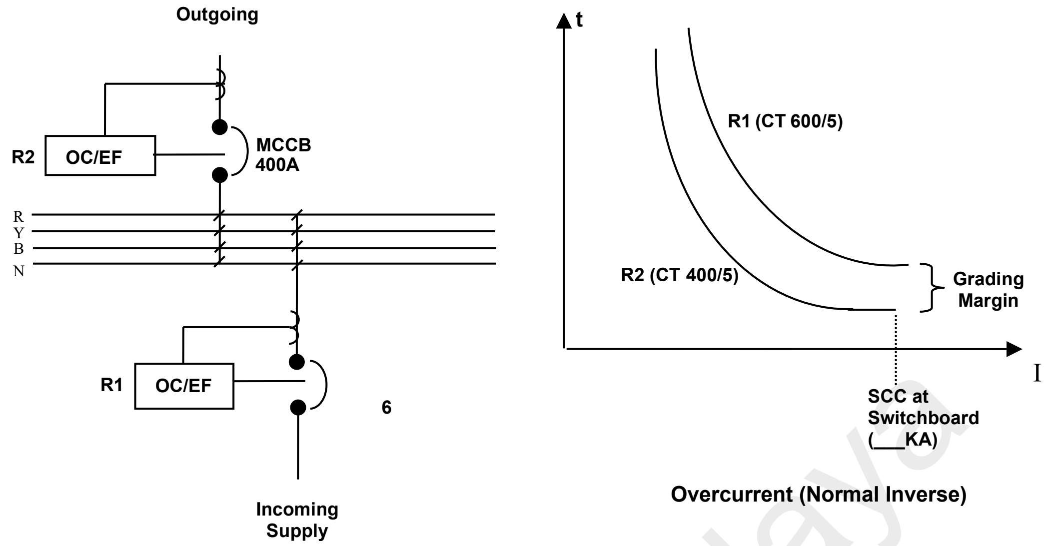


Figure 2. 7 : Coordination between OC relays

Figure 2.7 shows that R2 will trip first whenever the fault occurs at the outgoing. This can be explained by the characteristic curve between OC(R1) and OC(R2) where the grading margin gives OC(R1) time to trip. Plug Setting (PS) taken by OC(R2) is 80%(320A) of CT and is smaller than PS taken by OC(R1) which is 80%(480A). The PS value for OC(R1) and OC(R2) shall be higher than their load value.

Figure 2.8 illustrates the tripping characteristics for different TMS settings using the SI curve. Continuous adjustment may be possible in an electromechanical relay, albeit the curves are only shown for discrete values of TMS.

Exceedingly small setting steps of other relay types make it less effective to provide continuous adjustment. In addition, almost all overcurrent relays are also fitted with a high-set instantaneous element. Use of standard SI curve is adequate in most cases.

However, in case of inadequate grading cannot be achieved, VI and EI curves can be an alternative which may help to resolve the problem. Other characteristics may be provided when using digital or numeric relays which include the possibility of user-definable curves.

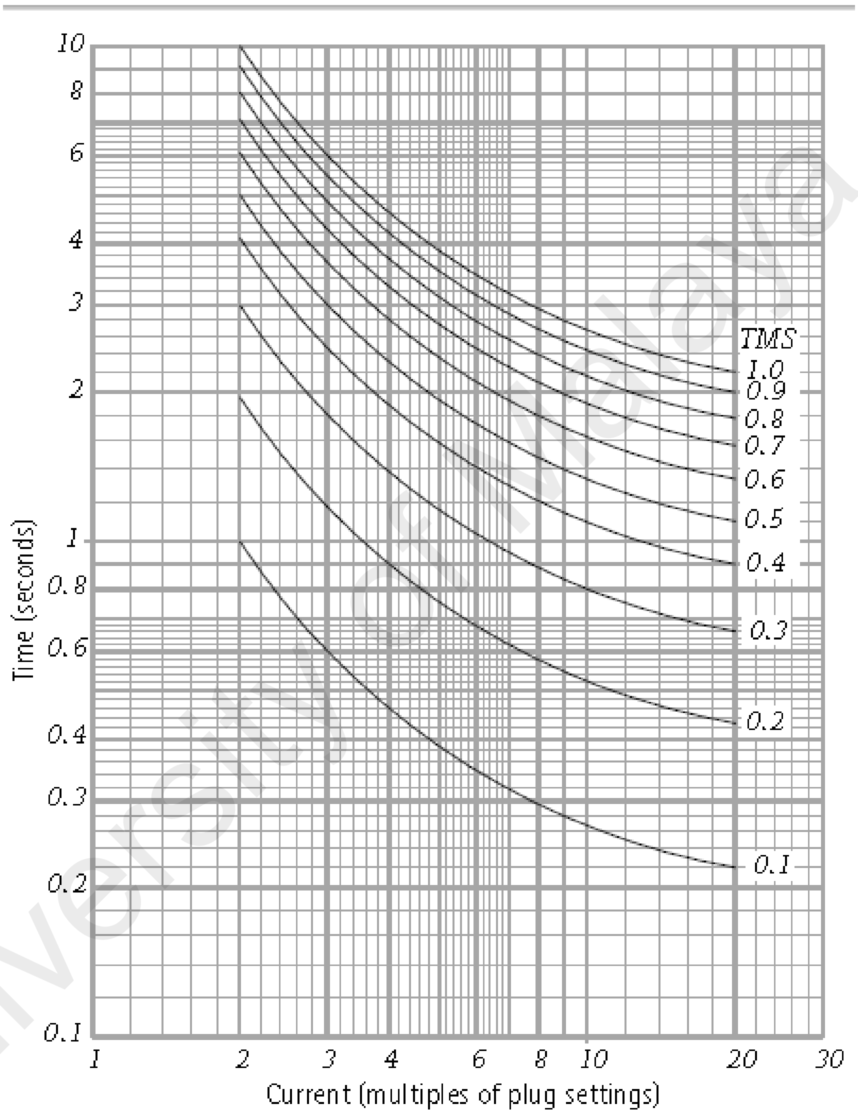


Figure 2. 8 : The tripping characteristics for different TMS settings using the SI curve

2.5.2 Earth Fault Relay

Earth fault is the most common fault which cause overcurrent or short circuit in an electrical system. Thus, and earth fault protection could be the most common of all. It is become normal practice to design a protection system which have the protection relay to detect at least (not necessarily trip) this fault condition. It becomes crucial as such fault arise will usually create current unbalance at all of the phases and ultimately create residual component in the system.

Equipment installed in a network is protected by earth fault protection by quantifying the earth fault current responds to the residual current. The residual component at the relay point usually can only exist when there is a fault current flow in a closed path from the fault location to ground through the earth return path to the source. Hence, this can be considered as a good design. The residual component is measured by protection relay; then, the current in a fault condition returned by earth is measured. A trip will be initiated to the system by the earth fault relay the moment earth loop exceeds the protection settings. This characteristic provided that the phase current under heavy load conditions give no impact on earth fault relay as the residual component is virtually zero.

Same rules and principle of coordination can be performed on time grading of earth relays to the phase overcurrent protection. However, earth fault current level seen on the protection relay could be vary due to the different neutral earthing method at different parts of the system give limitation in applying the same principle of coordination. Despite the limitation mentioned before, in some ways, the earth fault protection can be discriminated in time and/or fault currents, since they are designed to have the feeding circuit breakers tripped last in a radial feeder.

As in the phase overcurrent protection, standard discriminative curves for coordination can also be provided to earth fault protection relays. Same equation for operating and reset times as in phase overcurrent protection used to generate standard curves for earth fault protection; however, lower setting range is used.

2.6 Coordination Procedure

Selection of suitable settings to ensure the fundamental protective function should meet the requirements of sensitivity, selectivity, reliability, and speed is the main problem in protective relay coordination in power system [1, 2]. In a power system, there is variation of system condition and configuration which require all the requirements to be met and can be interpreted into different conditions for instance:

a) Appropriate relays must be able to detect variety of fault condition,

b) Operation is prioritized to the relays located closer to the fault,

c) Backup relay should operate in case of primary relay failure, and

d) The operation of the relay should be as fast as possible.

Coordination procedure is basically a procedure to determine the relay setting by the shortest operating times at maximum fault levels. Verification to confirm sufficient operation take place at the minimum fault current anticipated will be the next step of this procedure.

General basic rules for correct relay coordination as stated below [1, 2]:

a) Whenever possible, use relays with the same operating characteristic in series with each other
b) Ensure that the relay farthest from the source has current settings equal to or less than the relays behind it, that is, that the primary current required to operate the relay in front is always equal to or less than the primary current required to operate the relay behind it.

2.6.1 Principles of Time-Current Grading

Correct relay coordination can be achieved by using various methods. It is possible to use either time or overcurrent, or a combination of both. All of these three methods have common aim: to provide correct discrimination. In other words, each one of this method must be able to keep the rest of the system undisturbed by isolating only the faulty section of the power system network.

Three type of discrimination are:

a) Discrimination by Time
b) Discrimination by Current
c) Discrimination by both Time and Current.

In this research report, we will utilize the third type relay which is discrimination by both time and current.

2.6.2 Discrimination by both Current and Time

Brief justification on the type of discrimination selection is made in this section of research report. The fact that more severe faults required longer operating time to be cleared is the main disadvantage of discrimination only by time. In other circumstances, discrimination by current only applicable in the presence of appreciable impedance between two concerned circuit breakers. Evolution of the independent use of either time or current coordination that the inverse time overcurrent relay characteristic has imposed the limitations to this. It is clearly indicating that the actual characteristic is in a function of both 'time' and 'current' setting when the correlation between the time of operation to the fault current level is inversely proportional to each other. [2].

In the condition where fault level at the highest, faster operating time can be reached when there is huge difference of fault current between two ends of the feeder. As a result, we can overcome the disadvantages of grading by time or current independently. In general, selection of overcurrent relay characteristics is established with three essential steps. For the kickoff, the procedure starts with the selection of the correct characteristics to be used for each relay. Once the correct characteristics for the relay are selected, the relay current is set accordingly. Final steps of the procedure is determination of grading margins and time settings of the relay.

2.7 Relay Settings

A modern microprocessor protection is designed with a three-phase overcurrent unit and an earth-fault unit within the same case. Selection of parameters which define the required time/current characteristic of both the time delay and instantaneous units is the one of the procedures involved in overcurrent relays setting. This process is required once for the phase relays and another for the earth fault relays. Thus, this process needs to be performed twice. Despite the similarity of the two processes, it is performed to determine setting of different relays; the three phase short circuit current should be used for setting the phase relays and the phase to earth fault current should be used for the earth fault relays. To calculate the fault currents, assumption of normal operating state is made about the power system network [1].

2.7.1 Current Setting

Minimum operating current of an overcurrent relay is considered as the current setting of the relay. The main objective of choosing correct current setting is to make sure the relay does operate for a current equal or greater to the minimum expected fault current instead of operate for the maximum load current in the circuit being protected [2].

A certain degree of protection against overloads as well as faults may be provided even though the current setting used is just above the maximum current in the circuit. Misconception on main function of overcurrent protection need to be clarified. Overcurrent protection is not designed to provide overload protection, but it is supposed to perform isolation of primary system fault. Selection of the current setting is generally will be selected to be above the maximum short time rated current of the circuit involved. The current setting must be set sufficiently high to give allowance for the relay to reset when the rated current of the circuit is being carried. This condition needs to be considered since there are hysteresis exist in relays current setting. Pick-up/drop-off ratio of a relay indicates the amount of hysteresis in the current setting– the value for a modern relay is typically 0.95. Taking all these into account, it is likely that the requirement for minimum current setting is at 1.05 times the short-time rated current of the circuit.

2.7.2 Time Multiplier Setting

TMS is normally used as abbreviation for time multiplier setting. Whenever the fault current reached a value equal to, or greater than, the relay current setting, TMS functions to adjust the time delay before the relay operate. Adjustment of physical distance between moving and fixed contacts is the basic mechanism of electromechanical relays to control the time delay. In fact, shorter operating time can be obtained from a smaller time dial value.

Time dial setting is another term referred as TMS. Appropriate protection and coordination for the system can be achieved by considering the criteria and procedure used to calculate TMS. These criteria are mainly applicable to inverse-time relays, although the same methodology is valid for definite-time relays [6]:

a) For relay positioned furthest from the source, the required operating time can be determined by applying the lowest time multiplier setting by considering the pickup fault level at the instantaneous relay. In condition of the high load flows when the circuit is re-energized after supply loss (the cold load pick-up), the setting of this time multiplier need to be set higher.
b) Figure 2.9 shows relay associated with the breaker in the next substation towards the source. Operating time of this relay is determined. It is given by t_{2a}=t_1+tmargin where t_{2a} is the operating time of the back-up relay associated with breaker 2 and margin is the discrimination margin. Identical fault level used in determination of the time t_1 of the relay associated with the previous breaker is also be used for this calculation.
c) Time multiplier setting for relay 2 is calculated from the value of identical fault current in 1 and 2, pick-up for relay 2 and operating time $t_{2a.}$

d) The closest available relay time multiplier setting whose characteristic is above the calculated value is used.

e) Exceptional condition for relay 2, the operating time (t_2) is determined using the fault level which is just before the operation of its instantaneous unit.

f) For upstream relay, step (b) is repeated to determine the operating time.

The relays are assumed to have their characteristic curves scaled in seconds. The assumption of the relay's characteristic is made for above procedures to suit the purpose. In case of relays with time adjustment is given as a percentage of the operating curve for one second, the fastest multiplier applied to the curve for time multiplier l can be used to determine its time multiplier setting. Time settings for modern relays can be a value from 0,1s and in steps of 0.05s.

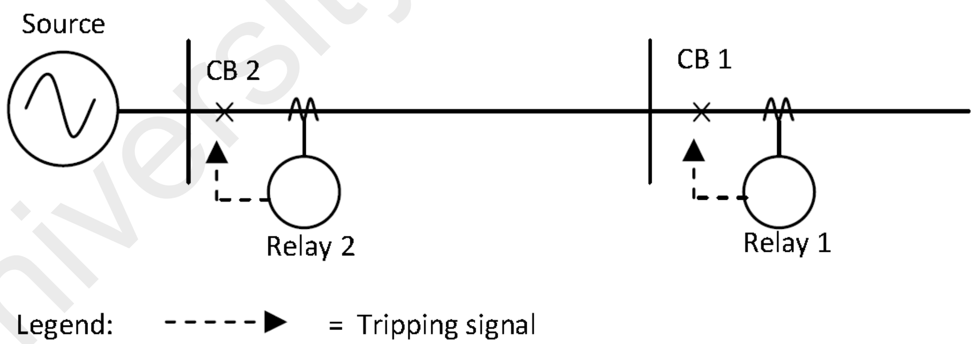


Figure 2. 9 : : Example of a distribution radial feeder

2.7.3 Grading Margin

Time interval between the operations of two adjacent relays is essential to obtain an accurate discrimination. Absence or insufficient grading margin will cause inefficient of relay operation where more than one relay will operate for a fault. Thus, it will be difficult to determine the fault location and unnecessary loss of supply to some consumers cannot. Several factors contribute to the time interval or grading margin [1, 7]:

a) the fault current interrupting time of the circuit breaker
b) relay timing errors
c) the overshoot time of the relay
d) CT errors
e) final margin on completion of operation

Factors (b) and (c) are dependence on relay technology used in the system to some extend the output is significantly difference. For instance, larger overshoot time can be seen in an electromechanical relay compare to a numerical relay. Initially, grading is performed for the maximum fault level at the relaying point under consideration. However, from some investigation made, it shows that the required grading margin exists for all current levels between relay pick-up current and maximum fault level. [7]

2.7.3.1 Circuit Breaker Interrupting Time

Complete interruption on current must be performed by circuit breaker in interrupting the fault before the discriminating relay ceases to be energized. Type of the circuit breaker used and the fault current to be interrupted determine the time taken for fault interruption by the circuit breaker. Fault interrupting time provided by manufacturers is normally at rated interrupting capacity. Usually, this value is used in grading margin calculation.

2.7.3.2 Relay Timing Error

Ideal characteristic of relay timing is clearly defined in IEC 60255 standard. In reality, there are errors in their timing. The maximum timing error of a relay is determined by the relay error index quoted for the specified relay in IEC 60255. It is important to note that, the timing error must be included when determining the grading margin.

2.7.3.3 Overshoot

It is normal for a relay to continue operate for a while after the relay get de-energized. This phenomenon is caused by the balance stored energy in the relay. The operation will cease after all the stored energy has been dissipated. Some examples of this phenomenon can be seen in an induction disc relay which gains and stores kinetic energy from the motion of the disc; static relay circuits may have energy stored in capacitors. Minimizing and absorbing this energy should the direction in designing relay. However, it is always necessary to have allowance.

The overshoot time is defined as the difference between the operating time of a relay at a specified value of input current and the maximum duration of input current, which when suddenly reduced below the relay operating level, is insufficient to cause relay operation.

2.7.3.4 CT Errors

Errors are common in all measuring devices. For example, relays and current transformers are measuring devices which subjected to some degree of error. For relays, the time characteristic may have either positive or negative errors. Magnetizing characteristic of current transformer (CT) is the main cause of the CT errors exist in the device. It is worth noting that the definite time overcurrent relays are not affected by the CT errors [5].

2.7.3.5 Final Margin

The discriminating relay is expected to fail in completing its operation after the above allowances have been made. To ensure that relay operation does not take place, extra allowance or safety margin is needed. Normally, correct discrimination can be obtained by considering a safety margin of 100 milliseconds added to the final calculated margin. Stable satisfactory contact gap (or equivalent) can be guaranteed by adding this additional time.

2.7.4 Earth Fault Relay Settings

Earth Fault Relays (EFR) setting is usually expressed as a percentage of the secondary current of the CT. In general, EFR are provided with 10 to 40 percent of range settings. It is important to reduce the shunting effect by considering lowest overcurrent setting possible.

2.8 Relay to Relay Grading

Operating speed of the circuit breakers and the relay performance are the main factor which determine the total interval required to cover above items. Formerly, normal grading margin is set at 0.5s. Nowadays, with the innovation of faster modern circuit breakers and relays with lower overshoot time, it is reasonable to set the grading margin at 0.4s and it may be practical to set at even lower intervals while under the best condition.

Fixed grading margin is a popular option to be considered. However, calculating the required value for each location is may be a better option. Consequently, we are able to obtain more precise margin comprises a fixed time, covering circuit breaker fault interrupting time, relay overshoot time and a safety margin, plus a variable time that allows for relay and CT errors.

Typical relay errors according to the technology used is summarized in Table 2.3. It is important to note that, the only relevant condition to use a fixed grading margin is at high fault levels whereby short relay operating times can be obtained.

Table 2. 3 : Typical relay timing errors - standard IDMT relays

	Relay Technology			
	Electro-mechanical	Static	Digital	Numerical
Typical basic timing error (%)	7.5	5	5	5
Overshoot time (s)	0.05	0.03	0.02	0.02
Safety margin (s)	0.1	0.05	0.03	0.03
Typical overall grading margin - relay to relay(s)	0.4	0.35	0.3	0.3

Fixed margin of 0.3s is used for an overcurrent grading to perform quite adequately in most of the systems. This only applicable when a number of stages are involved and it becomes essential to perform details investigation on margin times. In conclusion, every system has discrete characteristic and should be treated distinctively. It is impossible to impose rigid rules on grading margins and every grading exercise will ultimately be a compromise of some form.

2.9 Directional Overcurrent Relay

Adding directionality to the overcurrent relay is necessary for ring main system or parallel feeder. It is required for relay coordination to detect the fault correctly. In fact, providing directionality to an OC relay can be achieved with a suitable reference or polarizing signal. Directional overcurrent relay or simply directional relay are the terms used to describe relay with this characteristic.

Directional relay refers to relay that can use the phase relationship of voltage and current to determine direction to a fault [10]. Main feature which make it different from other relay is it only turn on when the voltage/current are at the right polarity and magnitude, on the other hand a regular relay just turns on if magnitude is large enough.

As both directional and non-directional relays are used to protect the power system under faulty condition, they are much more considered over voltage protection devices. Basic concept of directional relays operation is to operate under the direction of fault current flow. Direction of power flow is sensed by directional relays by means of angle between Voltage (V) and Current (I). Directional relays will operates with a condition that the current is above the setting value whenever the phase angle between V and I exceeded certain predetermined value. Thus, directional relay is a double actuating quantity relay with one input as current from CT and the other from input from PT. [8]

2.9.1 Relay Connections

Suitable connection of voltage and current inputs available in many possibilities. These possibilities are dependable on the phase angle, at unity system power factor, by which the current and voltage applied to the relay are displaced [2, 9].

Phase displacement is obtained differently according to type of relays. For instance, phase displacement is realized by software application in a digital or numerical relay, while electromechanical and static relays rely on suitable connection of the input quantities to the relay to obtain desired phase displacement.

2.9.2 90° Relay Quadrature Connection

Static, digital or numerical relays operate with 90° Relay Quadrature Connection as their standard connection. There are two types available depending on the angle by which the applied voltage is shifted to produce maximum relay sensitivity (the Relay Characteristic Angle, or RCA).

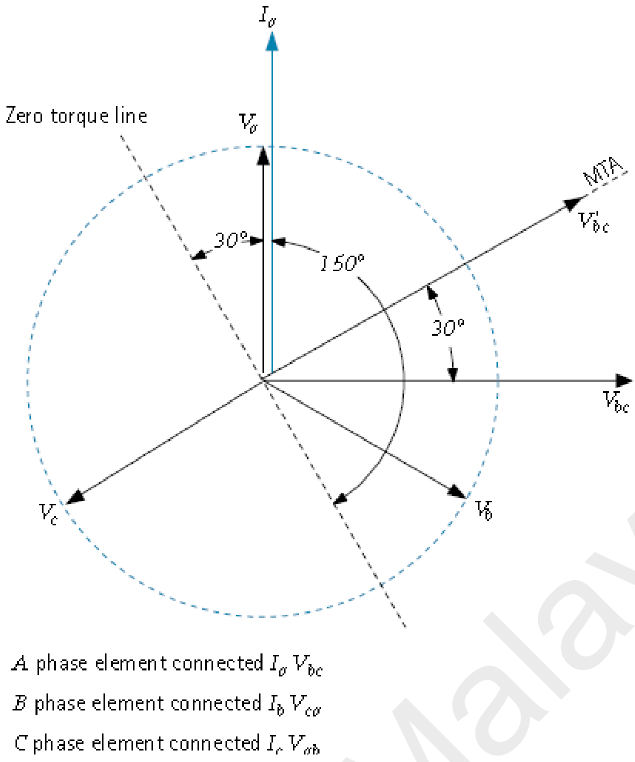


Figure 2. 10 : Vector diagram for the 90°-30° connection (phase A element)

2.9.2.1 90°-30° Characteristic (30° RCA)

The first type is the current *Ia* and voltage *Vbc* displaced by 30° in an anti-clockwise direction is supplied to the A phase relay element. For this characteristic, when the current lags the system phase to neutral voltage by 60°, the maximum relay sensitivity is produced. Figure 2.10 clearly illustrates that over the current range of 30° leading to 150° lagging, this connection can provide a correct directional tripping zone. The relay sensitivity at unity power factor is 50% of the relay maximum sensitivity and 86.6% at zero power factor lagging. It is a good recommendation to apply this characteristic when the relays are used for the protection of plain feeders with the zero sequence sources behind the relaying point.

2.9.2.2 90°-45° characteristic (45° RCA)

The second type is the current *Ia* and voltage *Vbc* displaced by 45° in an anti-clockwise direction is supplied to the A phase relay element. For this characteristic, when the current lags the system phase to neutral voltage by 45°, the maximum relay sensitivity is produced. Figure 2.11 clearly illustrates that over the current range of 45° leading to 135° lagging, this connection can provide a correct directional tripping zone. In this case, the relay sensitivity at unity power factor is 70.7% of the maximum torque and the same at zero power factor lagging; see Figure 2.11 below.

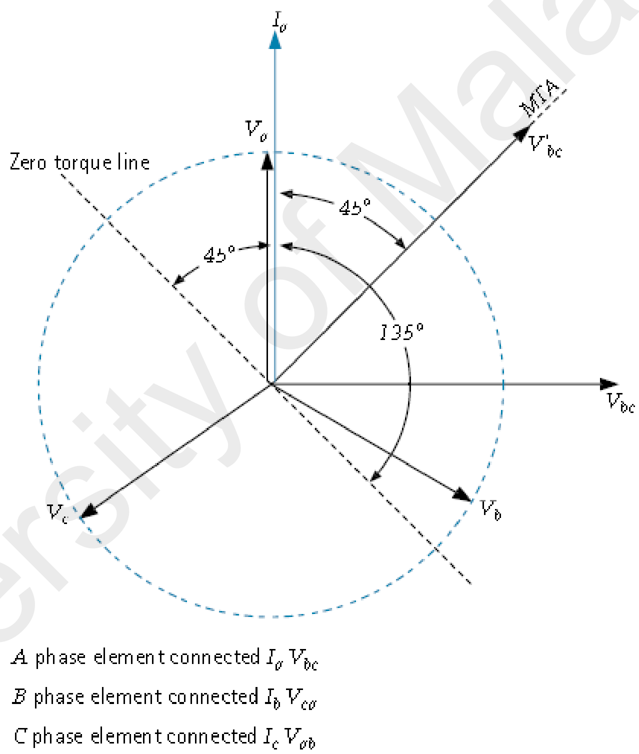


Figure 2. 11: Vector diagram for the 90°-45° connection (phase A element)

To protecting transformer feeders or feeders that have a zero-sequence source in front of the relay, this connection is reliable and recommended. In the case of parallel transformers or transformer feeders, adopting this connection is essential to ensure correct relay operation for faults beyond the star/delta transformer. In other circumstance, this connection should be utilized when single-phase directional relays are applied to a circuit where a current distribution of the form 2-1-1 may arise. Common practice for a digital or numerical relay is to allow user-selection of the RCA angle within a wide range.

In theory, maloperation of the directional element can be caused by three fault conditions:

a) a phase-phase-ground fault on a plain feeder
b) a phase-ground fault on a transformer feeder with the zero-sequence source in front of the relay
c) a phase-phase fault on a power transformer with the relay looking into the delta winding of the transformer

It is important to note that, the conditions assumed above to establish the maximum angular displacement between the current and voltage quantities at the relay is however not practical as the magnitude of the current input to the relay would be insufficient to cause the overcurrent element to operate. For all practical purposes, the possibility of maloperation with the 90°-45° connection is not existent and this can be proved analytically.

2.9.3 Directional Relay in a Ring Circuit

Ring Distribution Circuit is a particularly common arrangement within distribution networks. Maintaining supplies to consumers in case of fault conditions occurring on the interconnecting feeders becomes the primary reason of utilizing this type of arrangement. For this site study, a typical ring main with associated overcurrent protection was used.

Directional overcurrent relays are applied when considering such condition where current may flow in either direction through the various relay locations.

A directional facility is often available for little or no extra cost for modern numerical relays. Thus, considering of applying directional relays at all location may be simpler in practice.

2.9.3.1 Grading of Ring Mains

In a ring main circuit, normal grading procedure conducted for relays is by opening the ring at the supply point and grading the relays by order; clockwise and then anti-clockwise. In other words, relays operation is arranged in the sequence of n,(n+2),(n+4),(n+6),.. for relays looking in a clockwise direction around the ring. Given that, n is the first relay sequence in the path and will continue by adding the even number. For anti-clockwise, on the other hand, the opposite sequence was used.

Invariable rule is applied for directional relays setting and applicable to all forms of directional protection. The rule emphasizes that current in the system must flow from the substation busbars into the protected line in order that the relays may operate.

Relays are set differently at each substation in the ring. Considering the direction of current flow, one set of relays will be made inoperative and the other set of relays will be made operative. Grading down process are performed to the operative relays towards the fault. Among the operative relays, the last to be affected by the fault will operate first. This condition is applicable to both paths to the fault. Consequently, the power supply is maintained to all the substation as the faulted line is the only one to be disconnected from the ring.

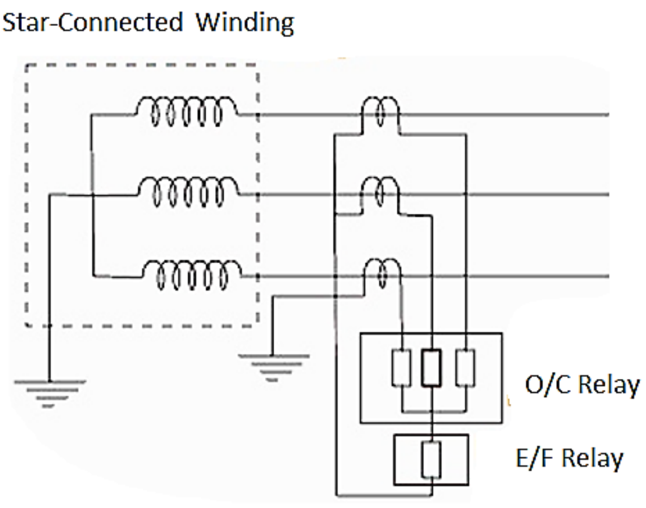


Figure 2.12: Back up O/C and E/F Protection Scheme

Even though backup protection is normally installed inside the transformer, it should trip at both side which is primary side and secondary side circuit breaker or transformer as in Figure 2.12. Application of time graded overcurrent protection is more difficult when two or more power sources feed into a ring main. Establishing the maximum fault current at each relay location is the first step needed. With assumption a fault located at one side of a bus (the actual location is not important), there are two possible consideration about the ring configuration; close ring and open ring. In Chapter 3, we will further elaborate on the relay setting calculations and the methodology.

CHAPTER 3: METHODOLOGY

3.1 Introduction

Focus of this chapter is to discuss on the methodologies implemented in this research report for verification and improvement of the grading and coordination of the relays in a distribution system of the site chosen.

To put it in order, division of the main area of this method of study is made as follow:

a. General overview and background study of fault current, Over current and earth fault relay coordination and distribution system.
b. Three phase fault and single line to ground fault calculation.
c. Calculation of relay setting to obtain the TMS.
d. Obtaining the best result in terms of relay coordination by plotting a graph of time discrimination by varying the current setting and grading margin.

3.2 Research Flow Implementation

Implementation of this research is divided into two main section; existing OCEF relay verification and suggestion for existing system improvement. Research flow implementation is summarized in the flow chart diagram as illustrated in Figure 3.1.

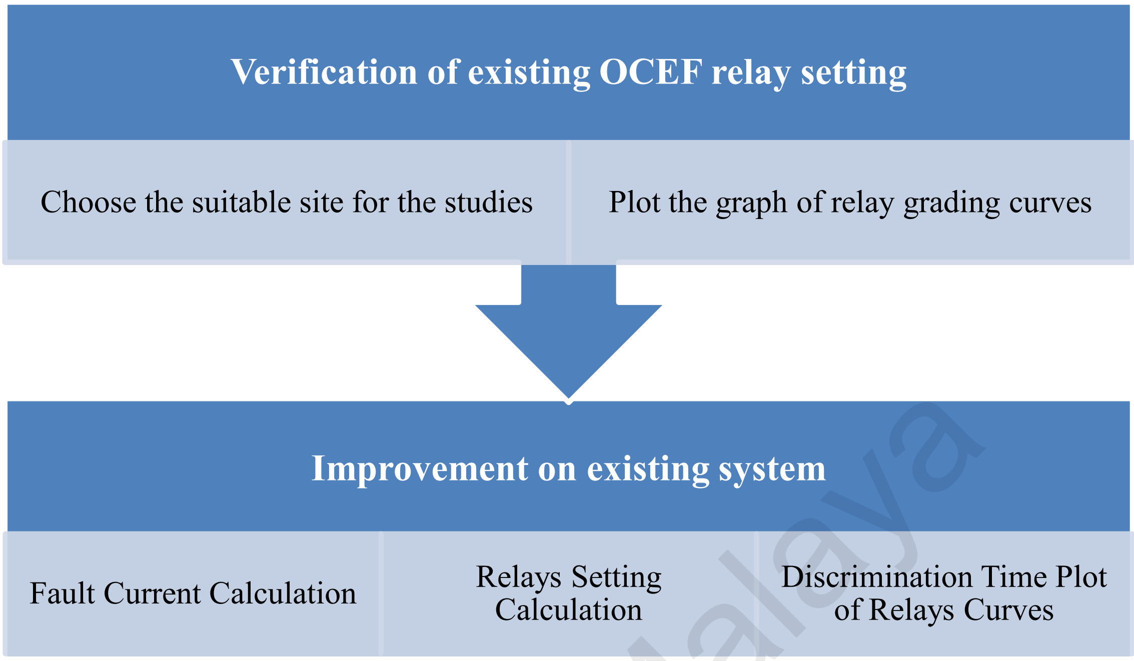


Figure 3. 1 : Summary of research flow implementation

3.2.1 Verification of existing OCEF relay setting

Research implementation steps are listed below:

a) Selection of suitable site for studies:

Basic requirement for the selection is a site consist of a ring circuit with Normal Off-Point and minimum of four buses which are using OCEF relays. Assurance of sufficient data available for the research is of paramount importance. The data must consist of latest relay setting test report, main schematic diagram, and the site layout.

b) Relay grading curves graph plot:

Relay grading curves was simulated by using Microsoft Excel. The analysis was focused on the gap between relay curves and its sequence of coordination.

Chapter 4 will present the results obtained from these steps. Details discussion on the results produced by this verification works will be presented in Chapter 5.

3.2.2 Improvement on existing system

Microsoft Excel was used to develop a simulation programs which consist of:

a) Fault Current Calculation
b) Relays Setting Calculation.
c) Discrimination Time Plot of Relays Curves.

Further explanations on the above processes can be found on the following section.

3.2.2.1 Fault Current Calculation

Calculation of fault current at each relay was performed for both closed and open ring circuit. The calculation is in fact tedious, massive and involves repetitive calculations. Hence, to expedite the process and obtain accurate result, the use of program to assist the process was considered. Calculation on relay setting was performed by using maximum fault current between both circuits condition. The fact that the three phase fault is the most severe fault, single phase to ground fault on the other hand, is the common fault, the program was dedicated for calculations of three phase fault and single phase to ground fault only. Details discussion on the calculation of both types of fault was described in Chapter 2 of Literature Review.

3.2.2.2 Relays Setting Calculation.

Explanation on the parameters to be considered will be presented in the following paragraphs.

a) Relay Characteristic

Selection of suitable characteristic of IDMT relays was needed to select relays characteristic which will best fit the time delay and fault current value. From observation made, application of standard inverse (SI) curves has been satisfactorily proven in most cases. However, the application of the very inverse (VI) or extreme inverse (EI) curves may help if the satisfactory grading cannot be achieved.

b) Time Multiplier Setting (TMS)

Formula for Relay Operating Time (ROT) calculation will be determined by the selection of relay characteristic. TMS calculation will be performed based on the ROT calculated for the last relay from the power source in the circuit. With reference to the circuit diagram with opened ring circuit, condition for this first relay to be graded was fulfilled where the load current cannot flow from the last bus to the adjacent bus nearest to source. Alternatively, the flow of the load current will be directed through other relay towards the source. Therefore, the initial value of 0.1 for low relay current and TMS settings can be selected to establish a rapid fault clearance time. Auto-calculation of the TMS was performed by the program for the remaining relays in path towards the source. The calculated value is dependable to the input value of current setting and grading margin selected.

c) Current Setting

It is important to note that relay never operates at value less than the current setting. Hence, a current setting value was required to grade a relay. Critical step that must be considered is to set the current setting above the load demand. This is to make sure the other relays will not pick up under conditions of normal load current. Unwanted pickup can be avoided by grading the next relay for at least 110% of previous relay. The fact that the maximum current setting should be 120% [8], choosing the highest possible current setting is of utmost importance to accommodate the load demand on the bus.

d) Maximum ROT

It is always the best practice to consider the time limit set by utility company at the upstream source for relay grading process. The basis of the consideration is that the time limit set is the maximum final ROT allowed at the relay connected to main incoming circuit breaker and that need to be achieved. Besides that, the grading margin value between the main incoming circuit breaker and the nearest relay at the outgoing feeder must also has been considered.

e) Grading Margin

Correct coordination can be achieved by adding the grading margin in the operating time of all the relays. In addition, all the relays will have sufficient time for discrimination. As explained in the previous Chapter 2 of Literature review, selection of grading margin value is according to type of relay technology. However, for this research report, selection for other grading margin value was performed for observation purpose on the impacts of the relay coordination process.

3.2.2.3 Discrimination Time Plot of Relays Curves.

For the analysis, relay grading curves with three different variables will be generated. The variables are listed below:

a) with TM Setting only

b) with TM Setting and Curret Setting

c) with TM Setting, Current Setting and best Grading Margin

Detail discussion on each figure of different variable will be presented for better understanding on the correlation between all the variables towards the relay coordination process.

3.2.3 Similarities on Implementation

Similar calculations methods will be applied for both phase and earth fault relay for all steps mentioned above. Exception will be made for analysis on suggestion of improvement, whereby application of directional relay will be considered. Analysis on this new proposed relay will be conducted for both direction of clockwise and anti-clockwise.

CHAPTER 4: RESULTS

4.1 Introduction

For this research report, study was performed on the electrical distribution system in a building complex where a ring circuit (feeder A3 and A4) has been chosen. Selected ring circuit consist of four substations with overcurrent (OC) and earth fault (EF) relays. Circuit of feeder A3 & A4 is illustrated in Figure 4.1

In this research report, analysis on the relays involved was simulated by the plotted graph of time discrimination. Input data from site and the calculated fault current were utilized for this analysis. Selection of accurate parameter is critical to establish the optimum relay coordination curves. To achieve this, the value of current setting and grading margin will be used as the parameters to obtain the curves.

Basically, the result shows the analysis to compare the difference of relay grading. Analysis was initiated with verification on the coordination of the existing setting of overcurrent and earth fault relay. Proposal for coordination improvement by using directional relays which involves both clockwise and counterclockwise direction of the current source will be presented in this research report based on the analysis on the plotted graph of time discrimination.

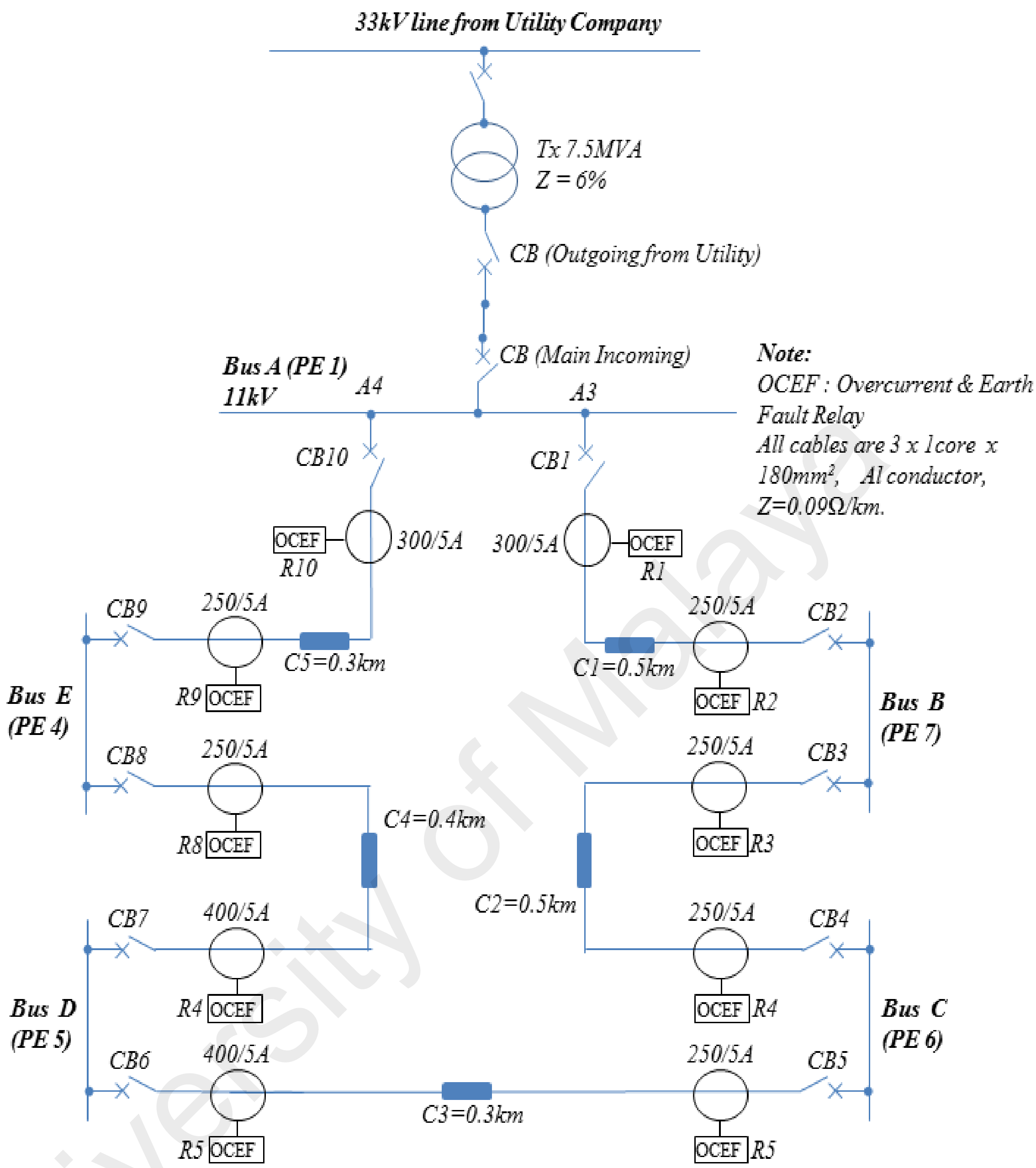


Figure 4. 1: Ring main circuit diagram for feeder A3 & A4

4.2 Existing Relay Setting

Ring main circuit diagram consist of two feeders (A3 & A4) and four load busbars used for this study is illustrated in Figure 4.1. The existing system was occupied with a normal overcurrent relays (devices 51) as a protection relay with the normal open point changing place accordingly.

Table 4.1 summarized all data gathered from relay test report, main schematic diagram, and site measurement. The original test report data sheet was shown in Appendix B.

Table 4.2 a : Summary of input data

Input Data											
Substations Name		Main Intake (to PE2)	Main Intake (to PE7)	PE7		PE6		PE5		PE4	
Substations Tagged		A		B		C		D		E	
Distance to next substations (kM)		0.3	-	0.5		0.5		0.3		0.4	
Relay Number		10	1	2	3	4	5	6	7	8	9
CB	In (A)	1250	1250	630	630	630	630	630	630	630	630
CT	CT Ratio	300	300	250	250	250	250	400	400	250	250
OC Relay	OC setting (%)	50	50	50	50	75	75	156	156	50	50
	TMS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Curve	SI	SI	SI	SI	SI	SI	SI	SI	SI	SI
EF Relay	EF Setting	0.1	0.1	0.1	0.1	0.1	0.1	0.16	0.16	0.1	0.1
	TMS	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	Curve	S.I	S.I	S.I	S.I	S.I	S.I	S.I	S.I	S.I	S.I

Relay grading curves for existing relays was plotted in discrimination time plot graph for IDMT type of protection relay based on its current setting value. Analysis can be performed on the relay grading curves plotted for both radial circuits of feeder A3 and A4 with NOP at CB10 and CB1 respectively (Figure 4.2(a) to Figure 4.2(b)). It was found that the curves were too closed or overlaps on each other which indicate that proper relay grading was not achieved. From this result, there are possibilities of unwanted tripping and poor backup protection system may occur.

To illustrate on this situation, Figure 4.2 (a) is the existing OC relay grading of direction *R1-R3-R5-R7-R9* and it shows the relays grading which are too closed (*R1 & R3*) and overlaps each other (*R3 & R9*). Particularly for *R7*, there was improper relay coordination sequence and similar situation happened for the opposite direction.

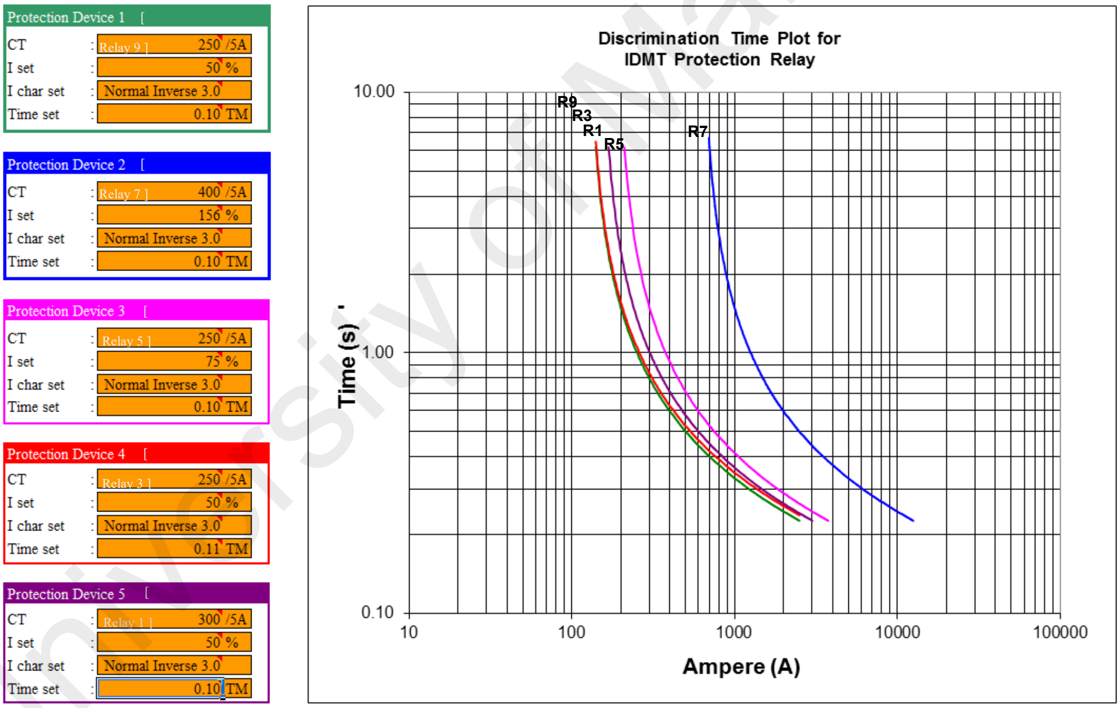


Figure 4.2 a : Existing OC relay grading for improper coordination lead to R7 deviated away from the R1, R3, R5 & R9

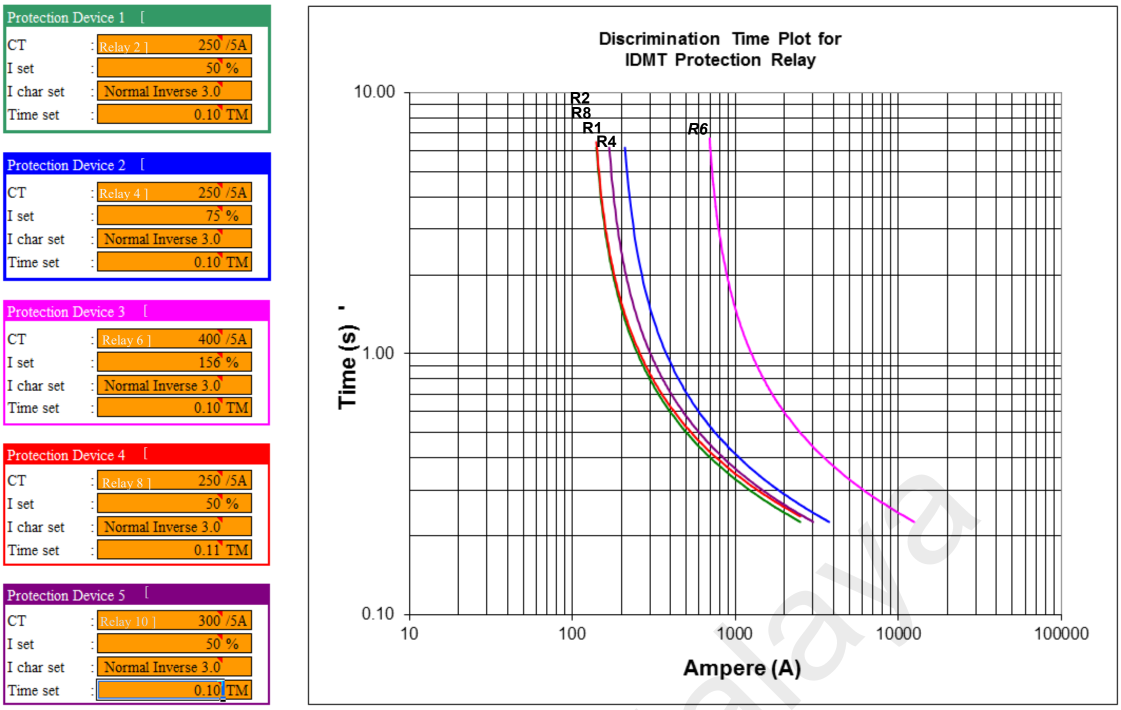


Figure 4.2 b : Existing OC relay grading for direction of *R10-R8-R6-R4-R2*

Similar pattern also found for EF relay. As displayed in Figure 4.2 (c), there are overlapping of the relays curve for *R9, R5* and *R3*. From this figure we also can conclude that there was improper relays coordination for R7. Similar situation was applied for the opposite direction as expected.

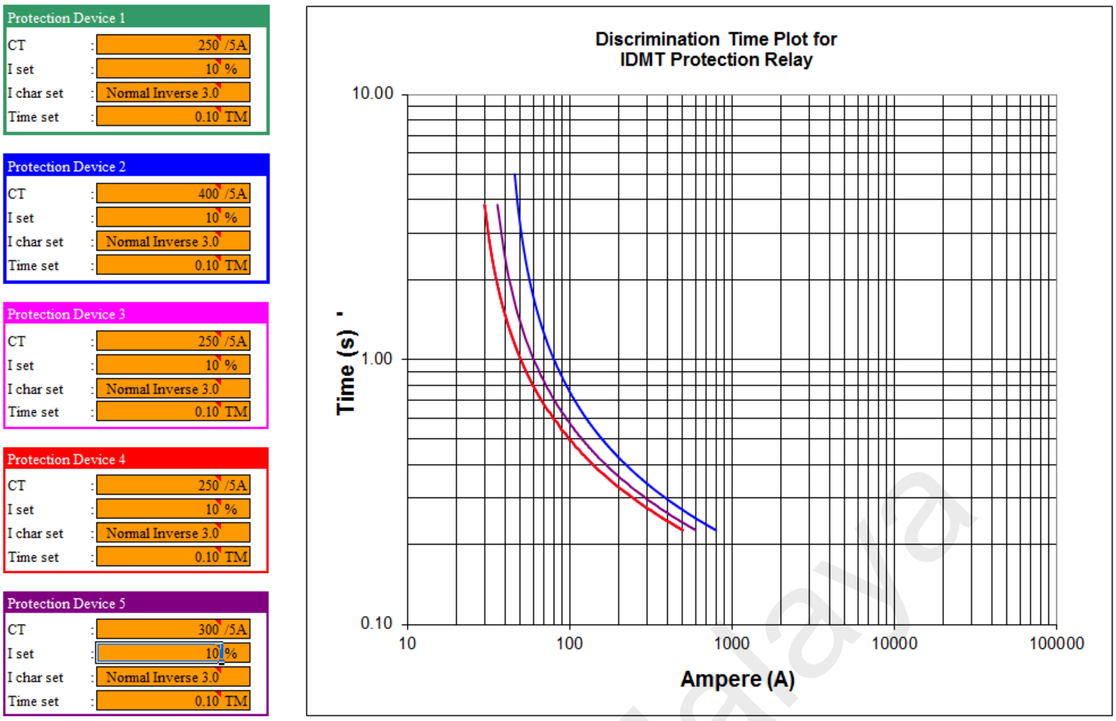


Figure 4.2 c : Existing EF relay grading for direction *R1-R3-R5-R7-R9*

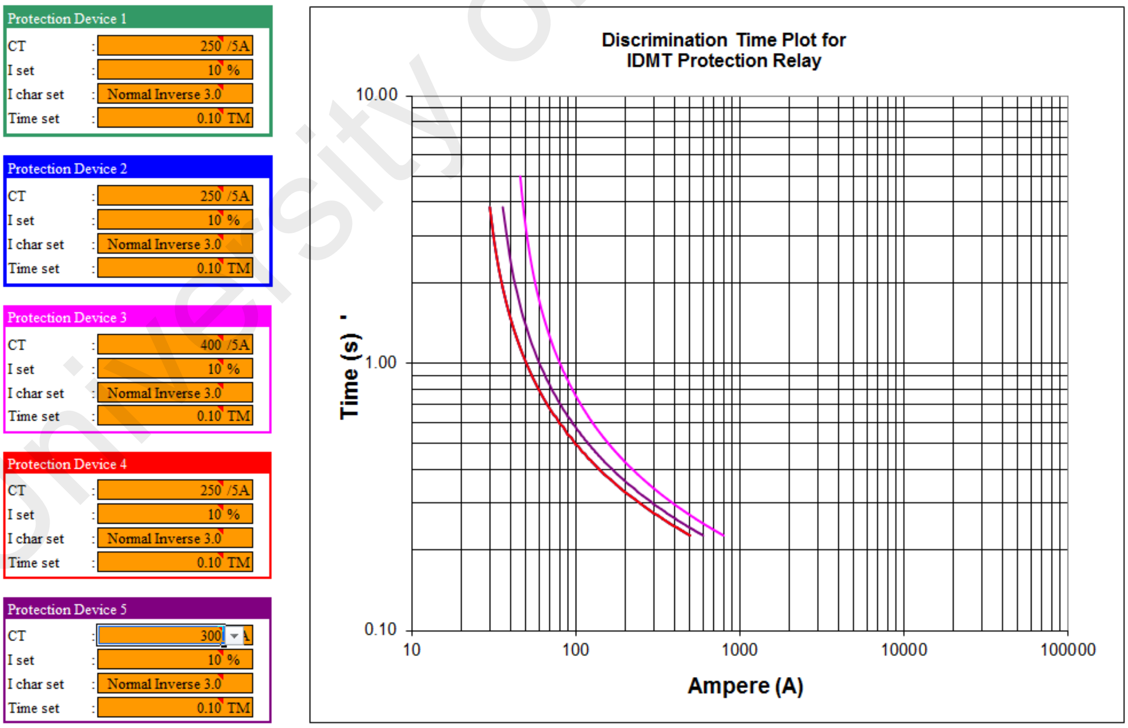


Figure 4.2 d : Existing EF relay grading direction of *R10-R8-R6-R4-R2*

4.3 Improvement by Using Directional and Non-Directional Relays

Improvement on existing system will focus on improving the maintainability and reliability of the system. Directional relay and non-directional relay were proposed to be installed for this purpose considering a ring circuit was selected for this relay coordination study. The setup process of the ring circuit was made by removing the NOP in the radial circuit of feeder A3 and A4.

The ability to maintain supplies in such situation where fault conditions occurring on the interconnecting feeders is the primary advantage for utilizing directional relay and non-directional relay. Operative relays was graded downwards towards the fault and same condition was also applied to both directions to the fault. As a result, we were able to disconnect the faulted line from the ring and power supply to all the substation can be maintained.

Improvement of the grading between relays was commenced by obtaining proper Time Multiplier Setting (TMS). For a start, fault current analysis was performed and followed by the calculation of grading in order to obtain proper TMS. Calculated value of TMS was plotted into Discrimination Plot to visualized proper grading achieved. Adjustment on the TMS value, the current setting on the relay and the grading margin between relays need to be performed accordingly.

Results from the steps discussed in the previous chapter 3 of methodology will be presented in the next section.

4.4 Simulation Results

In this research report, results were generated from a simulation program. In general, the simulation program has been developed in Microsoft excel to perform calculation on fault current and relay setting as well as plotting the relays curves. Thus, basic interface of the program consists of:

a) Fault Current Calculation.

b) Relays Setting Calculation.

c) Discrimination Time Plot of Relays Curves.

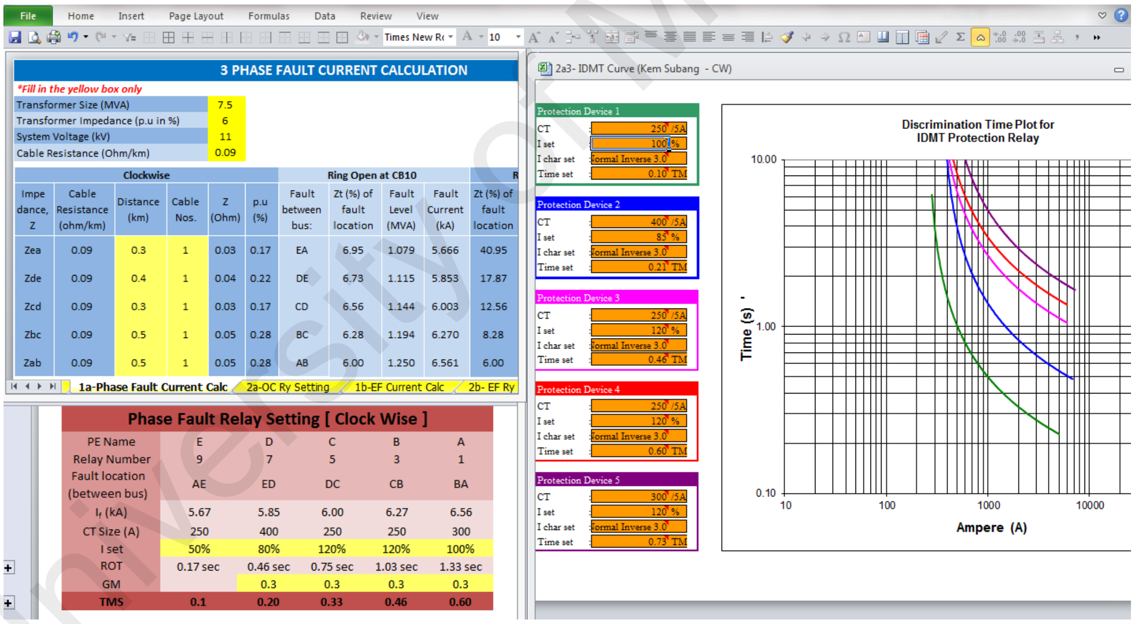


Figure 4. 2 : Three main windows of Fault Current Calculation, Relays Setting Calculation and Discrimination Time Plot of Relays Cures.

Figure 4.2 shows the interface of the program consist of three windows of Fault Current Calculation, Relays Setting Calculation and Discrimination Time Plot of Relays Cures. Input data was highlighted in yellow and by key in the input into the input box will allow the program to perform the simulation and generate the subsequence required result and graph. For each calculation, the input was taken from different sources. For example, data from relay test report and electrical main schematic was extracted for Fault Current Calculation windows. Different condition for Relay Setting Calculation windows, selection on current setting and grading margin was made by engineer. The selected values were use as the input for Relay Setting Calculation windows. Some discussion has been made in previous chapter on the current setting and grading procedure and it has been implemented in this program table. Both values will determine grading curves through the TMS value.

Phase overcurrent relay and earth fault relay settings, on the other hand, were determined separately due to the difference in fault current calculation.

4.5 Phase Overcurrent Relay Setting

Calculation for over-current protection relay system applies Standard Inverse (SI) formula that is ROT = TMS x (0.14/(((If/Is)^0.02)-1)). Impedance for every bus was calculated repetitively as well as the fault current.

The results for both directions of CW and ACW were summarized in Table 4.2(a) and Table 4.2(b) respectively. There are 6 sets of calculation and plotting combination for clock-wise, CW- and anti-clock-wise, ACW- cases been made for getting the most optimize value of setting current, I set (existing and new) and grading margin, GM, as per following: -

i. Table 4.3 a: Relay setting calculation for ACW - existing I set, GM = 0.3 s
ii. Table 4.3 b: Relay setting calculation for ACW - new I set, GM = 0.2 s
iii. Table 4.3 c: Relay setting calculation for ACW - new I set, GM = 0.3 s

iv. Table 4.4 a : Relay setting calculation for CW - existing I set, GM = 0.3 s

v. Table 4.4 b : Relay setting calculation for CW - new I set, GM = 0.2 s

vi. Table 4.4 c : Relay setting calculation for CW - new I set, GM = 0.3 s

From the calculation, it is found that, Table 4.3 c and Table 4.4 c shown the best option to be chose for I set and GM values. Through simulation made using Microsoft Excel, all curves that associating all protection relays at respective circuit breakers for Table 4.3 c and Table 4.4 c been plotted accordingly. All curves plotted with sufficient time margin and not crossing or overlapping each other.

In the event that crossing of the curves cannot be avoided, high set of the protection relay can be activated on protection relay module. It give reduction on operating time for high short circuit current level condition

4.5.1 Three Phase Fault Current Calculation

As a start, maximum fault current at each relay location need to be established. Microsoft Excel was utilized to perform calculation for both type of fault (three phase fault and single phase to ground) and the result was summarized in simplified Table 4.2 (a) and Table 4.2 (b). Below consideration were made for the calculation for both types of fault:

a) Closed ring circuit
b) Open ring circuit at the end circuit breaker of the respective direction.

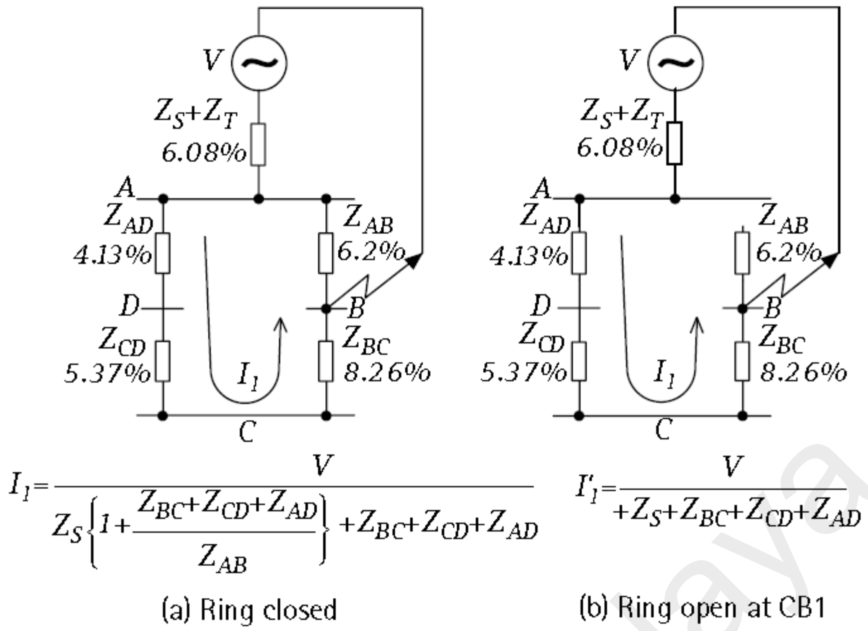


Figure 4. 3 : Impedance diagram for Ring closed and open at CB 1

The impedance diagram for ring closed and ring open conditions is illustrated in Figure 4.3 above. From the diagram, the total impedance is simply the sum of impedance at each faulty line. To clearly illustrate this, with assumption that a fault occurred at line AB or bus B, the total impedance in the faulted circuit was sum up. Similar calculation will be applied at each line. The three-phase fault currents for both conditions can be calculated respectively from the total impedance obtained. The analysis found that, opened ring condition possessed the maximum fault current. The results for both clockwise and anti-clockwise direction is summarized in Table 4.2. Details fault current calculation is provided in Appendix C for further reference.

Table 4.2 a : Three phase fault current for clockwise

Ring Open at CB10				Ring Closed			Max Fault Current (kA)
Fault between bus:	Zt (%) of fault location	Fault Level (MVA)	Fault Current (kA)	Zt (%) of fault location	Fault Level (MVA)	Fault Current (kA)	
EA	6.95	1.079	5.666	40.95	0.183	0.961	**5.666**
DE	6.73	1.115	5.853	17.87	0.420	2.203	**5.853**
CD	6.56	1.144	6.003	12.56	0.597	3.135	**6.003**
BC	6.28	1.194	6.270	8.28	0.906	4.755	**6.270**
AB	6.00	1.250	6.561	6.00	1.250	6.561	**6.561**

Table 4.2 b : Three phase fault current for anti-clockwise

Ring Open at CB1				Ring Closed			Max Fault Current (kA)
Fault between bus:	Zt (%) of fault location	Fault Level (MVA)	Fault Current (kA)	Zt (%) of fault location	Fault Level (MVA)	Fault Current (kA)	
AB	6.84	1.097	5.758	24.84	0.302	1.585	**5.758**
BC	6.56	1.144	6.003	12.56	0.597	3.135	**6.003**
CD	6.39	1.174	6.160	9.62	0.780	4.092	**6.160**
DE	6.17	1.216	6.383	7.23	1.038	5.448	**6.383**
EA	6.00	1.250	6.561	6.00	1.250	6.561	**6.561**

4.5.2 Relay Settings Calculation

Calculation of relays setting for both conditions of clockwise (ACW) and anti-clockwise (CW) are summarized in Table 4.3(a) to Table 4.4(c) respectively. Variation of the current setting (I_{set}) and grading margin (GM) shall be performed in order to achieve optimum relay grading curves. The variation of the I_{set} and GM values were inserted into the highlighted yellow box. Other input value such as fault current value, CT size and current setting were auto linked from the previous window of Fault Current Calculation and Input Data.

Table 4.3 a : Relay settings calculation for ACW - with existing Iset and GM of 0.3s

Phase Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	5.67	5.85	6.00	6.27	6.56
CT Size (A)	250	400	250	250	300
I set	50%	156%	75%	50%	50%
ROT	0.17 sec	0.47 sec	0.77 sec	1.07 sec	1.37 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.15**	**0.39**	**0.60**	**0.74**

Table 4.3 b : Relay settings calculation for ACW - with new Iset and smaller GM of 0.2s.

Phase Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	5.67	5.85	6.00	6.27	6.56
CT Size (A)	250	400	250	250	300
I set	50%	80%	120%	120%	100%
ROT	0.17 sec	0.37 sec	0.57 sec	0.77 sec	0.97 sec
GM		0.2	0.2	0.2	0.2
TMS	**0.1**	**0.16**	**0.24**	**0.33**	**0.42**

Table 4.3 c Relay settings calculation ACW – with new Iset and GM of 0.3s. (best grading curves and ROT).

Phase Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	5.67	5.85	6.00	6.27	6.56
CT Size (A)	250	400	250	250	300
I set	50%	80%	120%	120%	100%
ROT	0.17 sec	0.47 sec	0.77 sec	1.07 sec	1.37 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.20**	**0.33**	**0.46**	**0.60**

Table 4.4 a : Relay settings calculation for CW - with existing Iset and GM of 0.3s

Phase Fault Relay Setting [Anti Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	5.76	6.00	6.16	6.38	6.56
CT Size	250	250	400	250	300
I set	50%	75%	156%	50%	50%
ROT	0.18 sec	0.48 sec	0.78 sec	1.08 sec	1.38 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.24**	**0.25**	**0.61**	**0.75**

Table 4.4 b : Relay settings calculation for CW - with new Iset & smaller GM of 0.2s

Phase Fault Relay Setting [Anti Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	5.76	6.00	6.16	6.38	6.56
CT Size	250	250	400	250	300
I set	50%	75%	156%	50%	50%
ROT	0.18 sec	0.38 sec	0.58 sec	0.78 sec	0.98 sec
GM		0.2	0.2	0.2	0.2
TMS	**0.1**	**0.19**	**0.25**	**0.34**	**0.43**

Table 4.4 c : Relay settings calculation CW with new Iset and GM of 0.3s. (best grading curves and ROT).

Phase Fault Relay Setting [Anti Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	5.76	6.00	6.16	6.38	6.56
CT Size	250	250	400	250	300
I set	50%	75%	80%	120%	100%
ROT	0.18 sec	0.48 sec	0.78 sec	1.08 sec	1.38 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.24**	**0.33**	**0.47**	**0.61**

4.5.3 Discrimination Time Plot of Relays

In this section the graph of discrimination plot for IDMT protection relay will be presented. Similar with previous calculation, same methodology and program developed in MS Excel was used to plot the graph. The graph was generated from the auto-linked input obtained from previous window of Relay Setting Calculation. From the graph obtained, we could observe that all the relays involved with their individual grading curves.

For each direction (CW and ACW), condition of relay grading curves with three different variables as below were shown:

a) with TM Setting only

b) with TM Setting and Current Setting

c) with TM Setting, Current Setting and best Grading Margin

4.5.3.1 Discrimination Time Plot of Relays Curves for CW Direction

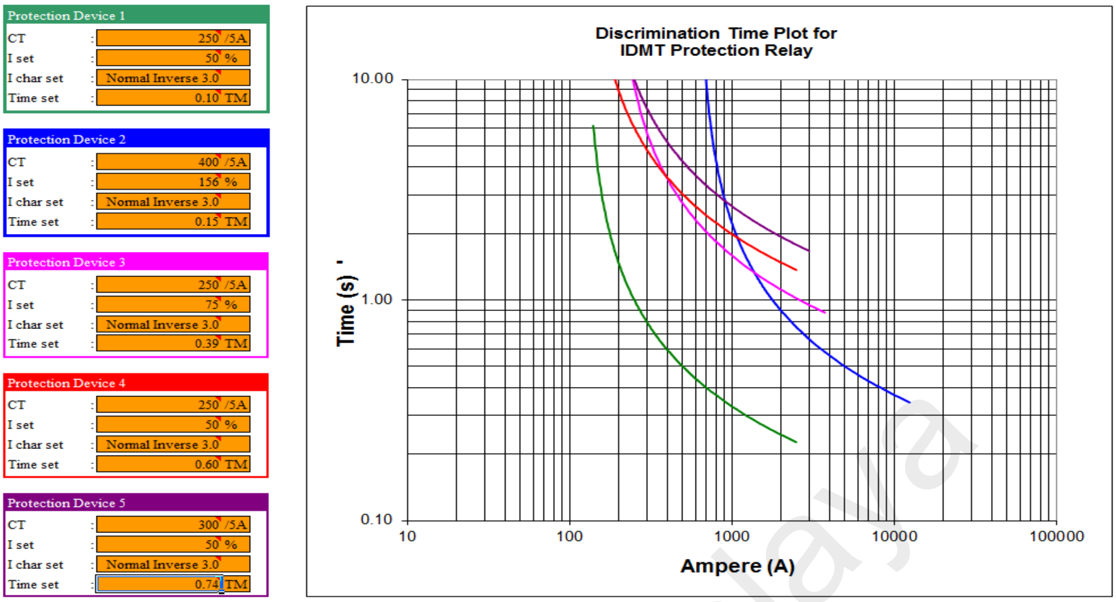


Figure 4.5 a : Relay grading curves for CW – with TM setting, existing Iset and GM of 0.3sec

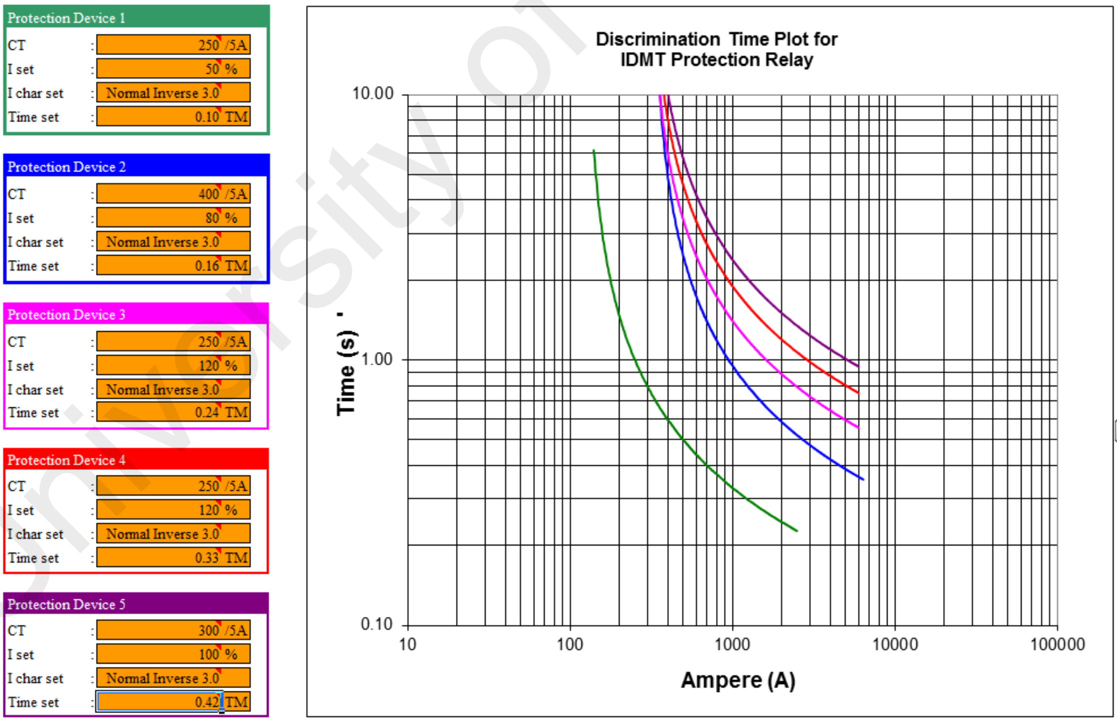


Figure 4.5 b : Relay grading curves for CW – with TM setting, new Iset and smaller GM of 0.2sec.

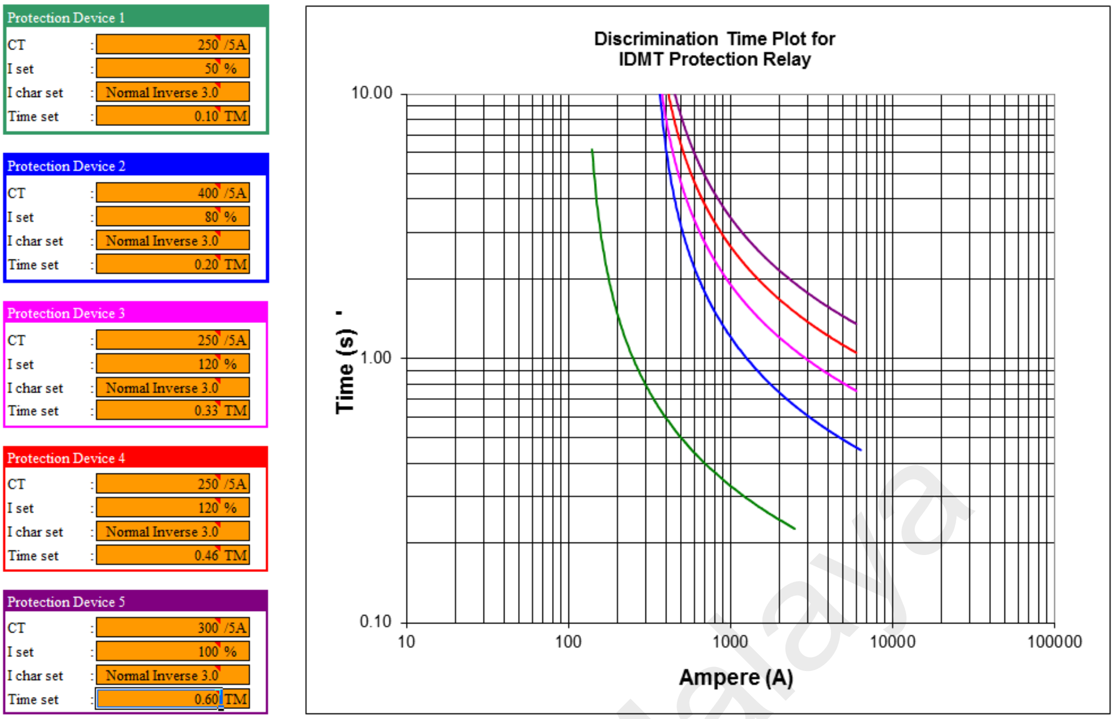


Figure 4.5 c : Relay grading curves for CW – with TM setting, new I_{set} and GM of 0.3sec. (best grading curves).

4.5.3.2 Discrimination Time Plot of Relays Curves for ACW Direction

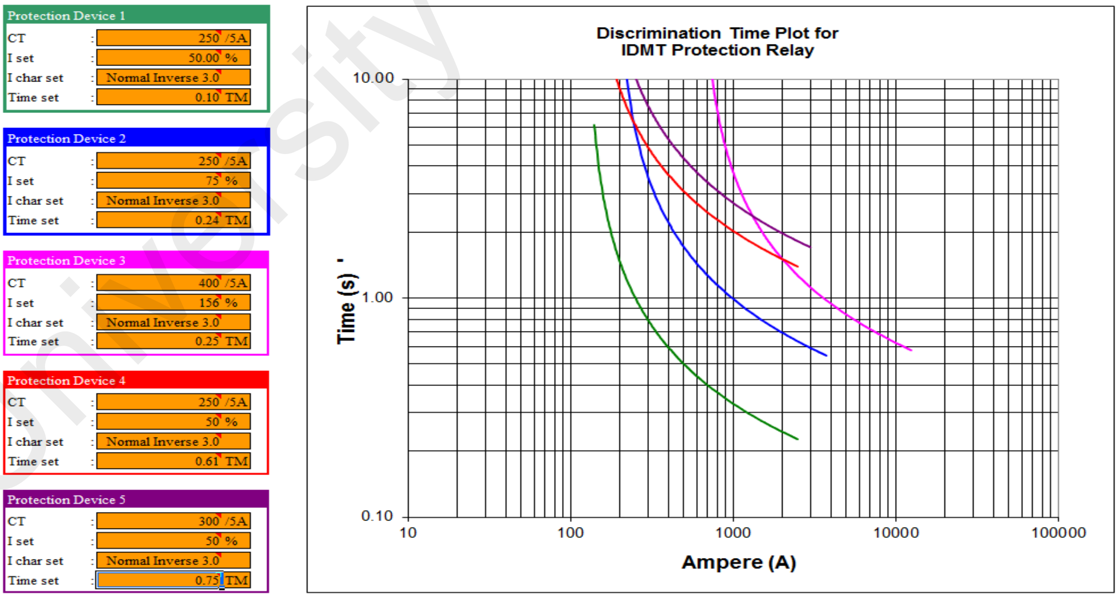


Figure 4.6 a : Relay grading curves for ACW – with TM setting, existing I_{set} and GM of 0.3sec.

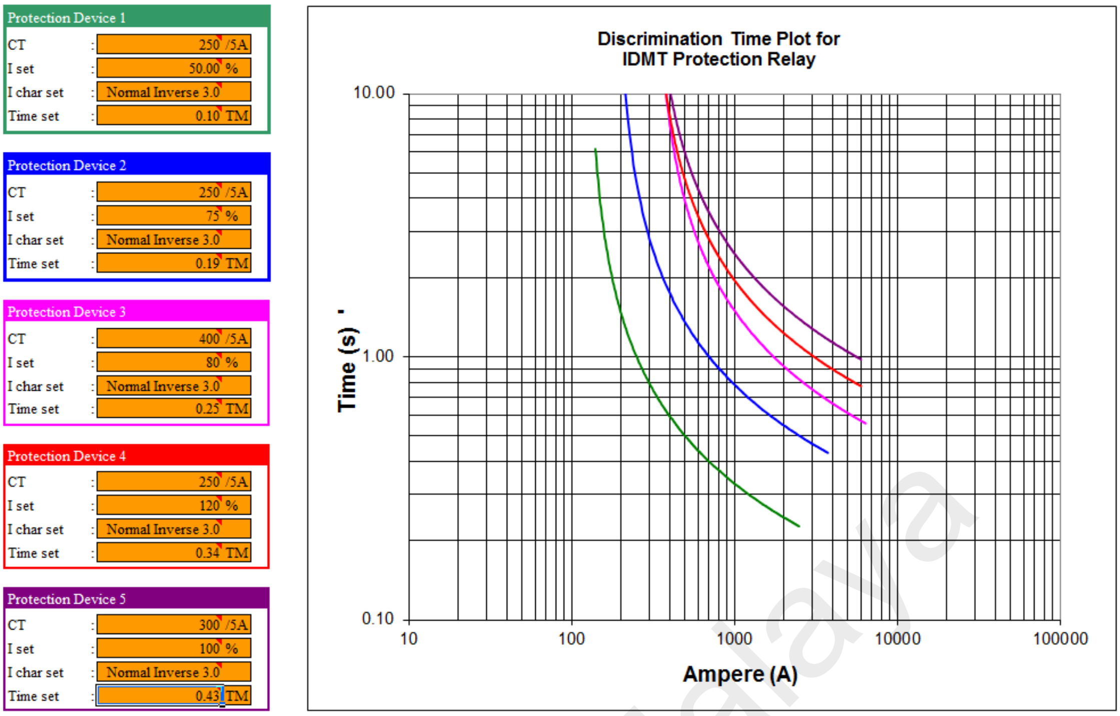


Figure 4.6 b : Relay grading curves for ACW – with TM setting, new Iset and smaller GM of 0.2sec.

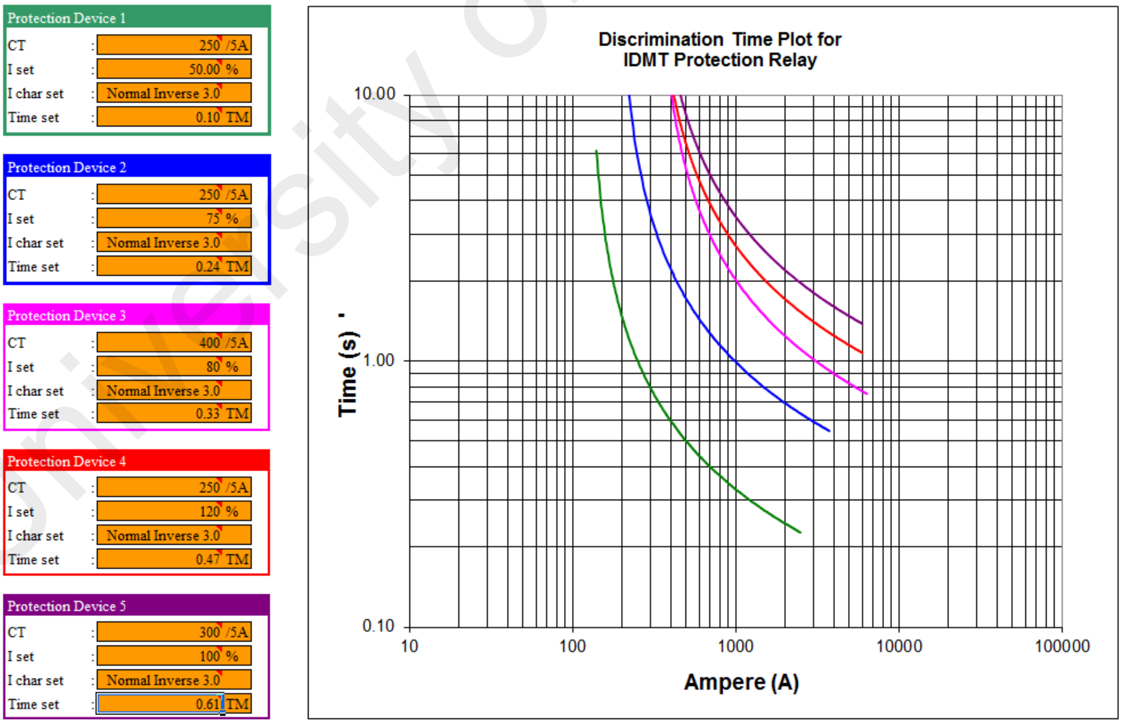


Figure 4.6 c : Relay grading curves for ACW – with TM setting, new I_{set} and GM of 0.3sec. (best grading curves).

4.6 Earth Fault Relay Setting

4.6.1 Single Line to Ground Fault Current Calculation

Calculation for single line to ground fault current applies identical step as previous section. The impedance was calculated repetitively as well as the fault current at different fault location. However, as described in Chapter 2 of literature review, the only difference in the calculation step is on the impedance which needs to consider the zero sequence, positive sequence and negative sequence.

The results for both directions of CW and ACW were summarized in Table 4.5(a) and Table 4.5(b) respectively. Appendix D was provided for further reference on details table of calculation.

Table 4.5 a : Earth fault current for CW

Ring Open at CB10					Ring Closed				**Max Fault Current (kA)**
Fault between bus:	$Z_{o\ p.u}$ (%)	$Z_{1\ p.u\ (\%)}$ (similar to Z_2)	Zt (%) of fault location	Fault Current (kA)	$Z_{o\ p.u}$ (%)	$Z_{1\ p.u\ (\%)}$ (similar to Z_2)	Zt (%) of fault location	Fault Current (kA)	
	0.95	6.95	14.85	2.22	0.95	40.9	82.8	0.40	**2.22**
DE	0.73	6.73	14.18	2.33	0.73	17.9	36.5	0.91	**2.33**
CD	0.56	6.56	13.67	2.41	0.56	12.6	25.7	1.29	**2.41**
BC	0.28	6.28	12.84	2.57	0.28	8.3	16.8	1.96	**2.57**
AB	0.00	6.00	12.00	2.75	0.00	6.00	12	2.75	**2.75**

Table 4.5 b : Earth fault current for ACW

Ring Open at CB1					Ring Closed				**Max Fault Current (kA)**
Fault between bus:	$Z_{o\ p.u}$ (%)	$Z_{1\ p.u\ (\%)}$ (similar to Z_2)	Zt (%) of fault location	Fault Current (kA)	$Z_{o\ p.u}$ (%)	$Z_{1\ p.u\ (\%)}$ (similar to Z_2)	Zt (%) of fault location	Fault Current (kA)	
AB	0.84	6.84	14.51	2.27	0.84	24.8	50.5	0.65	**2.27**
BC	0.56	6.56	13.67	2.41	0.56	12.6	25.7	1.29	**2.41**
CD	0.39	6.39	13.17	2.51	0.39	9.6	19.6	1.68	**2.51**
DE	0.17	6.17	12.50	2.64	0.17	7.2	14.6	2.26	**2.64**
EA	0.00	6.00	12.00	2.75	0.00	6.00	12	2.75	**2.75**

4.6.2 Relay Settings Calculation

Calculation of relays setting for both conditions of clockwise (CW) and anti-clockwise (ACW) are shown in Table 4.6(a) to Table 4.7(c). In each table the variation of current setting (I_{set}) and grading margin (GM) were performed in order to achieve optimum TC curves. As previous procedure, the value of I_{set} and GM be inserted in the highlighted yellow boxes as well as the input value of fault current value, CT size and current setting were auto-linked from the previous window of Fault Current Calculation and Input Data.

Table 4.6 a : Relay settings calculation for CW - with existing I set and GM of 0.3sec.

Earth Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	2.22	2.33	2.41	2.57	2.75
CT Size (A)	250	400	250	250	300
I set	10%	16%	10%	10%	10%
ROT	0.15 sec	0.45 sec	0.75 sec	1.05 sec	1.35 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.24**	**0.50**	**0.71**	**0.88**

Table 4.6 b Relay settings calculation for CW - with new I set and smaller GM of 0.2 sec.

Earth Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	2.22	2.33	2.41	2.57	2.75
CT Size (A)	250	400	250	250	300
I set	10%	6%	10%	10%	10%
ROT	0.15 sec	0.35 sec	0.55 sec	0.75 sec	0.95 sec
GM		0.2	0.2	0.2	0.2
TMS	**0.1**	**0.24**	**0.37**	**0.51**	**0.62**

Table 4.6 c Relay settings calculation CW – with new Iset and GM of 0.3 sec. (best grading curves and ROT).

Earth Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	2.22	2.33	2.41	2.57	2.75
CT Size (A)	250	400	250	250	300
I set	10%	6%	10%	10%	10%
ROT	0.15 sec	0.45 sec	0.75 sec	1.05 sec	1.35 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.30**	**0.50**	**0.71**	**0.88**

Table 4.7 a : Relay settings calculation for ACW - with existing Iset and GM of 0.3sec

Earth Fault Relay Setting [Anti-Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	2.27	2.41	2.51	2.64	2.75
CT Size	250	250	400	250	300
I set	10%	10%	16%	10%	10%
ROT	0.15 sec	0.45 sec	0.75 sec	1.05 sec	1.35 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.30**	**0.40**	**0.71**	**0.88**

Table 4.7 b : Relay settings calculation for ACW - with new I set and smaller GM of 0.2 sec.

Earth Fault Relay Setting [Anti-Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	2.27	2.41	2.51	2.64	2.75
CT Size	250	250	400	250	300
I set	10%	10%	6%	10%	10%
ROT	0.15 sec	0.35 sec	0.55 sec	0.75 sec	0.95 sec
GM		0.2	0.2	0.2	0.2
TMS	**0.1**	**0.23**	**0.38**	**0.51**	**0.62**

Table 4.7 c : Relay settings calculation ACW – with new Iset and GM of 0.3 sec. (best grading curves and ROT).

Earth Fault Relay Setting [Anti-Clock Wise]					
PE Name	B	C	D	E	A
Relay Number	2	4	6	8	10
Fault location (between bus)	AB	BC	CD	DE	EA
I_f (kA)	2.27	2.41	2.51	2.64	2.75
CT Size	250	250	400	250	300
I set	10%	10%	6%	10%	10%
ROT	0.15 sec	0.45 sec	0.75 sec	1.05 sec	1.35 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.30**	**0.51**	**0.71**	**0.89**

For each direction (CW and ACW), condition of relay grading curves with three different variables as below were shown:

a) with TM Setting only

b) with TM Setting and Current Setting

c) with TM Setting, Current Setting and best Grading Margin

4.6.2.1 Discrimination Time Plot of Relays Curves for CW Direction

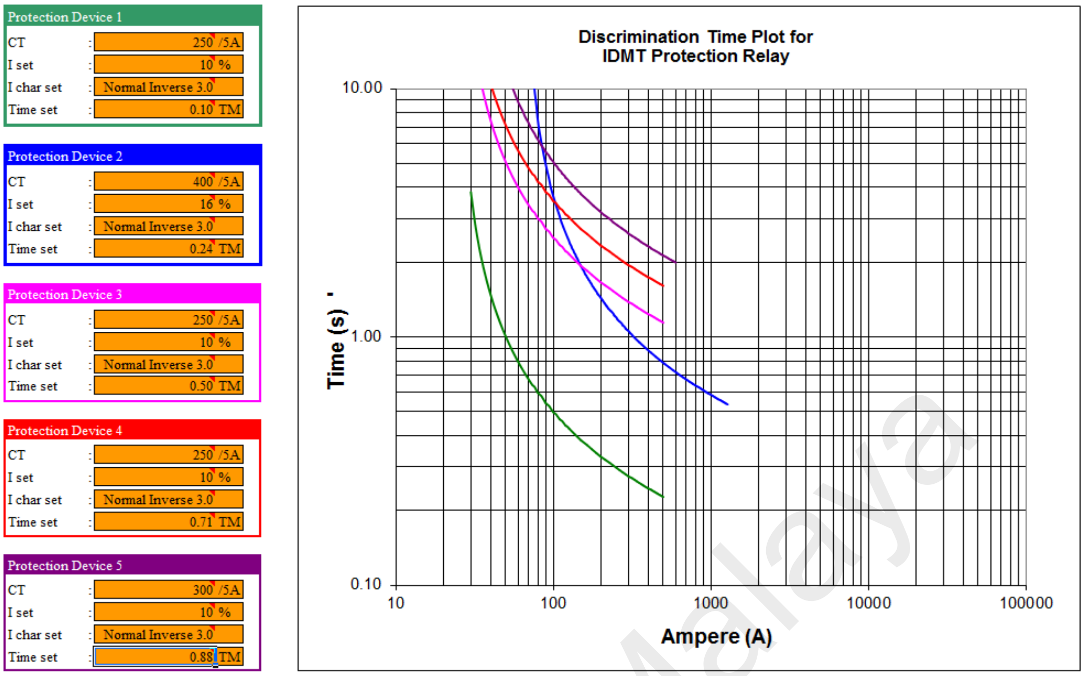


Figure 4.7 a : Relay grading curves for CW – with TM setting, existing Iset and GM of 0.3sec.

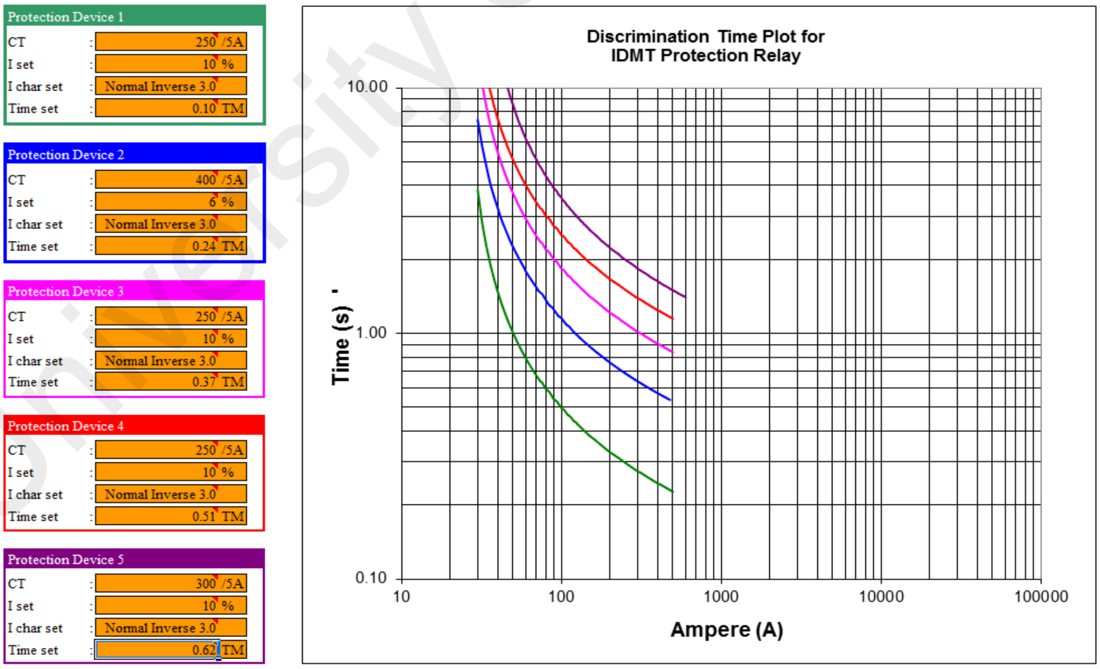


Figure 4.7 b : Relay grading curves for CW – with TM setting, new Iset and smaller GM of 0.2 sec.

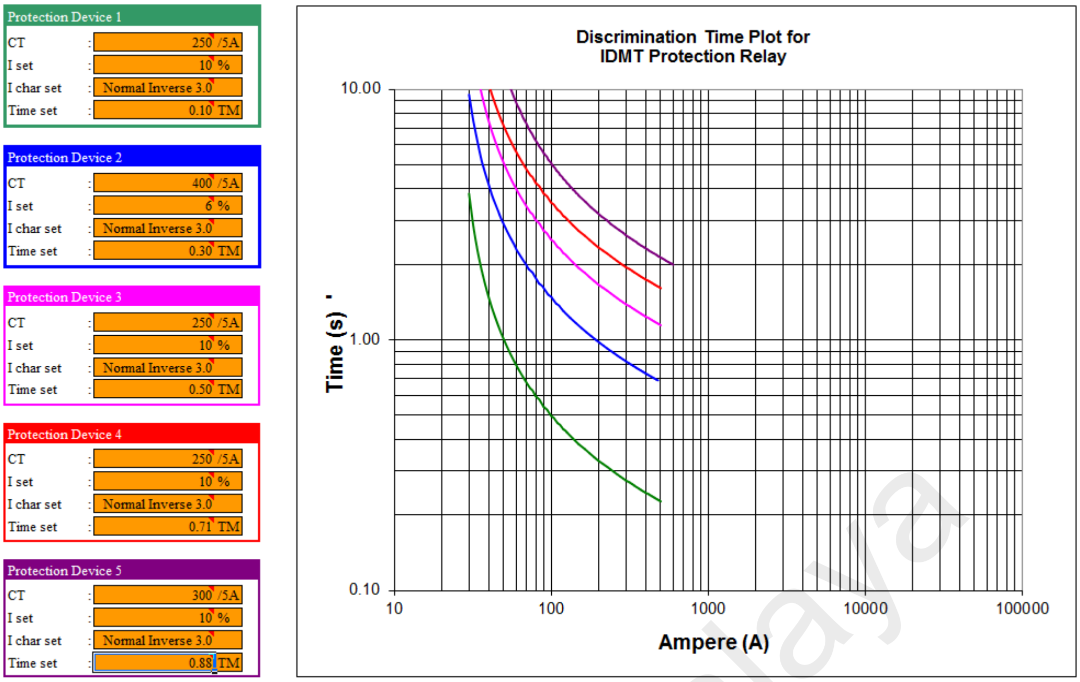


Figure 4.7 c : Relay grading curves for CW – with TM setting, new Iset and GM of 0.3sec. (best grading curves).

4.6.2.2 Discrimination Time Plot of Relays Curves for ACW Direction

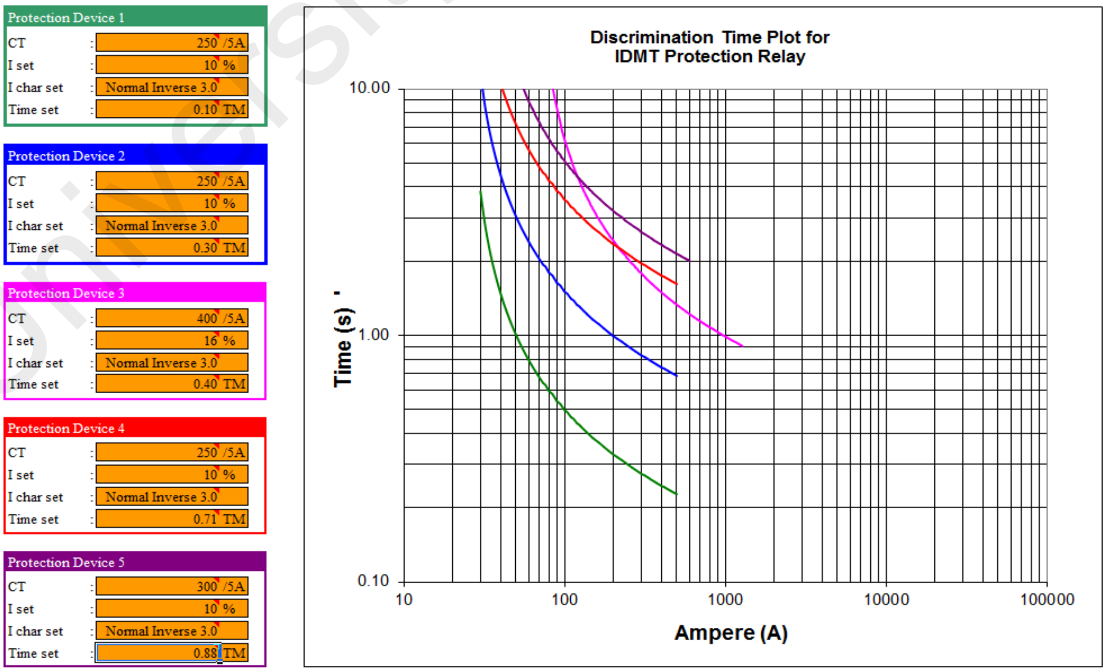


Figure 4.8 a : Relay grading curves for ACW – with TM setting, existing Iset and GM of 0.3sec.

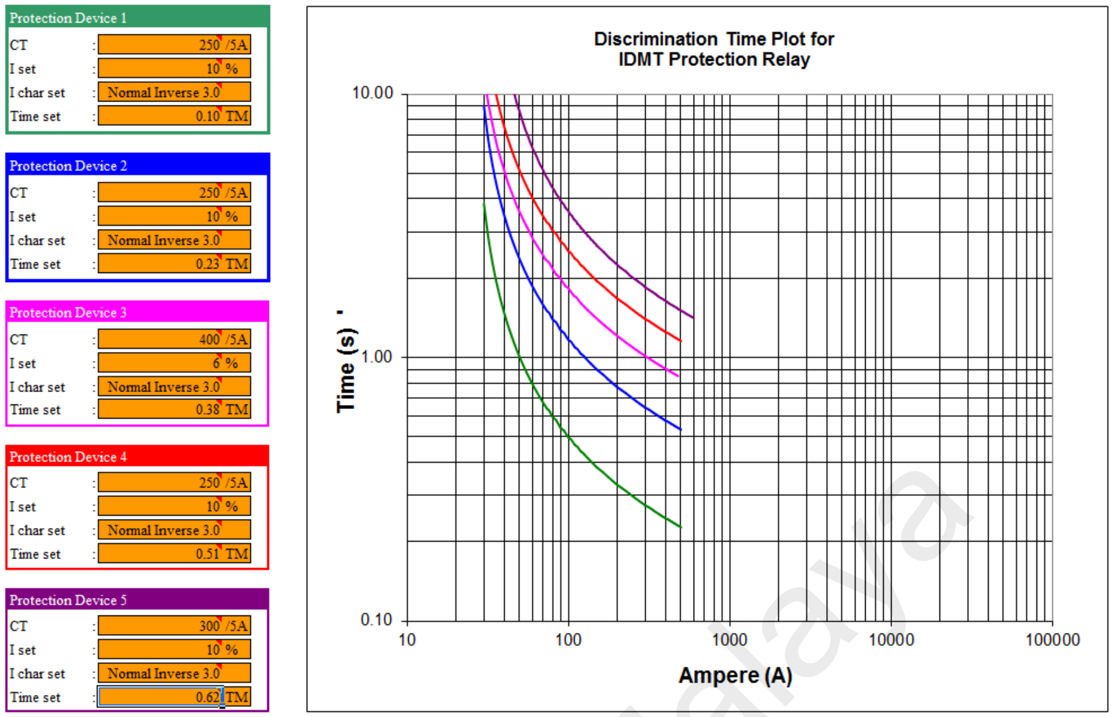


Figure 4.8 b : Relay grading curves for ACW – with TM setting, new Iset and smaller GM of 0.2 sec.

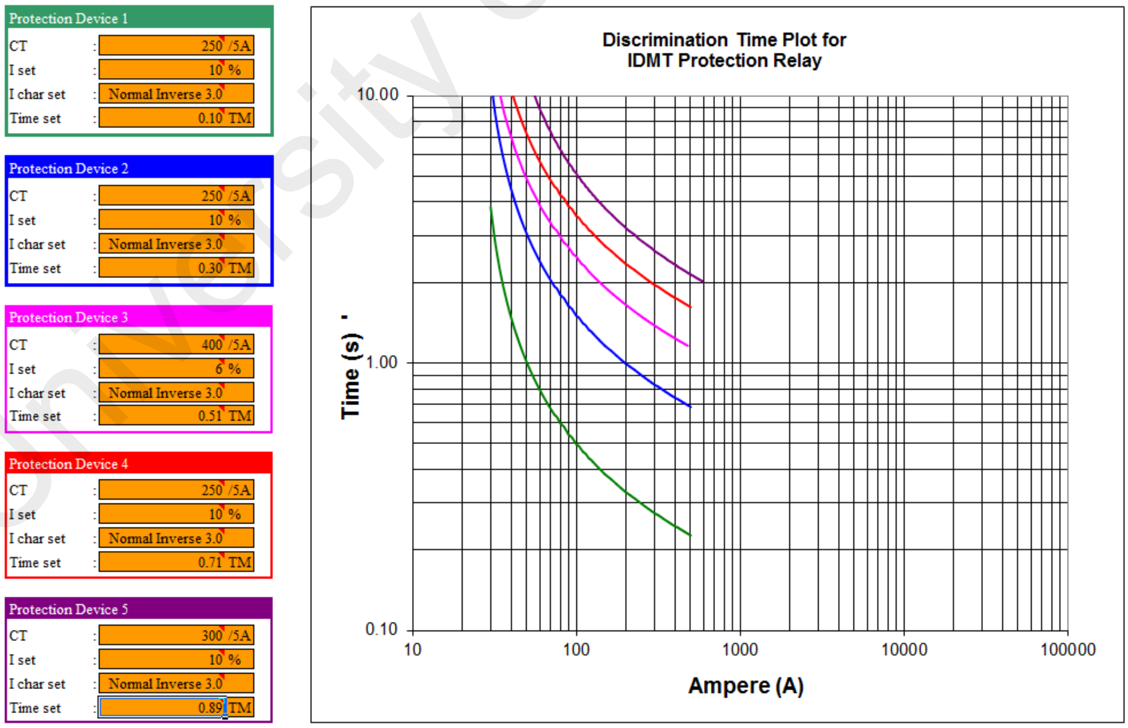


Figure 4.8 c Relay grading curves for ACW – with TM setting, new Iset and GM of 0.3 sec. (best grading curves).

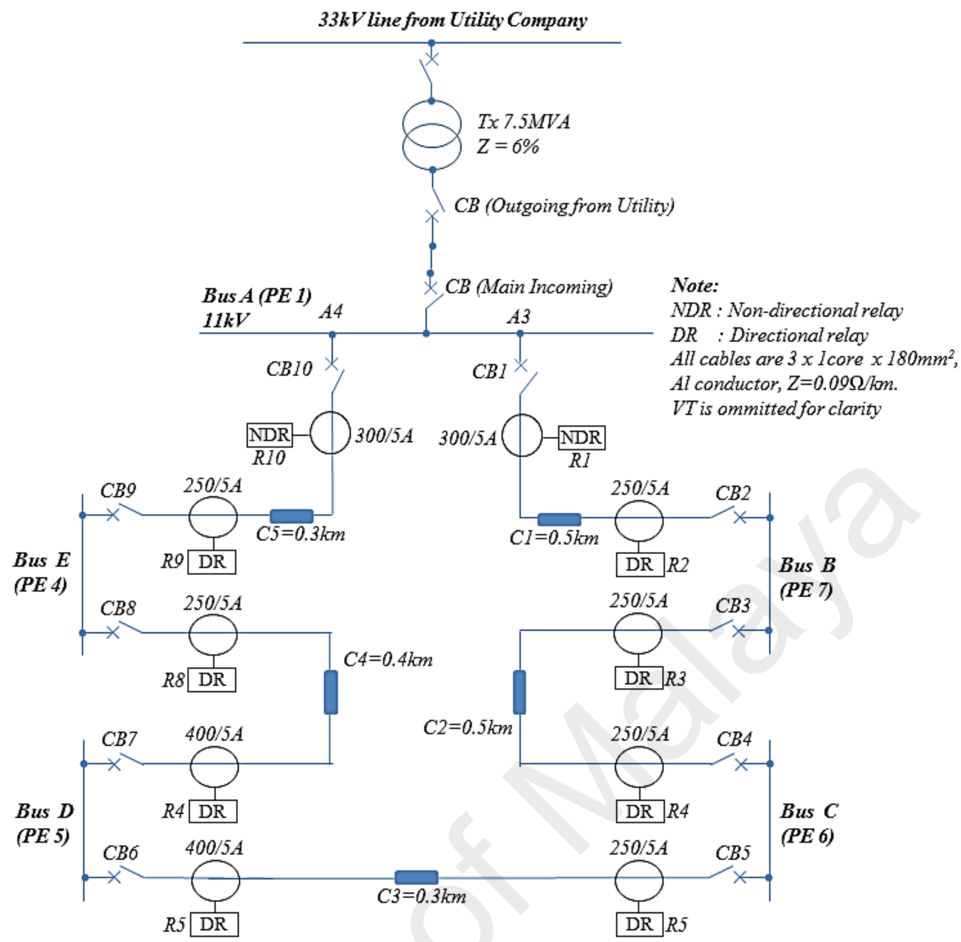


Figure 4. 4 Main circuit diagram of the proposed improvement of relay coordination setting using directional relay and non-directional relay.

An improvement on protection relay coordination setting is proposed by combining both Directional Relay (DR) and Non-Directional Relay (NDR) into this case study of 11kV distribution system as per Figure 4.4. Proposal of using DR and NDR is made in accordance with calculation that been made as per Table 4.2 a, 4.2 b, 4.3 a, 4.3 b, 4.3 c, 4.4 a, 4.4 b, 4.4 c for Over Current (OC) protection relays and as per Table 4.5 a, 4.5 b, 4.6 a, 4.6 b, 4.6 c, 4.7 a, 4.7 b, 4.7 c for Earth Fault (EF) protection relays.

In proposed system, 2 units of NDR are introduced into this 11kV distribution network system at CB 1 and CB 10 respectively, whilst other remaining CBs that are on CB 2, 3, 4, 5, 6, 7, 8 & 9 kept to be installed using DR.

CHAPTER 5: DISCUSSION

5.1 Existing Relay Setting

Improper coordination can be observed in each of the relay grading curves plotted (Figure 4.2(a-d)) which is in line with what has been discussed in previous Chapter 4. Poor setting value on TMS and current setting were the main factors contribute to non-existence of relay coordination sequence.

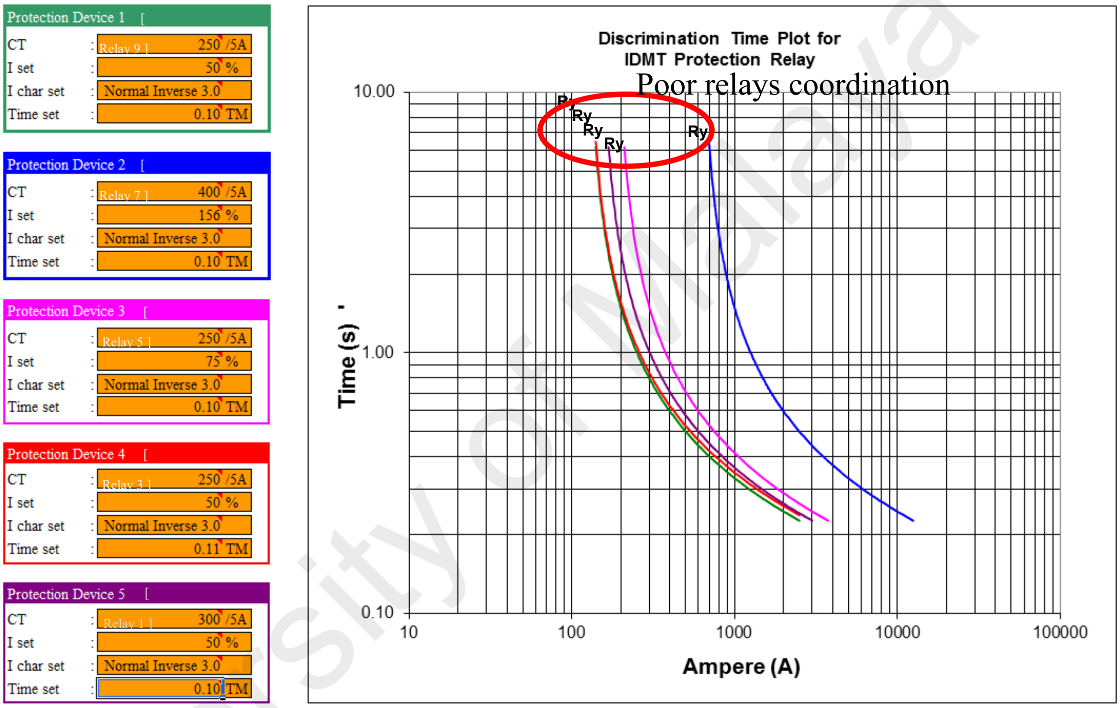


Figure 5.1 a : Existing OC relay grading for direction *R1-R3-R5-R7-R9*

With reference to Figure 4.1(a) in previous Chapter 4, Figure 5.1 displays the pattern of overcurrent grading for *R1-R3-R5-R7-R9.* From the observation, it was found that curves for relay 9 and relay 3 overlaps on each other. The explanation for this situation is that it occurred as both relays have same value of CT size, current setting and TMS. Despite having different fault value, the small difference of distance contributed to close grading curve plotted and ended up overlapped to each other. In this condition, the unnecessary loss of supply will be certained. To clearly explain this, when fault occurred, both relays will pick up the same fault and trip signal will be triggered to each circuit breaker by both relays. Besides that, observation on curve relay 7 (R7) found that the curve was plotted a bit off from other curves which was caused by current setting 156% more than the CT rated performance which was way too high. Similar scenario can be observed for the opposite direction, apart from the difference in current setting value which was depending on busbar location.

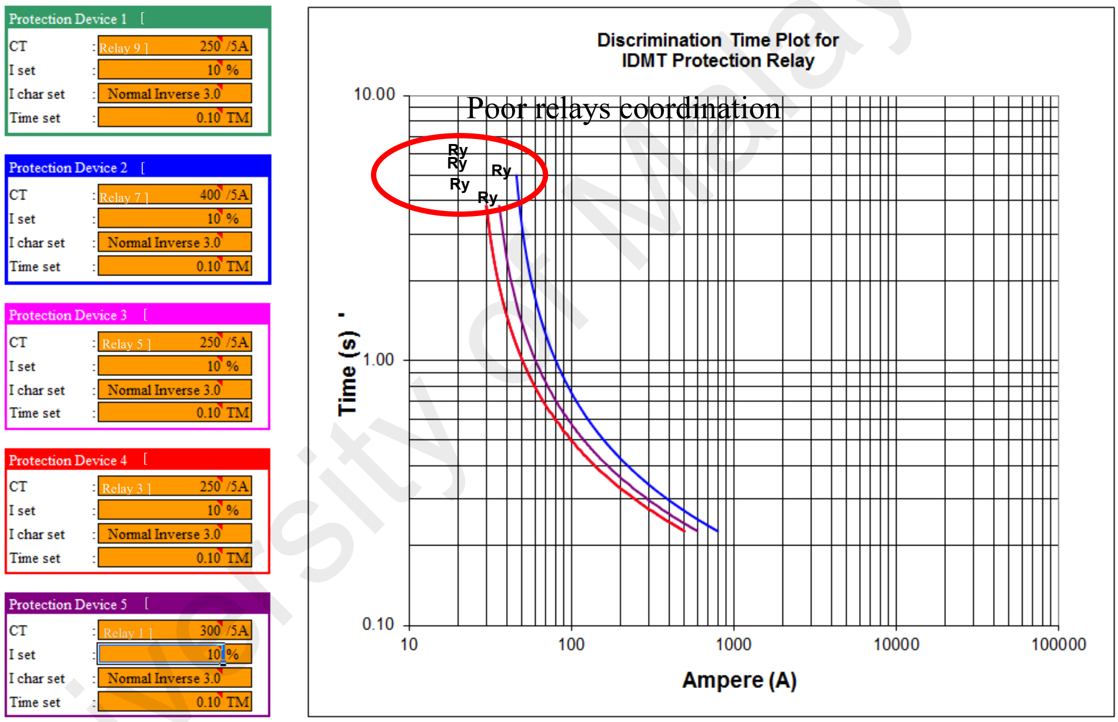


Figure 5.1 b : Existing EF relay grading for clockwise

In general, common setting of TMS (0.1) and current setting (100%) were used for all existing relays of earth fault relay except for relay with CT size 400A. Exception was made for relay connected to CT 400A whereby its current setting was set at 16%. From the curves plotted, overlap pattern of relay 9, relay 5 and relay 3 can observed. This was the result of no coordination on grading of TMS. Consequently, simultaneous trip for the three circuit breakers on each substation will be occurred. In addition, there was an improper grading sequence performed on relay 7 as it was graded to be the last to trip. In term of grading sequence, supposedly it should be a graded to the next relay to trip as relay 9 backup. Similar results is observed for the relay grading curve for the opposite direction.

It becomes crucial to conduct proper calculation on TMS with proper selection of current setting and grading margin to avoid relay curve from overlaps and too close on each other.

5.2 Improvement by Using Directional and Non-Directional Relays

5.2.1 Relay Setting Calculation

Calculation of fault current at each fault location clearly indicates that the most fit and suitable option is the selection of discrimination on time using the IDMT of standard inverse.

Table 5. 1 : Relay settings calculation CW – with proper Iset and GM of 0.3 sec

Phase Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	5.67	5.85	6.00	6.27	6.56
CT Size (A)	250	400	250	250	300
I set	50%	80%	120%	120%	100%
ROT	0.17 sec	0.47 sec	0.77 sec	1.07 sec	1.37 sec
GM		0.3	0.3	0.3	0.3
TMS	**0.1**	**0.20**	**0.33**	**0.46**	**0.60**

Grading process of the relay was performed by considering the relays sequence were set in a clockwise direction around the ring, i.e relays *R1/R3/R5/R7/R9*. In the next section, explanation will be focused on relay R9 and R7 grading process with Table 5.1 (extracted from Table 4.3(c)) as reference.

5.2.1.1 Grading of Relay R9

The fact that Bus A is the only source, flow of load current from Bus E to Bus A is not possible. With this condition, a rapid fault clearance time can be achieved by choosing low relay current and TMS settings at Relay 9. For current setting selection, a value above the load demand was considered. Current setting of 50% was selected for this purpose and initial value for TMS was set at 0.1. These parameters were set with intention to prevent pick up from other relays under condition of normal load current. At a fault current of 5.67kA, ROT on the Standard Inverse (SI) characteristic is 0.17 seconds.

ROT of *R9* with I_{fault} = 5.67kA, CT size 250A and I_{set} = 50%: -

$$\frac{5.67kA^{\ 0.02}}{125A} - 1$$

$$= 0.17 \text{ seconds}$$

5.2.1.2 Grading of Relay R7

In previous discussion, relay R7 should be a graded to the next relay to trip as relay 9 backup. Thus, it must be graded with relay R9 at 5.7kA to meet this condition. New minimum operating time was obtained by selecting grading margin of 0.3 seconds. Thus, new minimum operation time is 0.47s (ie: 0.17s + 0.3s).

Relative to R9, at least 110% current setting must be set to R7 to prevent occurrence of unwanted pickup. Thus, minimum current setting suitable for relay R7 is at 55%, while the maximum current setting should be set at 120%. Consideration must be made to choose the highest possible current setting to accommodate high existing load demand of bus D (i.e 400A x 156% = 624 A). Besides that, it is also important to put in consideration the factor of relay grading overlaps and also the final ROT limitation on the upstream in the selection process. Therefore, setting maximum current at 80% is the most suitable. A recommendation for the existing system to accommodate the high load demand is to establish new bus or substation. In addition, it will give advantage in term of longer life span of the equipment involved including CT and transformer.

TMS of *R7* with I_{fault} = 5.67kA, CT size 400A, I_{set} = 80% and ROT=0.47s is :-

$$\left(\frac{5.67kA}{320A}^{0.02}\right)\frac{0.47s}{0.14}$$

$$= 0.2$$

For calculation of other relays on the upstream for both clockwise and anti-clockwise direction, similar method was repeated.

5.2.1.3 Maximum ROT

The grading of the relays towards the downstream were performed based on ROT of 1.8 seconds. This ROT was considered as the longest operating time on consumer side specifically at main incoming breaker. The grading margin of 0.4 seconds was set between relays of this main incoming circuit breaker and the next relay at the outgoing feeder. As a result, remaining ROT of 1.4 seconds was provided to the downstream. Some parameters of relay setting such as current setting and grading margin need to be varied. The variation of the parameter was carried out to ensure the nearest relay to the source will have maximum ROT of 1.4 seconds.

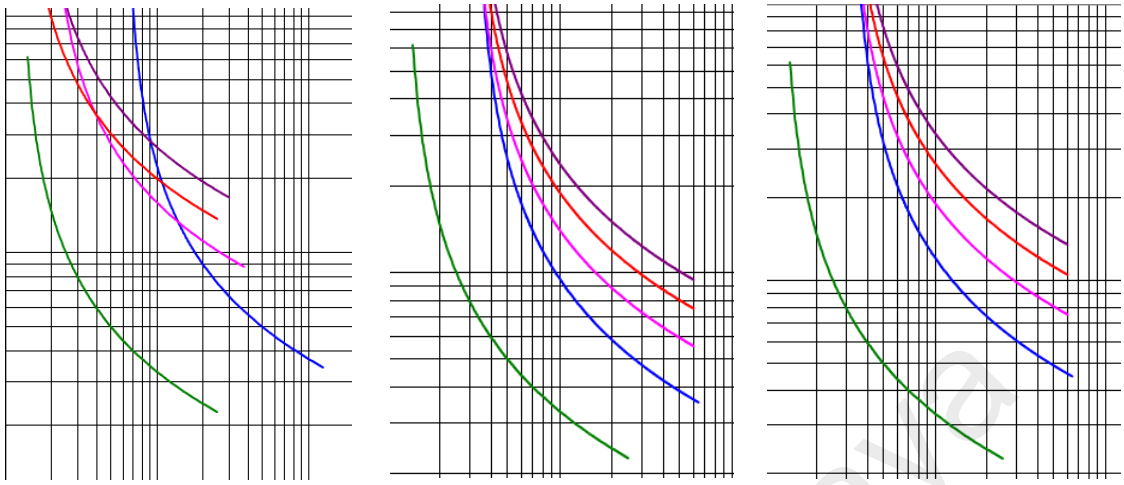
5.2.1.4 Grading Margin

Power distribution system of this facility was equipped with numerical relays. According to Table 5.2 in Chapter 2 of literature review, for numerical relays, grading margin of 0.3s between relays need to be considered as a reference in calculations. Besides that, testing with grading margin of 0.2s was conducted to observe the differences. Relay settings for both CW and ACW direction are summarized in Table 5.2.

Table 5. 2 : Overcurrent relay settings for ring circuit.

Bus	Relay Number	Relay Characteristic	CT Ratio (A)	Current Setting	Max Fault Current (kA)	TMS	ROT (sec)
E	R9	SI	250	50%	5.67	0.1	0.17
D	R7	SI	400	80%	5.85	0.2	0.46
C	R5	SI	250	120%	6.00	0.33	0.75
B	R3	SI	250	120%	6.27	0.46	1.03
A	R1	SI	300	100%	6.56	0.6	1.33
A	R10	SI	300	100%	6.56	0.61	1.35
B	R8	SI	250	120%	6.38	0.47	1.05
C	R6	SI	400	80%	6.16	0.33	0.76
D	R4	SI	250	75%	6.00	0.24	0.47
E	R2	SI	250	50%	5.76	0.1	0.1

5.2.2 Relay Grading Curves



(a) TMS with existing Iset (b) TMS with new Iset and GM 0.2s (c) TMS with new Iset GM 0.3

Figure 5. 1 : Relay grading curves in process for Figure 5.1 (a), (b) and (c)

Observation on the relay grading curves above will be discussed further in this section. We will emphasize on the impact of current setting and GM to the relay grading curves accordingly. Referring to Figure 5.1 (a) of the existing relay, despite the TMS setting has been graded properly, the coordination was strongly influenced by the current setting. After adjustment on the current setting for coordination was performed accordingly, the next approach taken was to ensure that relay grading curves were not close to each other. As discussed in previous section, close or overlap grading curves may contribute to risk of unwanted tripping to non-faulted bus.

Remarkably close gap between 4 relays on the longer fault time can be observed in Figure 5.1 (b). This pattern was produced by setting the grading margin of 0.2 seconds. However, as shown in Figure 5.2 (c), better gap between the relays curves was improved with higher grading margin of 0.3 seconds. Since the final ROT on the upstream had achieved 1.37 seconds, 0.3 seconds grading margin was considered as the maximum grading margin that can be set. It is important to emphasize that the maximum allowable

ROT was 1.4 seconds. Despite the relay curves not having wider gap to each other, there was lower risk and occurrence frequency for the fault to happen in longer time with lower fault current value. In contrast, higher risk and occurrence frequency can be observed with higher current in short time period. This scenario is the best example to illustrate the advantage of IDMT characteristic.

Figure 5.2 shows the gap difference for grading margin 0.2 seconds and 0.3 seconds measured along Y-axis.

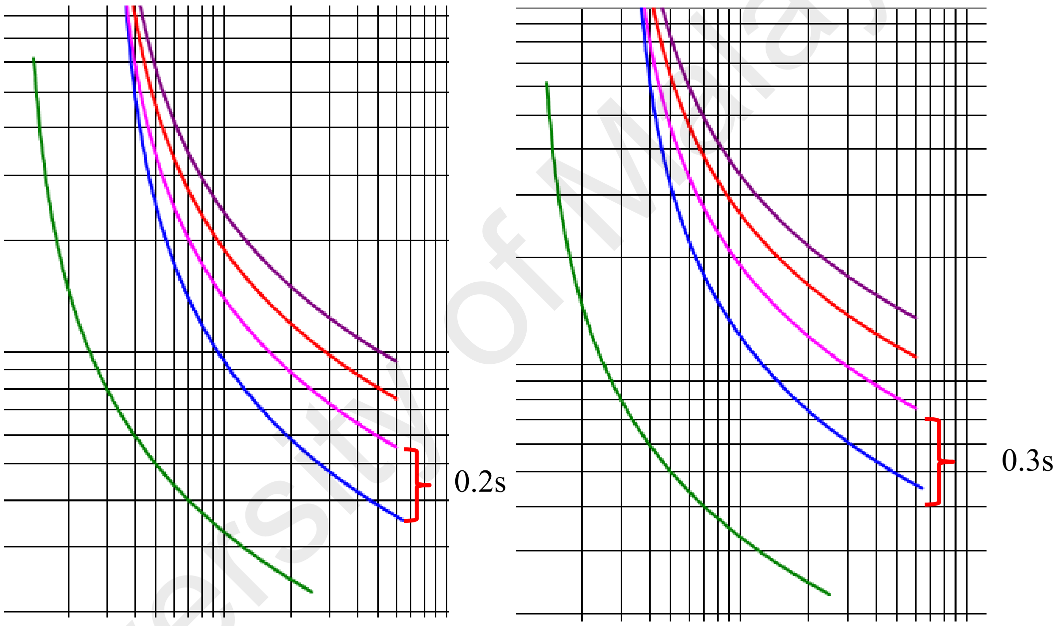


Figure 5. 2 : Different grading margin

Referring to the relay grading curves for clockwise direction, relay R9 has the lowest operating time and will be the first relay to operate if there is any fault occurs in the system. During abnormal condition for instance relay R9 failed to operate, the next upstream relay R7 will operate after some interval of time and so on as backup. Furthermore, when all downstream relays have failed, upstream relay such as relay R1 in this case, will trip the breaker and able to provide protection coordination. Consequently, overcurrent grading has been achieved.

5.2.3 Earth Fault Relay

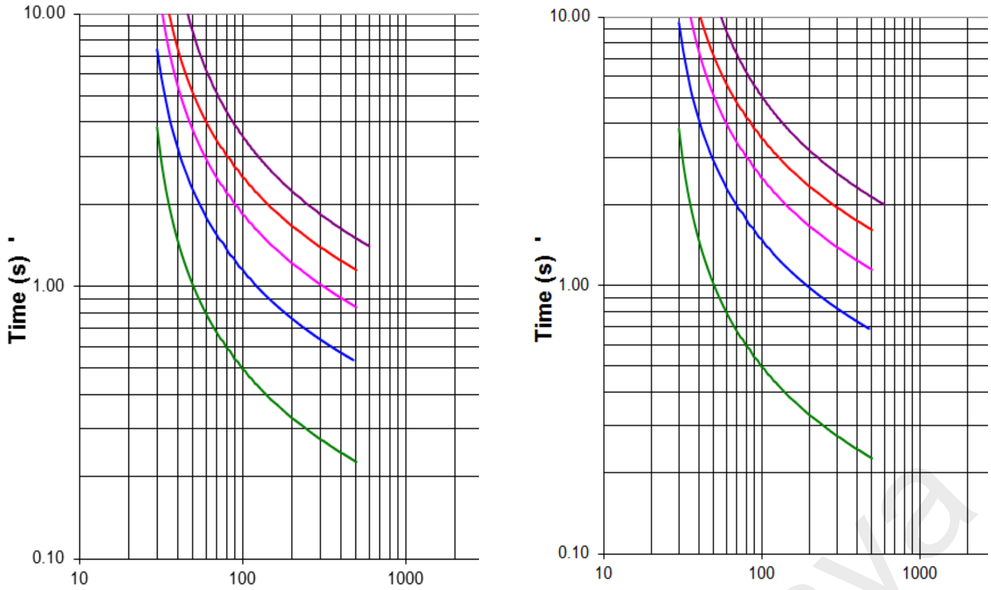
The fact that earth fault current calculated is smaller than the three-phase fault current does not assure the system is safe from interruption as the fault current has higher number of occurrences. Action taken by TNB as utility company to protect distribution system from being interrupted is by limiting the setting value on consumer side. This will require the consumer to set the setting with maximum of 10%.

In case of this building complex, CT size of 400A which is the highest among other relays in this ring system was installed at bus D. Thus, proper relays coordination can be achieved by reducing the current setting to 6% (refer Table 5.3 below).

Table 5. 3 : Earth fault relay settings calculation for CW.

Earth Fault Relay Setting [Clock Wise]					
PE Name	E	D	C	B	A
Relay Number	9	7	5	3	1
Fault location (between bus)	AE	ED	DC	CB	BA
I_f (kA)	2.22	2.33	2.41	2.57	2.75
CT Size (A)	250	400	250	250	300
I set	10%	6%	10%	10%	10%
ROT	0.15 sec	0.35 sec	0.55 sec	0.75 sec	0.95 sec
GM		0.2	0.2	0.2	0.2
TMS	**0.1**	**0.24**	**0.37**	**0.51**	**0.62**

As shown in Figure 5.4 below gap between curves is acceptable and the ROT of the upstream is small with grading margin of 0.2 seconds. However, 0.3 seconds earth fault relay setting was selected as grading margin with justification that the last ROT of the upstream is still less than maximum value of 1.4 seconds (ie: ROT *R1* = 1.35s).



(a) (b)

Figure 5. 3 : Relay grading curves in process where - (a) TMS with GM 0.2s, (b) TMS with GM 0.3

Figure 5. 4 : Summarizes the earth fault relay settings for both directions.

Bus	Relay Number	Relay Characteristic	CT Ratio (A)	Current Setting	Max Fault Current (kA)	TMS	ROT (sec)
E	R9	SI	250	10%	2.22	0.10	0.15
D	R7	SI	400	10%	2.33	0.30	0.30
C	R5	SI	250	10%	2.41	0.50	0.50
B	R3	SI	250	10%	2.57	0.71	0.71
A	R1	SI	300	10%	2.75	0.88	0.88
A	R10	SI	300	10%	2.75	0.89	0.89
B	R8	SI	250	10%	2.64	0.71	0.71
C	R6	SI	400	10%	2.51	0.51	0.51
D	R4	SI	250	10%	2.41	0.30	0.30
E	R2	SI	250	10%	2.27	0.10	0.10

CHAPTER 6: CONCLUSION AND FUTURE WORK

6.1 Conclusion

Continuous improvement on service or system is always relevant as there are a lot of loopholes that open for betterment. For a power system, continuous improvement is essential to ensure the system operates with high efficiency and minimize the waste in term of loss of power and unnecessary equipment operation, in this case any unwanted tripping of OCEF relays. The overall objective of this research paper to provide better ring distribution system in terms of maintainability and reliability is a success. Verification on overcurrent and earth fault coordination settings in the building complex was accomplished by using the developed program. The simulation program was successfully simulating relay curves from a set of input current and grading margin values. With this simulation, comparison of the existing relay curves with the improved relay coordination curves was successfully conducted. From the improved relay curves simulated, the proposal for improvement of relay coordination setting using directional and non-directional relay resulted to a better ring distribution in term of maintainability and reliability.

In line with Principle of Time-Current Grading, best relay grading and coordination can be obtained by varying the current setting (I_{set}) and grading margin values. It is also found that, relay coordination (sequence of tripping) is highly impacted with current setting. This condition enables the system to avoid any unnecessary trip of relay. In addition, the best current setting can be achieved by having gradual increment towards source for the multiplication value of CT size and I_{set} (CT size X I_{set}).

Final ROT nearest to the source is highly impacted to grading margin value. From the verification, it found that the grading margin of 0.3 seconds is the optimum value for the overcurrent and earth fault setting in this building complex ring distribution system with specification of four substation using numerical relay.

6.2 Future Work

Some recommended topics could be covered for system improvement in future work of this research topic as listed below:

1. Study on setting for relay grading for system with more than four substations.
2. Impact of different types of load to coordination such as equipment with high starting current (e.g: Chiller, aircond).
3. Further verification of calculated ROT with different grading margin. Verification should be conducted during site testing.
4. On site testing of different relay brand or manufacturer to confirm stability of the results and any investigation for any discrepancies exist.
5. Site testing using higher fault current to study the influence of fault current magnitude on the grading margin.
6. Verification on other system voltage such as 6.6kV, 22kV and 33kV.

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