" I hereby declare that I have read through this report entitle "Modelling and Analysis an Overcurrent Protection in Power System Network Using PSCAD" and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)'

Signature : ……………………………………….

Supervisor's Name : Dr. Mohd Hendra Bin Hairi……….

Date : 23/06/2016………………………..

MODELLING AND ANALYSIS AN OVERCURRENT PROTECTION IN A POWER SYSTEM NETWROK USING PSCAD

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A report submitted in partial fulfillment of the requirements for the degree of Electrical Engineering (Industrial Power)

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2016

I declare that this report entitle *"Modelling and Analysis an Overcurrent Protection in Power System Network Using PSCAD"* is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……………………………………………

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Date : 23/06/2016…………………………….

To my beloved mother, father

and my family.

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ABSTRACT

Protection scheme is desperately needed in the power system network. Protection system plays an important role in detecting the presence disorders and may prevent damage caused interference. This can improve the reliability of the system to maintain continuity of supply to the load. Overcurrent protection is among the important and earliest protection scheme in power system. However the interruptions in power system can happen by fault current. Besides, the improper setting or wrong selection and positioned of the power protection devices is among the reason. Therefore, to maintain and improve the performance of the protection system, this thesis presents a model of overcurrent protection scheme in power system. This thesis describes research carried out to investigate the performance of overcurrent relay on relay operation time (ROT) based on several cases. The model of overcurrent protection system and analysis is developed by using PSCAD simulation software. There are several requirement or conditions are set in order to understand and analyze the reaction and performance of protection system model. The various type and location of faults and relays is proposed in this project to see the changes in power system protection performance. Besides, the implementation of different curve characteristic and various standard also performed. Other than that, installation of distributed generator are also determined because it will give a different impact and result to the power system protection when faults are occur in the system. The result will be studied in order to understand the performance of overcurrent relay in protection scheme.

ABSTRAK

Skim perlindungan merupakan perkara yang sangat diperlukan didalam sesebuah rangkaian sistem kuasa. Sistem perlindungan memainkan peranan yang penting dalam mengesan kehadiran gangguan sekaligus mencegah kerosakan yang boleh berlaku akibat daripada gangguan ini. Perkara ini juga dapat meningkatkan tahap keberkesanan sistem dalam memastikan kesinambungan bekalan elektrik kepada beban secara terus. Perlindungan arus lebih adalah antara skim perlindungan yang penting dan terawal dibangunkan didalam sistem kuasa. Walaubagaimanapun, gangguan dalam sistem kuasa boleh berlaku bila-bila masa seperti gangguan arus tinggi. Selain itu, penetapan, kedudukan dan pilihan yang salah terhadap peranti perlindungan juga antara penyebabnya. Oleh hal yang demikian, untuk meningkatkan prestasi sistem perlindungan, tesis ini telah pun dijalankan dengan membina sebuah model skim perlindungan arus lebih. Projek ini mengenai penyiasatan prestasi skim perlindungan arus lebih berdasarkan masa operasi relay terhadap beberapa keadaan yang berbeza. Model skim perlindungan arus lebih dan analisa terhadap model yang dibina dilakukan dengan menggunakan perisian PSCAD. Terdapat beberapa pemboleh ubah yang ditetapkan dalam memahami dan mengkaji tindak balas dan prestasi model yang dibina terhadap pemboleh ubah. Antara pemboleh ubah yang digunakan adalah jenis dan lokasi relay yang digunakan dalam skim perlindungan dan juga jenis-jenis gangguan yang dikenakan. Selain itu juga, jenis graf dan standard relay turut dikaji. Selain itu, penambahan DG kedalam litar juga turut dikaji teutama ketika berlakunya gangguan Keputusan kajian yang didapati daripada simulasi akan difahami dan dikaji berdasarkan prestasi geganti arus dalam skim perlidungan yang dibina.

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LIST OF ABBREVIATIONS

UTEM	Universiti Teknikal Malaysia Melaka
FKE	Fakulti Kejuruteraan Elektrik
TNB	Tenaga Nasional Berhad
IDMT	Inverse Definite Minimum Time
SLG	Single-Line-to-Ground
DLG	Double-Line-to-Ground
TPG	Three-Phase-to-Ground
IEEE	Institute of Electrical and Electronic Engineer
IEC	International Electrotechnical Commission
SI	Standard Inverse
VI	Very Inverse
EI	Extremely Inverse
TDS	Time Dial Setting
MV	Mega Volt
MVA	Mega Volt Ampere
PMU	Pencawang Masuk Utama
PPU	Pencawang Pembahagian Utama

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CHAPTER 1

INTRODUCTION

1.1 Background

Power system protection is one of the branch in electrical power engineering. The protection term give a significant meaning in the electrical power engineering, where it is a division in electrical power engineering that concerned with the detection and isolations of fault and other type of unusual situation in power system. These fault often occur at the worst possible time and cause the maximum amount of inconvenient to the customer utility [11]. Thus the protection system is needed in providing the quick isolation of fault and faulty area from the service. This is to allow the largest possible part of the power system to continue in service.

There are several types of protection system that have been applied in the power system distribution by the utility company. The common protection system in distribution power system including distance protection, overcurrent protection and differential protection. This project focused on overcurrent protection scheme which is widely used in power system distribution for many years. Overcurrent protection system is use to detect the current magnitude which exceeds the specified adjustable current magnitude. This type of protection system is used with the overcurrent relay as the measuring instrument which it is respond to the current magnitude of the input current [1].

This project has been carried out to compare and analyze the effect on performance of the overcurrent protection model towards relay operation time based on the IDMT, overcurrent relay characteristic’s curve, different type of faults different type of curve standard and DG installation in power system. This is to make sure that, the protection system is isolate the fault and faulty area only while leaving the largest possible area of the system in service. Besides, the impact of installation distributed generation (DG) into power system to the protection scheme also studied.

1.2 Problem Statement

Protection is one of the important element in the power system. A power system must not only capable of meeting the present load but also requires the flexibility to meet. The system must be kept in operation continuously without major breakdown [1]. A good protection scheme must achieve the basic features of protection system such as selectivity, stability, speed and sensitivity [4]. However, sometimes the relay that should be operated due to the fault does not work properly- delay in operation or does not function at all. It might be due to the problems from the setting of the relay or several condition. So, related to the problem, the study will be focused to performance of overcurrent relay based on relay operation time. Several cases were performed in order to investigate and study the relationship between relay operation times with the condition or event happened. The PSCAD is used as the platform to performed and demonstrate performance of the proposed overcurrent protection scheme under various scenarios [8].

1.3 Objectives

The objectives of this project are:

a) To model an overcurrent protection circuit in the power system network.
b) To analyze the relay operation time of overcurrent protection for the power system network based on type of relay characteristic curve, type of fault and their location.
c) To study the effect of installation distributed generation (DG) on relay operation time.

1.4 Scope of research

This project totally focused on the overcurrent protection in distribution system. The circuit design involved five or less bus-bars and the power rating for the distributed generation is up to 10MW or less. The scopes for this research are specifically detailed as follows:

a) To analyze the effect of IDMT characteristic curve on relay operation time based on IEC 60255 and IEEE C37.112 standard.
b) Fault applied are three-phase-to-ground, double-phase-to-ground and single-phase to the ground.
c) To compare relay operating time between circuit without DG and circuit with DG installation.
d) The circuit modeled for distribution system of 132/33kV and 33/11kV.
e) Analysis using PSCAD software.

1.5 Thesis Outline.

This thesis consists of five chapters which are introduction, literature review, methodology, result and conclusion. The first chapter had reviewed the objective and scope of this project with background of the study. Follow by chapter 2 which focused more on the theory and literature review of past research that relevant to the project, topic on overcurrent relay, IDMT relay curve characteristic and protection components have been focused in this chapter.

In chapter 3, the methodology of the project such as the circuit diagram design and implementation has been summarized in this chapter. The result and discussion are presented in Chapter 4 while recommendation and suggestion for future research are outlined in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Electric power is generated and transmitted to the consumer through the large grid connection. The generation of electric power started from the power plant or generator, then the voltage will be step up before transmitting the electric power to the consumer. This practice is applied in order to minimize the losses of electric power through the transmission. The power is then transmitted to the commercial or residential consumers.

The main objective of all power system is to maintain and reliable power supply to the end user. In the normal condition, the power system will be works accordingly to the design. The current is distributed and flow in the pre-design value which suitable to the electrical power elements ratings. However, in some undesired condition the fault can be occurred. This conditions occur due to the natural event or human error such as weather, lightning, wind damage, human vandalism, insulation deterioration, falling tree and etc. This circumstances will lead to the unwanted situation where connection between phase conductor of transmission line and phase conductor to the ground happened.

The needs of protection scheme in the power system is important to ensure that the investment is made on existing equipment will get the maximum returns back, which goes to makeup the power system and to make sure the customer satisfied with the reliable service which the operation of the system must be kept in service where the system must continuously in process without major breakdown.

2.2 Fault type and effects

Fault is a failure or unusual condition that experience by the power system where it comes from several condition including lightning and etc. Fault can be divided into two main areas, which are ‘Active’ and ‘Passive’ fault. [1]

The ‘Active’ fault happening when the actual current flow from one phase of conductor to the other phase of conductor which also known as phase-to-phase fault, or the flowing of current from one phase of conductor to the ground known as phase-to-ground. The active fault also can be divided into two other type of faults which are ‘solid’ fault and ‘incipient’ fault [1].

The ‘solid’ fault is happened as the result of immediate complete breakdown of insulation happen when the pick struck of cable or cable was dug up by bulldozer and etc [1]. These circumstances will lead to the very high of fault current where it can resulting to the explosion. Besides, the ‘incipient’ fault is a fault that start in a small way before it changes into catastrophic failure afterwards [1].

While for the ‘passive’ faults is actually not a real fault where it is a condition that are stressing the system beyond its design capacity. The typical example of passive fault such as over voltage, power swing, and under frequency. But this type of fault can ultimately change to active fault.

Furthermore, there are several type of faults that can occur in a three-phase A.C. system where the power distribution system is globally a three-phase. The following figure shows the condition of faults that can occur in the three phase system.

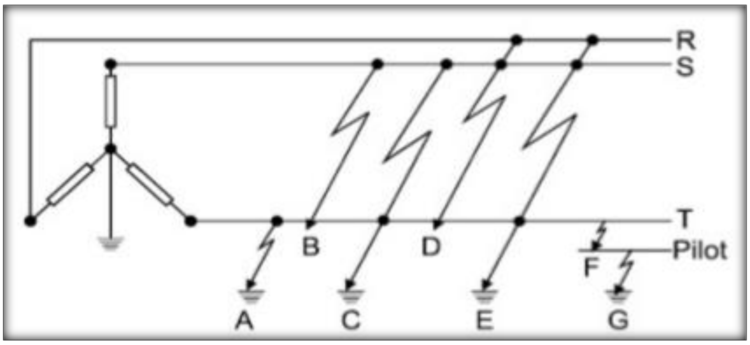

Figure 2.1: The condition of faults in three phase system.

(A) Phase-to-ground fault

(B) Phase-to-phase fault

(C) Phase-to-phase-to-ground fault

(D) Three-phase fault

(E) Three-phase-to-ground fault

(F) Phase-to-pilot fault

(G) Pilot-to-ground fault

2.3 Overcurrent

Based on the *National Electrical Code*, the overcurrent is a phenomenon when the current of conductor or equipment is larger or excess than the equipment rating or the ampacity of a conductor. This situation may result from short circuit, ground fault or overload. [2]

Heat is always produce from the flowing of current in a conductor. The higher the current, the more the heat produced. Heat produced from the conductor can damage the electrical components if it is too high, which cause by the excessive current flow. For that reason, conductors have a rated continuous current carrying capacity or ampacity [2]. To protect the conductor from the excessive flow of current, the overcurrent protection devices are used. The protective devices are used to protect the circuit conductors from overheating by allow certain level of current to flow through it where it is should not higher than the rated current [2].

2.4 Overcurrent Protection

Overcurrent protection is one of the most important and earliest protection principle that developed. The overcurrent protection is a scheme that protecting the devices or components in the power system from damage due to excessive of current flow. The protection system detects the fault based on the fact that the fault current is obviously larger than the usual load current after the fault occurs. The overcurrent is divided into two subtypes which are instantaneous overcurrent and inverse-time overcurrent. The instantaneous overcurrent will operates instantaneously if the input current is larger than the setting value. For the inverse-time overcurrent it is operates in the way which the operating time is inversely with the input current [4].

2.5 Principles of Relay Operation

There are a lot of different type of relays used in protective scheme. However, they are follow the same logic pattern. Figure 2.3 shows the protective scheme logic chart. There are inputs, measurement, determination and output. The input will represent current, voltage, frequency or perhaps other value that exist in protective circuit at any instant in time. The relay measures this values and then determines the circuit operating condition whether within in a normal parameters. Under normal operating condition output is zero which it is set to open or close contact at rest. However, in any intolerable fault level, the relay will imposes operating signal value under control circuit usually in terms of DC volt. This tripping signals is then fed into one or more circuit breaker to cause them to open, so as to isolate the faulty part from the rest of unfaulty power system.

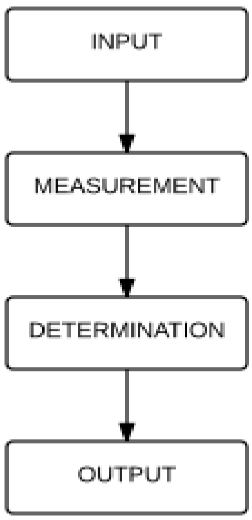

Figure 2.3: The protective scheme logic operation.

2.6 Overcurrent Relay

An overcurrent relay provides protection against over currents. This type of relay uses current input from the CT and compare with the preset current. Figure 2.4 shows the logical representation of this type of relay. If the input current is exceeds the value of preset current the relay detects an overcurrent and send the trip signal to the circuit breaker which open its contact to disconnect the protected equipment [12]. When relay detects a fault, the condition is called fault pickup. In case the relay is instantaneous overcurrent relay the relay will issuing the trip signal to the breaker instantaneously after picking up the fault or it can delay for a specific time before send a trip signal to the breaker in case of time-overcurrent relay. This time delay is also known as the operation of the relay, and is computed by the relay on the basis of the protection algorithm incorporated in the microprocessor [19].

Figure 2.4: Logical representation of Over-Current Relay.

The overcurrent relay usually combine both instantaneous and time overcurrent units. Instantaneous response provided by moving armature units which functioning to operate on a very large currents. Time response is provided by the inverse induction disk unit and it is set to operate at a lower noise current.

Induction disc unit operates on the same principle as a motor. As in the figure 2.5, metal plate attached to the shaft can rotate freely. The coil current is specified. The eddy current is induced in the metal disc by magnetic field that generated by current. Then, the magnetic field of stationary coil interacts with the magnetic field of eddy current which generates a torque on the disc.

The torque produced rotates the shaft and metal disc which at the same time bring and position the moving contact to the fixed contact in the closed position. When the flow falls below the preset value, the contact disc will move and return to the open position by the spring. Time to close the contacts depend on the distance of the contact which is set by the time dial. Pick-up current is set by choosing a tap on the coil current flows. The relay usually has three ranges of tap flow: 0.5 – 2.0A; 1.5-6.0A, and 4-16A. Time dial usually has a marked position from which 0 – 10, where it is permanently close when the setting is set to 0 [5].

There are two important principle of IDMT to understand which are inverse time and minimum time. Inverse time means when the current is increase the time will decrease where the operating time for relay is faster by increase in current. When the current in the circuit is higher than the current setting, the relay will take the shortest time to operate. Definite minimum time means when the current is high the operation of relay is faster where for every protection relay has their own fixed time depend on the time delay setting [6]. This can be clearly understand by referring to the IDMT characteristic's graph in Figure 2.6.

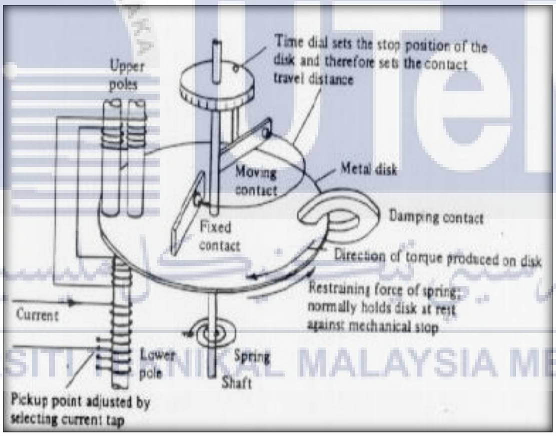

Figure 2.5: IDMT Relay Mechanism.

2.7 Classification of Over-Current Relays.

The operating time for the overcurrent relay have two type which are instantaneous time setting and time delayed. Overcurrent relays are classified on the basis of their operating time, in the following three categories.

2.7.1 Instantaneous Overcurrent Relay.

These type of relay sends the command to the breaker to trip as soon as the fault is detected. This type of relay do not have intentional time delay. This type of relay always implemented at the nearest part of source where the fault current is very high and a small delay in operation of relay is will cause the heavy damage to the equipment. Thus, instantaneous relay is used to protect the equipment by detect and respond to a fault in a few cycles [12].

2.7.2 Definite Time Overcurrent Relay.

This type of relay is used as a back-up protection in transmission line. In transmission line the primary protection is distance relay. In certain cases, if the distance relay do not detect the line fault and not send the tripping signal to the breaker, in certain specific time delay the overcurrent relay will send the tripping signal to the breaker. In this case, the overcurrent relay is time delayed by a specific time which is just greater than the normal operating time of the distance relay plus the breaker operation time [12].

2.7.3 Inverse Definite Minimum Time (IDMT) Overcurrent Relay.

This type of relay has inverse time characteristic, which means the relay operating time is inversely proportional to the fault current [5]. If the fault current is higher, the operating time of relay will be lesser [20]. It can be graded for a very large range of operating times and fault currents [21]. The characteristic of IDMT overcurrent relay is depends on the type of standards selected. This can be ANSI, IEEE and IEC or user defined. The overcurrent relay will then calculate the operation time corresponding to that particular characteristic curve [22].

2.8 IDMT Electromechanical Relay.

Inverse Definite Minimum Time (IDMT) is affected by the inverse proportional relationship between the operating time of the relay and the function of current. For the electromechanical relay there are two adjustments which are plug setting and time dial setting. Plug setting determines the current at which the relay will start operate while time dial setting controls the relay's disc movement.

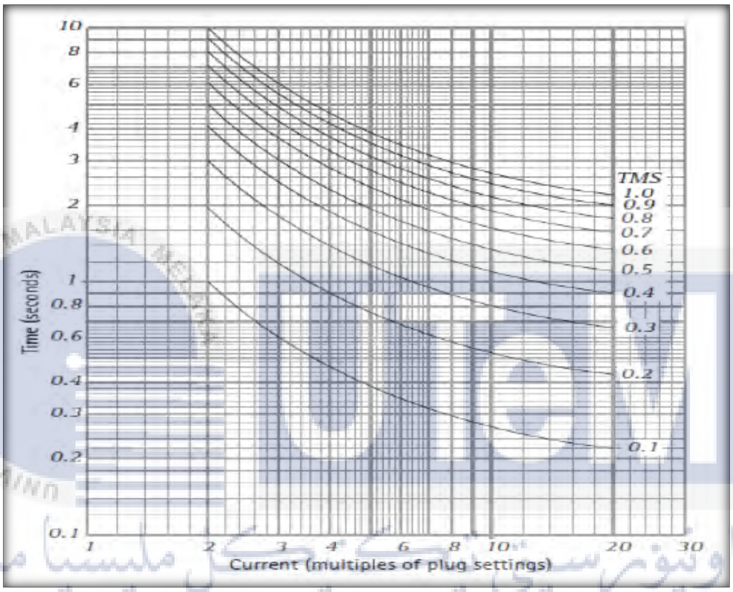

Figure 2.6: Inverse Time Characteristic Curve.

The curve in Figure 2.6 display the relation between operating current in terms of current setting multiplier along the x-axis and operating time in seconds along the y-axis. A current setting multiplier indicates the number of times the relay current is in excess of the current setting. The current setting multiplier is also referred to as plug setting multiplier (PSM) [14]. Thus,

$$PSM = \frac{Primary\ Current}{Primary\ Setting\ Current} = \frac{Primary\ Current}{Relay\ Current\ Setting\ x\ CT.Ratio} \tag{2.1}$$

This inverse time characteristic also can be shifted up or down by adjustment of the time-dial setting where by using the appropriate TDS settings, the grading of protection network system can be achieved where the range of TDS is normally 0.1 to 1.0 [19]

The current or time tripping characteristics of IDMT relays can be varied according to the tripping time required and the characteristics of other protection devices used in the network [5]. For these purposes, IEC 60255 and IEEE C37.112 defines a number of standard characteristics as follows [5]:

- Standard Inverse (SI)
- Moderately Inverse (MI)
- Very Inverse (VI)
- Extremely Inverse (EI)
- Long Time Inverse (LTI)

2.8.1 Mathematical Express.

The characteristics of an IDMT overcurrent relay depend on the type of standard selected for the relay operation. These standards can be ANSI, IEEE, IEC or user defined. The relay will calculate the relay operating time based on the chosen standard characteristic curves and the parameters defined [14].

In accordance of IEC and IEEE/ANSI standard, the characteristics of IDMT relays are represent mathematically by the following equation:

$$t = \frac{k\beta}{\left(\frac{I}{I_S}\right)^{\alpha} - 1} + L \tag{2.2}$$

- t = relay operating time in seconds
- k = time multiplier setting
- I = fault current level in secondary amps
- Is= pick-up current selected
- L = constant
- α, β and L for various standard overcurrent relay types manufactured under ANSI/IEEE and IEC standard.

The constants α and β determine the slope of the relay characteristics. The values of α and β and L for various standard overcurrent relay types manufactures under ANSI/IEEE and IEC standards are given as in Table 2.1

Table 2.1: ANSI/IEEE and IEC constants for standard overcurrent relays [26].

Curve Description	Standard	α	β	L
Moderately Inverse	IEEE	0.02	0.0515	0.114
Very Inverse	IEEE	2.0	19.61	0.491
Extremely Inverse	IEEE	2.0	28.2	0.1217
Inverse	CO8	2.0	5.95	0.18
Short-time Inverse	CO2	0.02	0.0239	0
Standard Inverse	IEC	0.02	0.14	0
Very Inverse	IEC	1.0	13.5	0
Extremely Inverse	IEC	2.0	80.0	0
Long-time Inverse	UK	1.0	1.20	0

2.9 Distributed Generation.

Distributed generation refer to the generation of electricity at or near to the place of consumption. DG systems are mostly connected to the distribution level where it is commonly based on renewable energy such as wind, solar, hydro and etc. There are several compelling advantages from DG installation such as [15]:

- Increasing the reliability of the distribution system through the availability of backup generation.
- Reducing pollution towards environment by mitigating electricity generation based on the traditional fossil fuels plants.
- Increasing power quality.
- Allowing grid expansion postponement.

Furthermore, a combination of several DG units can be form a microgrids where microgrids can increase power reliability for attached mode, or independently as islands, microgrids increase power reliability for attached loads, and allow for greater flexibility in terms of power flow control and more economical generation [15].

However, there are many issues associated with the DG systems and the integration of DG system with present power grid, whether it is stand-alone or microgrid configuration. One of the technical issues is the impact on the existing protection schemes [13].

2.9.1 Protection issues in presence of DG units.

Traditionally, the power flow is in single direction in distribution systems, which is from upstream to the loads. The common protection system are overcurrent relay coordination. Traditionally, relays coordinate in an upstream fashion, with sections farther away from the substation isolating first, until the fault is cleared [16]. However, the assumption on single power flow direction is not valid when DG is installed. The power flow in system can be from upstream of the feeder which will affecting the relay coordination and operation standard. Major concerns associated with the utilization of DG systems are protection under reach, sympathetic tripping, unsuccessful clearing faults and unintentional islanding [19]. Currently, many utilities limit the number, capacity and location of DG units.

Besides, the multiple sources also present issues for faults clearing and reclosure. When the grid is disconnected by the protection scheme, the DG units are still active and unfortunately will feed the occurred faults. This would results in large current or voltage where it can damage the DG units and feeder components.

2.10 PSCAD

PSCAD is stand for Power Systems CAD. PSCAD was first introduce in 1988 and began it long evolution as a tool to generate the data files for the EMTDC simulation process. Throughout the evolution of PSCAD there are at least four versions of PSCAD has been developed and produced. This software was started with largely experimental where user could not draw the systems rather than creating text listings. The software was then associated with software tolls which can performed circuit drafting, runtime plotting and off-line plotting. Until now the PSCAD developed with various and advancement of the design tools for the user [7].

There are several others protection software that available such as Computer Aided Protection (CAPE), Matlab and Simulink software which is use in modelling and analyze the protection scheme in power distribution system. The PSCAD software has been chosen in modelling and analyze the overcurrent protection for this project because the software is detail and easy to use where is as simple as point, click, and run. Besides, the components also can be design based on the designer requirement. In this project the PSCAD is used as a platform to performed and demonstrate the performance of the proposed overcurrent protection schemes under various scenarios. [8]

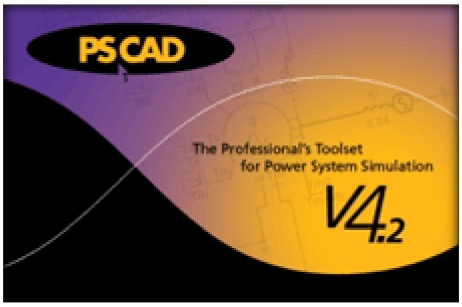

Figure 2.7: PSCAD software.

2.11 Summary

Protection of power system consists of several methods. Overcurrent protection is one of the famous way to protect the power system network. Unfortunately, there are several unfortunate event happened regarding to overcurrent protection. Therefore, the study was made to analyze the performance of the most important device for overcurrent protection which is overcurrent relay. The performance of relays are analyzed based on several factor such as type of fault, curve characteristic, curve standard and distributed generator installation. The analysis was made to evaluate the performance of relay for ROT with the effect of established cases. The simulation is done using PSCAD software.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss on method and procedure that could be suitable and used in this project. The procedure including the circuit modelling, description on circuit components, circuit setting and analysis on the circuit model will be discussed.

3.2 Flow Chart of Methodology

The objective of this project is to study the performance based on relay operation time (ROT) of the inverse-definite minimum time (IDMT) relay in protection scheme of distribution system. The overcurrent protection is chosen as the main study of relay performance in this project. After that, three analysis were made in order to study the performances of IDMT overcurrent relay on protection in circuit model. The analysis are ROT based on various type of fault applied, various type of relay curve, IEC and IEEE relay curve and lastly relay operation with distributed generator (DG) and without DG installed.

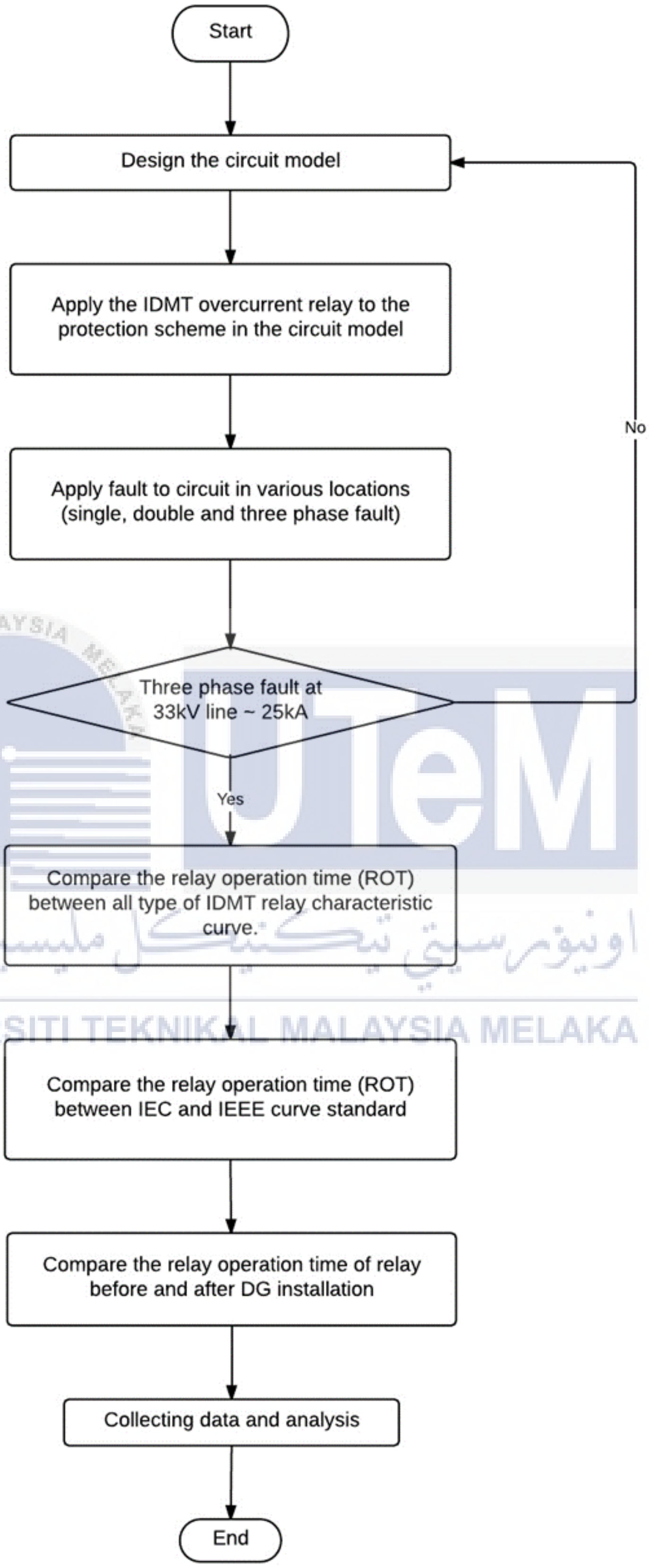

Figure 3.1: Flowchart of Methodology.

3.2.1 Design the circuit model

The circuit modelling is done by using PSCAD software. The circuit model is based on the medium voltage network of Perak distribution system. The circuit model consist of grid supply, transformer and loads. The network's supply for the system is 132kV. The supply voltage was step down to 33kV and 11kV to the load through 132/33kV and 33/11kV transformer for each feeder.

3.2.2 Apply the IDMT overcurrent relay to the protection scheme.

The inverse definite minimum time (IDMT) overcurrent relay was chosen to apply in the protection scheme. The relay will monitor and operate if the magnitude of current flow in the line is greater than the setting current set in the relays. The current setting of the relays are varies based on the rated current at each of the relays.

3.2.3 Apply fault in the circuit model.

In order to study the circuit network behavior, the fault was applied in circuit network. The fault were applied in several locations in the circuit model, the location are at grid side, primary side of transformer 2, primary side of transformer 3 and at load 1. Faults were also applied for three conditions which are single-phase-to-ground, double-phase-to-ground and three-phase-to-ground fault.

3.2.4 Compare the relay operation time (ROT) between IDMT relay characteristic curves

There are several characteristic of relay curves were studied in this project. They are standard inverse (SI), very inverse (VI) and extremely inverse (EI). This curve is based on the IEC 60255 curve standard. The IEC 60255 is the standard that also used by utilities companies in Malaysia. The relay operation time was studied for all relays with implementation of all type of curves characteristic stated.

3.2.5 Compare the ROT between IEC and IEEE curve standard

The relay operation time were studied for two different type of relay curve standards which are IEC 60255 and IEEE C37.112. IEC 60255 is the standard that used in Europe while IEEE C37.112 is standard used in North America. Both graph are sharing the same formula of equation (2.2) but differ in constants value which result IEEE C37.112 Standard more sensitive in relay operation time than IEC 60255 Standard curve.

3.2.6 Compare the ROT before and after distributed generator (DG) installation.

The relay operation time (ROT) of all relays are compare for condition of before and after DG installation. The effect of DG installation to the current flow performance were also determined and studied.

3.2.7 Data Analysis

The data were analyzed to determine the relay operation time (ROT) based on several case stated before. The analysis and discussion of this experiment were made based on the objective of this project research as stated in chapter 1. The conclusion is then can be made.

3.3 Circuit Modelling

The circuit model of this project study were based on the distribution network in Perak. The distribution network were covered area of Bukit Merah to the nearby area. The 132 kV, 50Hz external grid supplies the system through a 132/33 kV transformer to the loads. All loads were connected to the 11 kV collection busbar via the 33/11 kV transformers. The selected area to fault application are at load, transformers and grid side. This area was selected as a fault point because the important equipment for the power system are placed in the area. Besides, the overcurrent relay has been used to protect the system where relays are positioned at the grid, load, primary side of transformer and secondary side of transformer. The simulation study was made based on the circuit model in PSCAD software.

3.3.1 Circuit Components.

The project were designed for six bus system which included two generators, transformers, busbar, current meters, loads and overcurrent relays. Therefore, the understanding on the component setting and characteristic are important in order to model the overcurrent relays scheme in circuit network. This is because, by selecting and setting the wrong equipment will leads to abnormal condition of circuit where the circuit could not run or operate and it will takes a long time to figure out the problem.

3.3.1.1 Three-Phase Voltage Source.

The source of the system was three-phase voltage source with RLC type. The voltage source was replacement of supply from grid.

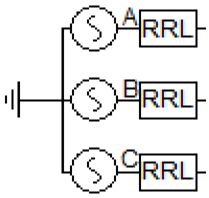

Figure 3.2: Three-phase voltage source.

Figure 3.2, shows the diagram of generator used in the network model. The generator is used as a power source for the power system where it is not actual component apply in the circuit. The generator is just the replacement for the supply from the grid. The generator used is a 3-phase Ac voltage source, where source impedance is specified as ideal. This generator source may be controlled through either fixed, internal parameters or variable external signals. The generator is set to produce 132 kV to the system.

3.3.1.2 Transformer

Transformer of the circuit model is shown as in Figure 3.3 below. The transformer is power transformer type where type of transformer winding can be change accordingly.

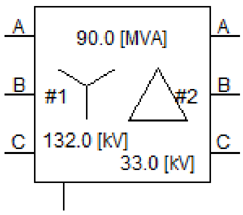

Figure 3.3: 3-Phase 2-Winding Transformer.

Figure 3.3 shows the three-phase transformer used in circuit model. This component model is a 3-phase, 2-winding transformer and it is based on the classical modeling approach. The generated power from the transformer is 33kV which then step down to 11kV. The transformer is set for 50Hz operation frequency with several setting for the MVA based on TNB single-line diagram. There are two types of transformer winding applied in the circuit which are 132/33 kV, and 33/11 kV. The setting of transformer was based on the reference in single line diagram.

3.3.1.3 Load

One of the parameters in the circuit design is load. Load used in this project is three phase type where all the three phases were connected to one load. Load were setting for frequency of 50Hz and rated voltage of 11kV with several other parameters such as rated active power (MW) and rated reactive power (MVAR).

Figure 3.4: Load

Unfortunately, for this project one of the disadvantages or limitation was the value of load were not acquired from TNB. Therefore, the load for the system is determined by using following formulas.

$$\frac{MW}{MVA} = \cos\theta \qquad (3.1)$$

$$\frac{MVAR}{MVA} = \sin\theta \qquad (3.2)$$

Where;

- MW – Rated Active Power.
- MVA – Rated Apparent Power.
- MVAR – Rated Reactive Power.
- Cos θ – Power factor.

The load was determined from the simple calculation based on the stated formulas. The value of power factor of the system were fixed to 0.90.

3.3.1.4 Measurement and Output Device.

Measurement is one of the most important things in simulation where current meter is the only measuring device in the simulation while output device were used to monitor the input quantities.

Figure 3.5: Current Meter and output meter.

Both device was actually interconnected each other where this devices were used to send input and display output of the system. The current meter was used as a measuring device to measure several quantities. There are several quantities that are measured such as voltage, current and power. In this project the current meter was also represent current transformer where the ratio is 1:1, input current equal to output current. The current meter was placed for each of the phase line. The base unit for the current meter is in kA.

3.3.1.5 Three phase fault logic.

Figure 3.6 shows the fault components that used in the circuit model. The fault is given for analysis purpose which to observe the relationship between faults and relay performance for all cases. The fault given to the system are single-line-to-ground, double-line-to-ground and three-phase-to-ground. The fault is given at t=1s for duration of 8s. The duration of fault need to be as long as it can be in order to make sure all relays are performed. If the duration of fault is too short, it is feared that the relays might not have enough time to operate.

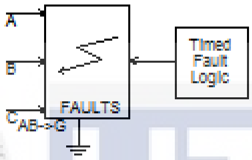

Figure 3.6: Three phase fault logic.

3.3.1.6 Overcurrent relay.

Overcurrent relay is the main protection device used in this project. This project were used phase-over current protection (51) for each of the phase on the relay.

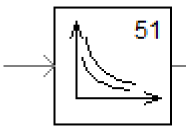

Figure 3.7: Overcurrent Relay.

Overcurrent relay is a protection algorithm block which implement into the system as the main protection study. The input to this component is a measured current signal which is in kilo Amp (kA). The relay functioning to compute and compares the current in value with the pickup value. The algorithm of the relay will defined as a trip when the input current is higher than the pickup current.

3.3.2 Overcurrent relay modelling

The block diagram presented in Figure 3.8 shows the three major functional components of an overcurrent relay. These components and their functionality are discussed below.

Figure 3.8: Functional Block Diagram of an Overcurrent Relay.

The current input are measured from each of the current meter for each phases. The current measured was in peak value. Next, the current from current meter was fed into RMS converter before protection relay. The current are converted from peak current to the RMS current. In this project all the current measured and recorded are in RMS value.

Once the RMS value of the current is obtained, this current is fed into the relay protection algorithm block. The function of this block is to compares the current value with the pickup value. If the input current is exceeds the pickup current value, the relay will operate with taking consideration of characteristic curve (Standard Inverse, Very Inverse and Extremely Inverse) and sends a trip signal once the operation time is elapsed [12].

Furthermore, in overcurrent relay modelling, the most important setting is pickup current setting and time dial setting.

3.3.2.1 Time-Dial Setting

Time dial setting (TDS) is also known as time multiplier setting of relay. TDS is the operating time of an electrical relay mainly depends upon two factors which are:

1. How long the moving parts of the relay to traveled for closing relay contacts and
2. How fast the relay covers this distance.

The distance of moving parts of relay traveled can be adjusted by choose the right TMS/TDS. The TDS is calibrated from 0 to 1 in steps of 0.05s. For this project the TDS is chosen for 0.1 and fixed for all of the relays in the circuit.

3.3.2.2 Pickup-current setting.

To guarantee a reliable, fast and safe operation of overcurrent relay. The overcurrent relays setting such as time dial setting, pickup value, and curve characteristic should be choose carefully. Otherwise, the relay will not properly functioning (not tripping) or gives the wrong tripping command. The pickup current of the relays are varies which depends on their rated current. The pickup current setting of overcurrent relay is generally ranged from 50% to 200%, in steps of 25%. Therefore, for this project the pickup current for overcurrent relay setting is 70% was chosen, therefore the current pickup at 0.7 x rated current.

Table 3.1: a) Pickup current for normal circuit, b) Pickup current for circuit with DG.

Relay	Rated Current (kA)	Pickup Current (kA)
R1	0.278	0.49
R2	1.118	1.96
R3	0.263	0.46
R4	0.751	1.31
R5	0.525	0.92
R6	1.549	2.71
R7	0.387	0.68
R8	0.774	1.35

(a)

Relay	Rated Current (kA)	Pickup Current (kA)
R1	0.141	0.25
R2	0.558	0.98
R3	0.681	1.2
R4	2.063	3.61
R5	0.53	0.93
R6	1.549	2.76
R7	0.418	0.73
R8	0.79	1.39

(b)

The table 3.1 shows the tables of pickup current for two different condition. Table (a) shows the pickup current setting for normal circuit. Whereas Table (b) shows the pickup current for circuit with installed DG. The pickup current setting for both conditions are different due to different in rated current. In normal circuit the rated current was contribute by grid supply only, while the rated current with DG installation were contributed by both supply sources of DG and grid.

3.3.3 Circuit Model.

The figure shows the circuit simulation and design of medium voltage distribution network**.** The system is interconnected circuit with total of six buses. The circuit covers the area from PMU Bukit Merah to several other substation such as PPU Bukit Merah, PPU Kubu Gajah, PPU Kuala Gula and PPU Kuala Kurau. The system was supplied from the grid of 132kV, then step down to the 33kV and 11kV through several transformer with different rating. The load of the system are varies, and determined using the method stated before.

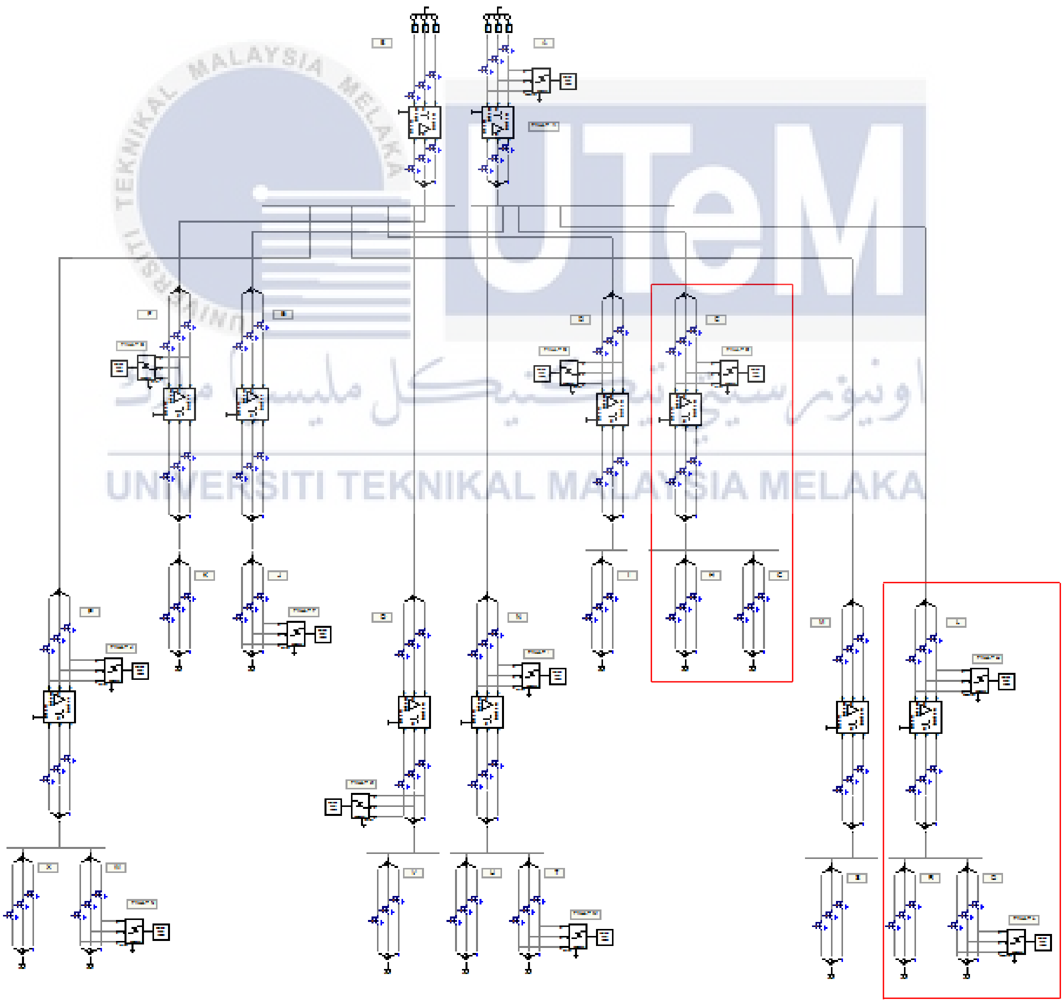

Figure 3.9: Simulation model of MV distribution network.

3.3.4 Circuit analysis.

For circuit analysis, only certain part from overall system which is as circle in Figure 3.9 will be study in details. Figure 3.10 shows the circuit model from Figure 3.9 for analysis designed in PSCAD software to investigate the performance of overcurrent relay when subjected to faults, characteristic curve, curve standard and DG installation. The major components and parameters of the test case are:

- Three phase voltage source, 50Hz, 132kV phase voltage.
- Three phase fault block to introduce single-phase-to-ground, double-phase-to-ground and three-phase-to-ground faults.
- Three phase load.
- Duration of simulation time = 10s
- Time to apply fault = 1s

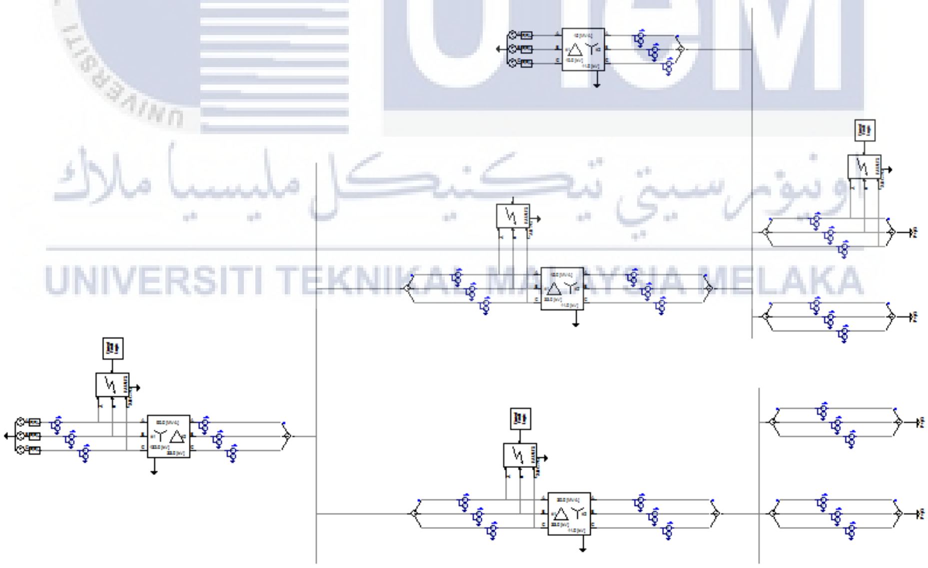

Figure 3.10: Circuit model for analysis study.

The load in circuit model is supplied with 132kV from the grid through the transformers of 132/33kV and 33/1kV at both feeder. In normal condition and many occasion, the distributed generator (DG) are not in service. The DG was only operated for the study on effect of DG installation to the performance of relay operation time. In the circuit model, the faults were applied at t=1 sec. The analysis was made based on relay operation time study. There are four cases were studied which are various type of faults, different type of relay curve characteristic, different of curve standard and impact of DG installation. All data was recorded and discussed in Chapter 4.

3.4 Summary

The methodology is to investigate the performance of relay operation time with follow a procedure according to the flow chart. In this chapter is began by modelling the circuit with setting and selecting various parameters before doing the analysis on ROT of all relays based on stated cases.

CHAPTER 4

RESULT AND DISCUSSION.

4.1 Introduction.

In this chapter the result of the project will be discussed in details. As stated in Chapter 1, the objective of this project is to investigate the performance of protection system based on relay time operation (ROT). Several situations and conditions are performed in order to study the IDMT overcurrent relay performance. The relay and protection scheme performances were studied based on several cases which are various type of faults, various IDMT relay curve characteristic, different of IEC 60255 and IEEE C37.112 curve's standard and impact of distributed generation (DG) installation in power system.

4.2 Network Model.

The circuit model of this project study is shown as in Figure 4.1. The circuit diagram are based on the medium voltage distribution network in Perak. The distribution network are covered area of Bukit Merah to the nearby area. The 132 kV, 50Hz external grid supplies the system through a 132/33 kV transformer with load rated of 6.75MW and 13.5MW for load 1 and load 2 respectively. Both loads were connected to the 11 kV collection busbar via the 33/11 kV transformers. The figure also shows the location of fault applied in the power system. A range of fault types, including SLG, DLG and TLG are simulated at the selected locations presented such as at load 1, transformer 1, transformer 2 and grid side. This area was selected as a fault point because the important equipment for the power system were placed in that area. Besides, the overcurrent relay has been used to protect the system where relays are positioned at stated locations. The simulation study was made based on the circuit model in PSCAD software.

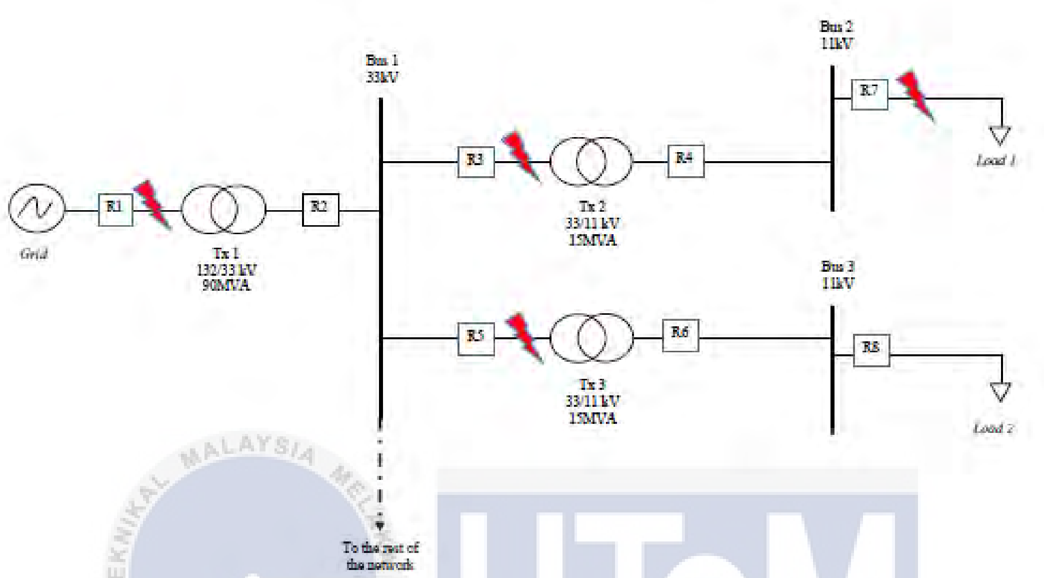

Figure 4.1: Distribution of Medium Voltage (MV) Network.

4.3 Result & Discussion.

4.3.1 Various Type of Fault.

Various type of faults is one of the ways to study the performance of protection scheme (overcurrent relay). In this project various types and locations of fault were applied to the circuit to study the performance of protection scheme based on relay operation time (ROT). The result were recorded for standard inverse characteristic curve of IEC 60255. IEC 60255 is a common standard used by most of utility company in Malaysia. The fault is given in several location such as grid, transformer 2, transformer 3 and load 1 as shown in Figure 4.1 where each fault given are single-phase-to-ground, double-phase-to-ground and three-phase-to-ground.

4.3.1.1 Case 1: Fault at Phase A at Different Location.

Table 4.1 shows the relay operation time (ROT) at phase A with standard inverse characteristic setting. The table shows several parameters of fault given which are location of fault and type of fault. Based on the table, result shows the different parameter of fault applied result the different of ROT.

Table 4.1: Relay Operation Time (ROT) at Phase A.

Fault Location	Fault Type	Relay Tripping Time Based on Curve Characteristic (sec)							
		Standard Inverse							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1Ø	1.156	NO	NO	NO	NO	NO	NO	NO
	2Ø	1.156	NO	NO	NO	NO	NO	NO	NO
	3Ø	1.156	NO	NO	NO	NO	NO	NO	NO
Transformer 2	1Ø	NO	NO	NO	NO	NO	NO	NO	NO
	2Ø	1.328	1.351	1.2	NO	NO	NO	NO	NO
	3Ø	1.328	1.334	1.195	NO	NO	NO	NO	NO
Transformer 3	1Ø	NO	NO	NO	NO	NO	NO	NO	NO
	2Ø	1.328	1.351	NO	NO	1.253	NO	NO	NO
	3Ø	1.327	1.334	NO	NO	1.244	NO	NO	NO
Load	1Ø	NO	NO	1.568	1.398	NO	NO	1.28	NO
	2Ø	3.268	NO	1.585	1.407	NO	NO	1.283	NO
	3Ø	3.161	3.394	1.431	1.413	NO	NO	1.287	NO

It can be seen that, when fault of three-phase-to-ground is given to the system the ROT of relays is faster compared to when the double-phase-to-ground and single-phase-to-ground fault were applied. It can be seen, when fault were given at transformer 3, the three-phase fault gives the fastest ROT where the recorded ROT of relay 2 (R2) is 1.334s while when the double-phase-to-ground fault is applied the ROT of R2 lags to 1.351s. However, some relays are shown only small significant of different in ROT, besides when the fault were applied at the load side, the ROT recorded is vice-versa which ROT of SLG fault is faster than the ROT of DLG and TLG fault. The recorded ROT of R4 shows that when the single-phase fault were applied, the ROT is 1.398s whereas the ROT of three-phase fault is 1.412s which is slower than the single-phase fault. Moreover, the result also shows that the same pattern of not-operate (NO) when SLG fault were given at transformer 2 and transformer 3. This event were happened due to the type of transformer winding in the circuit where both start (secondary of Transformer 1) and end (primary of transformer 2 and 3) of the transformer winding is delta type winding. When the single-phase-to-ground fault is applied at line in between delta winding configuration, the fault current will circulate in the winding since the delta type winding do not have common connection. Therefore, the fault given will not operate the relay at phase A. Furthermore, the result in the table also shows the same pattern of NO at relay 6 (R6) and relay 8 (R8) where the relay does not operate for all occasion. The relay does not operate because of the fault point in the circuit is situated before the relay or in different line where this will cause the R6 and R8 will detect the small current which is smaller than the current set in the relays setting.

4.3.1.2 Case 2: Fault at Phase B at Different Location.

ROT of relays at Phase B was presented in Table 4.2. The speed of ROT characteristic is the same as been discussed for ROT at Phase A. The applied TPG fault will result in fastest ROT compare to the other two type of faults. Based on the table, the recorded ROT of relay 1 (R1) shows that when TPG fault were applied at transformer 3, the ROT recorded is 1.329s while for the DLG fault result in ROT of 1.522s where the percentage different is 14%. The same thing happened to other relays for all location of fault applied. Besides that, the not operate (NO) pattern can be observe for all relays when SLG fault were applied at transformer 2 and transformer 3. This scenario happened due to the disadvantages of the delta-delta winding transformer where the transformer does not have neutral or common connection where core will be equal to the full line voltage in case of earth fault at one phase [24]. The current recorded at R1 when this event (SLG fault) happened is 0.285kA where the current magnitude is the same as in normal condition without fault. Furthermore, the result in the table also shows the same pattern of NO at relay 6 (R6) and relay 8 (R8) where the relay does not operate for all occasion. The relay does not operate because of the fault point in the circuit is situated before the relay or in different line where this will cause the R6 and R8 will detect the small current. Besides that, the NO pattern also can be detected in most occasions when single-phase fault are applied. This is because when the fault type is single-phase-to-ground, the fault is given at the Phase A only where the other phase (Phase B and Phase C) do not effected in terms of relay operation due to the small current detection.

Table 4.2: The Relay Operation Time (ROT) at Phase B.

Fault Location	Fault Type	Relay Tripping Time Based on Curve Characteristic (sec)							
		Standard Inverse							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1∅	1.766	NO	NO	NO	NO	NO	NO	NO
	2∅	1.155	NO	NO	NO	NO	NO	NO	NO
	3∅	1.155	NO	NO	NO	NO	NO	NO	NO
Transformer 2	1∅	NO	NO	NO	NO	NO	NO	NO	NO
	2∅	1.522	1.36	1.201	NO	NO	NO	NO	NO
	3∅	1.328	1.33	1.191	NO	NO	NO	NO	NO
Transformer 3	1∅	NO	NO	NO	NO	NO	NO	NO	NO
	2∅	1.522	1.36	NO	NO	1.255	NO	NO	NO
	3∅	1.329	1.33	NO	NO	1.24	NO	NO	NO
Load	1∅	NO	NO	1.64	NO	NO	NO	NO	NO
	2∅	6.469	3.368	1.419	1.42	NO	NO	1.293	NO
	3∅	3.216	3.369	1.419	1.428	NO	NO	1.295	NO

4.3.1.3 Case 3: Fault at Phase C at Different Location.

The relay operation time (ROT) of all relays at phase C are shown in Table 4.3. Based on the table, the result shows that there are many relays are in not operated (NO) condition compare to the relays at Phase A and Phase B. This is due to the fault given to the system were on the Phase A and Phase B. The SLG fault was applied on Phase A only, whereas the DLG fault was applied to the Phase A and Phase B while the only fault applied to the Phase C is TPG fault. Moreover, the ROT of relays is faster when TPG fault was applied than the other faults. Based on the table the recorded ROT of relay 1 (R1) shows that, when the TPG fault is applied to the system, the ROT is 1.333s while when DLG fault was applied to the system the recorded ROT is 1.464s with percentage different of 9.8%. The table also shows that, when fault was given to the load, the ROT of relay 4 become the most fastest with the recorded time of 1.441s followed by 1.447s, 3.464s and 3.244s for relay 3, relay 2 and relay 1 respectively. The R4 have the fastest ROT because fault point is near to the relay which the current magnitude is high and this will result in the fast relay operation since the mechanism of relay operation is also related to the current magnitude, where the higher the current the faster the relay operation. The ROT of the relays also follow the coordination protection which the nearest relay to the fault to trip first unless the relay 1 and relay 2. Based on the protection scheme practice, R2 should trip first before R1 because the location of R2 is much near to the fault compare to R1. Besides, based on the recorded current the R1 having smallest current magnitude compare to R2 which is 0.802 kA and 2.458 kA respectively. This is happened due to the ratio of fault current to pickup current of R1 and R2 is insignificant which result in condition where in some occasion the ROT of R1 is faster than R2. Therefore, the setting of the relay must be adjusted in order to have a good coordination for the protection scheme in the power system network.

Table 4.3: Relay Operation Time (ROT) at Phase C.

Fault Location	Fault Type	Relay Tripping Time Based on Curve Characteristic (sec)							
		Standard Inverse							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1∅	1.602	NO	NO	NO	NO	NO	NO	NO
	2∅	1.647	NO	NO	NO	NO	NO	NO	NO
	3∅	1.156	NO	NO	NO	NO	NO	NO	NO
Transformer 2	1∅	NO	NO	NO	NO	NO	NO	NO	NO
	2∅	1.464	NO	NO	NO	NO	NO	NO	NO
	3∅	1.332	1.336	1.195	NO	NO	NO	NO	NO
Transformer 3	1∅	NO	NO	NO	NO	NO	NO	NO	NO
	2∅	1.464	NO	NO	NO	NO	NO	NO	NO
	3∅	1.333	1.336	NO	NO	1.245	NO	NO	NO
Load	1∅	NO	NO	NO	NO	NO	NO	NO	NO
	2∅	NO	NO	1.678	NO	NO	NO	NO	NO
	3∅	3.244	3.464	1.447	1.441	NO	NO	1.304	NO

4.3.1.4 Comparison Case 1, Case 2, and Case 3.

Based on all cases, the obvious different that can be observed from the cases is the not operate (NO) pattern where the NO pattern in Phase C is higher compare to the other NO pattern recorded in Phase B and Phase A. This situation occurred due to the fault, when the SLG fault was applied to the system, the fault is only given to the Phase A, while when the fault is apply as DLG, the fault was applied to the Phase A and Phase B only. Only if the fault type is TPG, the fault is affected to Phase C which leads to the most NO pattern when the fault is SLG and DLG. The same things goes to Phase B where the NO pattern is higher than the Phase A. However, in the practical perspective, when fault is apply to the single phase or double phase, the other phases will also affected due to the unbalance condition or under voltage which will affect the power system equipment. In real this situation will lead to the circuit breaker (CB) operation.

4.3.1.5 Conclusion.

Based on all cases, the relays will functioning faster when the fault is applied for TPG followed by DLG and SLG. The relays also operated based on the location of fault applied, if the fault was occurred before relay, the relay will not operate since the recorded current is smaller compare to pick up current. Besides, the relay will operate faster when the fault point is near to the relay which the higher the fault current magnitude the faster the relay operation. Moreover, the relays also operated accordingly, this can clearly understand when the applied fault is given at the load, and relays will operate from the nearby relay (R7) at the load followed by other relays of R4, R3, R2 and R1.

4.3.2 Various Type of Relay Curve.

There are a hundred of type of protection standard practice in the world. Among of them are IEEE C37.112 and IEC 60255. IEEE C37.112 is a standard for relay characteristic curve which mainly used in North America. IEC 60255 is a standard that are famously used in Europe countries. IEC 60255 sharing the similarities in many ways with British Standard. In Malaysia most of the standard were follow the British Standard or IEC Standard. For utility company such as Tenaga Nasional Berhad (TNB), the IEC 60255 Standard were used in practice for the protection system [5].

4.3.2.1 Comparison IDMT curve characteristic.

In this part, the study focused on IDMT relay curve characteristic for the IEC 60255 Standard. This standard is chosen because the utilities companies in Malaysia such as TNB apply this standard in their practice. The standard defines four type of current curve which are standard inverse (SI), very inverse (VI), extremely inverse (VI) and long-time inverse (LTI). However, the study will focus on SI, VI and EI only.

Table 4.4: Relay Operation Time (ROT) for IDMT Relay Curve Characteristic.

Fault Location	Fault Type	Relay Tripping Time Based on Curve Characteristic (sec)																	
		Standard Inverse						Very Inverse						Extremely Inverse					
		R1	R2	R3	R4	R5	R7	R1	R2	R3	R4	R5	R7	R1	R2	R3	R4	R5	R7
Grid	1Ø	1.156	NO	NO	NO	NO	NO	1.024	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO
	2Ø	1.156	NO	NO	NO	NO	NO	1.024	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO
	3Ø	1.156	NO	NO	NO	NO	NO	1.024	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO
Transformer 2	1Ø	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	2Ø	1.328	1.351	1.2	NO	NO	NO	1.183	1.214	1.044	NO	NO	NO	1.104	1.144	1.012	NO	NO	NO
	3Ø	1.328	1.334	1.195	NO	NO	NO	1.183	1.193	1.042	NO	NO	NO	1.104	1.119	1.014	NO	NO	NO
Transformer 3	1Ø	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
	2Ø	1.328	1.351	NO	NO	1.253	NO	1.183	1.215	NO	NO	1.092	NO	1.103	1.144	NO	NO	1.028	NO
	3Ø	1.327	1.334	NO	NO	1.244	NO	1.183	1.193	NO	NO	1.084	NO	1.103	1.119	NO	NO	1.028	NO
Load	1Ø	NO	NO	1.568	1.398	NO	1.28	NO	NO	1.556	1.267	NO	1.11	NO	NO	1.75	1.196	NO	1.041
	2Ø	3.268	NO	1.585	1.407	NO	1.283	4.767	NO	1.865	1.282	NO	1.115	NO	NO	1.821	1.22	NO	1.043
	3Ø	3.161	3.394	1.431	1.413	NO	1.287	4.569	4.998	1.326	1.29	NO	1.118	NO	NO	1.299	1.236	NO	1.048

The table 4.4 shows the relay operation time (ROT) for IDMT relay curve characteristic. The table shows several parameters to study the ROT of the relays in the circuit network. The parameters are the different location and type of fault given, and type of curve characteristic which are standard inverse (SI), very inverse (VI) and extremely inverse (EI). Based on the table, all ROT of relays are monitored and tabulated except R6 and R8. The reason is the R6 and R8 have a not-operate (NO) pattern for all occasion due to the fault that occurred before the relays which result in small magnitude of current. The result shows that the fastest ROT of relays is the relay with EI characteristic followed by VI characteristic and SI characteristic. The data shows that when three-phase-to-ground fault was given at grid side, the relay 1 (R1) was operate at time of 1.006s for EI characteristic followed by 1.024s and 1.156s for VI characteristic and SI characteristic. All relays are show the same behavior for all occasion except when fault is given at the load 1.

Table 4.5: Comparison relay model between curve characteristic.

Summary of Results From Relay Model (Fault Applied at t= 1.00s)			
Curve Time (sec)	Standard Inverse	Very Inverse	Extremely Inverse
Operating Time (s)	0.328	0.183	0.104
Ideal Operating Time (s)	0.268	0.115	0.050
Trip Signal Time (s)	1.328	1.183	1.104
Ideal Trip Signal Time (s)	1.268	1.115	1.050
Percentage Error (%)	6	6.8	5.4

Trip signal time = time at which fault is applied + Operating time

Based on the table 4.5, the table shows the comparison of relay model between all the three types of curve characteristic. The result is calculated by using equation 2.2, based on the relay 1 (R1) when three-phase-to-ground fault was given at transformer 2, the result shows that the fastest ROT of R1 is for the curve characteristic of extremely inverse which is 0.104s followed with 0.183 and 0.328 for very inverse and standard inverse respectively. The table also shows the comparison between the ROT from simulation and ideal ROT based on calculation by using formula [2.2]. The result from simulation is a bit different from the ideal calculation where the percentage different or error for the standard inverse is 6%, while the very inverse having 6.8% error and extremely inverse has the smallest percentage error of 5.4%.

4.3.2.2 Comparison IEC 60255 & IEEE C37.112 Relay Curve Standard

The result in Table 4.6 is to show the different of (ROT) between two different standards which are IEEE C37.112 and IEC 60255. This two standard have different type of curve characteristic graph. The result in Table 4.6 is based on the relays at Phase A with extremely inverse characteristic is set in the relay setting. The extremely inverse type curve is used in comparing this two standard which this type of curve characteristic exist in both standards. Based on the table, the result shows that when IEEE C37.112 Standard curve is applied, the ROT of the relays is much faster compare to the IEC 60255 curve. The differences can be seen obviously at relay 1 (RI), when fault is applied at the transformer 2. The ROT recorded in the table for R1 with IEEE Standard is 1.049s compare to R1 with IEC 60255 with 1.104s of ROT. The percentage different between this two type of curve is around 5%. The reason is, IEEE Standard and IEC Standard sharing the same formula of equation (2.2) but having different value of constant as in Table 2.1 which gives IEEE Standard more sensitive compare to IEC Standard. In real application of power system, North America region have small voltage compare to European region where to supply the same power, the voltage for North America region is 120V while the European region is 240V. Therefore, the lower the value of voltage, the higher the amount of current. When the fault is occurred at power line of North America region, it will results such high value of current compare to European region. That is why the relay constant for IEEE C37.112 Standard is need to be more sensitive in time operating compare to relay with IEC 6022 Standard. All of the relays shows that behavior in most occasion except when fault is given at the generator side with percentage error of 0.9%, this event might due to several factor which one of them is the relay setting.

Table 4.6: Relay Operation Time (ROT) of IEEE C37.112 and IEC 60255.

Fault Location	Fault Type	Relay Operation Time, ROT (sec)															
		IEEE C37. 112								IEC 60255							
		R1	R2	R3	R4	R5	R6	R7	R8	R1	R2	R3	R4	R5	R6	R7	R8
Grid	1∅	1.015	NO	NO	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO	NO	NO
	2∅	1.015	NO	NO	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO	NO	NO
	3∅	1.015	NO	NO	NO	NO	NO	NO	NO	1.006	NO	NO	NO	NO	NO	NO	NO
Transformer 2	1∅	NO	NO	NO	NO	NO	NO	NO	NO	NT	NO	NO	NO	NO	NO	NO	NO
	2∅	1.048	1.06	1.019	NO	NO	NO	NO	NO	1.104	1.144	1.012	NO	NO	NO	NO	NO
	3∅	1.049	1.055	1.021	NO	NO	NO	NO	NO	1.104	1.119	1.014	NO	NO	NO	NO	NO
Transformer 3	1∅	NO	NO	NO	NO	NO	NO	NO	NO	NT	NO	NO	NO	NO	NO	NO	NO
	2∅	1.05	1.061	NO	NO	1.026	NO	NO	NO	1.103	1.144	NO	NO	1.028	NO	NO	NO
	3∅	1.05	1.055	NO	NO	1.026	NO	NO	NO	1.103	1.119	NO	NO	1.028	NO	NO	NO
Load	1∅	NO	NO	1.222	1.073	NO	NO	1.032	NO	NO	NO	1.75	1.196	NO	NO	1.041	NO
	2∅	4.299	NO	1.245	1.078	NO	NO	1.033	NO	NO	NO	1.821	1.22	NO	NO	1.043	NO
	3∅	4.09	4.538	1.106	1.081	NO	NO	1.033	NO	NO	NO	1.299	1.236	NO	NO	1.048	NO

4.3.2.3 Conclusion.

There are two comparison has been made for various type of relay curve. First, comparison between IDMT curve characteristic based on the IEC 60255 standard. The result shows that the fastest ROT of relays is the relay with extremely inverse characteristic followed by very inverse characteristic and standard inverse characteristic.

Secondly, the comparison were made between two different types of relay curve standard which are IEC 60255 and IEEE C37.112 curve standard. Based on result, the practice of IEEE C37.112 Standard for the relay protection will result in the fastest (ROT) compare to when the IEC 60255 Standard is used. The different of this two standard is due to the different curve characteristic. Even though, the characteristic curve is same for both standard which is extremely inverse curve, but the characteristic of the curve is differ from one another. North America region have small voltage compare to European region where the voltage for North America region is 120V while the European region is 240V. Therefore, when fault is occurred at power line of North America region, it will results such high value of current compare to European region. That is why the relay constant for IEEE C37.112 Standard is need to be more sensitive in time operating compare to relay with IEC 6022 Standard Besides, the flexibility of the setting for phase over current (51) protections should appreciated.

4.3.3 Relay Operation With DG and Without DG Installation.

This part is to examine on how the installation of distributed generation (DG) effect to the power system network especially on protection scheme. The installation of DG commonly offer several compelling advantages but in certain circumstances the presence of DG in power system will lead to the protection problem. One of the obvious condition is when there is no longer single direction power flow commonly from upstream generator or grid supply. With multiple sources, reverse power flow from DG unit also happened, this event will affect the coordination and operation of the standard overcurrent protection scheme [13].

4.3.3.1 Network Model.

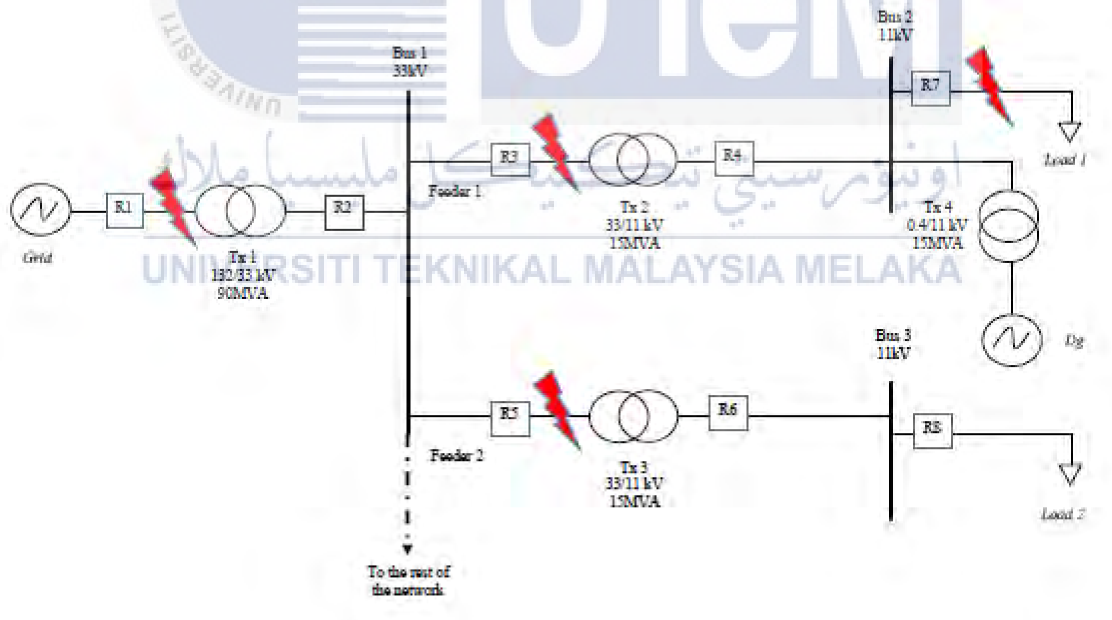

Figure 4.2: Circuit Model of Power System with DG Installation.

The circuit model with installation of distributed generation (DG) is shown as in Figure 4.2. The 132 kV, 50Hz external grid supplies the system through the 132/33 kV transformer and bus 1 (33kV) to feeder 1 and feeder 2 through 33/11kV transformer. In the simulation, the distributed generation (DG) is connected to bus 2 through a 0.4/11kV transformer. In the simulation also the load applied is 6.75MW and 13.5MW for load 1 and load 2 respectively. The same location and type of faults were applied to the network model.

4.3.3.2 Relay Operation Time with DG and without DG.

The comparison of the relay operation time (ROT) before and after DG installation are studied. The result are shown in table 4.7, the tabulated result was based on the ROT for all relays at Phase A with setting of standard inverse characteristic with applied three-phase-to-ground fault at various location. Based on the table, the ROT of the relays is faster when the DG was installed compare to before the DG installation.

Table 4.7: Relay Operation with DG and Without DG.

Fault Location	Relay Operation Time, ROT (sec)															
	With DG Installation								Without DG Installation							
	R1	R2	R3	R4	R5	R6	R7	R8	R1	R2	R3	R4	R5	R6	R7	R8
Grid	1.13	1.893	2.588	2.336	NO	NO	NO	NO	1.156	NO	NO	NO	NO	NO	NO	NO
Transformer 2	1.25	1.249	1.27	2.609	NO	NO	NO	NO	1.328	1.334	1.195	NO	NO	NO	NO	NO
Transformer 3	1.25	1.249	2.898	2.61	1.238	NO	NO	NO	1.327	1.334	NO	NO	1.244	NO	NO	NO
Load	1.71	1.702	2.143	2.143	NO	NO	1.217	NO	3.161	3.394	1.431	1.413	NO	NO	1.287	NO

In the table, it can be seen that when the DG was in-service and fault was given at load 1, the ROT of relay 1 (R1) is 1.71s compare to R1 when DG is out-of-service which the ROT recorded is 3.161s. This relay behavior is shown by other relays too where the relay operation is faster after DG installation. Moreover, the false tripping or sympathetic tripping is happened when fault were applied at transformer 2, transformer 3, and grid side. Before the DG installation, the relay 4 (R4) were not operated since it is located after the fault location where the current should drop and smaller from the pickup current. But in this case, when the DG is install the R4 was operated with 2.609s and 2.610s for the transformer 1 and transformer 2 respectively. This situation happened due to the changes of current flow where the current is flowing from two different sources which are grid and DG where it is result in two different current flow from upstream and downstream of circuit network.

Table 4.8: Comparison of ROT Before and After DG Installation.

Fault Location	Time (sec)	With DG	Without DG	Percentage Different (%)
Grid	Operating	0.134	0.156	14
	Trip	1.134	1.156	
Transformer 2	Operating	0.249	0.328	24
	Trip	1.249	1.328	
Transformer 3	Operating	0.247	0.327	24
	Trip	1.247	1.327	
Load	Operating	0.710	2.161	85
	Trip	1.710	3.161	

Trip signal time = time at which fault is applied + Operating time

Based on the Table 4.8, the result shows the comparison of percentage different of ROT before and after distributed generator (DG) installation. The result calculated is based on relay 1 (R1). As discuss before, the ROT for the relay in a system with DG is much faster compare to relay in a normal system. Furthermore, based on the table, the percentage different is increase from generator to the load, from 14% to 85%. The differences shows that the farthest the fault location from grid the higher the percentage different of ROT. When fault happened at grid, the percentage different is 14% while when fault happened at the load the percentage different is 85%. This situation happened due to the combination of current to the fault point. When fault occurred at the grid, the grid is near to the fault point, therefore the contribution from the grid to the fault is higher compare to when the fault happened at load side where the contribution of the grid to the fault point is low due to the distance of the fault point, compare to the contribution from DG result in slow operating time. Besides, the current recorded is higher when fault at grid which is 40.97kA compare to 1.039kA in normal circuit where the network is absent of DG. This phenomena also result in faster operation of relay when DG units were installed.

4.3.3.3 Current Flow Study.

The current flow was studied for each of the fault location in the power system which are at grid, transformer 2, transformer 3, and load 1. The following figures shows the details of current flow when fault occurred in the power system.

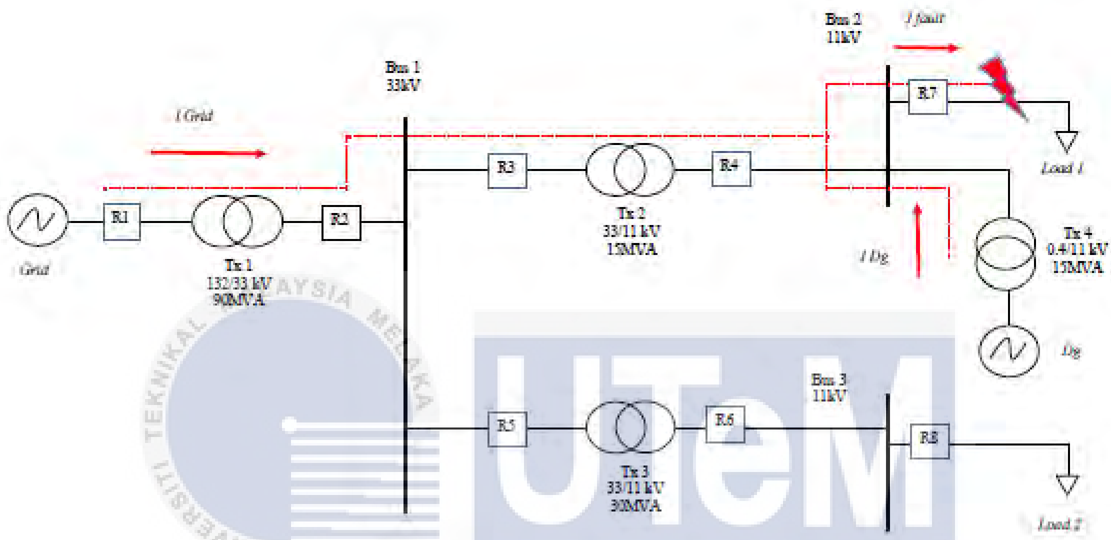

Figure 4.3: The current flow when fault is happened at Load 1.

When fault is happened at load 1, the current are flow from two sources which are DG and Grid. Besides, the operated relay are R1, R2, R3, R4 and R7. The relays are operate since the high inrush current from the grid and distributed generator (DG) to the fault point result in detection of high magnitude of current by relay. The fastest operated relay is R7 which is 1.217s compare 1.287s for the normal circuit. The fastest operation was resulted from the large inrush current detection by relay which is 25.907kA. The current is high due to the combination of current from DG and grid. The current in normal circuit was recorded with magnitude of 11.38kA, while after DG was installed, the current increase to 25.907kA where the percentage different before and after DG installation is around 54%.

Next, when fault was given at Transformer 2 as shown in Figure 4.4, the direction of current are from two different direction which from upstream (grid) and downstream (DG). Based on the circuit in the figure, the operated relay are R1, R2, R3 and R4. The ROT of the relays are recorded in the Table 4.5 which are 1.249s, 1.2490s, 1.270s and 2.609s for R1, R2, R3 and R4 respectively. Based on the normal condition the R4 was not operated since the current flow are in one direction from the grid to the downstream, the current should flow from the grid and end at fault point of transformer 2, but for this case there are current flow from the DG from the downstream which result for R4 to operate. This condition is also known as false tripping (in-term of circuit breaker) where the undesired relay also operate for the undesired condition. In this case the undesired operated relay is R4.

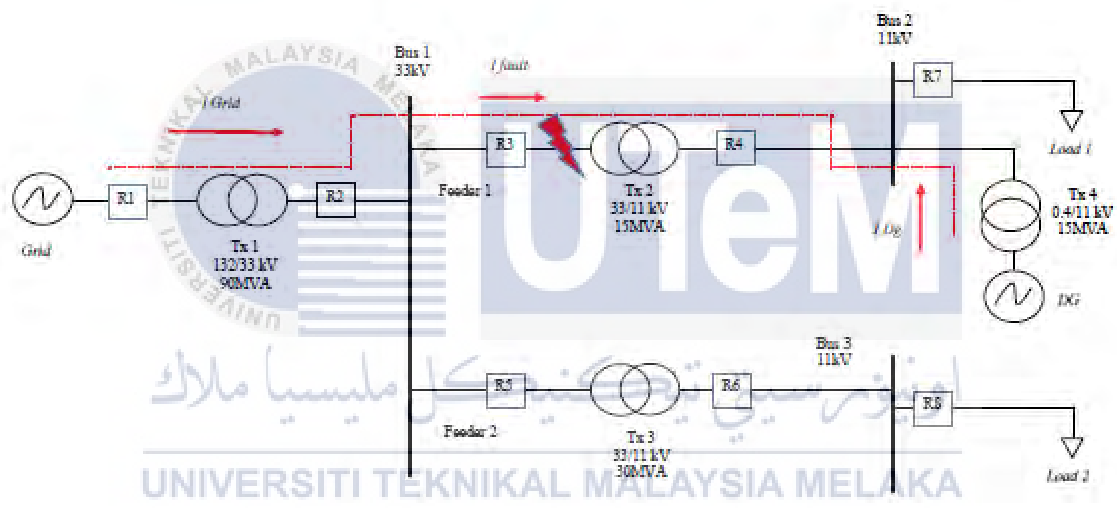

Figure 4.4: The current flow when fault is happened at Transformer 2.

Furthermore, if fault is given at transformer 3 as shown in the figure 4.5, the event will result in flowing of current from DG and grid to the fault point at primary side of transformer 3 with magnitude of 25.208kA. There are five relay that are operated which are R1, R2, R3, R4, and R5. From the grid R1 and R2 is operate at almost the same time which are 1.247s and 1.249s. While 2.898s and 2.610s for R3 and R4 respectively. The fastest operated relay was R5 which is 1.238s where the relay situated near to the fault point. This is show that the highest fault level will result in fastest ROT. Besides that, the false tripping also occurred in this condition where the undesired relay of R3 and R4 are operated. This condition will disable the system at area from bus 1 to bus 2 to continue the operation, where this situation does not comply the good protection scheme practice. The good protection system is to isolate the faulty area from the other part of the power system whereas in this condition the unfaulty system also isolated.

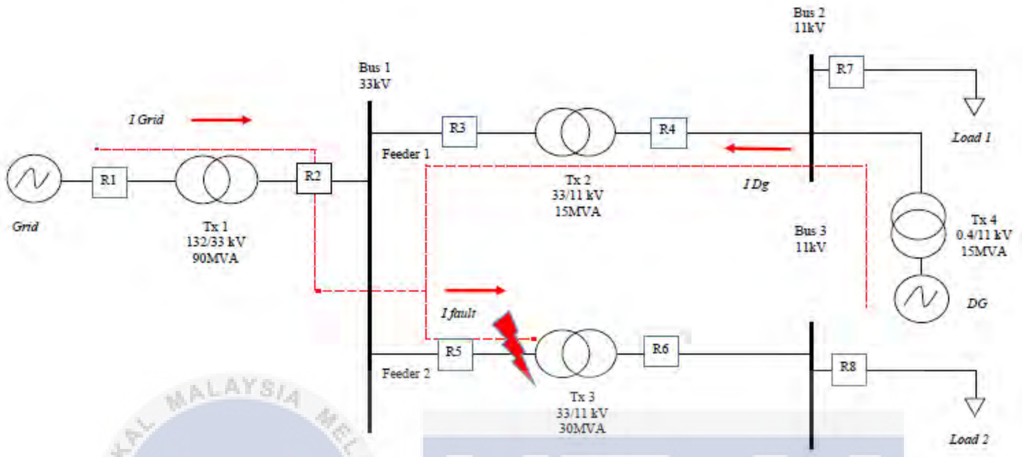

Figure 4.5: The current flow when fault is happened at Transformer 3.

Lastly, when the fault is applied at the grid side, as seen in the Figure 4.6, the current flow from the grid to fault point before transformer 1 and the other current flow is from DG to upstream where the fault located. The magnitude of fault current recorded at the fault point is 40.97kA. Based on table 4.5 and figure 4.6, the operated relay are R1, R2, R3, and R4, where the ROT are 1.134s, 1.893s, 2.588s and 2.336s respectively. The fastest operate relay is R1 where the fault point is located near to relay followed by R2, R4 and R3. While the ROT for the R3 and R4 is a little bit slower compare to R1 and R2 which is lag 1 second. This is because the different current level from two different supplier. Besides, the R4 is operate before R3 due to the current flow from the downstream to the upstream of power system. There are false tripping occurred in this event where R3, R4 and R2 should not operate since the fault point is located before them. But due to the DG installation, the DG contribute to the current flow and larger fault current. If false tripping does not occur, the distributed generation installed can be used to supply power for the unaffected area while the grid supply is blocked since the circuit breaker is tripped.

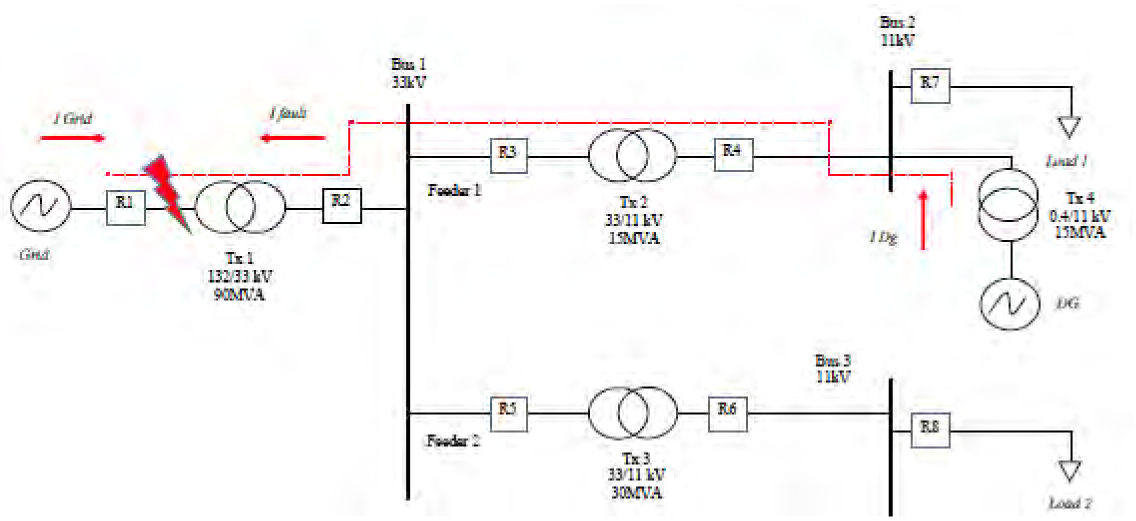

Figure 4.6: The current flow when fault is happened at Generator.

4.3.3.4 Conclusion.

Based on the project study, there are several effect of DG to the protection in circuit network such as different in relay operation time (ROT), different in current flow and false tripping.

The relay operation time of all relays will operate much faster when the relay is operated in circuit network with DG installation, whereas the ROT will drop for relays in circuit network with absent DG. This is happened due to the combination of current from two different source which are grid and DG. This will result in larger in rush current detection by the relay and make the relay operation faster.

Besides, the DG installation also made the current flow in two different direction. This situation will lead to the false tripping, where the condition when the undesired relay to operate and isolating the healthy feeder to continue operate.

4.4 Summary

In a nutshell, the project was studied on the performance of protection scheme in medium voltage distribution network of Bukit Merah area. The performance studied is based on the relay operation time (ROT) with various type and location of faults been applied to the circuit network. Several comparison also have been made based on different type of faults applied, different type of IDMT curve characteristic of IEC 60255, different type of relay curve standard (IEC 60255 and IEEE C37.122) and lastly the comparison of circuit network with and without DG installation.

Based on the analysis on various type of fault applied, the ROT of the relays will operating fast when the fault were applied for three-phase-to-ground and followed by double-phase-to-ground and single-phase-to-ground. The ROT of the relays also operated based on the magnitude of current which depends on the location of fault applied.

Furthermore, there are two comparison has been made for various type of relay curve. First, the comparison between IDMT curve characteristic based on the IEC 60255 standard and second is comparison between two different types of relay curve standard which are IEC 60255 and IEEE C37.112 curve standard. For the IEC 60255 there are three type of curve studied which are SI, VI and EI. Result shows that the fastest ROT of relays is the relay with EI characteristic followed by VI characteristic and SI characteristic. Besides, the practice of IEEE C37.112 Standard for the relay protection will result in the fastest (ROT) compare to when the IEC 60255 Standard is used. The different of this two standard is the curve for IEC is grouped as type 1.2 while curve for IEEE was grouped as type 1 curve which the ROT of the relays will faster than the relay with curve of type 1.2.

Lastly, the study shows that, there are several effect of DG to the protection in circuit network such as different in relay operation time (ROT), different in current flow and false tripping. Besides that, the ROT of all relays will operate much faster when the relay is operated in circuit network with DG, whereas the ROT will drop for relays in circuit network with absent DG.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

In protection system, there are several type of protection scheme that are used in order to protect the power system from fault or any unwanted condition, among of it, is overcurrent protection. This project study is to determine the performance of overcurrent relay in protection system. The study of performance relay are based on relay operation time (ROT). The project study was based on the medium voltage distribution network. The data for the circuit diagram was obtained from TNB. To analyze the performance of relay operation time, several tests or cases were performed. There are four test have been done which are various type of fault given, different type of IDMT curve characteristic, implementation on different standard of curve and lastly installation of single-DG to the power system. Each of the cases were studied and discussed as in previous chapter. The curve characteristic study is based on IEC 60255 which are standard inverse, very inverse and extremely inverse. Whereas for the curve standard, IEC 60255 and IEEE C37.112 were compared. It can be concluded that, the ROT of relays were varies and changed with all variables in the performed test. The relay operation time is faster when three phase to ground fault, EI curve characteristic curve, IEEE C37.112 Standard and DG installation were implemented for each of the cases respectively. The failure of relay operation will interfere the continuity of supply to the load and decrease the reliability of protection system.

5.2 Recommendation and Future Work

There are a few recommendations for future work to be done in this project. In order to make the protection system more safe, reliable and faster operation of overcurrent relay, the coordination of overcurrent relay in the power system protection scheme should take into account. The coordination is one of the important criteria for the good protection practice. The overcurrent relays must operate in sequence based on the location and type of fault occurred. Besides, the cable characteristic also can be studied for the future work where the cable characteristic gives a significant impact to the system. Therefore, in the future work, there are new additional parameter to be analyze.

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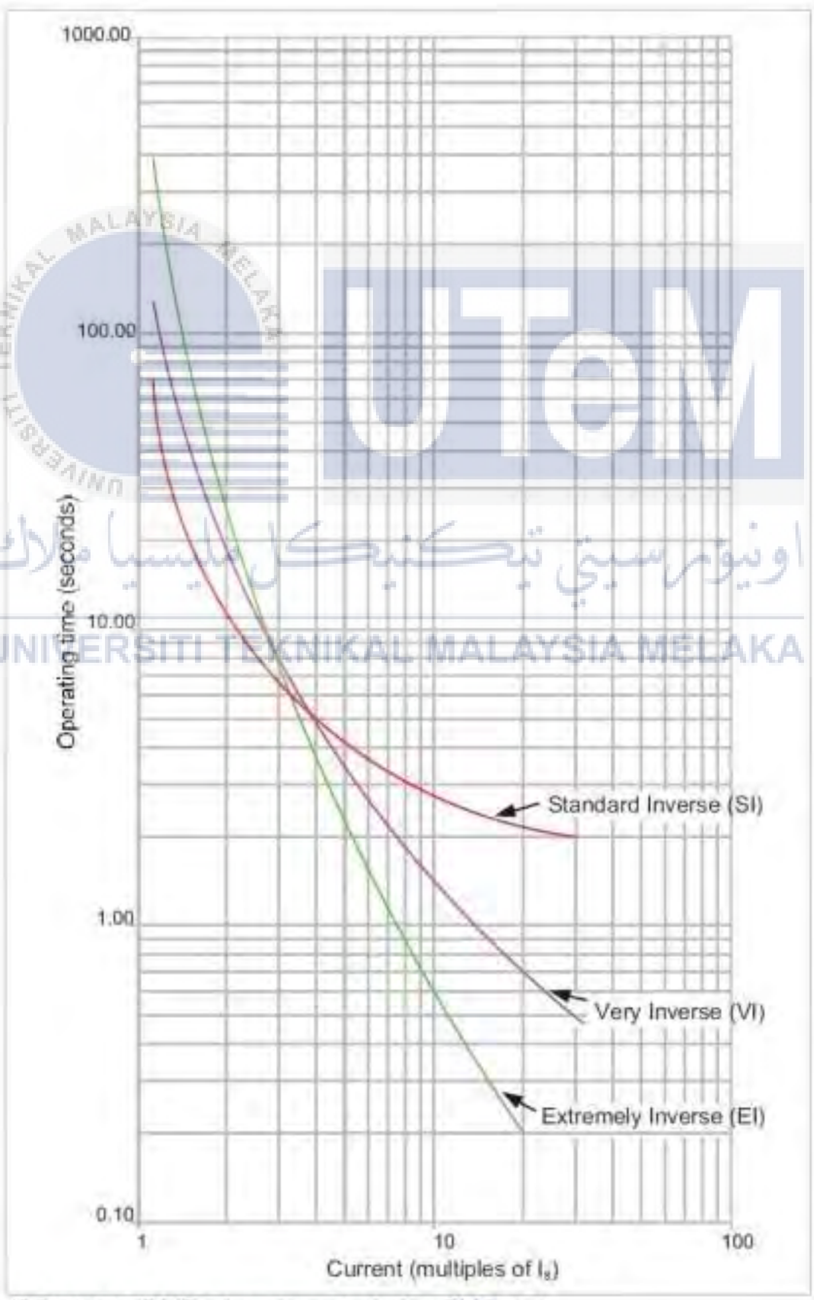
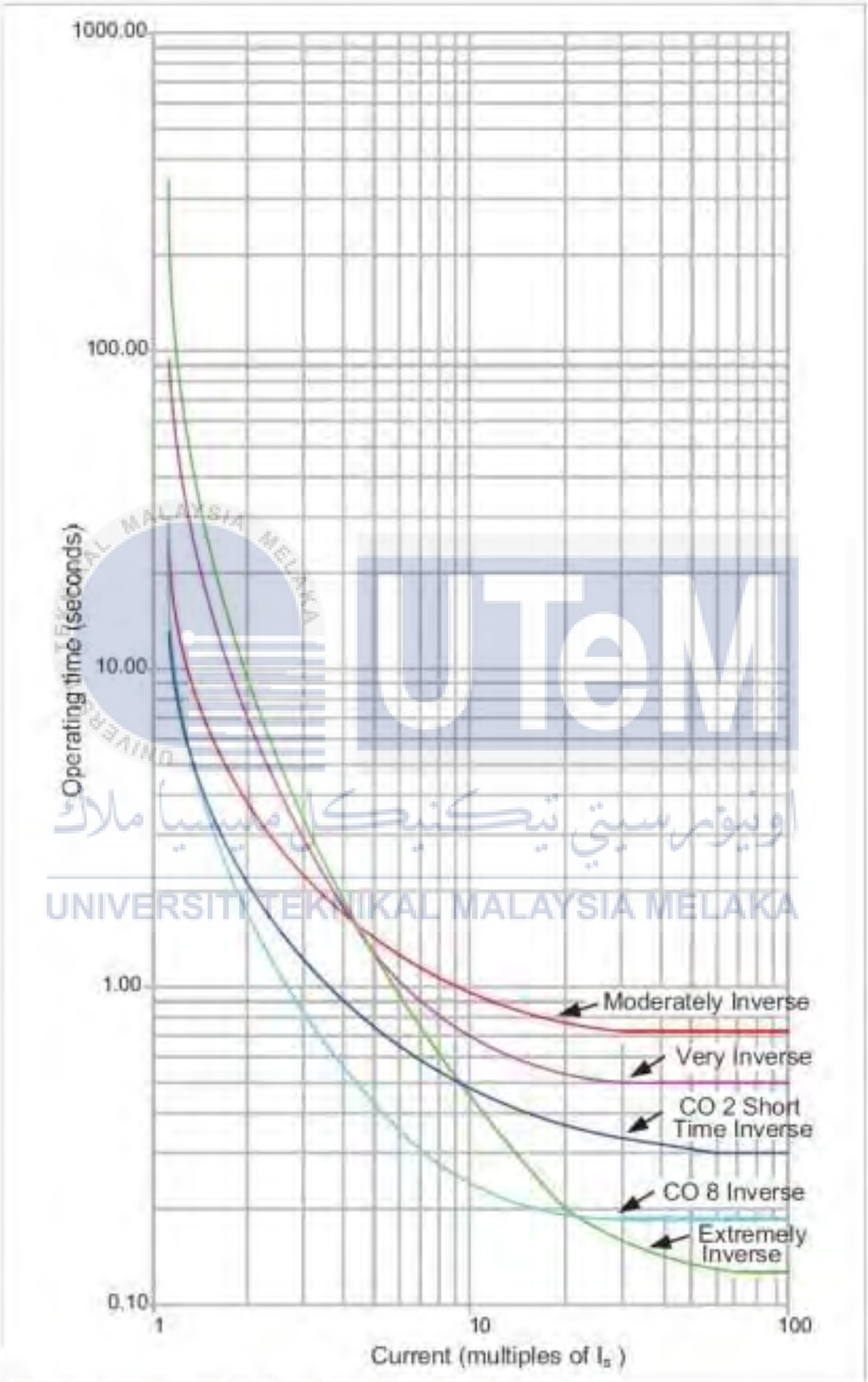
APPENDICES

APPENDIX A: IEC 60255 TIME-CURRENT CURVE CHARACTERISTIC.



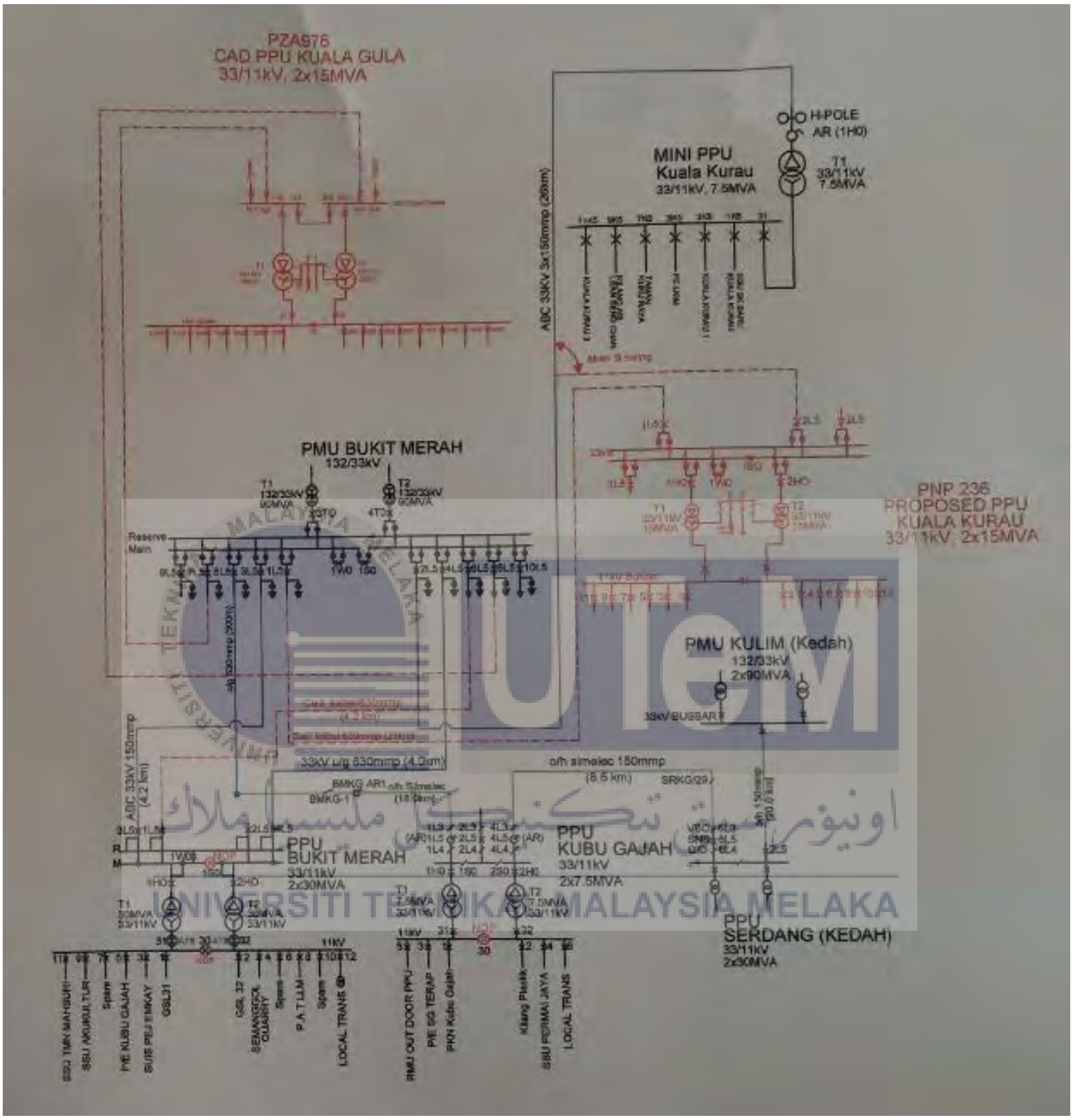
IEC 60255 IDMT relay characteristics; TMS=1.0

APPENDIX B: IEEE C37.112 TIME-CURRENT CURVE CHARACTERISTIC.



North American IDMT relay characteristics; TD=7

APPENDIX C: SINGLE LINE DIAGRAM FOR TNB MV DISTRIBUTION NETWORK.



APPENDIX D: CURRENT RECORDED AT NORMAL CIRCUIT

Fault Location	Fault Type	Current Measured at Relays (kA)							
		Phase A							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1Ø	40.97	1.118	0.263	0.774	0.525	1.549	0.387	0.774
	2Ø	40.97	1.118	0.263	0.774	0.525	1.549	0.387	0.774
	3Ø	40.97	1.118	0.263	0.774	0.525	1.549	0.387	0.774
Transformer 2	1Ø	0.279	1.118	0.263	0.774	0.525	1.549	0.387	0.774
	2Ø	6.112	21.481	21.591	0.774	0.531	1.549	0.387	0.774
	3Ø	6.112	22.494	22.773	0.774	0.551	1.549	0.387	0.774
Transformer 3	1Ø	0.279	1.118	0.263	0.774	0.525	1.549	0.387	0.774
	2Ø	6.112	21.48	0.266	0.774	21.55	1.549	0.387	0.774
	3Ø	6.112	22.494	0.263	0.774	22.686	1.549	0.387	0.774
Load	1Ø	0.791	3.077	2.484	12.309	0.525	1.549	12.467	0.774
	2Ø	0.987	2.989	2.395	11.84	0.525	1.549	11.99	0.774
	3Ø	1.045	3.814	3.455	11.589	0.525	1.549	11.738	0.774

Fault Location	Fault Type	Current Measured at Relays (kA)							
		Phase B							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1Ø	2.064	1.118	0.263	0.808	0.525	1.616	0.404	0.819
	2Ø	40.868	1.118	0.263	0.808	0.525	1.616	0.396	0.791
	3Ø	40.873	1.118	0.263	0.808	0.525	1.616	0.396	0.791
Transformer 2	1Ø	0.285	1.118	0.263	0.791	0.525	1.582	0.396	0.791
	2Ø	2.937	20.884	21.452	0.814	0.525	1.629	0.407	0.815
	3Ø	4.72	23.227	23.566	0.795	0.567	1.582	0.413	0.826
Transformer 3	1Ø	0.285	1.118	0.263	0.791	0.525	1.582	0.396	0.791
	2Ø	2.937	20.884	0.263	0.674	21.277	1.629	0.407	0.814
	3Ø	4.72	23.227	0.263	0.791	23.461	1.582	0.396	0.791
Load	1Ø	0.379	2.506	2.308	0.795	0.525	1.591	0.398	0.796
	2Ø	0.825	4.055	3.754	9.572	0.525	1.582	9.666	0.791
	3Ø	0.882	4.055	3.754	9.512	0.525	1.582	9.603	0.791

Fault Location	Fault Type	Current Measured at Relays (kA)							
		Phase C							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1Ø	40.97	1.133	0.263	0.799	0.525	1.599	0.387	0.774
	2Ø	40.97	1.133	0.263	0.799	0.525	1.599	0.387	0.774
	3Ø	40.97	1.133	0.263	0.799	0.525	1.599	0.387	0.774
Transformer 2	1Ø	0.279	1.133	0.263	0.791	0.525	1.582	0.387	0.774
	2Ø	6.112	1.133	21.591	0.829	0.531	1.657	0.387	0.774
	3Ø	6.112	16.817	22.772	0.791	0.551	1.582	0.387	0.774
Transformer 3	1Ø	0.279	1.133	0.263	0.791	0.525	1.582	0.387	0.774
	2Ø	6.112	1.133	0.266	0.829	21.55	1.657	0.387	0.774
	3Ø	6.112	16.817	0.263	0.791	22.686	1.582	0.387	0.774
Load	1Ø	0.791	1.133	2.484	0.791	0.525	1.582	12.467	0.774
	2Ø	0.987	2.035	2.395	0.791	0.525	1.582	11.99	0.774
	3Ø	1.045	2.887	3.455	8.261	0.525	1.582	11.738	0.774

APPENDIX E: CURRENT RECORDED AT CIRCUIT WITH DG

Fault Location	Fault Type	Current Measured at Relays (kA)							
		Phase A							
		R1	R2	R3	R4	R5	R6	R7	R8
Grid	1∅	40.97	2.116	2.084	6.395	0.529	1.58	0.418	0.79
	2∅	40.97	2.011	2.009	7.392	0.529	1.58	0.418	0.79
	3∅	40.97	2.643	2.339	7.577	0.529	1.58	0.418	0.79
Transformer 2	1∅	0.141	0.558	0.681	2.063	0.53	1.584	0.418	0.79
	2∅	6.133	21.25	2.548	7.925	23.656	1.58	0.418	0.79
	3∅	6.133	22.83	2.449	7.925	25.208	1.58	0.418	0.79
Transformer 3	1∅	0.141	0.558	0.681	2.063	0.53	1.584	0.418	0.79
	2∅	6.134	21.25	21.34	7.93	0.542	1.58	0.418	0.79
	3∅	6.133	22.83	23.13	7.925	0.529	1.58	26.581	0.79
Load	1∅	3.745	2.577	2.098	12.317	0.529	1.58	26.581	0.79
	2∅	0.869	2.554	2.081	12.088	0.529	1.58	26.283	0.79
	3∅	1.039	4.098	3.8	11.631	0.529	1.58	25.907	0.79