ASSESSMENT OF OVERCURRENT PROTECTION OF PMU PAGOH USING PSCAD SOFTWARE

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Bachelor of Electrical Engineering with Honours
UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

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A report submitted
in partial fulfillment of the requirements for the degree of
Bachelor of Electrical Engineering with Honours

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2024

DECLARATION

I declare that this thesis entitled "ASSESSMENT OF OVERCURRENT PROTECTION OF PMU PAGOH USING PSCAD SOFTWARE is the result of my research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

Signature :

Name : Tan Hong Yi

Date : 11/1/2024

APPROVAL

I hereby declare that I have checked this report entitled "title of the project", and in my opinion, this thesis fulfils the partial requirement to be awarded the degree of Bachelor of Electrical Engineering with Honours

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DEDICATIONS

To my beloved mother and father

ACKNOWLEDGEMENTS

I would like to express our heartfelt gratitude to my supervisor, Dr Mohd Hendra bin Hairi, for his unwavering support, guidance, and invaluable insights throughout this project. His expertise and mentorship played a pivotal role in shaping the direction and success of my assessment.

I would also like to extend our most profound appreciation to my parents for their constant encouragement, understanding, and belief in our abilities. Their love and support have been a constant source of motivation.

Lastly, I would like to thank my friends for their unwavering support and encouragement during this project. Their presence, enthusiasm, and willingness to lend a helping hand have been invaluable.

I am truly grateful for the contributions of my supervisor, parents, and friends, as their support has been instrumental in the completion of this project.

ABSTRACT

Overcurrent protection is critical in protecting power systems from the damaging effects of high currents. Ensuring the efficacy and dependability of over-current protection in the context of the TNB (Tenaga Nasional Berhad) network is critical for sustaining a stable and resilient power supply. The purpose of this research is to evaluate the performance of overcurrent protection methods in the Pencawang Masuk Utama (PMU) at Pagoh using the extensive simulation capabilities of PSCAD software. The project begins with a detailed examination of the TNB network, which includes transmission lines, transformers, and distribution networks. PSCAD has accurate modelling of these components, allowing for detailed simulation of their behaviour under various failure circumstances. The software's considerable capabilities in simulating and analysing over-current reactions are used to assess existing protection methods. The TNB network model simulates many fault situations, including single-phase and three-phase faults of varying magnitudes and locations. The reactions of the protection system are thoroughly analysed to assess their efficiency and dependability, such as fault-clearing time and coordination among protective devices. The study also looks at potential enhancements to the over-current protection scheme, such as relay settings, coordination mechanisms, and the integration of new protection technologies. By evaluating the performance of overcurrent protection in the TNB network, this research hopes to discover flaws and propose solutions that would improve the system's overall dependability and stability. The study's results and suggestions will be useful for optimising over-current protection methods within TNB and can be adopted by other power utilities experiencing similar difficulties. Finally, this project contributes to the continual enhancement of the TNB network's protective infrastructure, guaranteeing that customers have a reliable and uninterrupted power supply.

ABSTRAK

Perlindungan arus lebih adalah penting dalam melindungi sistem kuasa daripada kesan kerosakan arus tinggi. Memastikan keberkesanan dan kebolehpercayaan perlindungan arus lebih dalam konteks rangkaian TNB (Tenaga Nasional Berhad) adalah penting untuk mengekalkan bekalan kuasa yang stabil dan berdaya tahan. Tujuan penyelidikan ini adalah untuk menilai prestasi kaedah perlindungan arus lebih dalam Pencawang Masuk Utama (PMU) di Pagoh menggunakan keupayaan simulasi meluas perisian PSCAD. Projek ini bermula dengan pemeriksaan terperinci rangkaian TNB, yang merangkumi talian penghantaran, transformer, dan rangkaian pengedaran. PSCAD mempunyai pemodelan yang tepat bagi komponen-komponen ini, membolehkan simulasi terperinci kelakuan mereka dalam pelbagai keadaan kegagalan. Keupayaan besar perisian dalam mensimulasikan dan menganalisis tindak balas arus lebih digunakan untuk menilai kaedah perlindungan sedia ada. Model rangkaian TNB mensimulasikan banyak situasi kerosakan, termasuk kerosakan fasa tunggal dan tiga fasa dengan magnitud dan lokasi yang berbeza-beza. Tindak balas sistem perlindungan dianalisis dengan teliti untuk menilai kecekapan dan kebolehpercayaan mereka, seperti masa pembersihan kerosakan dan penyelarasan antara peranti perlindungan. Kajian itu juga melihat potensi peningkatan pada skim perlindungan arus lebih, seperti tetapan geganti, mekanisme penyelarasan, dan penyepaduan teknologi perlindungan baharu. Dengan menilai prestasi perlindungan lebihan arus dalam rangkaian TNB, penyelidikan ini berharap dapat menemui kelemahan dan mencadangkan penyelesaian yang akan meningkatkan kebolehpercayaan dan kestabilan keseluruhan sistem. Keputusan dan cadangan kajian akan berguna untuk mengoptimumkan kaedah perlindungan arus lebih dalam TNB dan boleh diguna pakai oleh utiliti kuasa lain yang mengalami kesukaran yang sama. Akhir sekali, projek ini menyumbang kepada peningkatan berterusan infrastruktur perlindungan rangkaian TNB, menjamin bahawa pelanggan mempunyai bekalan kuasa yang boleh dipercayai dan tidak terganggu.

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LIST OF SYMBOLS AND ABBREVIATIONS

TNB	-	Tenaga Nasional Berhad.
SESB	-	Sabah Electricity Sendirian Berhad
SEB	-	Sarawak Energy Berhad
CO2	-	Carbon Dioxide
IDMT	-	Inverse Definite Minimum Time
SCC	-	Short circuit capacity
DC	-	Direct current
AC	-	Alternative current
PV	-	Photovoltaic
PSCAD	-	Power System Computer Aided Design
Top	-	Operating time
TFL	-	Time fault logic
PMU	-	Pencawang Masuk Utama

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CHAPTER 1

INTRODUCTION

1.1 Background

In the era of globalization, electricity has become an essential part of our daily life, whether in the city or rural area. Before discovering it, the people lived in the dark world at night. Everywhere we go, we are going to use the electricity. Starting from home, we need electricity to supply the appliances such as refrigerators, air conditioning, and more. When we leave home, we need electricity to provide the transport. The lights are needed at night so we can live in the dark. Thus, an electricity power station is crucial to everyone living on the earth.

The electrical power system in Malaysia can be divided into three main categories: generation, transmission, and distribution. Three companies are responsible for the supply of electricity, Tenaga Nasional Berhad (TNB) in peninsular Malaysia, Sabah Electricity Sdn Bhd (SESB) in Sabah, and Sarawak Energy Berhad (SEB) in Sarawak. These three companies own electricity generation, transmission, and distribution. According to Suruhanjaya Tenaga, total electricity consumption was 152866Kwh, while total electricity generation was 36182.8 MW in 2018 [1].

After electricity, transmission is essential since the transmission line covers a wide area; the transmission line carries electricity over long distances from the generation facility to demand areas. The transmission line is transferred at high voltage to maximise efficiency. The transmission line is usually made of extensive lattice steel material. Since the transmission line carries a high voltage of up to a few kilovolts, protecting the cable and station is crucial as electricity consumption benefits people [2].

A protective relay is used in the electrical power system in Malaysia. A protective relay is a device that protects the transmission line from fault. When any fault happens, the current at fault will be extremely high, up to a few thousand amperes. The cable at fault will become very hot, nearly 250 °C. It is hazardous to humans as humans can only withstand a maximum current of 10 amperes. The fault will also cause damage to the appliances. Thus, a protection relay is essential to use electricity safely.

1.2 Problem Statement

The distribution system in TNB is essential to ensure the availability of electricity to the consumer. A lot of equipment uses electricity to maintain our daily life. For example, public transport, smartphone, and internet connectivity. Without the presence of electricity, we are not able to live better. Thus, protecting the distribution system is crucial to ensure the presence of electricity supply.

The first issue related to this project is inadequate Assessment of Overcurrent Protection effectiveness of the overcurrent protection relay in the PMU Pagoh in detecting and isolating the fault. The existing overcurrent protection system at PMU Pagoh may not have undergone a comprehensive evaluation, raising concerns about its effectiveness in identifying and mitigating faults within the power distribution network. A relay should be selected to ensure no fault will pass through the relay, while the average current should not be blocked. This is to allow the persistent function of equipment.

The second issue revolves around the dynamic behavior of fault currents within the PMU Pagoh network. Changes in system voltage, fault impedance, and network configuration can significantly impact fault currents, posing a challenge to the efficient operation of the existing overcurrent protection system. The project aims to meticulously analyze these fault current dynamics to understand how variations in these parameters influence the performance of the protection system. This investigation is crucial for identifying potential vulnerabilities and optimizing the overcurrent protection strategy at PMU Pagoh, ensuring a reliable and stable power distribution network under diverse conditions.

Moreover, the problem that needs attention is whether the overcurrent relay setting can be optimised to enhance responsiveness and reliability. The relay current sets the tripping time and the current that the relay starts to operate. Thus, the relay's setting needs to be precise to ensure no fault can pass through the relay.

Last but not least, this project leads to a problem: how can the protective relay protect the equipment across different voltage levels to ensure proper fault isolation without causing disruption?

The study intends to give valuable insights into the functioning of overcurrent protection devices inside the TNB network by answering these topics. The results and recommendations will help TNB engineers and operators make educated decisions about improving the network's protective mechanisms, resulting in a more robust and dependable electricity distribution system.

1.3 Objectives

The project aims to:

i. To model the electric circuit for 132/11KV Pencawang Masuk Utama (PMU) Pagoh by using PSCAD simulation software.

ii. To model and simulate the response time of an overcurrent protective relay under various fault conditions and at different fault locations

iii. To ensure a reliable, selective, fast, and safe tripping operation during all conditions.

1.4 Project Scope

The scope of the project "Assessment of Overcurrent Protection of TNB Network using the PSCAD Software" encompasses the following aspects:

- Pencawang Masuk Utama (PMU)

The Pencawang Masuk Utama (PMU) is used on the 132kV system to connect the 132kV network with the 11kV network. It injects capacity into the 11kV network through a 132/11kV transformation. Electric substations are capacity injection points from 11kV, 22kV and 33kV systems to the low voltage network (400V, 230V).

- 132/11kv substation network

The substation receives 132kv from the power generation and steps down the voltage to 11kV. The voltage will be delivered to pencawang eletrik (PE).

- Using Power System Computer Aided Design (PSCAD)

PSCAD (Power Systems Computer Aided Design) is a software program that simulates and analyses the behaviour of power systems. Engineers and researchers may use it to model and simulate various power system components, including generators, transformers, and transmission lines. PSCAD includes a graphical user interface and is widely used for power system analysis and optimisation in academia, research, and the power business.

- Inverse Definite Minimum Time (IDMT) Overcurrent Relay

IDMT relays, also known as Inverse Definite Minimum Time relays, are safety devices used in electrical systems to detect and respond to aberrant current circumstances. It works on the idea that the relay's operational time is inversely proportionate to the size of the fault current, resulting in effective fault protection.

1.5 Thesis Outline

This project is organised into five parts, with its chapter organised as such:

Chapter 1 explains the background of the project. The background explains the introduction and overview of the PMU network and IDMT relay. Next, the problem of the project is listed in the problem statement. The problem listed is the problem to overcome and solve. Besides that, the objective and scope are listed in this chapter to show the reason for preparing this project and the specifications of the project. The thesis statement introduces the content in every chapter and the motivation for doing this project.

Chapter 2 discusses the literature review by obtaining information regarding the project. The content discussed in this chapter is from the generation to the transmission network. Besides that, this chapter explains different types of fault and protective relay types. Last but not least, the interpretation and the setting of the IDMT relay are discussed in this chapter.

Chapter 3 is about the methodology of the project. The methodology includes the process flow and the steps for preparing this project. Simulating, modelling, and analysing the circuit in PSCAD is also discussed. The flow chart of the project is also included.

Chapter 4 discusses the expected result obtained from the PSCAD simulation software. The result of the network for different levels of fault. Next is the effect and which relay tripped from the result of different fault locations. The result was explained and discussed well in this chapter with the bits of help of the picture.

Chapter 5 describes the conclusion of the project. This will be the summary of the achievement and the thesis of the simulation. Next, the overall conclusion of knowledge after completing the design, simulation, and analysis of the IDMT relay. Besides that, this chapter will also explain the future work and problems we might face by developing the project.

1.6 Motivation

Short circuits and equipment failures threaten the TNB network infrastructure, resulting in power outages and severe damage. The project aims to evaluate overcurrent prevention technologies to assure network safety and dependability while minimising power outages.

Overcurrent accidents can harm essential equipment in the TNB network. The project intends to improve fault detection and isolation by analysing the protective mechanisms, lowering the risk of equipment damage and related repair or replacement costs.

A well-designed and coordinated overcurrent protection mechanism is critical to the TNB network's functioning. The project aims to find weaknesses or limits in existing security methods and propose solutions to increase system performance and efficiency.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes the literature review regarding the project. The topic includes the national grid system in Malaysia, the distribution network in TNB, faults in the power system, and protection relays against fault. The information regarding this project is obtained from several sources, such as journals, books, websites, and articles.

2.2 National grid system in Malaysia

The national grid system in Malaysia was established in 1953. The beginning of the National grid system took shape in 1964. The first power station located at Bangsar was connected to the Connaught Bridge Power System, and the line subsequently extended to Melaka. By 1965, gourmet decided to connect the power plant. There are several power plants were first connected, including Port Dickson in Negeri Sembilan Temengor, Kenering, Bersia, and Batang Padang in Perak, Connaught Bridge, Kapar, and Serdang in Selangor Paka in Terengganu, Perai in Penang Cameron Highlands in Pahang, Pergau in Kelantan, Pasir Gudang in Johor, and Malacca. Late in the 1980s, the loop of the grid system was considered when the power station in Kota Bahru joined the grid[3].

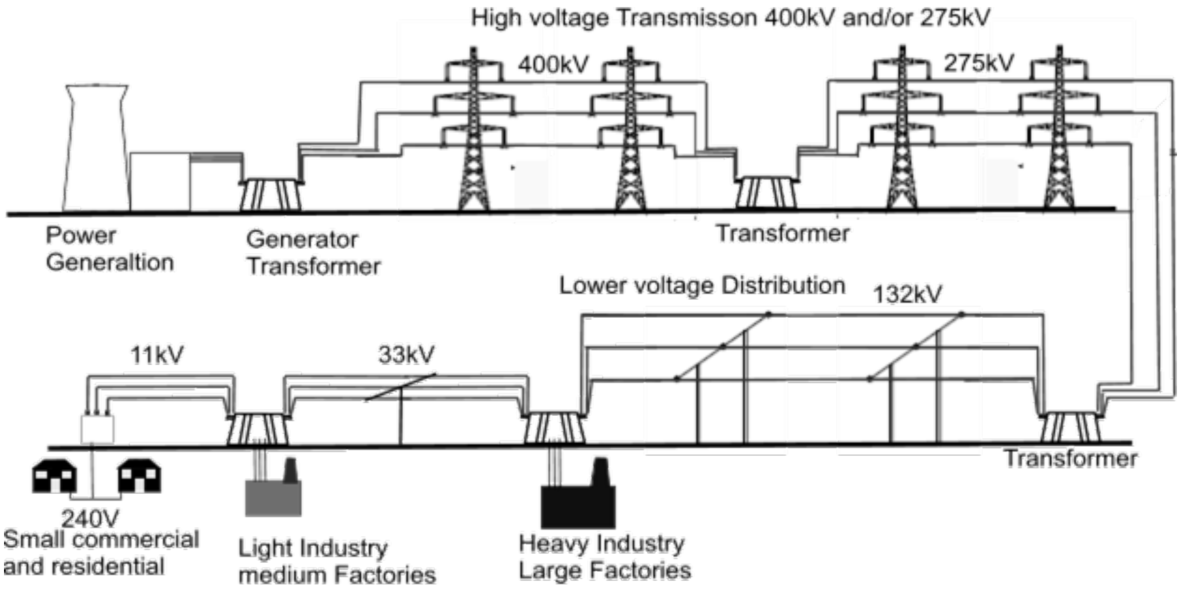


Figure 2.1: National grid system in Malaysia

The national grid system in Malaysia is divided into three parts, generation, transmission, and distribution. Power generation generates electricity. The types of power generation in Malaysia include hydropower, coal-fired, and gas-fired. The generated electricity is transmitted to the distribution station through a transmission line. The transmission line is designed to carry a high voltage of up to 500kV to reduce electricity losses. The distribution system in TNB is divided into several categories: residential, commercial, and industrial. This system distributes electricity to every people.[4]

2.2.1 Power generation in Malaysia

According to the Department of Statistics Malaysia regarding the electricity sector in Malaysia, the electricity generated by the power plant was 156665GWh in 2016 [5]. This demand in every sector has rapidly increased due to the innovation of appliances. The electricity demand will keep growing until the year 2050.

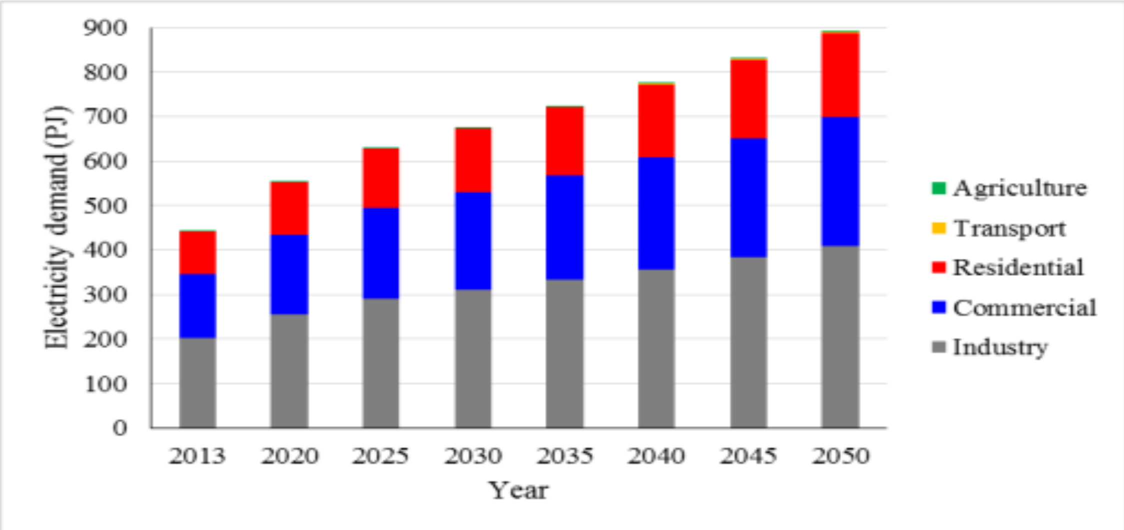


Figure 2.2: Expected electricity demand by sector

Malaysia's four central power plants are natural gas, crude oil, coal, and hydropower. The Natural gas power plant has slightly decreased from 46.6% to 41%. In 1983, crude oil and petroleum power plants were one of Malaysia's main power stations. The government has decided to generate power by burning coal to replace the burning oil power plant. These two power plants negatively impact humans as carbon dioxide (CO_2) is produced during burning. Carbon dioxide is dangerous to humans as it could cause global warming and greenhouse effect. Thus, when Malaysia keeps improving power generation, hydropower generation generates electricity. The hydropower plant will benefit as the carbon dioxide produced while burning coal and oil is reduced.[6]

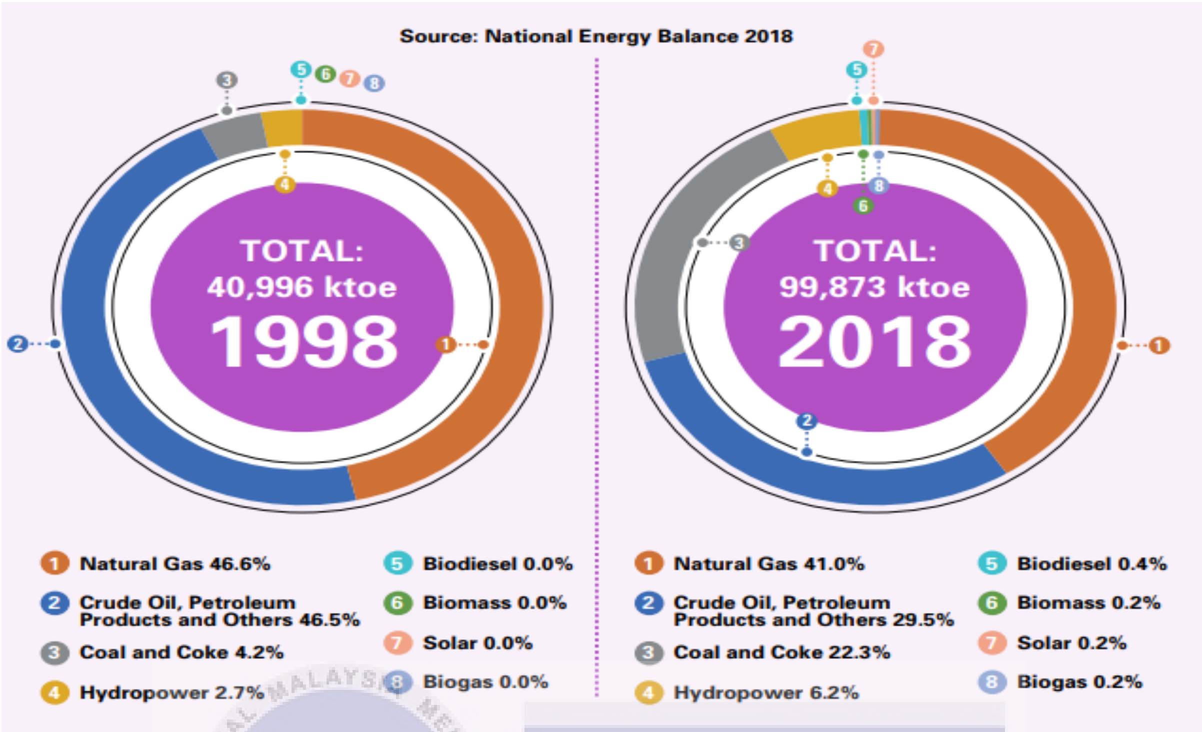


Figure 2.3: Percentage of electricity generated by different types of power plant

2.2.1.1 Hydropower generation

Hydropower generation among one of the green electricity generations. Another generation used in Malaysia produces harmful environmental gases, such as carbon dioxide. Hydropower does not produce any harmful gas during the generation of electricity. This type of electricity generation has increased from 2.7% to 6.2% of total generation in Malaysia [1]. According to the International Hydropower Association, hydropower installed capacity has reached 6174MW, while electricity generation by hydropower has achieved 15.66TWh in 2021 [7].

A hydropower plant includes a reservoir or headpond, penstock, turbine, dam, and generator. The reservoir is the place to store the water and make it ready to flow. There is a valve to control the inflow of water. The dam is in charge of controlling the flow of water. The valve of a power plant located at the dam. Penstock is usually open or closed to carry water to the turbine. The turbine is located at the bottom of the power plant. And it is used to turn the turbine. The generator functions to produce voltage to the generator.[8]

The operating principle hydroelectric power plant starts at the reservoir. Water will flow through the penstock when the valve opens due to the height difference. The turbine will turn on the water after the water flows through the penstock. The turbine is connected to the generator. The generator will turn, and voltage will be produced. According to energy conversion theory, hydropower generation converts mechanical energy to electrical energy.

Hydropower energy benefits humans as it is a renewable source of energy. It does not depend on non-renewable sources such as gas and oil. Hydropower generation is a domestic source, allowing each state in the power plant to produce the energy on its own. Moreover, hydropower benefits beyond electricity generation. It provides flood control, irrigation support, and clean drinking water. [9]

Although hydropower generation contributes many benefits, it negatively impacts humans. Hydropower generation has a huge environmental impact. A hydropower plant requires prominent places, and the surroundings of the plant are not suitable for humans to live in. When the dam is damaged, the water could easily flow to the surroundings and cause dangerous floods. Besides that, hydropower plants are costly, and the time for the project to complete is long. The hydropower plant in Sungai Nenggiri in Kelantan is expected to cost RM311,421 million, and the plant will enter into commercial operation after four years of construction[10].

Figure 2.4: Hydropower plat in Ulu Jerai, Cameron Highland, Pahang

2.2.1.2 Gas-fired power generation

Gas-fired power generation is a fossil fuel generation that converts chemical energy into mechanical energy. There are four central gas-fired power plants, simple cycle gas turbine, combined cycle gas turbine, and reciprocating engine. In Malaysia, the primary electricity generation uses natural gas. Over 62.4% of generated electricity is from gas-fired power plants [1] The natural gas used in the plant usually is methane.

A gas-fired power generator has three main parts: compressor, combustor, and turbine. The compressor function takes in the air outside the turbine and increases its pressure. The combuster burns the fuel and produces high-velocity and high-pressure gas. The turbine extracts the energy from gas which is produced by the combustor.

The working principle of a gas-fired power generator starts at the pipeline. Natural gas flows to the power station through a pipeline. Air is compressed and drawn through the filter. Then natural gas combines with compressed air, and the mixture burns in a combustor. High-pressure and high-velocity gases produce and turn the turbine. The turbine is connected to a generator and causes the generator to turn. When the generator turns, electricity is produced. The generator turns at a very high speed due to the high velocity of gasses. Thus, the efficiency of the power plant will be increased as the generator turns fast. The exhaust gas from the turbine is directed to the Heat Recovery Steam Generator, which boils water in pipes and produces superheated steam. Almost 10000 litres of seawater are pumped into the system in one second.[11]

Gas-fired power generator contributes some advantages to humans and the environment. First and foremost, the size of the power plant is small in size as compared to the hydropower power plant. For this reason, the initial cost of the gas-fired power plant is low. Besides that, this power plant is easy to install quickly. The environmental restrictions of this power plant are lesser than other types of power generation. Last but not least. Water consumption is less as compared to steam and hydroelectric power plants.

The disadvantage of the gas-fired power plant is the overall efficiency is relatively low, as two-thirds of the power is used to drive the compressor. Besides that, high starting torque is required to start the electric motor in the power plant. In generating power, noise from the compressor is noticeable compared to hydropower generation. Most importantly, there are gasses produced by the power plant and going to pollute the environment.

2.2.1.3 Solar power generation

When most people think of clean and renewable energy, they will think about solar energy. Solar panels, also known as photovoltaic modules (PV modules). It turns sunlight into electrical energy. It entails capturing the sun's energy and converting it into usable power using solar panels or photovoltaic cells.

Humans first used solar energy in the 7th century B.c. Human uses sunlight to light up the fire. This is also a kind of energy. In 1839, French physicist Edmond Becquerel discovered the photovoltaic effect of the experiment. The experiment is about a cell of metal electrodes in a conduction solution. He concluded that the cell would produce more electricity when exposed to light. PV technology was moved forward by Daryl Chapin, Calvin Fuller, and Gerald Pearson. They worked together and invented the first solar cell to convert sunlight to electricity.

The solar panel consists of some solar cells usually made up of silicon. There are also semiconductor elements that convert electricity when exposed to sunlight. When sunlight hits the solar cells, it excites the electrons within the cells, causing an electrical current to flow.

In Malaysia, solar power generation has become the trend for power generation. People believe that it can produce clean and cheap electricity. According to Smart Energy International, the Malaysian government plans to increase solar power generation to 40% of total power generation in 2035 under the Malaysian Investment Development Authority[12]. The largest solar power plant in Malaysia is located in Sepang. It is made up of 238140 solar panels and generated around 110000MWH in the year 2019.

2.2.1.4 Coal power generation

Coal power generation, often known as coal-fired power generation, is the process of generating electricity by coal combustion. It entails burning coal in a power plant to generate heat, which is then used to create steam. The steam powers a turbine, which powers a generator, which produces electricity. Coal power generation contributes over 40% of total power generation in the world. Coal-fired power generation requires large amounts of coal. Thus, most of the country that mainly depends on coal power generation can produce coal independently. In Victoria, coal power plants use 9000 tons of coal per day.

The coal power plant is located at the riverside. It comprises a coal intake, boiler or furnace, turbine, and transmission line. The operation of the coal power plant is simple, starting when coal is added. The stove will burn the coal and transfer the steam to the turbine. Next, the turbine will turn the generator and the electricity the synchronous generator produces. When the coal is burning, the temperature will become extremely high and will further cause damage to the system. To solve this situation, the power plant condensed water from the river and cooled down the power plant.

Although coal power plant contributes to producing electricity, they have severe impacts on the environment. It mainly causes air pollution and water pollution. The burning of coal produces smoke and steam in the surroundings and causes a reduction in air quality. Since the power plant uses water to cool the system, it will cause water pollution. After the water fulfils its task, it will flow to the river. This water usually contains chemical substances and waste material. Thus, it will pollute the river.

2.2.1.5 Other types of power generation

There are some other types of power generation available in Malaysia. For example, biodiesel, biomass, and biogas power generation. These types of power generation are less than 1% of the total power generation in Malaysia. The operation of these power plants is similar to gas-fired power generation. It burns the substance and produces steam to turn the turbine, and the generator produces electricity. The difference between these power generation is the type of substance burned.

Biodiesel is a renewable fuel from vegetable oil, animal fats, or recycled cooking grease. It involves converting the unusable waste into electricity. It can blend with petroleum to produce cleaner and more sustainable energy. The biogas is often used in a combined heat and power (CHP) system, where it drives a generator to generate electricity, and the waste heat is utilised for heating or other uses.

By properly using organic resources that would otherwise go to waste or contribute to environmental difficulties, these kinds of power production diversify energy sources, reduce greenhouse gas emissions, and encourage sustainable development.

2.2.2 Transmission system

Transmission network, also known as transmission system. It comprises an electric line or cable to transmit electricity from one power station to another. This line or cable is owned by Tenaga National Berhad (TNB). Transmission in connection with electricity transmission between substations or to or from any external connections.

In Peninsular Malaysia, over 420 transmission substations with a total installed capacity of 105,305 MVA are linked by roughly 21,000 circuit kilometres of overhead lines and underground cables running at 132, 275, and 500 kilovolts (kV). The 500 kV transmission system is Malaysia's most significant transmission system ever created. Phase 1 began in 1994 with the design and installation of 500kV overhead lines from Gurun, Kedah in the north along the west coast to Kapar in the middle area and Pasir Gudang to Yong Peng in the south of Peninsular Malaysia.[13]

As of February 2017, the distance covered by the 500 kV transmission lines was 784, while the 275 kV part was 9,257. The 500 kV transmission system was extended from Bukit Tarek to Yong Peng via interconnection to cater for the new plant of generators, namely the 3,100 MW Janamanjung Power Plant on the west coast, 372 MW Ulu Jelai Hydro Electric Power Plant on the east coast, and 4,100 MW Tanjung Bin Power Plant in the south. Completing this link enables energy transmission to the load centre located in Peninsular Malaysia's Klang Valley area.

The rating of a transmission system in the national grid system includes 500kV, 275kV,132kV, and 33kV. The rating of the transmission line is differentiated by its length. There are three types of transmission lines which are the short model, medium model, and extended model transmission line. Short-model transmission lines are typically less than 50 km. medium model transmission lines are usually greater than 50 km but less than 250KM while extended model transmission lines are more than 250km. The voltage rating of the transmission line is much related to the length of the model. The voltage rating will also be high when the transmission line is long. It is to overcome the losses of voltage to the surroundings when transmitted. Thus, higher voltage values need to be considered for an extended model transmission line so that the system's efficacy is increased.[14]

2.2.3 Distribution system

Electrical power is dominant as it can transmit and distribute efficiently. After the power plant is generated, the electricity is transmitted along the wire. Before that, the electricity is step-up or increased to reduce transmission losses. The electricity is stored in the substation. Distribution substations are usually located near cities, towns, villages, and industries. The substation's location needs to be near the electricity consumption to minimise the losses at the transmission line. The voltage at the substation must be reduced or stepped down to a certain level for distribution. Different type of customers uses a different level of voltage. Some examples of voltage levels include 33Kv, 11kv, and 400/230kv.

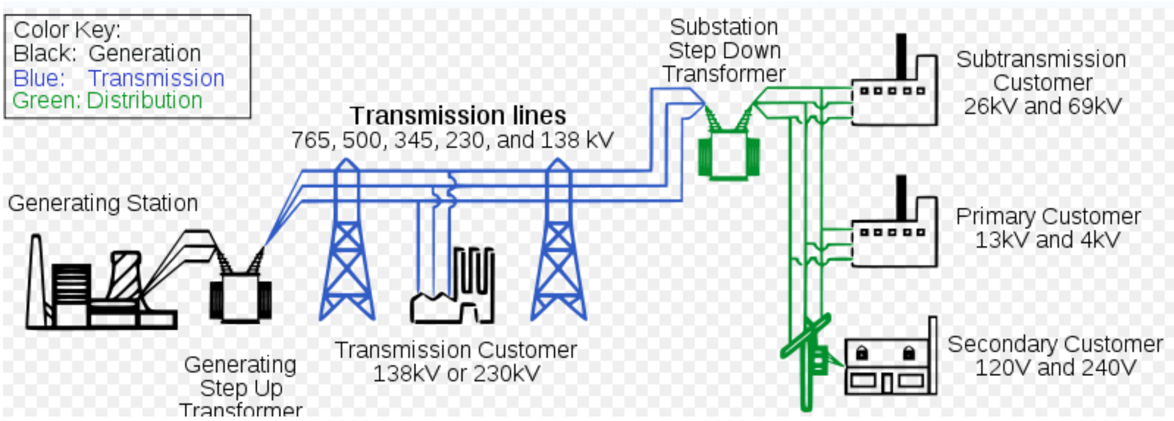


Figure 2.5: Electricity distribution system of national grid system in Malaysia

There are three main categories of a customer, which are indicated by consumption. The three categories are high, extra high, medium, and low voltage. Low voltage from 50V to 1kV, medium voltage from 1kV to 50kV, and high voltage from 50kV to 230kV. The customer category is divided into six parts: domestic, commercial, industrial, mining, street light, and specific agriculture. Each category has its tariff rate. The tariff rate is fixed according to the use of electricity.

2.3 Fault in the power system

The electrical power system is extensive and complex and transmits over a large area. A power system comprises a generator, transformer, transmission line, and load. The fault could happen in any place in the system. A fault in a power system is abnormal when a conductor or a portion of a power system comes into contact with another conductor or an earthed surface. This can result in an undesired flow of current, which can damage equipment, cause power outages, and even pose a safety risk to people.[15]

Faults are unwanted conditions connected. The fault usually occurs due to flashover, physical damage, insulation failure, and human error. Faults in power systems can be dangerous not only to the equipment but also to humans and might cause damage to the whole system [16]. For a three-phase system, there are four lines: R, Y, B, and ground. Usually, the power system operates under balanced conditions, meaning all R, Y, and B have the same voltage or current value. When a fault happens, the current and voltage within two lines are different. The current flow is not balanced, causing the current to flow to a fault.

When the fault current exceeds the current value for the protective relay, the equipment or cable could be damaged [17].

Many incidents happened due to electrical faults. For example, the New York City Blackout of 1977. On July 13, 1977, a lightning strike caused an electrical fault at a substation in New York City, leading to a massive power outage that lasted for 25 hours. The blackout resulted in widespread looting, arson, and vandalism, and over 3,000 people were arrested.

Since fault has a dangerous impact on humans, fault analysis is crucial to prevent fault. By performing fault analysis, the system's information, such as the choice of switchgear, the conductor's size, the relay's setting, and the relay's rating [17]. All the equipment must be chosen to work together with fault current so that we can protect the system with the protective device[17].

2.3.1 Type of fault

Electrical power systems are susceptible to a variety of faults that can compromise the integrity and functionality of the system. One frequent kind is a short circuit, which happens when two conductors unintentionally contact each other and cause an abrupt spike in current. System disruptions and equipment damage can result from short circuits. An open circuit is a different kind that is defined as a breach in a conductor that prevents current from flowing normally. Power outages and inefficient operations can be caused by open circuits. When current leaks from a live conductor to the ground, it can result in equipment damage and safety risks. This phenomenon is known as a ground fault. A direct connection between two-phase wires causes phase-to-phase faults, which can cause imbalances and perhaps harm equipment. Temporary disruptions like as lightning strikes or brief insulation failures are known as transient faults, and they frequently self-correct following the fleeting occurrence. Comprehending various forms of faults is essential for putting into practice protective schemes that work, like circuit breakers and overcurrent relays, to quickly identify and reduce problems, guaranteeing the dependability and security of electrical power systems.

2.3.1.1 Symmetrical fault

The symmetrical fault is balanced in a three-phase power system when all three phases experience a fault at the exact location and with the same fault impedance. An example of a short circuit fault is a three-phase short circuit. All three points are short at some point in the circuit. In this condition, all three faults are short to earth or ground. There are two methods to determine the short circuit capacity for the circuit breaker. There is the Thevenin method and bus impedance matrix. After the calculation, the value of short circuit capacity can be determined to protect the device from the short circuit.

2.3.1.2 Unsymmetrical fault

An unsymmetrical fault is also an unbalanced fault. This fault occurs when only two phases experience fault. The types of unsymmetrical fault include line-to-line fault, single line-to-ground fault, and double line-to-ground fault. These faults can result in unbalanced currents and voltages, leading to uneven power distribution and potential damage to electrical equipment. Various factors, including insulation failure, lightning strikes, or faulty equipment, can cause unsymmetrical faults. There are more challenges when detecting which phase experiences, a short circuit fault.

2.3.2 Cause of fault

Electrical power system faults can be caused by a number of things, such as ageing-related insulation degradation, mechanical stress, or environmental toxins. Faults are frequently caused by malfunctioning equipment, such as circuit breaker failures or relay mistakes. Faults can be caused by misoperations, faulty switching methods, and human mistakes during maintenance or operation. Transient faults are caused by external events such as lightning strikes, storms, and harsh weather. Intermittent defects may be caused by problems with power quality, such as voltage variations. Fault growth is further aided by material fatigue, corrosion, and natural wear and tear over time. In order to improve the resilience and dependability of electrical power systems and reduce the impact of failures on system performance and safety, it is essential to identify these many causes and apply preventative measures, routine maintenance, and strong protective tactics.

2.3.3 Effect of fault

Open circuit faults can decrease the load on the alternator, leading to the alternator running slightly faster than its synchronous speed. This increased speed can then cause the alternator to generate an over-frequency. Besides that, the fault will create a shallow impedance path for current flow. This situation will cause a significant current value to flow through the wire, causing the relay to trip and damaging the equipment.

Faults might also cause shocks to humans. Sometimes, a human gets shocked when a fault touches the cable. Humans can only survive under 10mA of current. Usually, the fault current can go up to 2000A. Humans cannot survive under this much current.
Moreover, faults can cause damage to the equipment or components. As a high current passes through the element, the temperature will increase to a few hundred degrees Celsius. This temperature value can cause the equipment to burn and other cause improper equipment working in the device.

Short circuit faults will cause flashovers and sparks due to ionisation between two conducting parts. It will cause a fire in the equipment or further damage the building or shopping complex, which could be easily observed in the news.

2.4 Power system protection

The fault usually occurs in the equipment. Faults can have a significant impact on the device and environment. Some of the faults can be prevented from happening, but most of the faults cannot. The protective system against fault focuses on protecting the equipment or transmission line from damage. The protective device will cut the high-level current flow into the device.

A protective system should respond to the abnormal operating condition. Some abnormal operating conditions exist, such as the motor's starting current, the inrush transformer's current, and stable power swings. It might be considered a fault, but no protection is required for the device. Thus, it may not view abnormal operating conditions as a fault[18].

The power systems have gone through a transformation, moving from self-contained generators supplying limited loads to interconnected systems covering entire nations. This transformation has shifted from low-voltage and low-power handling capacities to high-voltage and high-power handling capacities. The protective system requirements are directly related to the characteristics of the power system.

There is some protective device used in the system. Examples of protective devices are fuse, circuit breaker, and protective relay. System transducers link between a power system and a defensive system. The transducer extracts information regarding current and voltage. Besides that, transducers are used to lower the voltage or current to prevent damage to the protective device.

2.4.1 Fuse

A fuse safeguards circuits from overcurrent and overload by either electric, electronic, or mechanical means. Thomas Alva Edison invented the electric fuse in 1890. Although various fuses are available, they all serve the same purpose of protecting the circuit.

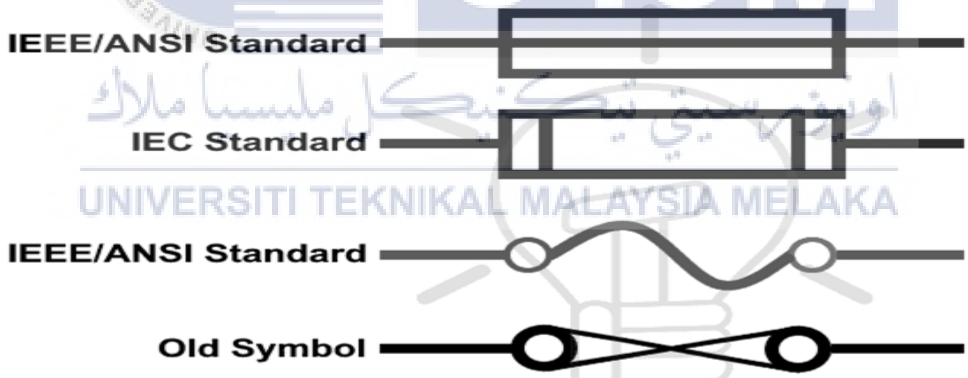


Figure 2.6: Symbol of fuse according to different standard

A typical fuse is a low-resistance metallic wire enclosed in a non-combustible material. It is installed in series with a circuit and device that require protection from short circuits and overcurrent. Excessive currents can damage electrical appliances beyond their rated limits without a fuse or circuit breaker.

The working principle of a fuse is based on the heating effect of current. When a short circuit, overcurrent, or mismatched load connection occurs, the heavy current flowing through the thin wire inside the fuse generates heat, causing it to melt. This action disconnects the power supply from the connected system, preventing damage. During the regular operation of the circuit, the fuse wire functions as an external resistance component and does not interfere with the regular operation of the system connected to the power supply[19].

The speed of the fuse blown depends on how much current flows into it. When more current passes through the fuse, the temperature will rise. Thus, the response time will be faster. Fuses are mainly categorised into DCC fuse and AC fuse; as observed from the name, the DC fuse is used to prevent DC overcurrent, while the AC fuse is used to avoid AC overcurrent. DC fuses are typically larger than AC fuses to increase the distance between the electrodes, which helps to reduce the arc that forms within the fuse.

2.4.2 Circuit breaker

The circuit breaker is an essential device in the modern world today. It had become one of our house's most critical protection devices apples. Whenever electrical wiring in a building has much current flowing through, it can protect the device from getting damaged [20]. Without a circuit breaker, our house is not protected from fire or equipment failure.

The power distribution grid transmits electricity from a power plant to the residence. Within your home, the flow of electricity occurs within a complex network of circuits, both large and small. The hot wire, which connects to the power plant, comprises one end of the circuit, while the neutral wire, which leads to the earth, constitutes the other end. As the hot wire links to a high-energy source and the neutral wire links to an electrically neutral source, a voltage is established across the circuit, causing the charge to move once the circuit is closed. The electricity within the circuit is alternating current, as it changes direction rapidly.

A simple circuit breaker consists of fixed and moving contacts. Those contacts are connected when the circuit is closed, allowing current to flow through the circuit breaker. The circuit breaker cuts the circuit automatically when it senses a fault current in the circuit breaker. After the fault has been cleared, the breaker can be closed and allow the circuit to run. It stored potential energy in the operating mechanism. A metal spring, compressed air, or hydraulic pressure can store potential energy in the circuit breaker. These potential energies differentiate the types of circuit breakers. When the potential energy is released, the contact of the breaker will move far apart, causing the current not to flow. Circuit breaker usually deals with high currents. Thus, the arcing between the moving contact and fixed contact is increased. Arcing in the circuit breaker can be considered safe if the dielectric strength between the conductor.[21]

Low, medium, and high levels differentiate the circuit breaker. Low-level circuit breakers usually apply at the house as the voltage level is low. Low-level circuit breakers include a miniature circuit breaker (MCB) and moulded case circuit breaker (mccb). MCB characteristics usually are not adjustable. The rated current is less than 100A. Mccb has a higher-rated current than MCB. The rated current can reach up to 2500A. There are some other low-level circuit breakers: thermal magnetic circuit breakers and standard trip breakers. The medium-level circuit breaker is rated between 1kv to 72kv. It usually applies to industries and substations. The most common medium-level circuit breaker is the air circuit breaker. The breaker contacts by using air.

Figure 2.7: Miniature circuit breaker

2.4.3 Protective relay

For almost 150 years, protective relays have been an essential component of electrical systems, playing a critical role in maintaining their safe and dependable functioning. When paired with switchgear, these relays detect any problems that may arise inside the system.

Circuit breakers can efficiently isolate the hard part by depending on the instructions supplied by the relays, reducing the impact of the malfunction.

A protective relay's principal role is to monitor the electrical properties of circuits and detect abnormal circumstances. It monitors frequency, voltage, current, impedance, and phase angles, among other things. If the measured values deviate beyond permitted limits, indicating a problem, the protective relays receive a signal identifying the location and kind of fault.[4]

When a problem is detected, the protective relay automatically closes the trip circuit of the circuit breaker. This step disconnects the defective circuit from the system and opens the circuit breaker to cease current flow. The protective relay helps avoid additional damage and preserves the overall stability and dependability of the electrical system by quickly isolating the damaged part.

2.5 Protection relay design criteria

The sensitivity of the protective relay can detect the smallest value of fault current. Selectivity is selecting fault current from other currents, such as the starting current. Speed of protective relay refers to how fast a protective relay detects fault to minimise the damage to the device. The reliability and dependability of a protective device should be reliable when a fault happens.

2.6 Overcurrent protection relay

An overcurrent protective relay is applied to specific appliances. The function of the relay is similar to the circuit breaker, protecting the device from overcurrent faults. Relay usually has its setting, which we can apply at a particular time at a certain level. The relay will react if the current exceeds a predetermined threshold. This type of relay consists of two main components, sensing and control. The sensing device detects fault current, while the control device determines when the relay starts working.

Since the function of an overcurrent relay is similar to a circuit breaker, why is an overcurrent relay still needed? This relay usually applies to the motor and other appliances considering starting criteria. For example, the relay is used for the induction motor. An induction motor requires a high starting current to ensure the motor has enough energy to move the motor. The starting current is very high, 5-10 times of rated current. If a circuit breaker applies to the motor, the circuit will cut off easily when the predetermined current is too low. Appliances will become hotter if the predetermined current is high, causing low efficiency. Thus, protective relays are suitable for motor protective devices. It can not sense the starting current and start operating after the starting criteria.

One of the advantages of using an overcurrent relay is it can protect the devices by eliminating the starting current. Another advantage of an overcurrent relay is its simple circuit and low cost. Besides advantages, the overcurrent relay can cause some disadvantages, such as causing whole tripping and may not provide suitable protection against all fault types [22].

Figure 2.8: Overcurrent relay

2.6.1 Importance of overcurrent protective relay

The importance of overcurrent protective relays in electrical systems cannot be overstated. These devices play a critical role in safeguarding against the harmful consequences of high currents. Specifically, they are engineered to identify irregularities in electrical circuits related to current flow and intervene by triggering a power cut-off. By doing so, they prevent harm to equipment, potential fires, and electrical hazards that could cause damage to individuals.

The protective relay's first importance is its use to protect electrical equipment. Overcurrent protective relay protects the devices, equipment, and transmission line from excessive current. Besides that, it contributes to the prevention of fire. Electrical fire is usually caused by a high value of current flow to the devices. The high value of current can cause overheating of devices.

Moreover, the importance of a protective relay can lead to personal safety. High-level currents can cause human death when humans come into contact with the fault. Lastly, an overcurrent protective relay helps improve the device's reliability by preventing unnecessary downtime and minimising equipment damage.

2.6.2 Type of overcurrent protective relay

Overcurrent relays are essential parts of power system protection and come in a variety of forms designed to meet different operational requirements. The inverse time-current characteristic of the Inverse Time Overcurrent Relay allows it to respond more quickly as current magnitudes increase. When the current exceeds a preset threshold, Instantaneous Overcurrent Relays guarantee instantaneous circuit breaker triggering without any time delay, providing prompt protection against extreme overcurrent situations. By taking into account the direction of current flow, Directional Overcurrent Relays provide selectivity and facilitate the localization of faults. In order to improve system safety, ground overcurrent relays are designed to detect overcurrent situations in grounded conductors. Time-Overcurrent and Instantaneous Relays offer versatility for a variety of overcurrent circumstances by combining instantaneous tripping capabilities with customisable time delay settings. In particular, neutral overcurrent relays protect against unbalanced current conditions in the neutral conductor and ground faults. Together, these relays help power systems operate safely and dependably by quickly and selectively cutting circuits in reaction to unusual current situations. The power system's distinct features are taken into consideration when choosing a particular type of relay, highlighting the necessity of specialised protection plans to maximise operating efficiency and reduce potential hazards.

2.6.2.1 Instantaneous overcurrent relay

An instantaneous overcurrent relay is a protective relay to ensure devices are free from overcurrent faults. The word 'instantaneous' in this type of relay shows its characteristics. It means this relay does not have a time delay. The tripping of this relay is instantaneous and does not deal with device starting criteria. This relay contributes advantages of reducing the operation time to a minimum fault and protecting the device from fault. Since there is no time delay in this relay, there is only a pick-up current setting but no time setting.

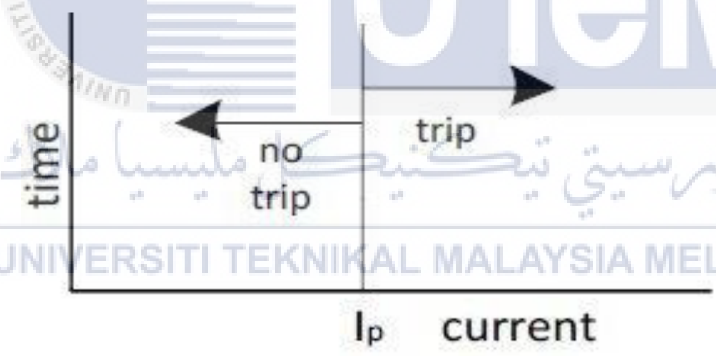


Figure 2.9: Time versus current graph of instantaneous overcurrent relay

2.6.2.2 Definite time overcurrent relay

Definite time overcurrent relay is another type that protects devices from overcurrent faults. This type of overcurrent relay can deal with the machine's starting condition, especially the motor. The definite time overcurrent relay must satisfy two requirements to cut off the current. These two conditions must exceed the setting value, and fault must be continuous for at least equal to the setting time. Figure 1.25 shows the characteristics of a definite time overcurrent relay. The zone above the red curve is the operating zone, while the zone below the red curve will be the off zone.

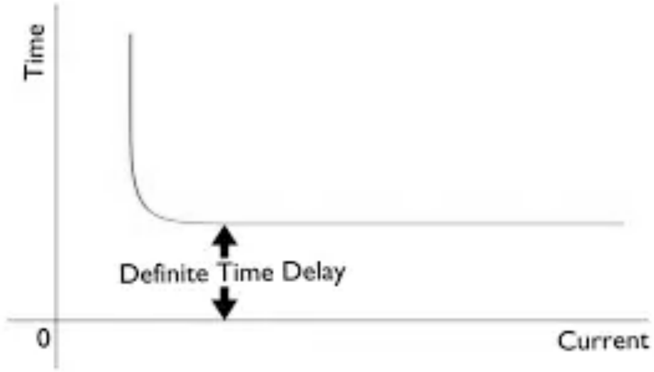


Figure 2.10: Time versus current graph of definite time overcurrent relay

2.6.2.3 Inverse definite minimum time overcurrent relay (IDMT)

IDMT relay is a protective device whose operating time is inversely proportional to the fault current. The relay will quickly clear the fault when the fault current is high. IDMT relay is usually used as a circuit breaker. When the relay senses any overcurrent fault, a signal will be sent to the circuit breaker, and the circuit breaker will cut the current. Generally, IDMT relays work with a current transformer to sense any fault current [23]. The current transformer will lower the current level to reach a suitable level for the IDMT relay. The sensitivity of the IDMT relay is higher than another overcurrent relay. There are three IDMT overcurrent relays: inverse relay, very inverse relay, and extreme inverse relay.

The core working principle of an IDMT Relay is simple. It entails placing a current transformer next to the line to be protected, with the current transformer's output linked to the relay coil. A circuit breaker is linked to the relay output. With new IDMT relays incorporating digital displays that indicate the current flow value, the CT continually measures the current flow in the line. The IDMT relay is activated when the current flow exceeds the threshold. The amount of the present dictates the operational time of the relay.

As a result, the relay is triggered based on the amount of the current. When the relay is engaged, it sends a signal to the circuit breaker, causing the electricity to be switched off.

The application of IDMT relay is wide. For example, IDMT relays are placed in the transmission line or substation. It ensures the safe level of the equipment. Besides that, the IDMT relay uses a continuous current circuit to monitor the current level. Moreover, IDMT relays are also used to protect electrical power, load, and safety circuits.

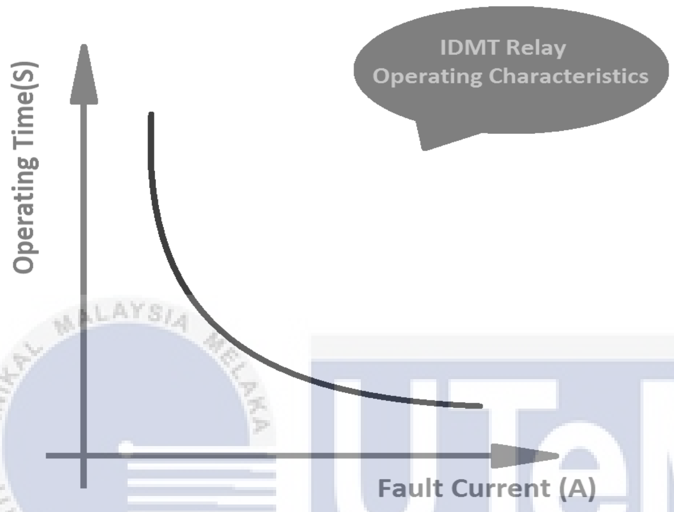


Figure 2.11: Time versus current graph for IDMT relay

2.6.3 Why IDMT relay used in the TNB substation rather than the DT relay?

Table 2.1: Calculated result for DT and IDMT relay

Fault Location	Relay	Definite time Relay	IDMT relay
Location A (If = 10k)	CB 1	-	-
	CB 2	1.2s	0.48s
	CB 3	1.6s	1.13s
Location B (If = 5k)	CB 1	0.8s	0.32s
	CB 2	1.2s	0.65s
	CB 3	1.6s	1.82s

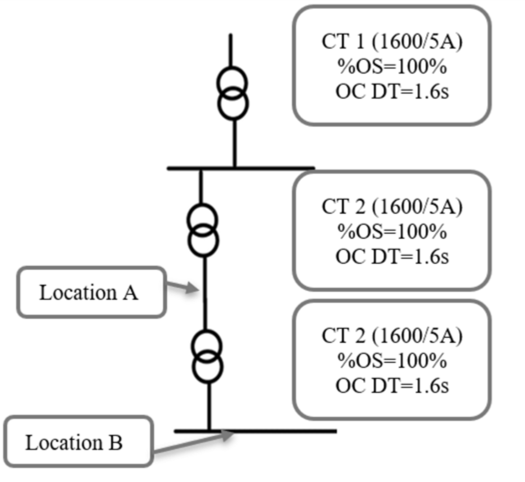


Figure 2.12: Circuit to prove IDMT and DT relay

The table above shows the comparison between the definite time overcurrent relay and the inverse definite minimum time overcurrent relay. In this experiment, there are 2 fault locations, location A and location B. The fault currents at each location are different. The table above shows the relay trip time for both relays. According to the table, the IDMT relay will trip faster when the fault current is higher. For a definite time, relay, the relay trip time is the same for different fault currents. The result for IDMT relay trip time had fulfilled the theory of the relay which is the relay trip time is inversely proportional to the fault current flow to the relay. This characteristic is important for the high level of fault current. Since TNB is using a very high current level in the substation, the IDMT relay is suitable to be used in the system. When relay tripping time is faster, the components are protected from high-level fault current. It can help to avoid damage to the equipment.

2.7 Inverse Definite Minimum Time (IDMT) relay

An essential part of power system protection is the Inverse Definite Minimum Time (IDMT) relay, which is made to recognise and react to overcurrent situations. The IDMT relay exhibits an inverse connection between operating time and the fault current magnitude, in contrast to conventional relays that have fixed time delays. Relay operation time reduces inversely with fault current, enabling faster tripping during severe overcurrent situations. This feature makes sure the IDMT relay is sensitive to different fault sizes and provides a more responsive and focused reaction. The IDMT relay is a commonly used component in distribution and transmission systems. Its adaptability and customisation enable engineers to adjust its parameters in accordance with the unique demands of the power system. It works by quickly isolating malfunctioning areas, averting equipment damage, and improving the overall dependability and security of the electrical system.

2.7.1 The setting of IDMT overcurrent relay

The way that an inverse definite minimum time overcurrent relay is set depends on the electrical system's characteristics and the type of equipment it is meant to protect. The relay settings are primarily based on the current levels at which the relay should trigger and the time delay before the relay starts operating.

Inverse time overcurrent relays utilise a curve designed to have a quicker trip time for higher current levels while having a slower trip time for lower current levels. This curve is known as the "inverse definite minimum time" curve. Generally, the curve is adjusted to align with the specific characteristics of the electrical system and equipment requiring protection.

Inverse definite minimum time overcurrent relay has four settings: pick up current, current setting, plug setting multiplier (PSM), and time setting multiplier (TSM).

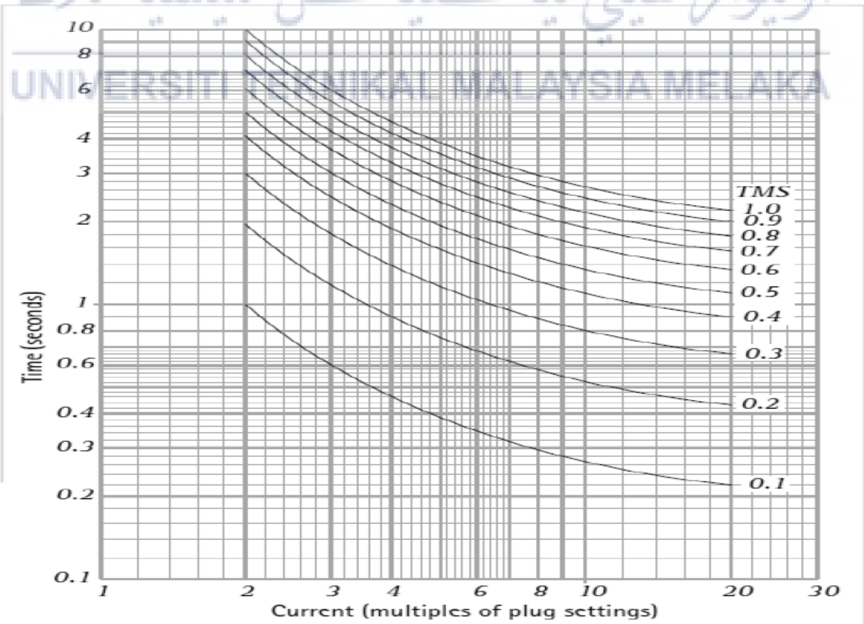


Figure 2.13: Typical time versus current characteristics of IDMT relay

2.7.1.1 Pick up the current setting

The IDMT relay's pick-up current is the minimum current value at which the relay coil starts to operate. If the current is lower than the pick-up current, the relay will not work. If the current through the relay is more than the pick-up current, the relay will run [18]. The graph below shows the operating and actuating times of the IDMT relay. As the actuating quantity increases, less time is required to operate the relay.

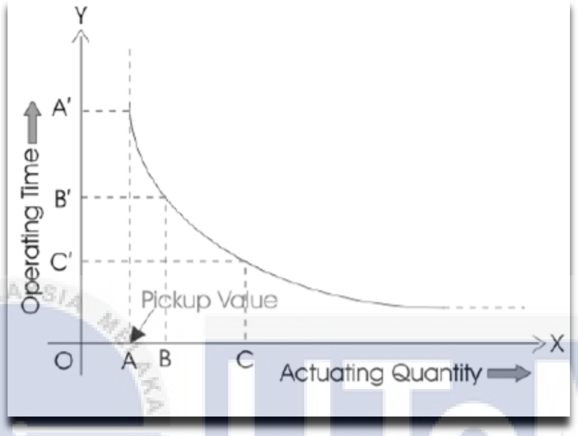


Figure 2.14: Operating time versus actuating quantity graph

2.7.1.2 Current setting

It is possible to use the same model of relays in different systems with some adjustments. The pick-up current of the relay needs to be modified to meet the specific requirements of each design. This is called the current setting of the relay, and it is done by adding the necessary number of taps to the coil. These taps are connected to a plug bridge, and by inserting a plug-in at different points on the bridge, the number of active turns in the coil can be changed. The current setting of the relay is expressed as a percentage ratio of the relay's pick-up current to the rated secondary current of the current transformer (CT).

$$Current\ setting = \frac{Pick\ up\ current}{Rated\ secondary\ current} \times 100\%$$

2.7.1.3 Plug setting multiplier

The PSM value is calculated using the required operating parameters of the overcurrent relay, which generally follow a curve established by applicable standards or technical criteria. Normal inverse, very inverse, significantly inverse, and long-time inverse are all standard IDMT relay curves. The plug setting for an IDMT decides the relay's current requirement to pick up. An electromechanical overcurrent relay has shorting plugs in the plug-setting bridge. The plug setting multiplier is estimated and may vary based on the relay type, standard, or engineering purpose. Examine the relay manufacturer's literature or applicable standards to find the suitable PSM value for a given IDMT relay application.

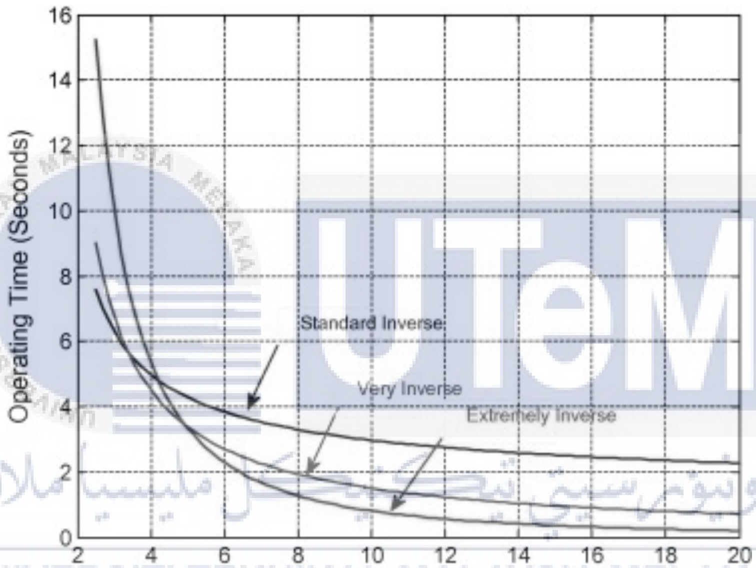


Figure 2.15: Different type of overcurrent relay curve.

2.7.1.4 Time setting multiplier

The operating time characteristic of an inverted definite time overcurrent (IDMT) relay is determined by the time setting multiplier (TMS). The TMS determines the relay's operating time based on the ratio of the fault current to the relay's pick-up current.

$$t_{op} = \frac{0.14\,TSM}{PSM^{0.02} - 1}$$

2.8 Summary

This chapter reviewed the literature review for IDMT relay. From the chapter, the information and knowledge regarding the project are listed and brief. A study concluded that inverse minimum time overcurrent relays are the most suitable to be placed in the substation to protect end-users and equipment.

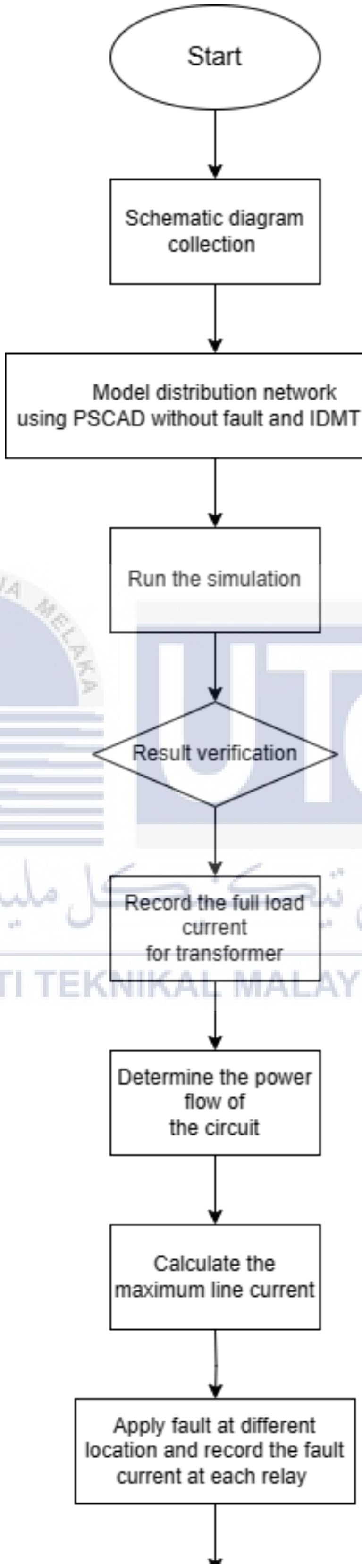
CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter lists the methodology used to complete the project to achieve the objective and goals. The project uses PSCAD simulation software to simulate the circuit for the 132/11KV Pencawang Masuk Utama (PMU) substation. In this chapter, the project flow chart, list of equipment in PSCAD software, data collection, and modelling of the circuit will be discussed.

3.2 Project flow chart



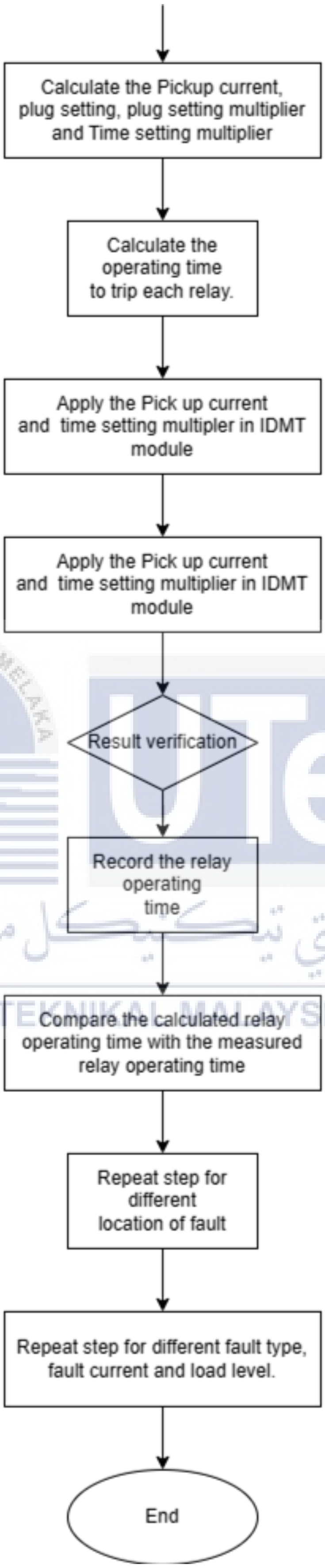


Figure 3.1: Flow chart of the project.

3.3 Data collection

The research was first carried out by searching for data. The most critical data needed to collect is the circuit diagram for Pencawang Masuk Utama (PMU). The circuit network is managed by Tenaga National Berhad (TNB). After receiving the circuit diagram for PMU, the rating related to each electrical component must be verified and listed for future planning. Each component's rating was obtained from the data sheet of the circuit itself. The rating of the component is crucial when considering fault current. We need the correct rating value so the protective device can work properly.

3.3.1 132/11kV Pencawang Masuk Utama (PMU) network from TNB

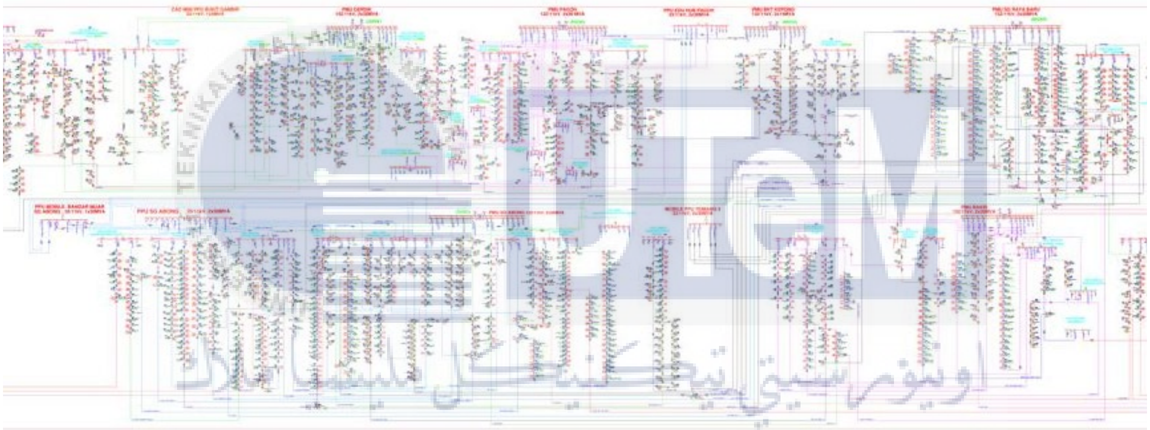


Figure 3.2: Distribution network at Melaka and Muar.

132/11kv PMU network is one of the substations in the distribution system of electricity in Malaysia. PMU indicates the main distribution substation which differentiates from other substations by the rating of the main transformer. For the PMU substation, the transformer rating is 132/11kv. The figure above shows the PMU substations that are located at several locations which are Melaka and Muar. The distribution network also includes loads like Universities, houses, shop lots and others. The network is extremely huge and complicated. For this project, we are using the PMU Pagoh substation for analysis.

3.4 Modelling of the network using PSCAD software

The electrical network will be modelled after collecting all the data needed for this project. The modelling of the electrical network uses Power System Computer Aided Design (PSCAD). All the components are found in the component list in the software. After placing the suitable part in the right place, connect each component by wire. Make sure the wire is connected correctly to each other. Next, each component's rating is clarified in each component. The component's rating is essential to ensure the protective device works successfully. Before applying the fault to the system, the voltage, power, and current level need to be verified so that the value is the same as the component nearby. After confirming each line rating, a fault is applied by connecting to the load. The current value at each line is essential to use in the calculation. From the analysis, we can obtain the operating time for each relay. The plug setting multiplier, time setting multiplier, and pick-up current obtained from the calculation are applied to the IDMT relay in PSCAD software. After simulating the circuit, we can accept each relay's operating time and verify the calculated result.

3.4.1 PSCAD simulation Tool

PSCAD (Power Systems Computer Aided Design) is a software program for simulating and analysing power system behaviour. It is widely utilised in electrical engineering and power systems research. Engineers and researchers may use PSCAD to model and simulate different power system components such as generators, transformers, transmission lines, and loads.

The program has a graphical user interface (GUI) that enables users to create and build power system models from a library of pre-built components. These parts can be linked together to form sophisticated power system setups. Users may define each component's electrical properties and control settings, allowing for extensive modelling and analysis.

PSCAD is widely used in academia, research, and the power sector for power system analysis, protection studies, renewable energy integration, and control system development.

It is a valuable tool for investigating and optimising complicated power systems' behaviour before real-world deployment.

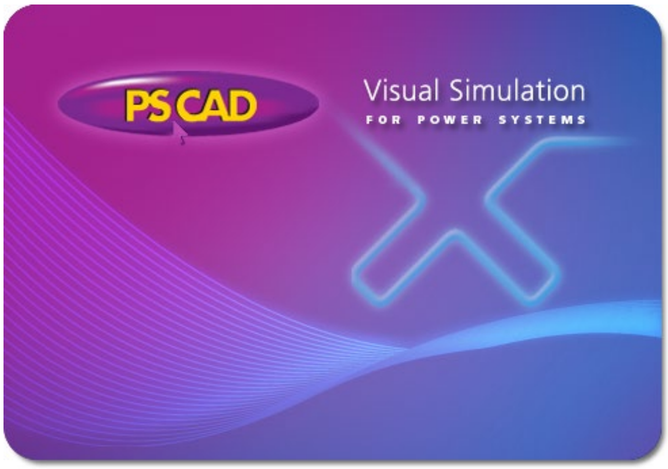


Figure 3.3: PSCAD software

3.4.2 List of equipment in PSCAD software

- Three-phase voltage source
- Transformer
- Inverse Definite Minimum Time (IDMT) overcurrent relay
- Load
- Three phase fault
- Multimeter
- Output channel

3.4.2.1 Three-Phase Voltage Source

The voltage source is used to supply the whole circuit network. In the actual circuit at PMU, the source indicates the incoming voltage from the power plant. In this circuit, the voltage is set as 11kv with 50Hz frequency. The source is set to the ideal type by setting the internal impedance and resistance to 0. When there is no internal resistance, the power losses are zero, and the total current will flow to the line. Overall, two sources were used in the circuit.

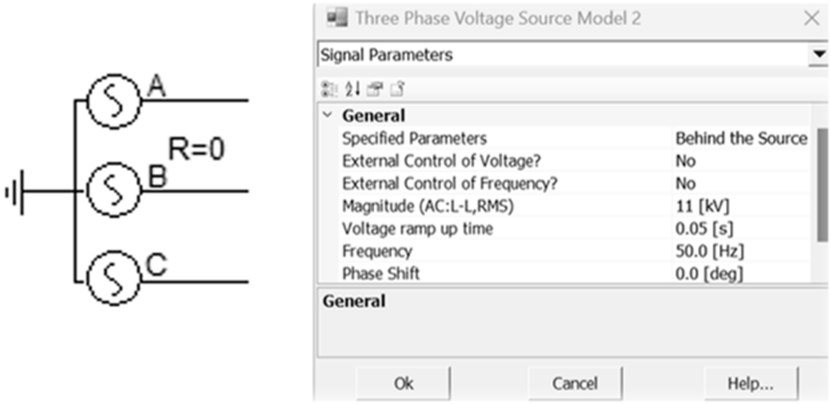


Figure 3.4: Three phase voltage source and setting parameter.

3.4.2.2 Transformer

The circuit transformer decreases or increases the current to a safe level for a relay. In the TNB distribution system, the current level is usually up to 132kV, and the current will be very high. When a fault happens, the current level can rise to ten thousand amperes, and the component's temperature will be very high. Thus, a transformer decreases the current level to a value suitable to the component. It will not affect the tripping of the overcurrent relay when decreasing the current value since the pick-up current can decrease based on the transformer ratio.

There are three relays used in this circuit. The transformer-rated apparent power is set to 100MVA, and the rated frequency is 50 Hz. The transformer is assumed to be ideal as no internal resistance appears in the transformer. The primary winding of the transformer is set to 11kV, while the secondary winding is set to 33kV. His transformer is used to increase the current level.

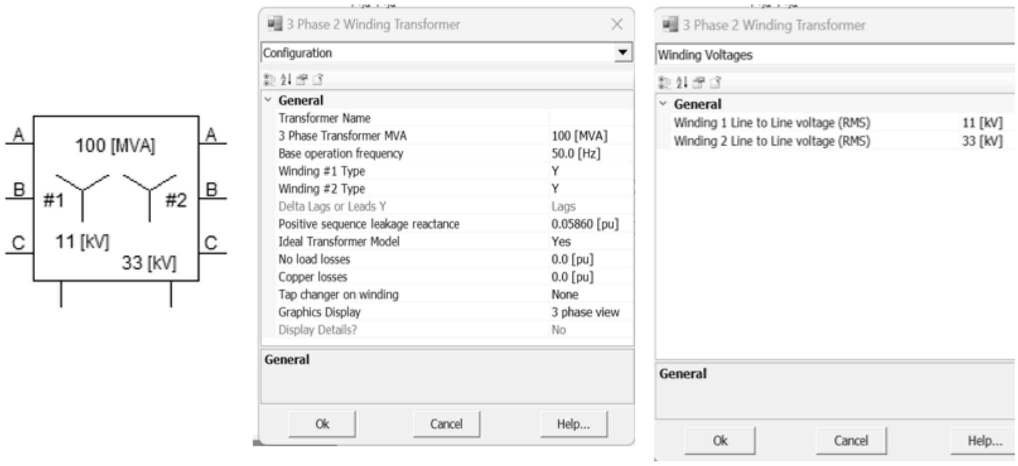


Figure 3.5: Transformer and setting parameter

3.4.2.3 Inverse Definite Minimum Time Overcurrent Relay (IDMT)

IDMT relay is the device to cut the current flow when a fault happens. The relay will trip when the current exceeds the calculation's pre-set level. In a simple motor, the starting current can rise to 7 times the rated current. The starting current of the motor should not be treated as a fault current. Thus, the IDMT relay has introduced the delay in starting the circuit. This means the relay will delay for a specific time only to begin to detect the fault current.

Only two settings can apply to the IDMT relay: pick-up current and time dial setting. The pick-up current is the current level that the relay will start to detect the fault current. The time dial setting is also called the time setting multiplier. It is the setting related to time delay. The type of curve standard is IEC std 255-3, and the type of relay characteristic is standard inverse.

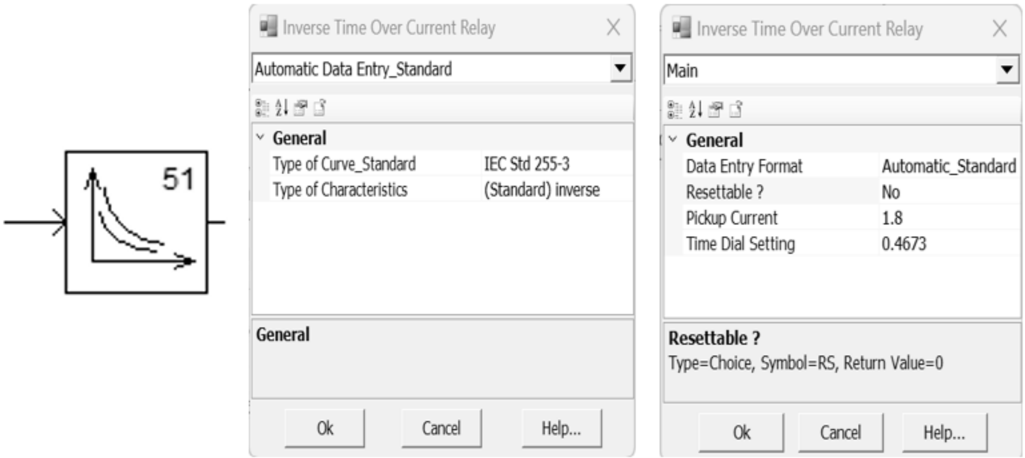


Figure 3.6: IDMT relay and setting parameters

3.4.2.4 Load

The load is placed at the end of the circuit. It indicates the voltage level of the source at the next substation. The load usually has its rating and is expressed by apparent power (MVA), reactive power (MVAR), and active power (MW). There are different types of load applied to the circuit. The rated rms phase voltage of the load is 19.05 and 6.358kV per phase. The rated apparent power calculated from reactive and active power should not exceed the transformer-rated apparent power so that the full load current can supply to load. All loads are set to Malaysia's standard frequency of 50 Hz.

$$P = S\cos\theta \quad (3\text{-}1)$$

$$Q = S\sin\theta \quad (3\text{-}2)$$

$$Pf = \cos\theta = \frac{P}{S} \quad (3\text{-}3)$$

$$S = \sqrt{P^2 + Q^2} \quad (3\text{-}4)$$

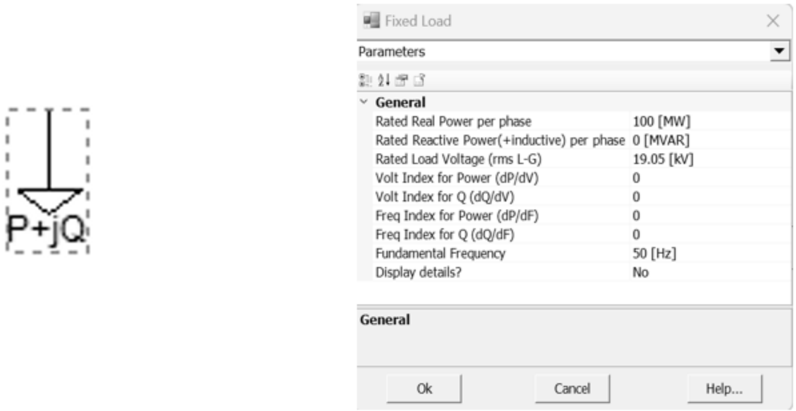


Figure 3.7: Load and setting parameter

3.4.2.5 Three-phase fault logic

Three-phase faults indicate the real-life fault that happened to the line or equipment. The fault in this circuit is to observe the tripping effect during any overcurrent fault. When considering the three-phase fault logic, there are two parts: three-phase fault and time logic. The three-phase fault sets the type of fault that includes line to a line fault or line to ground fault. The time fault logic indicates the time to apply fault to the system and the duration of the fault.

In this project, the type of fault is line to line to line to ground fault. The fault is balanced at each phase. The time to apply fault is 0.1s, and the fault duration is 10s. The fault period is extended so that it will be easy to observe the tripping time of real.

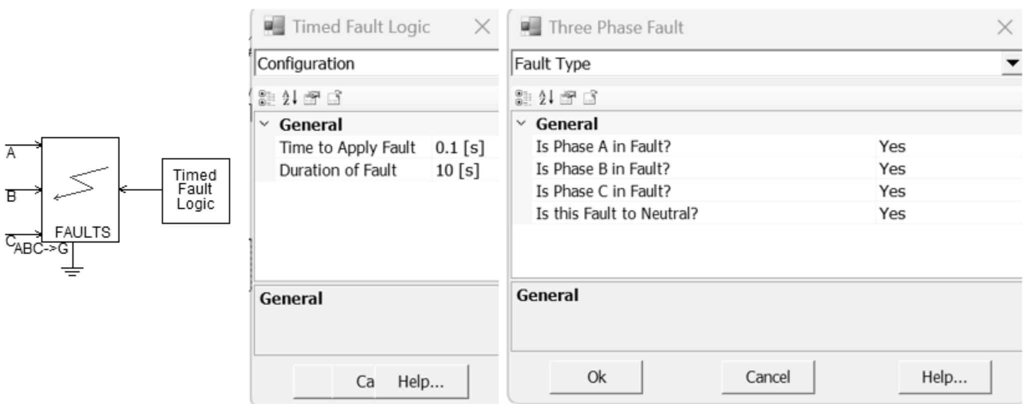


Figure 3.8: Setting parameters of three phase fault and time fault logic

3.5 Measurement of data

Data is often monitored in electrical circuits using various parameters based on the individual features of the circuit and the type of data being analyzed. Some examples of common data measures in electrical circuits are voltage, current, resistance power, frequency, impedance, capacitance, and inductance.

Two tools are used in the measurement: a multimeter and an output channel. Multimeter function to record the value of current and voltage. And output channel is used to convert the current flow to the graph.

3.5.1 List of equipment in measurement

- Multimeter
- Output channel

3.5.1.1 Multimeter

A multimeter is an essential item used in electrical circuit measurement. A multimeter is used to measure the voltage and current in a circuit. The multimeter is usually placed in the middle of two components or the line. The current flow toward the component will be measured by the multimeter and displayed. There are several parameters in the multimeter, which are voltage (kV), current (kA), active power (kW), and reactive power (kVAR). The current will convert to voltage by the apparent power pre-set in the multimeter. The multimeter current will be named and used in the IDMT relay and output channel.

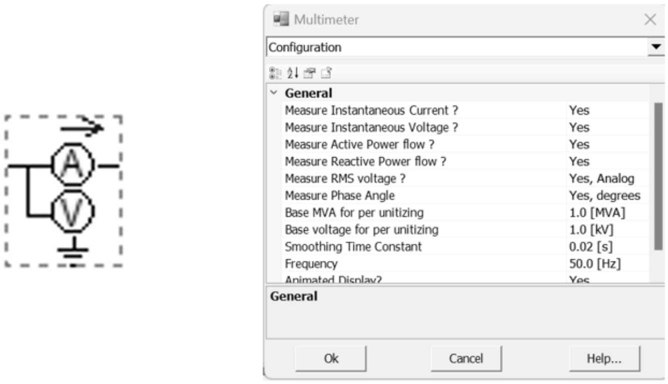


Figure 3.9: Multimeter and setting parameters

3.5.1.2 Output channel

The output channel is a component that displays the current flow or voltage flow in the graph. The source of the is in the AC signal. Unlike a DC waveform, an AC signal is represented in a sine wave which would have a positive or negative value. It will not display the current flow as an exact value. Thus, representing the waveform in the graph will show the behaviour of the current or voltage source. The scale factor is set as one so that the values displayed in the graph are kA or kV.

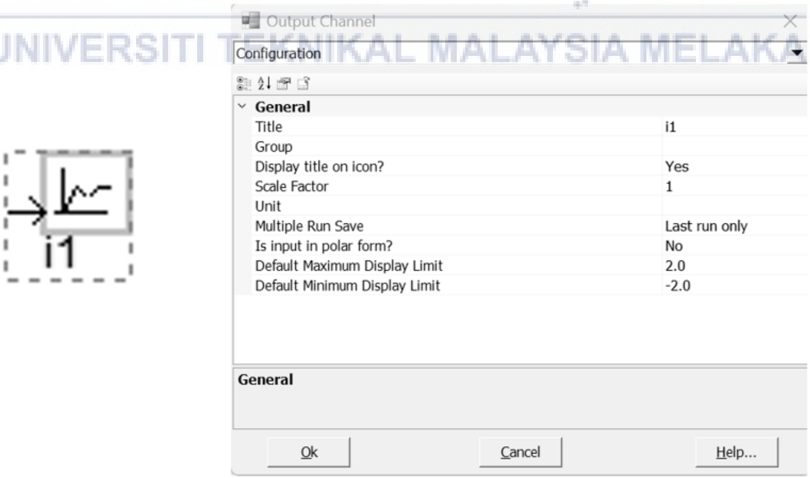


Figure 3.10: Output channel and setting parameters

3.6 Conclusion

In conclusion, this chapter shows the components that are used in the PSCAD simulation software. There are a few components that are included in the network which are IDMT relay, transformer and load. All of the components are explained in detail to illustrate the characteristics of each component. All the components are listed according to their function which are measurement, IDMT relay and transformer. This chapter also shows the project flow chart to conduct the project.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the results obtained from simulation software. The parameters set by TNB are obtained and the rating of the components is calculated before the simulation. This chapter also discusses the parameters that will affect the line current and relay trip time. The simulation results show the network's tripping time, relay current, and load current. Lastly, the simulation result is verified by comparing it with the calculation result.

4.2 PMU Pagoh

The Pencawang Masuk Utama (PMU) is a vital hub in our power distribution network and stands as the nerve centre where electricity transforms from raw generation to a synchronized force powering our daily lives. With a symphony of transformers, circuit breakers, and cutting-edge technology, it is here that the electricity undergoes its final metamorphosis, ready to illuminate homes, drive industries, and fuel progress.

The circuit for PMU pages is obtained from TNB. The original circuit is connected with other substations, PPU or PMU. The PMU is connected with the PPU at Melaka. The PMU is also connected to the downstream substation at UIAM and UTHM. The Pmu also deliver the electricity to the house and shop nearby. PMU will receive electricity from the generation plant and deliver it to the downstream substation.

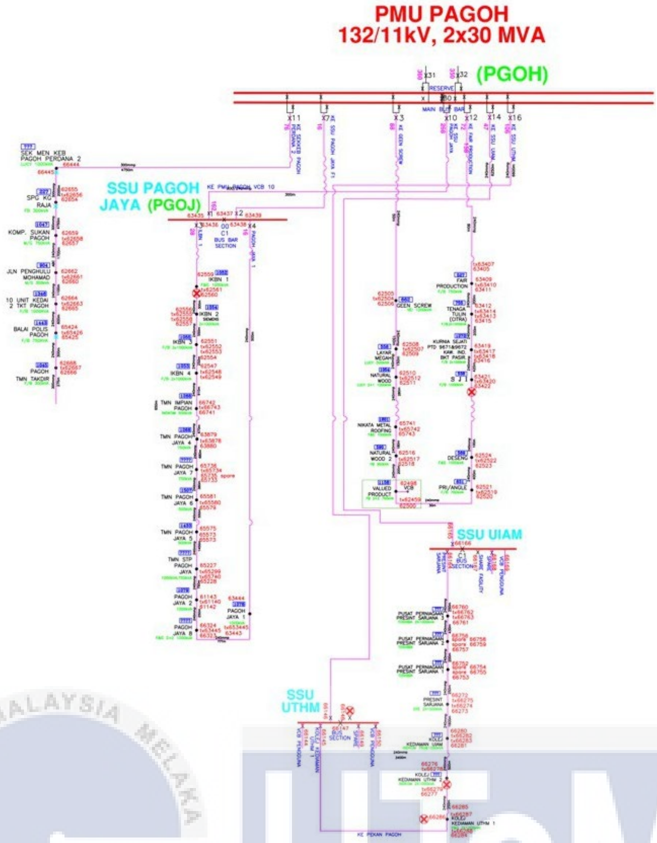


Figure 4.1: Single line diagram at PMU Pagoh

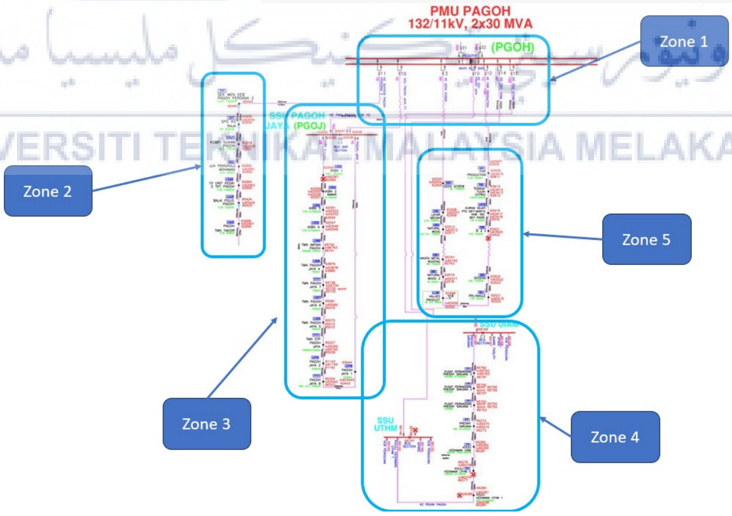


Figure 4.2: single line diagram with zone

The circuit is divided into 5 zones. Each zone contains a transformer, load and relay. The first zone indicates the supply of the substation. It transfers the power that is produced from the grid and delivers it to the other substation. This zone will be the first substation that receives electricity from the grid. The rating of the transformer will be extremely high to reduce the loss during the transmission. Zone 2 – zone 5 is the direct supply to the daily use. It contains the University, shop lot, house, and others. [24]

4.2.1 Parameters of equipment without fault

Table 4.1: Transformer rating

Zone	Turn ratio, (kV)	Type of configuration	Power rating, (MVA)
1	132/11	Y-Y	60.00
2	11/0.4	Y-Δ	2.00
	11/0.4	Y-Δ	1.50
	11/0.4	Y-Δ	0.90
3	11/0.4	Y-Δ	11.00
	11/0.4	Y-Δ	2.25
	11/0.4	Y-Δ	1.50
4	11/0.4	Y-Δ	9.00
	11/0.4	Y-Δ	0.75
5	11/0.4	Y-Δ	9.00
	11/0.4	Y-Δ	2.25
	11/0.4	Y-Δ	0.50
	11/0.4	Y-Δ	0.30

Table 4.2: Source rating

Source	RMS line voltage, (kV)	Frequency, (Hz)
Source	132	50

Table 4.3: Load rating

Load	RMS phase voltage, (kV)	Apparent power, (MVA)	Frequency, (Hz)
Load	0.4	0.05	50

4.2.2 Simulation diagram in PSCAD software

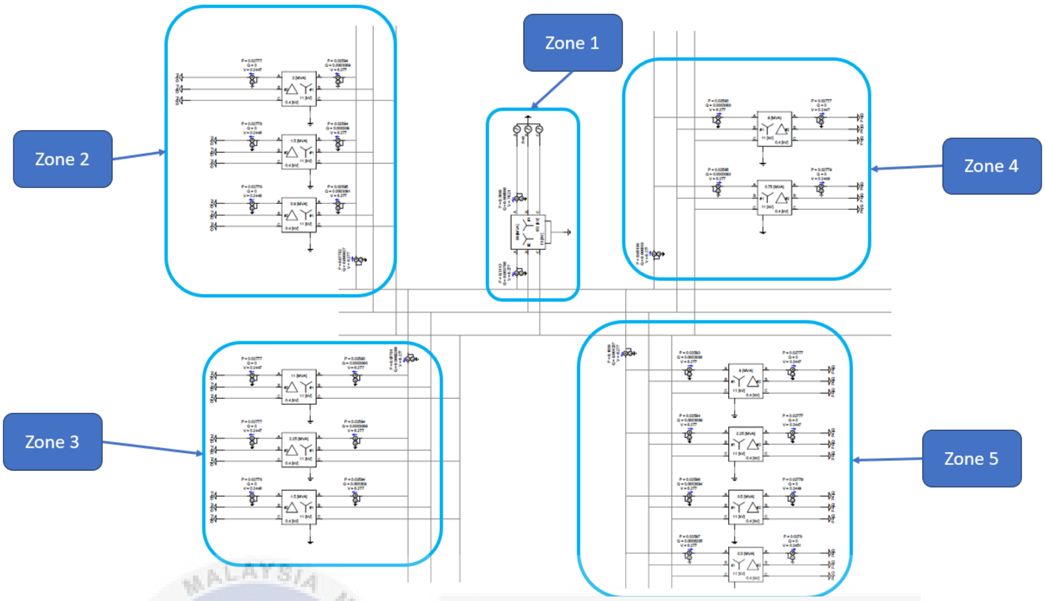


Figure 4.3: Simulation diagram according to zone.

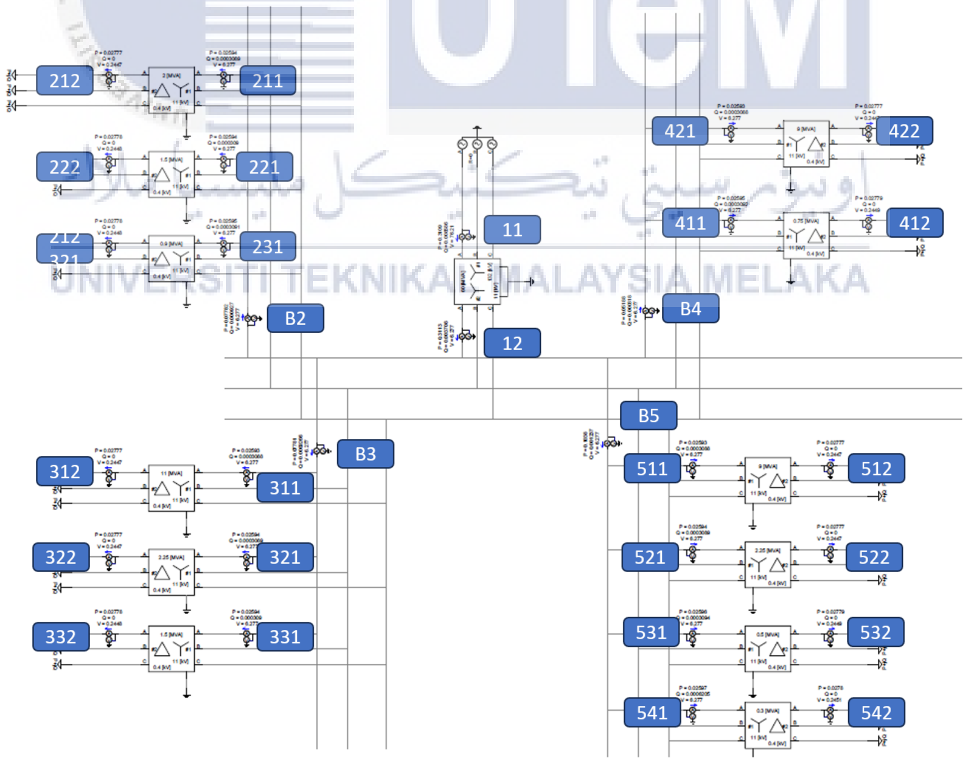


Figure 4.4: Circuit with each relay labelled.

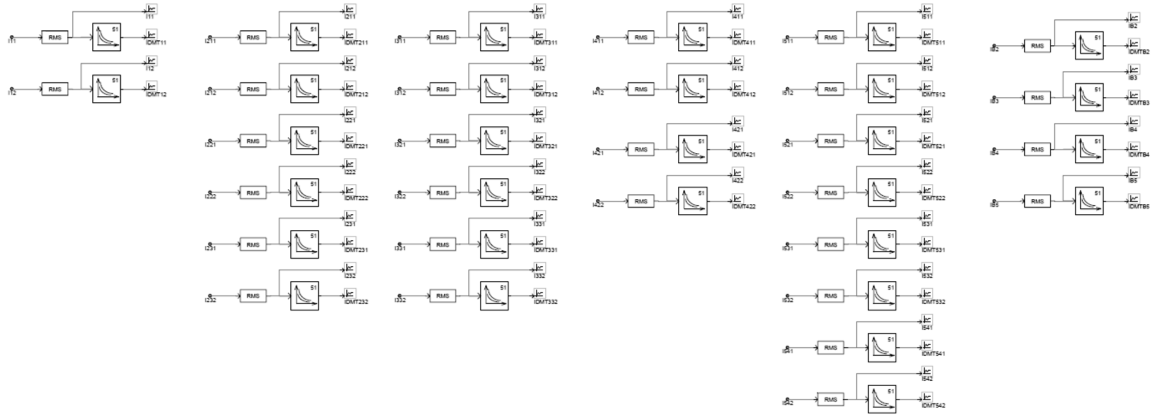


Figure 4.5: Circuit for IDMT relay.

There is a total of 30 IDMT relays in this circuit. The multimeter represents the IDMT The multimeter will measure the current and send it to the IDMT relay for further operation. The IDMT relay will receive the current value and trip according to the pick-up current set for each relay. The IDMT relay is applied before and after the transformer because the current will step up or down after passing through the transformer. Since the current value is different, each cable will have a different maximum current for the cable. Thus, the settings for each relay will be different from each other. The graph shows the relay operating time. It represents the relay will start operating and trip the circuit breaker. Since the relay trip time depends on the fault current, the relay will trip very fast for high fault current while the trip slow for low fault current. The graph also shows the time coordination for each relay.

4.3 Case Study

This project aims to assess overcurrent protection in the TNB network through six diverse fault scenarios: 3-phase balanced with ground, increased fault current, double line fault, double line to ground fault, triple line fault, and load increase. By simulating these cases, the study evaluates the adaptability and coordination of protective devices, aiming to uncover strengths, weaknesses, and potential improvements in the system for the overall reliability and safety of the Tenaga Nasional Berhad network. These scenarios encompass various challenges, providing insights into the network's resilience and the need for effective protective measures.

In an electrical network, a three-phase balanced fault with ground often results from equipment or insulation failures, causing imbalanced current flow and current leakage to the ground. This can lead to severe consequences such as equipment damage, service interruptions, and safety risks. The fault current in this scenario can be substantial, underscoring the importance of promptly identifying and isolating the fault to minimize potential damage and enhance protective measures.

The second case involves an increase in fault current achieved by elevating fault resistance. This can occur due to degraded insulation, poor connections, or corrosion, introducing higher resistance along the fault path. The severity of this fault depends on the network's design and condition. Proactive measures, including well-coordinated protective devices, advanced relaying, regular maintenance, equipment upgrades, and safety training, are crucial to mitigate potential impact and enhance overall network resilience.

A double line fault occurs when two lines simultaneously experience faults due to external factors or equipment failure, potentially disrupting service and causing equipment damage. Similarly, a double line to ground fault, resulting from two lines being grounded simultaneously, poses increased risks of equipment damage, safety hazards, and potential prolonged downtime. Effective protective device coordination is essential in both cases to minimize significant effects on network reliability and safety, as fault currents can be high.

In a triple line fault, simultaneous faults occur in all three phases, increasing the likelihood of equipment damage, serious disruptions, and safety risks. Effective protective measures and coordination are essential to mitigate potential serious impacts on network reliability and safety, given the potential for high fault currents in all scenarios. An increase in load in an electrical network, resulting from heightened demand or unforeseen events, can strain the system's capacity, potentially causing equipment overheating, unstable voltage, and compromised stability. While the fault may not cause immediate harm, sustained high loads can stress infrastructure and protective devices, posing long-term risks to network reliability. Effective load management and protective measures are crucial to ensuring network resilience and mitigating potential serious impacts.[25]

4.3.1 Parameters for equipment of each case

Table 4.4: Parameters for each case

Type	Load power (MW)	Fault resistance, Ω	Fault Type
3 phase balanced grounded	0.05	0.01	ABC-G
High fault current	0.05	0.001	ABC-G
Double line fault	0.05	0.01	AB
Double line to ground fault	0.05	0.01	AB-G
Triple line fault	0.05	0.01	ABC
Load increase by 100%	0.1	0.01	ABC-G

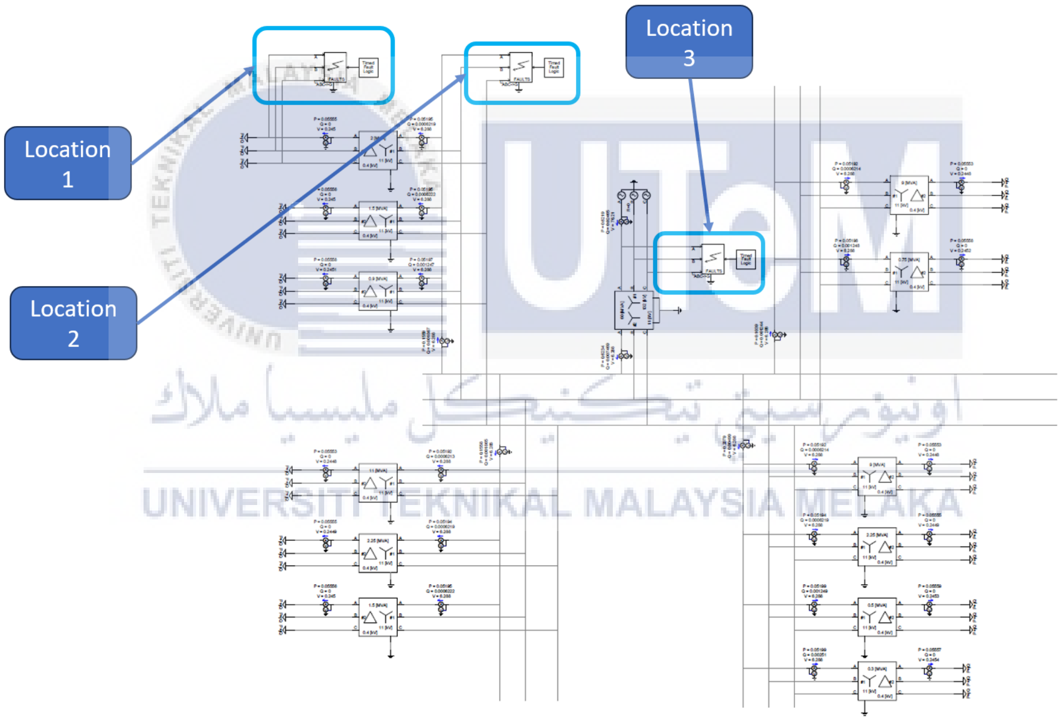


Figure 4.6: Fault location for the circuit.

There are 6 cases to show the characteristics of IDMT relay. The first case will be the most common fault type which is 3-phase balanced ground which means all the lines are fault to ground. For this case, the power at load is set to 0.05MW while the Fault resistance is 0.01Ω. The fault type of this case is A B C to G. The second case is similar to the first case but now the fault current is increased. Based on the voltage law, the fault current can be increased by decreasing the fault resistance. When fault current increases, the relay should operate fast and trip the relay in a short period. Fault resistance is decreased to 0.001 Ω.[26]

The third case is a double-line fault. Line A and line B are misconnected with each other. The line faults are not grounded. For this case, we are comparing the double line fault with the 3-phase balanced grounded fault. The following case will be a double line to ground fault. The lines A and B are grounded. This fault should have similar characteristics as the double-line fault. Besides that, triple line fault is also analysed in the project. All the lines are faulted and not connected to the ground. The above three cases will have the same load power and fault resistance as the case 3 phase balanced grounded fault.

The last case is load increase by 100%. When the load increases, the fault current at the location will increase. Thus, the relay should react and trip faster if the load increases. Load power is increased from 0.05MW to 0.1MW.

4.4 Calculation

4.4.1 Calculation on maximum line current

Step 1 Find line current

$$I_L = \frac{S_{rated}}{\sqrt{3} \times V_L}$$

Step 2 Find phase current

$$I_\emptyset = \sqrt{3} \times I_L$$

Table 4.5: Calculation result for line current and phase current.

Zone	Apparent Power (MVA)	Line voltage, V_L (kV)	Line current, I_L (kA)	Phase current, $I_\emptyset$ (kA)
11	60.0000	132.0000	0.2624	0.4545
12	60.0000	11.0000	3.1492	5.4545
211	2.0000	11.0000	0.1050	0.1818
212	2.0000	0.4000	2.8868	2.8868
221	1.5000	11.0000	0.0787	0.1364

222	1.5000	0.4000	2.1651	2.1651
231	0.9000	11.0000	0.0472	0.0818
232	0.9000	0.4000	1.2990	1.2990
311	11.0000	11.0000	0.5774	1.0000
312	11.0000	0.4000	15.8771	15.8771
321	2.2500	11.0000	0.1181	0.2045
322	2.2500	0.4000	3.2476	3.2476
331	1.5000	11.0000	0.0787	0.1364
332	1.5000	0.4000	2.1651	2.1651
411	9.0000	11.0000	0.4724	0.8182
412	9.0000	0.4000	12.9904	12.9904
421	0.7500	11.0000	0.0394	0.0682
422	0.7500	0.4000	1.0825	1.0825
511	9.0000	11.0000	0.4724	0.8182
512	9.0000	0.4000	12.9904	12.9904
521	2.2500	11.0000	0.1181	0.2045
522	2.2500	0.4000	3.2476	3.2476
531	0.5000	11.0000	0.0262	0.0455
532	0.5000	0.4000	0.7217	0.7217
541	0.3000	11.0000	0.0157	0.0273
542	0.3000	0.4000	0.4330	0.4330
B2	4.4000	11.0000	0.2309	0.4000
B3	14.7500	11.0000	0.7742	1.3409
B4	9.7500	11.0000	0.5117	0.8864
B5	12.0500	11.0000	0.6325	1.0955

The current in a Tenaga Nasional Berhad (TNB) network plays a crucial role in controlling the movement of electric charge through the conductors in the system. This current is usually alternating, and its direction and magnitude depend on the network configuration, transmission line impedance, and load demands. To mitigate overheating, prevent overloads, and prevent potential equipment damage, precise management and monitoring of current levels are crucial. TNB engineers use precise measurement and control techniques to maintain the integrity of the network, ensuring a reliable and efficient supply of electricity. The TNB electrical system operates best, is reliable, and lasts a long time when current-carrying capacities, protective devices, and overall network architecture are regularly evaluated.

The highest possible level of current flow in an electrical system is represented by the maximum line current in a Tenaga Nasional Berhad (TNB) network. It is an important parameter to comprehend because it aids in the design of safety precautions and the estimation of the current-carrying capacities of network conductors. Numerous elements, including the system's design, phase voltage, and total line impedance, affect this maximum line current. This parameter is constantly monitored by engineers and operators to avoid overloading, which could cause equipment to overheat and possibly sustain damage. For the TNB network to be reliable and safe, as well as to contribute to the general effectiveness and functionality of the electrical distribution system, it is imperative that the maximum line current stays within safe bounds. Regular assessments and adjustments are made to accommodate changes in demand and maintain optimal network performance.

The maximum line current is calculated using the formula above where I_L is the line current, S_{rated} is the rated apparent power that is set by the TNB is the V_L is the line voltage, and $I_\emptyset$ is the phase current. All the value shows the nominal current when the system is run at the rated condition. The line current is converted to phase current by using the formula. The reason to convert to phase current is because the relay is applied at each phase. The phase current at rate condition shows the maximum current that the cable, equipment or system can withstand. This current is a key parameter when designing an overcurrent relay because it shows the maximum current that is used in the calculation of the relay. [27]

According to the result calculated, we can observe that the voltage upstream will be higher than downstream due to the high apparent power for transformer at the upstream. Based on the simple voltage law V=IR, current is inversely proportional to voltage. Thus, the current downstream will be higher than upstream after the current is stepped up. Normally downstream are connected to daily use equipment and are directly connected to our home, high current will result in dangerous issues and accidents for us. That is the main reason why the overcurrent relay is applied to the system.

4.4.2 Calculation on time setting multiplier and pickup current

Step 1 find pick up current

$$I_{P-up} = 1.1 \times I_{max}$$

Step 2 find plug setting multiplier

$$PSM = \frac{I_F}{I_{P-up}}$$

Step 3 find operating time

$$t_{op} = \frac{0.14 \times TSM}{PSM^{0.02} - 1}$$

Step 4 find operating time for next relay

$$t_{op,new} = (t_{op,old} + t_{cb}) \times 110\%$$

Step 5 find time setting multiplier for next relay

$$TSM = \frac{(PSM^{0.02} - 1) \times t_{op}}{0.14}$$

Table 4.6: Calculation for pick up current and TMS

Type	Fault Location	Zone	Fault Current (KA)	Pick up current calculated	Pick up current + 10% overshoot (kA)	PSM	TMS	operating time, (s)
3 phase balanced grounded	Location 1	212	15.7995	2.8868	3.1754	4.9756	0.1000	0.4293
		211	0.5745	0.1818	0.2000	2.8726	0.1390	0.9122
		B2	0.5802	0.4000	0.4400	1.3185	0.0572	1.4435
	Location 2	B2	3.1523	0.4000	0.4400	7.1643	0.1000	0.3485
	Location 3	11	7620.8810	0.4545	0.5000	15241.7619	0.1000	0.0659
High fault current	Location 1	212	21.5452	2.8868	3.1754	6.7850	0.1000	0.3586
		211	0.7835	0.1818	0.2000	3.9173	0.1650	0.8345
		B2	0.7843	0.4000	0.4400	1.7825	0.1128	1.3579
	Location 2	B2	4.3690	0.4000	0.4400	9.9296	0.1000	0.2980
	Location 3	11	76208.7708	0.4545	0.5000	152417.5416	0.1000	0.0519
Double line fault	Location 1	212	17.0093	2.8868	3.1754	5.3565	0.1000	0.4101
		211	0.7121	0.1818	0.2000	3.5603	0.1637	0.8911
		B2	0.7156	0.4000	0.4400	1.6264	0.0992	1.4202
	Location 2	B2	3.6698	0.4000	0.4400	8.3405	0.1000	0.3231
	Location 3	11	13199.7492	0.4545	0.5000	26399.4984	0.1000	0.0620
Double line to	Location 1	212	13.7352	2.8868	3.1754	4.3255	0.1000	0.4710
		211	0.5745	0.1818	0.2000	2.8726	0.1460	0.9581
		B2	0.5801	0.4000	0.4400	1.3185	0.0592	1.4939

ground fault	Location 2	B2	4.7178	0.4000	0.4400	10.7223	0.1000	0.2881
	Location 3	11	7620.8810	0.4545	0.5000	15241.7619	0.1000	0.0659
Triple line fault	Location 1	212	20.6434	2.8868	3.1754	6.5010	0.1000	0.3670
		211	0.7507	0.1818	0.2000	3.7533	0.1615	0.8437
		B2	0.7532	0.4000	0.4400	1.7118	0.1056	1.3681
	Location 2	B2	3.8580	0.4000	0.4400	8.7683	0.1000	0.3155
	Location 3	11	22862.6341	0.4545	0.5000	45725.2682	0.1000	0.0585
Load increase by 100%	Location 1	212	15.7991	2.8868	3.1754	4.9754	0.1000	0.4293
		211	0.5745	0.1818	0.2000	2.8726	0.1390	0.9122
		B2	0.5858	0.4000	0.4400	1.3314	0.0592	1.4435
	Location 2	B2	4.2771	0.4000	0.4400	9.7206	0.1000	0.3008
	Location 3	11	7620.8851	0.4545	0.5000	15241.7701	0.1000	0.0659

Pickup current and the Time Setting Multiplier (TSM) are two crucial parameters that the Inverse Definite Minimum Time (IDMT) relay, a crucial part of power systems, depends on. To balance sensitivity and selectivity, TSM functions as a multiplier to modify the relay's response time. Relay sensitivity is reduced with a higher TSM, which also ensures that other protective devices operate in unison and avoid needless tripping during moments of disruption. Alternatively, a lower TSM increases sensitivity, which enables the relay to react quickly to real faults. This is especially useful for protecting critical equipment. Set higher than the maximum load current to prevent false trips under normal circumstances, the Pickup Current is the threshold at which the relay starts to operate. For effective protective coordination, TSM and Pickup Current must work together in the best possible way. This will allow the relay to respond quickly to faults and keep the system stable while conducting regular operations.[28]

The curve characteristic (n), in combination with TSM and Pickup Current, shapes the response curve of the IDMT relay. The relay's response time to fluctuating fault currents is influenced by its typical setting of 0.02 for moderate inverse-time characteristics. To ensure that the IDMT relay effectively contributes to fault detection and coordination, engineers must carefully configure these parameters to match the unique requirements of a Tenaga Nasional Berhad (TNB) network. This will improve the overall performance and reliability of the electrical distribution system.

All the formulas are listed above. The first step for the calculation is to calculate the pickup current. For this project, we have set the pickup current at 110% of the maximum current to allow a 10% overshoot. Overshoot usually happens and is not considered as overcurrent. By allowing 10% overshot, we can avoid the relay trip during this condition. If the current has over the pick-up current, only the relay starts to operate. The next step is to find the plug setting multiplier (PSM). The value of PSM is calculated by dividing the fault current by the pick-up current. PSM in relay indicates how big the fault current is over the pick-up current. If the fault current is high, PSM will be high also.

The third step is to find the operating time and time-setting multiplier (TSM). For the first relay that touches the fault, TMS is set to 0.1. The operating time for the first relay will be calculated. For the next relay in conjunction, the operating time will add the previous relay's operating time with 0.4 discrimination time and 10% overshoot. The reason for the discrimination time is to make sure not all relay trips at the same time when faults occur. The first relay should trip first and continue by the next relay. After the relay operating time is calculated, the TMS will be calculated. In the simulation software, the parameters that need to be set are the pick-up current and time-setting multiplier.

4.5 Result

4.5.1 Graph for relay operation time

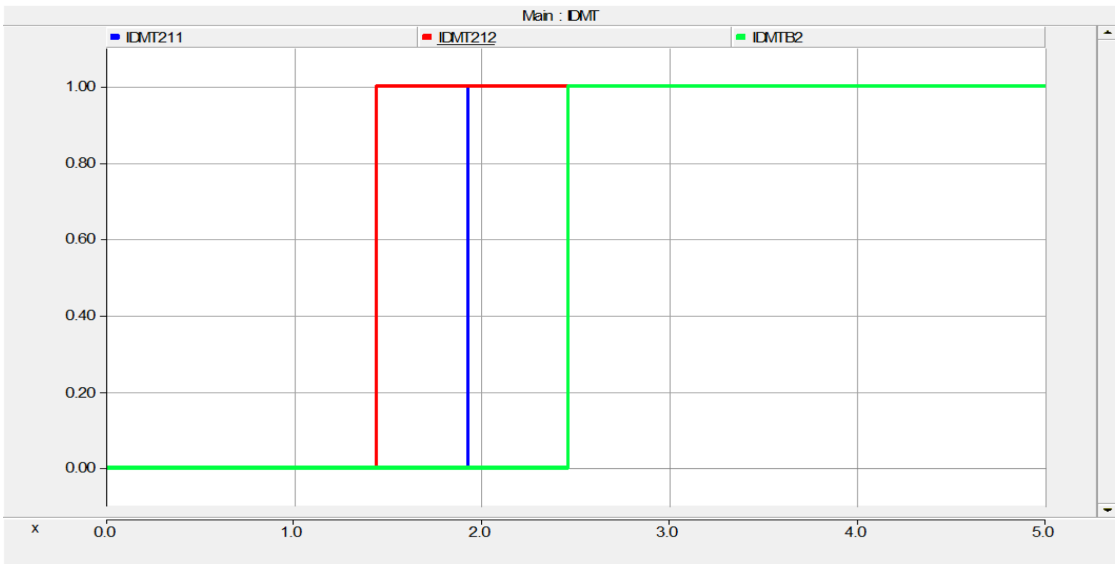


Figure 4.7: Relay operation time for location 1

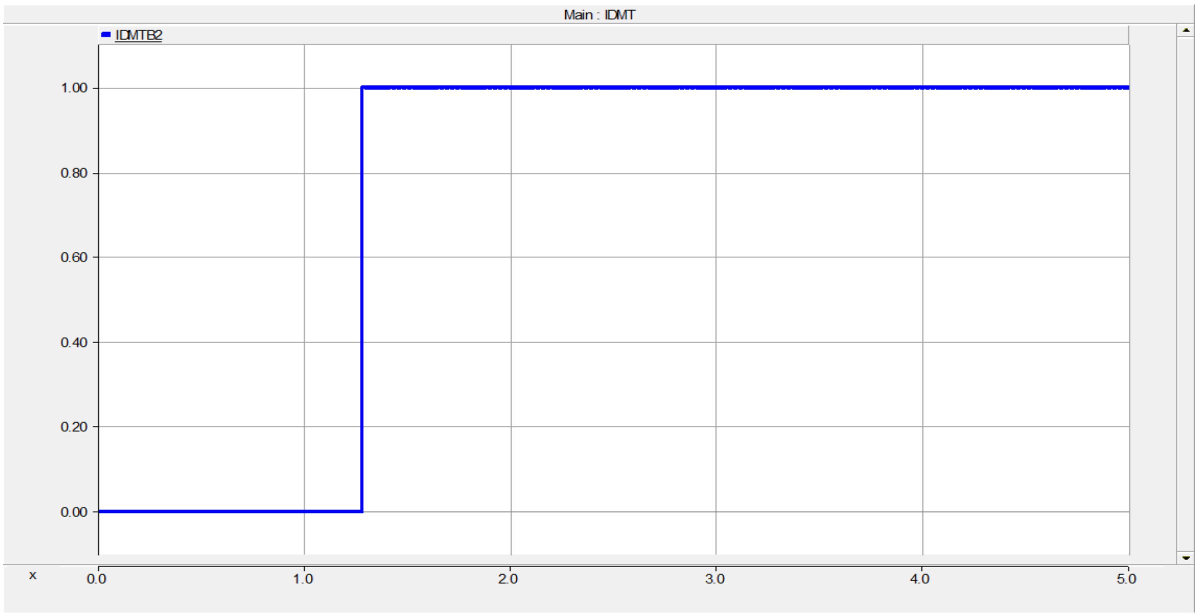


Figure 4.8: Relay operation time for location 2.

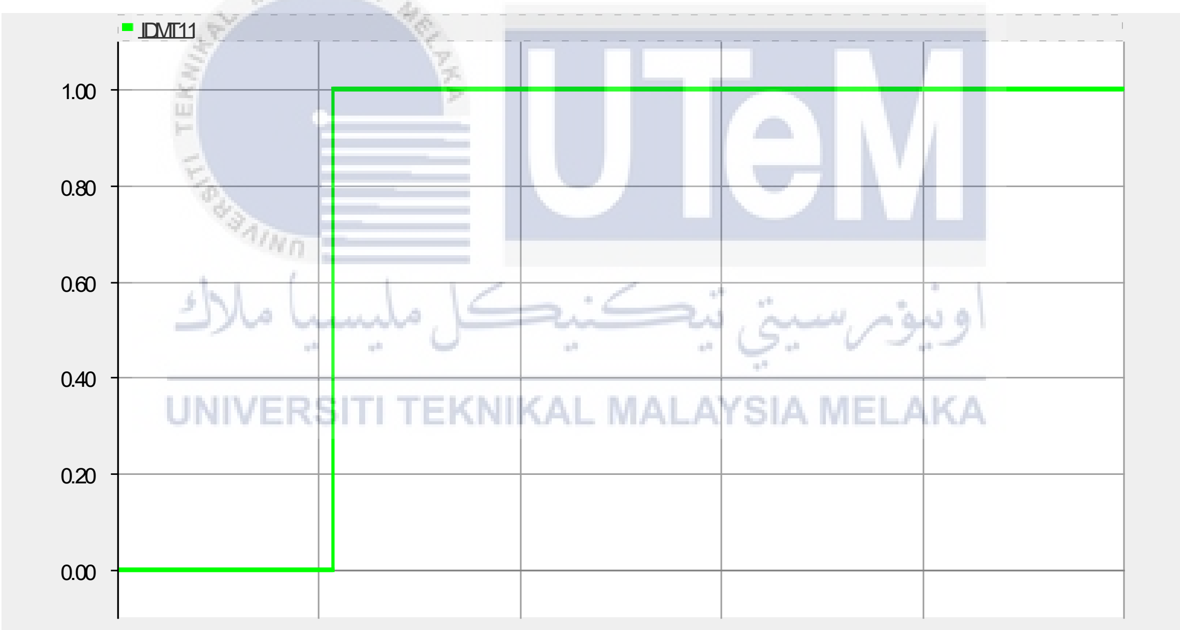


Figure 4.9: Relay operation time for location 3.

4.5.2 Result for simulation operation time.

Table 4.7: Calculation result and simulation result for relay trip time.

Type	Fault Location	Zone	Fault Current (KA)	Calculation top + TFL (s)	Simulation operating time (s)
3 phase balanced grounded	Location 1	212	15.7995	1.4293	1.4390
		211	0.5745	1.9122	1.9220
		B2	0.5802	2.4435	2.4530
	Location 2	B2	3.1523	1.3485	1.2940
	Location 3	11	7620.8810	1.0659	1.0680
High fault current	Location 1	212	21.5452	1.3586	1.3620
		211	0.7835	1.8345	1.8330
		B2	0.7843	2.3579	2.3460
	Location 2	B2	4.3690	1.2980	1.2800
	Location 3	11	76208.7708	1.0519	1.0540
Double line fault	Location 1	212	17.0093	1.4101	1.4170
		211	0.7121	1.8911	1.8980
		B2	0.7156	2.4202	2.4280
	Location 2	B2	3.6698	1.3231	1.3130
	Location 3	11	13199.7492	1.0620	1.0630
Double line to ground fault	Location 1	212	13.7352	1.4710	1.4790
		211	0.5745	1.9581	1.9680
		B2	0.5801	2.4939	2.5090
	Location 2	B2	4.7178	1.2881	1.2650
	Location 3	11	7620.8810	1.0659	1.0680
Triple line fault	Location 1	212	20.6434	1.3670	1.3750
		211	0.7507	1.8437	1.8490
		B2	0.7532	2.3681	2.3720
	Location 2	B2	3.8580	1.3155	1.2840
	Location 3	11	22862.6341	1.0585	1.0680
Load increase by 100%	Location 1	212	15.7991	1.4293	1.4390
		211	0.5745	1.9122	1.9220
		B2	0.5858	2.4435	2.4580
	Location 2	B2	4.2771	1.3008	1.2940
	Location 3	11	7620.8851	1.0659	1.0680

4.6 Discussion

4.6.1 Relay discrimination

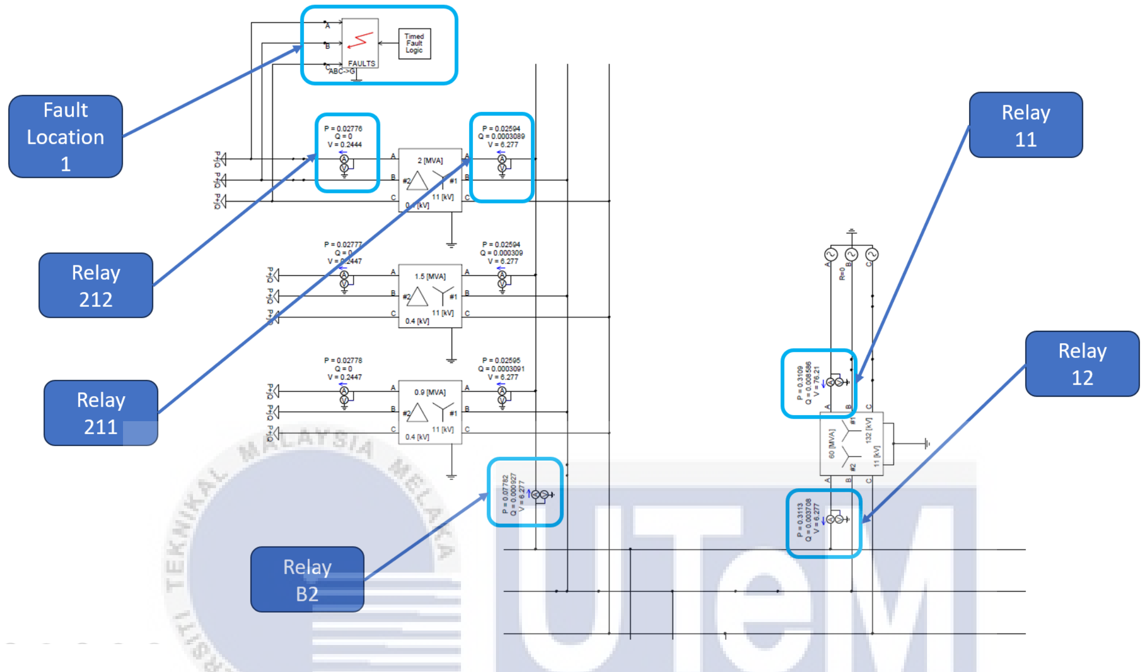


Figure 4.10: Protection coordination for fault location 1.

An important component of power system protection is the protection discrimination time of an IDMT (Inverse Definite Minimum Time) relay, which affects how the relay reacts to faults and disturbances. This parameter sets the time interval between a fault occurring and the relay initiating tripping action. It is commonly configured depending on variables like the Time Setting Multiplier (TSM), Pickup Current, and Curve Characteristic (n). Finding the ideal discrimination time requires careful balancing of selectivity and sensitivity. Reduced discriminating time increases sensitivity, allowing the relay to identify and react to faults faster, but it also increases the possibility of unwanted tripping for small disturbances. Conversely, a longer discrimination time decreases the possibility of needless tripping, which increases selectivity, but it may also cause the relay to react to errors later. Within the larger power system protection architecture, the proper adjustment of discrimination time is essential to the IDMT relay's efficient operation.

For the IDMT relay to function in harmony with nearby protective devices, coordination studies are essential in determining acceptable discrimination times. A useful tool in this process is Time-Current Coordination (TCC) curves, which show the relationship between the fault current magnitude and the working time of the relay. The visual depiction of coordination regions that these curves offer helps to identify possible conflicts and makes sure that the IDMT relay functions selectively without interfering with the coordinated protection mechanism. To put it briefly, the protection discrimination time is an important parameter that affects how responsive the relay is to faults and also helps to selectivity, stability, and overall reliability of the power system, protecting against disruptions and guaranteeing the effective operation of protective devices.

When the fault occurs at location 1, the first relay that will detect the abnormal current is relay 212. Thus, to reduce any damage to the system, relay 212 should react within a very fast time. If relay 212 does not react and trip the breaker, the fault current will pass through the transformer and flow to relay 211. The relay 212 should react within a time after the operation time for relay 212. This discrimination time between both relays is to ensure no simultaneous tripping of the relay. When a fault occurs, the nearest relay will be the main tripping relay and the other relay will be the backup relay. It is because the fault current may be a thousand or ten thousand amperes. It will have a major impact on the system. Thus to avoid the relay 211 trip when the relay 212 trip, the discrimination time is set to 0.4s plus 10% overshoot. After relay 211, relay B2 will trip after the discrimination time. After relay B2, the next relay that should trip is relay 12 and relay 11. Both relays do not trip during this condition because the fault current that flows within the line does not exceed the maximum line current that is calculated.

To prove the theory about the relay discrimination time, the simulation operation time is analysed. For the case of a phase-balanced fault, relay 212 trips at 1.4390s. After the discrimination time, relay 211 trips at 1.9220s and continue by relay B2 at 2.4530s. For the other case at fault location 1, the relay tripping order are same as the case of the 3-phase balanced fault. The difference between times is determined by the fault current.

4.6.2 Relationship between plug setting multiplier and operating time

An important consideration when installing protective relays in power systems is the correlation between the plug setting multiplier (PSM) and running time for an IDMT

(Inverse Definite Minimum Time) relay. The PSM is a parameter that directly affects the IDMT relay's working time and is essential for maintaining a balance between the selectivity and sensitivity of the relay's reaction to various fault events.

For an IDMT (Inverse Definite Minimum Time) relay, the plug setting multiplier (PSM) is a multiplier that is applied to the product of the time characteristic and the nominal current. It establishes the operating relay point for a specific fault current on the time-current characteristic curve. The relay becomes more sensitive to lower fault currents and trips faster when the PSM is higher since the two have an inversely proportional connection. In contrast, a lower PSM lengthens the operating period and necessitates a greater fault current for the relay to trip; this feature offers selectivity and prevents the relay from triggering small-scale faults or transitory disturbances needlessly.

The working time of the relay decreases as the PSM increases, and vice versa, indicating an inversely proportional relationship. For a given fault current, a relay with a higher PSM will run faster due to its increased sensitivity. On the other hand, a lower PSM causes the relay to be less sensitive, requiring a greater fault current to cause a trip and lengthening its running duration. The first graph below shows the graph of operating time versus plug setting multiplier obtained from the simulation result. The second graph shows the Theoretical graph of operating time versus plug setting multiplier. As observed, both graphs get a similar pattern which is the operating time is inversely proportional to the plug setting multiplier.

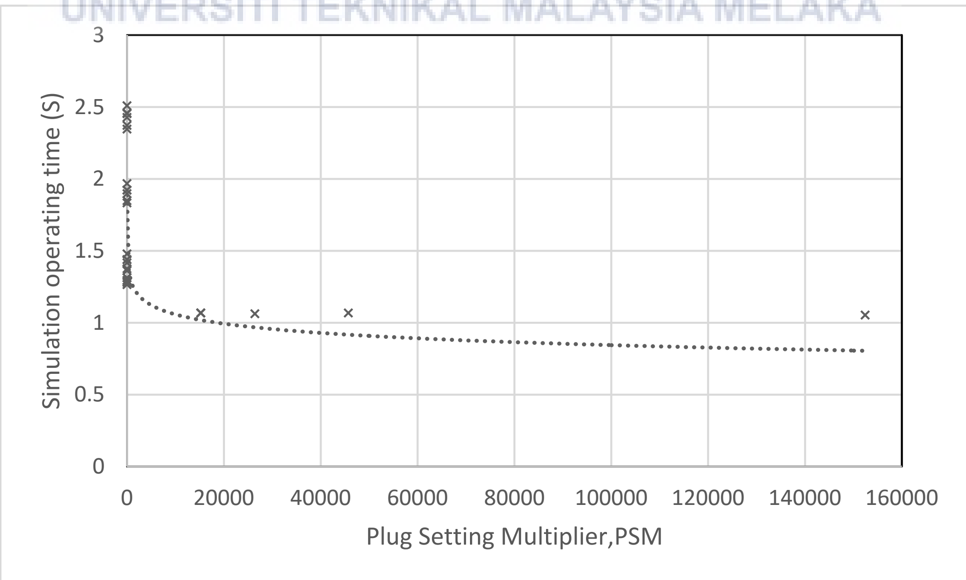


Figure 4.11: Simulation graph of operating time versus plug setting multiplier.

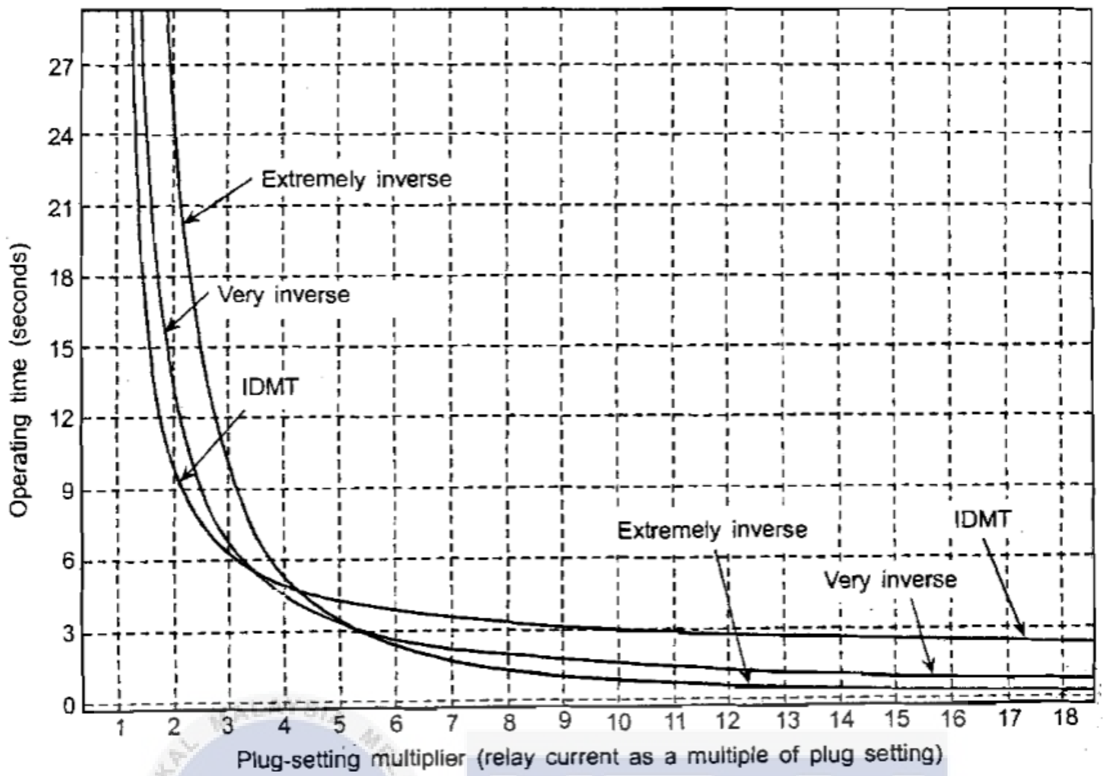


Figure 4.12: Theoretical graph of operating time versus plug setting multiplier. [18]

4.6.3 Percent Error for simulation and calculation time

Table 4.8: Percent Error for simulation and calculation time

Type	Fault Location	Zone	top + TFL (S)	Simulation operating time, (S)	Error	Percent Error,(%)
3 phase balanced grounded	Fault 1	212	1.4293	1.4390	0.0097	0.6741
		211	1.9122	1.9220	0.0098	0.5083
		B2	2.4435	2.4530	0.0095	0.3892
	Fault 2	B2	1.3485	1.2940	0.0545	4.2145
	Fault 3	11	1.0659	1.0680	0.0021	0.1966
High fault current	Fault 1	212	1.3586	1.3620	0.0034	0.2471
		211	1.8345	1.8330	0.0015	0.0817
		B2	2.3579	2.3460	0.0119	0.5093
	Fault 2	B2	1.2980	1.2800	0.0180	1.4058
	Fault 3	11	1.0519	1.0540	0.0021	0.1962
Double line fault	Fault 1	212	1.4101	1.4170	0.0069	0.4853
		211	1.8911	1.8980	0.0069	0.3616
		B2	2.4202	2.4280	0.0078	0.3192
	Fault 2	B2	1.3231	1.3130	0.0101	0.7664

	Fault 3	11	1.0620	1.0630	0.0010	0.0948
Double line to ground fault	Fault 1	212	1.4710	1.4790	0.0080	0.5404
		211	1.9581	1.9680	0.0099	0.5026
		B2	2.4939	2.5090	0.0151	0.6011
	Fault 2	B2	1.2881	1.2650	0.0231	1.8280
	Fault 3	11	1.0659	1.0680	0.0021	0.1966
Triple line fault	Fault 1	212	1.3670	1.3750	0.0080	0.5829
		211	1.8437	1.8490	0.0053	0.2875
		B2	2.3681	2.3720	0.0039	0.1664
	Fault 2	B2	1.3155	1.2840	0.0315	2.4503
	Fault 3	11	1.0585	1.0680	0.0095	0.8909
Load increase by 100%	Fault 1	212	1.4293	1.4390	0.0097	0.6736
		211	1.9122	1.9220	0.0098	0.5079
		B2	2.4435	2.4580	0.0145	0.5915
	Fault 2	B2	1.3008	1.2940	0.0068	0.5291
	Fault 3	11	1.0659	1.0680	0.0021	0.1966

When it comes to IDMT relay operation in the TNB network, per cent error denotes the difference between the estimated and simulated operating times. This measure assesses how accurate simulation results are about values that have been calculated analytically. When the % error is positive, it means that the simulated time was longer than the calculated time; when it is negative, it means the opposite. A high degree of agreement is implied by a value that is near zero. By examining this inaccuracy, one can enhance simulation models or analytical calculations and guarantee the dependability of the protective function of the IDMT relay in the TNB network.

There could be several reasons for the per cent mistake in the IDMT relay calculation and simulation times in the TNB network. To begin with, modelling assumptions are important because they might lead to deviations if the simulation model oversimplifies the behaviour of the relay or if the expected conditions differ from the real operational complexity. Second, discrepancies between the estimated and anticipated operating timeframes are caused by errors in the fault parameters utilised in the simulation, such as the fault current magnitude. Finally, errors in relay specification—such as the plug setting multiplier or time-current characteristic curve—may result in disparities that affect the coherence of computed and simulated outcomes. To account for these aspects, the simulation model must be carefully validated to make sure that the relay's properties and actual operating conditions in the TNB network are appropriately represented.

The next reason that denotes the per cent error is the level of fault current. The fault current is in AC form, it will have different levels at different times. When the fault current exceeds the maximum current, at what level is the current treated as fault current and used in the calculation. In calculation, we have chosen fault current at 2 seconds. In the simulation, we are not able to determine the current that is used to determine the operating time of the relay. Thus, there will be an amount of error. Most of the results have errors below 1% but there are some cases where the errors are more than 1%. The result is acceptable since the simulation and calculation time are similar.

4.6.4 Impact on fault type

IDMT relay operation in power systems is largely dependent on the type of fault and how it affects the fault current. Line-to-line, line-to-ground, and three-phase faults are only a few of the different types of electrical network problems that can be identified. IDMT relays respond differently to different fault types, and each fault type has a unique effect on the fault current. Different fault types will have different fault impedances resulting in different fault currents. The fault current will affect the setting and the operating time of the IDMT relay.

First, there is a significant increase in fault current when a double line fault occurs, which is defined as a direct short circuit between two conductors. Due to its sensitivity to fault current magnitudes, IDMT relays react quickly to this increased current, guaranteeing rapid tripping to isolate the fault and stop more system damage.

The fault current in a double line to ground fault is often lower than in a double line fault, as two conductors make contact with the ground at the same time. Grounding lowers the fault current by adding more resistance to the fault path. To safeguard the network and preserve system integrity, IDMT relays continue to respond to this lower fault current and promptly trigger tripping actions.

The maximum fault current magnitude is produced by triple line faults, which involve simultaneous short circuits in all three phases. To ensure synchronised tripping to minimise potential damage and preserve the stability of the power system, IDMT relays are essential for quickly detecting and responding to such high fault currents.

Last but not least, a triple line to ground fault produces a significant fault current, albeit marginally less than a triple line fault, by combining grounding with concurrent faults in all three phases. IDMT relays play a crucial role in effectively identifying and handling these fault currents, offering protection and reducing the burden on the electrical grid.

The fault currents for these types, in decreasing order from high to low, are typically triple line fault, double line fault, triple line to ground fault, and double line to ground fault. This pattern is influenced by the nature of the fault, the number of phases involved, and the grounding conditions in each scenario.

In conclusion, the sensitivity and selectivity of IDMT relays are influenced by fault types, which are important factors in determining the magnitudes of fault currents. By quickly isolating faults and reducing possible damage, these relays, with their capacity to customise responses based on fault characteristics, greatly enhance the overall protection and dependability of the power system.

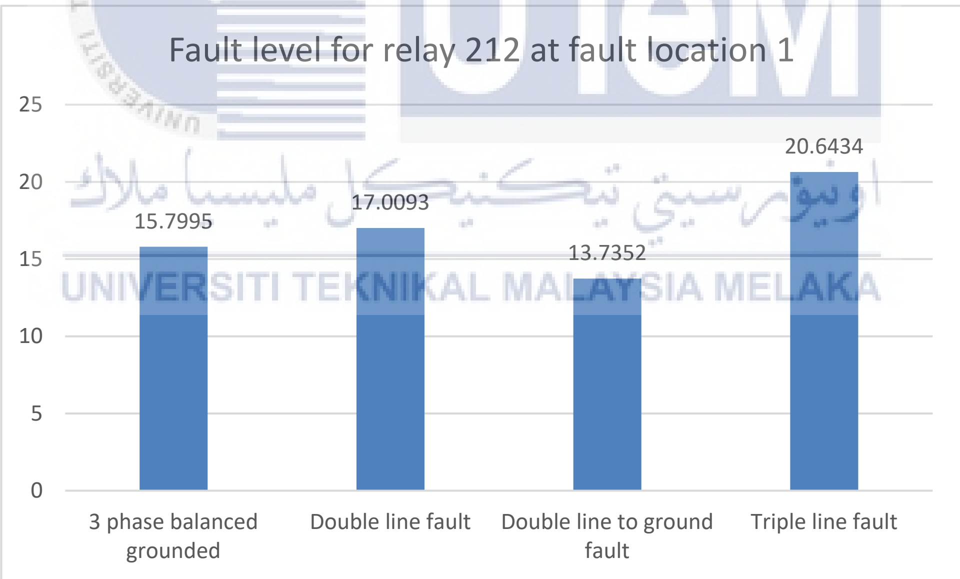


Figure 4.13: Graph for fault current level for relay 212 at location 1

4.6.5 Impact on fault current increase

An electrical power system's fault current may rise as a result of modifications to the network configuration, system voltage, or fault impedance. A drop in fault impedance or a rise in system voltage might result in a larger fault current since fault current is inversely proportional to impedance and directly proportional to voltage. The dynamics of the power system as a whole may be impacted by modifications to the network topology or the installation of new hardware, which can also affect fault current levels.[29]

The configuration and operating time of an IDMT (Inverse Definite Minimum Time) relay are directly affected by this rise in fault current. There is a noticeable impact on the relay's setting time, which is established by the plug setting multiplier (PSM) and clock dial setting.[30] Relays shorten setting times by reaching their pickup current faster when the fault current increases. The increased sensitivity of the IDMT relay allows it to react quickly to different types of faults, maximising its protective function by starting tripping operations more quickly and reducing possible harm to the electrical system.

As a result, the fault current's amplitude greatly affects how long the IDMT relay operates. The relay responds more quickly as the fault current rises because it is made to run quicker at larger fault currents. This quick reaction is essential for identifying and isolating faults quickly, avoiding significant equipment damage, and preserving the power system's overall stability.[31]

However, coordination becomes more difficult due to the rise in fault current. Because the IDMT relay operates quicker, coordination parameters might need to be changed to avoid downstream protection devices accidentally tripping. The reliability of the complete protection architecture depends on striking a fine compromise between the high sensitivity of the IDMT relay and the selectivity of the protective strategy.

Finally, an increase in fault current resulting from variations in system voltage or fault impedance has a significant effect on the IDMT relay. Although this increased sensitivity makes the relay more responsive to failures, the stability and dependability of the power system's protective architecture depend heavily on meticulous coordination and changes.

4.6.6 Impact on load increase by 100%

A load increase in an electrical power system denotes an increase in the amount of electricity that is required due to various factors including the expansion of industrial and residential activities or the inclusion of more connected devices. The operational dynamics of protective devices like the IDMT relay are impacted by this spike in demand, which causes a proportionate rise in the current flowing through the system.

An IDMT relay's time dial setting and plug setting multiplier (PSM) are closely related to one other. When the load is increased, the relay's reach to its pickup current can be accelerated by the increased current flow, which can shorten the setting time. The increased load affects the relay's sensitivity and setting, which is determined by the PSM, a crucial component of relay settings. This increased sensitivity maximises the protective function of the IDMT relay by enabling it to react quickly to overcurrent situations.

At the same time, the amount of overcurrent has a big impact on how long the IDMT relay can operate. Higher current levels in the event of a load rise may cause the relay to operate faster. Rapid reaction to overcurrent circumstances is given top priority in the design of IDMT relays, enabling the relay to quickly identify and isolate faults or overcurrent circumstances. In order to minimise any harm to the power system and guarantee the general stability of the electrical network, this quick response is crucial.

On the other hand, the effect of an increase in load brings coordination issues. Because the IDMT relay operates quicker, coordination parameters might need to be changed to avoid downstream protection devices accidentally tripping. In order to maintain the stability of the entire protective architecture while guaranteeing the effective functioning of the relay, engineers must carefully assess and modify coordination systems.

Ultimately, a rise in load has a substantial impact on the IDMT relay's setup and operational duration since it modifies the power system's current levels. In order to guarantee the dependable and effective functioning of protective devices under varying load situations, engineers must carefully navigate these effects and make adjustments to relay settings and coordination schemes.

4.7 Conclusion

By using PSCAD software to evaluate the overcurrent protection in the TNB network, a thorough understanding of the system's operation under various fault scenarios has been made possible. Simulation results have indicated the network's strong points and regions that need improvement. Specific effects of fault scenarios, coordination issues, and possible fixes have all been covered in detail throughout the conversation. All things considered, this study emphasises how crucial strong security measures are to maintaining the dependability and security of the Tenaga Nasional Berhad network. The knowledge acquired supports continuous attempts to improve the network's robustness and adaptability to changing operational

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The utilization of PSCAD software for evaluating overcurrent protection in the TNB network has provided valuable insights into the existing protective systems' performance and reliability. Through extensive modelling and simulation of various failure scenarios, the research successfully assessed the effectiveness of overcurrent protection, identifying areas for improvement. While the current protection method demonstrated success in minimizing faults and ensuring power system stability, the assessment revealed opportunities for enhancing dependability and efficiency.

The project underscored the importance of precise modelling and simulation using PSCAD software, enabling in-depth analysis of network behaviour during fault circumstances and offering critical data for decision-making. Proposed improvements include adjustments to relay settings, coordination methods fine-tuning, and the incorporation of advanced protection technologies to enhance fault identification and resolution, reduce downtime, and bolster overall system reliability. The findings and recommendations serve as a valuable resource for TNB and similar power utilities facing overcurrent protection challenges, laying the groundwork for future enhancements in power system dependability.

The first objective is to model the electrical circuit for 132/11kV Pencawang Masuk Utama (PMU) Pagoh by using PSCAD simulation software. This objective is achieved by obtaining the circuit diagram for PMU Pagoh from TNB and model in the simulation software. The next objective which is to model and simulate the response time of an overcurrent protective relay under various fault conditions and at different fault locations is achieved by applying and analysing the result at different locations of fault for PMU Pagoh. The last objective which is to ensure a reliable, selective, fast and safe tripping operation during all conditions is achieved by analysing the impact and reason for different conditions such as load increased by 100%, different types of fault and fault current increased. Thus, all the objective is achieved during the final year project.

5.2 Future Works

Based on the assessment conducted in this project, there are several future plans to further enhance the overcurrent protection of the TNB network using PSCAD software.

Monitoring and analysis in real-time are an essential component of the project's future work. By continuously monitoring the TNB network's performance, advanced real-time monitoring capabilities can be implemented to quickly detect anomalies or departures from typical operating conditions. The system can evaluate fault circumstances, relay answers, and network behaviour in real-time by incorporating advanced analytics. Because of this proactive strategy, operators may intervene promptly and take preventive action before possible problems worsen. Furthermore, real-time analysis makes it easier to extract useful insights from the massive volume of data produced during network operation, enabling data-driven decision-making that improves the TNB network's overall resilience and dependability by optimising overcurrent protection strategies.

Important considerations for future work include optimising protection coordination and incorporating dynamic system modelling. In order to provide a more thorough knowledge of system dynamics, dynamic system modelling will entail improving simulations to capture the transient behaviour of the power network during and after faults. At the same time, protection coordination optimisation will adjust relay settings using sophisticated algorithms in an effort to achieve the best possible compromise between selectivity and sensitivity. By using two different approaches, the power system's reaction to faults is represented more accurately and nuancedly, which opens the door to improved safeguards and increased network efficiency in the TNB.

By implementing these future plans, the TNB network can strengthen its overcurrent protection infrastructure, improve system reliability, and effectively address emerging challenges in the power sector. These initiatives will contribute to the overall stability and resilience of the network, ensuring a reliable power supply for consumers and supporting the growth and development of the TNB utility.

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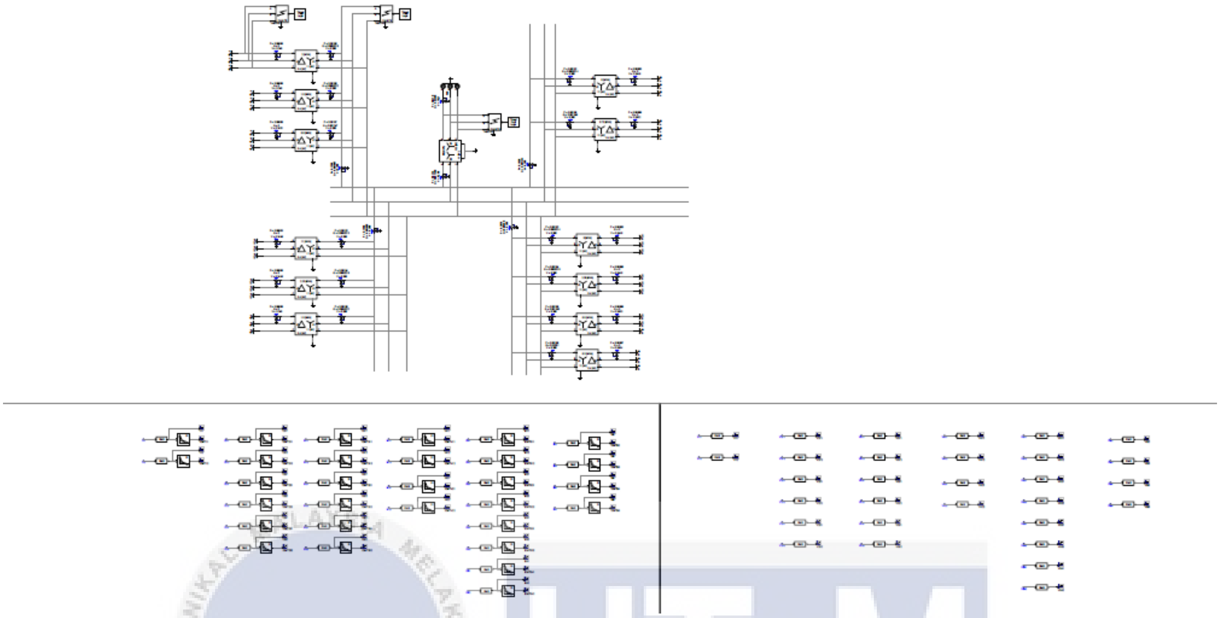
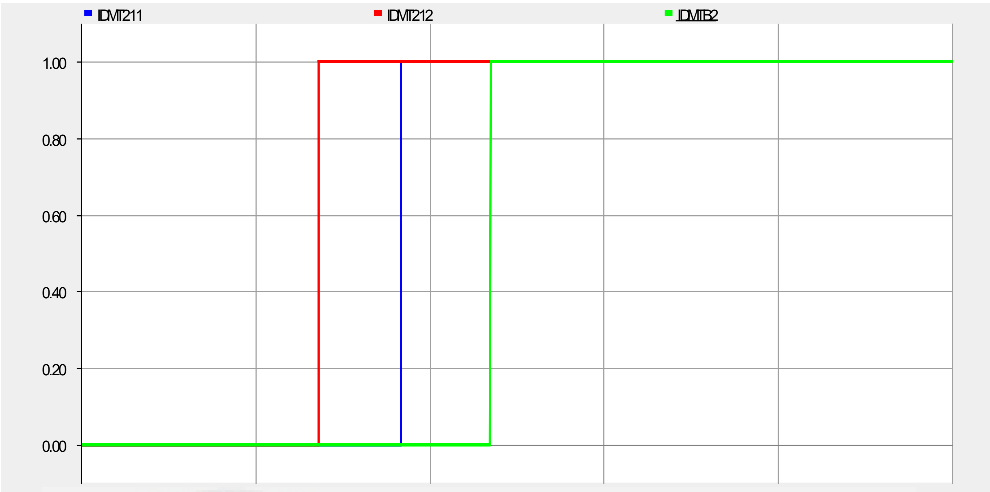
APPENDICES A: SIMULATION DIAGRAM FOR THE PROJECT



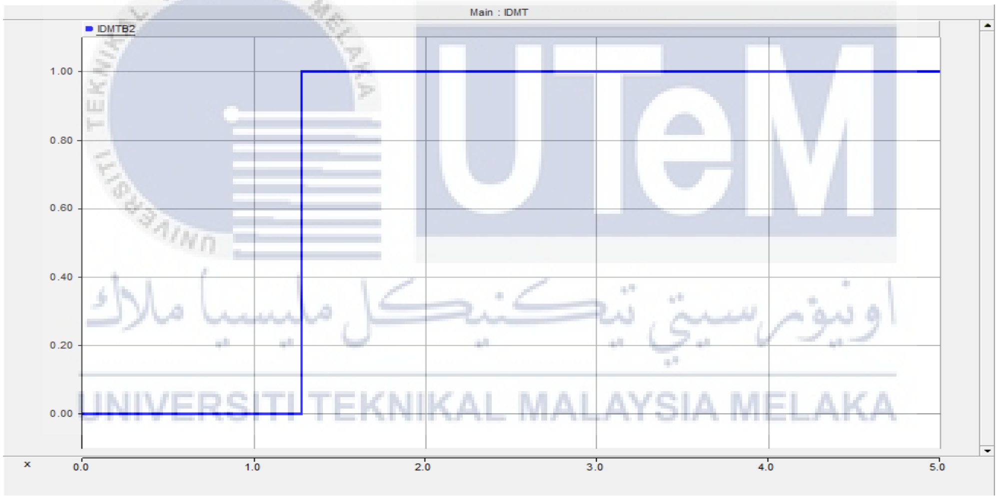
APPENDICES B: SIMULATION GRAPH FOR THE PROJECT

High fault current

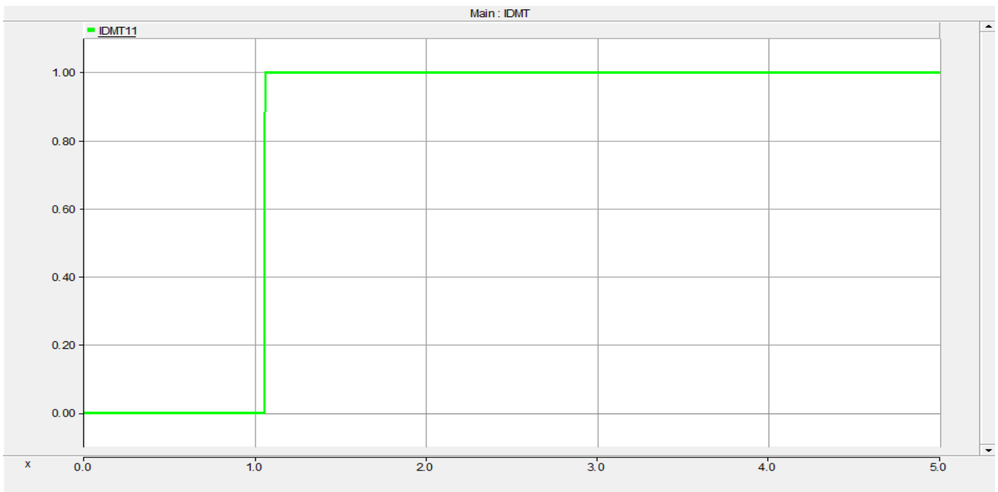
Location 1



Location 2

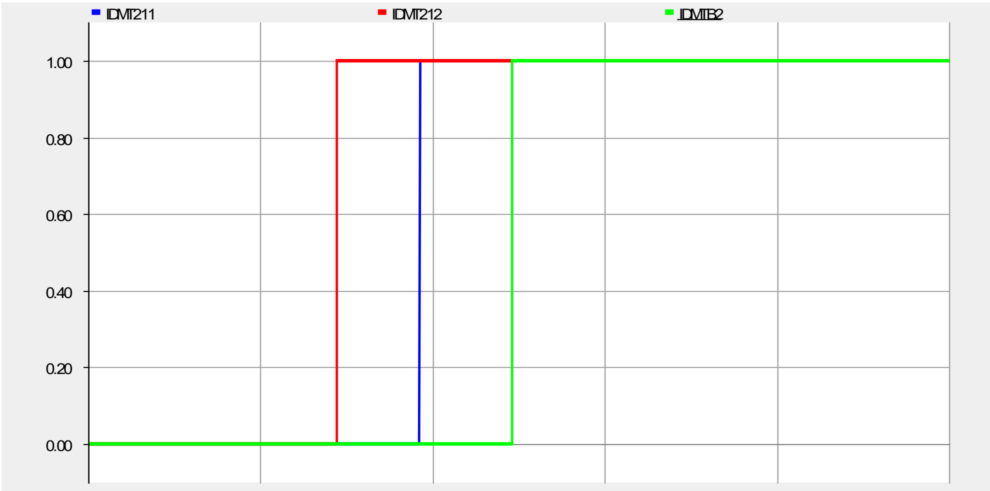


Location 3



Load increase by 100%

Location 1



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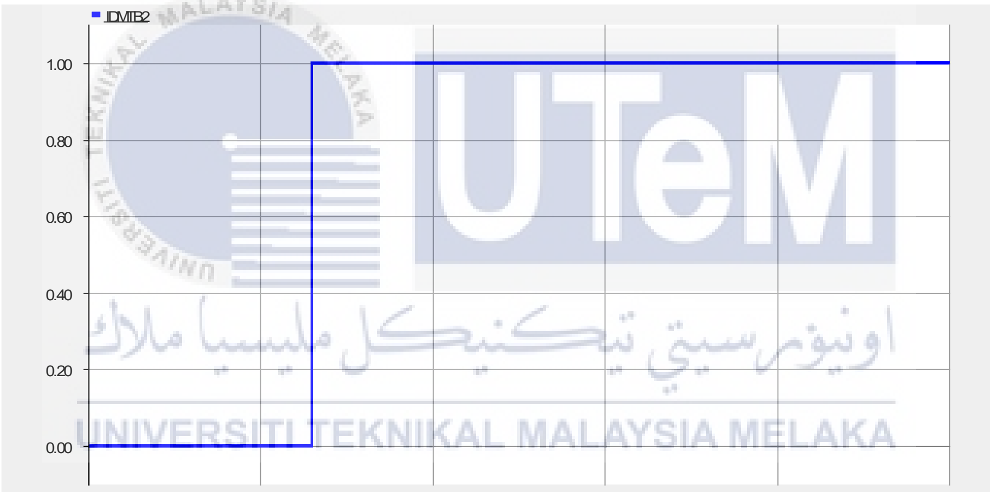

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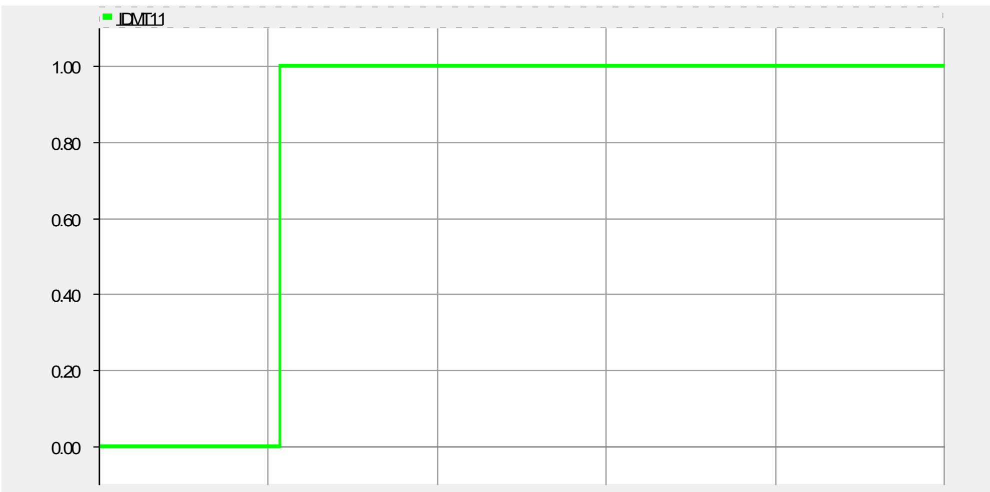
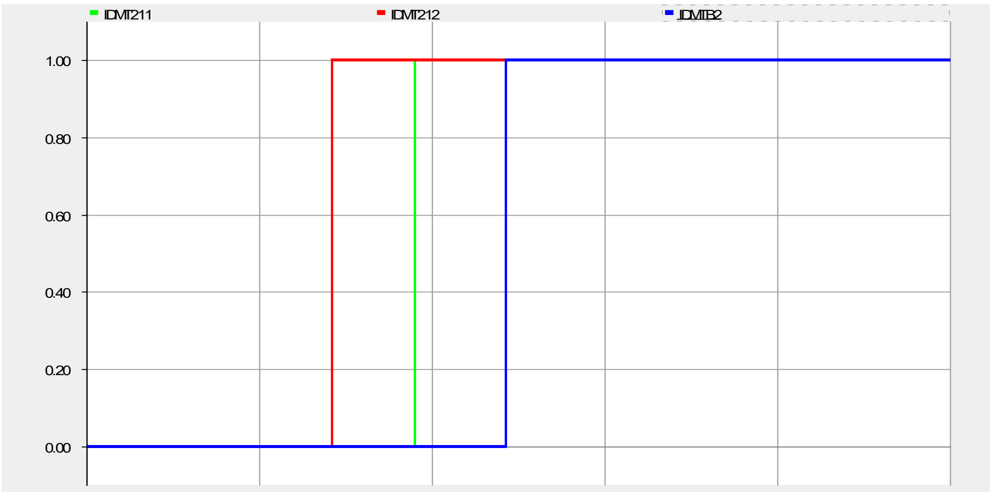


Double line fault

Location 1



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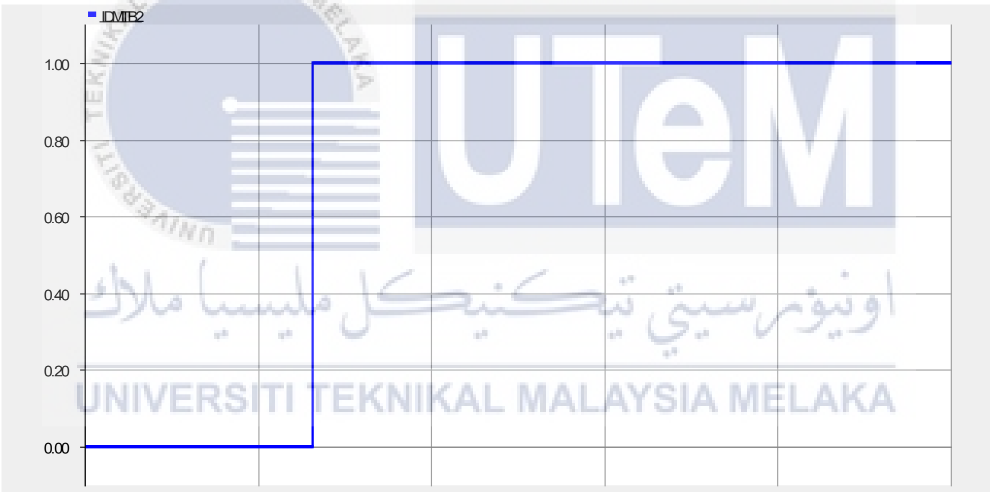
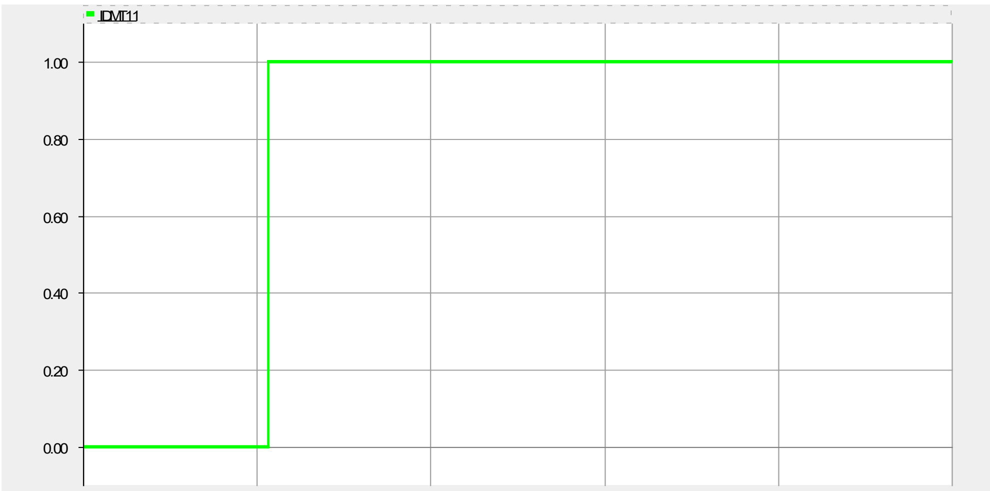
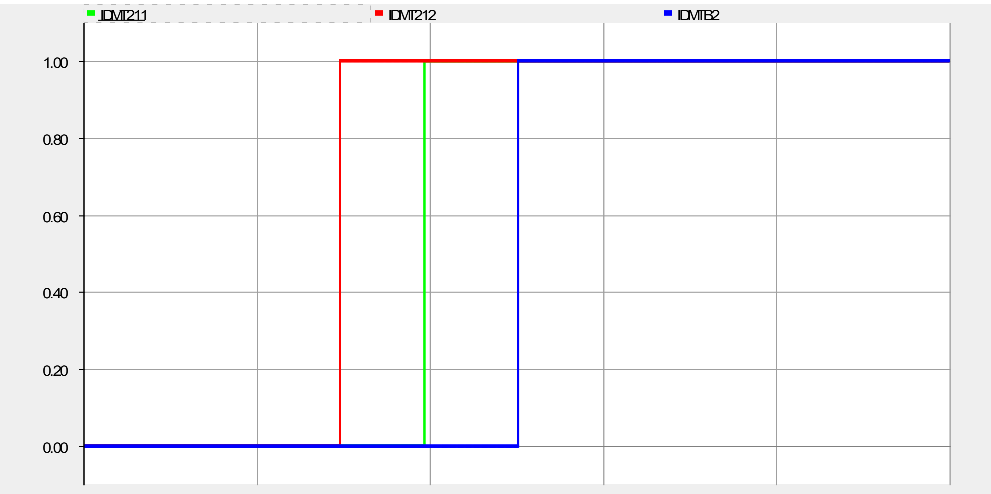


Location 3

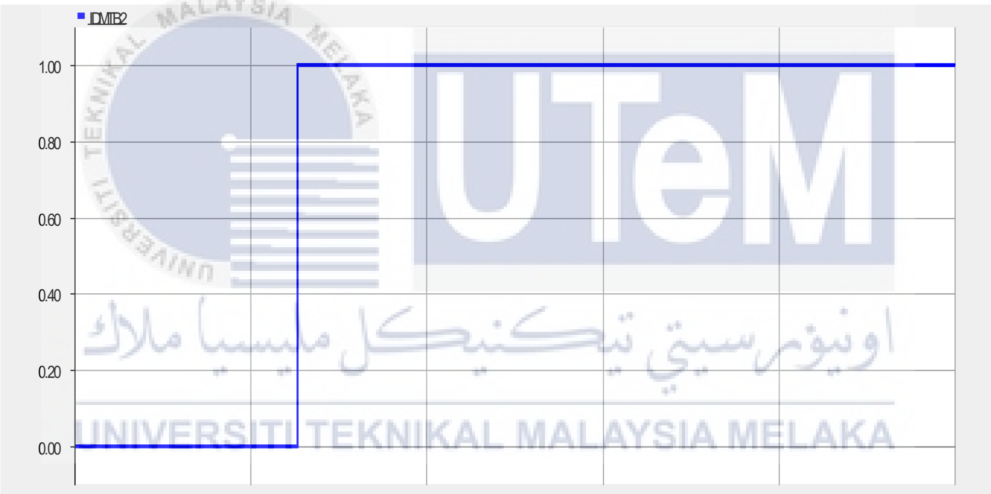


Double line to ground fault

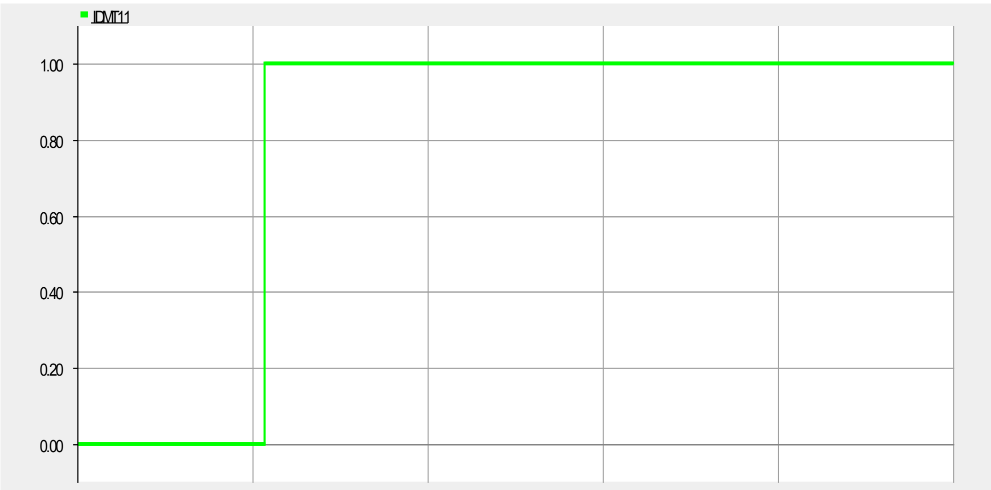
Location 1



Location 2

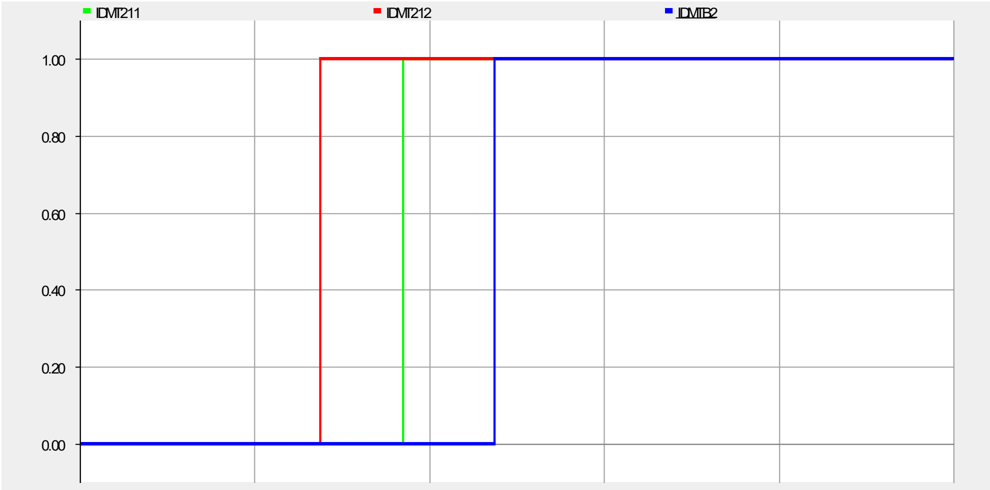


Location 3

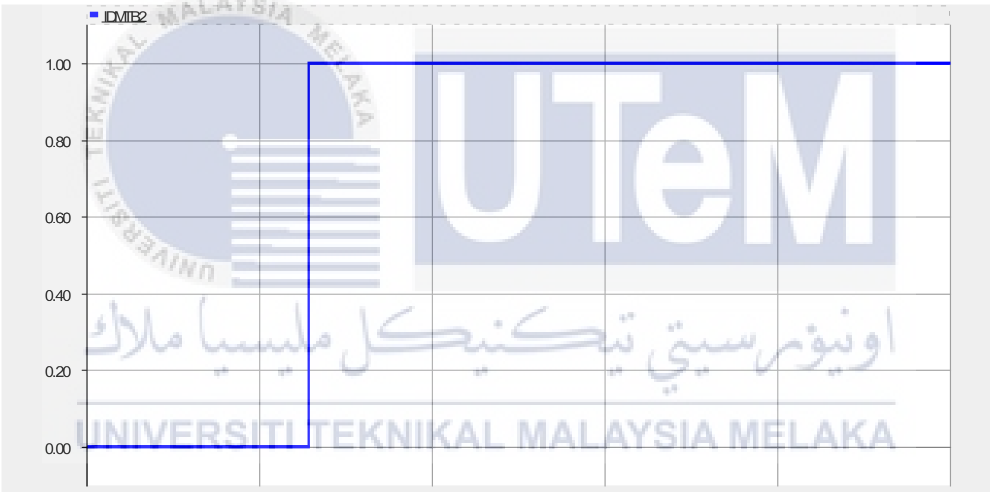


Triple line fault

Location 1



Location 2



Location 3