"I hereby declare that I have read through this report entitle *"Modelling and Assessment of Transformer Differential Protection in Power System Network Using PSCAD Software"* and found that it has been comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power).

Signature : ……………………………………………

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Date : 17.06.2016

MODELLING AND ASSESSMENT OF TRANSFORMER DIFFERENTIAL PROTECTION IN POWER SYSTEM NETWORK USING PSCAD SOFTWARE

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

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

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

Signature : ....

Name : MUHAMAD ROZAIRI BIN ZAKARIA

Date : 17.06.2016

To my beloved mother and father

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In the name of Allah, the Most Beneficent and The Most Merciful. It is a deepest sense gratitude of the Almighty that give me strength and ability to complete my thesis for PSM 2.

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ABSTRACT

The transformer is commonly being used nowadays in order to transfer the electrical power from the power plant to transmission line and also distribute it to the people in the distribution system. The power transformer is an important electrical equipment that should be protected. It is because if there are fault current flow through the transformer, it can make the transformer damage and also will harm the human lives. The protection of transformers means that to protect the transformer from internal fault such as fault current. In order to analyze the protection performance for transformer, this thesis presents a modelling and assessment of transformer differential protection in the power system network using PSCAD software. The modelling of the protection system uses a dual slope current differential relay that acts as a protection tool. This dual slope current differential relay is used to monitor the current that enters and leaving the transformer on the primary side and secondary side. The simulation result shows that the relay not show the tripping signal when the transformer in balance condition or the current that flow through it is a normal current. When fault current exist, the dual slope current differential relay send the signal to circuit breaker to trip the circuit .The value of the online plotting graph for the relay shows the value of one. The PSCAD software is used because it is easy to model the circuit and simulate it to get the result. When the simulation is run, the location of fault can be determined. This is help to get more understanding about differential protection.

ABSTRAK

Transformer biasanya diguanakan pada hari ini untuk memindahkan tenaga elektrik daripada janakuasa kepada talian penghantaran dan juga diagihkan kepada orang ramai dalam bentuk sistem pembahagian. Transformer adalah barangan elektrik yang sangat penting untuk dilindungi. Ini kerana jika terdapat kesalahan arus yang mengalir melalui transformer, ia akan menyebabkan transformer rosak dan akan mengancam nyawa manusia. Perlindungan transformer adalah untuk melindungi transformer daripada kesalahan dalaman seperti kesalahan arus. Dalam usaha menganalisis prestasi perlindungan untuk transformer, thesis ini dilaksanakan untuk mereka dan menilai pembezaan perlindungan transformer dalam rangkaian sistem kuasa dengan menggunakan perisian PSCAD. Dalam mereka bentuk sistem perlindungan, pembezaan alat geganti digunakan untuk bertindak sebagai alat perlindungan. Pembezaan alat geganti digunakan untuk memantau arus keluar dan masuk pada transformer di bahagian pertama dan bahagian kedua. Keputusan simulasi menunjukkan alat geganti tidak menunjukkan isyarat pemutus bila transformer dalam keadaan yang seimbang atau arus mengalir melaluinya dalam keadaan normal. Bila arus kesalahan hadir, alat pembezaan akan menghantar isyarat kepada pemutus litar untuk memutuskan arus. Nilai pada graf alat geganti akan menunjukkan nilai satu. Perisian PSCAD digunakan kerana senang untuk mereka bentuk litar dan mensimulasikannya untuk mendapatkan keputusan. Bila simulasi berjalan, tempat berlakunya kesalahan boleh di tentukan. Ini dapat membantu untuk lebih memahami tentang perlindungan pembezaan.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

1.1.1 Power Transformer

A transformer is a device that transfers electrical energy from one voltage level to another voltage level. There are several types of transformers that are commonly being used such as step-up transformer, step-down transformer, and also auto- transformer which can be step- down or step-up transformer. This type of transformer can be determined by their turn of the winding. If the primary side of the transformer has more than of winding compared to the secondary side, which means that it is a step-down transformer. That also vice versa for step-up transformer.

For auto-transformer, it is very different with the other two types of transformer because it only have one winding. This type of transformer share the same common single winding and it acts as both the primary and secondary sides of the transformer. The single winding at least has three taps to make an electrical connection. The auto-transformer have the advantages compares to other types which it's smaller, lighter, and cheaper. It's also have a lower leakage reactance, lower excitation, lower losses, and increased VA rating.

The power transformer sometimes faced a condition of abnormal thermal and electrical stresses. This happened because of gases that produce due to decomposition of transformer insulating oil. The buchhloz relay is used to detect and solve the problem. However, buchhloz relay does not have the ability to predict the condition of the total internal healthiness of power transformer. Dissolved Gas Analysis (DGA) of transformer oil can be used to predict the actual condition of internal health of a transformer. This test will extracted the gases in oil and the quantity of gasses will be analyse in a specific amount of oil. The internal condition of transformer can be predict by observing the percentages of different gasses present in the oil.

1.1.2 Differential Protection of Power Transformer

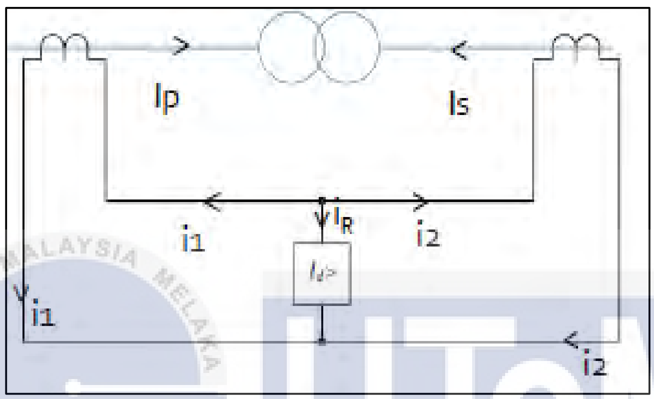


Figure 1.1: The relay for transformer protection.

In transformer protection, there are a lot type of protection and one of them is differential protection. The differential protection is a per unit protection that only protect the transformer. It compares the current on the primary side of a transformer with that on the secondary side. This protection only operate for internal fault or in protection zone and insensitive for any fault outside. The protection zone is between both sides of the current transformer.

The current from both side of primary and secondary current will flow through the relay. The differential relay will compare both current. In a normal condition, the primary current and secondary current will be the same and the current relay will be zero. So that, the relay will not operate. When a fault occurred in the protection zone, the primary and secondary current will not be same and the current relay will not equal to zero. The relay will operate and the current relay must higher than relay current setting.

1.1.3 PSCAD Software

PSCAD stand for Power System Computer Aided Design is a powerful and flexible graphical user interface to the world renowned, EMTDC solution engine. PSCAD is used by engineers, researches and students for planning, designing, developing new concepts, and testing ideas. This software is used to modelling and simulate the circuit. The circuit modelling in three phase and the three phase fault was placed close to the transformer. The three phase fault also was placed on the bus bar and the transmission line. A transformer will have three dual slope current differential because it represent for each phase. The graph for relay will show the graph in value of one when there are in fault condition.

1.2 Problem Statement

The PSCAD software is used in this project because it is the easiest way to model and to simulate the circuit compare with the field test. If the field test is conducted, the circuit cannot be modelling. The existing of power system network must be follow. The available protection system in the field is much complicated to understand. Therefore, with using the PSCAD software is easy to simulate it and get the result. The differential protection operation also can be understand clearly because the circuit can be modelling in any form.

1.3 Objective

The objective of this experiment is:

1. To understand the differential protection operation.
2. To model the transformer differential protection using PSCAD software.
3. To set the dual slope current differential relay to protect the transformer.

1.4 Significant of the Study

The overall study is about how to protect the transformer when in a fault condition. The fault condition can cause the transformer to damage. The PSCAD software is used for modelling and simulate the result. The dual slope current differential relay is used as an additional connection for transformer to create a protection system. This dual slope current differential relay function to monitor the current entering and leaving the power transformer. The properties of the value of the dual slope current differential relay must be determined based on the current entering and leaving the transformer. The calculation is made to verify the formula given at the dual slope differential relay. Based on the calculation for the power transformer, the dual slope differential relay allows the current flow through it in normal condition and for the fault condition the dual slope current differential relay will gives the signal to the circuit breaker to trip the circuit.

1.5 Thesis Outline

There are five chapters in this report, which are introduction, literature review, methodology, result and discussion, and the conclusion as the last chapter. The introduction chapter was explained the detail about the concept of transformer differential protection, problem statement, the scope of the project and the significance of the study. In second chapter is a literature review that pass researches are related to this project. Third chapter is a methodology that explains how to modelling the transformer differential protection using PSCAD software. Chapter four of project is to get the result from the modelling such as the simulation, graph relay and the value of current for each cases. Lastly, chapter five is to conclude about overall of the project and give a recommendation.

1.6 Scope

This project is emphasis on model the circuit for the transformer differential protection by using the PSCAD software. The dual slope current differential relay is used to protect the transformer from fault. The result of simulation in the form of plotting graph.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The transformer is one of the most important equipment that been used to increase and also decrease the voltage of the power system network. It's also important in the transfer the electrical power through a transmission line from the power plant. The fault sometimes occurs in power transformer that caused the transformer to damage and also human lives in danger. This chapter will study the recent development on transformer protection, inrush current and protective relay.

2.2 Types of Transformer Protection

2.2.1 Overcurrent Protection

The basic principle for overcurrent explained that the fault current is greater compared to load current because the load impedance is greater than the fault impedance. The overcurrent relay function to detect the fault current and overload current. This overload current consists of overload current and short circuit current. For overload current, the fault condition, runs through with a short period of time because of high current. Therefore, the power of high thermal and thermal equipment is disappeared. The thermal relay cannot detect it because of short time for a temperature to rise. The high stage overcurrent working as a backup protection. The main protection is a differential protection. When in low stage, the differential protection not trip and also not for a backup protection if the fault through the transformer. The transformer would face the overloaded. Then, the whole power transformer must be disconnected from the power system network if the transformer circuit breaker does not trip. In the short circuit current, it‘s would include phase fault, earth faults and winding fault. The short circuit current difference is 5 to 20 times of the full load current. So that, fault clearance must be conducted [10].

2.2.2 Earth Fault Protection

The other types of the transformer protection are earth fault protection. This fault is the most frequent fault that occurred. Earth fault states that the current flow through neutral conductor of the grounded system. The earth fault detected by phase fault relay, but it lacks of sensitivity. To prevent this problem, the new relay that is earth fault relay are used to contact with current from residual component. This earth fault relay not affected by the unbalanced load conditions. The low setting is used because of the neutral earthing resistance. There are two types of earth fault protection which are restricted and unrestricted. For a restricted earth fault (REF), the both current transformer would have the same value of current under normal condition. If there has earth fault, some current will go through the current transformer and the sum of current could not be zero. Therefore, the faults between both current transformers can easily be known quickly. The restricted earth fault will not senses the fault that outside the restricted zone. This restricted earth fault is very sensitive differential protection. REF have many advantages which are it very fast protection and can isolate the winding faults very fast. Therefore, it can reduce the damage of the transformer and also the cost to repair it. The protection zone must be extended because the secondary current transformer is placed in the distribution board. So that, the main cable will be included. Without REF, the fault that occurred in the secondary winding cannot be detected. The reflected current on the primary are used to detect it. The winding fault will move its position to the neutral. The magnitude of the current cannot be detected because the primary current decreased rapidly. As the magnitude of the current for secondary is large, the whole winding can be protected by using REF. For the normal conditions, the current transformer is balanced and the high impedance relays have been implemented. The next earth fault protection is an unrestricted earth fault. This method is used to detect and sense the earth fault at any point in the power system network. If the earth fault detected, the sum of three line's current is zero and the three secondary currents is also zero. The formula below shown in term of mathematical [5].

Ias + Ibs +Ics = 0

Irs = 0

Where,

Irs = residual current

Ias + Ibs + Ics = per phase currents (red, yellow, blue)

When a fault is occurring, the residual current is not zero. The figure below show that the earth fault relay is connected.

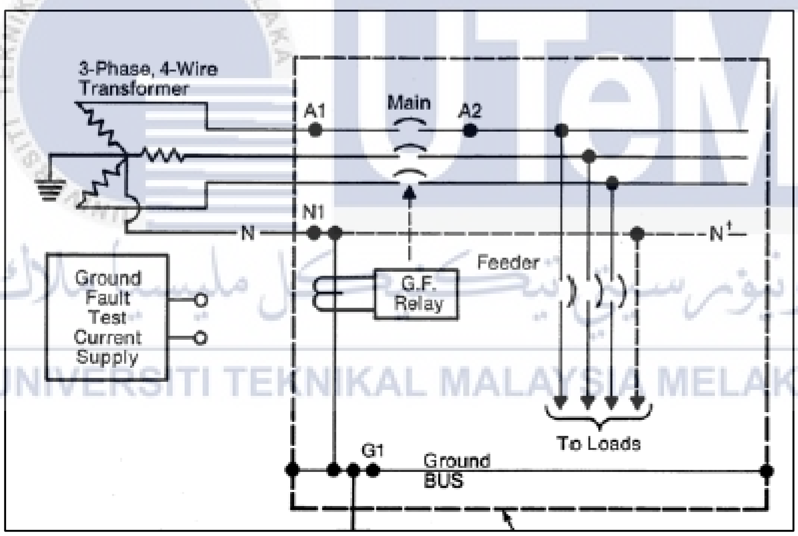


Figure 2.1: The typical earth fault protection schemes.

2.2.3 Differential Protection

Hamed Dashti, et.al [1] agree that a transformer is the most important equipment in electrical system. The low impedance of the differential protection is usually been used for transformer protection. The transformer protection with the large scale is important devices to protect the substation and the operating time is limited to 20ms [2]. A differential protection to protect the transformer is using second harmonic retrain and fifth harmonics to block the schemes. The differential protection is one of the types of protection for specified zone or for a piece of equipment. This method is to determine the difference between input and output current. The internal faults from the zone that differential will be high. Sometimes, the value of differential current can be high without an internal fault. This is happened because of the characteristics of current transformer that function to measure the input and output current and also the transformer being protected [3]. The ferromagnetic magnet circuit cause the transformer differential protection to action in 100%. However, the setting value for relay still can improve the differential protection. For the high voltage side, it has no load during differential protection. High voltage side become the transformer differential protection [4]. The last transformer protection types is differential protection. The basic principle of differential protection is in normal condition, the current can flow without any disturbance to the protection zone. The current through relay is zero. The relay would not operate for an external fault. The relay will operate between two current transformers in fault condition [10].

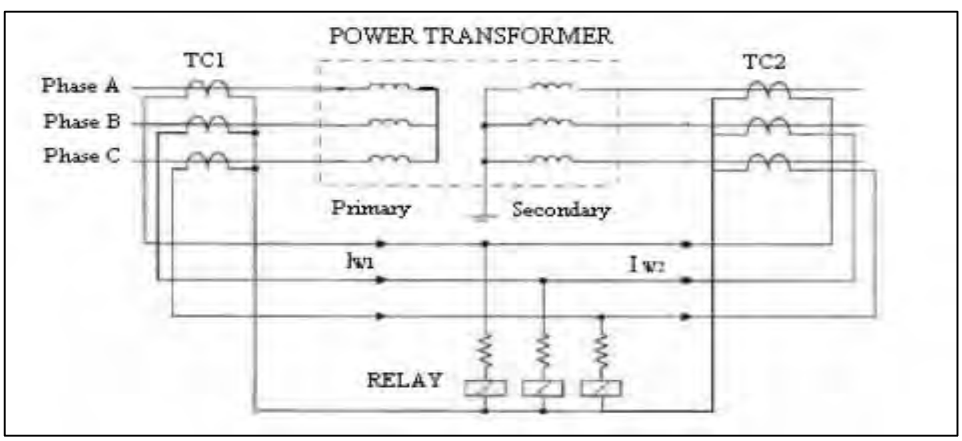


Figure 2.2: Simple diagram for transformer differential protection.

Protective relay or specifically the dual slope differential relay is the most important component in the power system network. The main function of the relay is to reduce the harmful damage to electrical equipment and other things when an electrical fault occurs. The design of the relay for protection system is to prevent or to clear the electrical fault as fast as possible. Therefore, to prove it, the high speed relay has been widely used with the upstream protective device. The most effective ways to protect the electrical equipment based on the operating speed is by using differential relays. The differential protection for the transformer is tripping the power system network because of the unbalanced current from current transformer on the both sides. The current transformer is saturated due to unbalance currents. For transformer differential protection concept, one side of current transformer is high voltage, whereas the other side is low voltage. From that, each side of the transformer has the different turn ratios and different accuracy class. The wave shape of output current for both sides could be different because of current transformer saturation. This problem could make the differential relay activate. In order to avoid this problem, the engineer that worked with protection unit must consider the size of the current transformer based on applicable standard such as IEEE C37.110. Nowadays, the modern microprocessor relay could prevent the unwanted trip because the current transformer was modified for algorithm detection. The relay could block the trip for output signal for an external fault. The current transformer should be enough for stable protection in system stability [11].

2.3 Inrush Current

The inrush current happened when the transformer energize under no load condition and also because of fault from external. These inrush current have harmonic-rich current that that generated when the transformer in energization condition which the transformer cores are driven into saturation. This inrush current has a bad effect for transformer such as potential damage or life for transformer would be short and also the power quality of the system was reduced [5][8].

The transformer is an equipment that has an electromagnetic induction because of the static electrical tools. The core of magnetic flux is in maximum value when the instantaneous voltage is zero because the iron core not change fast. The core is saturated when in winding excitation current condition. It produces a flux that needed the greater excitation current. At the adverse closing moment, core flux density and excitation current is increasing. Therefore lastly the inrush current is produced [4].

Internal fault for transformer include winding insulation and winding defect have a failed result in ground fault or turn to turn fault. This insulation happen because of several reason such as magnetizing inrush current, lightning strikes and many more [6]. To avoid the relay from malfunction, the inrush current and fault current must be identify. The harmonic restrain method is used as a technique to solve the problem [7]. The magnetizing inrush current can cause the differential protection of power transformer to be mal-operation [8]. The inrush current is exist in transformer. It value for magnitude and duration based on residual field present and the point on the ac cycle at the re-energization [10].

The excitation inrush current basically is:

- The value of the inrush current is very big.
- Time axis side reveals the excitation inrush current waveform.
- Second harmonic current is higher and obvious.
- "Intermittent corner" is excited inrush current wave between adjacent waveform.

The transformer excitation inrush current is a problem that cannot be prevented for transformer high voltage test. Therefore, the differential relay that acts as a protection tool must understand a high voltage test for transformer to operate effectively [5].The inrush current produce when the transformer is switch on. The magnitude, shape, and duration of inrush current depend on the following factors [9]:

- The power transformer size.
- The source impedance.
- The condition when the transformer is switched.
- The core material.

The inrush current can be emerge in three phases and also in a grounded neutral. The magnitude of current is different for both three phases and grounded neutral. The maximum inrush current can be produced when the switching occurs at the zero crossing of the voltage and when the new flux from the inrush current get the same direction. Inrush current have a large dc component and rich in harmonics [9].

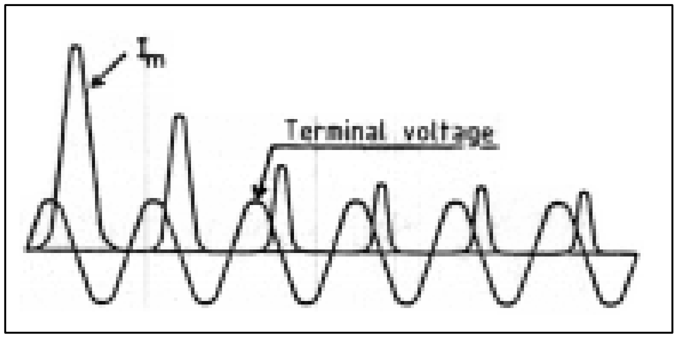


Figure 2.3: Theoretical inrush current Im.

2.4 Buchholz Relay

Nishant Kumar, et.al [12] agree that a buchholz relay is a gas and oil operated device which connected in the pipe work. This buchholz relay is placed between the conservator and the transformer tank. This relay is completely filled with oil.

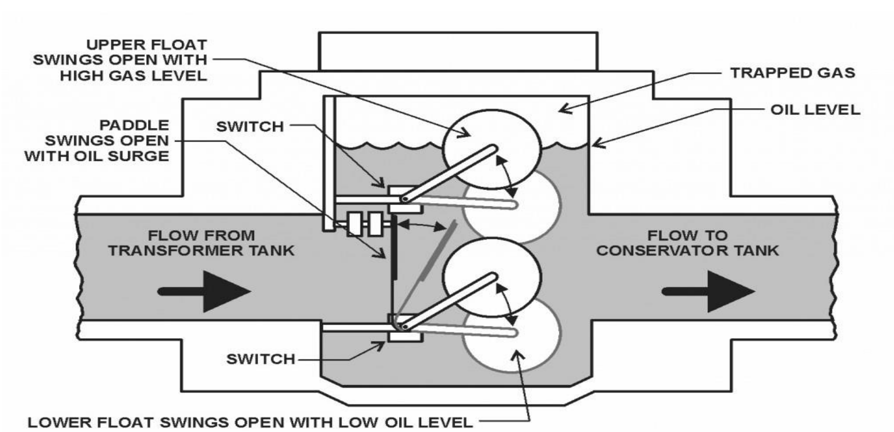


Figure 2.4: The inner part of buchhloz relay.

In this relay, there are two switches that are presents for alarm and trip. When in fault condition, the gas bubbles are produced and the oil level in the relay drops on the upper bucket. This can cause the alarm signal to operate. The lower bucket of the relay is not change its position. It is because the gas can escape into the conservator when the gas reaches the upper inside wall. Thus, the lower switch will not be operated and will not trip the transformer because of the minor fault. If there are case that the liquid level continuous to drop due to loss of oil, the lower switching system operates.

The buchholz relay have a problem with its measuring. It’s can only show how much gas since the last emptying. Thus, the result can give an erroneous alarms. The buchholz relay is poor sensitivity if it is combined with a computer aided monitoring. This relay cannot be used as a diagnosis tool. In order to reduce the problem for erroneous alarm, the chamber should be empty from the gases that produced during a long time period [13]. By using a sensor, the buchholz relay function are extended. The gas rate can be detected. So that, it can be used for diagnostic purposes. The capacitance of the sensor can detect the small amount of the entering gas. The gases will transfer into gas collector to store and also to analyse it after measuring the gas volume. The time of the gas detection and the amount of the measured gases are stored in a memory [14].

CHAPTER 3

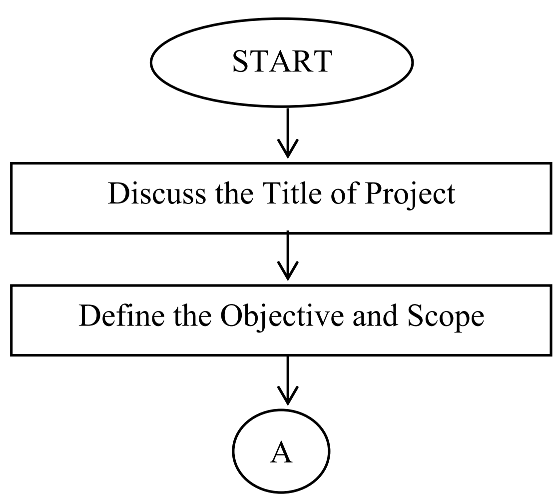
METHODOLOGY

3.1 Introduction

In this chapter, the whole of methodology to complete this project will discuss. This chapter will be divided into several sections to give an explanation for the development of the transformer differential protection. The detail of tools such as the function and their connection will be discuss in this chapter.

3.2 Flow of Project

The flow chart of methodology is shown in figure 3.1 to complete the whole of the project. This is to make sure that the project is finished at the right time for every section of the project.



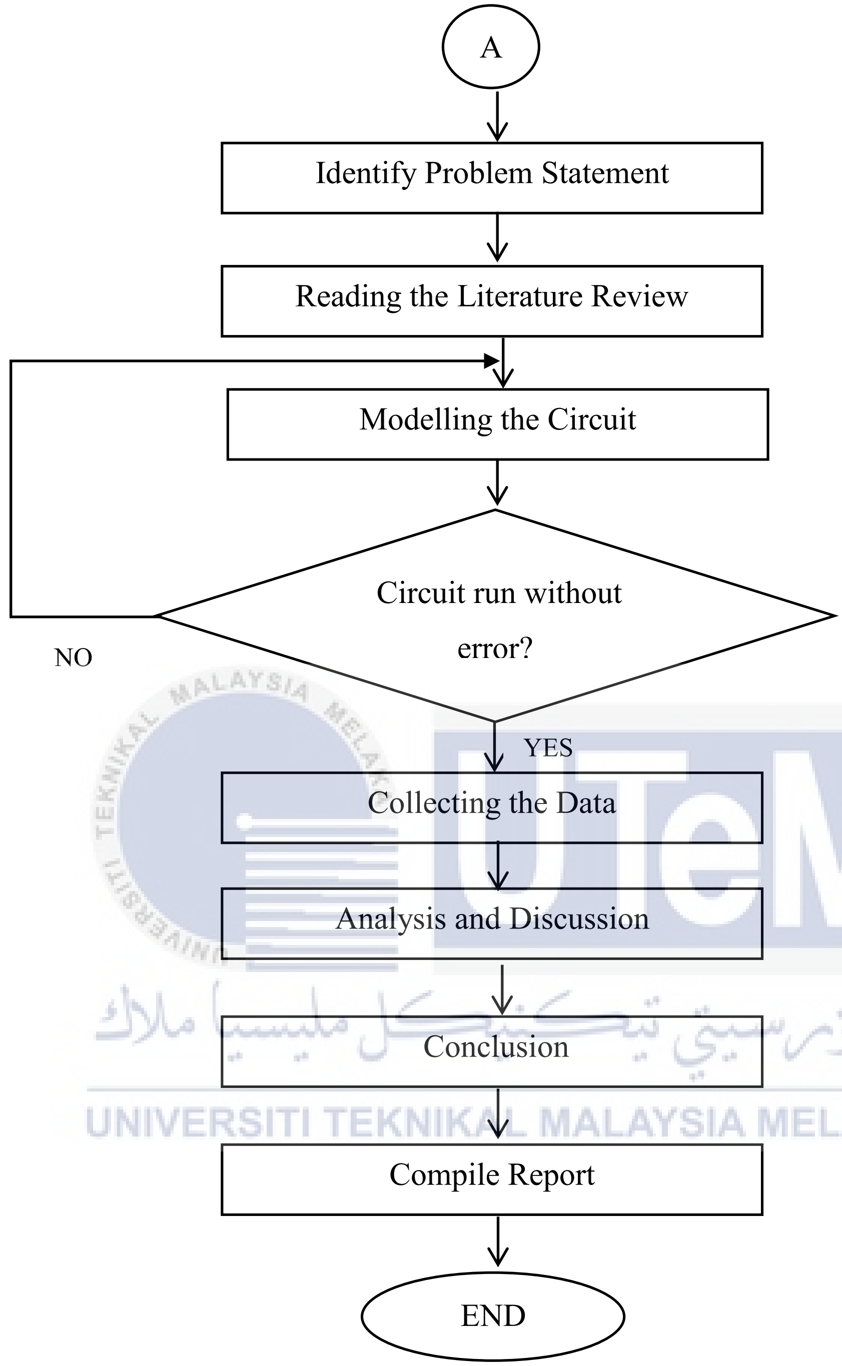


Figure 3.1: Flow chart of project

3.3 Description Operation of The System

For the normal condition, the relay will not operate or the signal value is equal to zero. If the fault current is simulate, the relay signal will show the value of one. If not, the setting of relay must be changed. The complete operation is shown in figure 3.2 below.

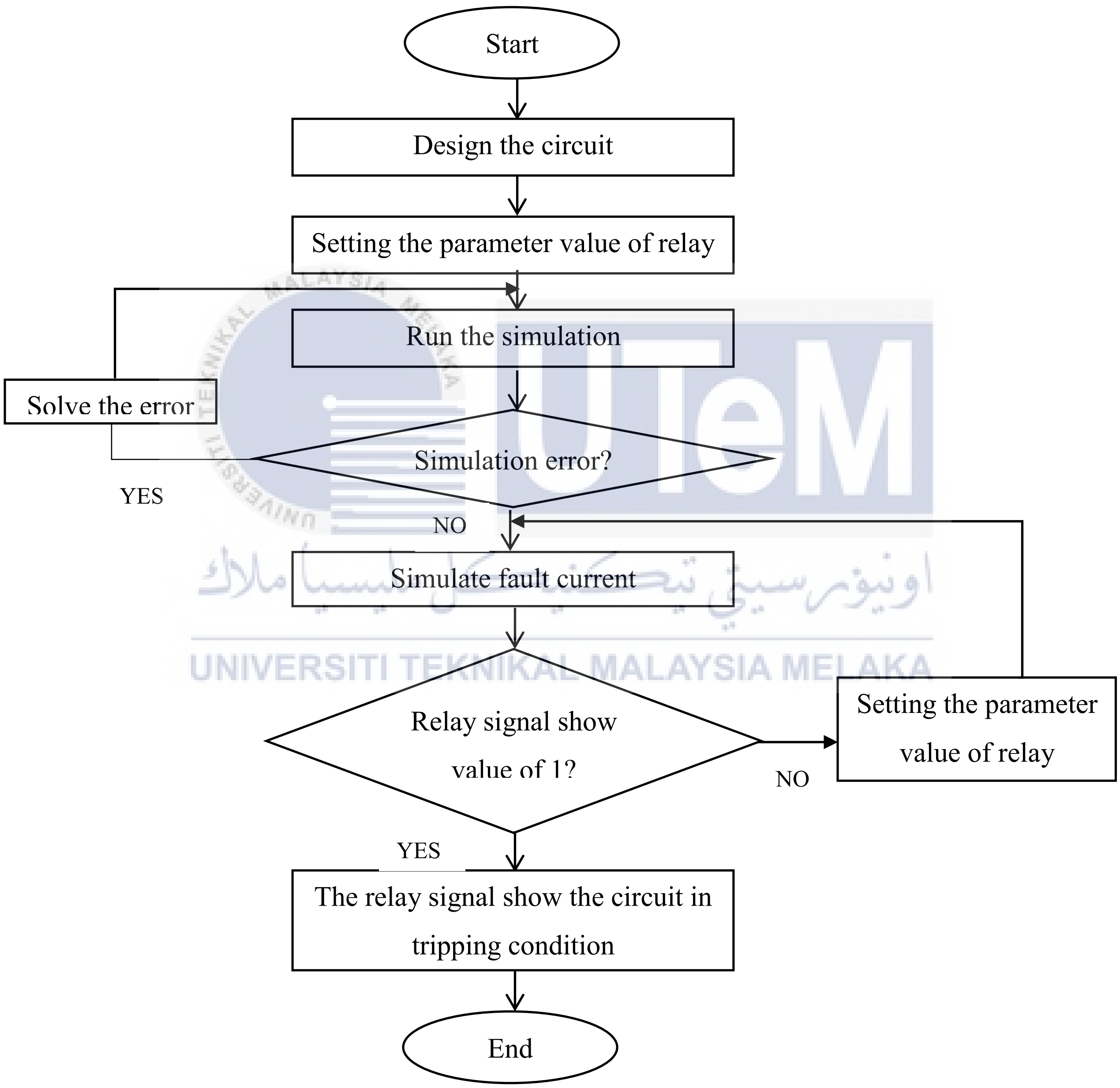


Figure 3.2: Flow chart for transformer differential protection

The process of operation for a figure above can be summarized as follows:

i. Design the circuit and setting the parameter value of relay based on the value of the fault current.
ii. Run the simulation.
iii. If the simulation have error, solve the error and run the simulation again. The information of error will be shown and can pointed the error at circuit
iv. Simulate the fault current and relay signal show the value of one.
v. If the relay signal not show the value of one, setting back the parameter value of the relay
vi. If the relay signal show the value of one, the relay signal show the circuit in tripping condition.

3.4 Tools of PSCAD and Modelling the Circuit

3.4.1 Three Phase Voltage Source/Generator

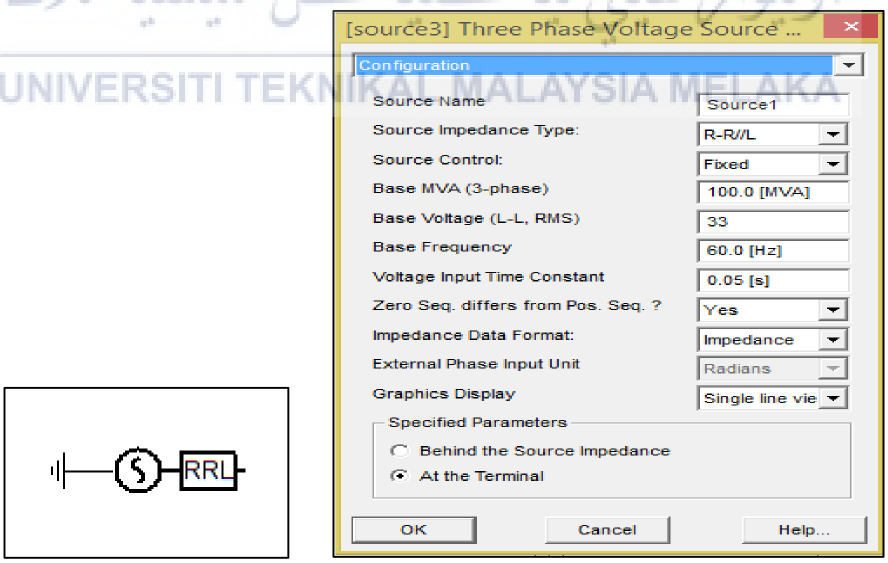


Figure 3.3: The three phase voltage source/generator and the properties.

The three phase voltage source/generator tools is used to supply the voltage to the circuit. The three phase voltage source is used at the first busbar and the generator at the last busbar to supply the power to the whole circuit before step up or step down by the transformer. From the properties, the power of the source is set to 100MVA and the base voltage is 33kV. The frequency is set to 60Hz.

3.4.2 Three Phase Two Winding Transformer

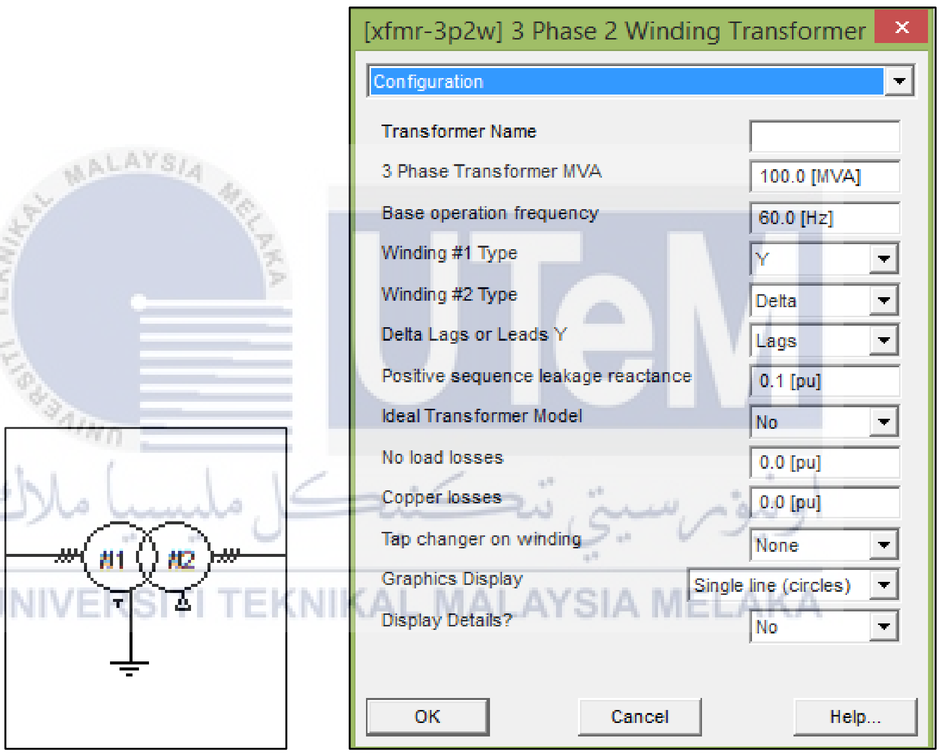


Figure 3.4: The three phase two winding transformer and the properties.

The three phase transformer with wye-delta connection is used for four transformer in this project. It has a three phase connection on the primary and secondary side that can be connected to the transmission line. The voltage of primary and secondary side can be set to be step up or step down transformer. The apparent power is set to 50MVA, 80MVA and 100MVA in this project based on the position of transformer in the circuit.The frequency is set to 60Hz.

3.4.3 Multimeter

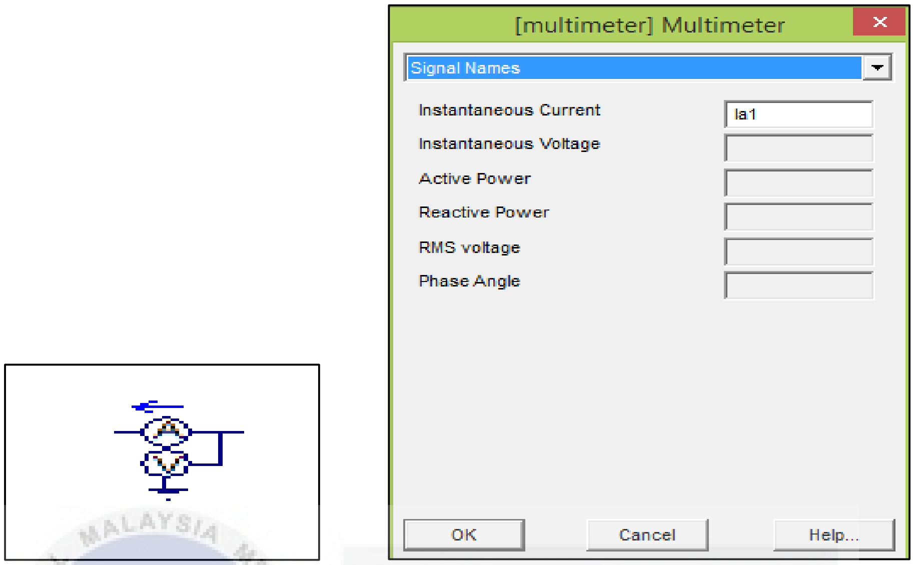


Figure 3.5: The multimeter tool and the properties.

The multimeter is used in this project is to measure the current. The direction of the current in the circuit must be same with the direction of the multimeter. The instantaneous current is label as a ‘Ia1’ to give the output of the value of current. In this simulation, ‘Ia1’ is used to make a connection between the multimeter and the fast fourier transform (FFT).

3.4.4 Three Phase Fault

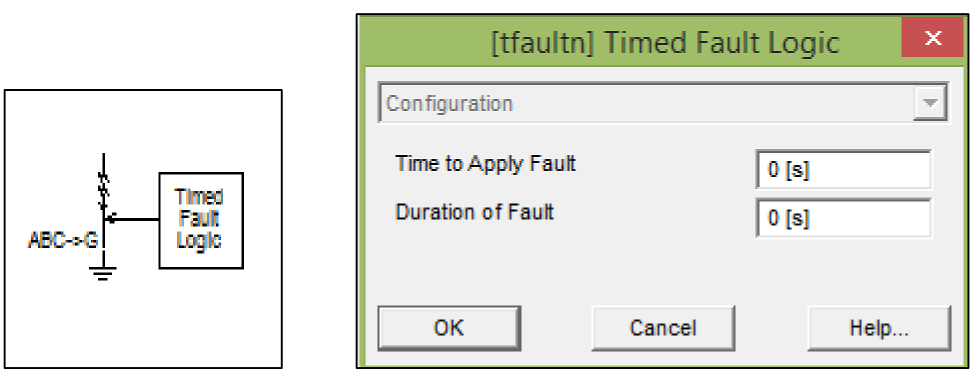


Figure 3.6: The three phase fault and time fault logic.

The three phase fault will be placed on the zone of protection transformer. It also can be placed at the busbar and transmission line as an external fault for this project. It will produce the abnormal current that flow through transmission lines and to the transformer. It also can be set to fault at which phase for example fault at phase a only or fault at phase a and b or fault at phase a, b, and c or vice verse. Timed fault logic function to setting the time to apply fault and the duration of the fault. In this project, time to apply fault is set to 1.0 second and duration of fault is set to 3.0 second. The duration of simulation for the whole circuit is 5.0 second.

3.4.5 Transmission Line

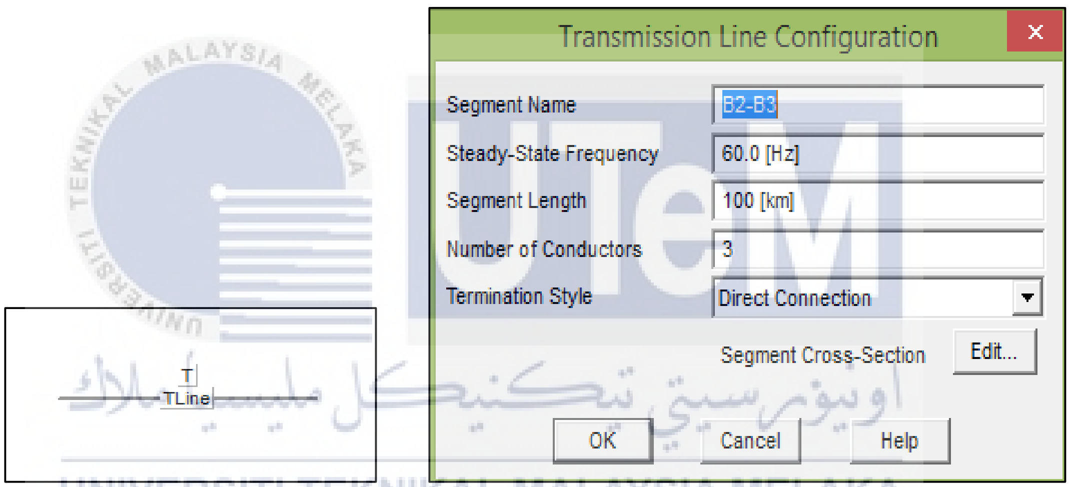


Figure 3.7: The transmission line tool and transmission line configuration.

The transmission line is used to make a connection between the busbar. The length of the transmission line and the number of conductor can be set. In this simulation, the length of transmission line is set to 30km, 50km and 100km. The number of conductor is three. The steady state frequency is 60Hz.

3.4.6 Fixed Load

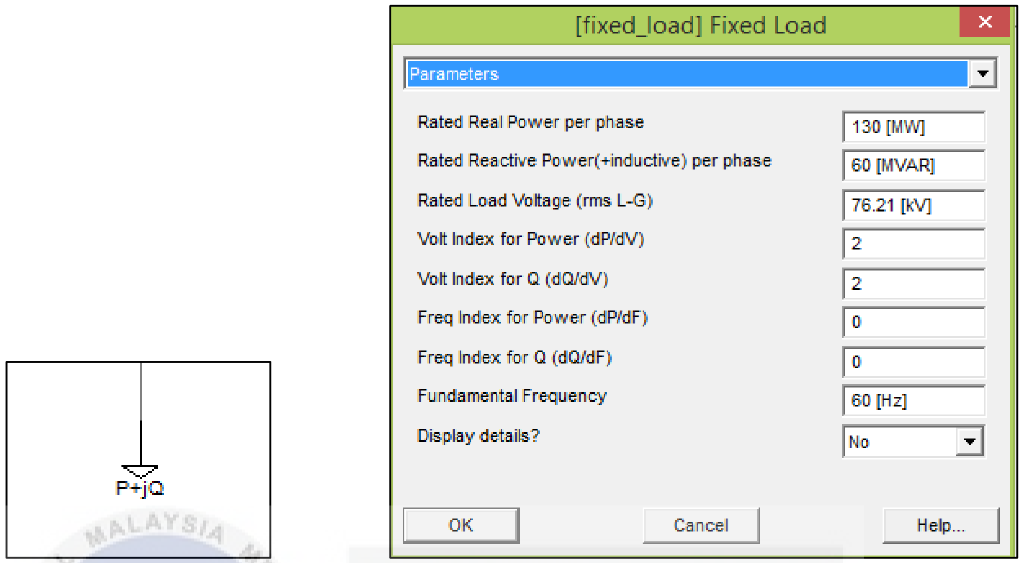


Figure 3.8: The fixed load and the properties.

The fixed load is used in this simulation because this project involve in measure the current of the transformer. The rated load voltage is calculate by dividing the voltage of the transformer by s √ 3. The value of fundamental frequency is 60Hz for every fixed load. The fixed load consist of the rated real power per phase and rated reactive power per phase. The both value is depend on the apparent power setting of the transformer. The power factor is set to 0.9. The figure and formula below shows how to calculate the fixed load.

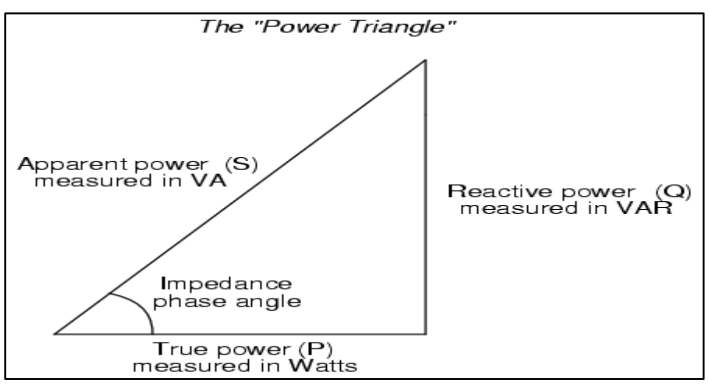


Figure 3.9: The power triangle.

Power Factor = cos θ

Active Power, P = S × cos θ

Reactive Power, Q = S × sin θ

Table 3.1: The value of fixed load after calculation

Transformer	Apparent Power, S	Active Power, P	Reactive Power, Q
1	100MVA	90MW	44MVAR
2	80MVA	72MW	35MVAR
3	50MVA	45MVA	22MVA
4	50MVA	45MVA	22MVAR

3.4.7 Current Transformer

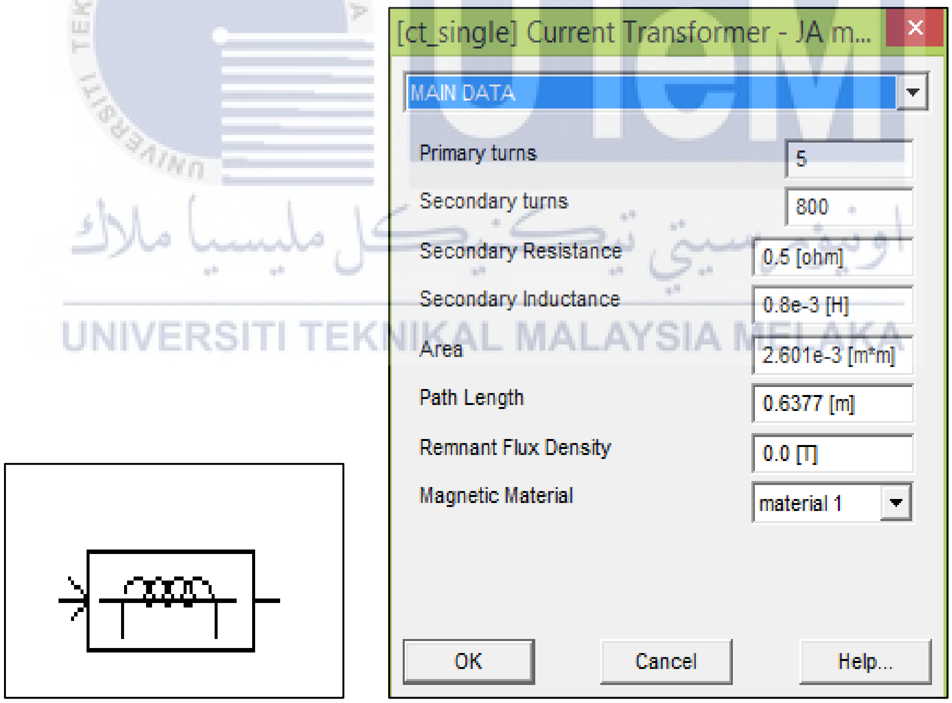


Figure 3.10: The current transformer and the properties.

The current transformer is an important equipment in differential protection. The zone of protecion is between both current transformer. The function of current transformer is to produce an alternating current in its secondary winding which is proportional to the current being measured in its primary. In the zone of protection, the current that flow throught it is small because the relay only can read the small current to know the differential of current. In this simulation, the current transformer will connect with the fast fourier transform. The properties of current transformer show the primary turns and secondary turns to be set. It will involve the value of current flow throught the transmission line.

Table 3.2: The value of current transformer ratio.

Transformer	Primary Turns	Secondary Turns
1	4000/5	600/5
2	800/5	2000/5
3	800/5	2000/5
4	800/5	2000/5

3.4.8 Fast Fourier Transform

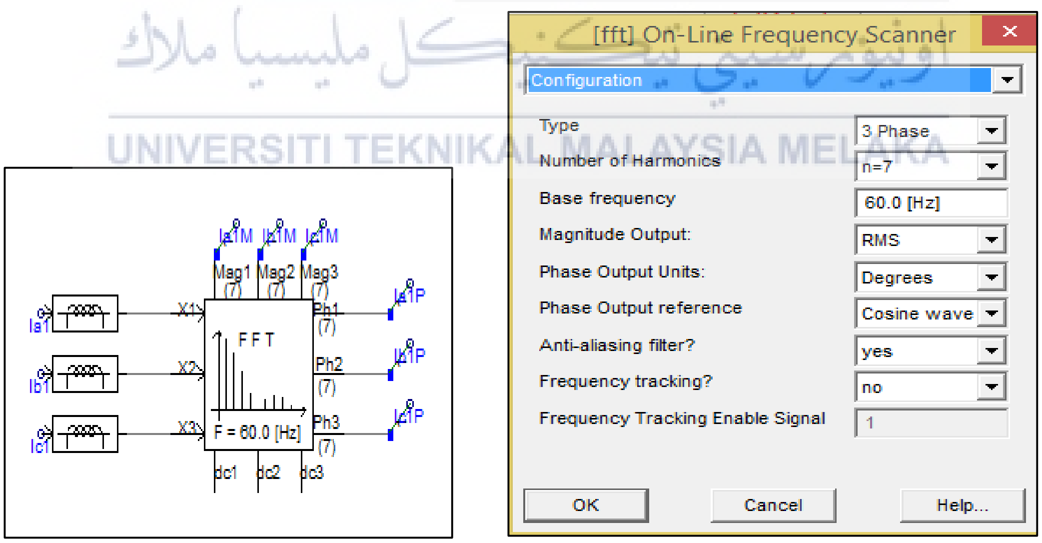


Figure 3.11: The fast fourier transform and on-line frequency scanner

The fast fourier transform is used in this project because it provide the operating quantity for the dual slope diferential relay.The dual slope current differential relay only can read in degree. It also will change the current into rms to make easier to read the value of current from the graph. Another function of fast fourier transform is to prevent the relay from mal-operation. This fast fourier transform also can determine the harmonic phase and magnitude of the input signal as a function of time. However, in this project the fast fourier transform just only used to make a connection with relay and not used determie the harmonic. From the figure above, the connection of fast fourier transform with current transformer is only on primary side. So that, another one connection is needed for secondary side. The base frequency is set to 60Hz.

3.4.9 Dual Slope Current Differential Relay

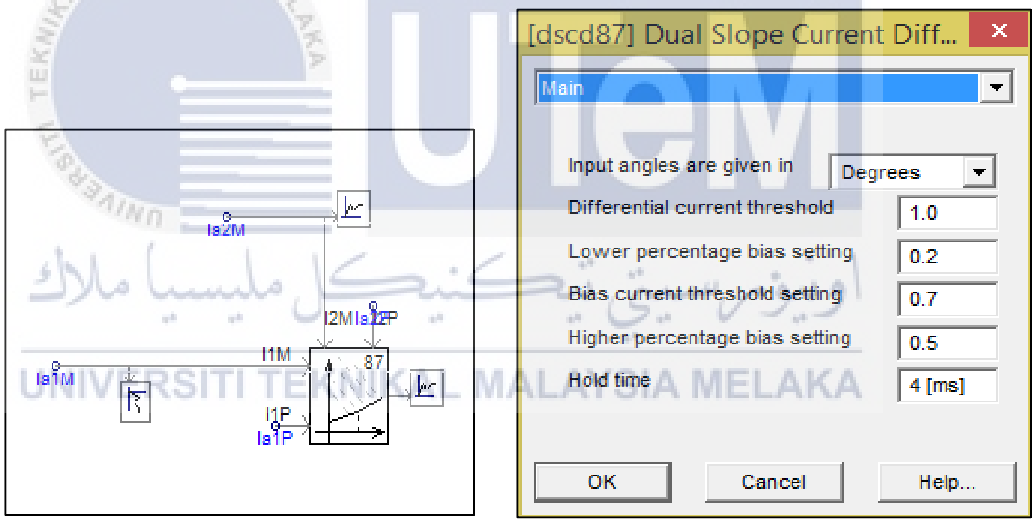


Figure 3.12: The dual slope current differential relay and the properties.

The dual slope current differential relay is function to measure and compare the current from the both side of transformer. The relay will connect between both current transformer to protect the transformer. If the differential current is exceed the value of differential current threshold, the relay will operate. In order to protect one transformer, three relay is used because one relay represent for one phase only. The connection of relay is from fast fourier transform that the value of current is convert to degree that are suitable for relay. The label of ‘Ia1M’ and ‘Ia1P’ is for primary side and 'Ia2M' and 'Ia1P' is for secondary side. From the properties of relay, all of the value must be determined by calculation and the graph operation of relay. The differential current threshold is setting higher than differential current in normal condition. The bias current threshold is the minimum current level that gives the effect to the system.

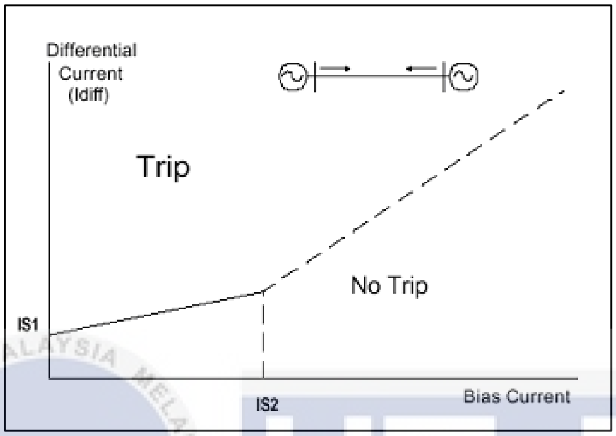


Figure 3.13: The graph operation of dual slope current differential relay.

The dual slope percentage biased restraint characteristics can be determined by the following 4 settings:

- IS1: The basic differential current setting
- K1: The lower percentage bias setting
- IS2: The bias current threshold setting
- K2: The higher percentage bias setting

The differential current:

$I_{DIFF} = I_1 + I_2$

The bias current:

$$I_{BIAS} = \frac{I_1 + I_2}{2}$$

Lower percentage bias setting:

Slope K1 = $\frac{IDIFF}{IBIAS}$

Slope K2 will be selected based on the relay operating criterion given for the dual slope relay.

The tripping criteria can be formulated as:

Case 1

Ibias<Is2

Idiff>K1*Ibias+Is1 then trip

Case 2

Ibias>=Is2

Idiff>K2*Ibias-(K2-K1) *Is2+Is1 then trip

3.4.10 Circuit Design

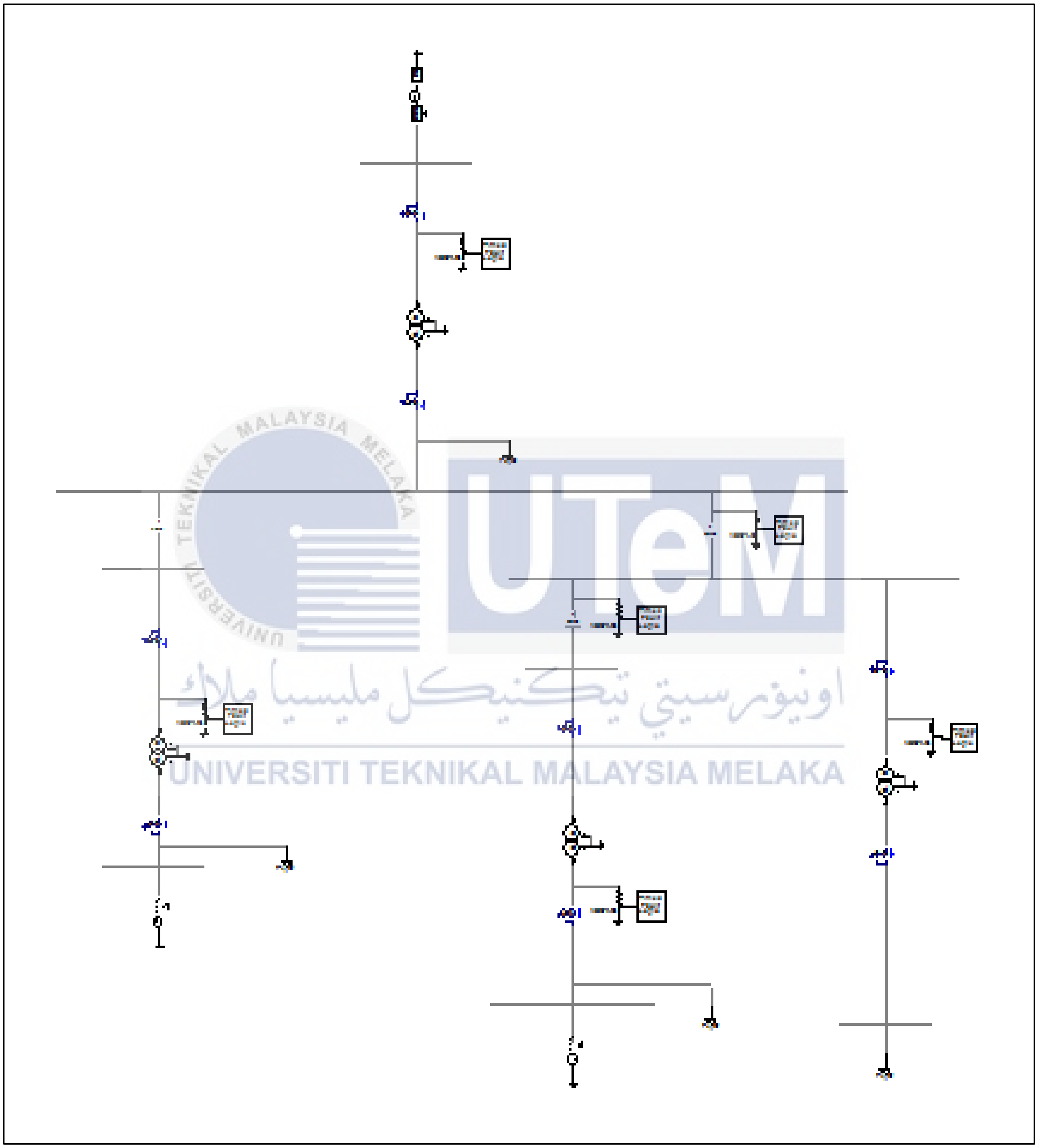


Figure 3.14: The full modelling transformer differential protection in single line view.

From the figure 3.13, the circuit starting with the generator that produced 33kv with 100MVA and connected with busbar 1. From the busbar 1, there is step up transformer voltage rating 33/132kV and generated 100MVA. The three phase fault is placed on the primary side of the tranSformers as case 1. The fixed load for this transformer is 90MW and 44MVAR. Then, the transformer connected with the busbar 2.

At the busbar 2, there is transmission line with 100km length and connected with busbar 3. Between busbar 3 and 4, the step down transformer rating voltage 132/33kV is placed. The transformer rating is 80MVA. The three phase fault is placed on the primary side of the transformer as a case 2. The 72MW and 35MVAR of fixed load is placed on the transformer. The generator that produced 33kv with 100MVA connected at busbar 4.

Next is also from the busbar 2, there is transmission line with 50km length connected with busbar 5 with an external fault 1 is placed on that trasmission line. Another transmission line with 30km length is connected to busbar 6 with an external fault 2 is placed on that transmission line.Then, the step down transformer is connected between busbar 6 and 7. The rating voltage of the transformer is 132/33kV with rating power 50MVA. The fixed load value 45MW and 22MVAR is also connected with the transformer. The three phase fault is placed on the secondary side of the tranformers as case 3. The generator that produced 33kv with 100MVA connected at busbar 7.

Another connection is from busbar 5, the step down transformer is connected to busbar 8 with voltage rating 132/33kV and power rating is 50MVA. The three phase fault is placed on the primary side of the tranformers as case 4. The last connection for this branch is fixed load with rating 45MW and 22MVAR at busbar 11.

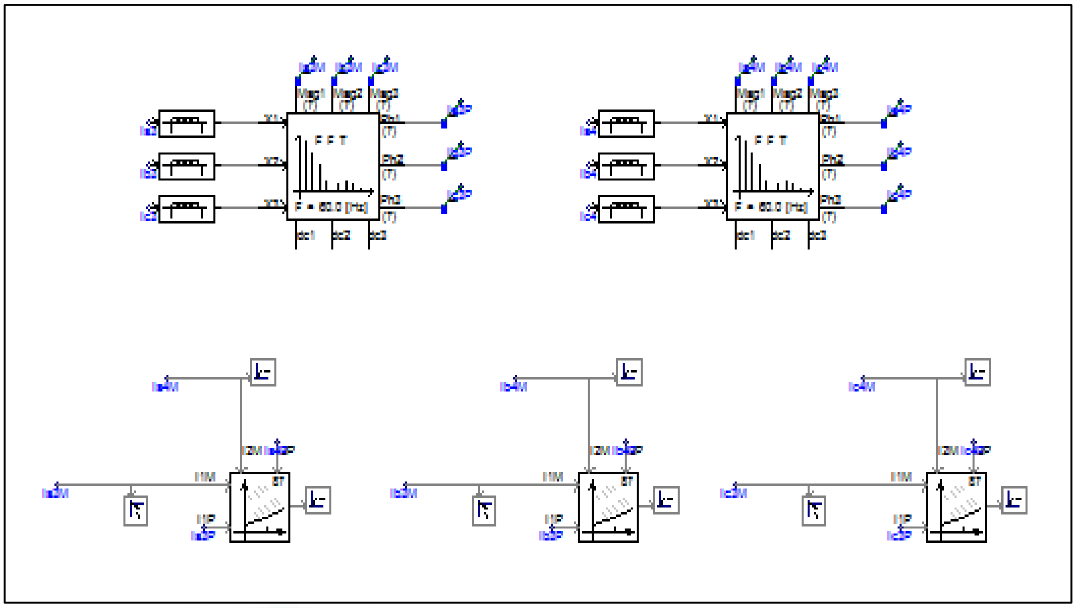


Figure 3.15: The designing of equipment for protect one transformer.

From the figure above, two fast fourier transforms and three relay is used to protect one transformer. The setting of relay for three relay is using the same value because the differential current from phase a, b, and c very similar. The result also will show for a one phase only.

3.5 Gantt Chart and Key Milestone

3.5.1 Gantt Chart

Tasks	2015															2016																					
	September			October				November				December				January				February				Mac				April				Mei				June		
Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	16	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37
Search/Register for Supervisor and Project Title	■	■																																				
Research about the previous project that be related	■	■	■	■	■																																	
Literature Review			■	■	■	■																																
Ready PSM I Report						■	■	■	■																													
Design the circuit and the system						■	■	■	■	■																												
Send PSM I Report									■	■	■	■																										
Seminar and Alter of Commented Report														■																								
Design and modified the circuit												■	■	■	■	■	■	■																				
Send alter PSM I Report															■																							
Improved the circuit																■	■	■	■	■	■	■	■	■	■													
Collecting Data																						■	■	■	■	■	■	■	■	■								
Ready PSM II Report																							■	■	■	■	■	■										
Send PSM II Report																									■													
Seminar and Alter of Commented Report																									■	■	■	■	■	■	■							
Send Final Report																													■	■	■	■	■	■	■	■	■	■

3.5.2 Key Milestones

Table 3.3: Key Milestones for full final year project.

Project Movement	Period
Assortment of Article and Literature Review	14 September 2015-30 September 2015
Research related calculation involved	1 October 2015-8 October 2015
Research on the transformer differential protection	15 October 2015- 2 November 2015
Modelling the circuit	3 November 2015 – 18 November 2016
Prepare PSM I Report	6 November 2015
Send PSM I Report	7 December 2015
First seminar	15 December 2015
Improve the circuit design	20 December 2015 – 4March 2016
Prepare final report	May 2016
Send final report	June 2016
Final seminar	June 2016

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

In the chapter 4, the result that gain from calculation and simulation are stated in detail. This chapter have been divided into two section that is the result for whole simulation and result by cases with analysis.

4.2 Result for Complete Simulation

The table below shows the whole result for the simulation based on the fault location that represent the cases with relay signal. If the relay signal is trip, this is means that the relay shows value of one and it operate. The single line drawing on figure below show the location of fault in transmission line.

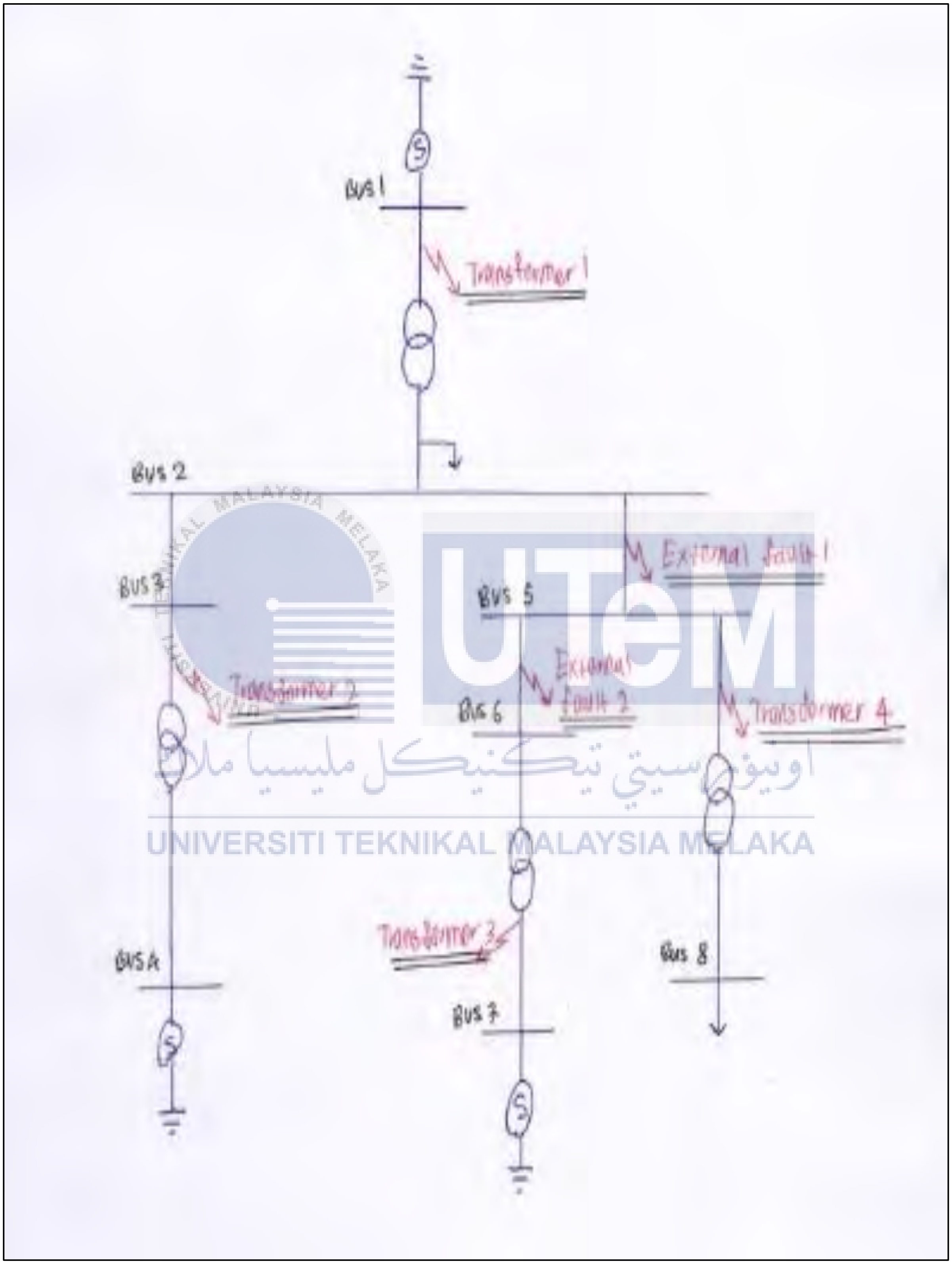


Figure 4.1: The single line drawing of the circuit.

Table 4.1: The result for relay based on the fault location.

Relay Signal / Fault Location	1	2	3	4
Transformer 1	Trip	No trip	No trip	No trip
Transformer 2	No trip	Trip	No trip	No trip
Transformer 3	No trip	No trip	Trip	No trip
Transformer 4	No trip	No trip	No trip	Trip
External fault 1	No trip	No trip	No trip	No trip
External fault 2	No trip	No trip	No trip	No trip

4.3 Result by Cases with Analysis

Transformer 1

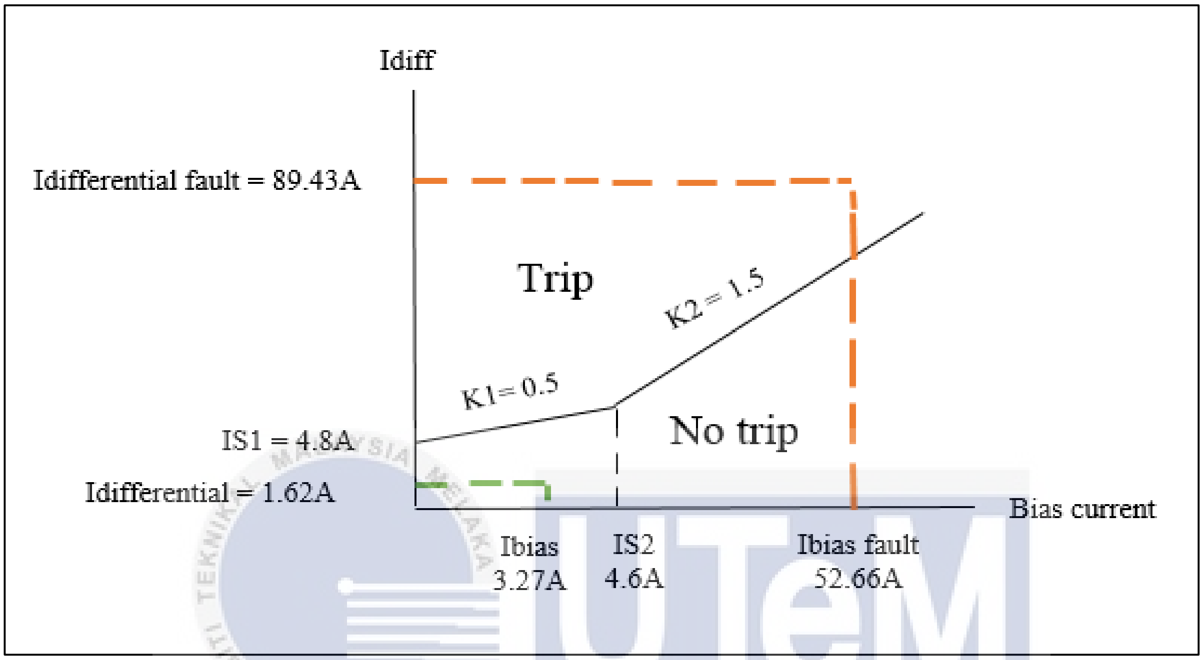


Figure 4.2: The operation of dual slope relay for transformer 1.

For transformer 1, the set of bias threshold current is higher than differential current and bias current in normal condition. Based on the figure, the intercept point is in no trip region which shows that the relay is not operate. In fault condition, the relay will operate because the higher percentage bias setting, K2 is lower than percentage bias for fault condition. The intercept point from current differential fault and bias current differential fault is in trip region. The detail calculation is shown below.

In normal condition,	In fault condition,
$Ip = 4.08A$ $Is = 2.46A$ $Idifferent = 4.08 - 2.46 = 1.62A$ $Ibias = \frac{4.08 + 2.46}{2} = 3.27A$ $K1 = \frac{1.62}{3.27} = 0.49 \approx 0.50, 50\%$ $Ibias < IS2$ $\text{Idiff} > \text{K1} * \text{Ibias} + \text{Is1 then trip}$ $1.62 > (0.5)(3.27) + (4.8)$ $1.24 < 6.44$ The relay is not operate in normal condition because it not satisfy the case 1.	$Ip = 97.37A$ $Is = 7.94A$ $Idifferent = 97.37 - 7.94 = 89.43A$ $Ibias = \frac{97.37 + 7.94}{2} = 52.66A$ $K = \frac{89.43}{52.66} = 1.7, 170\%$ $Ibias\ >= IS2$ Idiff>K2*Ibias-(K2-K1) *Is2+Is1 then trip $89.43 > (1.5)(52.66) - (1.5 - 0.5)(4.6) + (4.8)$ $89.43 > 79.19$ Therefore, the relay will operate because it satisfy the case 2 and value of K2 is lower than K in fault condition.

Transformer 2

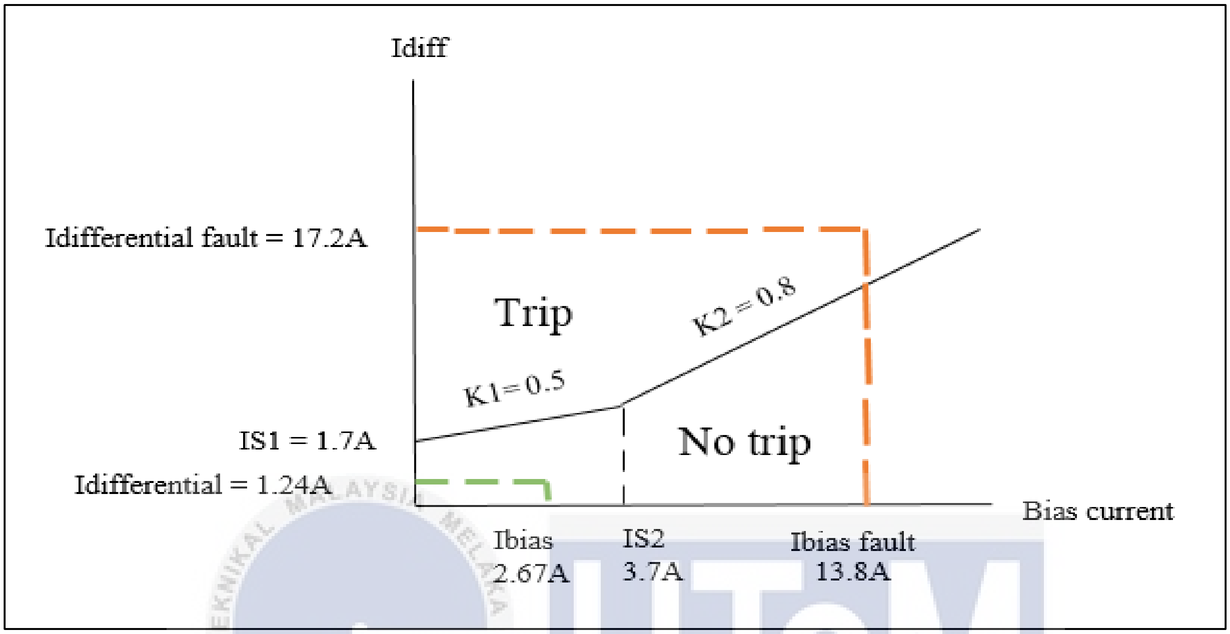


Figure 4.3: The operation of dual slope relay for transformer 2.

In a normal condition, the differential current is 1.24A and bias current is 2.67A. The value of differential current threshold, IS1 and bias current threshold, IS2 is setting higher than value to avoid relay operate in normal condition. It also must be setting higher because of the current transformer mismatch. Based on the figure above, the current at normal condition is not exceed the set bias threshold value. So that, the relay remain insensitive. When in fault condition, differential current and bias current is increase. Therefore, it will exceed the set bias threshold value. So that, the relay will operate. The detail calculation is shown below.

In normal condition,	In fault condition,
$Ip = 2.05A$ $Is = 3.29A$ $Idifferent = 3.29 - 2.05 = 1.24A$ $Ibias = \frac{3.29 + 2.05}{2} = 2.67A$ $K1 = \frac{1.24}{2.67} = 0.46 \approx 0.50, 50\%$ $Ibias < IS2$ $\text{Idiff} > \text{K1} * \text{Ibias} + \text{Is1 then trip}$ $1.24 > (0.5)(2.67) + (1.7)$ $1.24 < 3.04$ The relay is not operate in normal condition because it not satisfy the case 1.	$Ip = 5.2A$ $Is = 22.40A$ $Idifferent = 22.40 - 5.2 = 17.2A$ $Ibias = \frac{5.2 + 22.40}{2} = 13.8A$ $K = \frac{17.2}{13.8} = 1.25, 125\%$ $Ibias >= IS2$ Idiff>K2*Ibias-(K2-K1) *Is2+Is1 then trip $17.2 > (0.8)(13.8) - (0.8 - 0.5)(3.7) + (1.7)$ $17.2 > 11.36$ Therefore, the relay will operate because it satisfy the case 2 and value of K2 is lower than K in fault condition.

Transformer 3

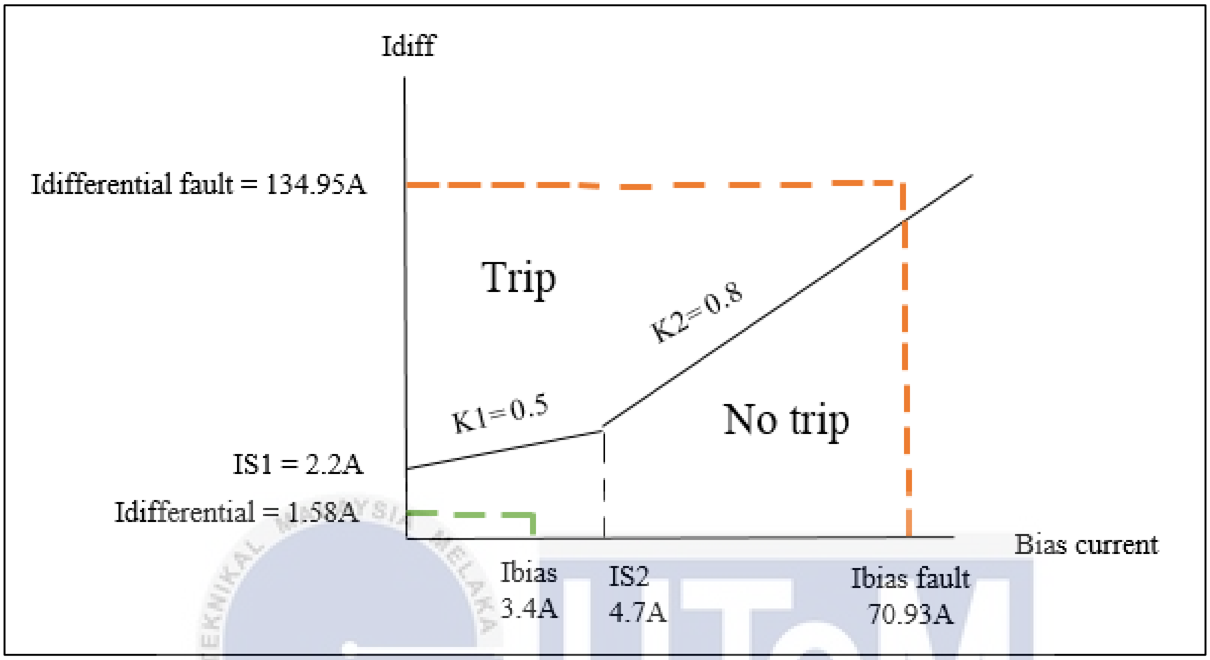


Figure 4.4: The operation of dual slope relay for transformer 3.

For transformer 3, the differential current threshold, IS1 is set to 2.2A that higher than differential current in normal condition. Based on figure above, the relay will not operate because the intercept point is in no trip region. The value of slope 1 is set to 0.5 based on the calculation. The value of bias current threshold also is setting higher than bias current in normal condition. For a fault condition, the value of current increase and exceed the slope 2. Therefore, the relay will operate. The detail calculation is shown below.

<u>In normal condition,</u>	<u>In fault condition,</u>
$Ip = 2.61A$	$Ip = 3.45A$
$Is = 4.19A$	$Is = 138.41A$
$Idifferent = 4.19 - 2.61 = 1.58A$	$Idifferent = 138.41 - 3.45 = 134.96A$
$bias = \frac{4.19 + 2.61}{2} = 3.4A$	$Ibias = \frac{138.41 + 3.45}{2} = 70.93A$
$K1 = \frac{1.58}{3.4} = 0.46 \approx 0.50, 50\%$	$K = \frac{134.96}{70.93} = 1.90, 190\%$
$Ibias < IS2$	$Ibias \ >= IS2$
$\text{Idiff} > \text{K1} * \text{Ibias} + \text{Is1 then trip}$	Idiff>K2*Ibias-(K2-K1) *Is2+Is1 then trip
$1.58 > (0.5)(3.4) + (2.2)$	$134.96 > (0.8)(70.93) - (0.8 - 0.5)(4.7) + (2.2)$
$1.58 \ < 3.9$	$134.96 > 57.53A$
The relay is not operate in normal condition because it not satisfy the case 1.	Therefore, the relay will operate because it satisfy the case 2 and value of K2 is lower than K in fault condition.

Transformer 4

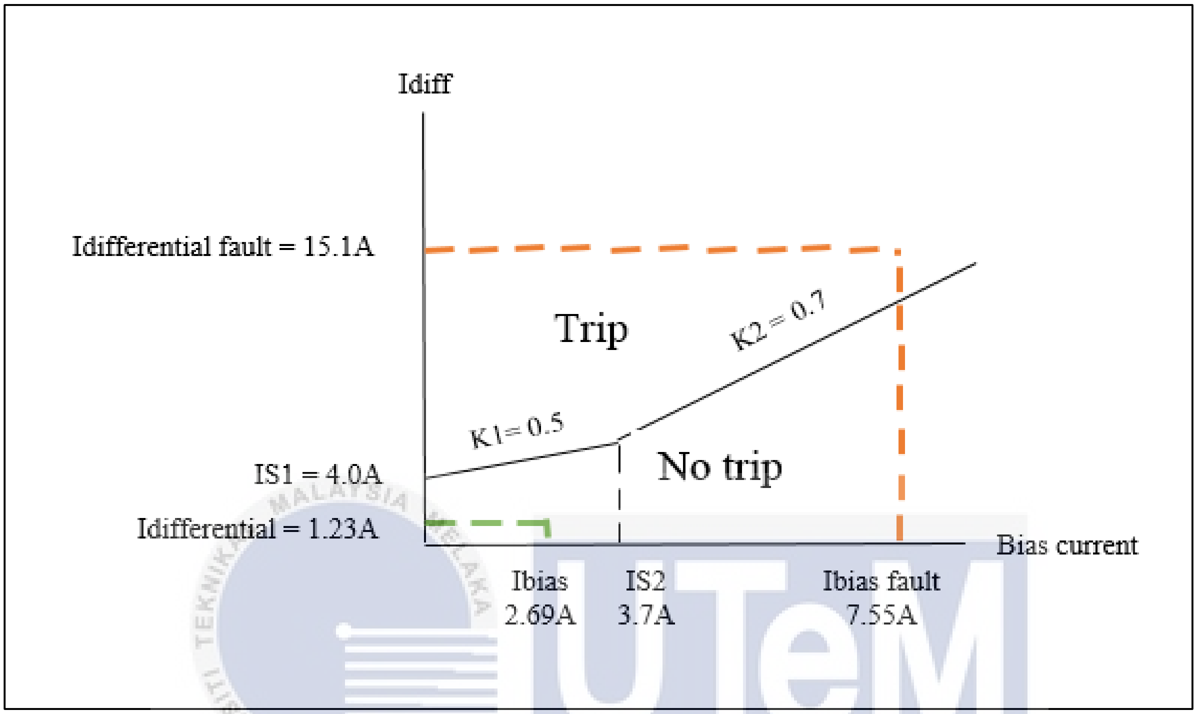


Figure 4.5: The operation of dual slope relay for transformer 4.

Based on figure above, the differential current is 1.23A and bias current is 2.67A. The set of threshold setting is higher than current in normal condition. So that, the relay is not operate I normal condition. The value of slope 1 is set based on the calculation and it is important to decide which region the position of current. When in fault condition, the relay will operate because the fault current is exceed the set bias threshold value. Other than that, the value of percentage bias setting is 2.0 which is higher than higher percentage bias setting, K2. The detail calculation is shown below.

In normal condition,	In fault condition,
$Ip = 2.07A$ $Is = 3.3A$ $Idifferent = 3.3 - 2.07 = 1.23A$ $Ibias = \frac{3.3 + 2.07}{2} = 2.69A$ $K1 = \frac{1.23}{2.69} = 0.46 \approx 0.50, 50\%$	$Ip = 15.1A$ $Is = 0A$ $Idifferent = 15.1 - 0 = 15.1A$ $Ibias = \frac{15.1 + 0}{2} = 7.55A$ $K = \frac{15.1}{7.55} = 2.0, 200\%$
$Ibias < IS2$ $\text{Idiff} > \text{K1} * \text{Ibias} + \text{Is1 then trip}$ $1.23 > (0.5)(2.69) + (4)$ $1.23 < 5.35$	$Ibias >= IS2$ Idiff>K2*Ibias-(K2-K1) *Is2+Is1 then trip $15.1 > (0.7)(7.55) - (0.7 - 0.5)(3.7) + (4.0)$ $15.1 > 8.55A$
The relay is not operate in normal condition because it not satisfy the case 1.	Therefore, the relay will operate because it satisfy the case 2 and value of K2 is lower than K in fault condition.

<u>External Fault</u>

In this project, there are two external fault has been placed in the simulation. External fault 1 and 2 is located at transmission line. The differential protection is a per unit system protection. That is means it only protect the equipment in the protection zone such as transformer and not protect the whole circuit. Therefore, if the fault occur at the busbar and transmission line, it will not affect the operation of all relay. The relay will not operate and the fault current will not affect the operation of the transformer. However, there will be error caused by the current transformer ratio. In order to remain the relay insensitive to the external fault, the operating threshold is raised by increasing the relay setting.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Introduction

This section is briefly explain about the conclusion of the transformer differential protection and focus the overall of result. Recommendation also included about the improvement that can be made.

5.2 Conclusion

All the process for modelling the circuit for the transformer differential protection was done properly. The PSCAD software is very helpful because the circuit is easy to construct. The concept of differential protection can be understand clearly and the simulation helping more because it shows the detail about it. The circuit was running without any problem and error. The design of relay is already show clearly in methodology. The result is represented in graph that follow the relay graph form. The parameter value of the dual slope current differential relay is setting based on the calculation by using the formula of the relay. The relay working successfully which it is not operate in normal condition and also for the external fault. The relay just only operate in fault condition. Therefore, the relay can save the transformer from damage and harm the human life.

5.3 Recommendation

This project is already be applied in the real life by Tenaga Nasional Berhad (TNB). TNB also used the relay to protect the equipment such as busbar, and transmission line. For this project, the circuit can be improved by expand the circuit and also adding the cases. From that, the further study can be made by compare the value setting of relay with other relay. This project has a lot of benefit and it's convenient to be used more widely.

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APPENDIX

Appendix A

Calculation for fixed load

Fixed load transformer 1

S = 100 MVA — p.f = 0.9

$P = S \times \cos\theta$ — $\cos\theta = 0.9$

$Q = S \times \sin\theta$ — $\theta = 25.84$

$P = 100 \times 0.9$ — $Q = 100 \times \sin 25.84$

$= 90$ MW — $= 44$ MVAR

Fixed load transformer 2

S = 80 MVA

p.f = 0.9

$P = 80 \times 0.9$ — $Q = 80 \times \sin 25.84$

$= 72$ MW — $= 35$ MVAR

Fixed load transformer 3 and 4

S = 50 MVA

p.f = 0.9

$P = 50 \times 0.9$ — $Q = 50 \times \sin 25.84$

$= 45$ MVA — $= 22$ MVAR

Appendix B

Calculation for current transformer ratio

Transformer 1

$I_{a1} = 2.1kA$

$I_{a2} = 0.52kA$

$i_1 = 5A$

$i_p = \frac{i_1}{\sqrt{3}} = \frac{5}{\sqrt{3}} = 2.89A$

$\frac{I_p}{i_p} = \frac{2.1kA}{2.89} = 726.6A$

$726.6A \times 5 = 3633.2$

Nearest CT ratio is 4000

$\therefore$ 4000/5

$i_p = 2.1k \times \frac{5}{4000}$

$= 2.63A$

$i_1 = \sqrt{3} \times 2.63 = 4.56A$

During full load, $i_1 = i_2 = 4.56A$

$i_s = i_2$

$\frac{I_s}{i_s} = \frac{0.52k}{4.56}$

$= 114.0A$

$= 114.0A \times 5$

$= 570.2$

Nearest CT ratio is 600

$\therefore$ 600/5

Transformer 2

$I_{a3} = 0.35kA$

$I_{a4} = 1.40kA$

$i_1 = 5A$

$i_p = \frac{i_1}{\sqrt{3}} = \frac{5}{\sqrt{3}} = 2.89A$

$\frac{I_p}{i_p} = \frac{0.35kA}{2.89A} = 121.11$

$= 121.11 \times 5 = 605.55$

Nearest CT ratio is 800

$\therefore$ 800/5

$i_p = 0.35k \times \frac{5}{800}$

$= 2.19A$

$i_1 = \sqrt{3} \times 2.19 = 3.79A$

During full load $i_1 = i_2 = 3.79A$

$i_s = i_2$

$\frac{I_s}{i_s} = \frac{1.40k}{3.79} = 369.39$

369.39×5

$= 1846.95$

Nearest CT ratio is 2000

$\therefore$ 2000/5

Transformer 3

$I_{a5} = 0.44kA$

$I_{a6} = 1.78kA$

$i_1 = 5A$

$i_p = \frac{5}{\sqrt{3}} = 2.89A$

$\frac{I_p}{i_p} = \frac{0.44k}{2.89} = 152.25$

$152.25 \times 5 = 761.25$

Nearest CT ratio is 800

$\therefore$ 800/5

$i_p = 0.44k \times \frac{5}{800}$

$= 2.75A$

$i_1 = \sqrt{3} \times 2.75A$

$= 4.76A$

During full load $i_1 = i_2 = 4.76A$

$i_s = i_2$

$\frac{I_s}{i_s} = \frac{1.78k}{4.76A} = 373.95$

$373.95 \times 5 = 1869.7$

Nearest CT ratio is 2000

$\therefore$ 2000/5

Transformer 4

$I_{a7} = 0.35kA$

$I_{a8} = 1.41kA$

$i_1 = 5A$

$i_p = \frac{5}{\sqrt{3}} = 2.89A$

$\frac{I_p}{i_p} = \frac{0.35k}{2.89} = 121.11$

$121.11 \times 5 = 605.55$

Nearest CT ratio is 800

$\therefore$ 800/5

$i_p = 0.35k \times \frac{5}{800}$

$= 2.19A$

$i_1 = \sqrt{3} \times 2.19$

$= 3.79A$

During full load $i_1 = i_2 = 3.79A$

$i_s = i_2$

$\frac{I_s}{i_s} = \frac{1.41k}{3.79} = 372.03A$

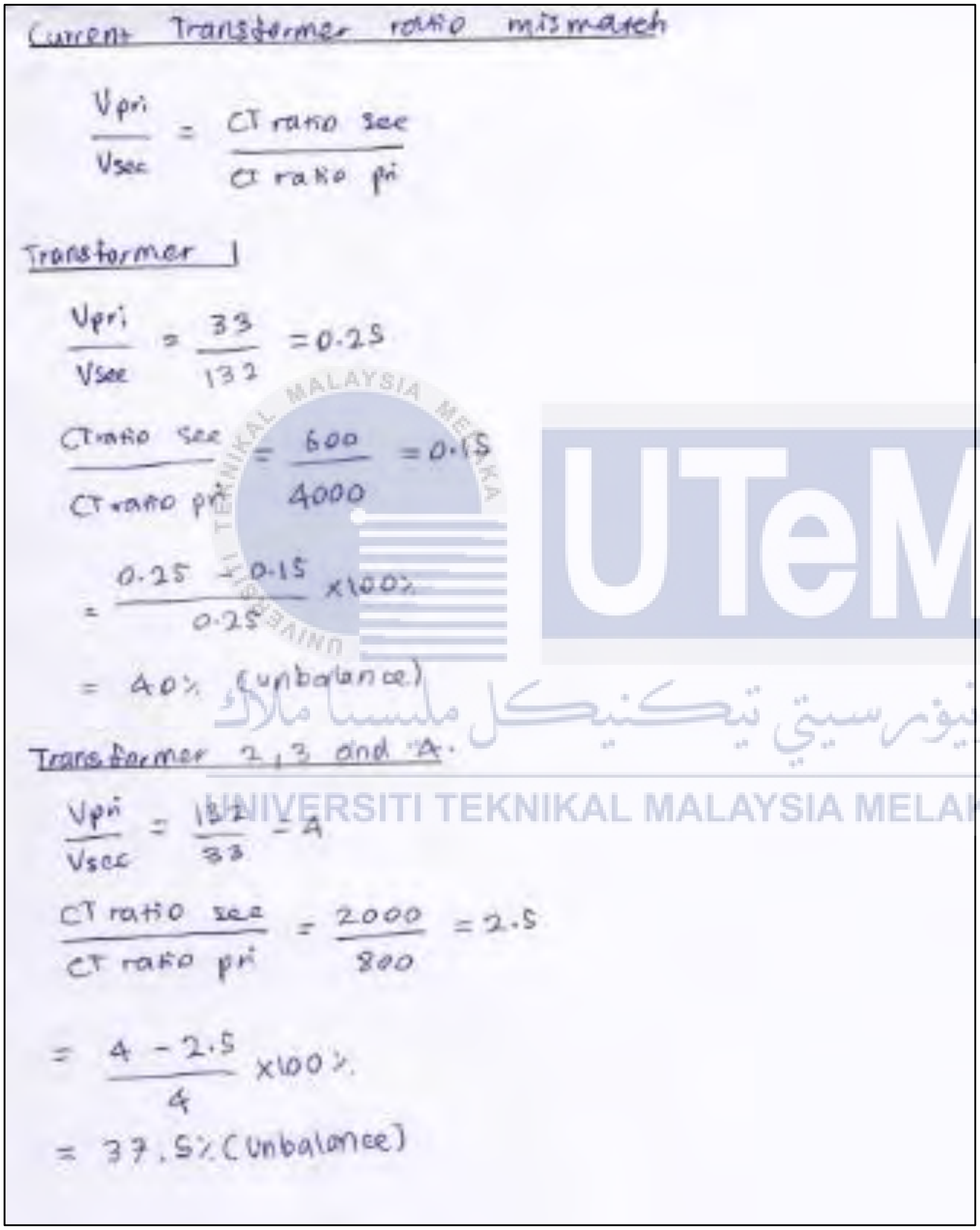
$372.03 \times 5 = 1860.15$

Nearest CT ratio is 2000

$\therefore$ 2000/5

Appendix C

Current transformer ratio mismatch



Current Transformer ratio mismatch

$$\frac{V_{pri}}{V_{sec}} = \frac{\text{CT ratio sec}}{\text{CT ratio pri}}$$

Transformer 1

$$\frac{V_{pri}}{V_{sec}} = \frac{33}{132} = 0.25$$

$$\frac{\text{CT ratio sec}}{\text{CT ratio pri}} = \frac{600}{4000} = 0.15$$

$$= \frac{0.25 - 0.15}{0.25} \times 100\%$$

$= 40\%$ (unbalance)

Transformer 2, 3 and 4.

$$\frac{V_{pri}}{V_{sec}} = \frac{132}{33} = 4$$

$$\frac{\text{CT ratio sec}}{\text{CT ratio pri}} = \frac{2000}{800} = 2.5$$

$$= \frac{4 - 2.5}{4} \times 100\%$$

$= 37.5\%$ (unbalance)

Appendix D

Dual slope current differential relay parameter setting

Transformer 1

No	PARAMETER	Symbol	Value
1	Differential current threshold	IS1	4.8
2	Lower percentage bias setting	K1	0.5
3	Bias current threshold setting	IS2	4.6
4	Higher percentage bias setting	K2	1.5

Transformer 2

No	PARAMETER	Symbol	Value
1	Differential current threshold	IS1	1.7
2	Lower percentage bias setting	K1	0.5
3	Bias current threshold setting	IS2	3.7
4	Higher percentage bias setting	K2	0.8

Transformer 3

No	PARAMETER	Symbol	Value
1	Differential current threshold	IS1	2.2
2	Lower percentage bias setting	K1	0.5
3	Bias current threshold setting	IS2	4.7
4	Higher percentage bias setting	K2	0.8

Transformer 4

No	PARAMETER	Symbol	Value
1	Differential current threshold	IS1	4.0
2	Lower percentage bias setting	K1	0.5
3	Bias current threshold setting	IS2	3.7
4	Higher percentage bias setting	K2	0.7