Analysis of Behaviour of Over-Current Protective Relay in Low Voltage Power System

By

Louisa Endona Bundan

Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Electrical and Electronics Engineering)

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Universiti Teknologi PETRONAS,

Bandar Seri Iskandar,

31750 Tronoh,

Perak Darul Ridzuan.

CERTIFICATION OF APPROVAL

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Approved by,

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(DR VIJANTH SAGAYAN A/L ASIRVADAM)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK.

SEPTEMBER 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(LOUISA ENDONA BUNDAN)

ABSTRACT

Electrical protection is an important essence to ensure continuous and smooth power delivery in any power system. Protective relays are employed to minimize immediate effect of disturbances caused by failure in the power system. Over-current relays are one of the protective relays used to achieve these objectives. This report proposes the use of digital protective relay over electromechanical relay in the power system due to several reasons. The analysis of behaviour of digital directional over-current protective relay is modeled in 415V three phase power system of MLNG Sdn Bhd, Bintulu, Sarawak. The simulation carried out using MATLAB Simulink provides understanding of the operation of digital directional over-current protective relay in an industrial distribution power system, with startup inrush current and back up relay for safe operation is considered. The performance of the protective relay is compared with IEC 255-3 standard to validate the accuracy of the proposed model.

ACKNOWLEDGEMENT

This present final year project was carried out from May 2012 under the supervision of Dr. Vijanth Sagayan A/L Asirvadam under Control and Instrumentation Cluster from Electrical & Electronic Engineering Department. This project was carried out in partial fulfilment of the requirement for the Bachelor (Hons) of Electrical & Electronic Engineering in Universiti Teknologi PETRONAS.

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The author wishes to express her love and gratitude to her beloved families, for their understanding & endless love, through the duration of her studies.

Thank you.

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LIST OF ABBREVIATION:

CT	Current Transformer
DSP	Digital Signal Processor
FMEA	Failure Mode Effect Analyis
FYP	Final Year Project
HV	High Voltage
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
LV	Low Voltage
MLNG	Malaysia LNG Sdn Bhd
SPS	Shipboard Power System
VT	Voltage Transformer
VTB	Virtual Test Bed

NOMENCLATURE:

I	measured input current
I_{RMS}	RMS value of input current
I_s	current setpoint / pick-up current
K	constant (factor)
L	ANSI/IEEE constant (zero for IEC and RECT curve)
t	operation time of over-current protective relay
TMS	time multiplier setting from 0.025 to 1.5
α	factor (constant for calculating operation time)

CHAPTER 1
INTRODUCTION

1.1 Background of Study

This final year project is carried out in collaboration with MLNG Sdn Bhd, Bintulu, Sarawak. During seven-month's industrial internship training undergone in the company, author had been exposed to protective relay field, and the knowledge regarding the subject has been accumulated since Protective Relay Database has become her industrial project. Author has been taught about functions of protective relays in the processing plant, apart from having being shown on the methods to test the functionality of electromechanical protective relays in MLNG.

In general, for industrial application, a transformer and switchgear line-up, together with metering, control and protection equipment are combined in one housing unit called substations. In MLNG, HV is defined as 6.6kV, 11kV and 33kV, while LV would be defined as 415V. Protective relays are set up together with other devices such as circuit breaker to protect transformer, generator, motors, busbar and feeder line of the system and other electrical equipments.

There are a lot of substations in MLNG process plants, presently total up to 65 substations, and in future the number of the substations will increase as Train 9 for MLNG TIGA is still under commissioning for the time being. Apparently electromechanical protective relays are still employed in process plants of MLNG SATU and MLNG DUA, since these two were built in 19^{th} century and early 20^{th} century. As MLNG TIGA was established in year 1995 [1], the equipment technology used in the process plant is much more sophisticated and advanced compared to the other two process plants. Digital protective relays are used instead of electromechanical protective relays in MLNG TIGA power system.

[2] Over-current relay works based on a principle: when the level of fault current increases dramatically and exceeds the nominal load current, it is assumed that a fault has occurred and trip signal will be transmitted. In the protection system, over-current protective relay is connected between the circuit breaker and CT. The protective relay receives input signals from secondary winding of CT and sends control commands to the circuit breaker to open or close its contact. CT is a necessity in the power system, as it is employed to reduce high magnitude of current to a more manageable level, and enable low energy devices such as digital protective relay to operate in the system. It reproduces a current in its secondary winding which is proportional to the primary current.

[3] Directional over-current protective relay operates in the same manners as non-directional over-current relay, except it has directionalizing element, which is known as torque control. This element permits the directional relay to operate only when the fault occurs within its zone of protection, not outside of its zone of protection, where this refers to the zone behind the relay. Directional relay senses direction of power flow by means of phase angle between voltage and current. When the phase angle exceeds certain predetermined value, relay with one condition in which the current is above its pickup value. Hence, directional relay is a double actuating quantity relay with one input as current from CT and voltage from VT.

In this project, it is proposed that MLNG SATU and MLNG DUA to use digital protective relays instead of electromechanical protective relays as power system protection due to high reliability and better performance of digital protective relays in minimizing the disturbances occurred in the power system. This project demonstrates the use of modeling and simulation tools to develop a protective relay model; hence, for simplicity this project will focus on modeling and testing of directional over-current protective relay in MLNG low voltage three phase power system. The methodology for designing and validating the model of directional over-current protective relay is described. Directional over-current protective relay is developed using a simulation tool. The operation of proposed protective relay model is tested in a simple power system during a normal condition and when a fault is applied to the transmission line. Simulation results prove that the proposed directional over-current protective relay model is successfully modeled, simulated and tested. The performance of the proposed relay model is then compared with IEC 255-3 standard. This modeling and simulation could actually help engineers to understand better how the proposed protective relay model behaves during normal condition and when fault occurs in the power system.

1.2 Problem Statement

Majority of the protective relays employed in the power system of MLNG SATU and MLNG DUA are still electromechanical protective relays. There are a few drawbacks of using electromechanical protective relays in the power system as listed below:

i. The performance of electromechanical protective relays is not so reliable. Electromechanical protective relays work on the principle of a mechanical force generated due to the current flow in a coil wound on a magnetic core. It is difficult to determine the life validity of protective relays. Only regular checkups on the protective relays give confident assurance that they will operate when it is supposed to, since they are most of the time idle components in their operational life.

ii. There is no data of operation of the protective relays recorded. The only indication of electromechanical relay being tripped is that the flag will become visible as it falls down from its original position. The signals generated by the relays are analogue. Hence, it is problematic for the working personnel to monitor the event of the operation of the relays. It is even more difficult for working personnel to analyze the fault when one occurs.

iii. Electromechanical protective relays have a lot of mechanical parts, such as moving coils, spring and contacts. This type of protective relay is subjected to wear and tear after a period of time as these mechanical parts may be clogged with dirt and dust or corroded due to the environmental condition, which would greatly affect the operation of the protective relays.

iv. As electromechanical protective relays have a lot of mechanical parts which are fragile and delicate, a skilful maintenance personnel is required in maintaining the protective relays. Some invasive actions such as adjustment of the springs and burnishing of the contacts need to be carefully done otherwise these parts would get damaged.

v. Electromechanical protective relays always require periodical maintenance and adjustment. They were checked regularly in intervals of at least once per year. This labor-intensive maintenance process comprises visual inspection, testing, recalibration, repair and refurbishing to an as new component if needed. These regular periodical checkups would cost the company a high maintenance fee.

1.3 Objectives

Basically, this project concentrates on analysing the behaviour of digital directional over-current protective relays in 415V three phase power system of MLNG during normal condition and when fault is applied to the power system. Hence, the objectives of this final year project are:

i. To model digital directional over-current protective relay using simulation technique;
ii. To analyse the behaviour and operation of directional over-current protective relay when fault is applied at the different locations of the designed power system;
iii. To validate the accuracy of the proposed relay model by comparing the performance of the directional over-current with IEC 255-3 standard.

1.4 Scope of Study

The main scope of this project consists of research, modelling, simulation and analysis results. The research work done in this project helps the author to understand the operation theories of digital protective relays and electromechanical protective relays. The evolution of technology in protective relay shifts from electromechanical era to digital era over the past few years is observed. The knowledge and understanding gained from the research work is applied in designing and modelling a virtual over-current protective relays in a simple power system using a simulation tool – MATLAB Simulink. The proposed model of directional over-current protective relay is tested in the power system and its operation during normal condition and when a fault is applied to the transmission line are observed and analysed. The fault is then applied to different locations on the transmission line. With this, the performance of both directional over-current protective relays can be observed and compared. The performance of the proposed over-current protective relay will be compared with IEC 255-3 standard.

CHAPTER 2
LITERATURE REVIEW

Defined by IEEE [4], relay is “an electric device that is designed to interpret input condition in a prescribed manner, and; after specified conditions are met, to respond to cause contact operation or similar abrupt changes in associated electric control circuits.” Meanwhile, IEEE [4] gives definition of protective relay as “a relay whose function is to detect defective lines or apparatus or other power conditions of an abnormal or dangerous nature and to initiate appropriate control circuit action.

2.1 Functions of Protective Relay in Power System

Given the scenario of power system in any electrical power plant or processing plant, the first impression that would come across the minds of most people would be the huge generators, massive motors, transformers, high voltage power cables, etc. Behind all these impressive components in plants, there are many other small yet crucial devices such as circuit breakers and fuses which play equally important roles in the power system. Protective relays are one of them.

[5] There are three main essences of power system: generating, transmission and distribution systems must be protected well against damage. In any power electrical plant or processing plant, smooth production and profit are highly prioritized, since an enormous amount of money is invested in buying and maintaining the electrical

equipment. Therefore, it is essential to take necessary measures to run it at peak efficiency in generating and transmitting electrical power apart from protecting it from any damage. Unfortunately, a certain number of accidents are unavoidable and unforeseen, such as deteriorated insulation, strokes of lightning or entry of large insects or animals like birds into the equipment. When such accident occurs, it is deemed to affect the production capacity and loss of revenue due to the shutdown of the damaged equipment. The failure of the electrical equipment would also incur expensive repair cost, as the damage is caused by extremely massive amount of electrical energy when short circuit or any abnormal conditions take place.

To keep the power system to operate continuously without any major breakdowns and unnecessary downtime, protective relays are employed to minimize the immediate effect of an electrical failure on the equipment, other than isolating the faulty element from the whole power system to avoid any interruption to the service. Protective relays also help recognize and locate faults by measuring the changes in electrical quantities of the system constantly. These values are in general different from its normal condition or in relation to another quantity. The basic electrical quantities of the system which are being compared usually are current, voltage, phase-angle (direction) and frequency. The common measured electrical quantity in most of the protective relays is the current entering the protected section. For an example, the protective relay may operate by comparing the current with a standard bias, or with the quantity of the current leaving the protected circuit. When short circuit or abnormal condition occurs, protective relays locate the fault immediately and trip the corresponding circuit breakers to isolate the faulty circuit. Such data gathered not only assist in expediting repair and identifying the type of failure, but also by comparing oscillograph record with personnel observation, the effectiveness of the fault prevention and mitigation features can be analyzed accordingly. Hence, in this context, the reliability, speed and selectivity of the protective relays are highly concerned.

[6] There are two set of protective relays usually used, namely primary and back-up relays. Sometimes, they are also respectively known as main and reserve relays. The primary relays operate as the first line of defense which clear faults in the protected section of the whole power system as quick as possible. Meanwhile, back- up relay will only operate on the condition when primary relay fails to operate or fails to clear the fault completely. Back-up relay usually have a longer time delay which is sufficient to permit the primary relay to operate. However, experience has shown that short circuit is preponderant type of power failure, which results in greater failure in the primary relay. Hence, back-up relay is an economically justifiable necessity in protecting the power system from any arising fault and abnormal conditions. Back-up relays normally when operate, not only protect the local section but also the adjoining section.

[7] Protective relays play their role only when there are faults in the power system. They generally do not operate when the power system is stable and normal. When faults occur, protective relay would cut off the power supply to the faulty part of the system, isolating the faulty part from the whole power system structure. This in turn would affect the whole operation of the power system. There are two sytem cut-off or relay-trip conditions, which can cause very significant losses: fail-to-trip and malfunction-trip. Fail-to-trip would affect the fault-involved equipment to remain in the critical conditions for too long, damaging the equipment either in short time or long time. Meanwhile, malfunction-trip cut off the healthy equipment from the power system, causing unnecessary downtime to the plant.

2.2 The evolution of Protective Relays

Protective relays have been used for the purpose of protection from the beginning of electrical and electronic industry, and since then, early solenoids and electromagnetic protective relays have transformed with time. They evolved to become a more accepted devices such as numerical and digital relays since the power systems have become more complex. The numerical and digital relays are sophisticated devices with capacity to record signals during abnormal conditions, monitor themselves and communicate with the other relays.

[8] Electromechanical protective relays work on the principle of mechanical force generated due to the current flow in a coil wound on a magnetic core. This force would cause the state of its contact to change, which is usually from normally closed to open condition. Most of electromechanical relays are provided with a control spring, though there are a few being re-strained by gravity, so that a de-energized state would be assume as initial state. When a current passes through magnetic core inside, a magnetic field is produced to attract the moving core. The electromagnet coil draws more current initially, until its inductance increases when the metal core enters a coil. The moving contact is propelled by the moving core; the force developed by the electromagnet holds the moving and fixed contacts together. When a high load current flow into the coil, the electromechanical relay will energize, causing the contact inside to open. This is when the relay is tripped.

[9] Digital protective relay has analog-to-digital converter to sample the analog signals coming from the transformer and other equipment, and use microprocessor to define the logic of the relay. Digital protective relays if compared to electromagnetic protective relays, show an improvement in terms of accuracy and control over incoming signals, use of more complex algorithms and extra functions in one unit. With current technology developed, the performance of relays can be simulated using computer-based-relay to appear either to operate incorrectly or fail to operate when fault occurs, instead of using the real model. With this simulation, engineers and consultants will be able to confirm the performance of the relay during system disturbances and normal operating conditions to make necessary corrective actions on the relay setting.

2.3 Protective Relay Modeling

As per discussed by Gulski, Effendi, Smit and Roger [10], FMEA method had been employed to document the evaluation of failure behavior of an electromagnetic over-current protective relay. Critical analysis had been carried out to focus on the critical failure mode of the protective relay, which would result in possible failure modes and causes of failure of the protective relays. The failure effects would explain how the failure mode upset the operation of the relay, in which each of the effects can be assigned to general categories. This categorization is useful when evaluating the performance of the protective relays.

Meanwhile, Hor, Crossley, Kangvansaichol and Shafiu [11] discuss that the blackouts in West USA which have cost a lump sum of money are related to failure of protection system. The protective relays which are supposed to clear non-catastrophic disturbance have failed to operate and allowed the disturbances to propagate through a wider area network and consequentially result in widespread blackouts and cascading trips. They describe that modeling and simulation of protective relays can help to understand the behaviour of the proposed relays during a fault and non-fault disturbance occur. Simulation of instantaneous over-current protective relay developed using FORTRAN in PSCAD/EMTDC would be helpful to engineers in protection study. Such understanding of the protective relay would help improve the quality of design and correct any weakness of the relay before applying it to an actual power system.

Zhang, Bastos, Schulz and Patel [12] develop digital instantaneous over-current protective relay by using two software tools, namely MATLAB Simulink and VTB. The model is designed for terrestrial and SPS since there are increased fault vulnerability and lack of electrical ground in the system. The proposed relay model has been tested for fault condition in a simple power system developed using MATLAB Simulink and the same test is repeated using VTB. The simulation test results prove that the proposed over-current relay modeled using the software tools is a success.

Additionally, Goh, Agileswari, Farrukh and Aidil [13] conducted two methods to simulate an over-current protective relay. Firstly, a simulation of an over-current protective relay using MATLAB Simulink is done, and it is downloaded into a high speed and high performance DSP TMS320F2812. In second method, they describe that code in C is written directly on DSP to represent the relay. The built relay performance would then be compared with IEC 255-3 standard.

Therefore, it is possible to model a directional over-current protective relay using simulation technique, which is MATLAB Simulink. Its performance can also be evaluated by testing the model in a three phase low voltage power system during normal condition and during fault occurs.

CHAPTER 3

METHODOLOGY

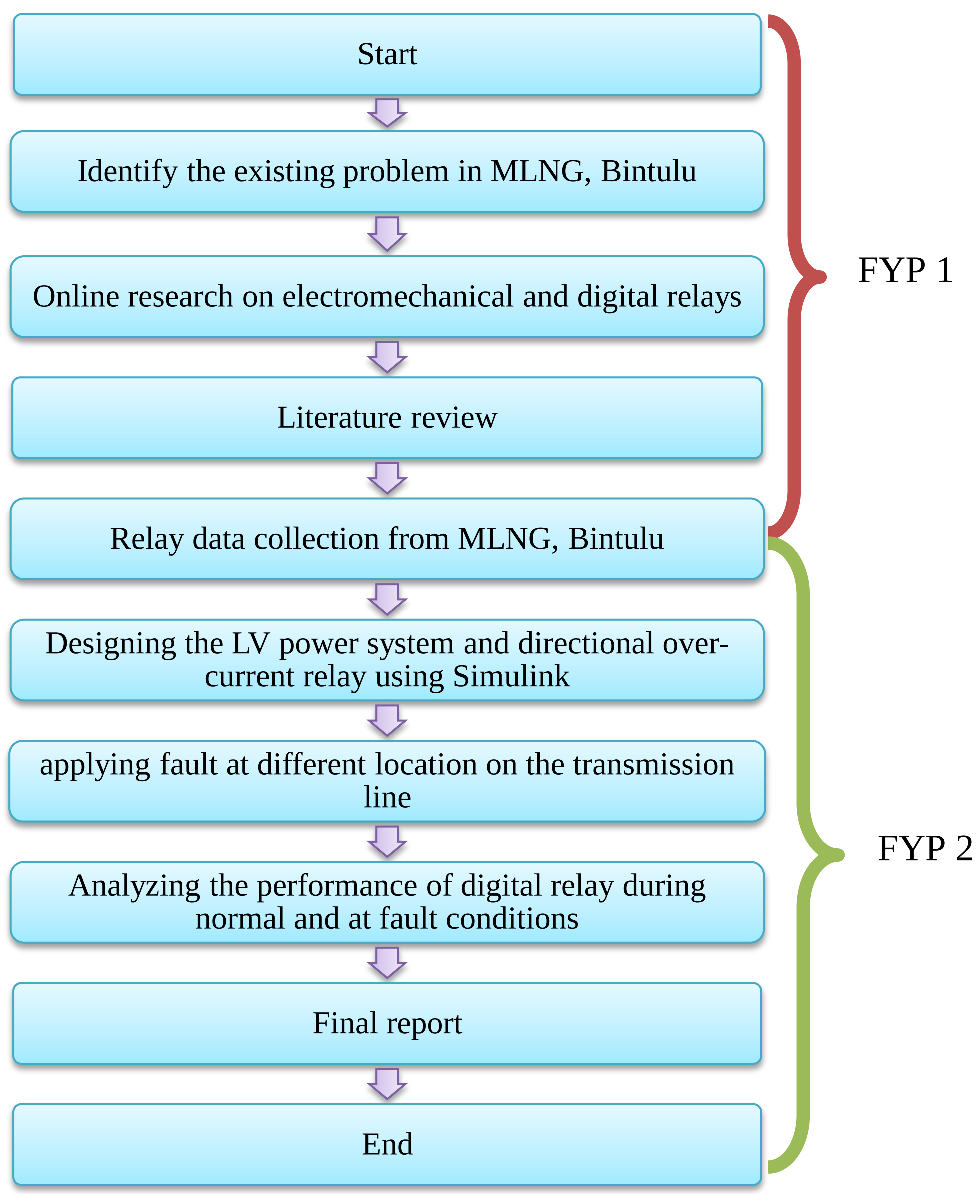

Figure 1: Project Activities Flow

As illustrated by Figure 1, the project title was started since the undertaking of FYP 1. After discussion with supervisor, it was decided to do a project related to protective relays since the author had done industrial project titled “Protective Relay Database” during the period of internship training in MLNG. Existing problem related to protective relay in MLNG was identified. The focus of the project was narrowed down to directional over-current protective relay, since there are a lot of protective relays used in the power system of MLNG. Once the topic of the project was confirmed, online research was conducted to gain a better understanding of operating principle of electromechanical protective relays and digital protective relays. Technical papers and reports being published online have been reviewed to obtain knowledge on implementation of this project. Work done by the published author is compared with the proposed work to check on the validity of the proposed work and to verify that the proposed work has not been done before. Review on the published papers helps the author to acquire ideas to carry out the project.

The data of over-current protective relay is collected with the aid of Testing Section, Electrical Engineering Department of MLNG. Consent to utilize the recorded data for the purpose of this project has been obtained in advance through an officer Mr Shazrizal Bakar, who was formerly a project manager of the industrial project taken by the author, and also previously was the Section Head for Testing Section. The progress of data collection was slow since during that period of time, MLNG staffs were busy with plant shutdown activities. After that, directional over-current protective relay is modeled using MATLAB Simulink, where [14] models simulated by Muhammad Mohsin Aman, Muhammad Qadeer Ahmed Khan as in Matlab Central webpage were referred. A simple low voltage three phase power system is developed in order to test the operation of the over-current protective relay model during no-fault condition and during faulty condition. The fault is applied at different locations on the transmission line. The performance of both the protective relays in both conditions is analyzed and compared. The performance of proposed relay model is compared against IEC 255-3 standard [15] to validate the accuracy of the relay.

3.1 Modeling of Simple 415V power system:

The development of the power system to test the model of directional over-current protective relay using MATLAB Simulink is guided by the following algorithm flow chart as shown in the Figure 2:

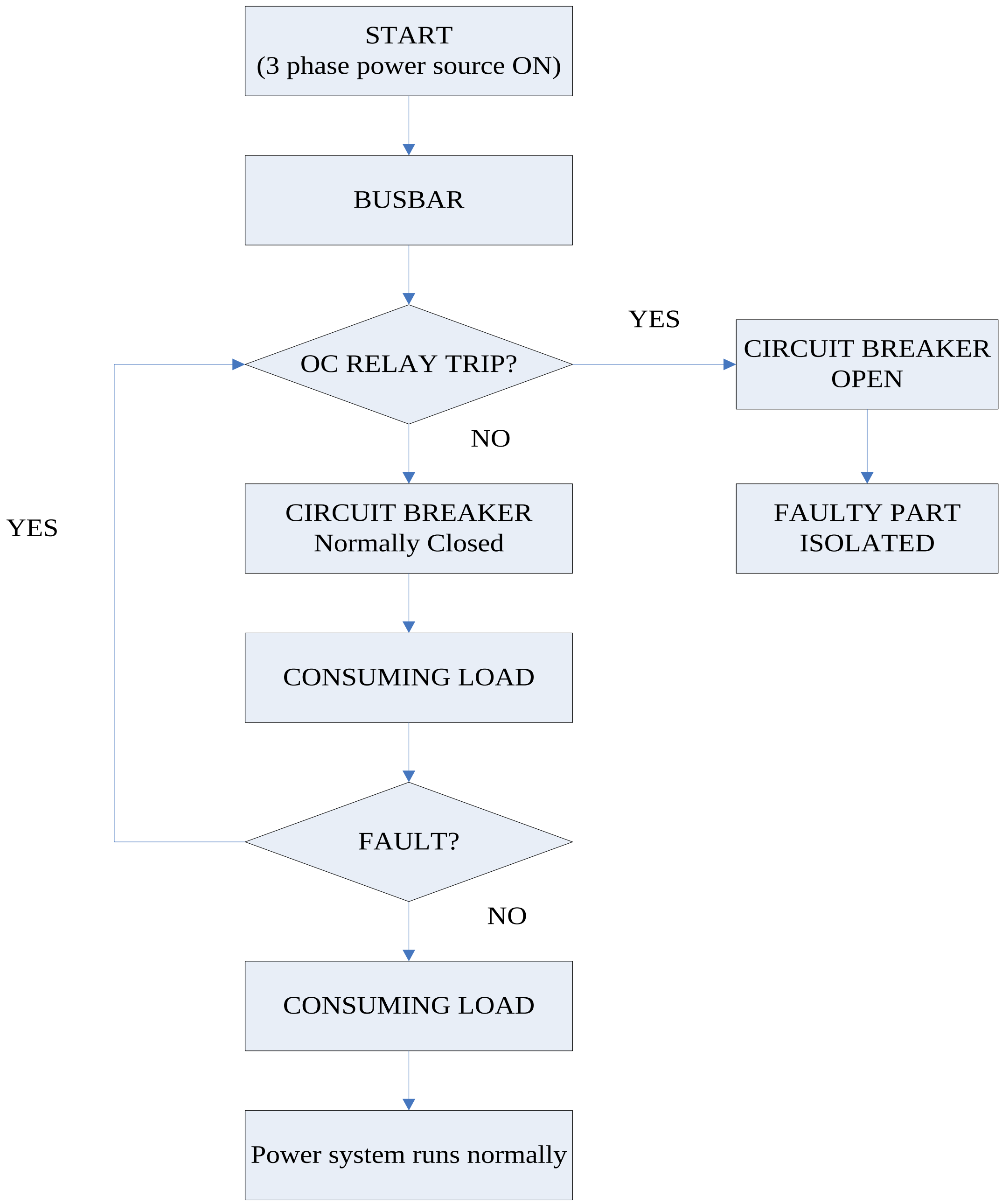

Figure 2: Flowchart for simple power system to test the relay model

3.2 Modeling of directional over-current protective relay:

The algorithm for development of the proposed directional over-current protective relay using MATLAB Simulink would be as follows:

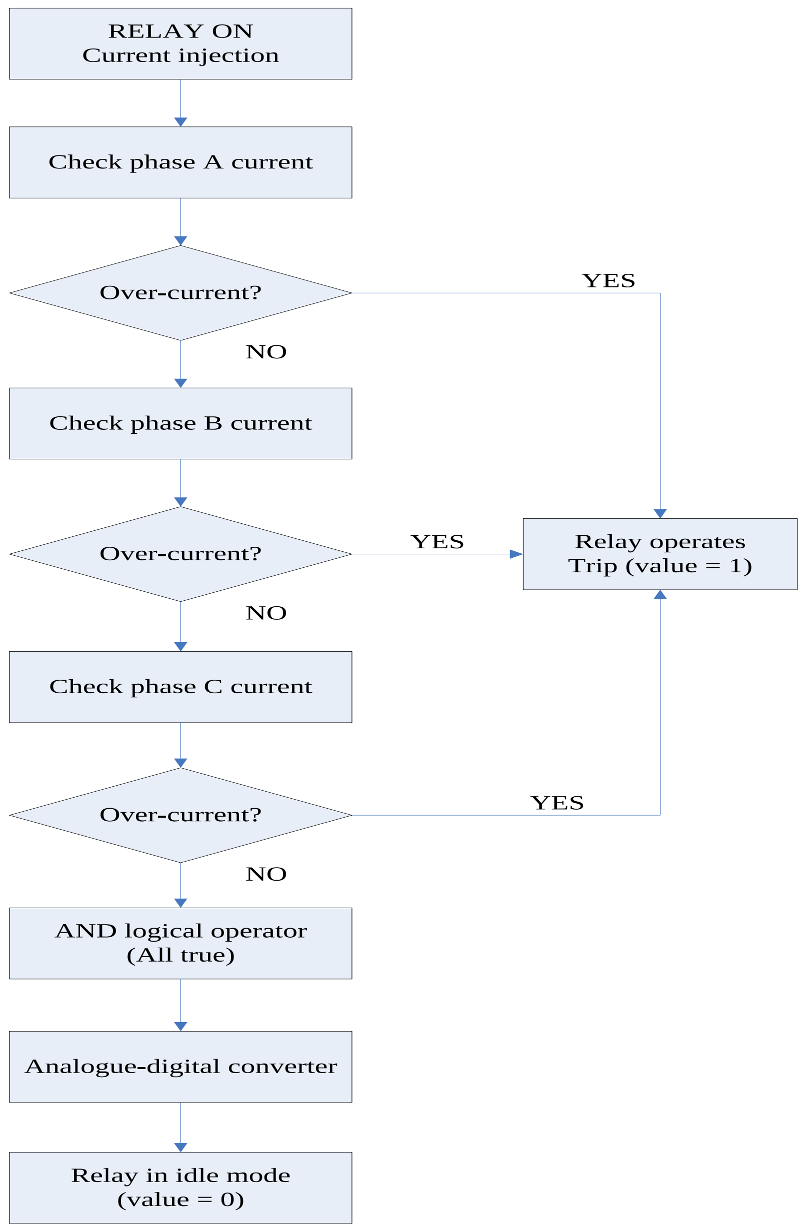

Figure 3: Flowchart for over-current relay model

3.3 Gantt Chart and Milestone Activities:

- See appendix.

CHAPTER 4
RESULT AND DISCUSSION

By using MATLAB Simulink, a simple 415V power system is developed and a model of directional over-current protective relay is built.

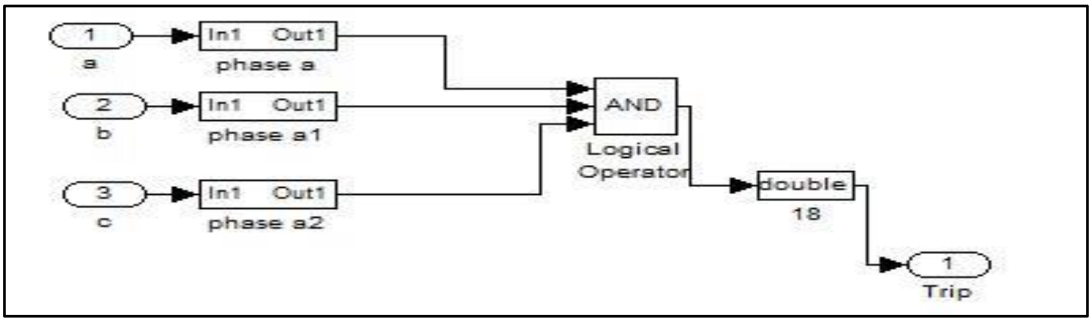

Figure 4: directional over-current relay model

Based on the figure above, ln 1 Out 1 functional block is a subsystem, where current signal is intergrated to as output 1. The three phases of current are connected to AND logical operator, where the input must all be TRUE (value = 1). Using the data type conversion functional block, the analogue signal is converted to digital signal. Note that over-current protective relay will only operate when there is disturbance occurs within its zone of protection. In the figure, the operation of the protective relay is in idle mode (set value = 1). The relay will only trip when the integrated signal of the current in any phase equals to 0, disabling the operation of AND operator, and this will send the signal to circuit breaker to open contact, cutting off the faulty part from the whole power system when a disturbance occurs.

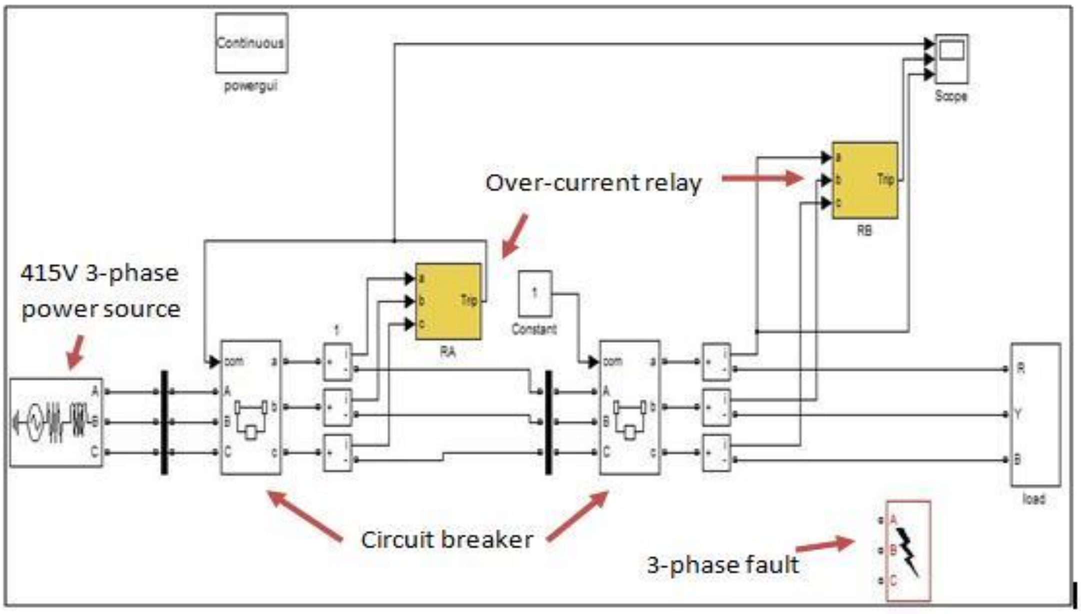

Figure 5: A simple 415V 3-phase power system (no fault applied)

Figure 5 above shows a simple 415V 3-phase power system with two directional over-current protective relays to safeguard the power system. The power is delivered through the transmission lines to busbar, where circuit breaker is connected in between. The last block in the figure is a 110kW consuming load with power factor of 0.85 lagging. Directional over-current protective relay is connected to the circuit breaker, and the current stepped down by CT is being fed as its input. The figures below are the setup of the 415V 3-phase power supply, followed by the setup of the circuit breaker:

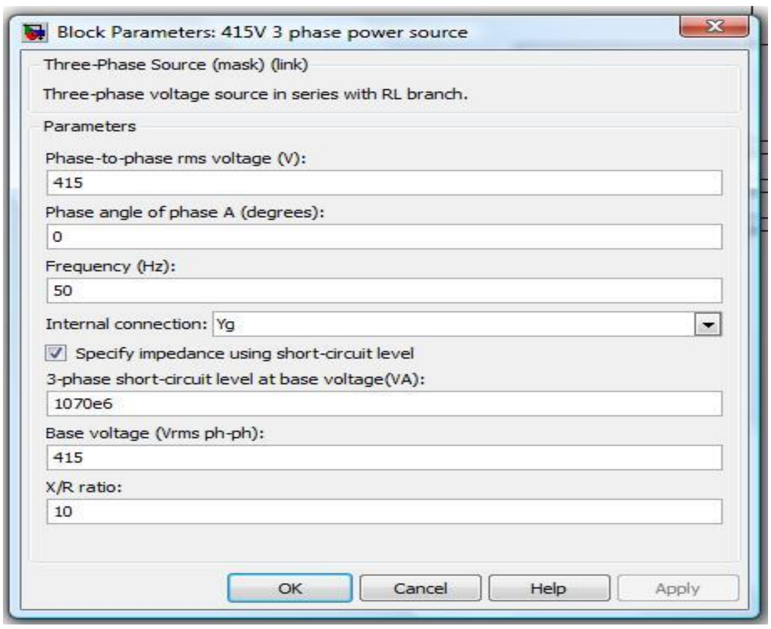

Figure 6: 415V 3 phase power supply setup

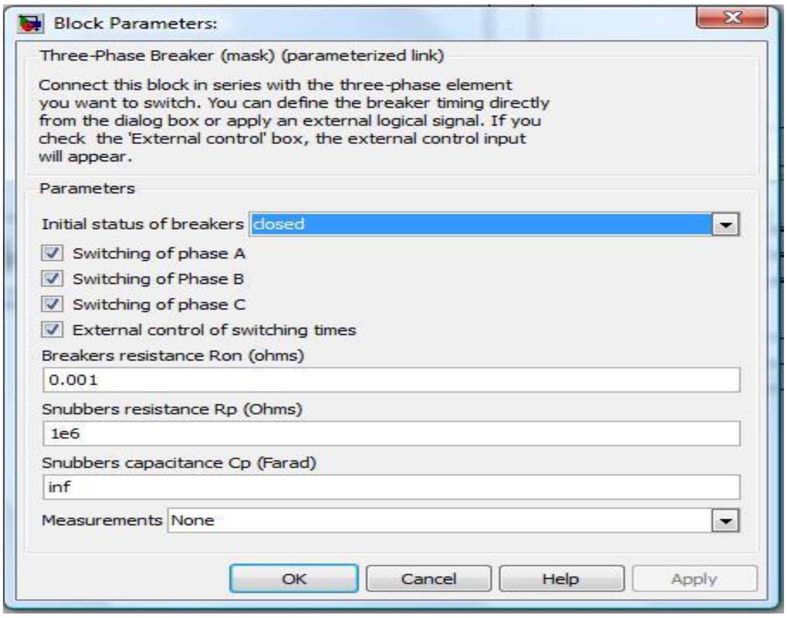

Figure 7: Circuit Breaker setup

During the simulation of the simple power system during normal condition, the following simulation result is obtained:

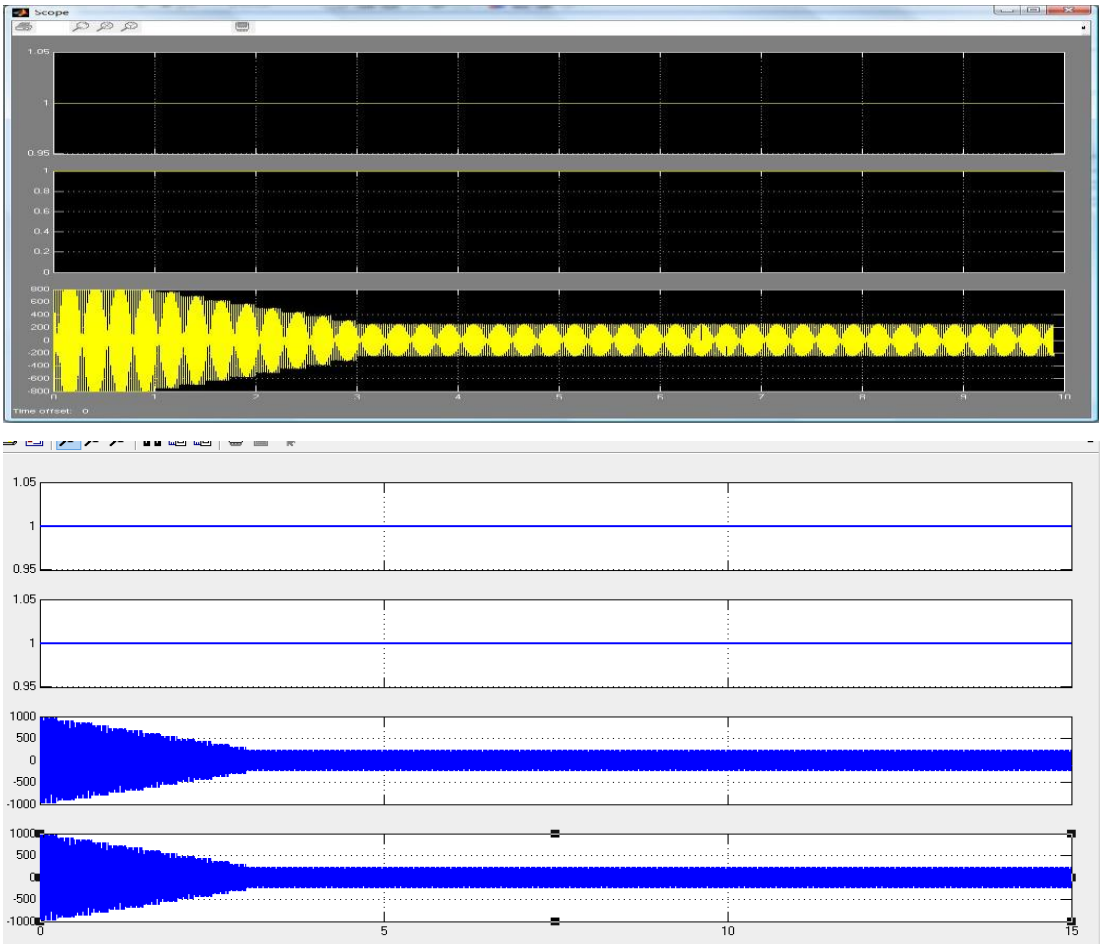

Figure 8: Simulation result of no fault power system

As seen in Figure 8, the first and second scope displays represent both directional over-current protective relays RA and RB. Both of them have a constant 1 as the output, which means they are in idle operating mode. From the third scope display, at the initial simulation time, there is a large amplitude of current flows into the power system. This large amplitude of current decreases and starts stabilizing to a constant waveform at around 3 seconds. This large amplitude of current is known as inrush current, which during the start-up of all the electrical consuming loads simultaneously, a several times of normal full load current is drawn when they are first energized, for a few cycles of the waveform.

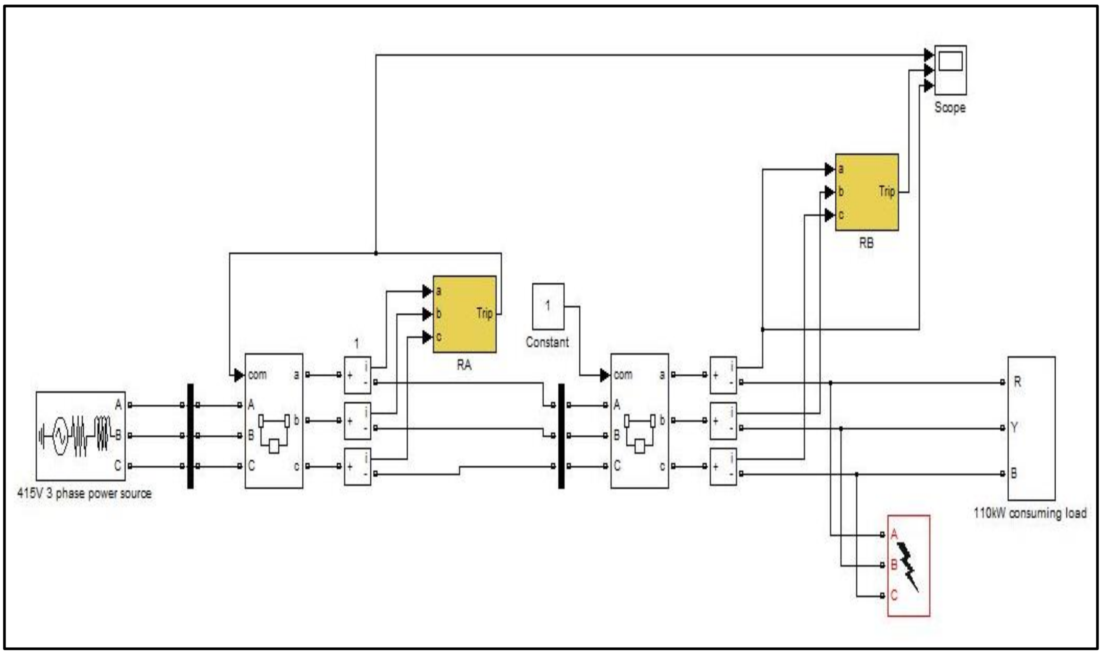

Figure 9: 415V 3 phase power system with fault applied

Figure above shows the power system with fault applied near to the consuming loads. The behaviour of both directional over-current protective relays are observed. The current waveform at phase A connected to second over-current relay RB is also observed when the fault is applied at 6^{th} seconds.

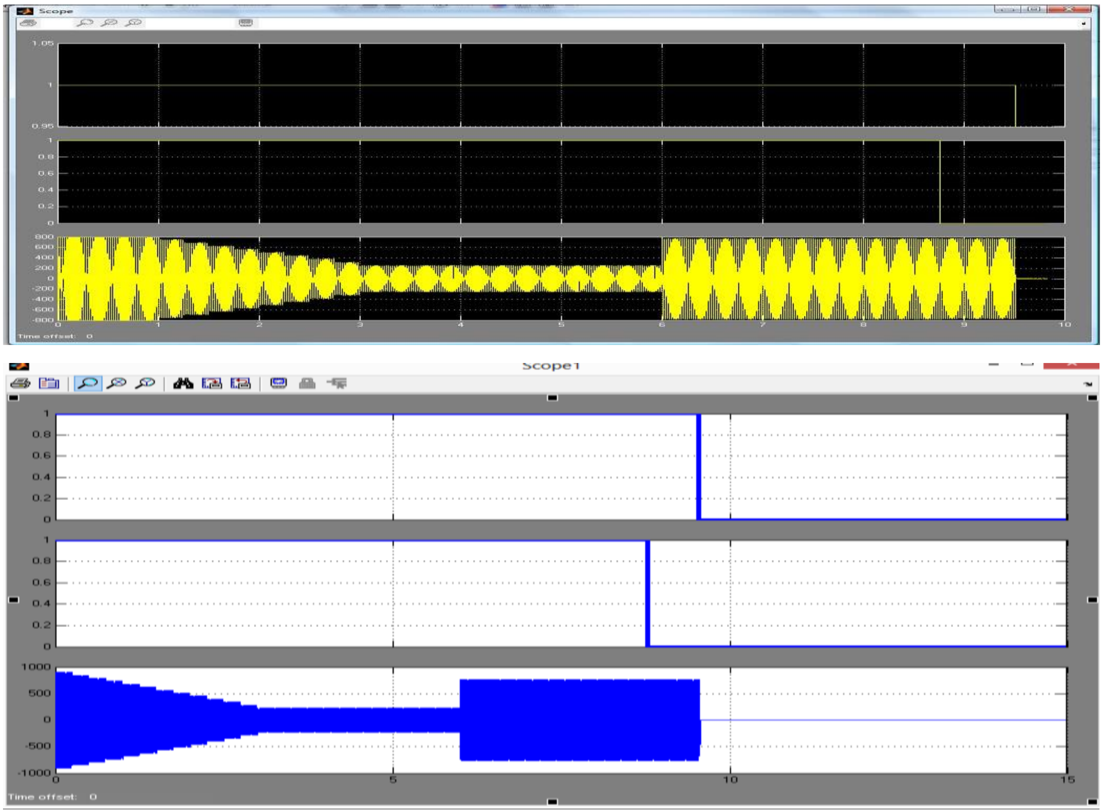

Figure 10: Simulation from scope when fault is applied

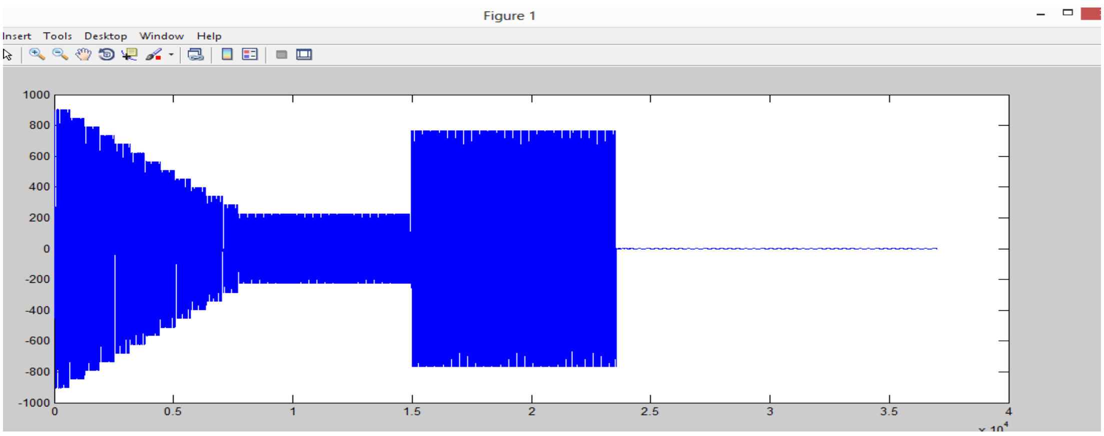

Figure 11: plot when fault is applied (from workspace)

From the simulation above, we can notice that both directional over-current protective relays trip. The fault is applied at 6th second. Constant current waveform changes drastically into large amplitude of current for a few seconds before it is being cut off – returning to 0 A. There is a delay observed in the operation of the second over-current relay, where it changes from 1 to 0 value at 8.8 second. There is a delay of about 2.2 second after the fault is being applied as an allowance time for the relay to recognize and differentiate overload current and inrush current. The first over-current relay RA trips at around 9.5 second as double protection to the power system, since the overload current does not return to zero value after relay RB trips. The overload current caused by the fault immediately return to zero value after relay RA trips since the first relay RA sends signal to circuit breaker to cut off the power supply from the system.

When another scope display is connected to the input current of first relay RA, we can notice that when fault is applied to the power system, the input current is affected and resulted in the same current waveform as input current of second relay RB. The input current waveform of first relay RA is represented by the third scope display while the fourth scope display represents input current waveform of second relay RB.

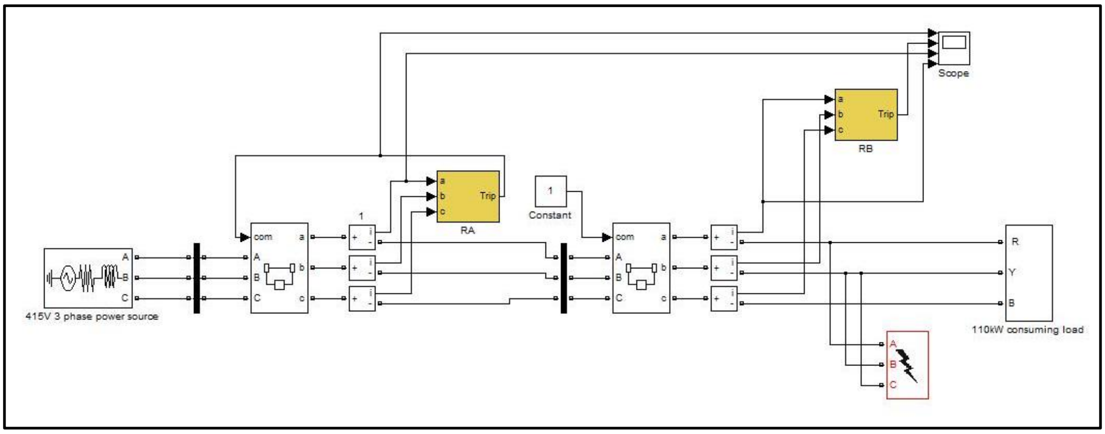

Figure 12: Four-scope display of faulty power system

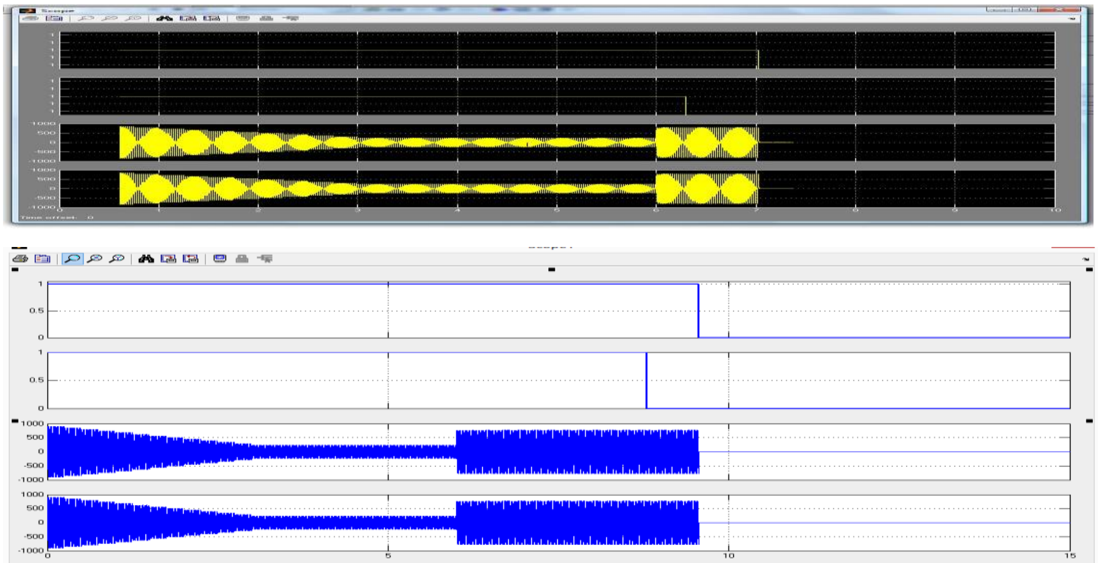

Figure 13: Comparison of input current between two relay models when fault is applied

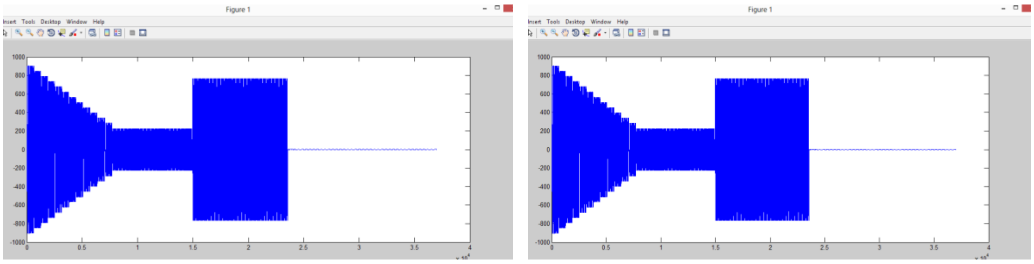

Figure 14: comparison of the current at two different transmission line when fault is applied (from the workspace)

When fault is applied at a different location in the power system, the input current waveforms of both protective relays are observed.

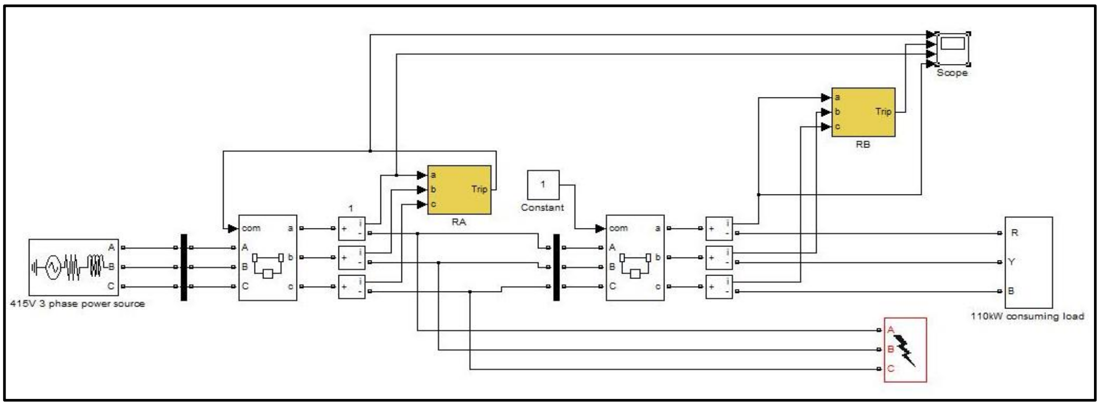

Figure 15: Fault is applied at different location

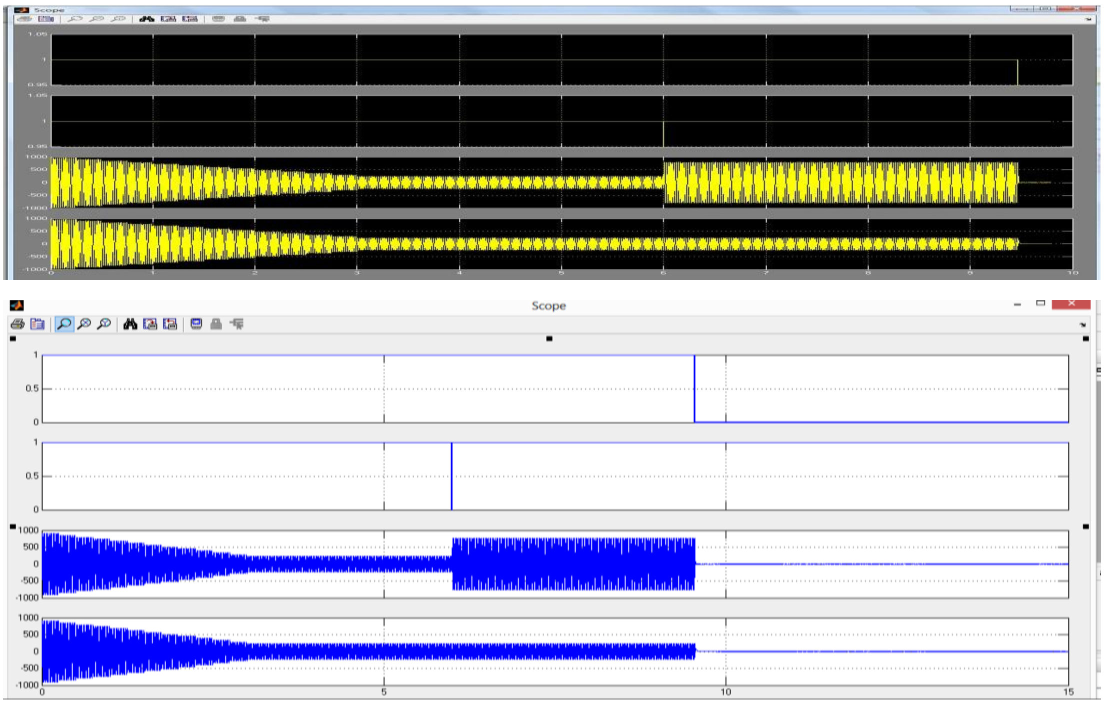

Figure 16: Simulation result of power system with fault at different transmission line

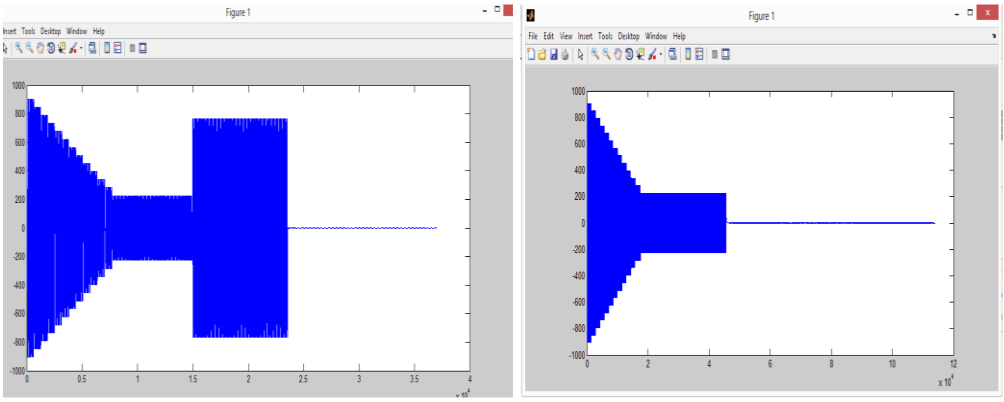

Figure 17: comparison of current when fault is applied at first transmission line (from workspace)

When the fault is applied to transmission line near to first relay RA, the above simulated waveforms are obtained. The first scope display denotes the behaviour of the first relay RA; second scope display is the behaviour of the second relay RB; third scope display represents the input current phase A waveform of first relay and lastly the fourth one represent the input current phase A waveform of the second relay. It is observed that the input current of second relay displays a normal waveform after inrush current but the input current of first relay shows an overload current occurs at 6^{th} second. The second relay almost trips due to the overload current but immediately returns to value of 1 instantaneously. It is deduced that the second directional over-current relay behaves in such a way since the fault is applied in front of it. In this case, it acts like a back-up relay for first relay RA while first relay RA is the primary protective relay in the zone the fault is applied. It displays an instantaneous drop but returns to idle mode since primary relay RA has not yet sent signal to the first circuit breaker to open contact. There is no need for second relay to trip if primary relay RA is successfully tripped, because the contact of the first circuit breaker will open, cutting off the power supply from the whole system. Second relay RB will only operate when there is still overload current disturbance in the power system after first relay RA is tripped. This is to ensure that the disturbance does not spread to part of the power system behind the fault.

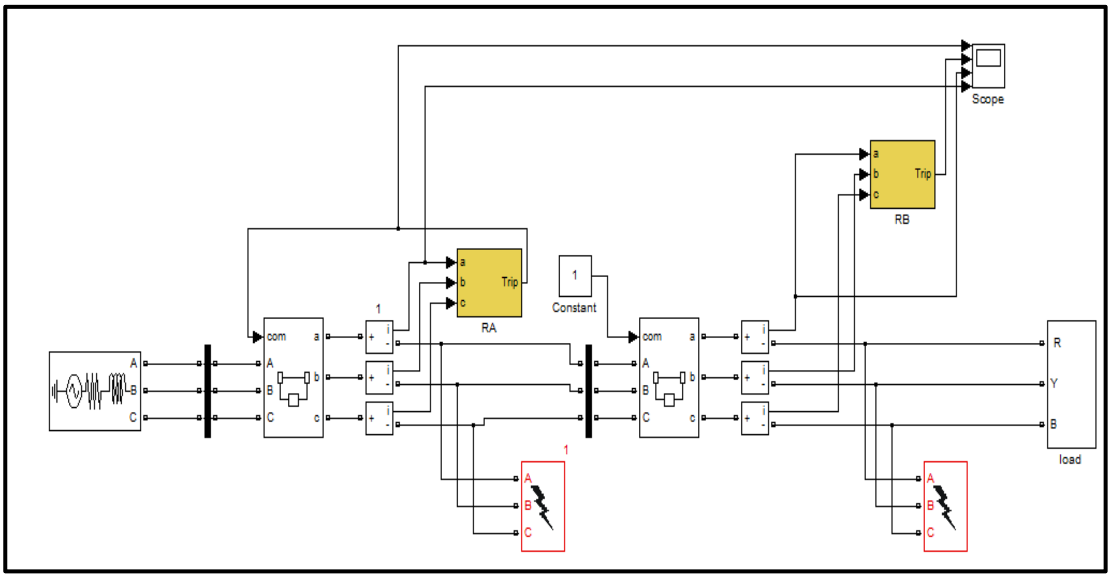

Figure 18: Two faults applied to two transmission lines

The behavior of the over-current protective relays is also observed when two faults are applied to the whole power system simultaneously at two different transmission lines. The simulation result is as illustrated in the following Figure 16:

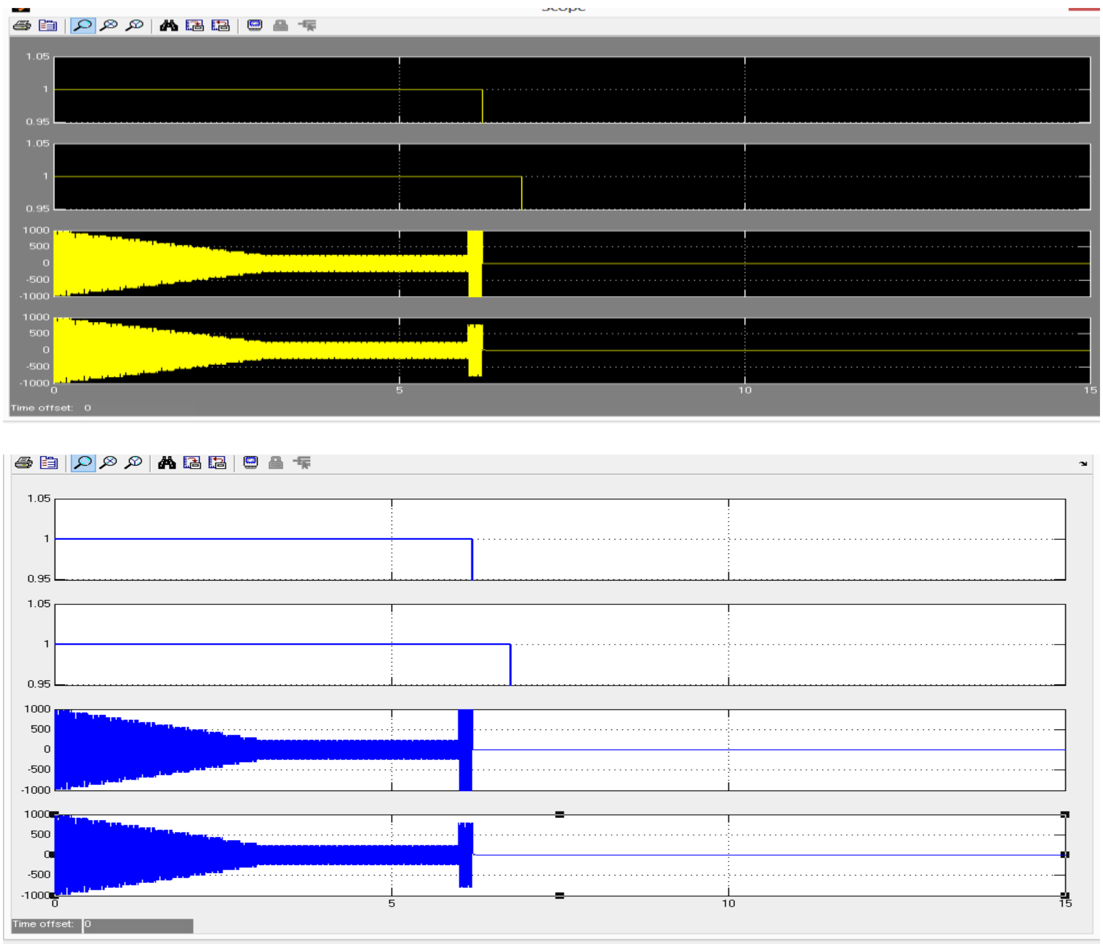

Figure 19: Simulation result of two fault applied to the transmission lines

The scope displays shows that both over-current relays trips at the same time when the two faults are applied at two transmission lines. Just as the previous case, the current waveform started with a very high magnitude due to the in-rush current for a few cycles before reaching stable state. When the first over-current protective relay detect fault at the first transmission line, it operates by sending the signal to open the circuit breaker, thus isolating the whole power system from the power supply. As observed, the current waveforms for both parts of the power system display an overload current at 6th second, since faults are applied simultaneously at both parts. The second relay trips after awhile as it acts as the back-up relay for the first relay in case there is any eddy current in the circuit, which can damage the second part of the power system as fault spreads very quickly.

The work of comparing the performance of this proposed directional over-current protective relay with IEC 255-3 standard [13] is done. In this way, the accuracy of the proposed over-curent protective relay can be validated. The data of the characteristic curve are acquired from the MiCOM P122 technical manual [15]. According to IEC 255-3 Standard, the over-current relay in terms of IDMT characteristic can be represented as in Eq. 1:

$$t = \left(L + \frac{K}{(\frac{I}{I_S})^{\alpha} - 1}\right) \times TMS \qquad (1)$$

Relay Characteristic Curve	K factor	α factor	L factor
Short time inverse	0.05	0.04	0
Standard inverse	0.14	0.02	0
Very inverse	13.5	1	0
Extremely inverse	80	2	0
Long time inverse	120	1	0

Table 1: Parameter of different type of Inverse Curve Characteristic

In order to calculate the operation time, the RMS value of the input current must be computed. The result will be displayed in the table below using Eq. 2:

$$I_{RMS} = \frac{I}{\sqrt{2}} \quad (2)$$

Input current (A)	RMS current value (A)	Ratio of current	Operation time (s)		Percentage error (%)
			IEC standard calculation	Simulation on MATLAB/ Simulink	
30.00	21.213	0.424	-	-	-
50.00	35.355	0.707	-	-	-
70.00	49.497	0.989	-	-	-
70.71	**50.000**	**1.000**	**-**	**-**	**-**
71.00	50.204	1.004	337.50	337.500000	0.000
77.78	55.000	1.100	13.50	13.500000	0.000
90.00	63.640	1.272	4.96	4.963235	0.065
100.00	70.711	1.414	3.26	3.260869	0.027

Table 2: Operation time calculation of over-current relay for very inverse curve

Input current (A)	RMS current value (A)	Ratio of current	Operation time (s)		Percentage error (%)
			IEC standard calculation	Simulation on MATLAB/ Simulink	
30.00	21.213	0.424	-	-	-
50.00	35.355	0.707	-	-	-
70.00	49.497	0.989	-	-	-
70.71	**50.000**	**1.000**	**-**	**-**	**-**
71.00	50.204	1.004	175.34	175.342767	0.0016
77.78	55.000	1.100	7.34	7.337443	0.0348
90.00	63.640	1.272	2.90	2.902514	0.0867
100.00	70.711	1.414	2.01	2.013662	0.1822

Table 3: Operation time calculation of over-current relay for standard inverse curve

Different inputs of current are applied to the over-current relay in order to investigate the accuracy of the operation time of the proposed over-current relay model. For the calculation, TMS is set to be 0.1, and I_s is set to be 50A, since this is the set-point used in MLNG Bintulu. The operation time of the relay is computed by using IEC standard for very inverse curve and MATLAB/Simulink. In this case, very inverse and standard inverse characteristic curves are chosen for the calculation since most of the over-current protective relays employed in MLNG Bintulu adhere to these characteristic curves. The measured RMS current must be greater than pick-up value current otherwise the operation time of the over-current relay cannot be calculated.

The ratio of RMS current I_{RMS} and pick up current I_s assist to evaluate the whether the operation time of the over-current relay can be calculated or otherwise. From the tabulation of result for both very inverse characteristic curve and standard inverse characteristic curve, the operation time for the input current less than 50A (represented by input current 30A) is not valid as it is a negative value, as the ratio of the current is less than 1. As highlighted in the table, the operation time for input current 70.71A cannot be computed even though the ratio of the current is 1. This is due to the that the minimum guaranteed value of the operating current (input current) for all the curves with the inverse time characteristic must be $1.1I_s$, with a tolerance of $\pm 0.05I_s$[15]. From the observation, we can see that the operating time of the over-current to trip when there is fault occurs is rational, with at most the operating time is 7.34s, if compared to the operating time for input current71A is 175.34s. A very long time required for the over-current protective relay to trip is not desired since any delay for trip will cause the fault to spread wider to the other part of the power system, causing more equipment to be damaged and unnecessary downtime to the process plant. The comparison of the operation time calculated by MATLAB/Simulink and IEC Standard is made. The percentage error is very small, with at most 0.182%. Such small percentage of error hence validates the operation of this over-current proposed model is accurate.

CHAPTER 5
CONCLUSION & FUTURE WORK

5.1 Conclusion

As conclusion, digital protective relay has many advantages over the electromechanical protective relay. Demonstrated by the project done, the fault can be analyzed when one occurs in the power system. Modeling of relays is crucial for the reliable operation of the complex power system. It helps to evaluate the protection system performance during fault and during normal conditions. Modeling of relay using software or simulation tools also helps generate useful data that can be used to analyze the fault and understand what happened during the event of fault. With modeling of protective relay virtually, a better protection planning and more reliable power system design strategy can be guaranteed. In addition, modeling of protective relays aids in protection study and correcting any weakness of the relay before applying it to an actual power system network.

It is also learned that protective relays are employed to minimize the immediate effects of an electrical failure on the equipment, other than isolating the faulty element from the whole power system to avoid any interruptions to the service. Protective relays also help recognize and locate faults by measuring the changes in electrical quantities of the system constantly. When short circuit or abnormal condition occurs, protective relays locate the fault immediately and trip the corresponding circuit breakers to isolate the faulty circuit.

Directional over-current protective relay has a directionalizing element, which is also known as torque control. This element permits the directional relay to operate only when the fault occurs within its zone of protection, not outside of its zone of protection, where this refers to the zone behind the relay. When the level of fault current increases dramatically and exceeds the nominal load current, it is assumed that a fault has occurred and trip signal will be transmitted to circuit breaker to open contact and thus, isolating the faulty part of the system from the rest of the network.

5.2 Future Work

i. The analysis of directional over-current protective relays in a high voltage power system can be studied since this project only focus on the behaviour of the over-current relays in low voltage power system.
ii. Analysis of the directional over-current protective relay operated during faulty condition can be furthered since the result of the project is believed to be the mere fundamental understanding for study of the behaviour of protective relay.
iii. Study on the health of the protective relay can be conducted to investigate whether the protective relay is tripped due to fail-to-trip condition or malfunction-trip condition.
iv. Optimal coordination of over-current protective relay in an interconnected MLNG power system can be studied to improve the overall performance of the over-current protective relay.

REFENCES:

[1] Malaysia LNG Sdn Bhd. (n.d.). *About us: Malaysia LNG Sdn Bhd*. Retrieved March 2012, from Malaysia LNG Sdn Bhd website: http://www.mlng.com.

[2] Chen, W.-K. (2005). *The Electrical Engineering Handbook.* Elsevier Academic Press.

[3] answers.com. (n.d.). *Answers.com > Wiki Answers > Categories > Technology > Engineering > Electrical Engineering*. Retrieved November 2012, from wiki.answers.com: http://wiki.answers.com/Q/What_is_directional_protection_relay_and_how_is_it_works

[4] Taylor and Francis Group, LLC. (n.d.). Retrieved March 2012, from crcnetbase: www.crcnetbase.com/doi/abs/10.1201/9781420026412.bmatt

[5] Shell U.K. Exploration and Production Training Department. (n.d.). Retrieved May 2012, from Scribd.com: http://www.scribd.com/doc/51072044/Electrical-Protection

[6] Warrington. (n.d.). *Protective Relays: their theory and practice.* Kluwer.

[7] Wang, F. (2003). *Power Quality Disturbances and Protective Relays: Component Switching and Frequency Deviation.* Göteborg, Sweden.

[8] Electrical, Electronics Engineering Department of Chisholm Institute of TAFE. (n.d.). Test, repair and calibrate protection relays and meters. Berwick.

[9] Zamora, M. V. (n.d.). Power Quality and Digital Protection Relays.

[10] Gulski, E. S. (2007). Evaluation Of Faliure Behaviour Of Service Aged Electromagnetic Protective Relays. *19th International Conference on Electricity Distribution* (p. paper no 179). Vienna: CIRED.

[11] C.L.Hor, K. P. (2003). Relay Model for Protection Studies. *IEEE Bologna Power Tech Conference.* Italy: IEEE.

[12] Zhang, B. S. (2007). Modeling and Testing of Protection Devices for SPS using MATLAB/Simulink and VTB. *IEEE Journal*.

[13] Goh, A. F. (n.d.). Numerical Relay for Overcurrent Protection using TMS320F2812.

[14] Mohsin, Q. Q. (n.d.). *Matlab Central*. Retrieved from Mathworks.com: http://www.mathworks.com/matlabcentral/fileexchange/30533-overcurrent-relay-directional-non-directional

[15] Areva Corporation. (n.d.). Retrieved from Scribd.com website: http://www.scribd.com/doc/22980565/AREVA-Directional-Overcurrent-Relay-MiCOM-P12x-EN-TechData

[16] Apostolopoulos, K. (2008). *Real-time Implementation of Digital Relay Models Using MATLAB/SIMULINK and RTDS*. Retrieved November 2012, from Wiley InterScience: www.interscience.wiley.com

[17] GE digital energy. (n.d.). The Philopsophy of Protective Relaying.

[18] Hebb, L. (n.d.). Protective Relay Modernization Program Releases Latent Transmission Capacity. *AIEE District Conference Paper 55-354*.

[19] Hewiston, B. B. (n.d.). Pratical Power System Protection. Retrieved May 2012, from http://www.scribd.com/doc/19842363/Protection-LHewistonEtAlElsevier2004WW

[20] Kezunovic, L. (2005). AUTOMATED ANALYSIS OF PROTECTIVE RELAY DATA. *18th International Conference on Electricity Distribution*. Turin: CIRED.

[21] Kulkarni, C. (2007). MATLAB/SIMULINK Simulation Tool for Power System. *International Journal of Power System Operation and Energy Management,*, 34-38.

APPENDIX:

Activities/ task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title selection / proposal.														
Literature review of the article and journals related to the project.														
Extended proposal submission.														
Progress report, collecting data and related information on implementing the project.														
Proposal defense and progress evaluation.														
submission interim report.														

Table 4: Gantt Chart for FYP1

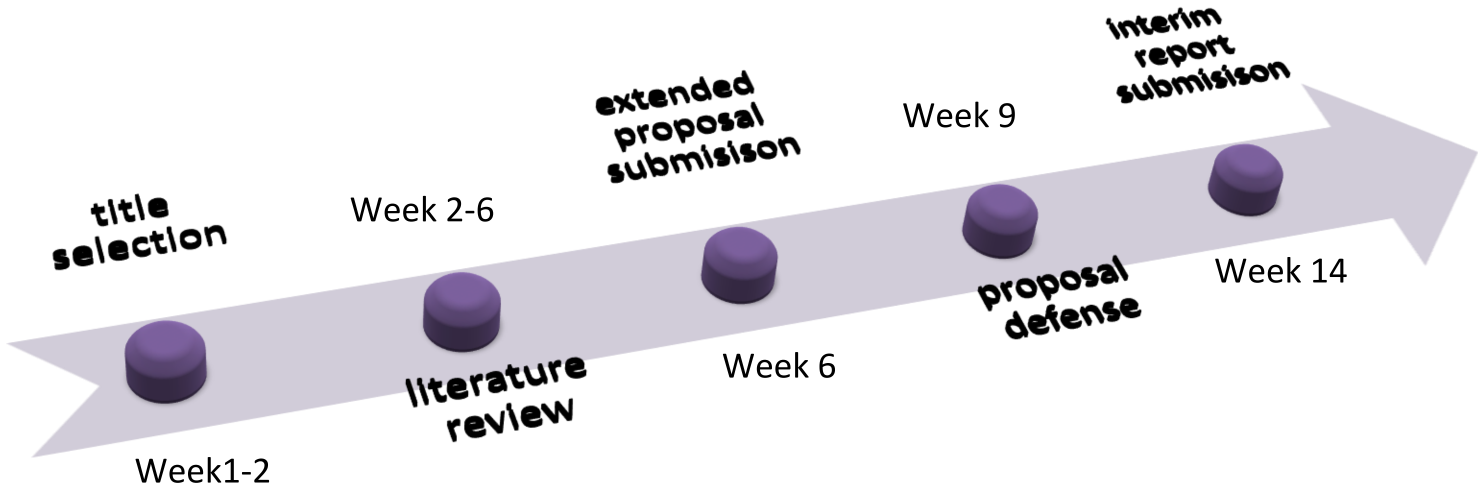

Figure 20: Milestone activities for FYP1

Activities/ task	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Collecting sufficient data for overcurrent relay from MLNG														
Working on MATLAB Simulink to develop proposed model and power system, debugging														
Progress report submission														
Submission of draft report														
Submission of Dissertation (softcopy)														
Submission of Technical Paper														
Oral presentation														
Submission of Hardbound Dissertation														

Table 5: Gantt Chart for FYP2

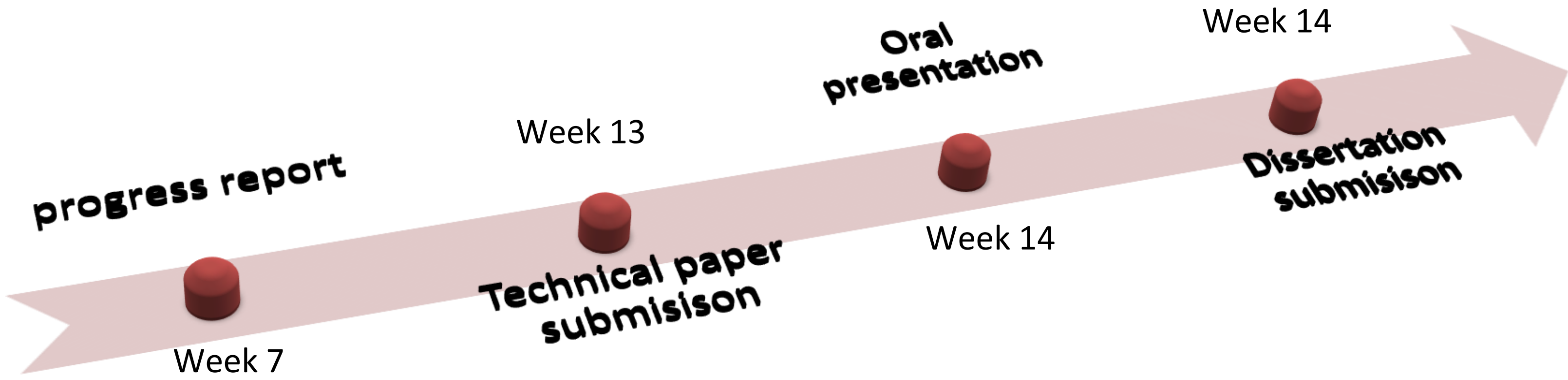

Figure 21: Milestone activities for FYP2

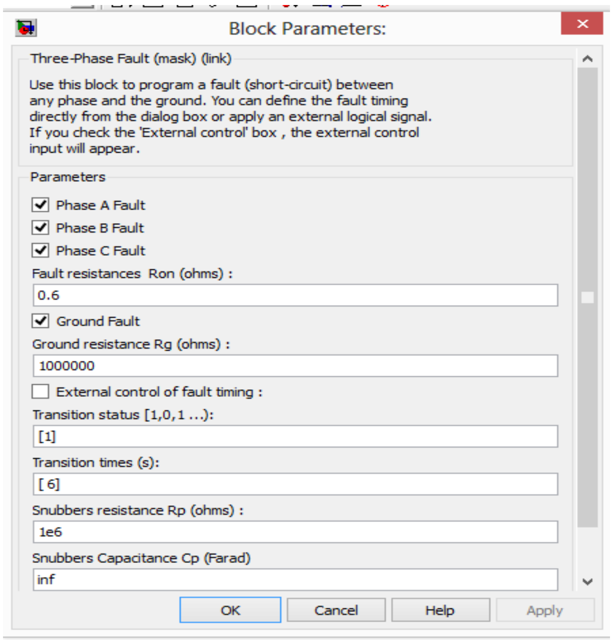

Figure 22: block parameter for three phase fault applied

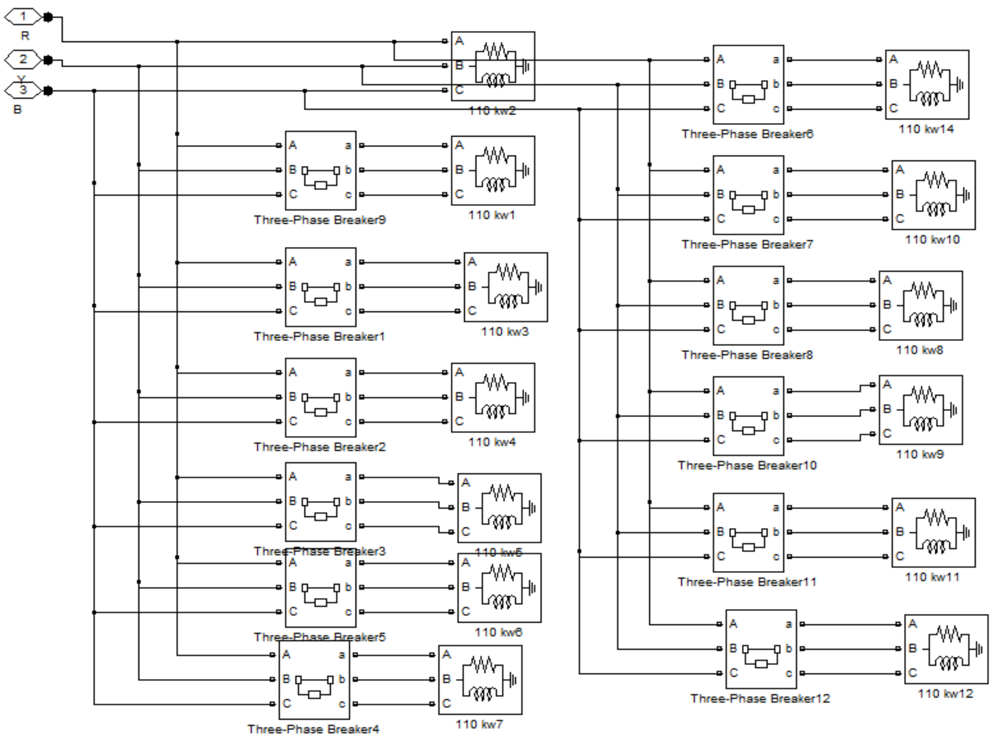

Figure 23: consuming three phase load Simulink

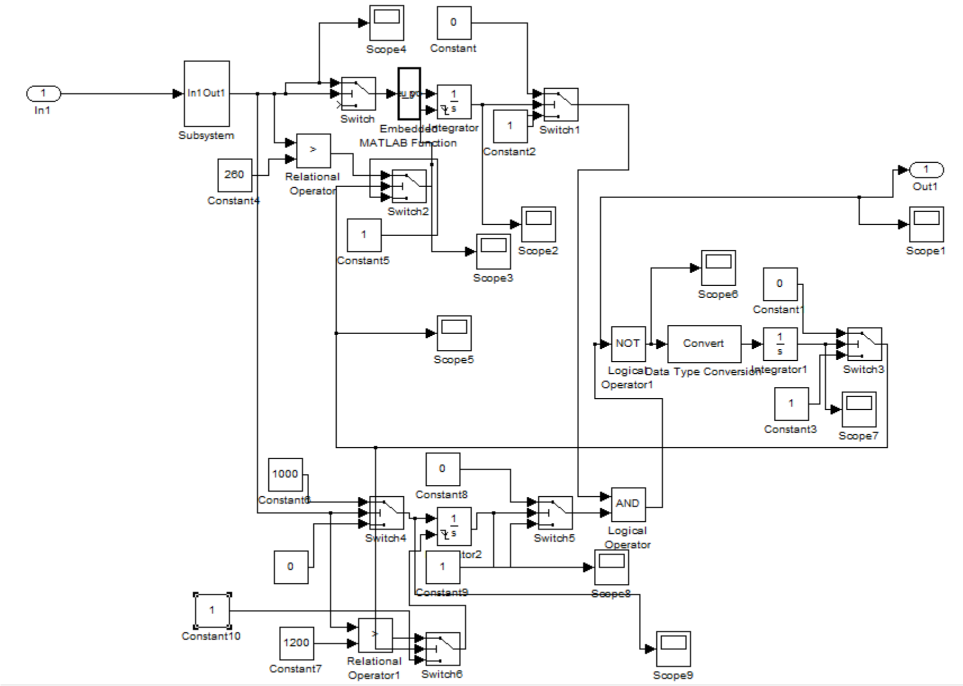

Figure 24: subsystem for every phase Red, Yellow, Blue

Operation time from the simulation for no fault condition:

TIME	RELAY 1	Current for Relay 1	RELAY 2	Current for Relay 2
0	1	-451.9301672	1	-451.9301672
4.47E-18	1	-451.9301672	1	-451.9301672
0.000314795	1	-364.6114282	1	-364.6114282
0.000849305	1	-208.6726972	1	-208.6726972
0.001383814	1	-46.87772483	1	-46.87772483
0.001537044	1	-8.33E-12	1	-8.33E-12
0.001537044	1	1.78E-14	1	1.78E-14
0.001537044	1	9.05E-12	1	9.05E-12
0.002071553	1	162.5881223	1	162.5881223
0.002448095	1	274.6847353	1	274.6847353
0.002965895	1	422.216999	1	422.216999
0.003483694	1	558.5894409	1	558.5894409
0.004001494	1	680.201074	1	680.201074
0.004519294	1	783.8409058	1	783.8409058
0.004869835	1	842.398913	1	842.398913
0.004869835	1	842.398913	1	842.398913
0.004869835	1	842.398913	1	842.398913
0.004869857	1	842.4024064	1	842.4024064
0.004869972	1	842.4198763	1	842.4198763
0.004870545	1	842.5072745	1	842.5072745
0.004873411	1	842.9446073	1	842.9446073
0.004887739	1	845.1229836	1	845.1229836
0.004959379	1	855.7568931	1	855.7568931
0.005317582	1	902.2963526	1	902.2963526
0.005967075	1	957.1388032	1	957.1388032
0.006616568	1	972.2540372	1	972.2540372
0.00726606	1	947.0149467	1	947.0149467
0.007915553	1	882.4687046	1	882.4687046
0.008201634	1	842.1923411	1	842.1923411
0.008201634	1	842.1923411	1	842.1923411
0.008201634	1	842.1923411	1	842.1923411
0.008201649	1	842.1904393	1	842.1904393
0.008201726	1	842.1808553	1	842.1808553
0.008202108	1	842.1312869	1	842.1312869
0.008204021	1	841.8598469	1	841.8598469
0.008213585	1	840.3995883	1	840.3995883
0.008261404	1	832.9536914	1	832.9536914
0.008500497	1	792.938461	1	792.938461
0.009149367	1	662.4673877	1	662.4673877
0.009798237	1	504.5491768	1	504.5491768
0.010447107	1	325.7240675	1	325.7240675
0.011095977	1	133.3973034	1	133.3973034
0.011533841	1	5.08E-11	1	5.08E-11

Operation time when fault occurs at second part of power system:

8.734873689	1	501.9083176	1	501.9083176
8.734873689	1	368.7672304	1	368.7672304
8.734873689	1	220.263961	1	220.263961
8.735529373	1	62.58230338	1	62.58230338
8.736007216	1	3.06E-08	1	3.06E-08
8.73666289	1	-1.76E-11	1	-1.76E-11
8.737318563	1	-3.08E-08	1	-3.08E-08
8.737974237	1	-159.4497318	1	-159.4497318
8.738207085	1	-177.2452938	1	-177.2452938
8.738207085	1	-194.944391	1	-194.944391
8.738207085	1	-211.5592487	1	-211.5592487
8.738862759	1	-228.0729167	1	-228.0729167
8.739340835	1	-233.3484236	1	-233.3484236
8.739996528	1	-235.6045834	1	-235.6045834
8.740652222	1	-236.8856416	1	-236.8856416
8.741307915	1	-237.4200572	0	-237.4200572
8.741540498	1	-237.4200572	0	-237.4200572
8.741540498	1	-238.7001347	0	-238.7001347
8.741540498	1	-245.0900006	0	-245.0900006
8.742196192	1	-276.7617513	0	-276.7617513
8.742674163	1	-420.1049082	0	-420.1049082
8.743329846	1	-546.0117669	0	-546.0117669
8.74398553	1	-649.2534232	0	-649.2534232
8.744641214	1	-680.6121897	0	-680.6121897
8.744873979	1	-680.6121897	0	-680.6121897
8.744873979	1	-680.6121897	0	-680.6121897
8.744873979	1	-746.1304184	0	-746.1304184
8.745529662	1	-751.5626357	0	-751.5626357
8.746007807	1	-756.6049719	0	-756.6049719
8.746663489	1	-761.0314453	0	-761.0314453
8.74731917	1	-765.1021232	0	-765.1021232
8.747974851	1	-766.2072941	0	-766.2072941
8.748207249	1	-767.282802	0	-767.282802
8.748207249	1	-767.8876296	0	-767.8876296
8.748207249	1	-768.4826333	0	-768.4826333
8.748862931	1	-768.604295	0	-768.604295
8.749340684	1	-768.604295	0	-768.604295
8.749996378	1	-768.9273041	0	-768.9273041
8.750652071	1	-769.1624675	0	-769.1624675
8.751307765	1	-770.3140615	0	-770.3140615
8.751540504	1	-775.4644994	0	-775.4644994
8.751540504	1	-785.8479812	0	-785.8479812
8.751540504	1	-770.5342633	0	-770.5342633
8.752196197	1	-730.0241923	0	-730.0241923

9.491540498	1	-3.37E-08	0	-3.37E-08
9.491540498	1	-159.4504032	0	-159.4504032
9.492196192	1	-272.8227256	0	-272.8227256
9.492674269	1	-416.7389938	0	-416.7389938
9.493329953	1	-543.3107274	0	-543.3107274
9.493985638	1	-647.2670405	0	-647.2670405
9.494641323	1	-680.6281459	0	-680.6281459
9.494873713	1	-680.6281459	0	-680.6281459
9.494873713	1	-680.6281459	0	-680.6281459
9.494873713	1	-746.2195069	0	-746.2195069
9.495529398	1	-774.7274342	0	-774.7274342
9.496007266	1	-785.4804784	0	-785.4804784
9.496662941	1	-784.3826361	0	-784.3826361
9.497318615	1	-782.6495536	0	-782.6495536
9.497974289	1	-780.5955529	0	-780.5955529
9.498207105	1	-778.0500152	0	-778.0500152
9.498207105	1	-777.2935318	0	-777.2935318
9.498207105	1	-776.5027018	0	-776.5027018
9.498862779	1	-775.310747	0	-775.310747
9.499340832	1	-775.3102414	0	-775.3102414
9.499996525	0	-775.3102414	0	-775.3102414
9.500652219	0	-775.2698517	0	-775.2698517
9.501307913	0	-775.2698517	0	-775.2698517
9.501540504	0	-775.2293967	0	-775.2293967
9.501540504	0	-775.0259261	0	-775.0259261
9.501540504	0	-773.9801307	0	-773.9801307
9.502196197	0	-768.0416092	0	-768.0416092
9.502674174	0	-720.9346645	0	-720.9346645
9.503329857	0	-680.6673138	0	-680.6673138
9.503985541	0	-680.6673138	0	-680.6673138
9.504641225	0	-680.6673138	0	-680.6673138
9.504873954	0	-680.6672686	0	-680.6672686
9.504873954	0	-680.6670429	0	-680.6670429
9.504873954	0	-680.6659232	0	-680.6659232
9.505529638	0	-680.6605407	0	-680.6605407
9.506007757	0	-680.637913	0	-680.637913
9.506663438	0	-680.5682938	0	-680.5682938
9.507319118	0	-680.3076504	0	-680.3076504
9.507974799	0	-678.9653293	0	-678.9653293
9.50820723	0	-671.3685504	0	-671.3685504
9.50820723	0	-626.3721864	0	-626.3721864
9.50820723	0	-559.4097466	0	-559.4097466
9.50886291	0	-472.7213809	0	-472.7213809
9.509340687	0	-456.9348979	0	-456.9348979
9.509996381	0	-440.7152886	0	-440.7152886
9.510652074	0	-426.2352975	0	-426.2352975
9.511307767	0	-425.1187137	0	-425.1187137

Operation time when fault occurs at first part of the power system:

9.466709553	1	727.5174018	1	243.4347267
9.467127244	1	681.8787907	1	239.6632168
9.467127244	1	681.8787907	1	239.6632168
9.467127244	1	681.8787907	1	239.6632167
9.467738551	1	594.1837299	1	226.7371708
9.468207966	1	511.8461248	1	211.1237993
9.468207966	1	511.8461248	1	211.1237993
9.468207966	1	511.8461247	1	211.1237993
9.468305518	1	493.2478332	1	207.2845826
9.468477488	1	459.3916497	1	200.0573282
9.46850375	1	454.1004098	1	198.9015814
9.468530013	1	448.7783612	1	197.7323128
9.468544501	1	445.8292111	1	197.081483
9.468549347	1	444.8407223	1	196.8628824
9.468550184	1	444.6699398	1	196.8250914
9.468550184	0	444.6699398	1	196.8250914
9.468550888	0	444.5262597	1	196.7932923
9.468550888	0	444.5262596	1	196.7932923
9.468551592	0	444.3825604	1	196.7614843
9.468555111	0	443.6637251	1	196.6022964
9.468572707	0	440.0614269	1	195.8027515
9.468660687	0	421.8503261	1	191.7156405
9.469100589	0	326.2414312	1	169.1432044
9.469753266	0	173.4897557	1	129.8452902
9.470405943	0	13.46771535	1	85.10585348
9.47046021	0	4.52E-10	1	81.18488195
9.47046021	0	-3.30E-08	1	81.18488194
9.47046021	0	-3.33E-08	1	81.18488194
9.470460211	0	-1.09E-07	1	81.18490018
9.470460213	0	-1.09E-07	1	81.1849914
9.470460222	0	-1.11E-07	1	81.18544377
9.470460271	0	-1.20E-07	1	81.18761646
9.470460511	0	-1.61E-07	1	81.19672631
9.470461716	0	-3.42E-07	1	81.22501196
9.470467738	0	-1.19E-06	1	81.33344079
9.470497847	0	-5.46E-06	1	81.87819151
9.470648394	0	-2.66E-05	1	84.61901592
9.471310433	0	-0.000116171	1	96.83296726
9.471402086	0	-0.000127974	1	98.52088456
9.47149374	0	-0.000139603	1	100.2022915
9.471565459	0	-0.000148575	1	101.5123198
9.471637179	0	-0.000157431	1	102.8164061
9.47169808	0	-0.000164856	1	103.9184885

10.63332816	0	-0.000320851	1	-0.000165097
10.63332817	0	-0.000322164	1	-3.06E-08
10.63332817	0	-0.000326181	1	1.29E-09
10.63332817	0	-0.000283154	1	-4.86E-05
10.63332817	0	-0.000282842	1	-0.000130933
10.63332817	0	-0.000282842	1	-0.000165228
10.63332817	0	-0.000282842	1	-0.000165144
10.63332817	0	-0.000213446	1	-0.000165099
10.63332817	0	-0.000213446	1	-0.000165061
10.63332817	0	-0.000213446	1	-0.000165012
10.63332817	0	-0.000202461	1	-0.000164974
10.63332817	0	-0.000193344	1	-0.000164994
10.63332817	0	-0.00014616	1	-0.000164991
10.63332817	0	-0.000120907	1	-0.000164991
10.63332817	0	-9.48E-05	1	-0.000164991
10.63332817	0	-8.02E-05	1	-0.000164991
10.6333282	0	-6.55E-05	1	-0.000164992
10.63332834	0	-2.05E-14	1	-0.000164997
10.63332905	0	1.38E-16	1	-0.000165021
10.63333259	0	2.14E-14	1	-0.000165143
10.63333333	0	1.12E-05	1	-0.000165168
10.63333333	0	1.48E-05	1	-0.000165168
10.63333333	0	1.83E-05	1	-0.000165168
10.63333824	0	1.98E-05	1	-0.000165185
10.63333824	0	2.13E-05	1	-0.000165185
10.63333824	0	2.19E-05	1	-0.000165239
10.63333824	0	2.21E-05	0	-0.000171208
10.63333824	0	2.21E-05	0	-0.000171242
10.63333824	0	2.28E-05	0	-0.000169502
10.63333824	0	2.58E-05	0	-0.000166412
10.63333824	0	4.12E-05	0	-0.000165184
10.63333824	0	0.000107475	0	-0.000165229
10.63333824	0	0.000107475	0	-0.000165309
10.63333824	0	0.000107475	0	-0.000165364
10.63333824	0	0.000175348	0	-0.000165332
10.63333824	0	0.000220547	0	-0.000165336
10.63333824	0	0.000282678	0	-0.000165336
10.63333824	0	0.000282678	0	-0.000165336
10.63333825	0	0.000282678	0	-0.000165337
10.63333828	0	0.000283422	0	-0.000165338
10.63333843	0	0.00028271	0	-0.000165343
10.63333917	0	0.000282843	0	-0.000165368
10.63334288	0	0.000282843	0	-0.000165495
10.63336144	0	0.000282843	0	-0.000166125
10.63345425	0	0.00028317	0	-0.000169192
10.63352796	0	0.00028317	0	-0.000171528

Operation time when fault occurs at both part of the power system:

0	1	-451.9301717	1	-451.930172
4.41E-18	1	-451.9301717	1	-451.930172
0.000310325	1	-365.8783125	1	-365.8783457
0.0008449	1	-209.9876504	1	-209.9877393
0.001379475	1	-48.20230687	1	-48.20244906
0.001537044	1	-1.42E-14	1	-0.000157193
0.001537044	1	8.27E-12	1	-0.000157193
0.001537044	1	1.73E-11	1	-0.000157193
0.001537045	1	0.000157193	1	-9.01E-12
0.001537045	1	0.000157193	1	1.53E-14
0.001537045	1	0.000157193	1	9.04E-12
0.00207162	1	162.6085216	1	162.6083166
0.002449382	1	275.0622696	1	275.0620343
0.002967189	1	422.5737788	1	422.5735073
0.003484997	1	558.9156989	1	558.9153984
0.004002804	1	680.487741	1	680.4874195
0.004520612	1	784.0798603	1	784.0795262
0.004869831	1	842.3993429	1	842.3990053
0.004869831	1	842.3993429	1	842.3990053
0.004869831	1	842.3993429	1	842.3990053
0.004869831	1	842.3994241	1	842.3990865
0.004869831	1	842.3994241	1	842.3990865
0.004869831	1	842.3994241	1	842.3990865
0.004869854	1	842.4029172	1	842.4025796
0.004869969	1	842.4203853	1	842.4200476
0.004870542	1	842.5077765	1	842.5074389
0.004873408	1	842.9450966	1	842.9447589
0.004887736	1	845.1234685	1	845.1231308
0.004959376	1	855.7573602	1	855.7570224
0.005317577	1	902.2967768	1	902.2964406
0.00596707	1	957.1394799	1	957.1391576
0.006616563	1	972.2549519	1	972.2546568
0.007266056	1	947.0160749	1	947.0158193
0.007915548	1	882.470013	1	882.4698075
0.008201633	1	842.1931192	1	842.1929386
0.008201633	1	842.1931192	1	842.1929386
0.008201633	1	842.1931192	1	842.1929386
0.008201634	1	842.1930486	1	842.192868
0.008201634	1	842.1930486	1	842.192868
0.008201634	1	842.1930486	1	842.192868
0.008201649	1	842.1911466	1	842.190966
0.008201726	1	842.1815616	1	842.181381
0.008202108	1	842.1319889	1	842.1318083
0.008204021	1	841.8605386	1	841.8603582
0.008213585	1	840.4002756	1	840.400096
0.008261403	1	832.9543711	1	832.9541958

6.960192027	0	0.000173173	1	0.000116622
6.960192027	0	2.02E-05	1	-1.44E-07
6.960192027	0	2.02E-05	1	-1.08E-07
6.960192027	0	2.04E-05	1	-1.63E-08
6.960192027	0	2.04E-05	1	1.24E-08
6.960192027	0	2.04E-05	1	2.12E-08
6.960192027	0	2.04E-05	1	3.35E-08
6.960192027	0	2.04E-05	1	4.54E-08
6.960192027	0	2.04E-05	1	4.04E-08
6.960192027	0	2.04E-05	1	4.12E-08
6.960192027	0	2.04E-05	1	4.12E-08
6.960192028	0	2.04E-05	1	4.12E-08
6.960192033	0	2.04E-05	1	4.15E-08
6.960192058	0	2.04E-05	1	4.31E-08
6.960192181	0	2.04E-05	1	5.07E-08
6.960192797	0	2.05E-05	1	8.90E-08
6.960195876	0	2.08E-05	1	2.80E-07
6.960211272	0	2.25E-05	1	1.24E-06
6.96028825	0	3.06E-05	1	6.02E-06
6.960352094	0	3.74E-05	1	9.99E-06
6.960415937	0	4.42E-05	1	1.39E-05
6.960479196	0	5.08E-05	1	1.79E-05
6.960542455	0	5.75E-05	1	2.18E-05
6.96055176	0	5.84E-05	1	2.24E-05
6.960557097	0	5.90E-05	1	2.27E-05
6.960559357	0	5.92E-05	0	2.28E-05
6.960559357	0	5.92E-05	0	2.28E-05
6.960564695	0	5.98E-05	0	2.32E-05
6.960591383	0	6.26E-05	0	2.48E-05
6.960724826	0	7.65E-05	0	3.30E-05
6.961392039	0	0.000143506	0	7.29E-05
6.96333274	0	0.000293452	0	0.000164949
6.96333274	0	0.000293452	0	0.000164949
6.96333274	0	0.000293452	0	0.000164949
6.963510135	0	0.000302148	0	0.000170604
6.963510135	0	0.000302148	0	0.000170604
6.963510135	0	0.000302202	0	0.000170649
6.963510135	0	0.000327753	0	0.00019229
6.963510135	0	0.000327795	0	0.000192326
6.963510135	0	0.000322909	0	0.000188187
6.963510135	0	0.000302148	0	0.000170604
6.963510135	0	0.000298202	0	0.000167262
6.963510135	0	0.000299011	0	0.000167947
6.963510135	0	0.000301792	0	0.000170303
6.963510135	0	0.000302444	0	0.000170855
6.963510135	0	3.02E-04	0	0.000170848