ANALYSIS OF FAULTS IN THREE PHASE VOLTAGE SOURCE INVERTER

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ABSTRACT

This project presents the analysis of faults in 3 phase voltage source inverter (VSI). VSI is widely used in motor drive and power quality applications. The majority of fault related the power switches, such as open-circuit faults and short-circuit faults. The problem statement of this project is the high cost of maintenance, the power electronic damage and interrupt the manufacturing process. Then the objective is to identify and analyze generated fault using fast Fourier transform (FFT) and short time Fourier transform (STFT) technique. FFT is very useful in the analysis of harmonic and is an essential tool for filter design. It has some drawbacks such as losses of temporal information, so that it can only be used in the steady state and cannot show the moment when the event is produced. The STFT is applicable to non-stationary signals and it has been used in power quality analysis. The advantage of this technique is its ability to give the harmonic content of the signal at every time-period specified by a define window. But, this technique also has the limitation of fixed window width chosen a priority and this causes limitations for low-frequency and high-frequency non-stationary signal analysis at the same time. In this analysis, the parameter such as instantaneous rms current (*Irms*), average current and total harmonic distortion (THD) are used to identify the characteristic of the signals. Matlab software is used for simulation in this project.

ABSTRAK

Projek ini menganalisis tentang kerosakan yang berlaku dalam penyongsang sumber voltan tiga fasa. Penyongsang sumber voltan digunakan secara meluas dalam aplikasi pemacu motor dan kualiti kuasa. Majoriti kerosakan berkaitan dengan suis kuasa, seperti kerosakan litar terbuka dan litar pintas. Pernyataan masalah projek ini adalah kos penyelenggaraan yang tinggi, kerosakan kuasa elektronik dan mengganggu proses pembuatan. Kemudian objektif projek ini adalah mengenal pasti dan menganalisis kerosakan yang dijana menggunakan teknik 'fast Fourier transform' (FFT) *dan* 'short-time Fourier transform' (STFT). *Teknik* FFT *sangat berguna dalam menganalisis harmonik dan ia adalah alat penting bagi reka bentuk penapis. Ia mempunyai beberapa kelemahan seperti kehilangan maklumat yang berkenaan dengan masa, jadi ia hanya boleh digunakan dalam keadaan tetap dan tidak boleh menunjukkan keadaan ini dihasilkan. Manakala* STFT *berkebolehan dalam isyarat bukan pegun dan ia telah digunakan dalam analisis kualiti kuasa. Kelebihan teknik ini adalah keupayaannya untuk memberikan kandungan isyarat harmonik pada setiap tempoh masa. Tetapi, teknik ini juga mempunyai had lebar window tetap yang keutamaannya dipilih dan ini menyebabkan had untuk frekuensi rendah dan pada masa yang sama analisis isyarat tidak bergerak frekuensi yang tinggi. Dalam analisis ini, parameter seperti arus rms (*Irms*), arus purata* (Iave) *dan jumlah herotan harmonik* (THD) *digunakan untuk mengenal pasti ciri-ciri isyarat. Perisian Matlab digunakan untuk simulasi dalam projek ini.*

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CHAPTER 1

INTRODUCTION

1.1 Overview

Inverter is circuits that convert DC input voltage to symmetric AC output voltage which both magnitude and frequency can be controlled. Voltage source inverters can be classified as an inverter. When input DC voltage remains constant, then it is called voltage source inverter (VSI). In industry, voltage source inverter (VSI) plays role in power supplies, motor drives, power quality application, etc. The percentage of failures in the power converter is estimated about 38% and mostly occur in power switches [1]. To overcome this situation, fast Fourier transform (FFT) and short-time Fourier transform (STFT) technique is used to analyze the signal.

The faults were related to power switches, such as open-circuit, short-circuit and gate misfiring fault [2]. The faults caused transistor failure, pulse width modulation (PWM) and inverter leg open [3].

1.2 Project Motivation

High cost of maintenance is required when the drive system shuts down due to the fault occurrences. The presence of fault causes damage to the power electronics such as inverter. Furthermore, it also interrupts manufacturing process when the drive system has to be stopped. Fast Fourier Transform (FFT) and Short-Time Fourier Transform (STFT) techniques is used to solve this problem. FFT is an essential tool for filter design and very useful in the analysis of harmonic. It has some drawbacks such as losses of temporal information, so that it can only be used in the steady state and cannot show the moment when the event is produced [4]. STFT is applicable to non-stationary signals and it has been used in power quality analysis. The advantage of this technique is its ability to give the harmonic content of the signal at every time-period specified by a define window. But, this technique also has the limitation of fixed window width chosen a priority and this causes limitation for low-frequency and high-frequency non-stationary signal analysis at the same time [5].

1.3 Objectives

The objective of this project is:

i. To study fault in three-phase voltage source inverter (VSI).

ii. To identify and analyze generated fault using fast Fourier transform (FFT) and short-time Fourier transform (STFT) technique.

iii. To simulate by using Matlab software.

1.4 Scope

In order to achieve this objective, several scopes have been outlined. In this analysis, Matlab software is used as simulation purpose and RMS current (Irms), average current (Iave) and total harmonic distortion (THD) are used to identify the characteristic of the signals. The technique used in this analysis is fast Fourier transform (FFT) and short-time Fourier transform (STFT). FFT is suitable for stationary signal [6] while STFT is non-stationary signal [7]. The limitation of three-phase inverter is the frequency of the output voltage waveform depends on the switching rate of the semiconductor devices and the upper limit of the frequencies is fixed by the device capability [8].

1.5 Report outlines

After doing some research for this project, this report is written and discuss about the analysis of fault in three phase VSI.

In chapter 1, there will be an introduction about this project, project background, problem statement, the objective, scope and report outlines.

In chapter 2, the literature review will review on the theory, basic principles of the fault and overview of related published results of a fault in voltage source inverter. This chapter also includes the summary of the review.

In chapter 3, the methodology will show the process and simulation approach of fault detection. In chapter 4, the result and discussion will discuss about the whole project.

Finally, in chapter 5 the conclusion will conclude the project that has been done. This chapter will also discuss about the future work or recommendation and suggestion.

CHAPTER 2

LITERATURE REVIEW

2.1 Theory

2.1.1 Inverter

The inverters are DC to AC converters. The application of inverter such as standby power supply, induction heating and variable speed AC motor drives [9].

The output voltage of the inverter can be controlled with the help of the drives of the switches. To control the output voltages of the inverter, the pulse width modulation (PWM) technique is used. Some inverters are called as PWM inverters. It contains harmonic whenever it is non-sinusoidal. These harmonics can be reduced by using proper control schemes.

Voltage source inverters or current source inverters can be classified as an inverter [9]. When input DC voltage remains constant, then it is called voltage source inverter (VSI) or voltage fed inverter (VFI). When input current is maintained constant, then it is called current source inverter (CSI) or current fed inverter (CFI). Rarely, the DC input voltage to the inverter is controlled to adjust the output. Some inverters are called variable DC link inverters. It can have single phase or three phase output.

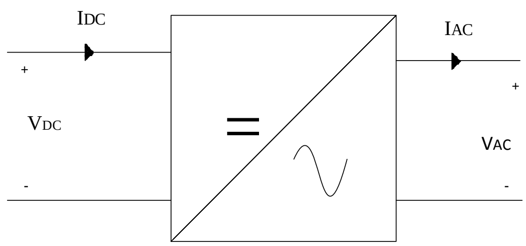


Figure 2.1: Inverter

2.1.2 Three-phase Inverter

The DC to AC converters are also known as an inverter, depending on the related topology of the power circuit and the type of the supply source. There are different basis of classification of the inverter. Inverters are broadly classified as a current source inverter (CSI) and voltage source inverter (VSI). Figure 2.2 and Figure 2.3 show the three-phase half bridge voltage source inverter and three-phase full bridge voltage source inverter. Single-phase VSIs cover low range power applications while three-phase VSIs cover medium to high power applications [10]. Three-phase full bridge voltage source inverter has six switches. The switching depends on the modulation scheme. The main objective of three-phase VSI topologies is to provide a three-phase voltage source, where the amplitude, phase and frequency of the voltages should always be controllable. Three-phase VSI are widely used in active filters, motor drives and uninterrupted power supplies to generate controllable frequency and AC voltage magnitudes using various PWM strategies [10].

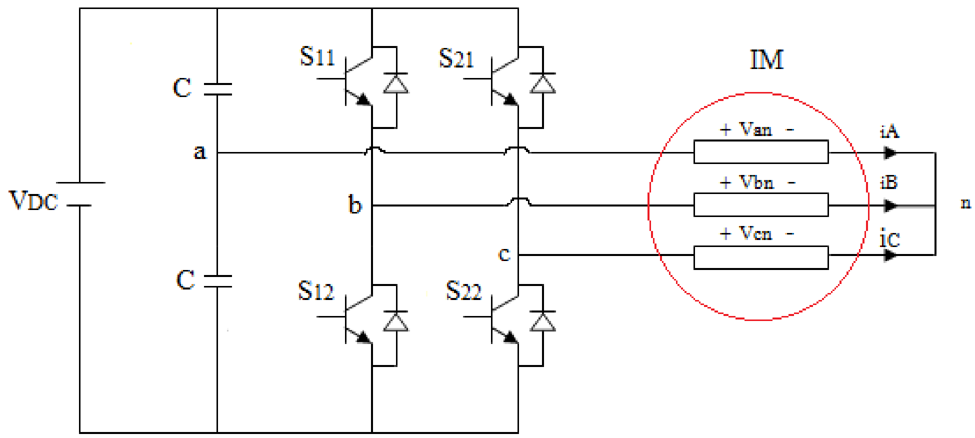


Figure 2.2: Three-Phase Half Bridge Inverter

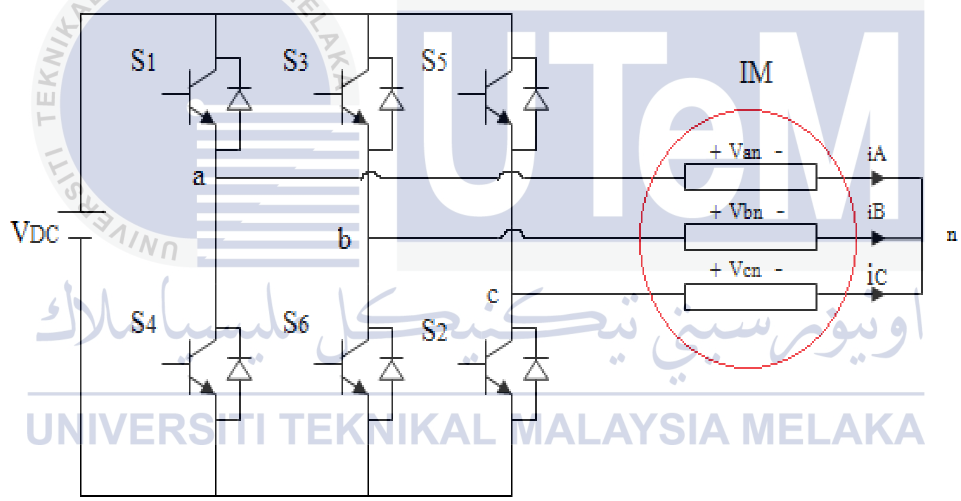


Figure 2.3: Three-Phase Full Bridge Inverter

2.1.3 Pulse Width Modulation

The output voltage of an inverter can also be adjusted by exercising a control within the inverter itself. The most efficiency method of doing this is by using pulse width modulation (PWM) control in inverter. In this method, a fixed DC input voltage is given to the inverter while controlled AC output voltage is obtained by adjusting the on and off periods of the inverter components [11]. The PWM provides a way to decrease the total harmonic distortion (THD) of load current. A PWM inverter output with some filtering can generally meet THD requirements easier than the square wave switching scheme. The unfiltered PWM output will have a relatively high THD, but the harmonics will be at higher frequency than for a square wave, result to ease to be filtered.

Besides, the advantage of PWM for three phase inverter is reduced filter requirements for harmonic reduction and controllability of the amplitude of the fundamental frequency. Then, the other advantages of PWM techniques are the output voltage control with this method can be obtained without any additional components. The lower order harmonics can be eliminated or minimized along with its output voltage control. In most AC motor loads, higher order harmonic voltage distortion can be filtered by the inductive nature of the load itself.

PWM inverter is most popular in industrial application. PWM technique is characterized by constant amplitude pulses. The width of these pulses is however modulated to obtain inverter output voltage control and reduce. The figure below shows the pulse width modulated signal.

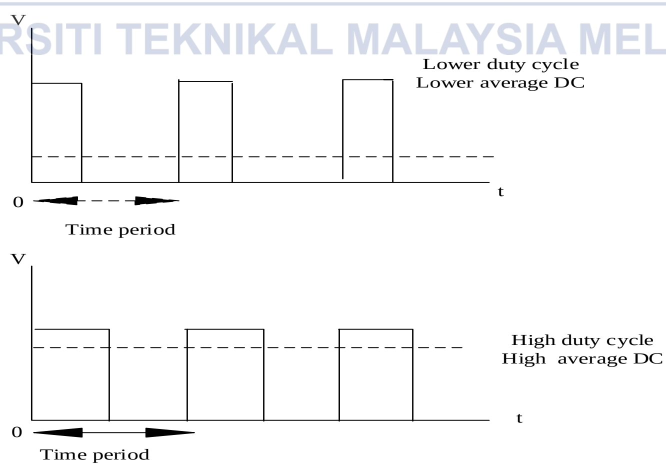


Figure 2.4: Pulse Width Modulation signal

2.1.4 Short-Time Fourier Transform

The short-time Fourier transform (STFT) is a transform. It involves both time and frequency and allows a time-frequency analysis [12]. The time-frequency analysis is motivated by the analysis of non-stationary signal that is characteristic of the spectrum is changing in time [13]. The objective of STFT is to capture the time variation in the frequency content of the signal. It represents a compromise between time and frequency based on signal perspectives and it also provides some information about when and what events occur. The basic principle of STFT is to slice up the signal into suitable overlapping time segments and then to perform a Fourier analysis on each slice to ascertain the frequencies contained in it [7]. It is defined as in Equation 2.1.

$$S(t,f)=\int_{-\infty}^{\infty} x(\tau)w(\tau-t)e^{-j2\pi ft}\,d\tau \tag{2.1}$$

$x(\tau)$ is the input signal and $w(t)$ is the window function. Some limitation of STFT is window length. In STFT, narrow window gives good resolution in time but poor resolution in frequency. Wide window gives good resolution in frequency but poor resolution in time [14].

2.1.4.1 Performance Parameter

i. Instantaneous Average Current

Instantaneous Average Current is the mean value of a signal that corresponds to a specific time, *t* and it can calculate as:

$$I_{ave}(t)=\frac{1}{T}\int_{0}^{T} x(\tau)w(\tau-t)d\tau \qquad .(2.2)$$

Where T is the period measured, $x(\tau)$ is the input signal and $w(t)$ is the window function.

ii. Instantaneous RMS Current

$$I_{rms}(t) = \sqrt{\int_{0}^{f_{max}} S(t, f)\,df} \tag{2.3}$$

$S(t, f)$ is the time-frequency representation (TFR) of the signal and f_{max} is the maximum frequency

iii. Instantaneous RMS Fundamental Current

$$I_{1rms}(t) = \sqrt{2\int_{f_{lo}}^{f_{hi}} S(t, f)\,df} \tag{2.4}$$

$$f_{hi} = f_1 + \frac{\Delta f}{2} \tag{2.5}$$

$$f_{lo} = f_1 - \frac{\Delta f}{2} \tag{2.6}$$

Where f_1 is the fundamental frequency that corresponds to the power system frequency and Δf is the bandwidth.

iv. Instantaneous Total Harmonic Distortion

$$I_{THD}(t) = \sqrt{\frac{\sum_{h=2}^{H} I_{h,rms}(t)^2}{I_{1rms}(t)}} \tag{2.7}$$

$I_{h,rms}(t)$ is the RMS harmonic current and H is the highest measured harmonic component.

2.1.5 Fast Fourier Transform

Fourier transform is mathematical technique which convert the signal from time to frequency domain. It is very useful for many applications where the signals are stationary, as in diagnostic faults of electrical machines [6]. The stationary signal is frequency or spectral contents are not changing with respect to time. Function of fast Fourier transform (FFT) is localized in the frequency domain; providing the user useful information on the operating conditions of the power distribution network. Not advisable to apply a methodology associated with FFT as the analysis tool if the signal is a stationary signal associated with a wide range of frequencies superimposed to the power frequency component. FFT has various obstacles and limitations associated with time-frequency resolution where it is not possible to identify at what times these high frequency components occurred [15]. It can be defined as:

$$X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ftt} dt \tag{2.8}$$

$x(t)$ is the signal of interest, t is the time and f is the signal frequency.

2.1.5.1 Performance Parameter

i. Current Measurement

$$I_{rms} = \sqrt{\frac{1}{N}\sum_{n=0}^{N-1}\left|i(n)\right|} \tag{2.9}$$

ii. Instantaneous Total Harmonic Distortion

$$I_{THD}(t) = \sqrt{\frac{\sum_{h=2}^{H} I_{h,rms}(t)^2}{I_{1rms}(t)}} \qquad (2.10)$$

$I_{h,rms}(t)$ is the RMS harmonic current and H is the highest measured harmonic component.

2.1.6 Stationary Signal and Non-stationary Signal

Stationary signal is a signal whose frequency content does not change in time. In this signal all frequency components exist at all time [16]. There is 10 Hz , 50 Hz and 100 Hz at all time.

Example for stationary signal. It has frequencies of 10, 25, 50 and 100 Hz at a given time instant. The signal is plotted in Figure 2.5.

x(t) = cos (2*pi*10*t) + cos (2*pi*25*t) + cos (2*pi*50*t) + cos (2*pi*100*t)

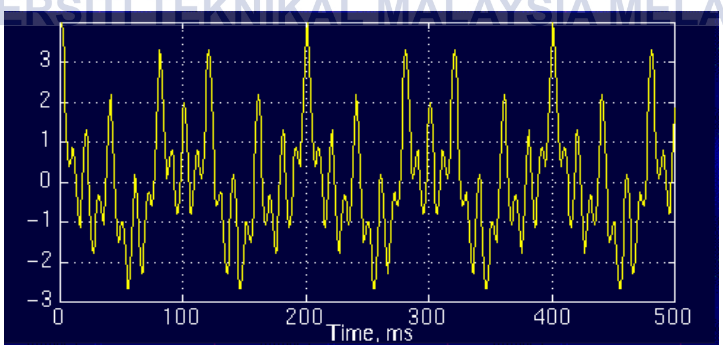


Figure 2.5: Example of stationary signal

Non-stationary signal is a signal whose frequency constantly changes in time [16]. Figure 2.6 is an example of a non-stationary signal. This figure shows a signal with four different time intervals. The interval 0 to 300 ms has a 100 Hz sinusoid, the interval 300 to 600 ms has a 50 Hz sinusoid, the interval 600 to 800 ms has a 26 Hz sinusoid and lastly the interval 800 to 1000 ms has a 10 Hz sinusoid. In this signals the frequency components do not appear at all time.

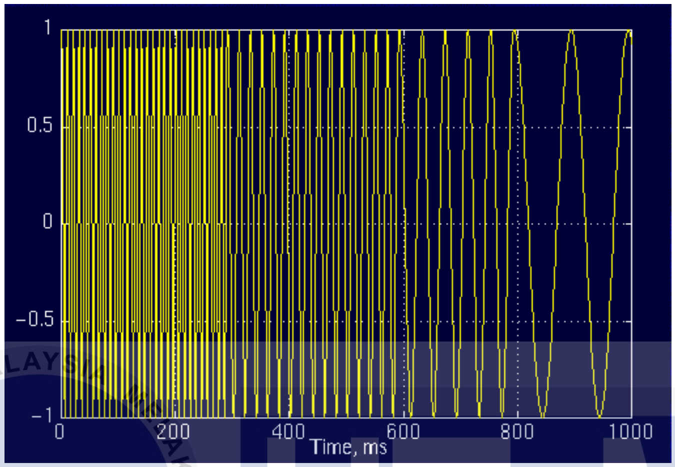


Figure 2.6: Example of non-stationary signal

2.1.7 Detection of Fault for Voltage Source Inverter (VSI)

2.1.7.1 Switching Function Model for VSI

Three-phase full bridge inverter consists of a classical three-leg inverter. To operate the power transistor such as an IGBT, an appropriate gate voltage must be applied in order to drive transistor into the saturation mode for low on-state voltage. The gate drive circuit generates the control voltage. The control voltage should be applied between the gate and source terminal. [17].

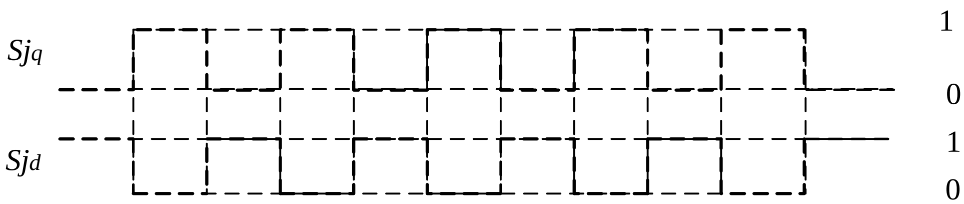


Figure 2.7: Gating signals of the inverter

A switching function of the VSI as is shown as Figure 2.7, where *j* represents the phase and variable *d* represents the lower and *q* represents upper components of the phase. When a three-phase VSI is considered, *j* = (*a*, *b*, *c*). The switch *Sj* is closed whenever current flow through the IGBT or the anti-parallel diode (D1-D6) and otherwise open show the gating signal when in an ideal case.

Table 2.1: Valid switch states for three-phase VSI

State	State	Line Voltage		
		Vab	Vbc	Vca
1	1,2,and 6 are on and 4,5,and 3 are off	VDC	0	-VDC
2	2,3,and 1 are on and 5,6,and 4 are off	0	VDC	-VDC
3	3,4,and 2 are on and 6,1,and 5 are off	-VDC	VDC	0
4	4,5,and 3 are on and 1,2,and 6 are off	-VDC	0	VDC
5	5,6,and 4 are on and 2,3,and 1 are off	0	-VDC	VDC
6	6,1,and 5 are on and 3,4,and 2 are off	VDC	-VDC	0
7	1,3,and 5 are on and 4,6,and 2 are off	0	0	0
8	4,6,and 2 are on and 1,3,and 5 are off	0	0	0

According the Table 2.1, at the output, two of them produce zero Alternating Current (AC) line voltage. In this condition, the AC line currents freewheel through either the upper or lower components. The remaining states produce no zero each output line voltages. To generate a given voltage waveform, the inverter switches from one state to another. The result of AC output line voltages consists of discrete values of voltages, which are $-V_{DC,}$ 0 and V_{DC} [17]. The calculation of load condition at state 1 and 2 are an example to prove Table 2.1.

a) Load condition at state 1

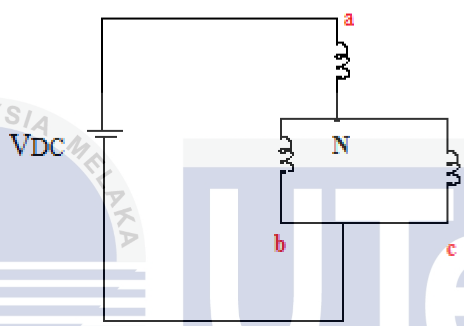


Figure 2.8: Switching sequence at state 1

The Figure 2.8 shows the switching frequency at state 1. In state 1, only S1, S2 and S6 turned ON.

VaN = VDC

VbN = 0

VcN = 0

Line to line voltage

Vab = VaN – VbN (3.1)

= VDC - 0

= VDC

$$Vbc = VbN - VcN \qquad (3.2)$$
$$= 0 - 0$$
$$= 0$$

$$Vca = VcN - VaN \qquad (3.3)$$
$$= 0 - VDC$$
$$= -VDC$$

b) Load condition at state 2

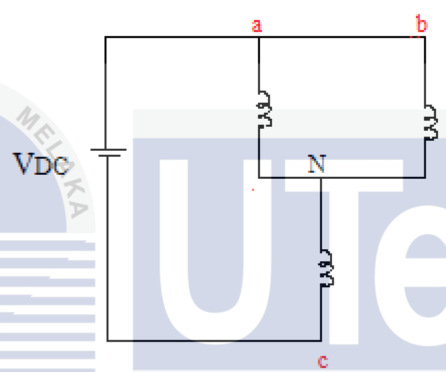


Figure 2.9: Switching sequence at state 2

The Figure 2.9 shows the switching frequency at state 2. In state 2, only S1, S2 and S3 turned ON.

$$VaN = VDC$$
$$VbN = VDC$$
$$VcN = 0$$

Line to line voltage

$$Vab = VaN - VbN$$
$$= VDC - VDC$$

= 0

Vbc = VbN – VcN

= VDC – 0

= VDC

Vca = VcN – VaN

= 0 – VDC

= -VDC

2.1.8 Type of Fault

2.1.8.1 Open-circuit Fault

Open-circuit fault in VSI makes the current in the phase be "0" for either the positive or negative half-cycle depending on whether it occurs in the upper or lower switch. On the other hand, it demonstrates an open-circuit switch fault allows the operation of the motor drive system, but at a much inferior performance due to the presence of significant torque pulsations. For illustration, consider the one inverter leg *a*, as shown in Figure 2.10. Figure illustrates which semiconductor is conducting, the output phase current and corresponding line-to-line voltage be considered [17].

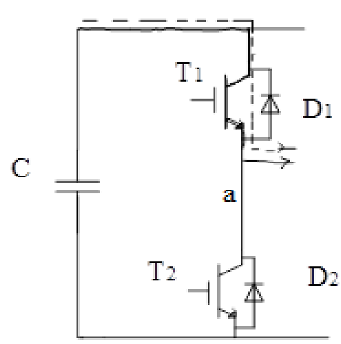


Figure 2.10: Gating signals of the inverter in an ideal case.

a. Open-circuit Fault of the Lower Switches

The open-circuit that considering the switch dead time and the basic configuration of phase *a* leg of a three-phase PWM voltage source inverter (VSI) is shown in Figure 2.11. The system is under the fault condition as can be seen in Figure 2.11 [17].

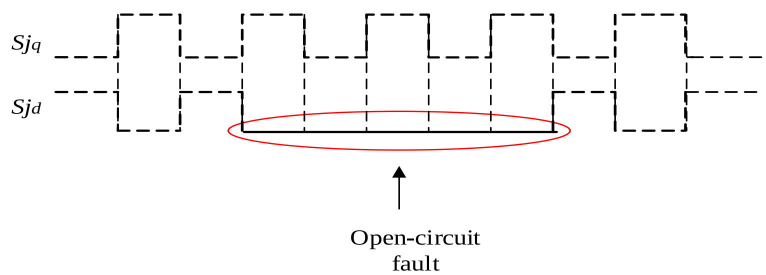


Figure 2.11: Gating signals of the inverter in an open-circuit fault (lower)

Figure 2.11 shows the gating signal of the inverter in an open-circuit fault for lower switch. The fault occur at lower power switch *S4* where *Sjq* and *Sjd* represent the upper and lower switching signals of phase *a*. In this case, the faults occur and detect at a certain time and back to normal operation [17].

b. Open-circuit Fault of the Upper Switches

For open-circuit fault of the upper switches, the fault occur at upper power switch *S1*. In this case, the upper switching consists delay at certain time then current drop occur at VSI. The normal operation switching for VSI, the upper and lower side are not same. It is because only one IGBT function for phase *a*. The switching gate signal consists delay at certain times as shown in Figure 2.12. That means, the switching is at the “0” condition until it returns to normal [17].

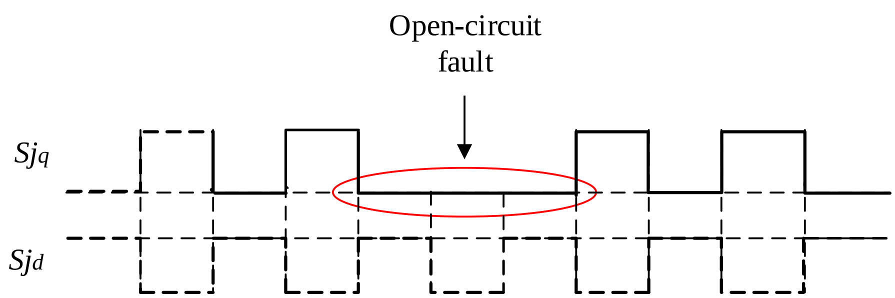


Figure 2.12: Gating signals of the inverter in an open-circuit fault (upper)

2.1.8.2 Short-circuit Fault

The Short-circuit can be classified into two conditions. The conditions are upper switch and lower switch

a) Short-circuit Fault of the Lower Switches

In lower switch, short-circuit fault occurs when the *Sjq* and *Sjd* are closed at the same time [18]. For the lower switch Figure 2.13 shows the switching gate signal consist delay at certain times where the switching at the "1" condition until return to normal.

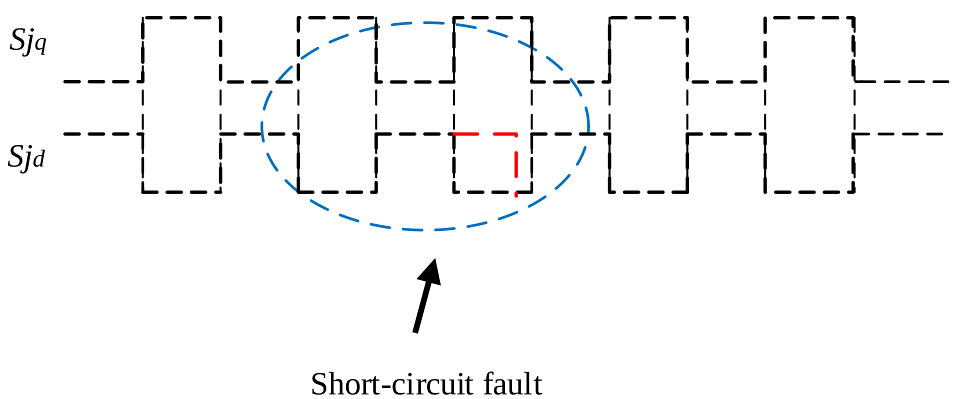


Figure 2.13: Switching signals of the inverter in short-circuit fault (lower)

a) Short-circuit Fault of the Upper Switches

Similar to the lower switch short-circuit fault, the short-circuit fault of the upper switch is occurred when *Sjq* and *Sjd* are closed at the same time [18]. Figure 2.14 shows the example of upper switch fault, the condition *Sjq* is normally opened while *Sjd* is closed at a certain time and then back to normal operation.

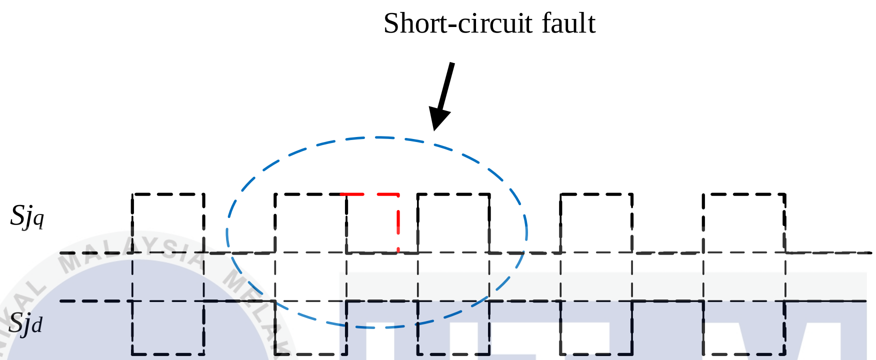


Figure 2.14: Switching signals of the inverter in short-circuit fault (upper)

2.2 Related previous work

Open Switch Fault Analysis in Voltage Source Inverter using Spectrogram, describes about the characteristic of open-circuit fault in voltage source inverter. The open switch fault makes the current in the phase be zero either in the positive or negative half cycle depends on whether it occurs in the upper or lower switch. In upper switch case, the fault occurs and detect at certain times and then back to normal operation while at normal operation switching of lower switch ,the upper and lower side has not had similarity in term of switching signal [17].

In "An MRAS-Based Diagnostic of Open-Circuit Fault in PWM Voltage-Source Inverters for PM Synchronous Motor Drive System" paper describes about open-circuit and short-circuit fault. The short-circuit fault may occur due to an improper gate signal so that both power switches in a leg of the VSI are turned ON. Slow response and less danger to the whole drive system are the characteristic of open-circuit fault [18].

Fault Type Classification in Transmission Line using short-time Fourier transform (STFT) paper describes about the STFT technique. STFT is a well-known method for time-frequency analysis of a non-stationary signal. The objective of STFT is to capture the time variation in the frequency content of the signal. It adapts the Fourier Transform (FT) to analyze only a small section of the signal at a time. The STFT represents a comprise between time and frequency-based signal perspective. It provides some information about both when and what even occur [7].

The other technique is fast Fourier transform. Based on "A Study on Different Fault Characteristics using Wavelet and Fast Fourier Transform" paper, fast Fourier transform (FFT) is that their basic function are localized in the frequency domain; providing the user useful information on the operating conditions of the power distribution network. Since the transient signals generated by disturbances are non-stationary signals associated with a wide range of frequencies superimposed to the power frequency component, it is not advisable to apply a methodology associated with FFT as the analysis tool. FFT has various obstacles and limitations associated with time-frequency resolution where it is not possible to identify at what times these high frequency components occurred [15].

2.3 Summary of Review

Based on the research papers, most of inverters use insulated-gate bipolar transistor (IGBT) as the power device because of their high voltage and current- ratings and ability to handle short circuit current for a period exceeding 10 microseconds. Though IGBTs are rugged, they suffer failures due to excess electrical and thermal stress that are experienced in many applications. IGBT failures can be broadly categorized as open-circuit faults, short-circuit fault and intermittent gate-misfiring faults.

Furthermore, the open-circuit fault and short-circuit fault has been discussed. An open-circuit fault in VSI makes the current in the phase be zero either in the positive or negative half-cycle depending on whether it occurs either in the upper or lower switch whereas the short-circuit fault may occur due to an improper gate signal so that both power switches in a leg of the VSI are turned ON.

The research paper also discusses about several techniques to detect faults in inverter such as spectrogram technique. This technique is able to present time-frequency representation and accurate.

CHAPTER 3

DESIGN METHODOLOGY

3.0 Introduction

This chapter discusses in detail about the work flows and the method use to accomplish the project. This project methodology is used to ensure this project walking fluently without any problem during the running. With conscientious planning and work use the step, this project can be reached the objectives. Flowchart is used to perform the sequence of this project. Basically, this project consists of software part. The analysis is simulated using by MATLAB/SIMULINK. The model is designed by using Matlab/Simulink 2011, the component are taken from the Simulink library browser and drag into the workspace.

3.1 Project Methodology

3.1.1 Overall Project Flow Chart

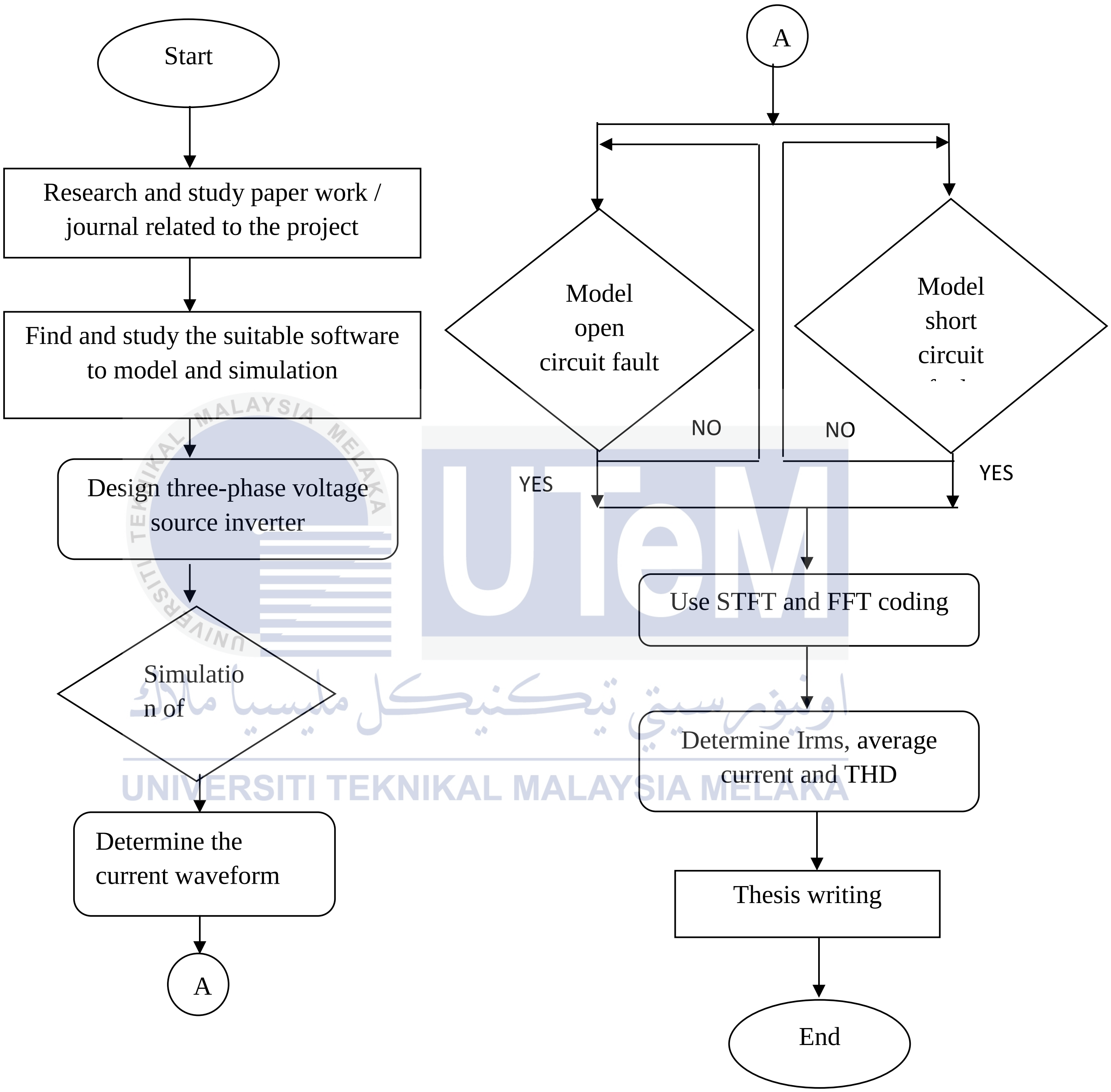


Figure 3.1: Overall Project Flow Chart

3.1.2 Flow Chart of Simulation

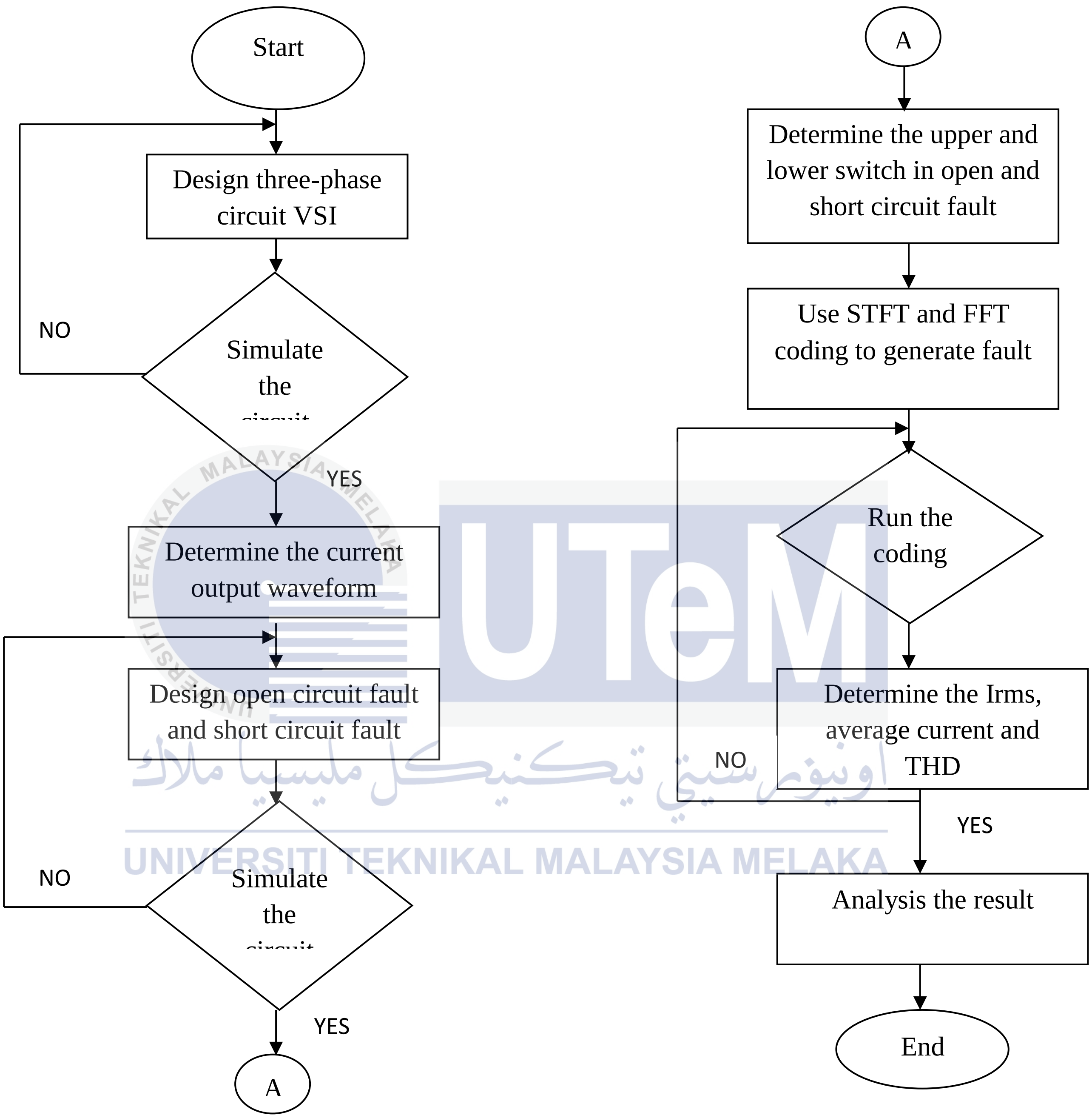


Figure 3.2: Flow Chart of Simulation

3.2 Simulation Circuit

3.2.1 Open-circuit Fault

3.2.1.1 Open-circuit Fault of the Upper Switches

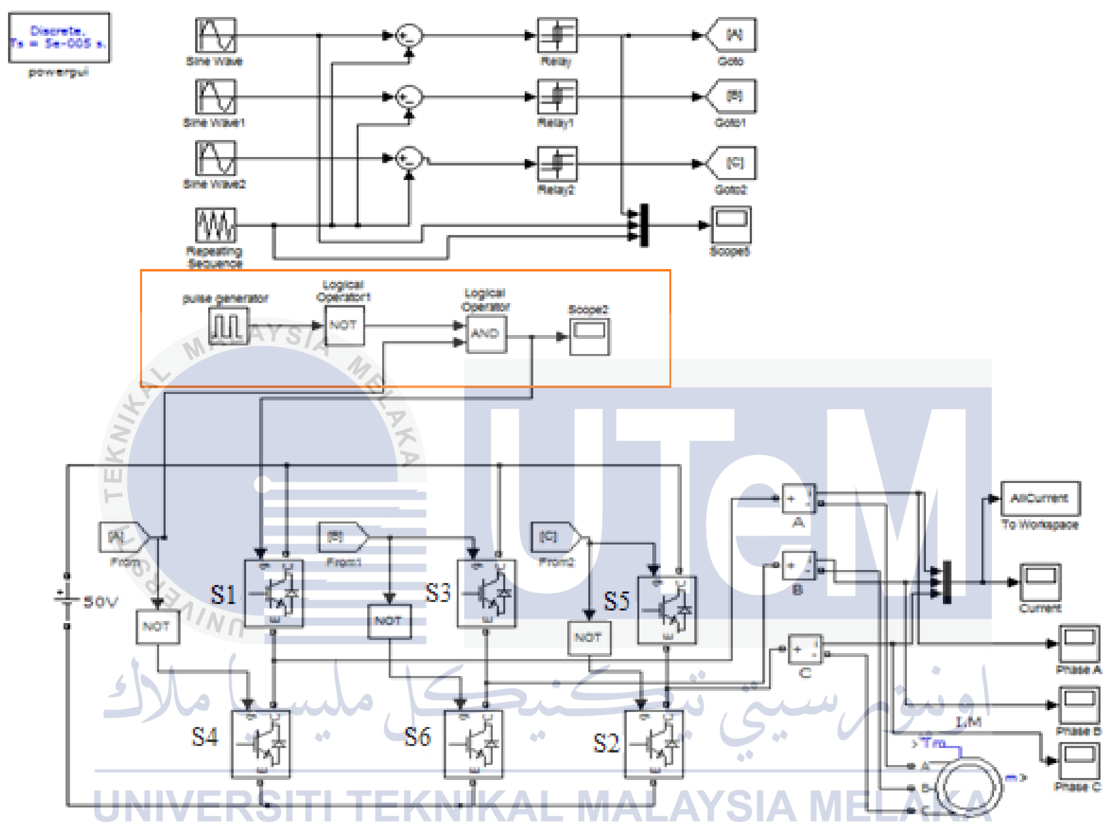


Figure 3.3: Simulation circuit of open-circuit fault (upper)

Figure 3.3 shows the open-circuit fault of the upper switch. In this simulation circuit, three-phase voltage source inverter (VSI) and PWM circuit is used. For upper switch, NOT and AND gate is used in the circuit to produce a fault. To produce a fault, input from AND gate will be connected to the PWM and NOT gate output while AND gate output will be connected to the leg of *S1*. The fault occurs in phase A between 0.2 – 0.4s.

3.2.1.2 Open-circuit Fault of the Lower Switches

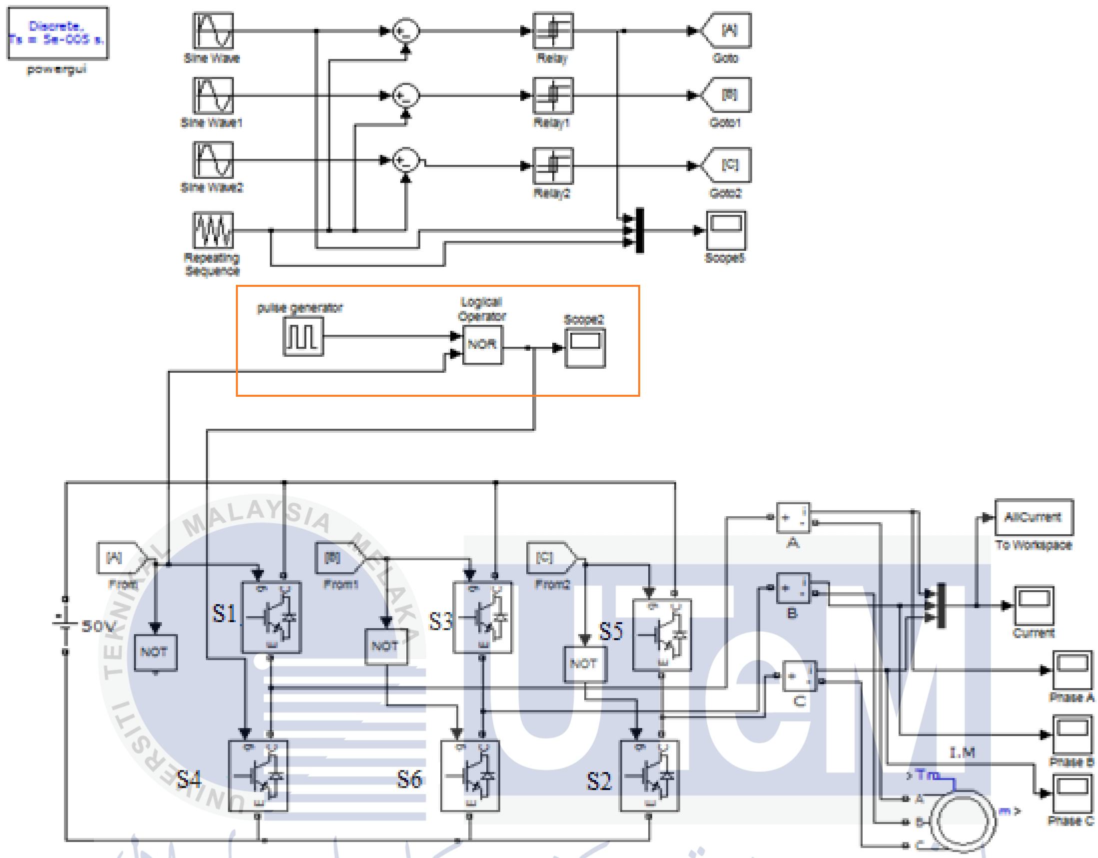


Figure 3.4: Simulation circuit of open-circuit fault (lower)

Figure 3.4 shows the open-circuit fault of the lower switch. In this simulation circuit, three-phase voltage source inverter (VSI) and PWM circuit is used. For a lower switch, NOR gate is used in the circuit to produce a fault. To produce a fault, input from NOR gate will be connected to the PWM and pulse generator while NOR gate output will be connected to the leg of *S4*. The fault occurs in phase A between 0.2 – 0.4s.

3.2.2 Short-circuit Fault

3.2.2.1 Short-circuit Fault of the Upper Switches

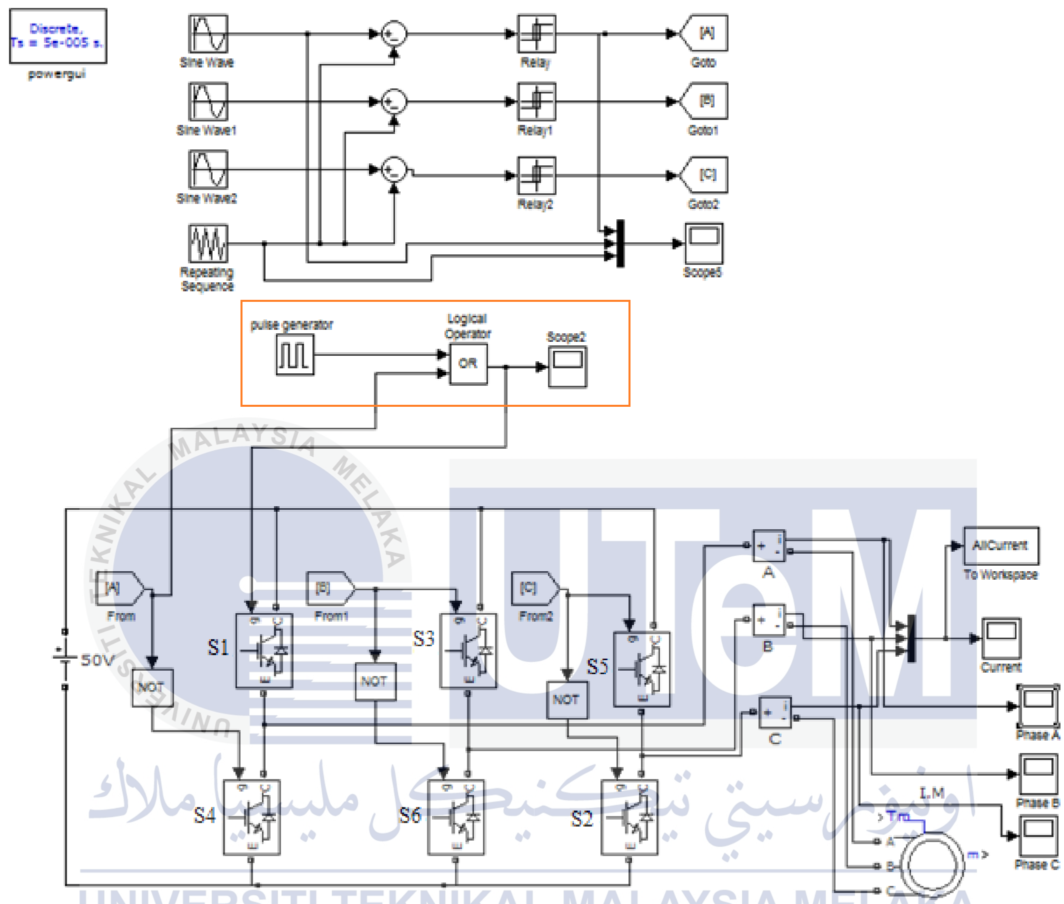


Figure 3.5: Simulation circuit of short-circuit fault (upper)

Figure 3.5 shows the short-circuit fault of the upper switch. In this simulation circuit, three-phase voltage source inverter (VSI) and PWM circuit is used. For a upper switch, OR gate is used in the circuit to produce a fault. To produce a fault, the input from OR gate will be connected to the PWM and the pulse generator while OR gate output will be connected to the leg of *S1*. The fault occurs in phase A between 0.2 – 0.4s.

3.2.2.2 Short-circuit Fault of the Lower Switches

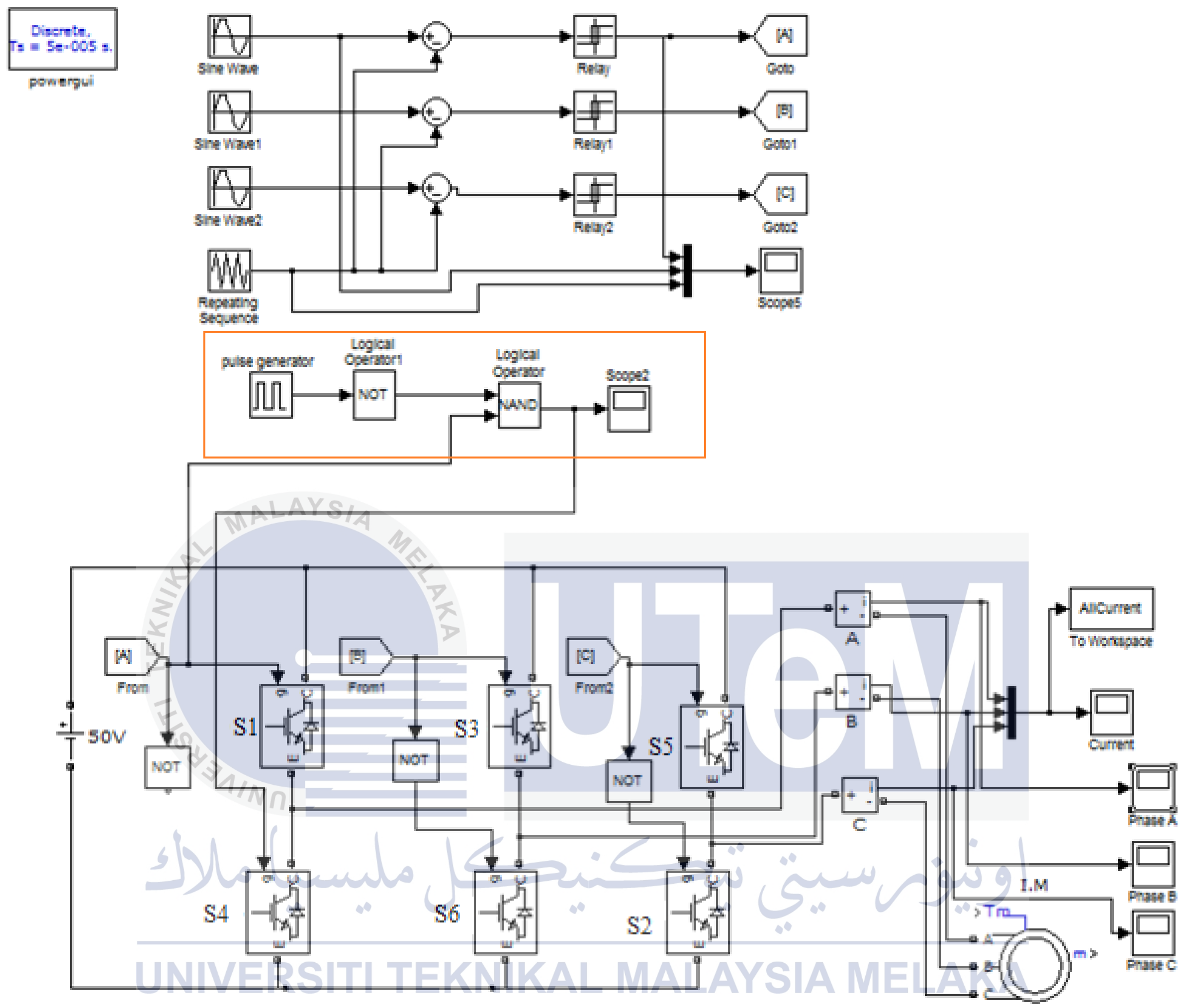


Figure 3.6: Simulation circuit of short-circuit fault (lower)

Figure 3.6 shows the short-circuit fault of the lower switch. In this simulation circuit, three-phase voltage source inverter (VSI) and PWM circuit is used. For a lower switch, NOT and NAND gate is used in the circuit to produce a fault. To produce a fault, the input from NAND gate will be connected to the PWM and NOT gate output while NAND gate output will be connected to the leg of *S4*. The fault occurs in phase A between 0.2 – 0.4s.

3.3 Analytical Approach / Simulation Approach

3.3.1 Switching Sequence for Three-phase Inverter Output

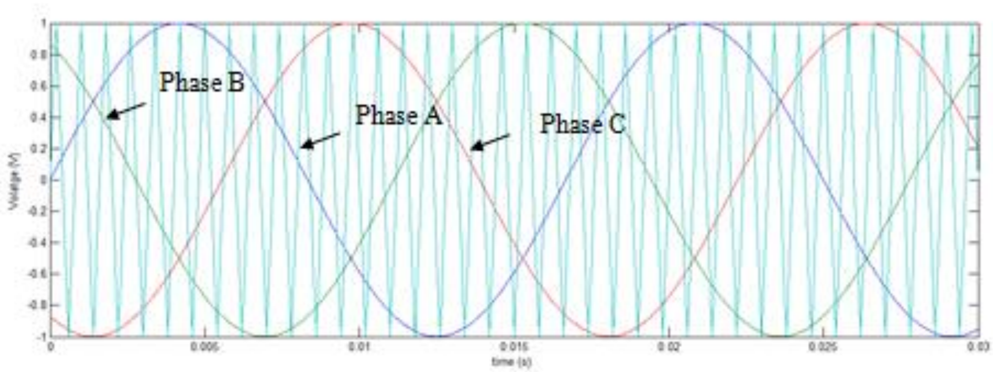
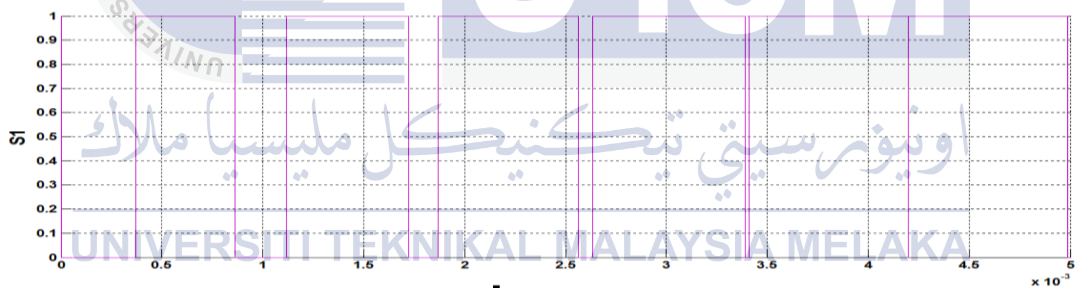
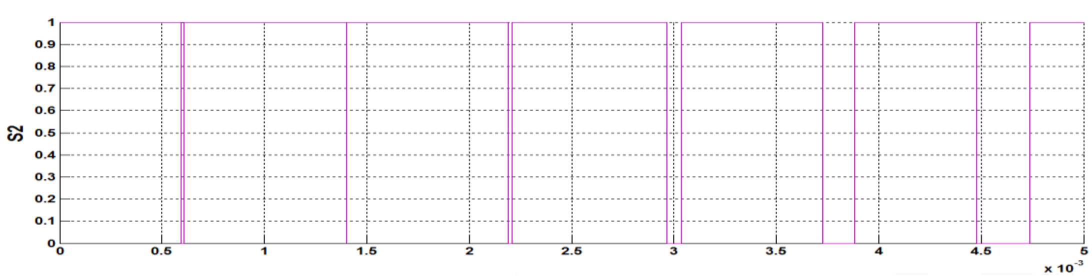


Figure 3.7: Waveforms of comparator voltage

a) Stage 1

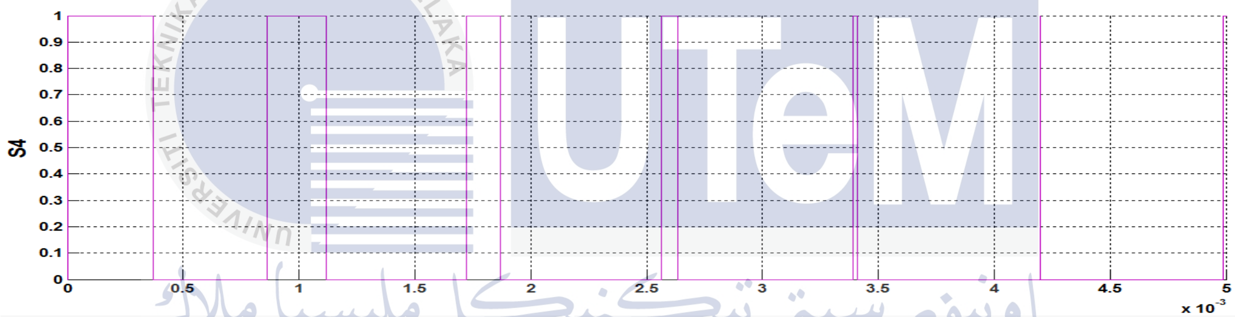


b) Stage 2



c) Stage 3

d) Stage 4



e) Stage 5

f) Stage 6

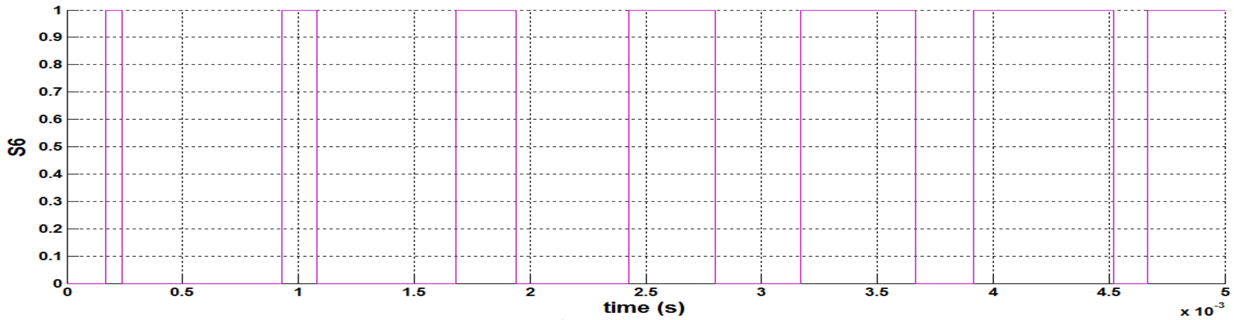


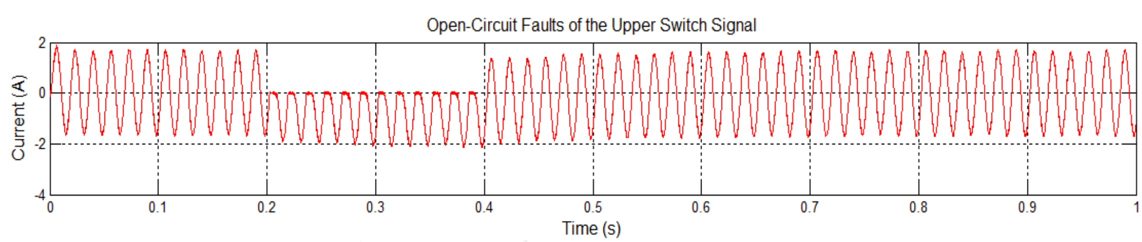
Figure 3.8 (a-f): Switching sequence for three-phase inverter output

Figure 3.8 (a-f) shows the switches are closed and opened in the sequence. The switching represents in term of "1" when the switch is closed and "0" when the switch is opened [16].

3.2.2 Open-circuit Fault

3.2.2.1 Open-circuit Fault of Upper Switches

The Figure 3.9 shows the output current of three-phase voltage source inverter (VSI) for open-circuit fault of the upper switch at S1. According to the signal, a fault occurs at 0.2-0.4s where current at phase A lower compared with phase B and C.



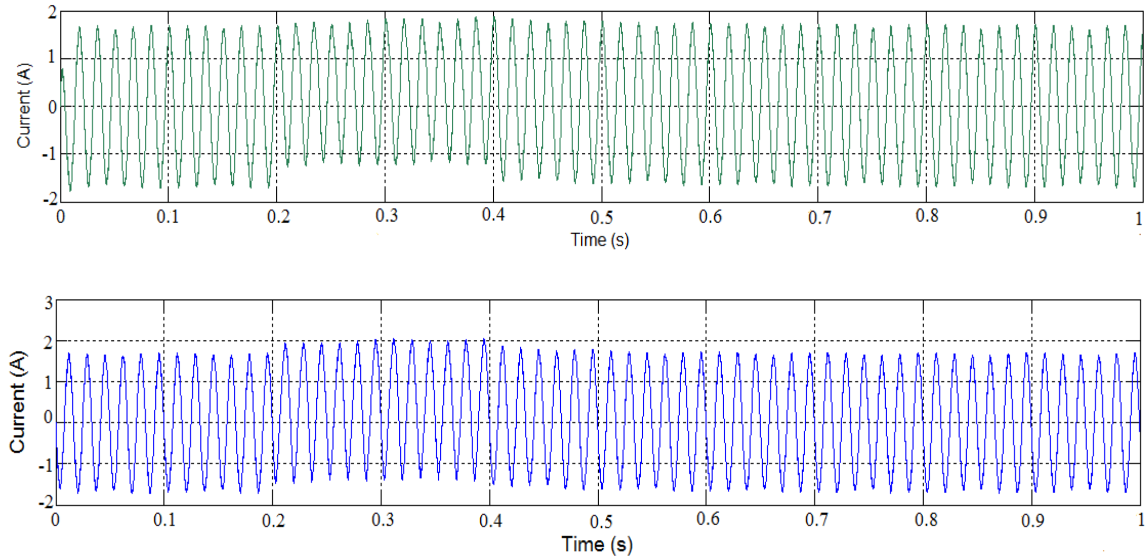
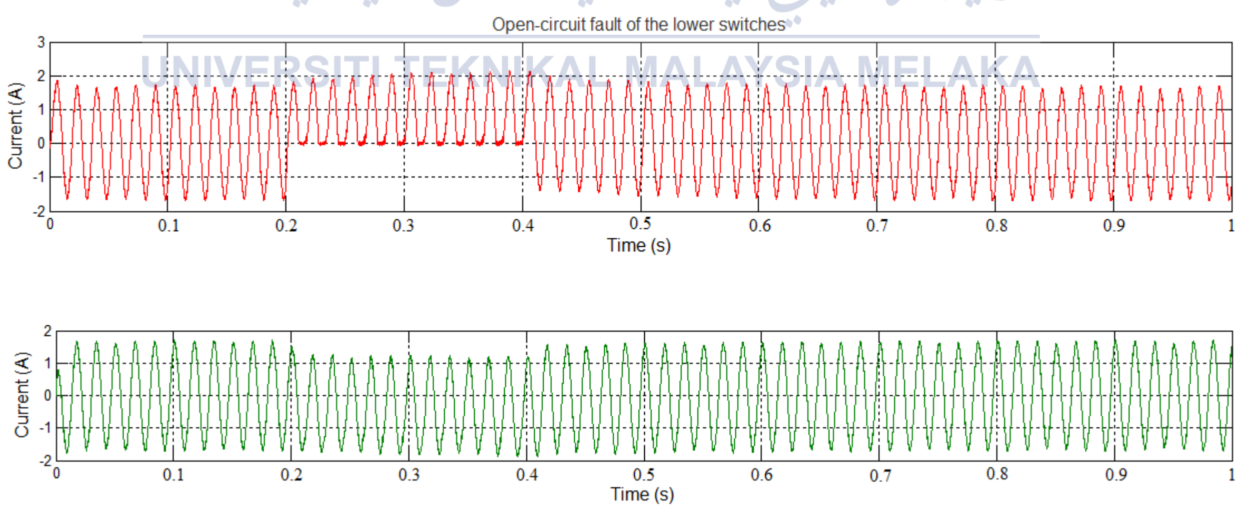


Figure 3.9: Signal of Open-circuit fault of upper switches

3.2.2.2 Open-circuit Fault of the Lower Switches

The Figure 3.10 shows the output current of three-phase VSI for open-circuit fault of the lower switch at S4. According to the signal, a fault occurs at 0.2- 0.4s is where current at phase A increase but phase B and C is decreased



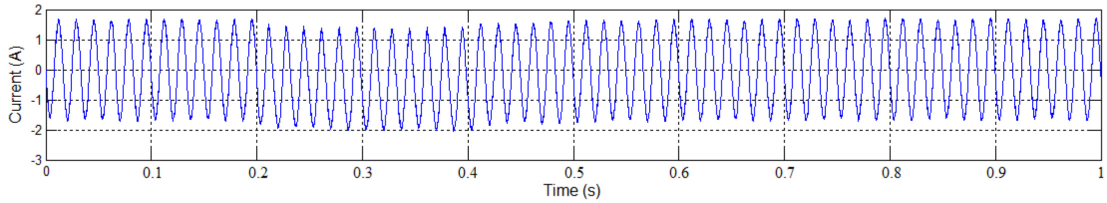


Figure 3.10: Open-circuit fault of the lower switches

3.2.3 Short-circuit Fault

3.2.2.1 Short-circuit Fault of Upper Switches

The Figure 3.11 shows the output current of three-phase VSI for short-circuit fault of the upper switch at S1. According to the signal, a fault occurs at 0.2- 0.4s where current at phase A increase while phase B and C is decreased.

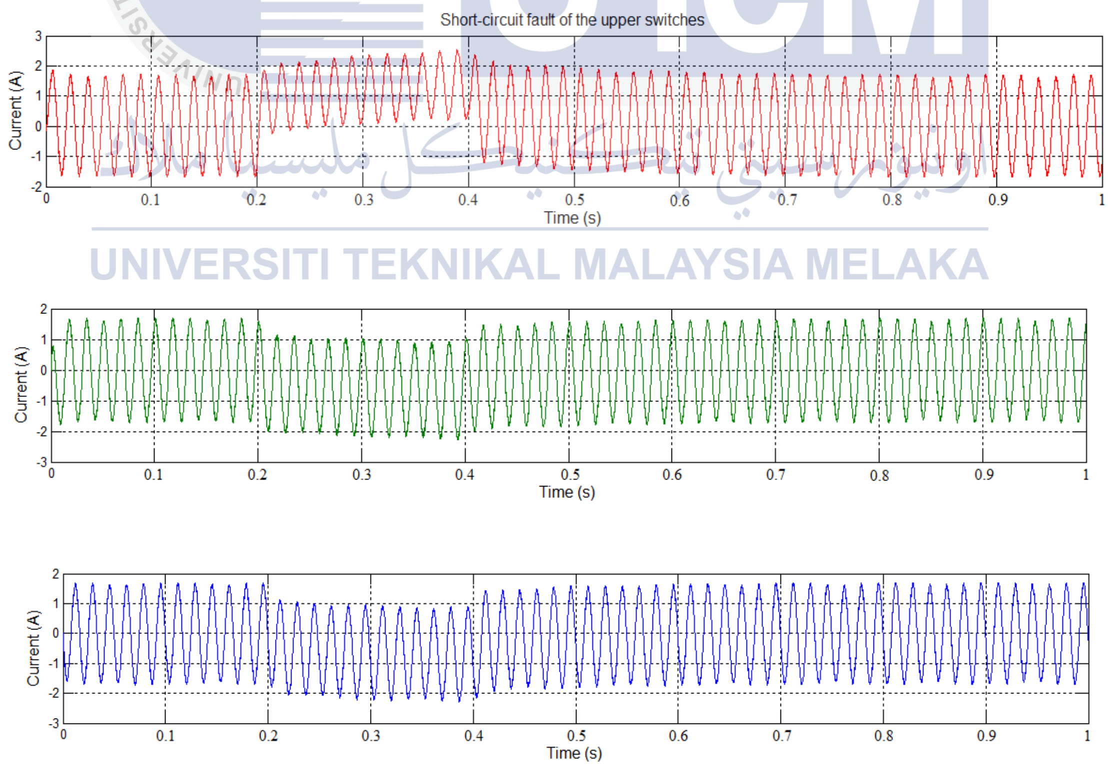


Figure 3.11: Short-circuit fault of the upper switches

3.2.3.2 Short-circuit Fault of the Lower Switches

Figure 3.12 shows the short-circuit fault signals of lower switch for three-phase VSI. The fault occurs in phase A. The current signal in phase A is decreased while for phase B and C have certain distortion.

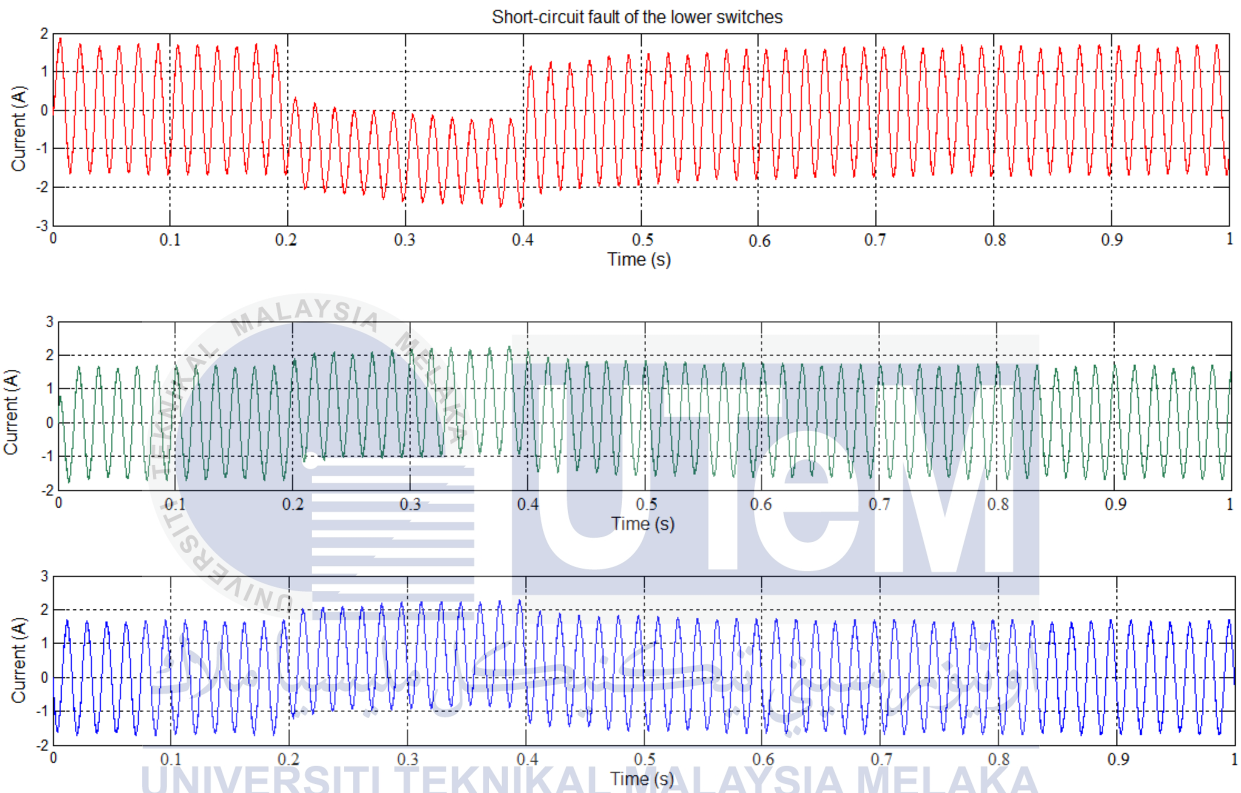


Figure 3.12: Short-circuit fault of the lower switches

CHAPTER 4

RESULT AND ANALYSIS

4.1 Short-Time Fourier Transform

The result of the voltage source inverter (VSI) analysis in open circuit fault and short circuit fault are represented at Figure 4.1 until Figure 4.12. The signal consists of three-phase which is phase A, phase B and phase C. The red colour represents phase A, green colour represent phase B and then phase C represent in blue colour.

4.1.1 Time Frequency Representation (TFR)

Time frequency representation (TFR) is used to analyze and characterize signal whose energy distribution varies in time and frequency.

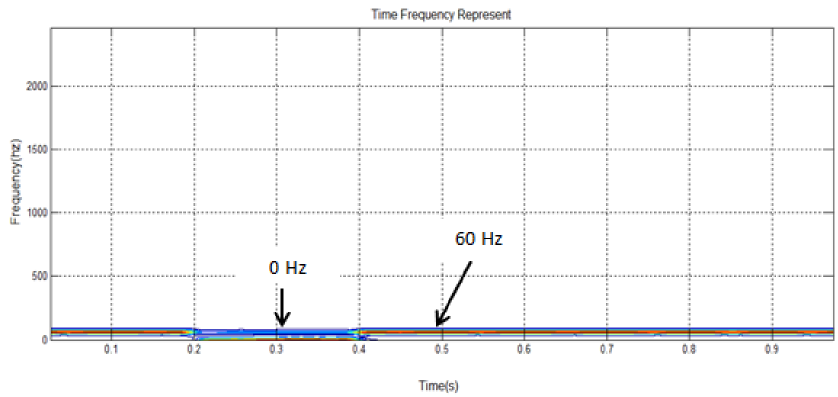


Figure 4.1: Time Frequency Representation of the fault signal for phase A

Figure 4.1 shows the time frequency representation (TFR) of the fault signal for phase A. TFR indicates that the fundamental frequency of the signal is 60 Hz and has a momentary power increase at 0 Hz (DC component) between 0.2- 0.4s.

4.1.2 Open-circuit Fault

4.1.2.1 Open-circuit Fault of the Upper Switches

For all phases, the parameters are estimated in per unit (pu) based on time-frequency representation (TFR). The fault occur at 0.2 – 0.4s and this situation occur at phase A. The average current shown in Figure 4.2. In Figure 4.3, the value of RMS current of the phase A is decrease between 0.2 – 0.4s compares with phase B and C. Total harmonic distortion (THD) used to measure harmonic distortion in the signal,. Harmonic have frequency that are integer multiples of the waveform's fundamental frequency. So the value of THD is zero because the fault signal only occurs at DC frequency component.

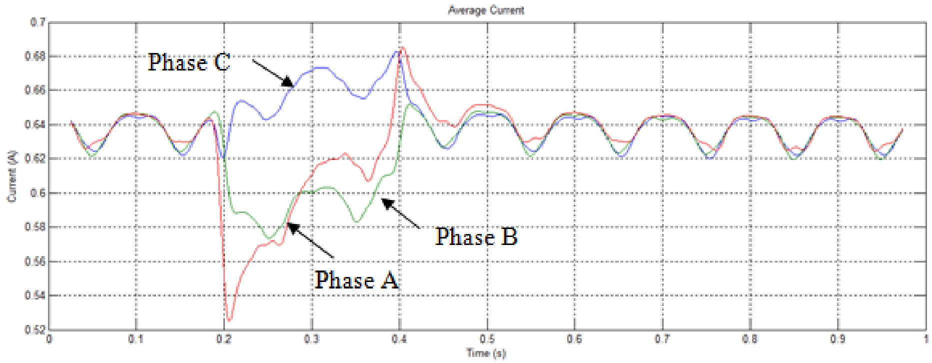


Figure 4.2: Average current of open-circuit fault (upper)

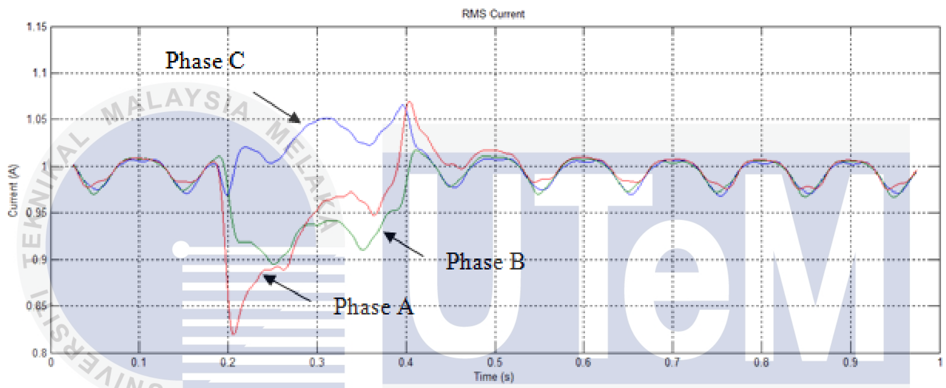


Figure 4.3: RMS current of open-circuit fault (upper)

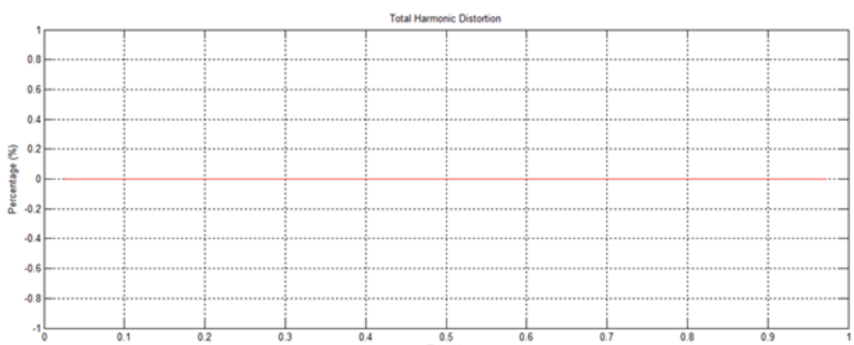


Figure 4.4: THD for open-circuit fault (upper)

4.1.2.2 Open-circuit Fault of the Lower Switches

Based on TFR, the parameter is estimated for phase A, B and C in per unit (pu). Figure 4.5 shows the average current of open-circuit fault of the lower switch. From the RMS current, the value for phase A is higher current while phase B and C is a lower current. This value shown in Figure 4.6. Total harmonic distortion (THD) used to measure harmonic distortion in the signal,. Harmonic have frequency that are integer multiples of the waveform's fundamental frequency. So the value of THD is zero because the fault signal only occurs at DC frequency component.

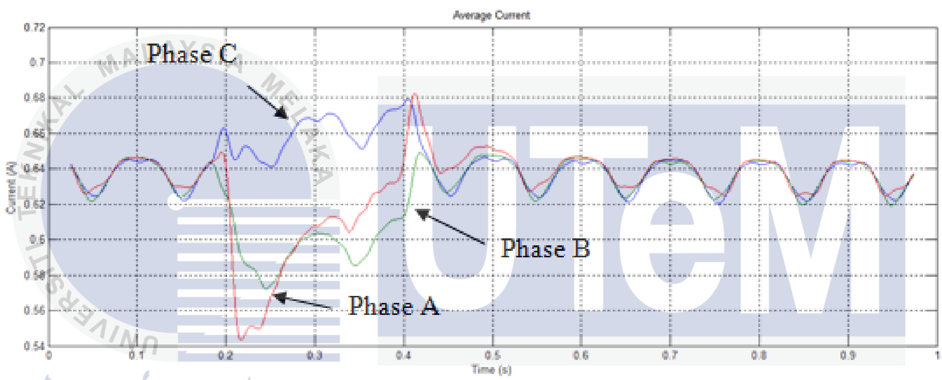


Figure 4.5: Average current of open-circuit fault (lower)

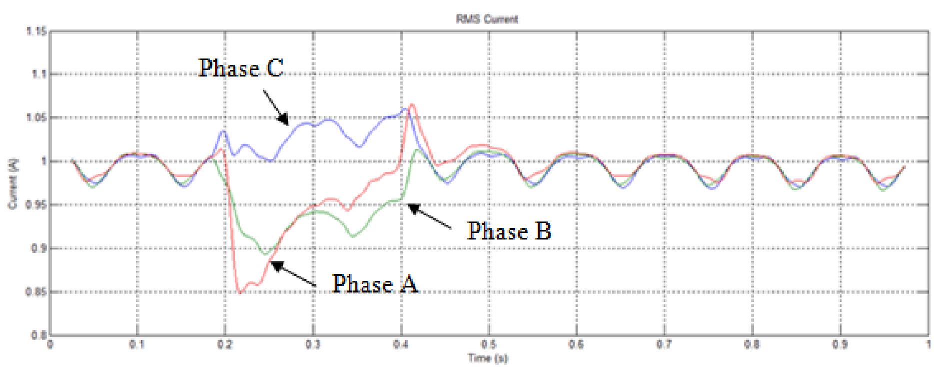


Figure 4.6: RMS current of open-circuit fault (lower)

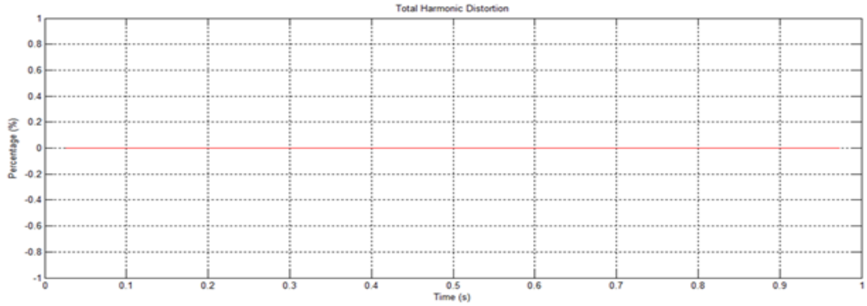


Figure 4.7: THD of open-circuit fault (lower)

4.1.3 Short-circuit Fault

4.1.3.1 Short-circuit Fault of the Upper Switch

Based on TFR, the average current, RMS current of the fault signal for all phases that estimated in per unit (pu). From the Figure 4.8, the average current of phase A is greater while phase B and C is lower between 0.2 – 0.4s. For the RMS current, Figure 4.9 shows phase A is higher than other phase. Total harmonic distortion (THD) used to measure harmonic distortion in the signal,. Harmonic have frequency that are integer multiples of the waveform's fundamental frequency. So the value of THD is zero because the fault signal only occurs at DC frequency component.

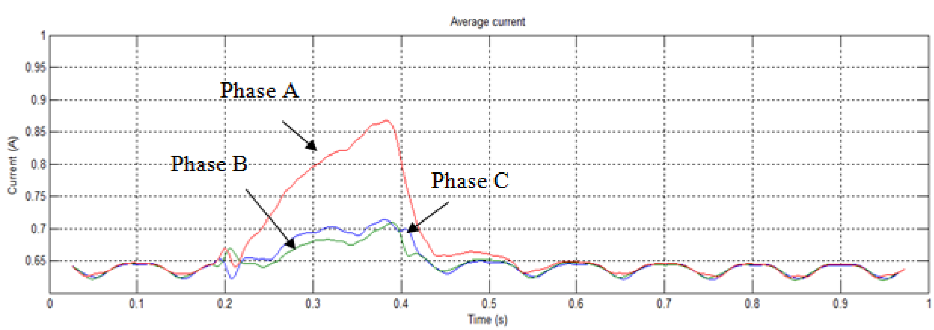


Figure 4.8: Average current of short-circuit fault (upper)

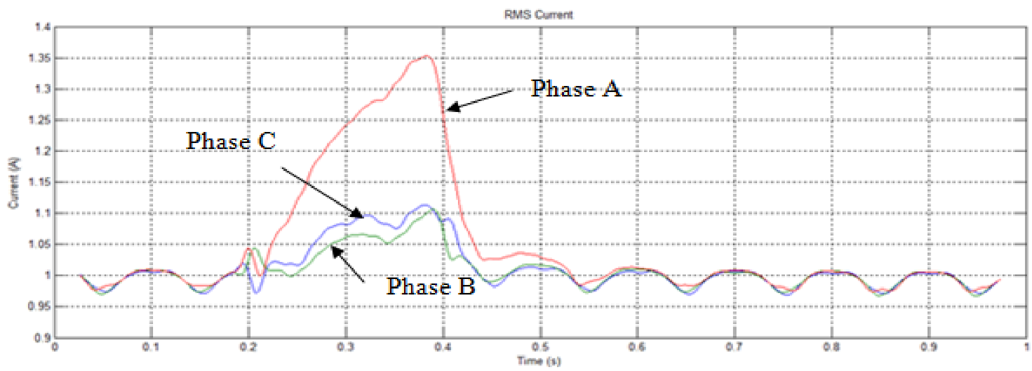


Figure 4.9: RMS current of short-circuit fault (upper)

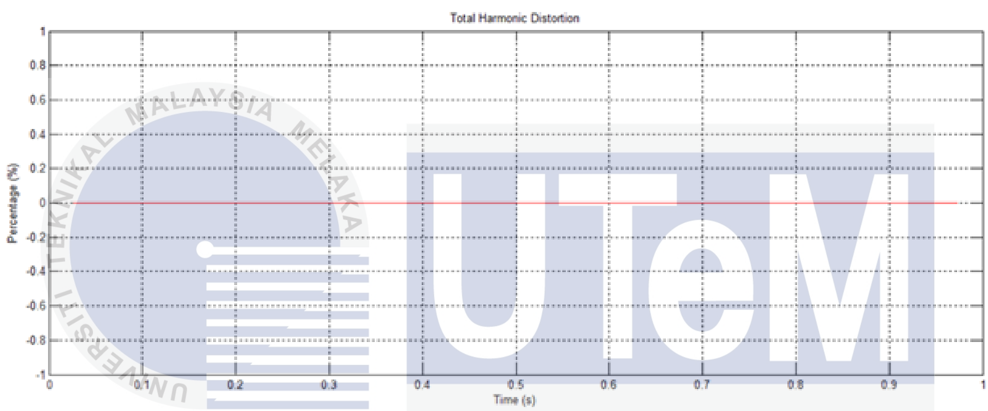


Figure 4.10: THD of short-circuit fault (upper)

4.1.3.2 Short-circuit Fault of the Lower Switch

The figure below shows the estimated of average current and RMS current of the signals for all phases. The fault occurs between 0.2 – 0.4s. The average current for all phase shown in Figure 4.11. From the Figure 4.11, the phase A is greater than phase B and C. While in the RMS current shown in Figure 4.12, the phase A is higher compare with phase B and C. Total harmonic distortion (THD) used to measure harmonic distortion in the signal,. Harmonic have frequency that are integer multiples of the waveform's fundamental frequency. So the value of THD is zero because the fault signal only occurs at DC frequency component.

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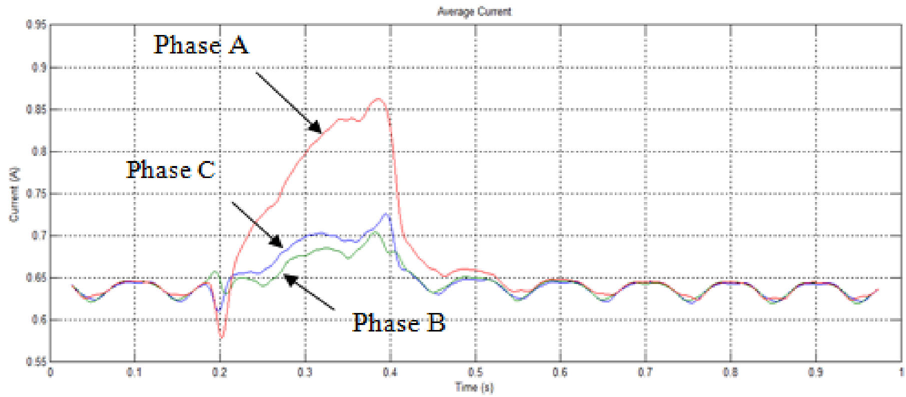

Figure 4.11: Average current of short-circuit fault (lower)

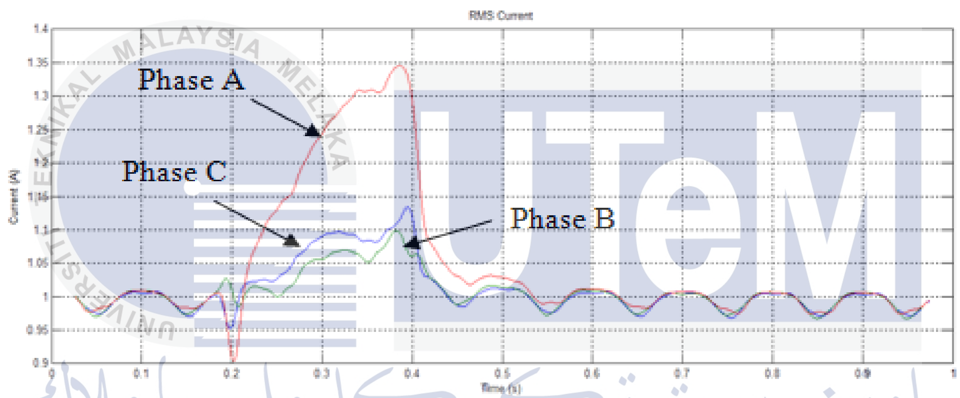

Figure 4.12: RMS current of short-circuit fault (lower)

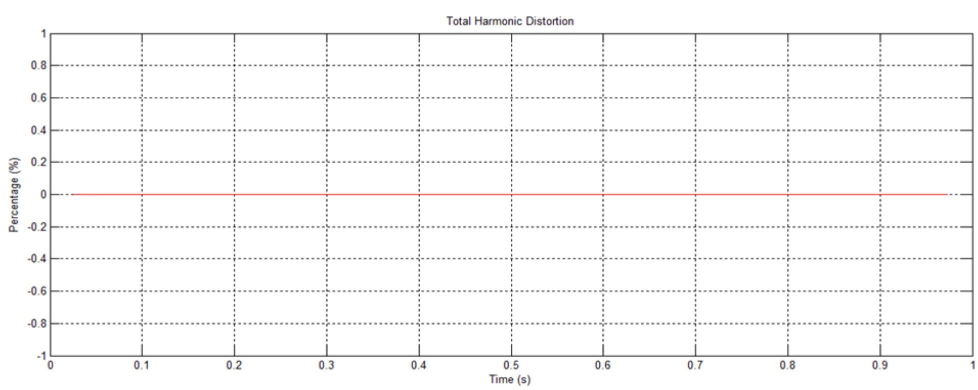

Figure 4.13: THD of short-circuit fault (lower)

4.2 Fast Fourier Transform

4.2.1 Frequency Spectrum

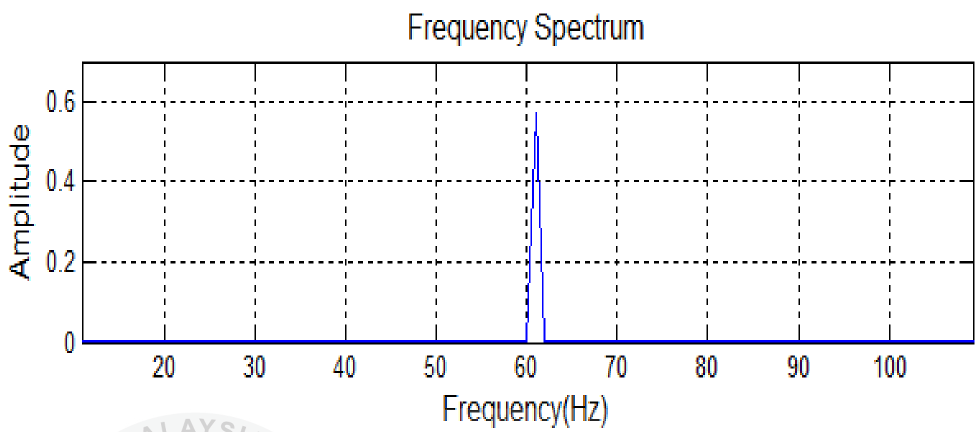

Figure 4.14: Frequency spectrum for phase A

Figure 4.14 shows the frequency spectrum for phase A. The fundamental frequency is 60 Hz.

4.2.2 Open-circuit Fault

4.2.2.1 Open-circuit Fault of the Upper Switches

Table 4.1: The value of RMS current, average current and THD for open-circuit fault of the upper switches

Open-circuit fault of the upper switches			
Phase	A	B	C
Iave	1.1470	1.1395	1.1643

Irms	0.4187	0.4133	0.4315
THD	0	0	0

Table 4.1 shows the value of RMS current, average current and THD for open-circuit fault of the upper switch. The average current and RMS current for phase C is higher than phase A and B. While the value of THD is zero percentage for the three phases.

Phase A

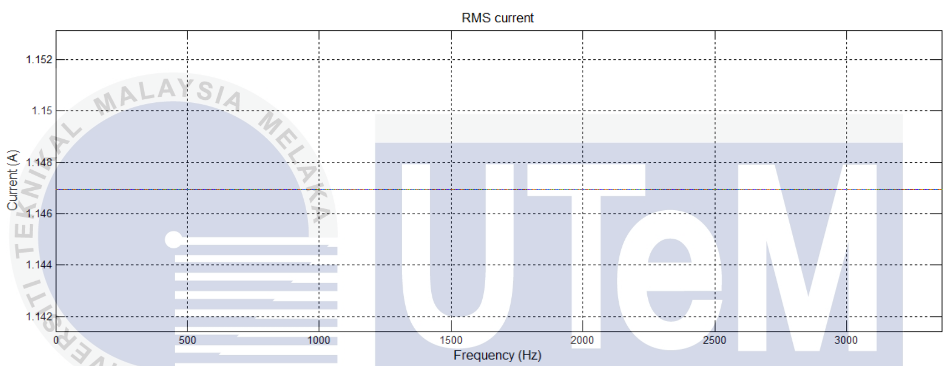

Figure 4.15: RMS current for open-circuit fault of the upper switch (phase A)

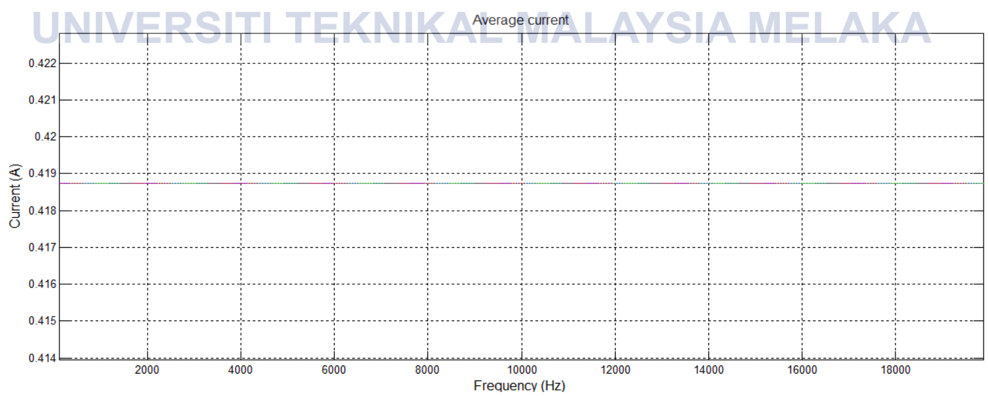

Figure 4.16: Average current for open-circuit fault of the upper switch (phase A)

Phase B

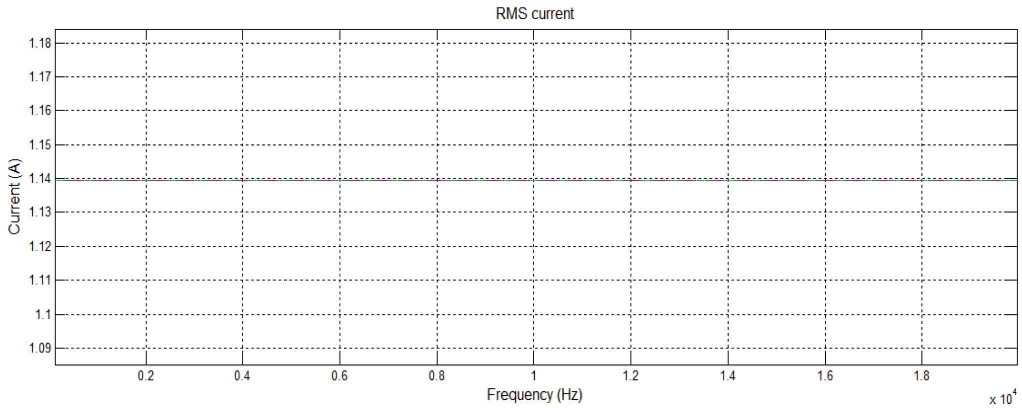

Figure 4.17: RMS current for open-circuit fault of the upper switch (phase B)

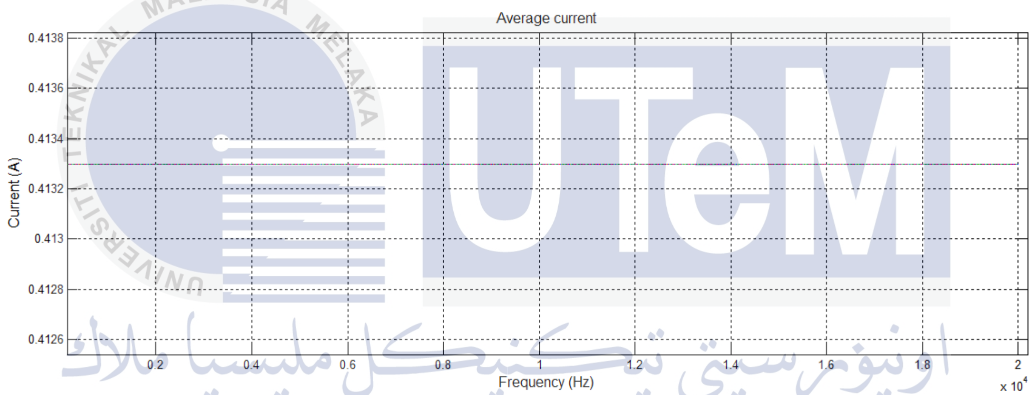

Figure 4.18: Average current for open-circuit fault of the upper switch (phase B)

Phase C

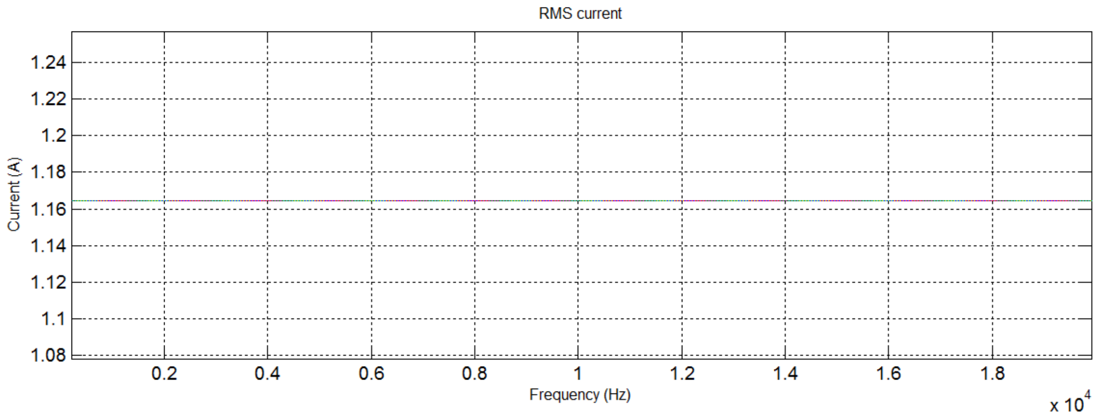

Figure 4.19: RMS current for open-circuit fault of the upper switch (phase C)

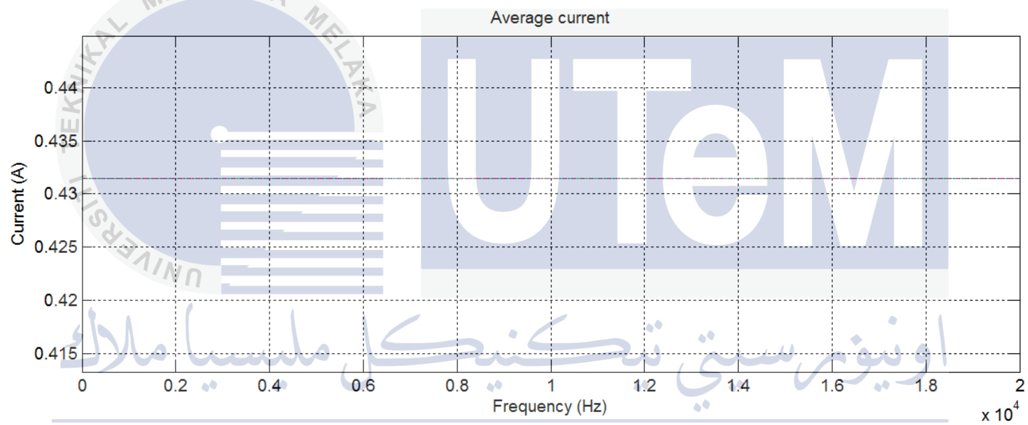

Figure 4.20: Average current for open-circuit fault of the upper switch (phase C)

The Figure 4.15 – Figure 4.20 shows the average current, RMS current and THD for phase A, B and C. The waveform is a straight line because it shows only one value. The frequency that exist in signal will exist throughout the entire duration of signal.

4.2.2.2 Open-circuit Fault of the Lower Switch

Table 4.2: The value of RMS current, average current and THD for open-circuit fault of the lower switch

Open-circuit fault of the lower switch			
Phase	A	B	C
Iave	1.1482	1.1392	1.1653
Irms	0.4197	0.4131	0.4322
THD	0	0	0

Table 4.2 shows the value of RMS current, average current and THD for open-circuit fault of the lower switches. The average current and RMS current for phase C is higher than phase A and B. While the value of THD is zero percentage for three phases.

Phase A

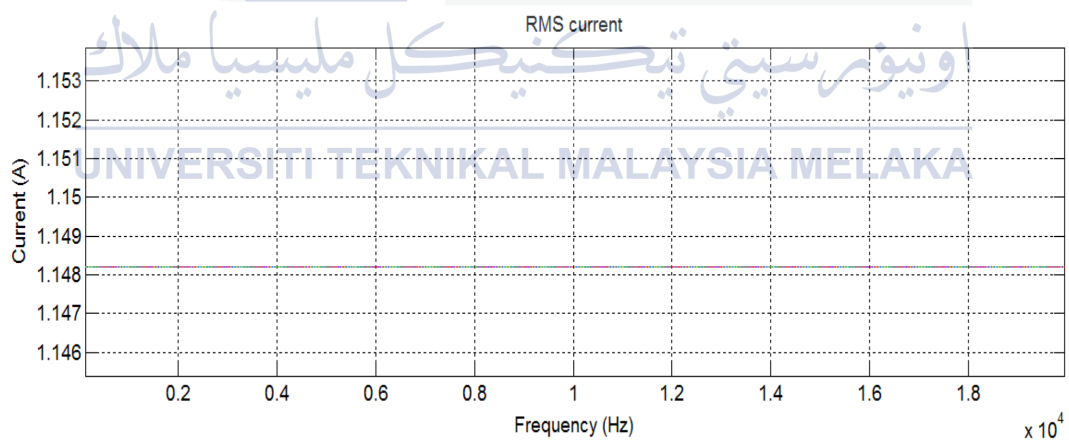

Figure 4.21: RMS current for open-circuit fault of the lower switch (phase A)

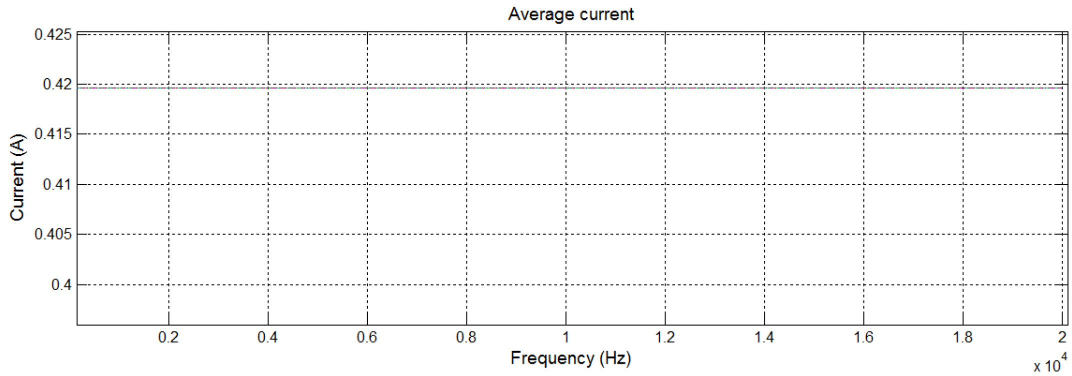

Figure 4.22: Average current for open-circuit fault of the lower switch (phase A)

Phase B

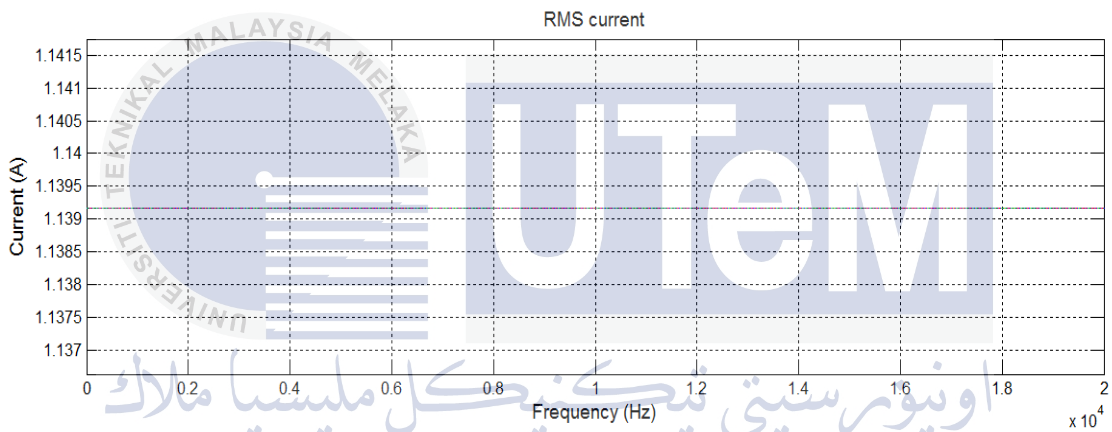

Figure 4.23: RMS current for open-circuit fault of the lower switch (phase B)

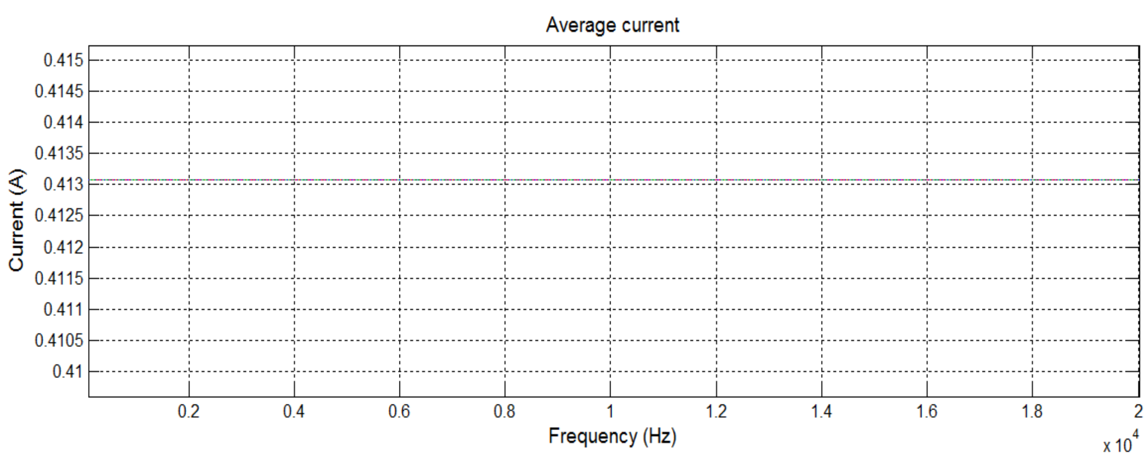

Figure 4.24: Average current for open-circuit fault of the lower switch (phase B)

Phase C

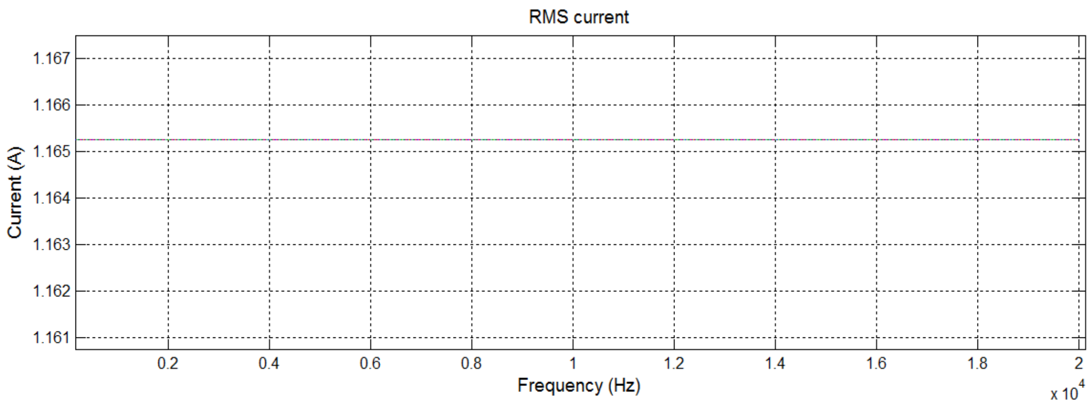

Figure 4.25: RMS current for open-circuit fault of the lower switch (phase C)

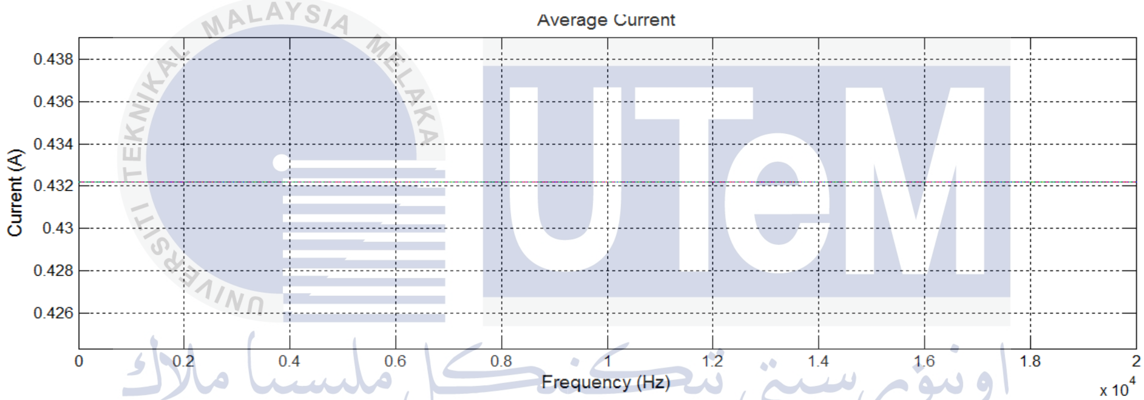

Figure 4.26: Average current for open-circuit fault of the lower switch (phase C)

The Figure 4.21 – Figure 4.26 shows the value of average current, RMS current and THD for phase A, B and C. The waveform is a straight line because it shows only one value. The frequency that exist in signal will exist throughout the entire duration of signal.

4.2.3 Short-circuit fault

4.2.3.1 Short-circuit fault of the upper switches

Table 4.3: The value of RMS current, average current and THD for short-circuit fault of the upper switches

Short-circuit fault of the upper switches			
Phase	A	B	C
Iave	1.2240	1.699	1.1752
Irms	0.4769	0.4357	0.4396
THD	0	0	0

Table 4.3 shows the value of RMS current, average current and THD for short-circuit fault of the upper switch. The average current for phase B is higher than phase A and C. While the value of RMS current for phase A is higher than others and the value of THD is zero percentage for the three phases.

Phase A

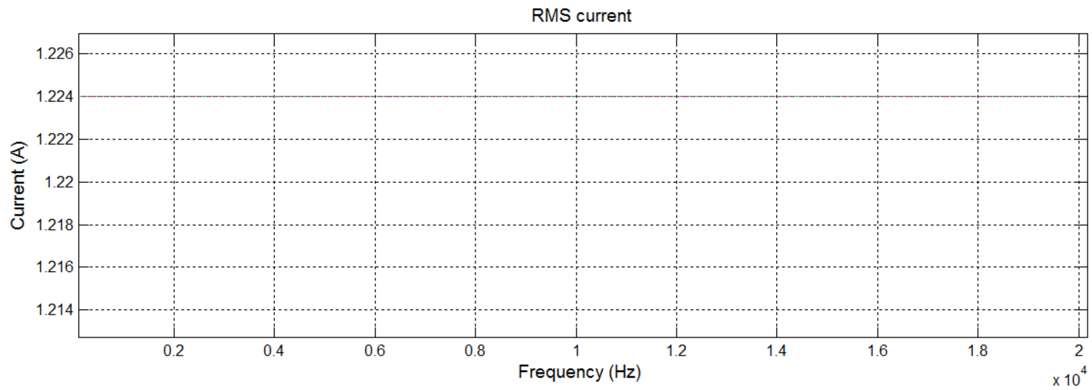

Figure 4.27: RMS current for short-circuit fault of the upper switch (phase A)

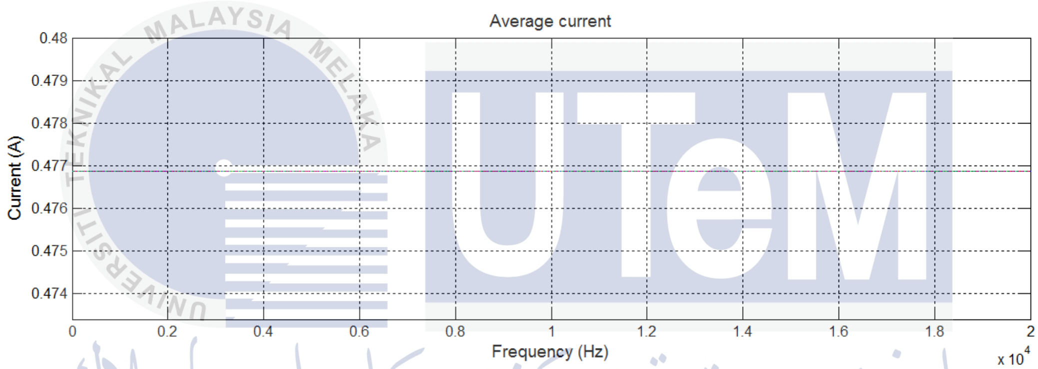

Figure 4.28: Average current for short-circuit fault of the upper switch (phase A)

Phase B

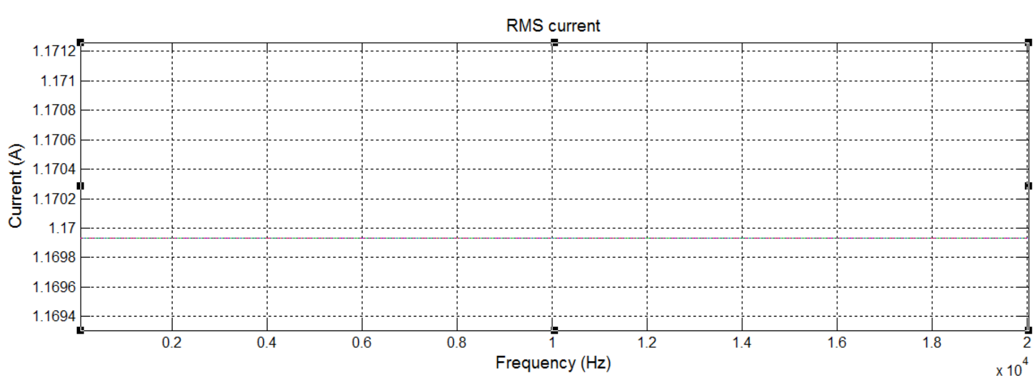

Figure 4.29: RMS current for short-circuit fault of the upper switch (phase B)

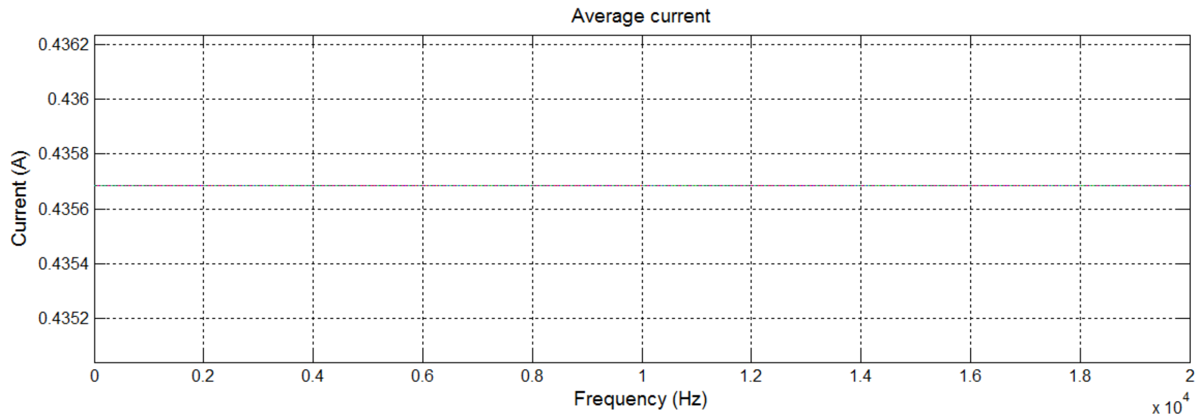

Figure 4.30: Average current for short-circuit fault of the upper switch (phase B)

Phase C

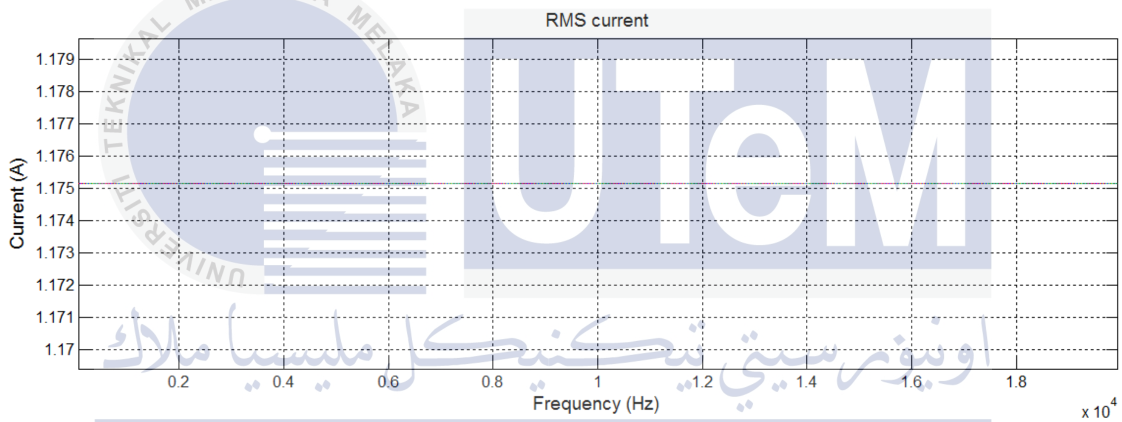

Figure 4.31: RMS current for short-circuit fault of the upper switch (phase C)

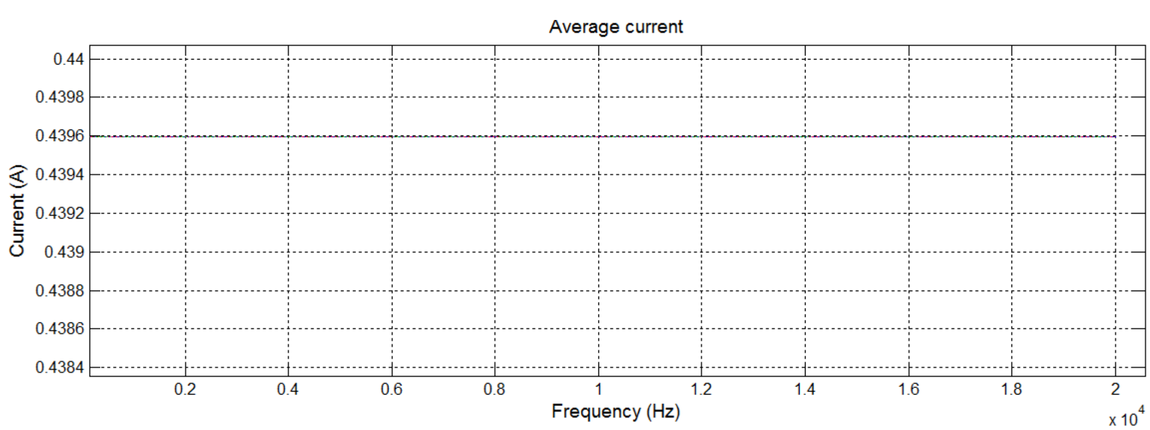

Figure 4.32: Average current for short-circuit fault of the upper switch (phase C)

The Figure 4.27 – Figure 4.32 shows the value of average current, RMS current and THD for phase A, B and C. The waveform is a straight line because it shows only one value. The frequency that exist in signal will exist throughout the entire duration of signal.

4.2.3.1 Short-circuit Fault of the Lower Switches

Table 4.4: The value of RMS current, average current and THD for short-circuit fault of the lower switches

Short-circuit fault of the lower switches			
Phase	A	B	C
Iave	1.2226	1.692	1.1751
Irms	0.4758	0.4352	0.4395
THD	0	0	0

Table 4.4 shows the value of RMS current, average current and THD for short-circuit fault of the lower switch. The average current for phase B is higher than phase A and C. While the value of RMS current for phase A is higher than phase B and C. The value of THD is the zero percentage for three phases.

Phase A

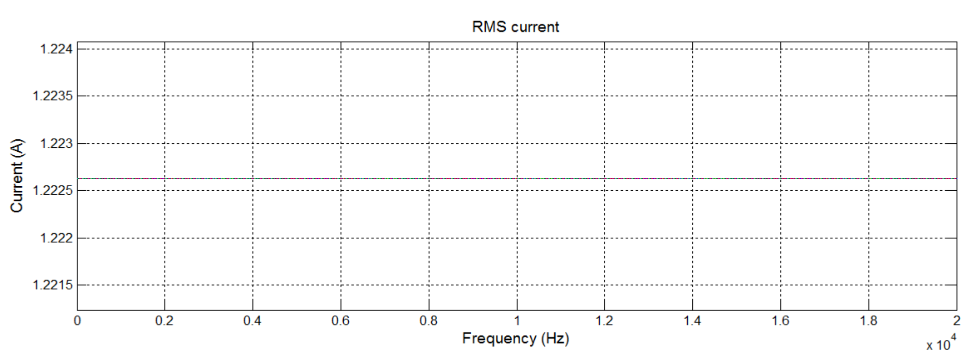

Figure 4.33: RMS current for short-circuit fault of the lower switch (phase A)

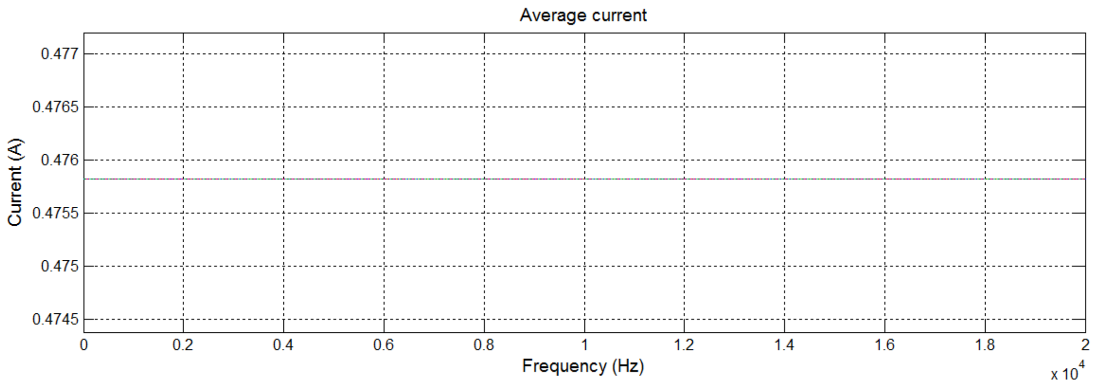

Figure 4.34: Average current for short-circuit fault of the lower switch (phase A)

Phase B

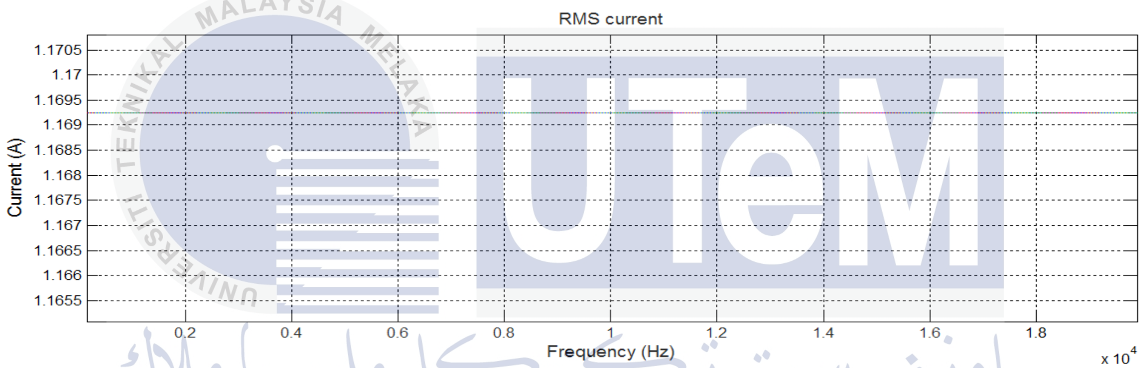

Figure 4.35: RMS current for short-circuit fault of the lower switch (phase B)

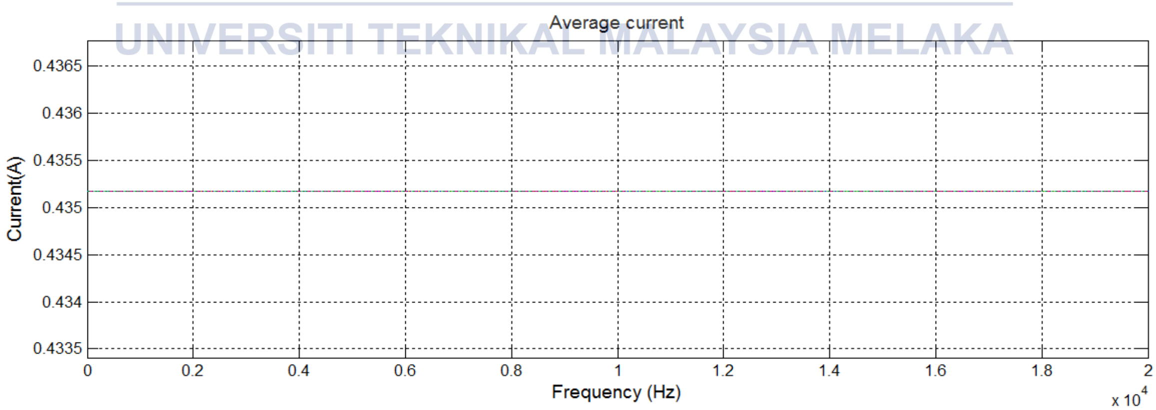

Figure 4.36: Average current for short-circuit fault of the lower switch (phase B)

Phase C

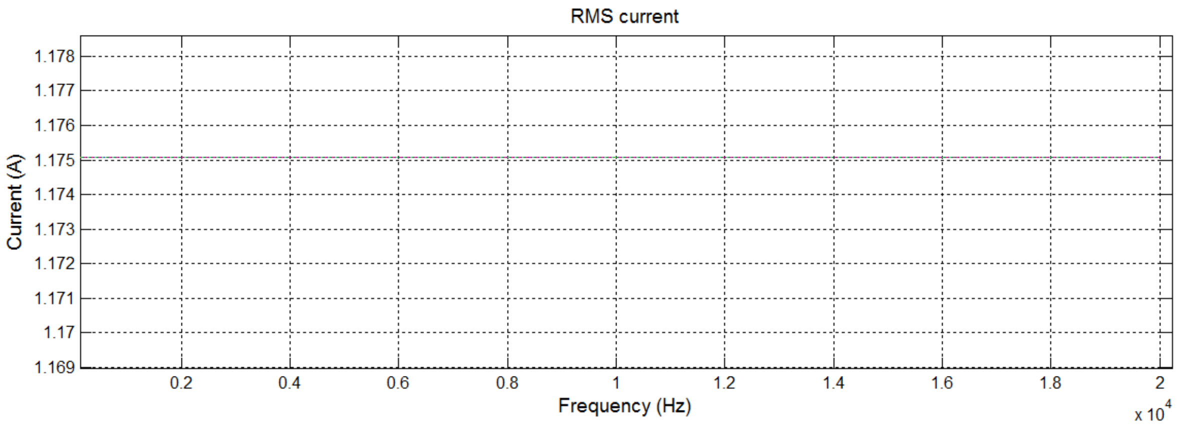

Figure 4.37: RMS current for short-circuit fault of the lower switch (phase C)

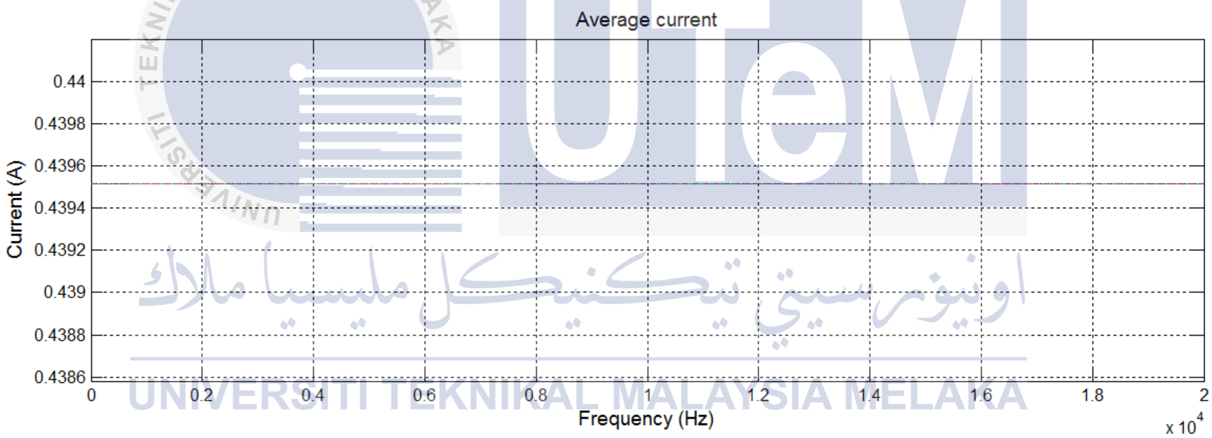

Figure 4.38: Average current for short-circuit fault of the lower switch (phase C)

The Figure 4.33 – Figure 4.38 shows the value of average current, RMS current and THD for phase A, B and C. The waveform is a straight line because it shows only one value. The frequency that exist in signal will exist throughout the entire duration of signal.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As a conclusion, this thesis has shown the estimated parameter such as average current, RMS current and total harmonic distortion (THD) to identify performance of open-circuit fault and short-circuit fault detection of voltage source inverter (VSI). The result is very important for monitoring, analysis fault condition and simulation for the open fault of switch and short fault of switch in voltage source inverter (VSI). It also can classify the upper and lower switch faults in short circuit and open circuit switches. This thesis has two techniques to detect the fault in VSI. The technique are short-time Fourier transform (STFT) and fast Fourier transform (FFT). The STFT is to capture the time variation in the frequency content of the signal while FFT is localized in the frequency domain. In this thesis, FFT not suitable for analyzing signal compare to STFT because FFT has various obstacles and limitations associated with time-frequency resolution where it is not possible to identify at what times these high frequency components occurred. In locating the fault position, time information is very essential and STFT become more useful while analyzing non-stationary signals.

5.2 Recommendation

Have several techniques to detect the fault in VSI. For this thesis use STFT and FFT technique. Then, for future work related this thesis will focus other techniques that are easier to detect fault.

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APPENDIX A: Coding of Short-Time Fourier Transform

```
clc;clear all; close all;
load('faultlowerS.mat')
N =20000;
f1=60;
Fs=20000;
ts=1/Fs;
Nw=1024;
fr1 = Fs/N;
fr  = Fs/Nw;
t1 =[0:ts:(N-1)*ts];
Nf1=(round(f1/fr)+1);
Thres = 0.1;
Iaveratio=0.5;

%%%% Generate signal  %%%%%
 %
x =faultlowerS(1:20000,1);
figure (1);plot (x);grid;

% H=10;
%
%
% %%%%%%%%%%%%%%%%%%STFT%%%%%%%%%%%%%%%%%

for n=1:N-Nw
x2(1:Nw)=x(1+n-1:Nw+n-1);
win=hann(Nw);
win=win';
y=x2.*win;
```

```
Y=(fft(y));
TFR(1:Nw,n)=Y(1:Nw);
end

%PLOT TFR
[Ny,Nx]=size(TFR);
freq=[0:fr:(Ny-1)*fr];
time=[(Nw/2)*ts: ts: ((Nx-1)*ts)+((Nw/2)*ts)];%half window shift


Hcomponent=zeros(1,Ny);
Hncomponent(8:Ny)=1;

for i=2:round(Fs/2/f1)-5;
        Hcomponent(round(i*f1/fr)+1)=1;
        Hncomponent(round(i*f1/fr)+1)=0;
end

%%%%%%%%%%%%%%%%IRMS STFT%%%%%%%%%%%%%%%%%%%%%%%

Nratio=1.5/sqrt(2)/0.6492;
Ibase=1.5/sqrt(2);
for n=1:Nx;
   Y2(1:Ny)=TFR(1:Ny,n);
   Y2(1:Ny)=Y2(1:Ny).*conj(Y2(1:Ny));
   It(n)=sum(Y2)/Nw/Nw;
   Irms(n)=sqrt(It(n));
   Irmsratio(n)=Irms(n)*Nratio;
   Irmspu=Irms/Ibase;
   Irmspu1=Irmspu*1.49;
   Iave1=Irms*0.9;
```

```
end

figure (2);plot (time,Irmspu1);grid;
figure (3);plot (time,Iave1);grid;

% % % %%%%%% B : FUNDAMENTAL CURRENT (I1) %%%%%% % %
% % % %%%%%% 1 - declaRE for function tem or location  %%%%%%%
for n=1:Nx

   temp=TFR(1:Ny,n);
   temp2=temp;

 %%%%%% 2 - calculate peak of signal
 %for n=1:Nx
   Fpeak=zeros(1,Ny);
   for k=2:Ny-1
      if (temp2(k) > temp2(k-1)) && (temp2(k) > temp2(k+1))&& (temp2(k) >= Thres)
         Fpeak(k)=1;
      end
   end

% %  %%%%% 3 - Identify Number of F1 component  %%%%%%
%for n =1:Nx

  if Fpeak(Nf1)==0
       I1(n) = 0.1;

  else
    i = Nf1;
      while (temp2(i) > temp2(i+1)) && (temp2(i)~=0)&& (i <=Ny-3)
         Nf1End=i+1;
```

```
            i=i+1;
            if (temp2 (i) < temp2 (i+1)) && (temp2(i)==0) && (i<=Ny-3)
            break;
            end
        end
    end
        Nf1Start=2;
        Nf1End=i+1;
      %figure(11);plot(Nf1);grid;title('Nf1')

      %I1(n)=(sum(temp2(3:6)))^0.5;
      I1(n)=(sum(temp2(Nf1Start:Nf1End)))^0.5;
      I1pu = I1/ I1(1);

% %%%%%% C : TOTAL HARMONIC DISTORTION (THD) %%%%%
%%%%%% 2 - Identify FHarmonic   %%%%%%%%%%

 FHarmonic=Hcomponent.*Fpeak;
 FnHarmonic=Hncomponent.*Fpeak;
%%%%% 3 - Calculate total harmonic %%%%%%%%%
%for n =1:Nx
Pharmonic=0;
%for k=Nf1+1:Ny
      if FHarmonic(k)==1
            NHStart=k;
            i=k;
            while ((temp2(i) > temp2(i-1)) && (temp2(i)~=0))
                NHStart=i-1;
                i=i-1;
            if ((temp2(i) < temp2(i-1)) && (temp2(i)==0))
              break;
```

```
        end
       end

        NHEnd=k;
        i=k;
        while (temp2(i) > temp2(i+1)) && (temp2(i)~=0)&& (i <=Ny-3)
           NHEnd=i+1;
           i=i+1;
           if ((temp2(i) < temp2(i+1)) && (temp2(i)==0))
             break;
           end
        end
        P0=(sum(temp2(NHStart:NHEnd)));
        Pharmonic=Pharmonic+P0;
     end
end

THD(n)=(((Pharmonic^2)^0.5)/I1(n));
 figure(20);plot(time,THD);grid;
(\%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

APPENDIX B : Coding of Fast Fourier Transform

```
clc;clear all;close all;
load('faultupperO.mat')
N0=20000;
fs=20000;
f=60;
```

```
Nw = 1024;
ts = 1/fs;
fr1 = fs/N0;
f1 =[1:fr1 :(N0)*fr1];
Nf1 = (round (f/fr)+1);
Thres = 0.00001;

%%%% Generate signal  %%%%%
x = faultupperO(1:20000,1);

%x=1*sin(2*pi*f*ts*(1:N0));

figure(1);plot(x);grid;

Y=fft(x);
Y=Y.*conj(Y);                 %Equation for energy
Y=Y/N0/N0;                    %equation for power
figure(2);plot(f1,Y);         %display frequncy domain ( FFT)

Ifrms = sum(Y)^0.5;           %%%rms value
figure (3);plot (f1,Ifrms);

Iave=sum(Y)/pi;
figure (4);plot (f1,Iave);

THD= Ifrms/Irms1
figure (5);plot (f1,THD);
```


APPENDIX C: Gantt Chart

Project Planning										
	2013				2014					
Project Activity	Sept	Oct	Nov	Dec	Jan	Feb	Mac	Apr	May	June
Confirmation										

for FYP title										
Research and study paperwork										
Identify objective and scope										
Proposal writing										
Design and simulation										
Data analysis										
Report writing										
Presentation										