DESIGN AND DEVELOPMENT OF ACTIVE POWER FILTER FOR HARMONIC REDUCTION IN ELECTRICAL DISTRIBUTION SYSTEM

NOR SYAMIMI FARHANA BINTI GHAZALI

A report submitted in partial fulfilment of the requirements for the degree of

Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2016

"I declare that this report entitle "Design and Development of Active Power Filter for Harmonic Reduction in Electrical Distribution System" and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)".

Signature :

Supervisor's Name : Associate Professor Ir. Dr. Rosli Bin Omar

Date : 24th June 2016

"I declare that this report entitle "Design and Development of Active Power Filter for Harmonic Reduction in Electrical Distribution System" is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature :

Name : Nor Syamimi Farhana Binti Ghazali

Date : 24th June 2016

ACKNOWLEDGEMENT

Firstly, I would like to thank Allah for giving me good health and will to finish this research paper. Other than that, a token of appreciation to my supervisors, Prof. Madya Ir Dr Rosli Bin Omar for my Final Year Project 1 & 2 for guiding me along the journey to complete this final year project. The foremost thanks to my family that always gives me support to complete this research. In addition, I would like to give my appreciation to my friend that helped me along the way to finish this project and special thanks to Siti Nordiana Binti Yunos because always be there for me in my upside down time.

Table of Contents **Pages**

List of figures **Page**

List of Table **Page**

ABSTRACT

Owing to the loads from power consumers and power equipment manufacturer, electrical equipment application has been grow drastically. These matters become more serious because the effect from the electrical equipment can cause high non-linear load for example electric drills, computer, TVs, printer and electronic equipment like thyristor converter, inverter and etc. This semiconductor can contribute in producing harmonics these is because the above load can produce non-sinusoidal currents from supply and lead to voltage distortion [1]. The effect from the harmonics to distribution system is it can increase a wire failure, overheating of transformer, low power factor, blackout in power system and in neutral current conductor, there is an excessive neutral current. To overcome harmonic distortion, passive and active filter is use. But, passive filter can cause resonance problem thus can affect the stability of the power distribution system. As for active power filter, it can use to extract the harmonic content [3].

For this project, two main objectives need to be achieved. First is to study the concept of active power filter (APF) for harmonic reduction in electrical distribution system and secondly, to model and develop active power filter configuration harmonic reduction. The distorted waveform in term of current and its controller based on PQ theory due to non-linear load in electrical distribution system will be monitored based on proposed circuit design with its controller using MATLAB/Simulink. The simulation results of currents and their THD at

source and load current will be discussed before and after compensation using active power filter (APF).

ABSTRAK

Disebabkan beban daripada pengguna kuasa dan pengeluar peralatan kuasa, permohonan peralatan elektrik telah berkembang secara drastik. Perkara-perkara ini menjadi lebih serius kerana kesan daripada peralatan elektrik boleh menyebabkan beban bukan linear yang tinggi sebagai contoh latihan elektrik, komputer, TV, pencetak dan peralatan elektronik seperti penukar thyristor, inverter dan lain-lain semikonduktor ini boleh menyumbang dalam menghasilkan harmonik ini adalah kerana beban di atas boleh menghasilkan arus bukan bentuk sinus dari bekalan dan membawa kepada voltan penyelewengan.

Kesan dari harmonik untuk sistem pengedaran adalah ia boleh meningkatkan kegagalan wayar, terlalu panas pengubah, faktor kuasa yang rendah, blackout dalam sistem kuasa dan konduktor semasa neutral, ada arus neutral berlebihan. Untuk mengatasi herotan harmonik, penapis pasif dan aktif digunakan. Tetapi, penapis pasif boleh menyebabkan masalah resonans dengan itu boleh menjejaskan kestabilan sistem pengagihan kuasa. Bagi penapis kuasa aktif, ia boleh menggunakan untuk mengeluarkan kandungan harmonik.

Untuk projek ini, dua objektif utama perlu dicapai. Pertama adalah untuk mengkaji konsep penapis kuasa aktif (APF) bagi pengurangan harmonik dalam sistem pengagihan elektrik dan kedua, untuk menjadi dan membangunkan aktif kuasa penapis konfigurasi pengurangan harmonik. Bentuk gelombang silap di dalam tempoh semasa dan pengawalnya berdasarkan teori PQ kerana tidak linear beban dalam sistem pengagihan elektrik akan dipantau berdasarkan reka bentuk litar yang dicadangkan dengan pengawalnya menggunakan

MATLAB / Simulink. Keputusan simulasi arus dan THD mereka di sumber dan beban semasa akan dibincangkan sebelum dan selepas pampasan menggunakan penapis kuasa aktif (APF).

CHAPTER 1

INTRODUCTION

This chapter covers the introduction of the project focusing on the research background. The motivation and significant of the research is will be explain in this chapter. Based on motivation, the problem statement of this project has been identified. The objectives for this project will be discussed briefly and the project scopes are determined and lastly, the report outline is implemented.

1.1 Introduction

Higher demand of power electronics equipment has contributed to increase in harmonics in the power system. One of the examples that contribute to higher current harmonics occurs is nonlinear load. These will lead to effect in a power factor reduction, decrease in efficiency, power system voltage instabilities and communications interference. It can be consider that harmonic can be categorized as pollutant in electrical power system. Conventionally, LC filters was used as a solution for the problems caused by the system harmonics, since they are easy to design, have simple structure, low cost and high efficiency but it also bring disadvantages like controllers many drawbacks. It provides only fixed compensation, generates resonance problems and is massive in size. To overwhelmed these weaknesses, active power filters are introduced which recompense for the current harmonics and reduces the total harmonic distortion. The APF is connected in parallel with the line through a coupling inductor. Its main power circuit contains of a three phase current source inverter with a DC link capacitor. An active power filter operates by generating a compensating current with 180 degree phase opposition and injects it back to the line so as to cancel out the current harmonics introduced by the nonlinear load. This will thus defeat the harmonic content present in the line and make the current waveform sinusoidal.

So the process includes of detecting the harmonic component present in the line current, producing the reference current, generating the switching pulses for the power circuit, making a compensating current and injecting it back to the line.

1.2 Motivation and Significant of the Research

Non-linear load can produce a distorted waveform in term of current and voltage in power system thus can reduce the performance of the system in short term or long term. The effect from the harmonic frequencies in the power grid is a common cause of power quality problems. Harmonics in power systems result in increased heating in the equipment and conductors, failing in variable speed drives, and torque pulsations in motors. Due to this, it is very important to protect the system supply from harmonic using APF. These devices will mitigate any harmonic due to nonlinear load.

1.3 Problem Statement

Current harmonics is very normal in electrical distribution system. The main problem of harmonic will distort electrical system due to high contents of harmonic. In order to avoid harmonic in electrical distribution, a proposed method based on filtering will be investigated. The proposed topology of a three phase active power filter will be modelling using MATLAB/SIMULINK. The load in electrical distribution system can be categories as linear and non-linear load. Non-linear load can produce non-sinusoidal current starting the load and top to distort and damage the electrical supply. Therefore, the current which contain high harmonic in system can be reducing. The main determination of this project is to design and develop of a three phase active filter for harmonic reduction in electrical system.

1.4 Objectives

Based on this project, objective that have been identified are as follows:

1. To study the concept of active power filter for harmonic reduction in electrical distribution system.
2. To model and develop active power filter configuration and its controller based on P-Q theory for harmonic reduction using MATLAB/SIMULINK.

1.5 Scope

The scope of this project will be focusing on model, develop of an APF based on P-Q theory. The performance of APF will be monitoring and analyzing before and after filter installation.

1.6 Report Outline

This report starts with the introduction of the research; the general view on harmonics reduction and active power filter is stated. Next, the motivation is build based on the previous research that have been done and upgraded it by using different ways. The problem statement is stated based on motivation. Then, the objectives to overcome the problem are itemized. Next, the research confines are stated in the project scope.

CHAPTER 2

LITERATURE REVIEW

For this chapter, it will cover theory and basic principle of active power filter, review of previous works and also summary and discussion of the review. For the section theory and basic principle, it covers the harmonics, the basic of active power filter and passive power filter. As for review of previous related works, it covers method use to mitigate the harmonic reduction in power system. Lastly, for the summary and discussion of the review it will extract the features of the previous study and try to implement to this project.

2.1 Theory and basic principle

2.1.1 Power Filter Topology

The limitation for the harmonic distortion is needed to be considering as a serious problem for both suppliers and also customer views. There are some standard that determine the maximum allowable for harmonic distortion. Two type of common filter is use which is capacitor and inductor. When there is any excessive harmonic current or voltage generated, the filter will be act to diminish the harmonic distortion.

The role of this filter is connected to the power system is to shrink the harmonic distortion also for the converter method it provide some of the reactive power to be absorb. By installing this filter, it will hoped that it can help to reduce the harmonic distortion and make power system become more stable and the power pollution plus low power factor can be overcome.

2.1.2 Introduction in harmonics

The distortion happen on current and voltage waveform is called harmonic distortion. Harmonic is produce when there is non-linear load occurs in electric power system and can affecting the line systems [2]. Thus, it will affect the high losses for the system and also the quality of power produce. This phenomenon in the power system is not new. So, this is very important to overcome or to reduce the harmonic reduction.

Cause of affecting harmonic is the current flow is too high. Besides that, the length of the cable also can affect the high voltage distortion; it also can come from inverters, DC converters, switch mode power supplies, and AC or DC motor supplies [3]. There are many ways to overcome this problem. The basic thing that can be done by adding the filter means that by blocking the current flow or supply the harmonic current. Besides that, modify the frequency response also can prevent this happens by filter, capacitor or inductance. Plus, by reduce the harmonic current from the source also can be one of the ways [4][5].

There are two types of harmonic, current harmonics and also voltage harmonics. As for current harmonics, it occurs when a non-linear load for example rectifier has been mention above is connected to the system and draws a current that is so complex in sinusoidal waveform depending on the type of load used. So, it is impossible to produce a perfect and smooth sinusoidal waveform. As for voltage harmonics, it caused by the current harmonics. Due to the source impedance, the voltage produce from the voltage source will be distorted from the current harmonics. If the source of voltage impedance is small, the voltage of harmonics also small due to current harmonics [2] [3].

2.1.2.1 The Impact of Harmonic in Electrical Distribution System

Based on power regulation and consumption, power quality becomes the main role in producing the high quality of power. When there is a harmonic in a system, it gives drastic effects onto the system. Harmonics occurs when power source acts as non-linear load. Below is an example of impact of harmonic in electrical distribution system.

- Transformers

Due to increase iron losses, it will affect the harmonics current at harmonic frequency and will result increase in core losses for example eddy current and hysteresis. If high rate of voltage is present, it will cause copper losses increase and stray flux losses produce heating and winding insulation stresses. Temperature cycling and resonance between transformer winding inductance and supply capacitance can contribute to additional losses. Normally, “K factor” rated unit be present typically acclaimed for non-linear load especially the distribution transformers used in four wire [6].

- Induction Motors

As in similar way, affect of harmonic distortion cause the raise of losses in AC induction motor. Thus, it can produce motor heating, due to losses iron and copper in the stator winding, rotor circuit and rotor lamination. Harmonic current in the stator and rotor end windings produce additional stray frequency eddy current dependent losses because of leakage magnetic field. Due to high frequency induced current and rapid flux changes in the stator and rotor, it will produce iron losses. Overheating can reduce the bearing lubrication and effect in bearing collapsed. The life span of the motor also can be reduced to 50% if the overheating always occurs. The squirrel cage motor can withstand in high temperature rather than wound motor [6].

- Cables

When the impedance is least, the current tend to flow near the surface of the conductor and this phenomenon called Skin Effect. This phenomenon occurs due to the arrangements of inductance of conductor is in closely parallel in one another. This effect depends on the conductor size, frequencies, resistivity and the permeability of the conductor material. When

- Lighting

A repeated fluctuation in light intensity is one of the phenomenon's that we called "flicker". Lighting is highly sensitive to rms voltage changes even there is only a slight deviation is perceptible to human eyes in some types of lamps. Causes of light flickers in incandescent lamp and fluorescent lamp are superimposed interharmonic voltage in distribution systems [6].

2.1.3 Types of devices been used in electrical distribution system in order to mitigate harmonic.

Other types of devices that can mitigate the harmonics besides filter is as follow:

- ✓ Using 6 pulse, 12 pulse, 18 pulse or 24 pulse rectifier

Six-pulse diode rectifier is the common rectifier use in three-phase PWM drives. The advantage of this rectifier is, rugged, robust and cheap but the input current have high low order harmonics. Two six-pulse rectifier have to be connect in parallel to feed the same DC bus for twelve pulse rectifier to be formed. By fed through a special transformer with two secondaries, it produce a smooth current waveform other than single six-pulse rectifier. The 18 and 24 pulse have same by connecting three or four six pulse rectifier and it cost a lot for the installation [14].

- ✓ Using an active IGBT rectifier

An active Insulated Gate Bipolar Transistor (IGBT) rectifier is a rectifier that can be used to control the power from the source of network. This can effect the power factor to be close to unity as rectifier is use to decrease the harmonic.

The advantage of IGBT rectifier is low sinusoidal current, unity power factor, voltage boost capability and possibility to generate reactive power. Compare to diode rectifier, the main drawback is high [15].

- ✓ Pulse Width Modulation Technique (PWM)

Pulse Width Modulation Technique (PWM) is a modulation technique used to encode a massage into signal pulse. PWM have two types which is Sinusoidal Pulse Width Modulation and Non-Sinusoidal Pulse Width Modulation.

- ✓ Sinusoidal Pulse Width Modulation

In sinusoidal pulse width modulation, all the pulse are modulated individually. Each pulse have to be related to the orientation sinusoidal pulse before being modulate . after that, it will create a waveform which is equal to the reference waveform [13].

- ✓ Non-sinusoidal Width Modulation

For non-sinusoidal width modulation, all pulse that have the equal pulse width will be modulated self-possessed. To remove the harmonics of the systems, the pulse width of pulse are attuned together in same quantity [13].

2.1.4 Active Filter

Modern active filter harmonic is more specialize in filtering performance, smaller in physical size and also more flexible in application. The highlight part for this filter is that it is faintly lower in cost and operating losses. This active filter can be divided into two categories which are single phase filter and three phase filter. Mostly, researcher only focus on three phase filter because single phase filter are narrow to lower power application nonetheless for electric traction or rolling stock[7][8] .

Besides that, active filter can be classified into Pure Active Filters and Hybrid Active Filters based on circuit structure. For Pure Active Filters, it can be used for example voltage source PWM with dc capacitor or current source PWM with dc inductor. Between this two, mostly voltage source PWM with dc capacitor is use due to cost, physical, size and efficiency. For Hybrid Active Filter, it consists of single or multiple voltage-sources PWM converters and also passive components (Capacitor, inductor and/or resistors). Hybrid Active Filter is more attractive than Pure Active Filters because of viability and economical points of view, and also particularly for high power application [9].The combination of series and parallel filter configuration is called as Hybrid Active Filter. These combinations can bring a lot of advantages to the both active and shunt filter. Besides that, the characteristics for shunt can be upgrade [10].

2.1.5 Passive Filter

Passive filter is commonly used to limit the flow of current in distribution system. But, only a few of harmonics only can be used and they also can produce resonance in power system. For each of frequency, a separate filter is needed. Two main components are used in this passive filter which is inductor and capacitor. Usually, shunt-tuned LC filters and shunt low pass LC filter is used among others passive filter.

The advantages for passive filters is simplicity, reliability, efficiency and cost but on the bad sides is that, this passive filter produce multi resonance into the AC supply as mention before [11][12]. Two types of passive filter that currently used in power system to reduce harmonic distortion, Shunt Passive Filter and Series Passive Filter. Single phase and three phase power system can use this type of filter. But, there are slightly diverse between this filter. Firstly, the series passive filter can carries full load current but for the shunt passive filter can only carry one part of the total load. Besides that, the series filter more expansive relate to the shunt passive filter [11] [12].

2.2 Review of previous related works

2.2.1 Fourier Analysis Control Method on parallel APF

This method is use to determine the magnitude and frequency for the harmonics. A harmonics component is called if the sin wave has a frequency which is on the multiple of fundamental frequency. From any non-sinusoidal waveform produce, it can be separated into pure sine wave. [20]

Harmonics in the system are creating by taking the Fourier transform of load current. And these harmonics are combined to create reference signal. With this transformation, wanted harmonic component or components can be deliberate in the system. From the Fourier series, the main parameters that take are load current. Then, the harmonics that produce will be combined together and become a reference signal. From that, the value of current load and voltage will be calculated based on this transformation. [18][19]

The main parameter for this method is magnitude of fundamental harmonic and phase angle of fundamental harmonic. This can be obtained by the formula. After calculate phase angle, the sine wave will be produce from the phase locked loop (PLL). For magnitude of fundamental harmonic, it will be combining with the sine wave but current loss at inverter will be loop back to the system. [21]

Finally, after first harmonic current be obtained from load currents it will be diminish and harmonic current can be found from power line. Reference signals are generated by reversing the harmonic currents. By subtracting the reference current from active filter, error signal will be generated then it will transmit to hysteresis band in order to eliminate the harmonics. The inverter will be function (on/off) based on trigger signal of Pulse Width Modulation (PWM).

2.2.3 Synchronous Reference Frame Control Method on Parallel Active Power Filters

Based on synchronous reference frame control method APF application, voltage and currents from three phases is converting to synchronous rotating reference frame control method in system voltage. Harmonic and reactive current from the load will be identified by using SRF control method and the case of non-linear load. [22]

Next step in synchronous reference frame control method on parallel active power filters is determine the value of Id and Iq based on types of compensation of APF. To ensure that the harmonics and reactive power eliminate, Id current in AC should be found. Id current will be obtained by passing through high pass filter (HPF). The obtained reference currents to eliminate harmonics in power line are directed to hysteresis current controller as Fourier transform.

Currently APFs offers an effective solution method on power quality problems. Topological structure and control method of APFs are parameters to be taken into thought to solve existing problems. Performance of both two methods have compared in terms of harmonic currents compensation and reactive power compensation. Based on experiment that have been conducted, with parallel active power filter based on FA algorithm, THD value of harmonic current in power line has reduced from %29.11 to %2.30. Additionally with PAPF based on Synchronous Reference Frame algorithm, THD value of harmonic current in power line has reduced from %29.11 to %2.32. The gained simulation results have showed that compensation of both methods is successful. At the same time THD value of current harmonics is under predetermined international standards. It has been practical that FA control method is a bit more successful in terms of both harmonic compensation and reactive power compensation.[22][21]

2.3 Summary and discussion of the review

From the review, this project is going to obtain the sinusoidal waveform by using PID controller. This is because this is easy to use and non-invasive. The inverter use is IGBT. The reason why is been chosen is because it guarantee compliance with IEEE 519 1992 if sized correctly. Besides that, it's providing VAR currents and improving system power factor.

From the literature review, they are many methods of feature extraction that can be performed to the harmonic reduction. However, the feature extraction methods that will be used to the harmonic reduction are the active power filter. This is because; active power filter is popular in time domain features of harmonic reduction rather than passive power filter.

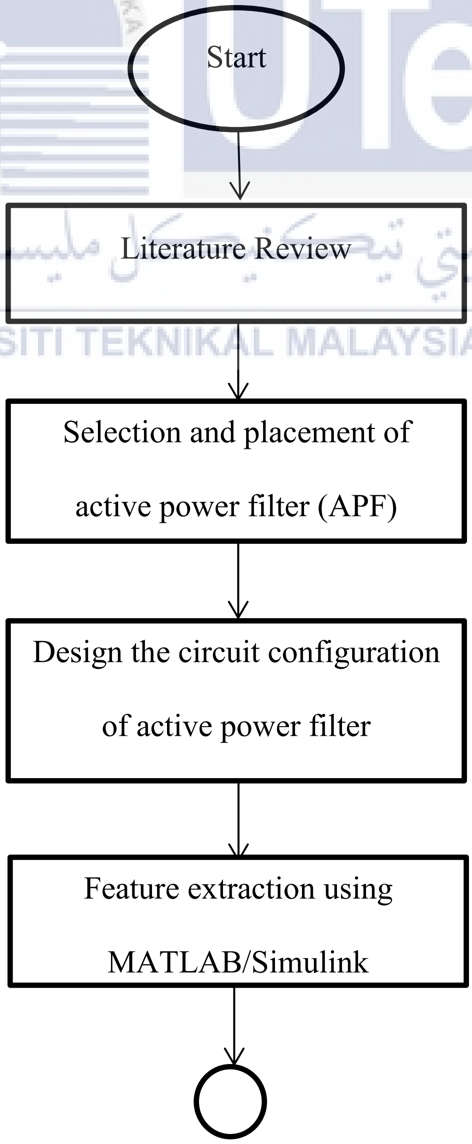
There are many techniques that can be done to analyse the performance of the feature extraction methods. In this research, the performance of active power filter feature extractions will be analysed by computing its THD values and current at load.

CHAPTER 3

METHODOLOGY

In this part, several procedures are conducted to fulfill the objectives. The step to get the result has been shown above.

3.1 Flowchart



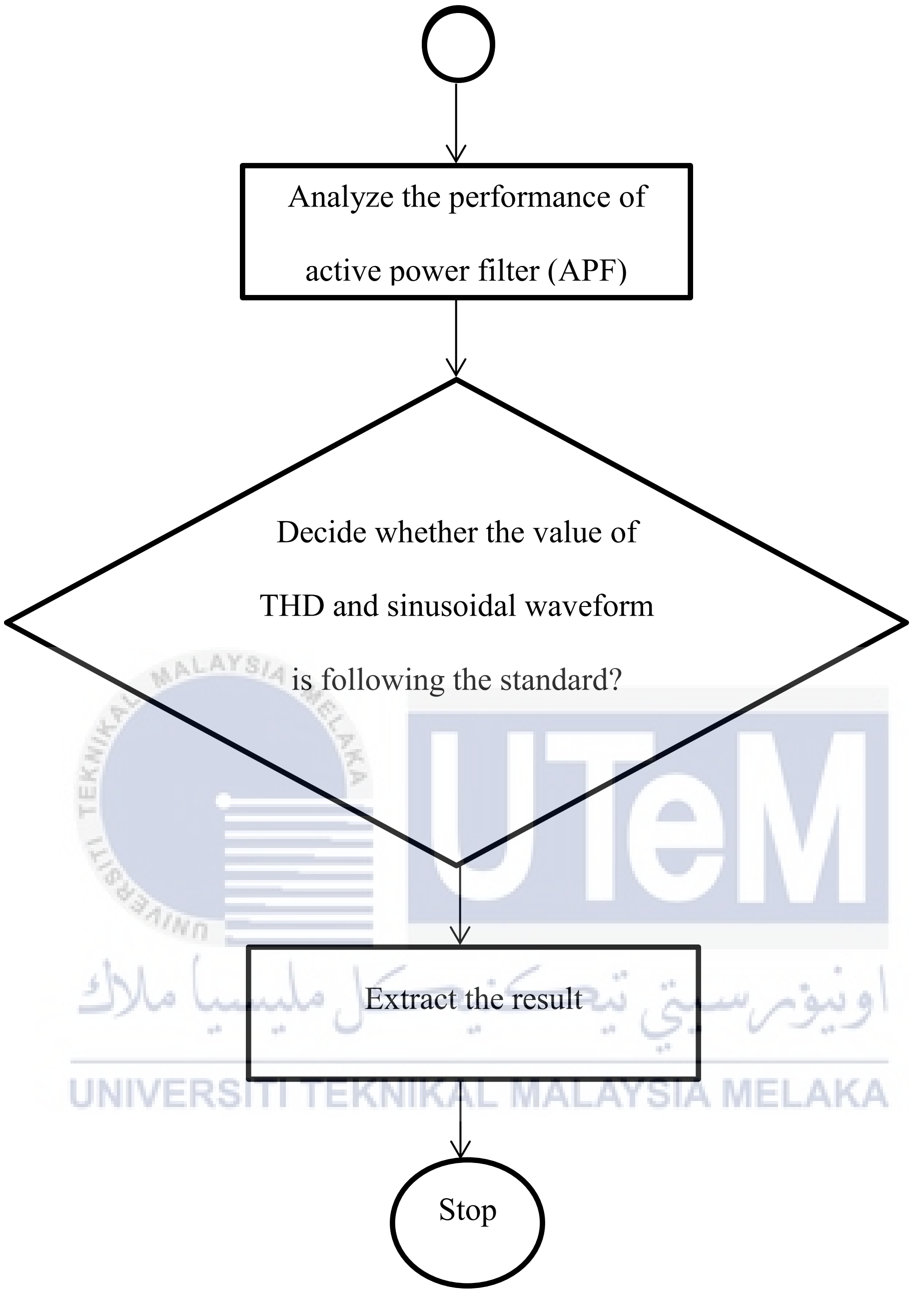


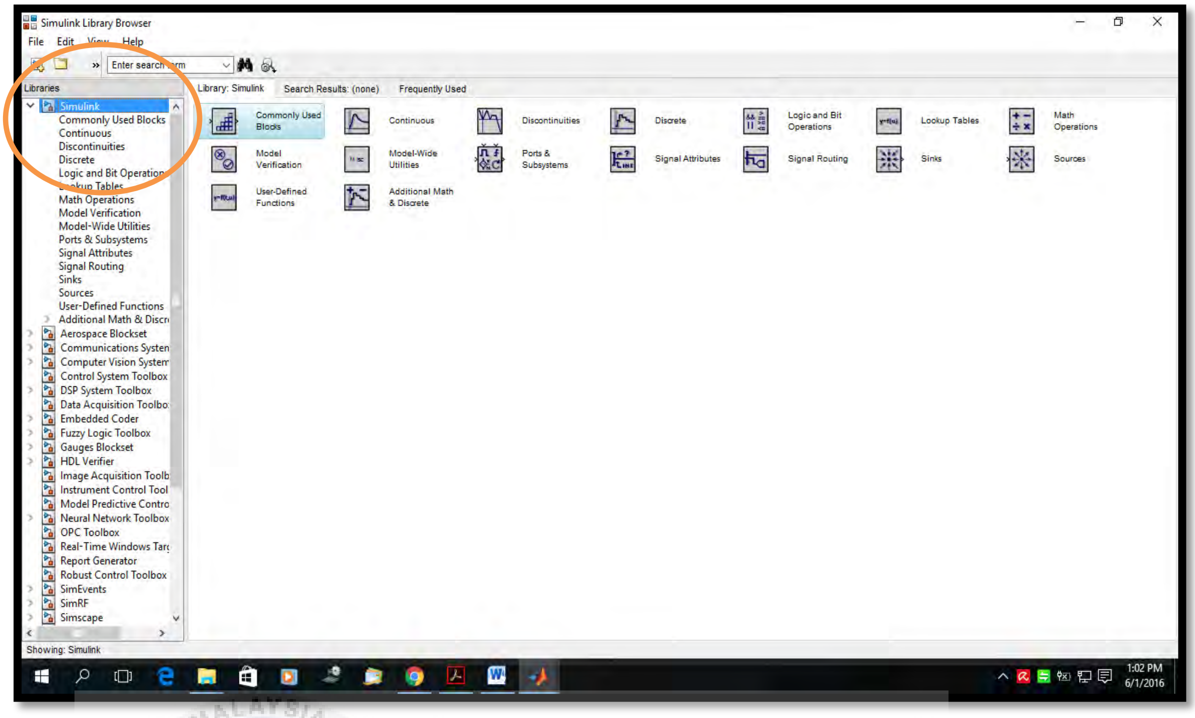
Figure 3.1: The flowchart of the methodology

3.2 Steps involves in simulation

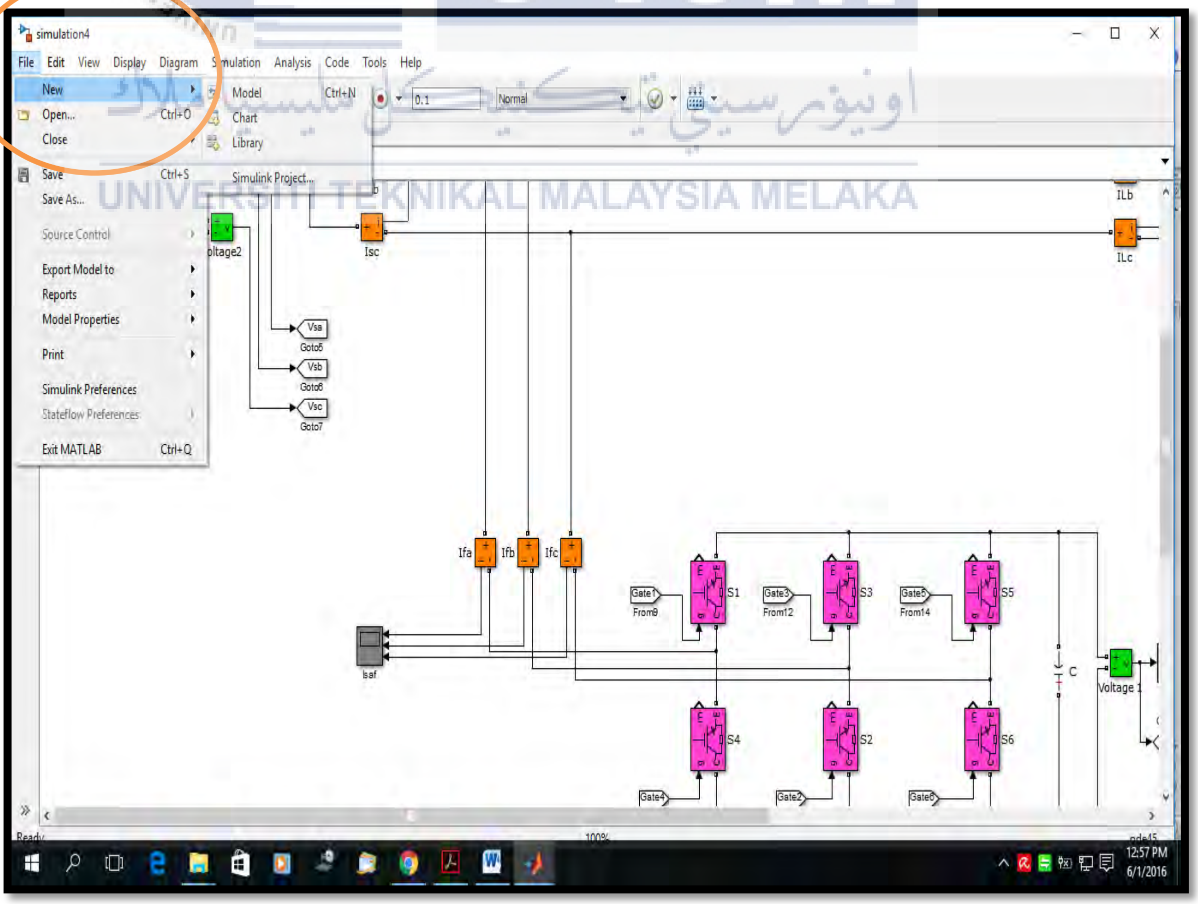
Investigates of the projected converters were carried out using MATLAB/Simulink. MATLAB/ Simulink established by math works is a graphical programming environment for modeling, simulating, analyzing multi domain dynamic systems .Its main interface is a graphical programming tool and a customizable set of block libraries.

1. Start MATLAB by click the MATLAB icon.

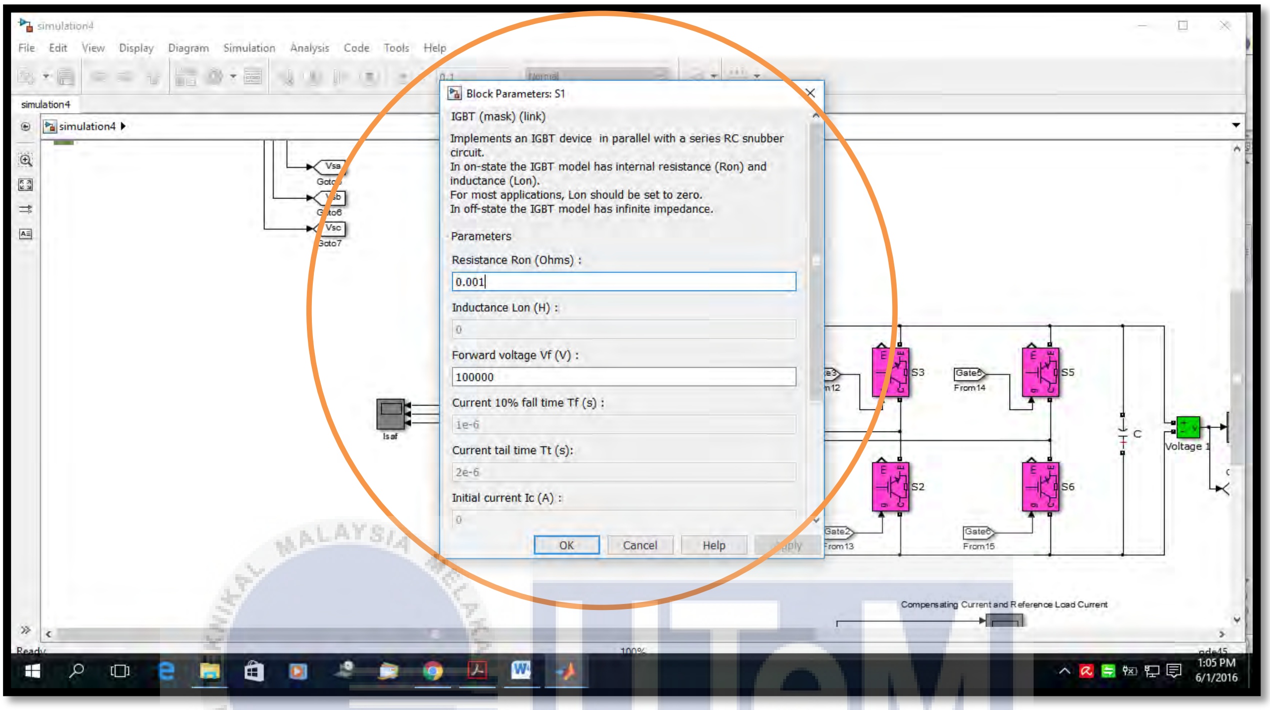
2. From MATLAB, click the Simulink icon.



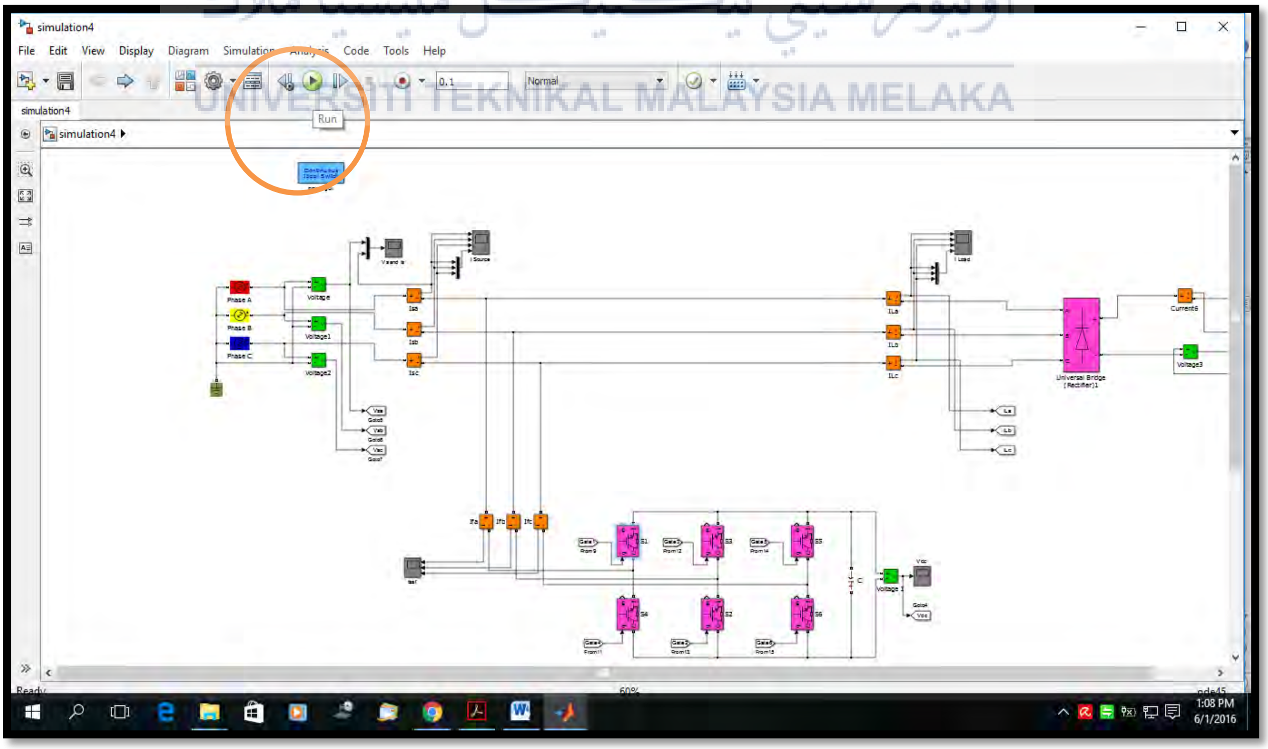
3. Click file, then select New for a new workspace and draw the block diagram of the system.



4. Wiring all the components in the circuit diagram by using Simulink browser. Determine the parameters and choose the start and stop time.



5. Click Play and view of waveforms will be displays through the respective scopes.



3.3 The principle of the operation

This system uses a shunt active filter for a three phase power system which is able to recompense for both current harmonics and power factor. So, to indicate whether this system can eliminate the harmonic reduction, reading from phase voltage, load currents, reference current and compensation currents is taken.

The reason why a shunt active filter be chosen to eliminate the harmonic reduction because its superior in clarifying performance, slighter in physical size and more springy in any application and because of that it slightly lesser in cost and operating losses. Unlike active filter, passive filter necessitate inductors large for lower frequencies, no power and voltage gain. The shunt active filter is the filter that attractions a compensating current from a power line to abandon harmonic currents on the source side, a grid location where power quality becomes vital. It is widely used to remove current harmonics, compensate reactive power and balance unbalanced currents by inserting (drawing) additional current.

The proposed three-phase active power filter is connected in parallel is shown in figure. It consists of power converter and DC link capacitor. To eliminate the current harmonic reduction cause by non-linear load, the voltage from the generator is connected to the alpha-beta transformation to get the value of real power (P, Watts) and reactive power (Q, VAR). Based on current supply (I_{Sa}, I_{Sb}, I_{Sc}) and voltages supply (V_a, V_b, V_c) it can produce value of Voltage alfa (V_{alfa}), Current alfa (I_{alfa}) and Voltage beta (V_{beta}) , Current beta (I_{beta}) to calculate the value of P and Q.

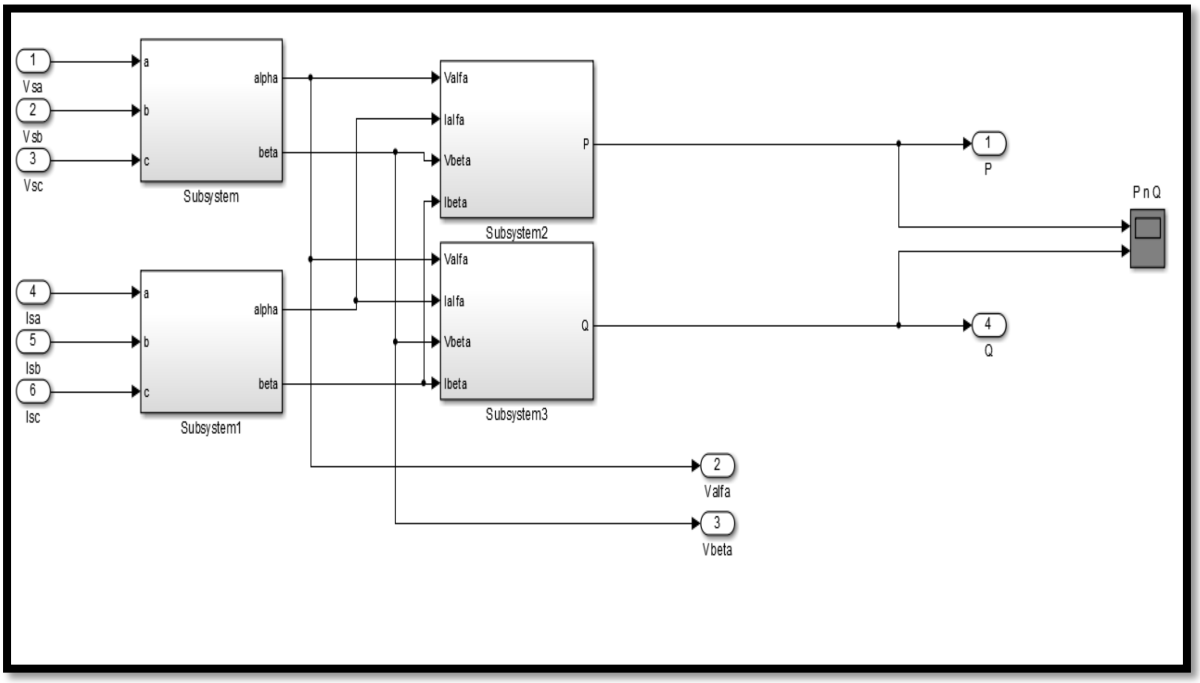


Figure 3.1: Configuration for the subsystem for P & Q

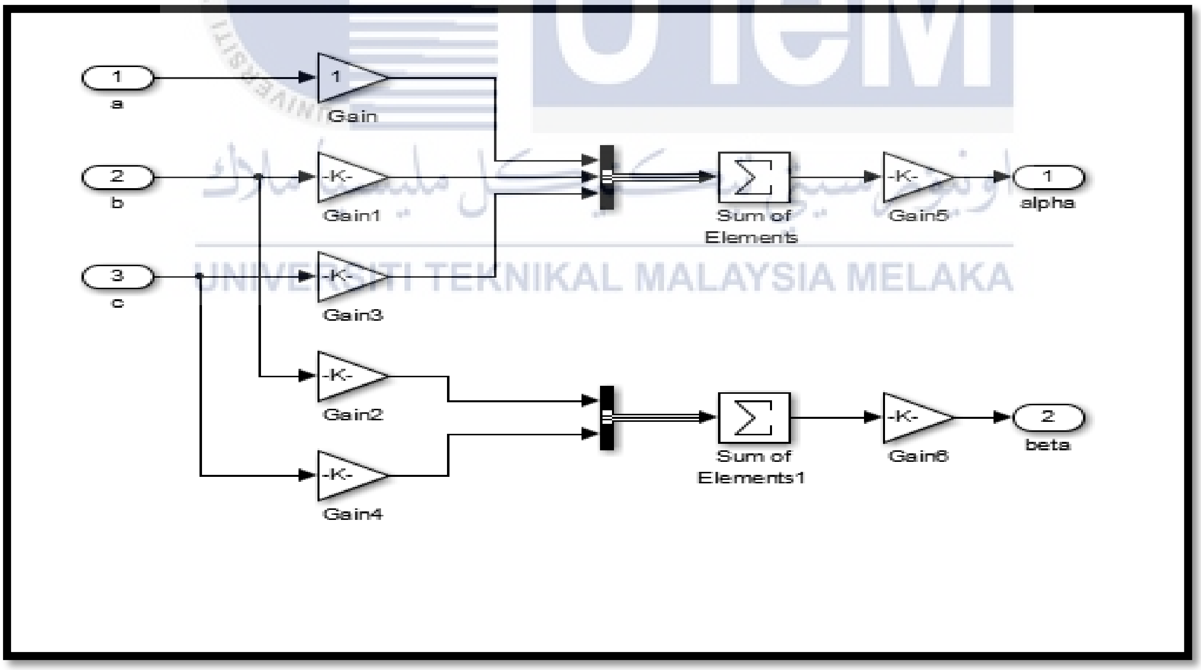


Figure 3.2: Configuration for each subsystem (subsystem and subsystem 1)

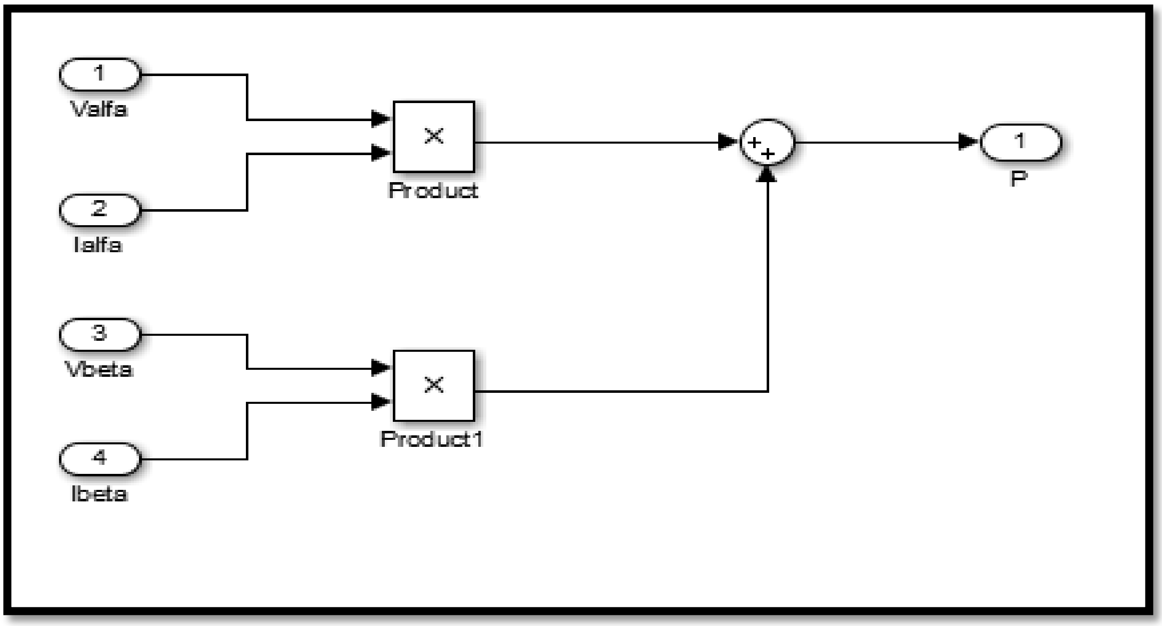


Figure 3.3: Circuit configuration for subsystem (subsystem 2)

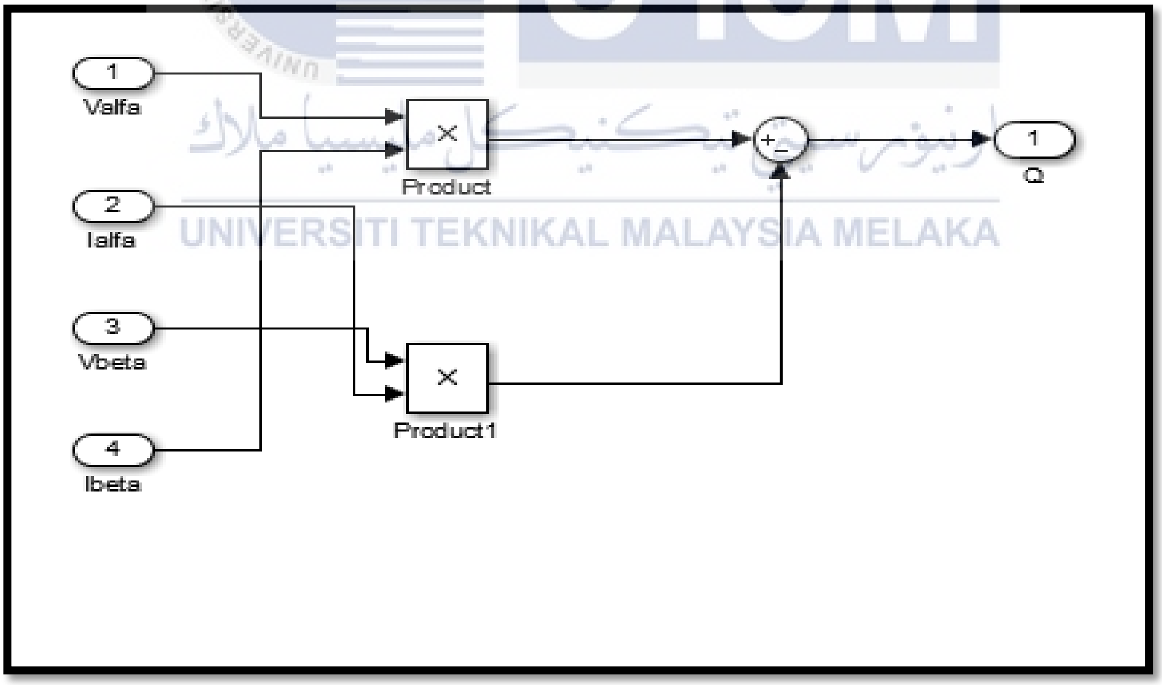


Figure 3.4: Circuit configuration for subsystem (subsystem 3)

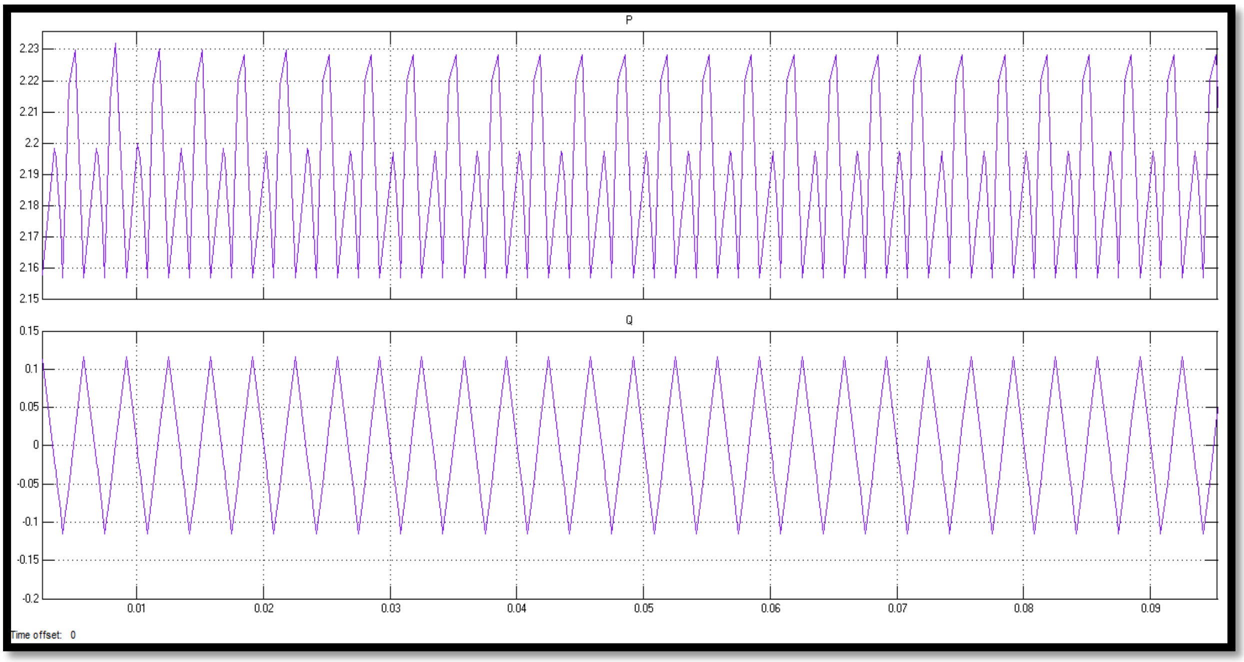


Figure 3.5: Waveform for value of P and Q

The value of P and Q is calculate in order to know the value for power factor and also to monitor the system because reducing reactive power to help increase the power factor and system efficiency is a decent thing, one of the difficulties of reactive power is that an adequate quantity of it is required to control the voltage and overcome the losses in a transmission network. This is because if the electrical network voltage is higher enough, active power cannot be full. But having too much reactive power flowing around in the network can cause additional heating (I^2R losses) and unwanted voltage drops and loss of power along the transmission lines.

The output from alpha-beta transformation in figure 5.6 is connected to another subsystem to measure the value of current alpha beta at current source. A proportional integral derivative controller (PID controller) in figure 5.7 is connected to the subsystem because the input of the block is normally an error signal, which is the alteration between a reference signal and the system output. Thus, DC voltage with the value of 1000V is connected to controller as a reference signal. The part of dc voltage at APF have to be exact and kept at a constant value to uphold the standard process of the inverter. Since there is energy defeat due to transmission and switching power losses related with the diodes and IGBTs of the inverter in APF, which incline to diminish the value of Vdc across capacitor at DC. A feedback voltage control circuit desires to be combined keen on the inverter for this purpose.

The alteration among the reference value, Vref and the feedback value (Vdc), an error function first permits a PI regulator and the output of the PI regulator is deducted from the harmonic current components.

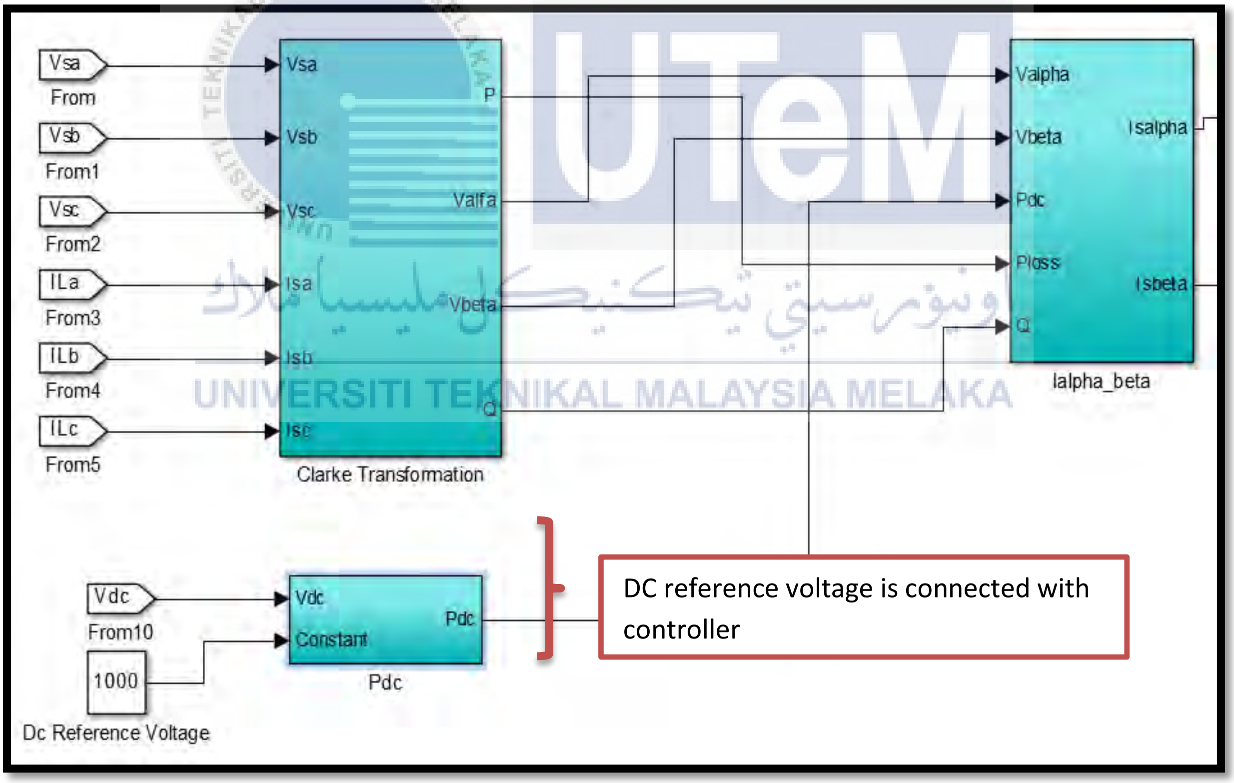


Figure 3.6: Parts of circuit configuration at PID controller

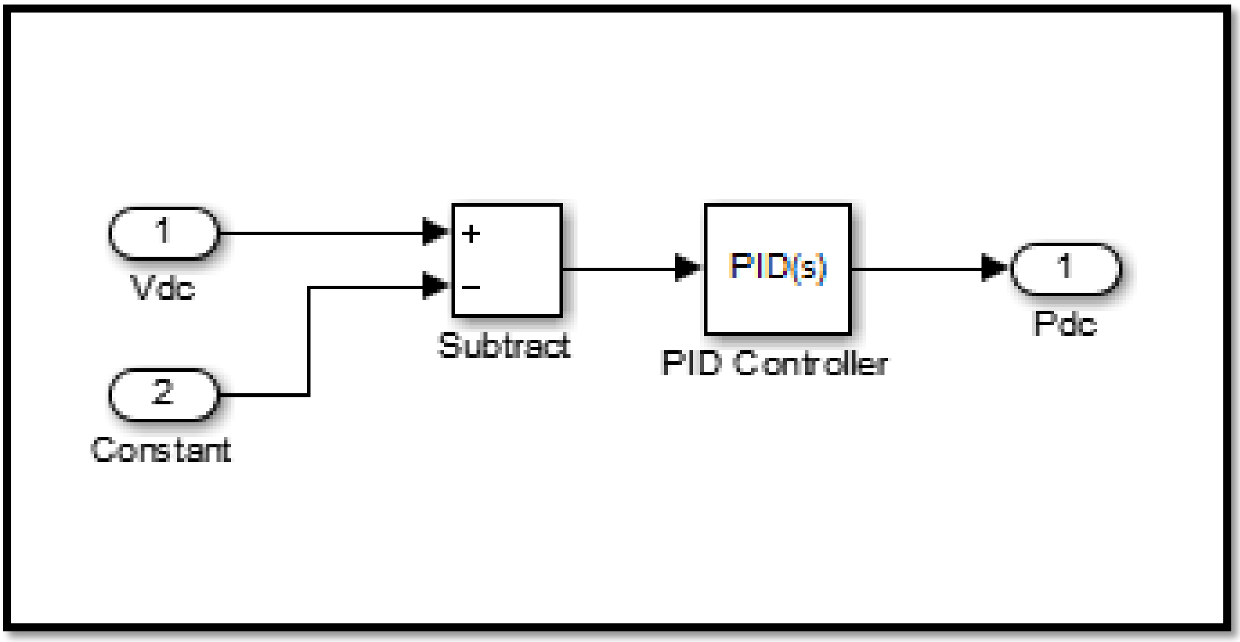


Figure 3.7: Configuration of PID Controller block

The output from Alpha-Beta Transformation is connected to the input of new subsystem to find new current source for alpha and beta.

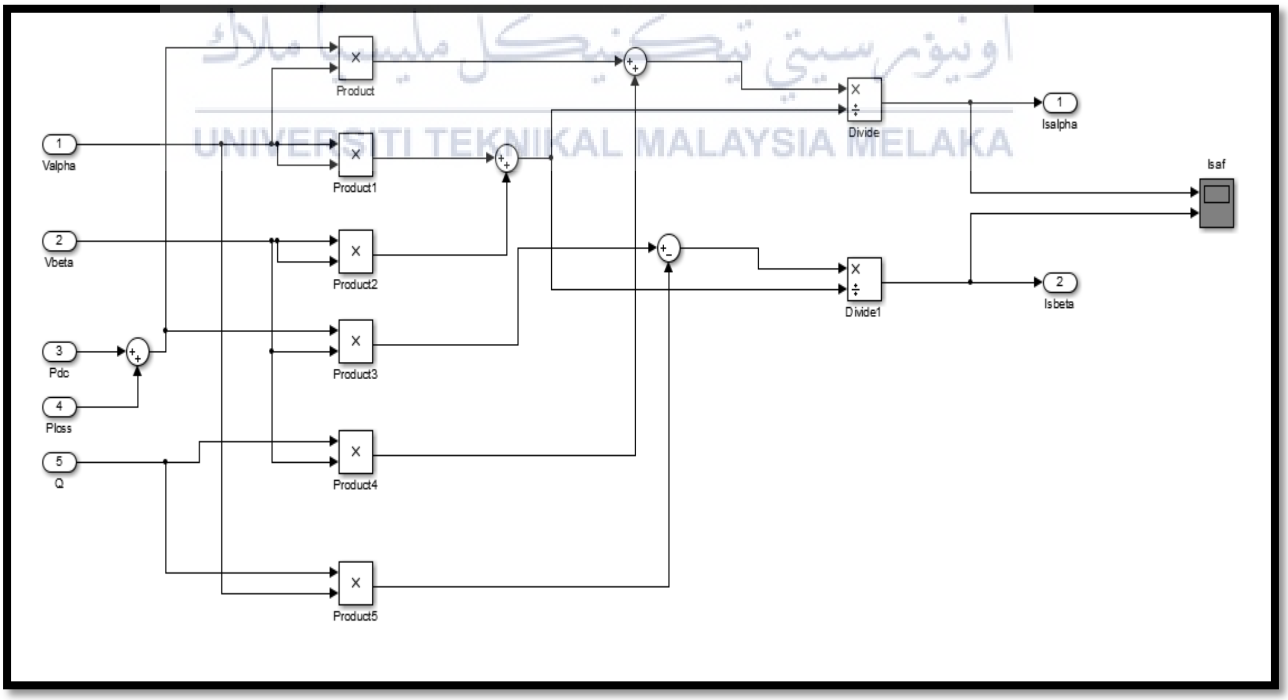


Figure 3.8: Circuit configuration to find current source for alpha (α) and beta (β)

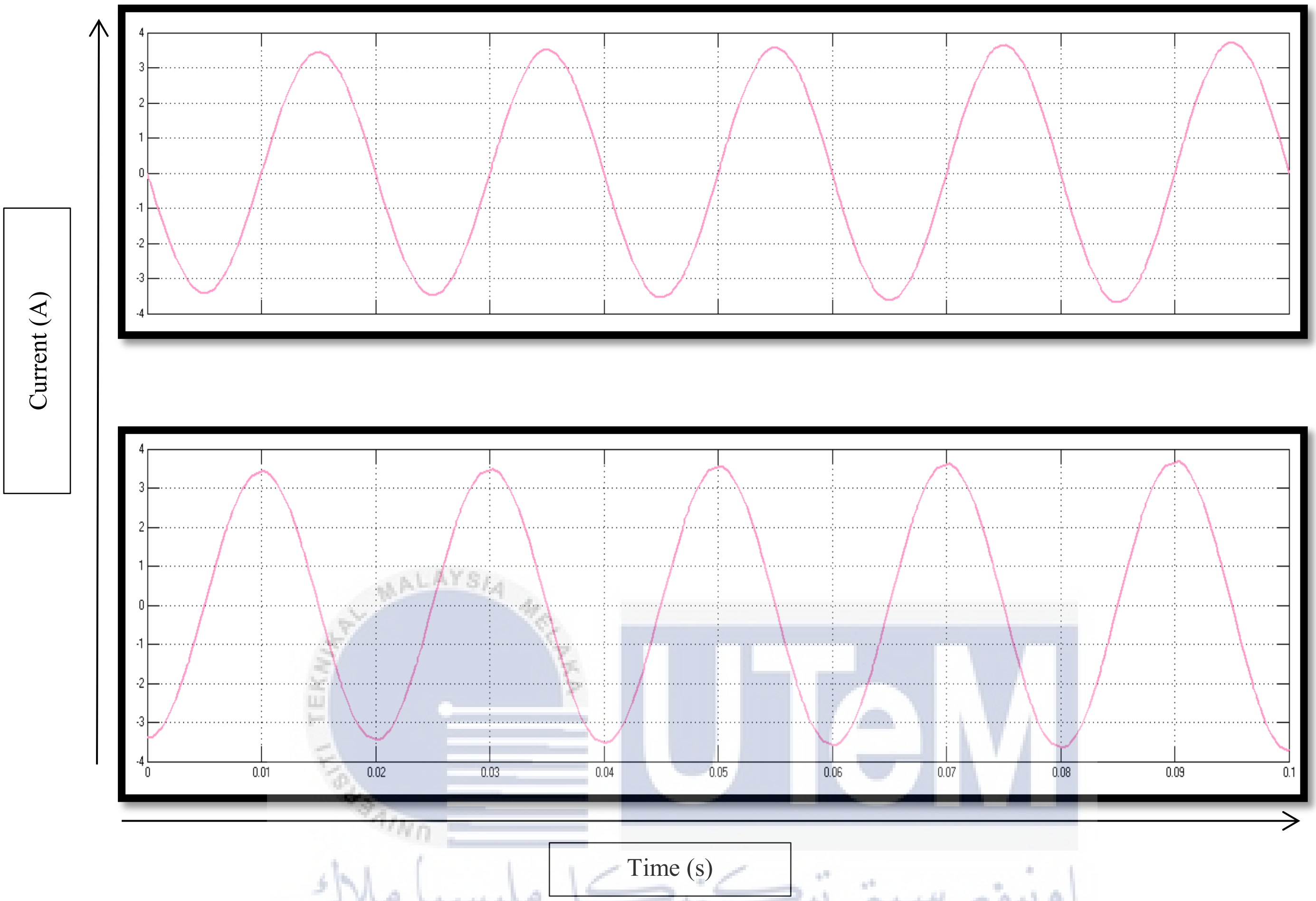


Figure 3.9: Waveform for current source for α and β

After current source for α and β is produce, then it having to inverse back to get the value of current reference (I_f) for each phase and to compensate reactive power. The output current can give the waveform for compensating current and reference load current.

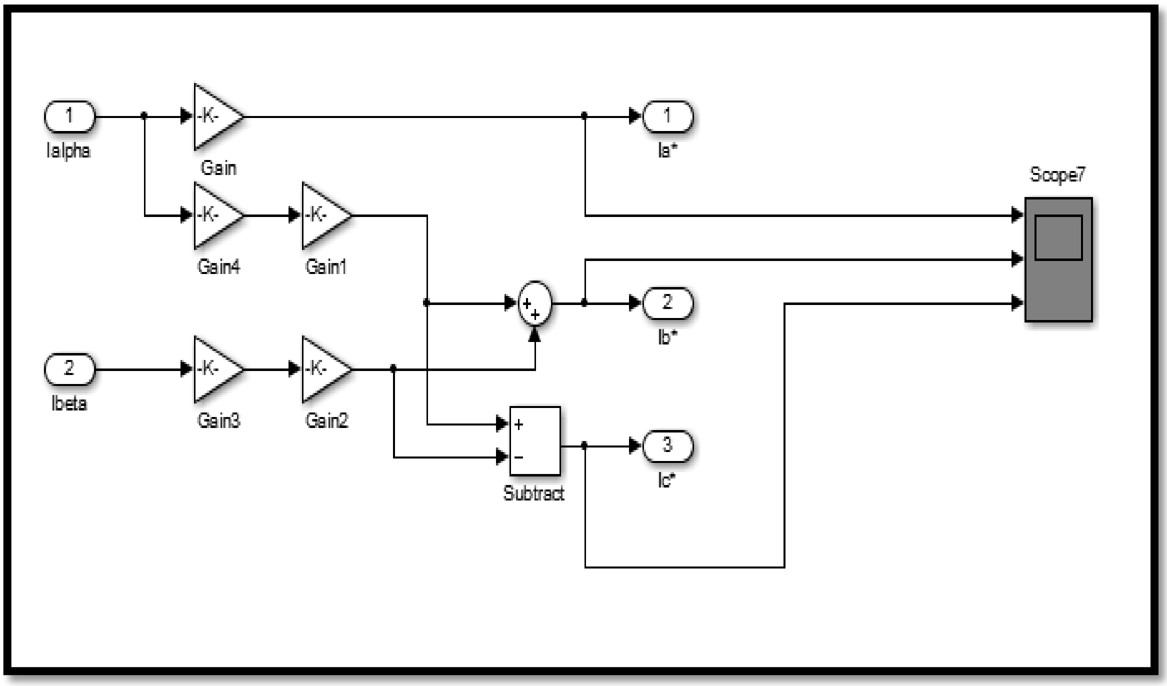


Figure 3.10: Circuit configuration for subsystem (inverse transformation)

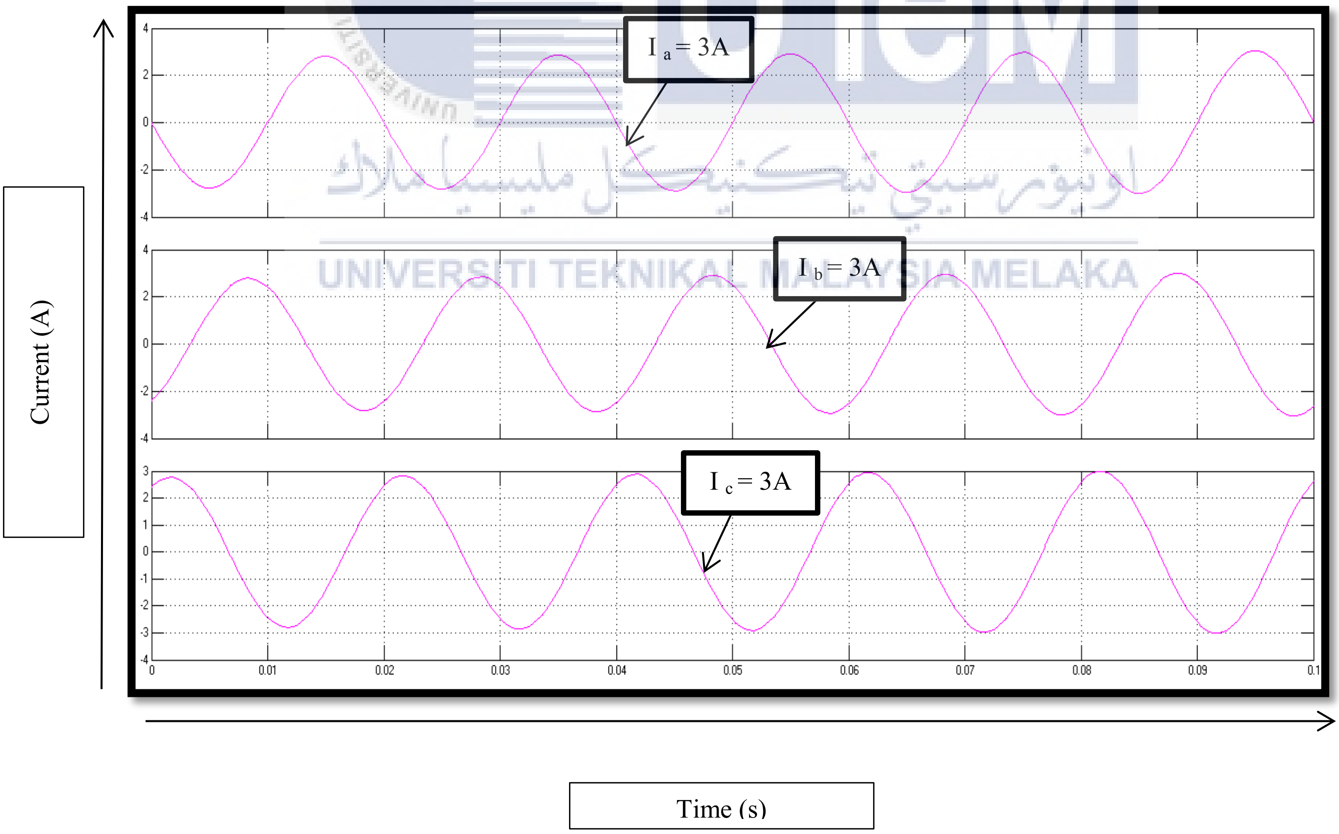


Figure 3.11: waveform from inverse transformation

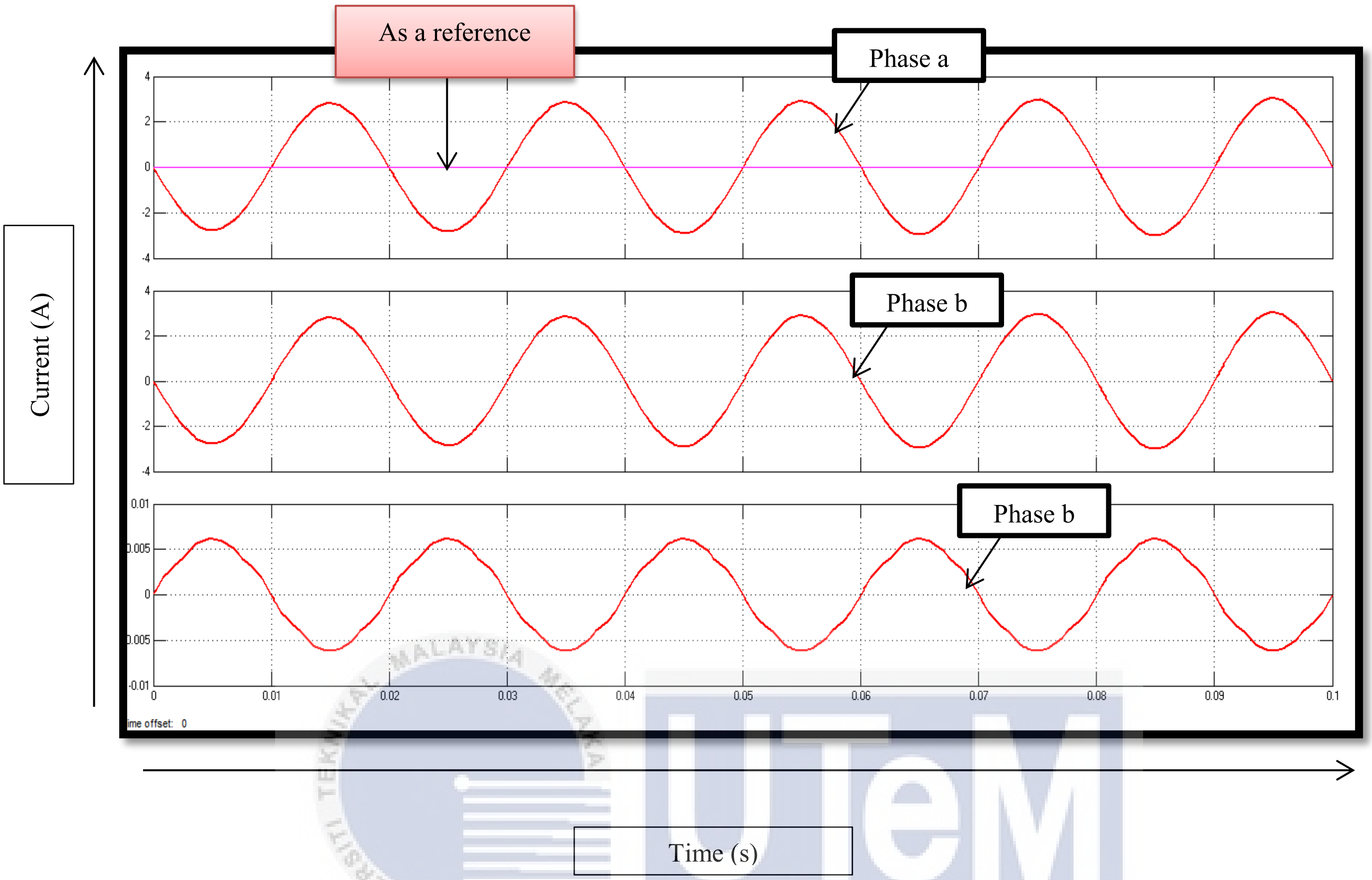


Figure 3.12: Waveform at Compensation Current and Reference Load Current

The output from subsystem inverse transformation is connected to subsystem name hysteresis band. The hysteresis band current control method has established to be most seemly for all the requirements of current controlled voltage source inverters in active power filters. The hysteresis band current control is categorized by unrestricted stability, very fast reaction, and more accurate [17] and [18]. Additional, the rudimentary hysteresis technique displays also numerous unwanted features; such as irregular switching frequency that reasons audio noise and trouble in scheming input filters [19].

The amount of alteration of the actual active power filter line currents differ the switching frequency, consequently the switching frequency does not endure constant during the switching setup, but contrasts laterally with the current waveform. The bandwidth of the hysteresis current controller defines the permissible current decisive error. By varying the bandwidth the user can switch the average switching frequency of the active power filter and estimation the performance for different standards of hysteresis bandwidth. In principle, increasing the inverter functioning frequency supports to get an improved reimbursing current waveform.

Yet, there are scheme limits and increasing the switching frequency reasons increased switching losses, and EMI related difficulties. The range of switching frequencies used is based on a negotiation between these features.

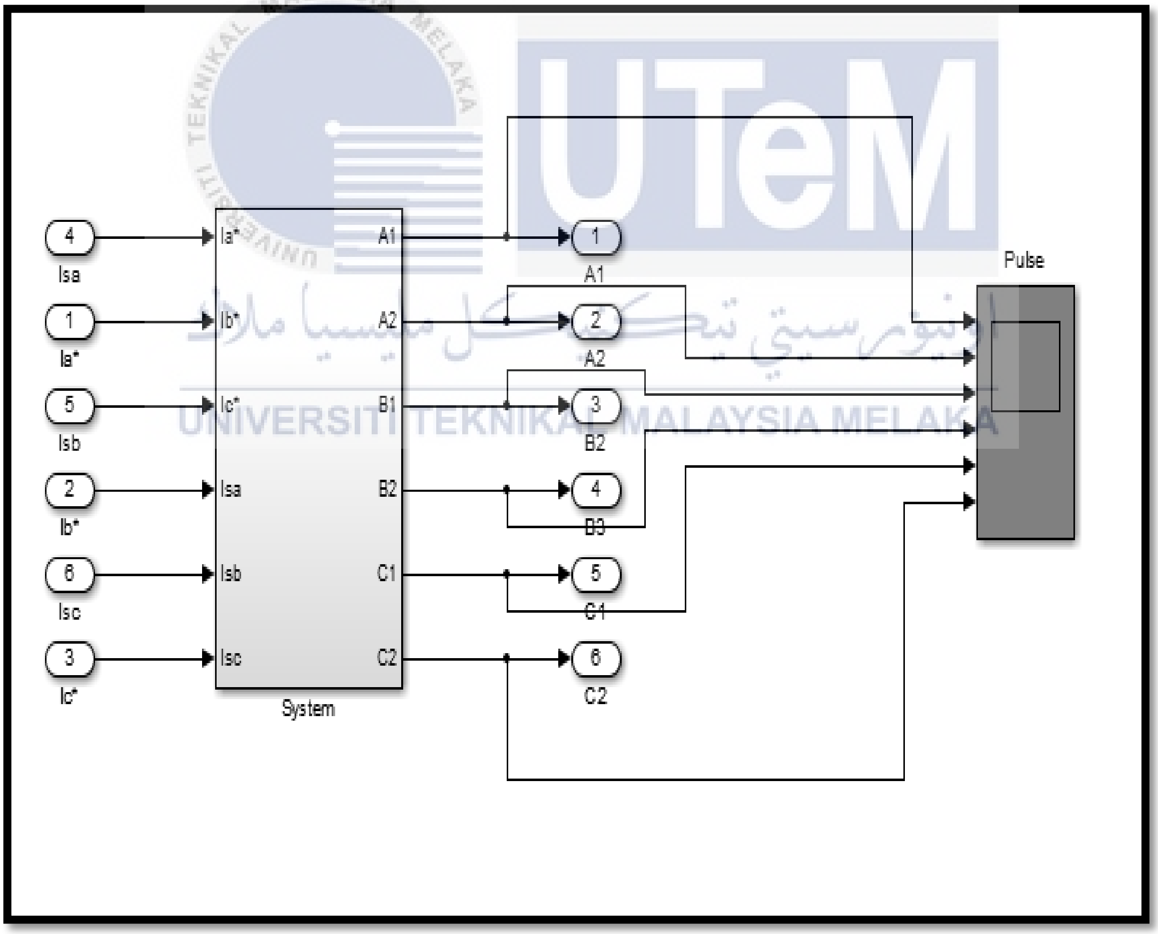


Figure 3.12: Figure of Hysteresis Controller

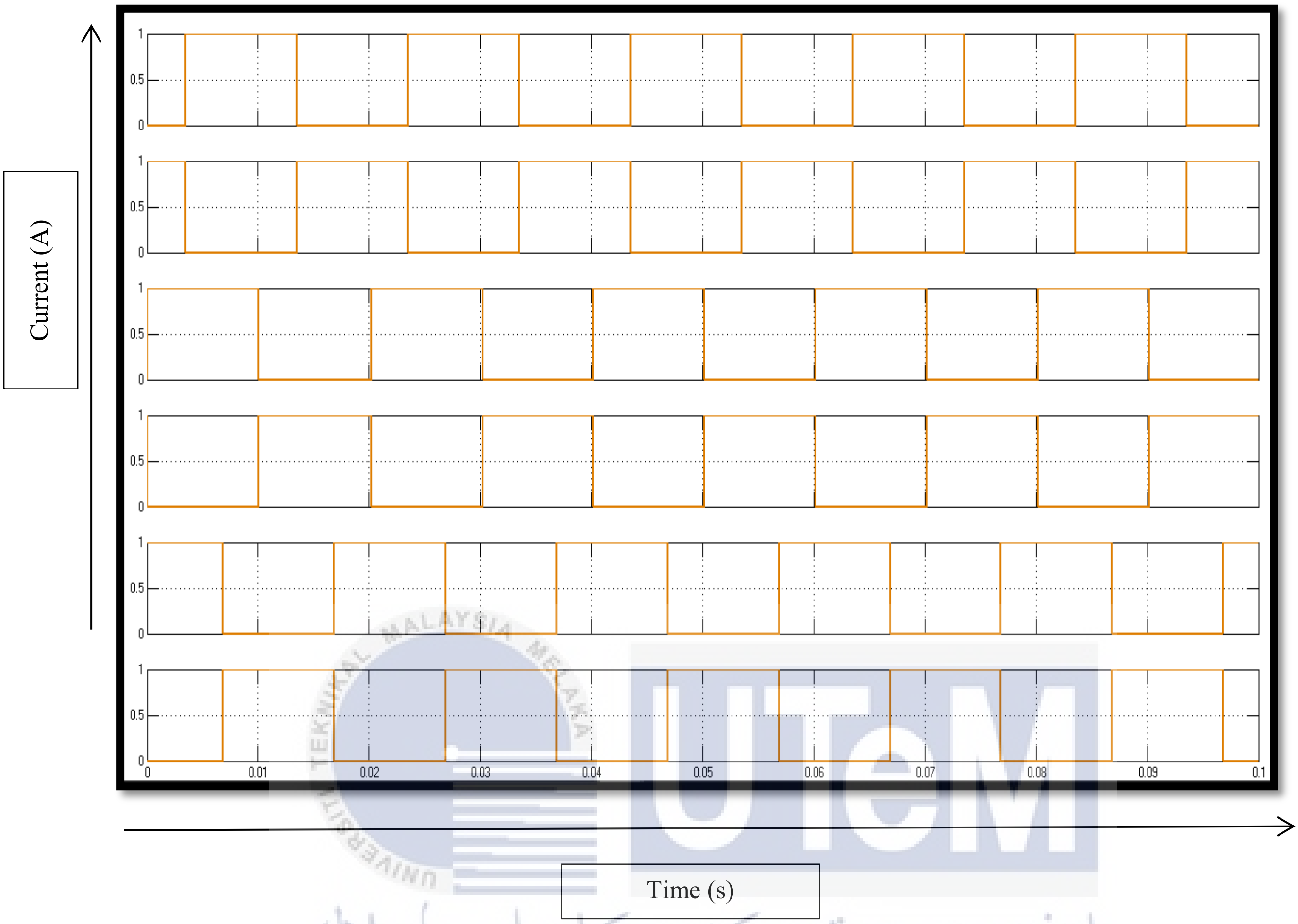


Figure 3.13: Waveform from each pulse in APF

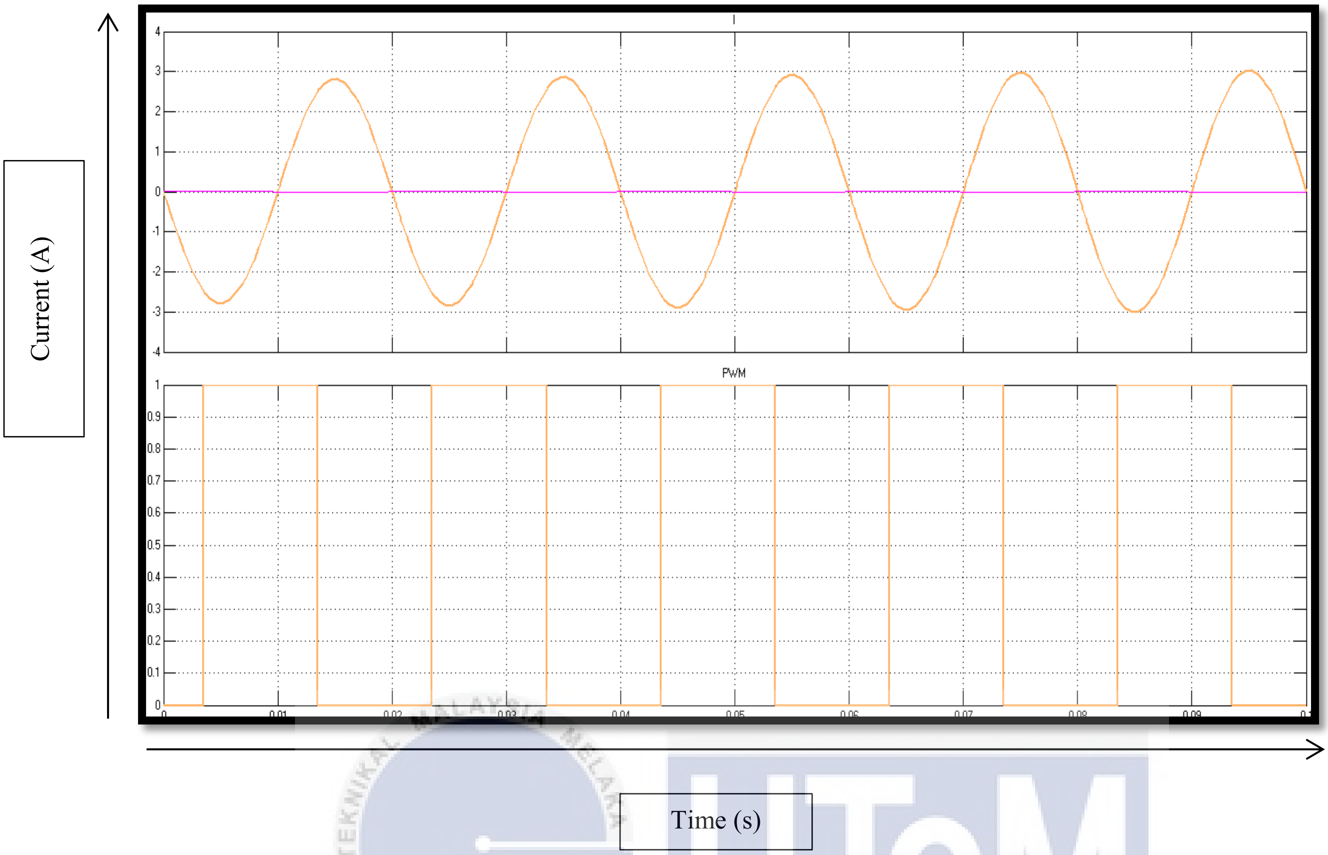


Figure 3.14: Waveform for current and PWM

By controlling the APF current from hysteresis band, a current controlled voltage source inverter is used to produce the compensating current and is inserted into the usefulness power source grid. This withdraws the harmonic mechanisms drawn by the nonlinear load and retains the helpfulness line current (I_{sf}) sinusoidal.

CHAPTER 4

RESULTS & DISCUSSION

This chapter had been discussing about the simulation of shunt three phase active filter. This simulation is based on MATLAB/Simulink. The parameter of the proposed design is shown in characteristic of project design below. In this chapter also the characteristics of the shunt three phase active filters due to the specification of the project design also had been discussed. The simulation result of the full model of shunt three phase active filter using MATLAB/Simulink also can be seen through this project.

4.1 Characteristic of Project Design

For this part, the characteristics of the three phase active filter had been discussed. The simulation is based on MATLAB/Simulink. The data for the components used in the system is given in the Table 4.0.

Table 4.0: List of component use.

Source Characteristics	
Source voltage	415V
Frequency	50 Hz
Shunt active filter characteristics	
Reference DC voltage	240V
DC capacitance	1100µF
Load Characteristic	
Rectifier	170V (forward voltage)
	100kΩ (snubber resistance)
	Inf (snubber capacitance)
Controller	
Clarke Transformation	

4.2 Full Model of Design Using MATLAB/Simulink

The full schematic diagram of a shunt active filter for a three-phase power system is shown in figure 4.1 by using MATLAB/Simulink. This simulation consist four main parts which is power source, non-linear load, inverter and controller.

4.3 Results of Simulation

4.3.1 Simulation result without using Active Power Filter

For this section, the simulation result for the waveform at the load current (I $_{Load}$), load source (I $_{Source}$) and THD value is shown. Figure 4.2 shows the circuit configuration of harmonic distortion without using APF. It comprise of voltage supply and the load. In this case, the supply is connected with the load. Example of load use is rectifier. Consequence of using non linear load, it will produce high content of harmonics in electrical distribution system. This can cause this harmonics move to supply and the voltage will distort .

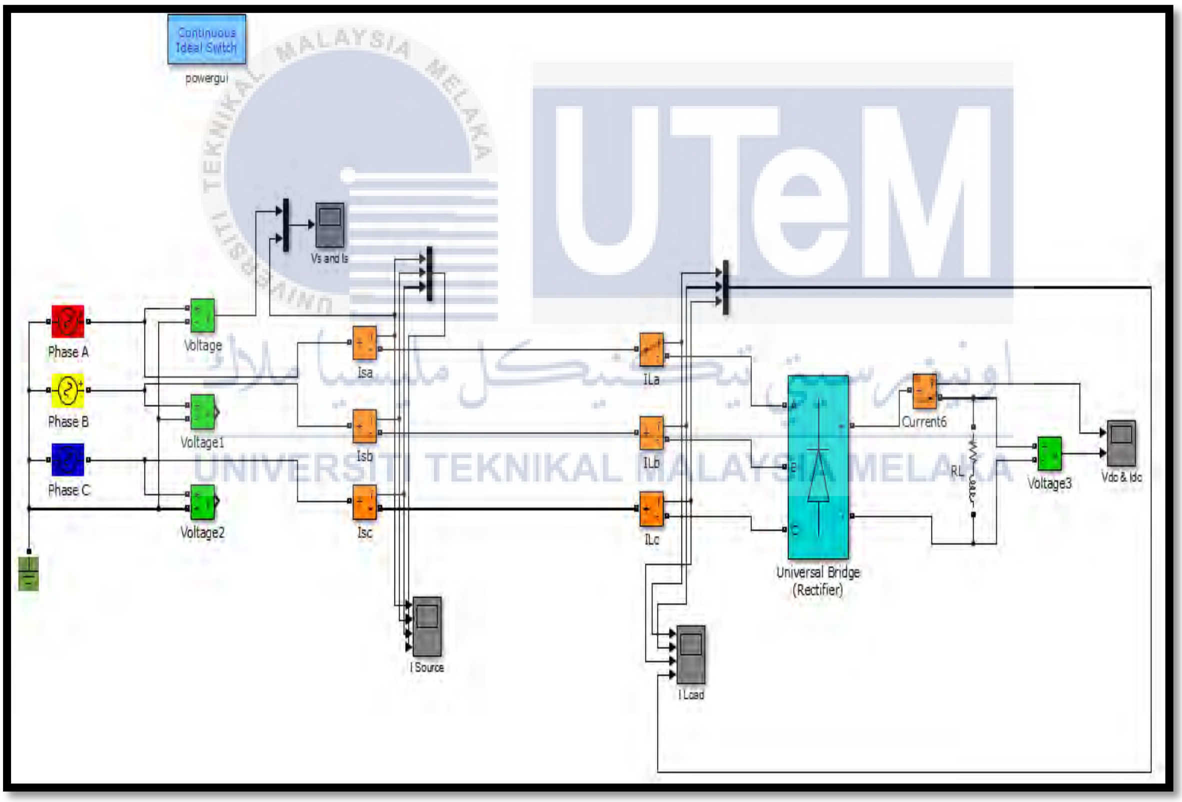


Figure 4.2: The Circuit Configuration of Harmonic Distortion without Filtering.

Based on figure 4.4.1, figure 4.4.2, and figure 4.4.3, it shows the effect of high content of harmonics for each phase (phase a, phase b, phase c) at power supply. The current produce at each phase is 0.6 A. The waveform shows none smoothly because the harmonic has interrupted the waveform. Harmonic from the load can bring a lot of negative effect for example it can lower the power factor, can cause overheating in transformer and the most important thing is that it can cause system failure. Plus, customer also can feel the impact due to the increasing the electrical bill.

Figure 4.6 shows the harmonic spectrum before adding APF. The value of THD is equal to 31.44% and not follows the standard of IEEE 519. To overcome this problem, the three phase active filter has to be adding to reduce and smooth the waveform produce from the load. In addition, also have to add the controller to detect the presence of harmonics in the system.

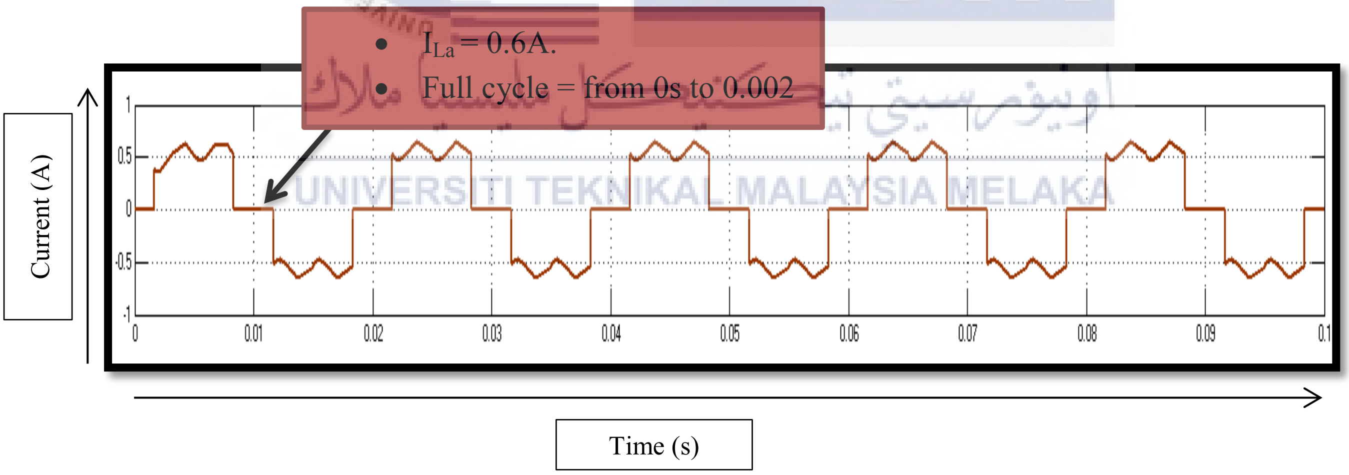


Figure 4.4.1: Waveform Current vs Time on phase a at Load Current, I_{La}

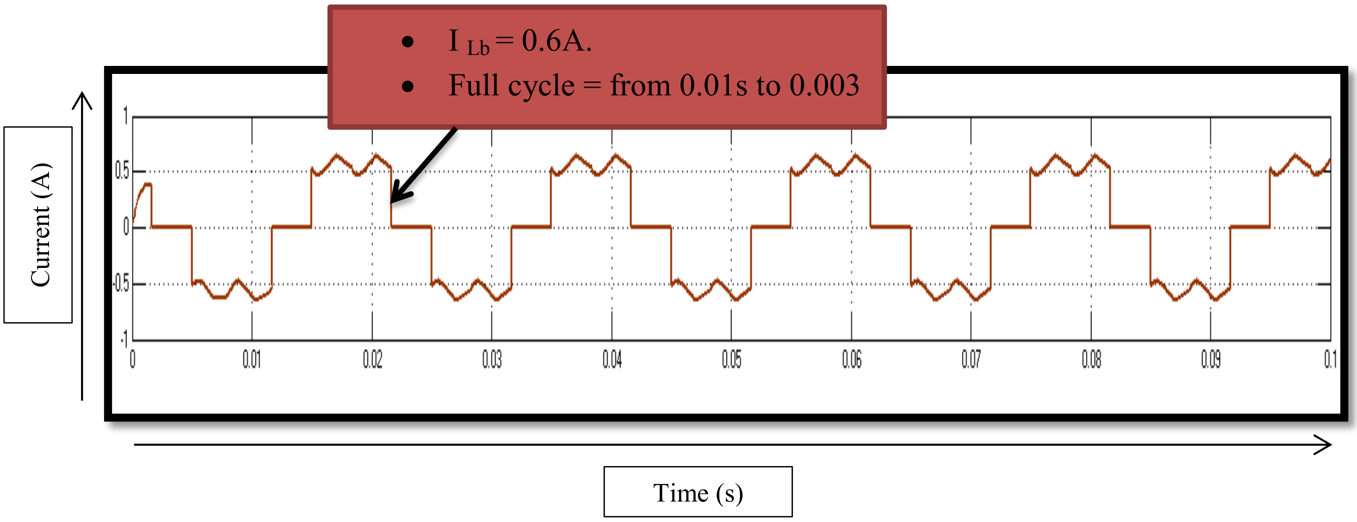


Figure 4.4.2: Waveform current vs time on phase b at load current, I_{Lb}

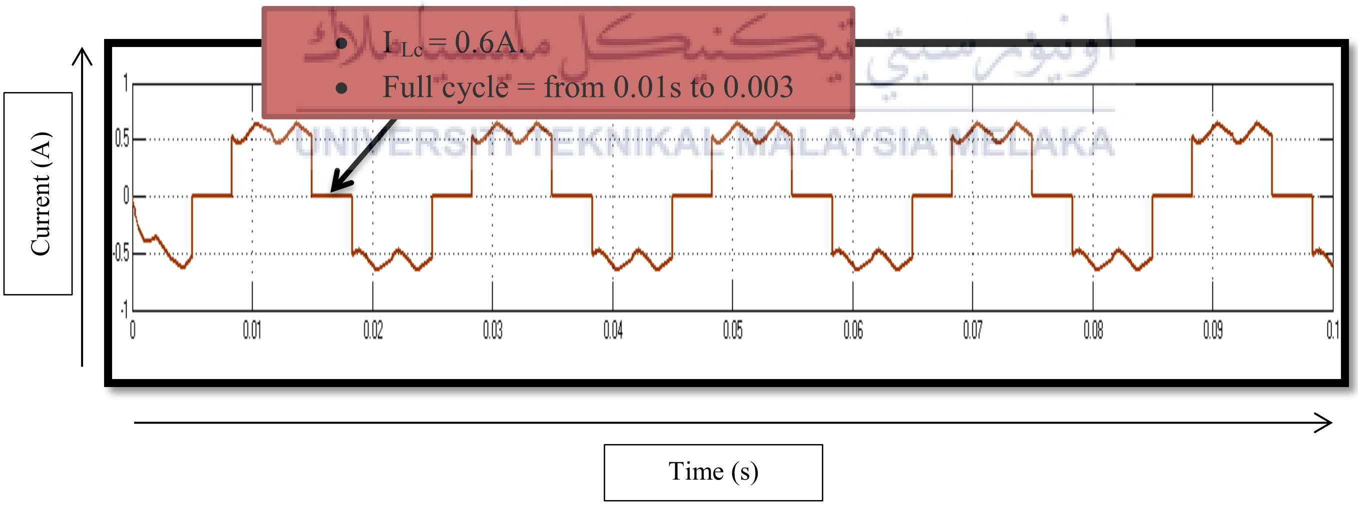


Figure 4.4.3: Waveform current vs time on phase c at load current, I_{Lc}

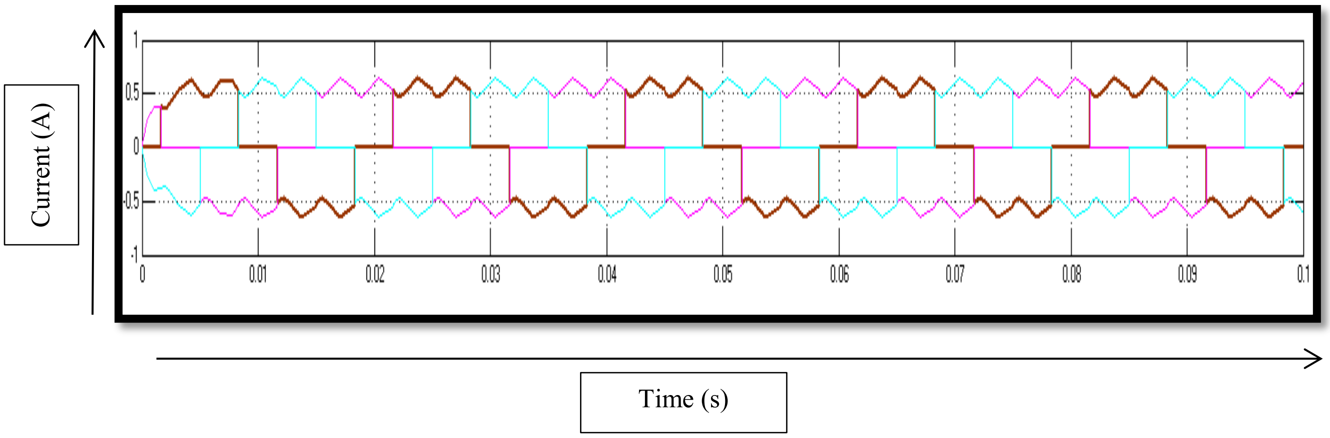


Figure 4.4.4: Waveform current vs time for total phase at load current, I_{LT}

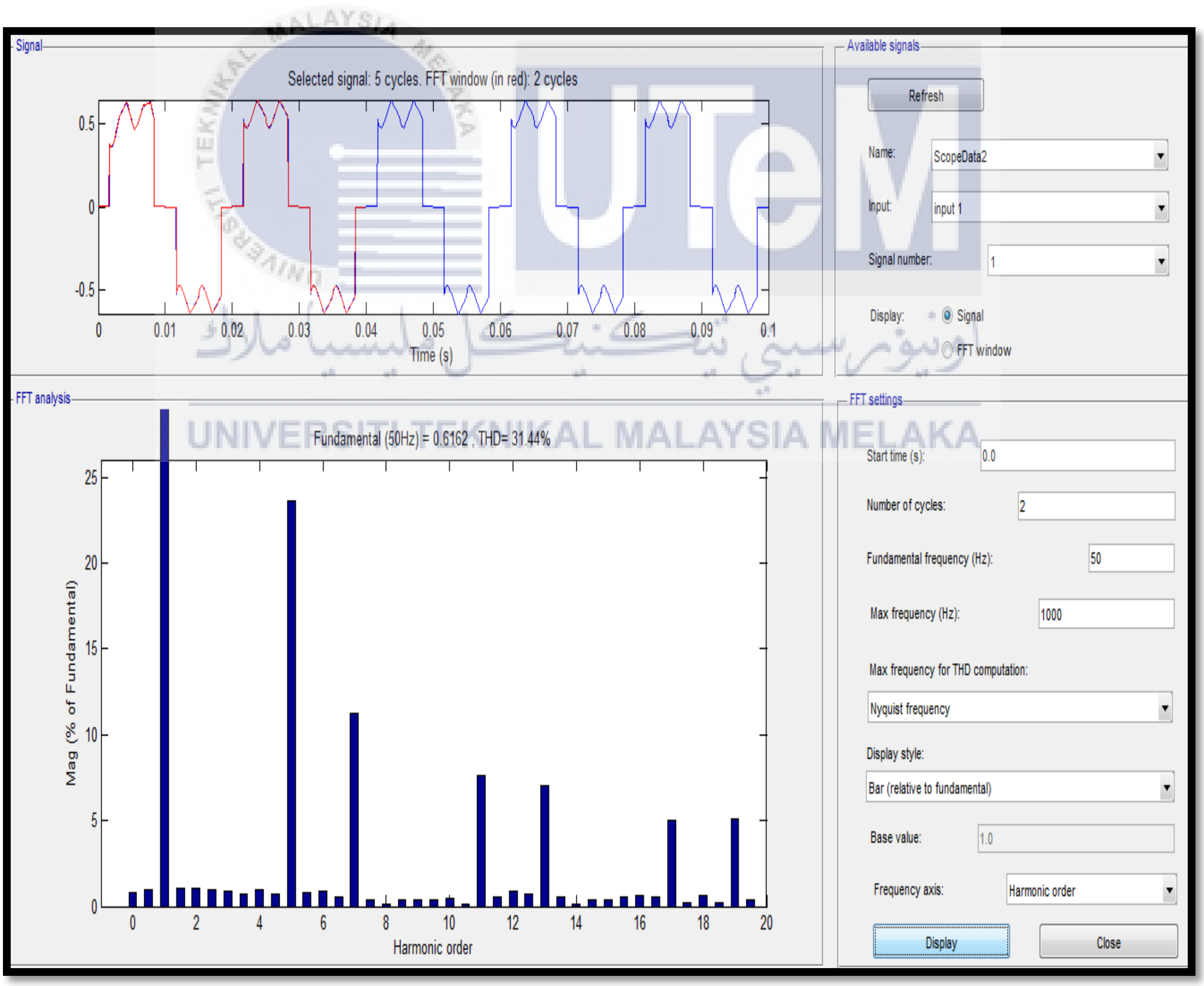


Figure 4.6: Harmonic spectrum before adding active filter

4.3.2 Simulation result using active filter

The simulation result for the waveform at the load current (I_{Load}), THD value, and comparison between sinusoidal waveform with non-linear load and linear load is shown after adding active filter in the circuit. For the linear load condition, RL is used to substitute the rectifier at the load in circuit configuration in order to make a comparison especially current produce at source, load and helpfulness line current (I_{Sf}) with the non-linear load. Plus, can be as an indicator in order to make a different between real current and harmonic current. When APF is connected in the system as shown in figure 4.1 the harmonics content in the power system can be eliminate. Current waveform at load is in sinusoidal waveform and current reading at phase a is 6mA. Unlike nonlinear, the current reading at phase a from figure 4.8.2 for linear load is decreasing by the time in order to make it stable at 50A.

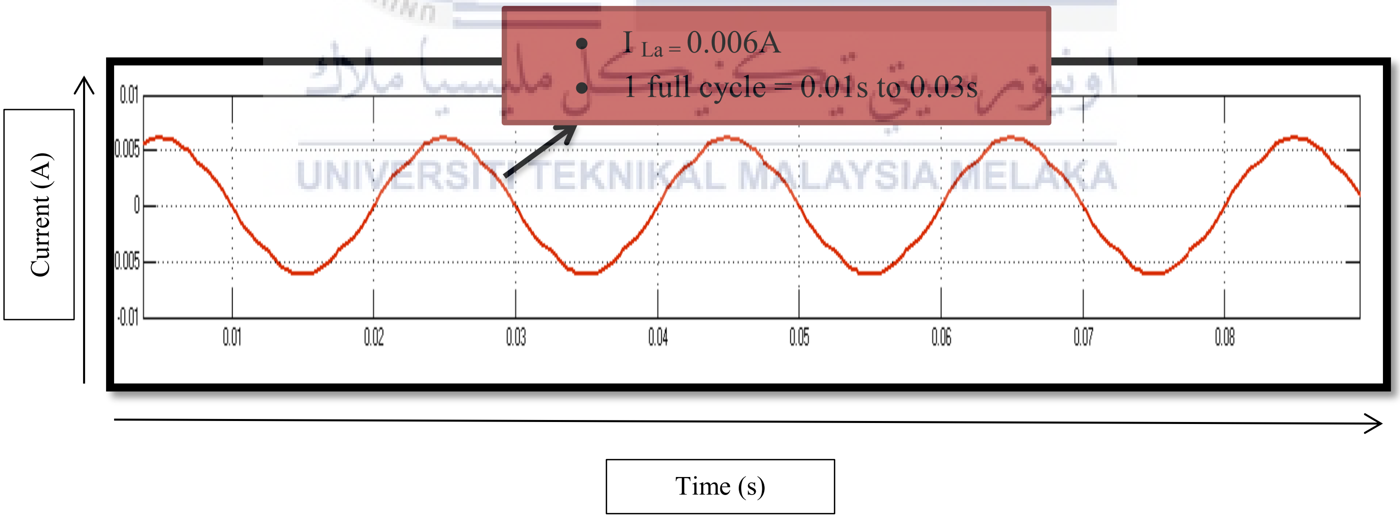


Figure 4.8.1: Waveform Current vs time on phase a at current load, I_{La} (Non-linear)

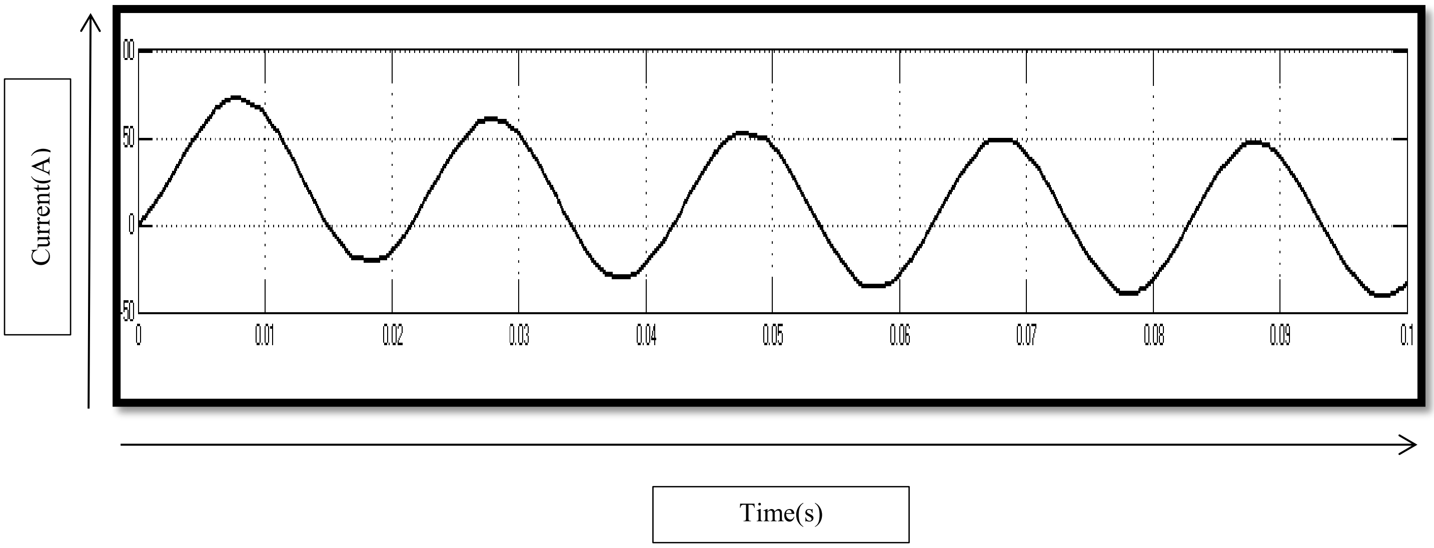


Figure 4.8.2: Waveform for current vs time on phase a at current load, I_{La} (Linear load)

From figure 4.8.4, the waveform for current load at phase b is increase from 30 A to 50A until it get nominal current which is at 50A the waveform become constant but for waveform current b at current load, the value of current is smaller which is 6mA but the waveform obtain is constant by the time.

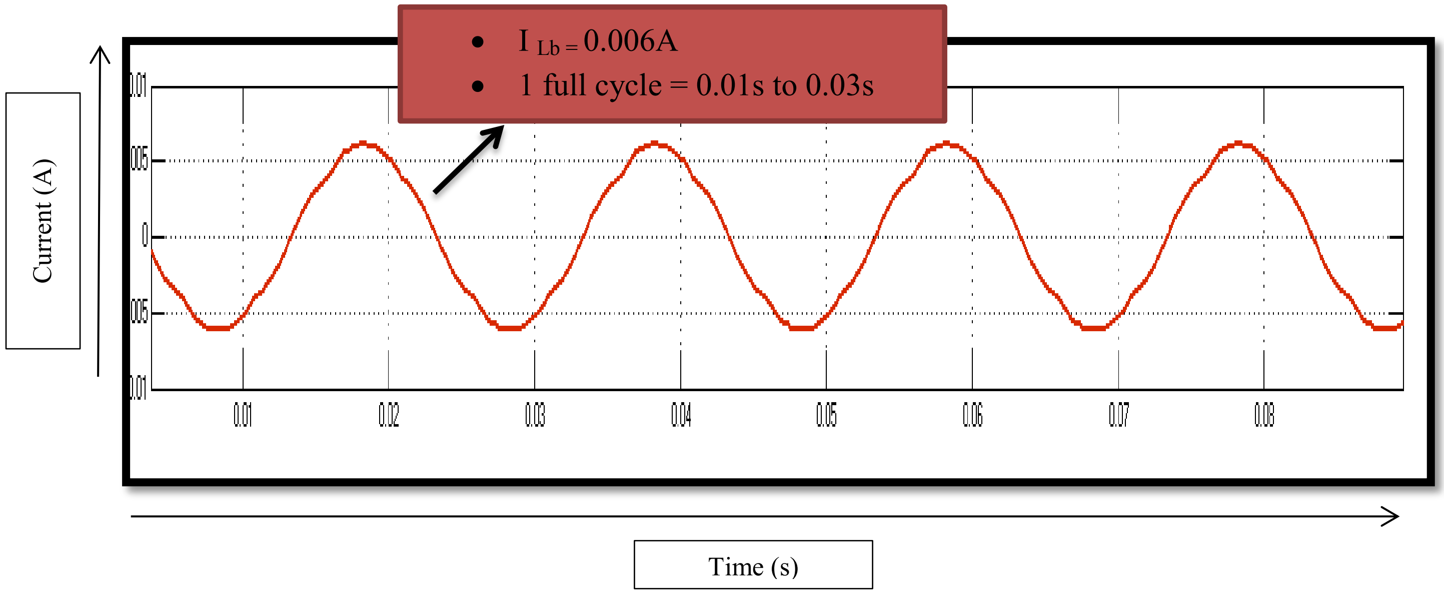


Figure 4.8.3: Waveform current vs time on phase b at current load, I_{Lb}

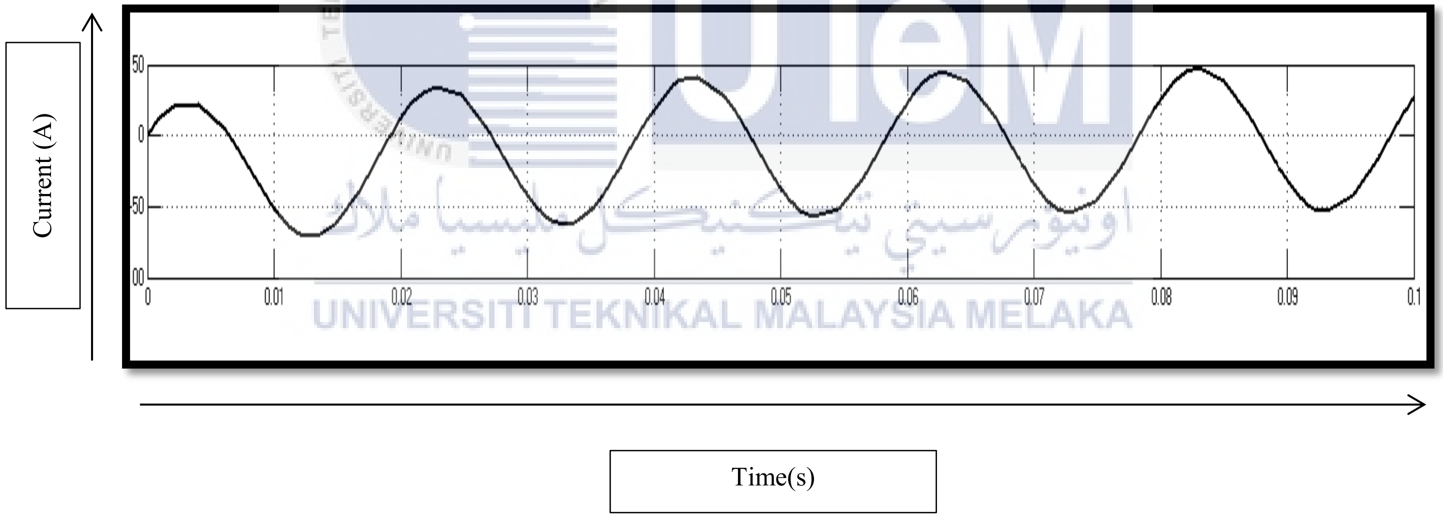


Figure 4.8.4: Waveform current vs time on phase b at current load, I_{Lb} (Linear load)

At phase c, the current load for linear load is increase from 30A to 50A. As for current load at non-linear load, the waveform still in constant from starting time and the value of I_{Lc} is 6mA.

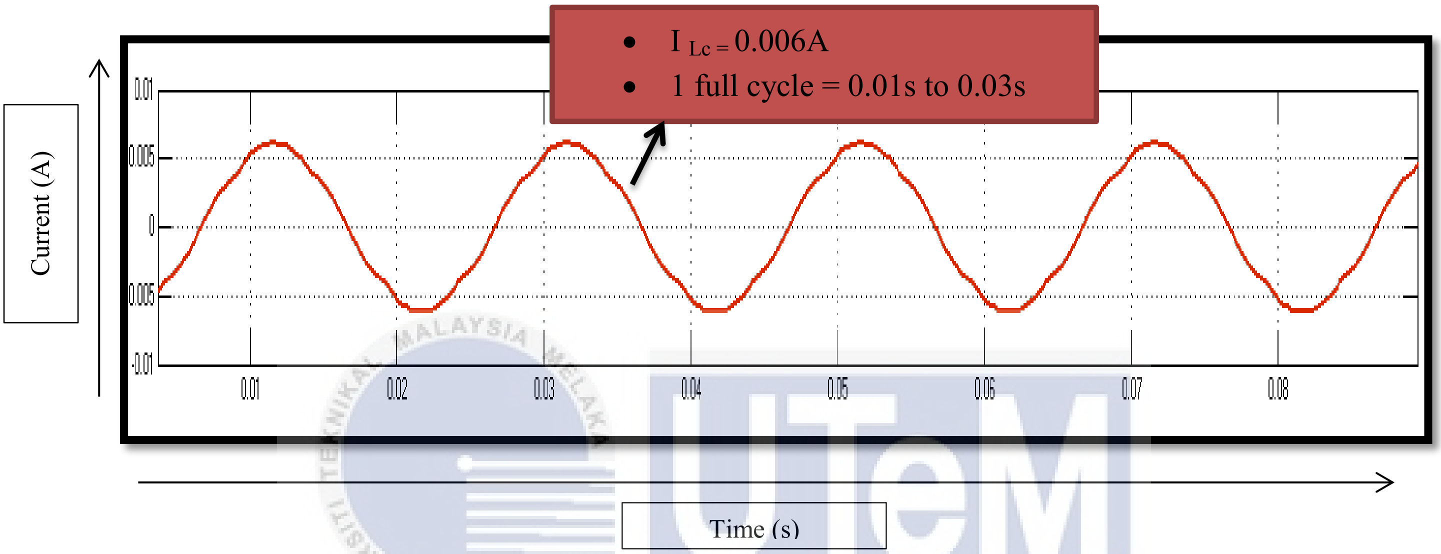


Figure 4.8.3: Waveform current vs time on phase c at current load, I_{Lc} (Non-linear load)

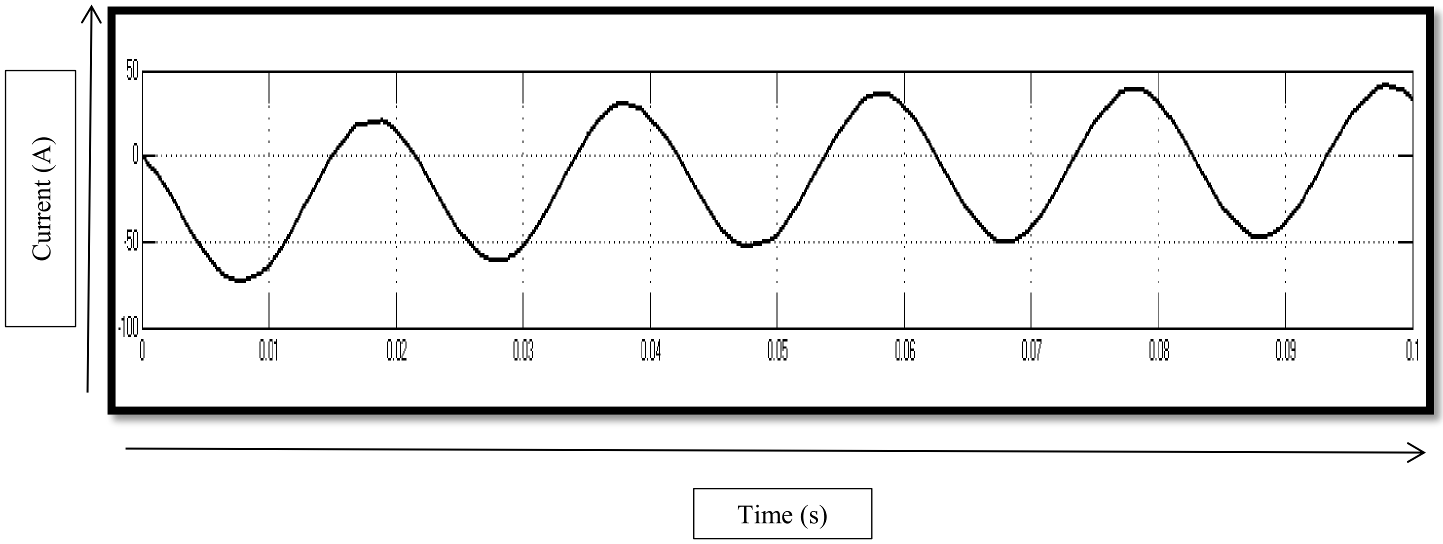


Figure 4.8.4: Waveform current vs time on phase c at current load, I_{Lc} (Linear load)

By referring to the figure above, it can be seen clearly that the waveform for total current load for nonlinear more stable than the linear load for figure 4.8.5 and figure 4.8.6.

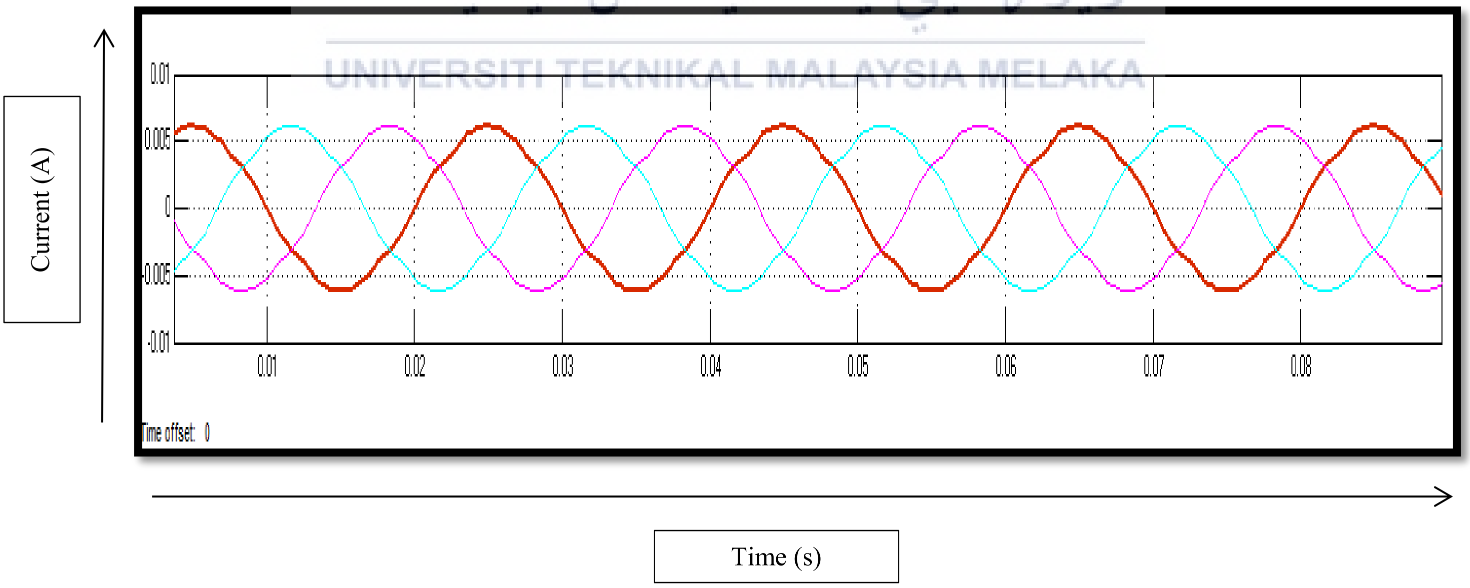


Figure 4.8.5: Waveform current vs time for total phase at current load, I_{LT} (Non-linear)

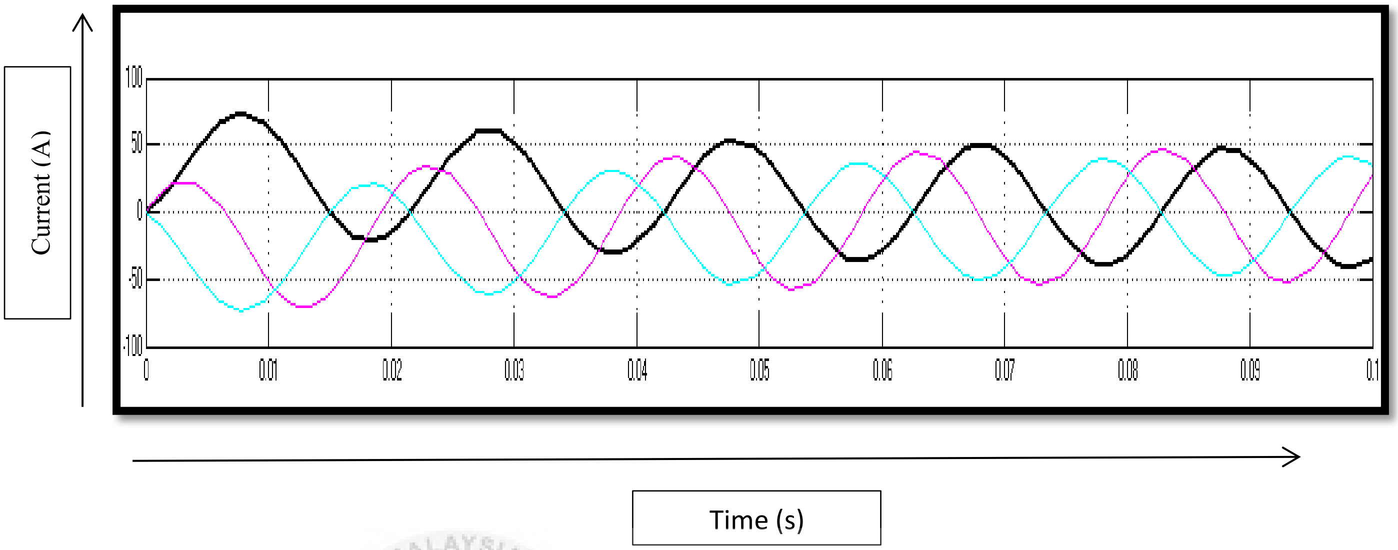


Figure 4.8.6: Waveform current vs time for total phase at current load, I_{LT}

Based on figure below, the waveform shows the sinusoidal waveform at current source. The current reading from the waveform for nonlinear load at phase a, b and c is 32A unlike for the linear load the current have to take time in order to achieve stable current source in 50A.

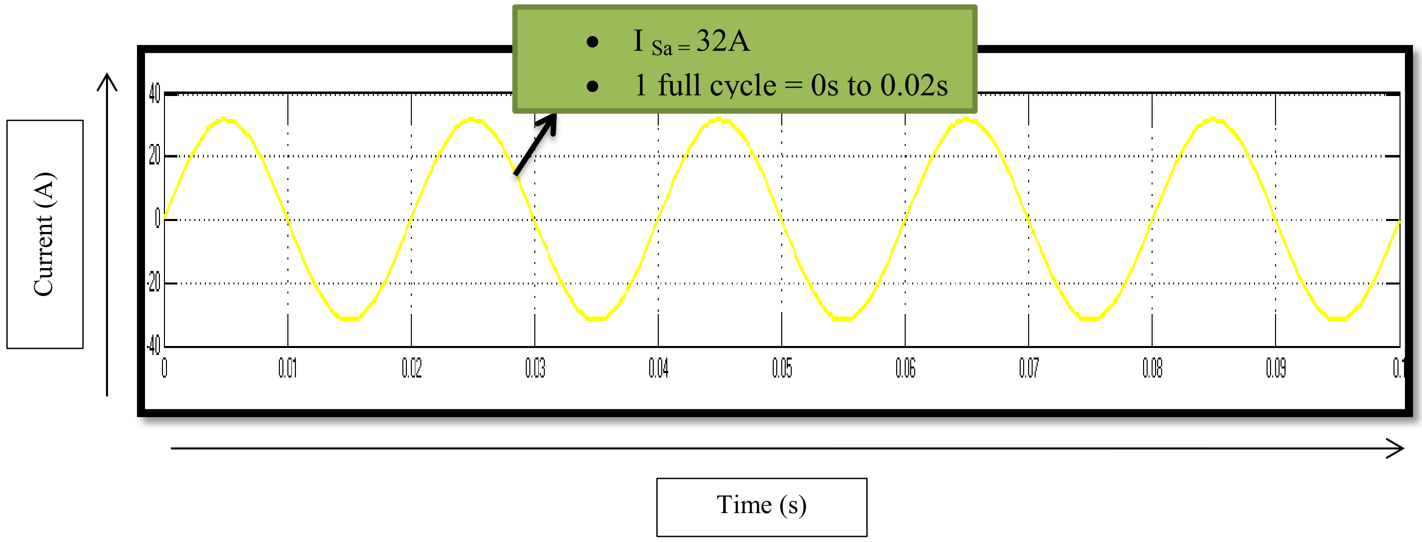


Figure 4.9.1: Waveform current vs time for phase a at current source, I_{Sa} (Non-linear)

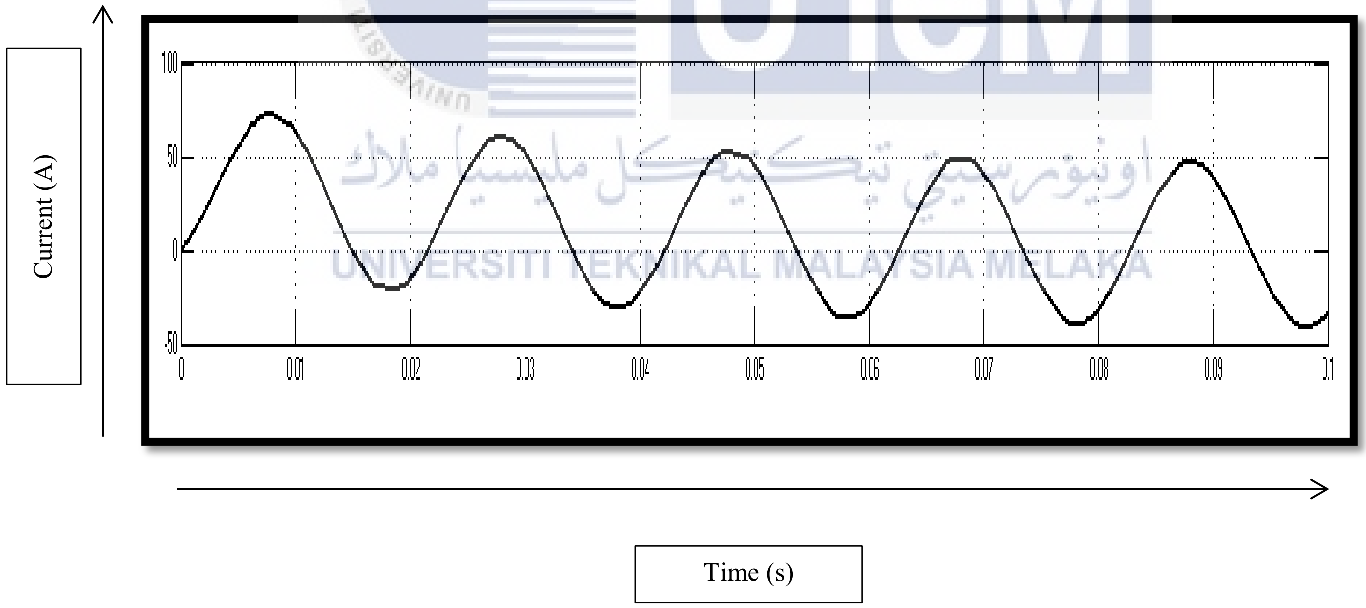


Figure 4.9.2: Waveform current vs time for phase a at current source, I_{Sa} (Linear)

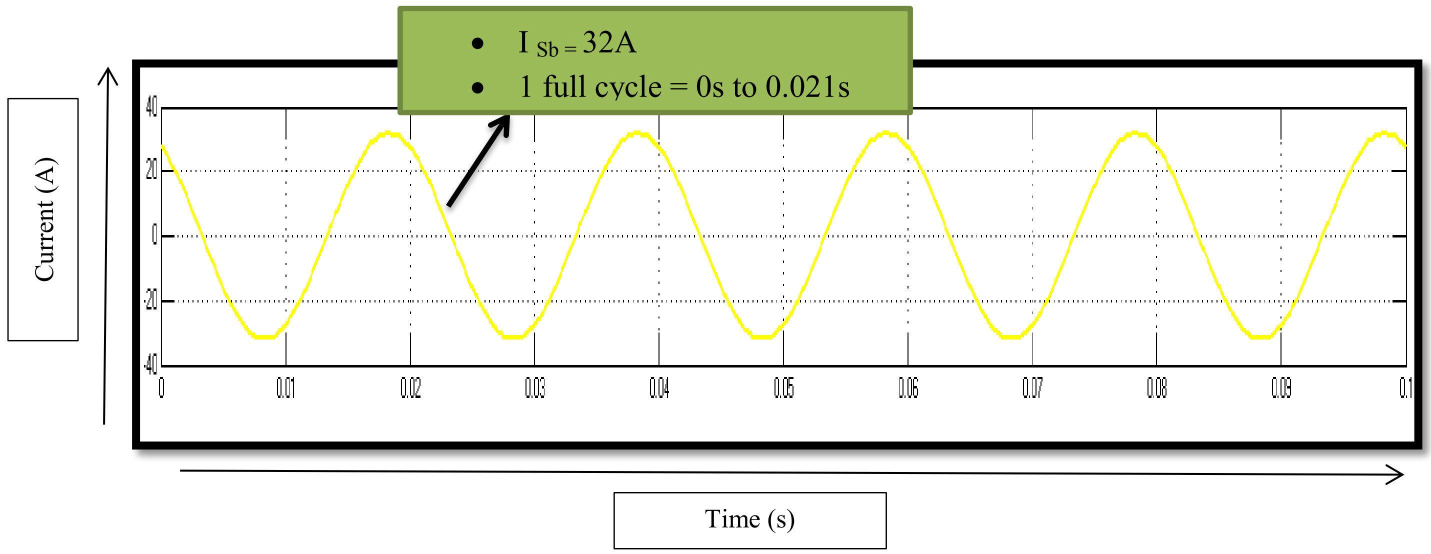


Figure 4.9.3: Waveform current vs time for phase b at current source, I_{Sb} (Non-linear)

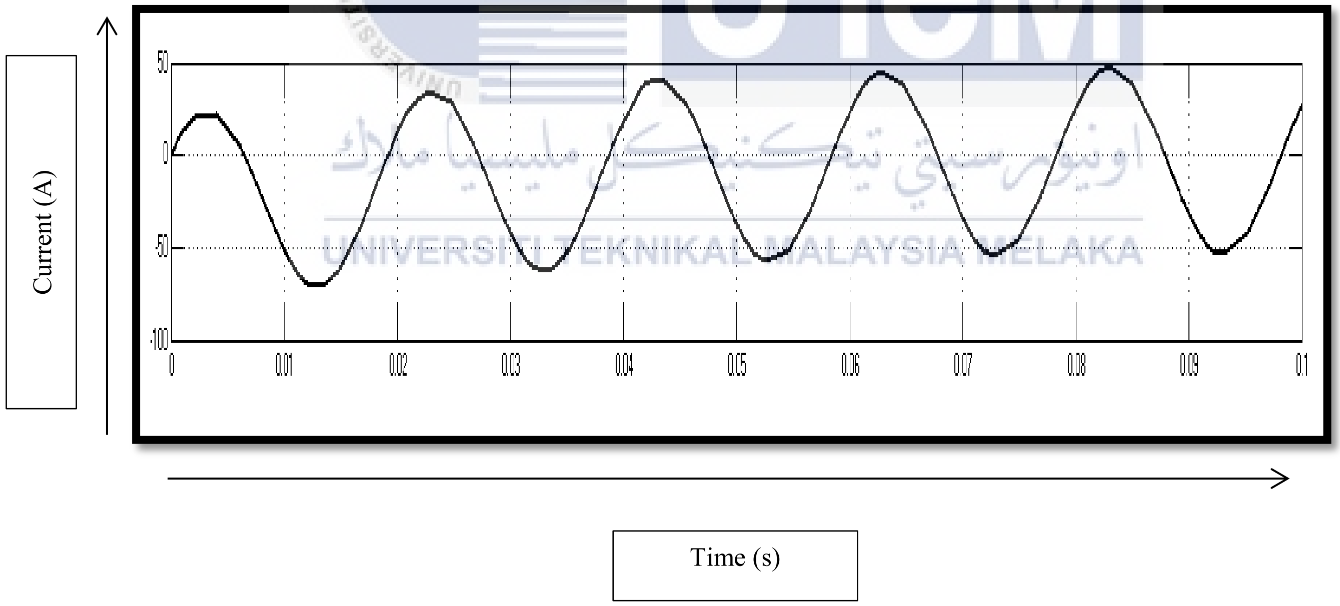


Figure 4.9.4: Waveform current vs time for phase b at current source, I_{Sb} (Linear)

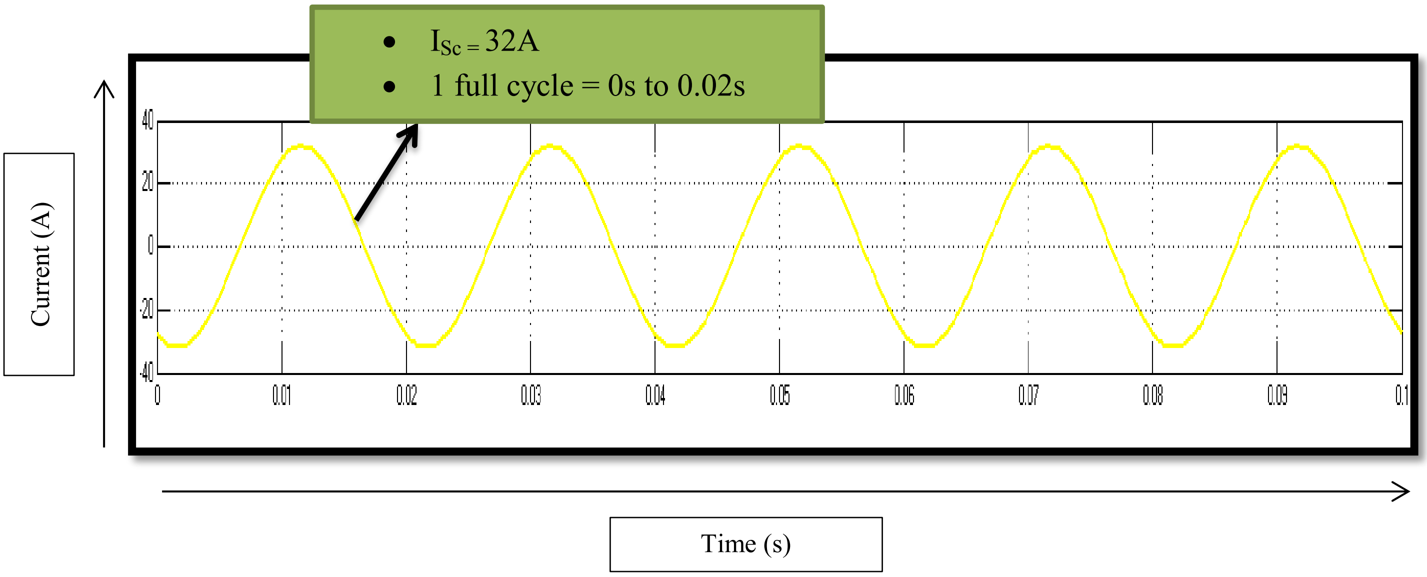


Figure 4.9.3: Waveform current vs time for phase c at current source, I_{sc}

Based on waveform for total phase at current source, it can be seen that the waveform for linear and nonlinear still in sinusoidal waveform whether it still in condition balance/unbalance or linear/nonlinear. This was useful to get the constant power supply and sinusoidal current waveform at point of common coupling. It can be seen on figure 4.9.4 and figure 4.9.5.

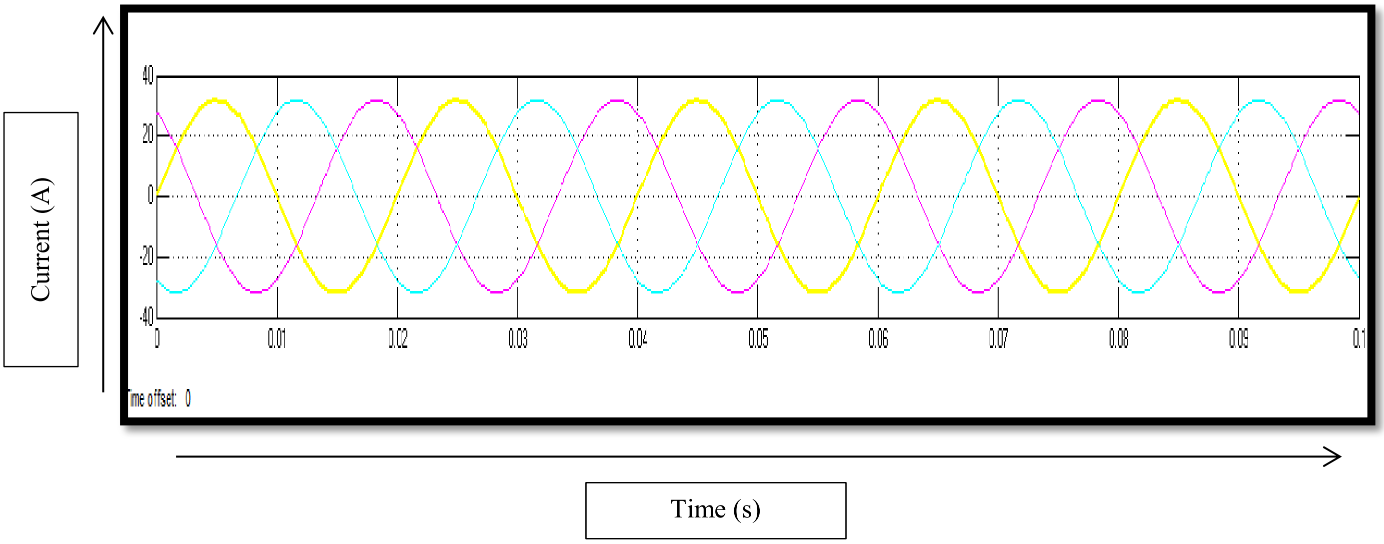


Figure 4.9.4: Waveform current vs time for total phase at current source, I_{ST} (Non-linear)

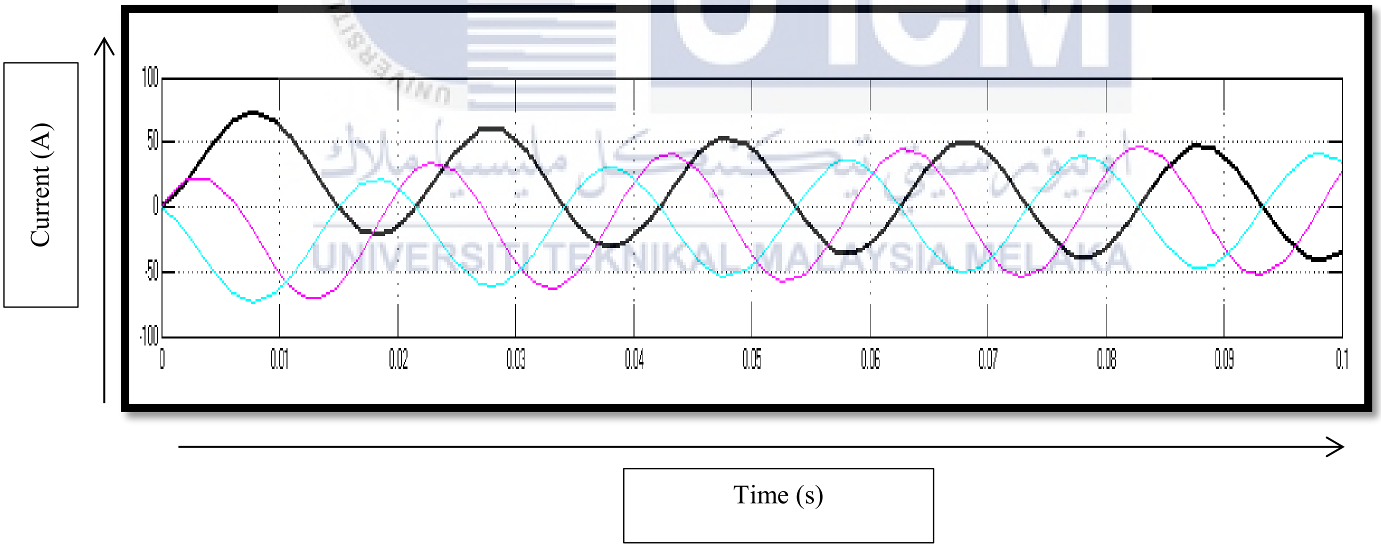


Figure 4.9.5: Waveform current vs time for total phase at current source, I_{ST} (Linear)

The helpfulness current (I_{sf}) is a current come from APF after the filtering is done. This current will be connect to the power source and it free from the harmonics. Figure below shows the waveform for I_{sf} for both linear and nonlinear load. The current drawn is 30A for both load.

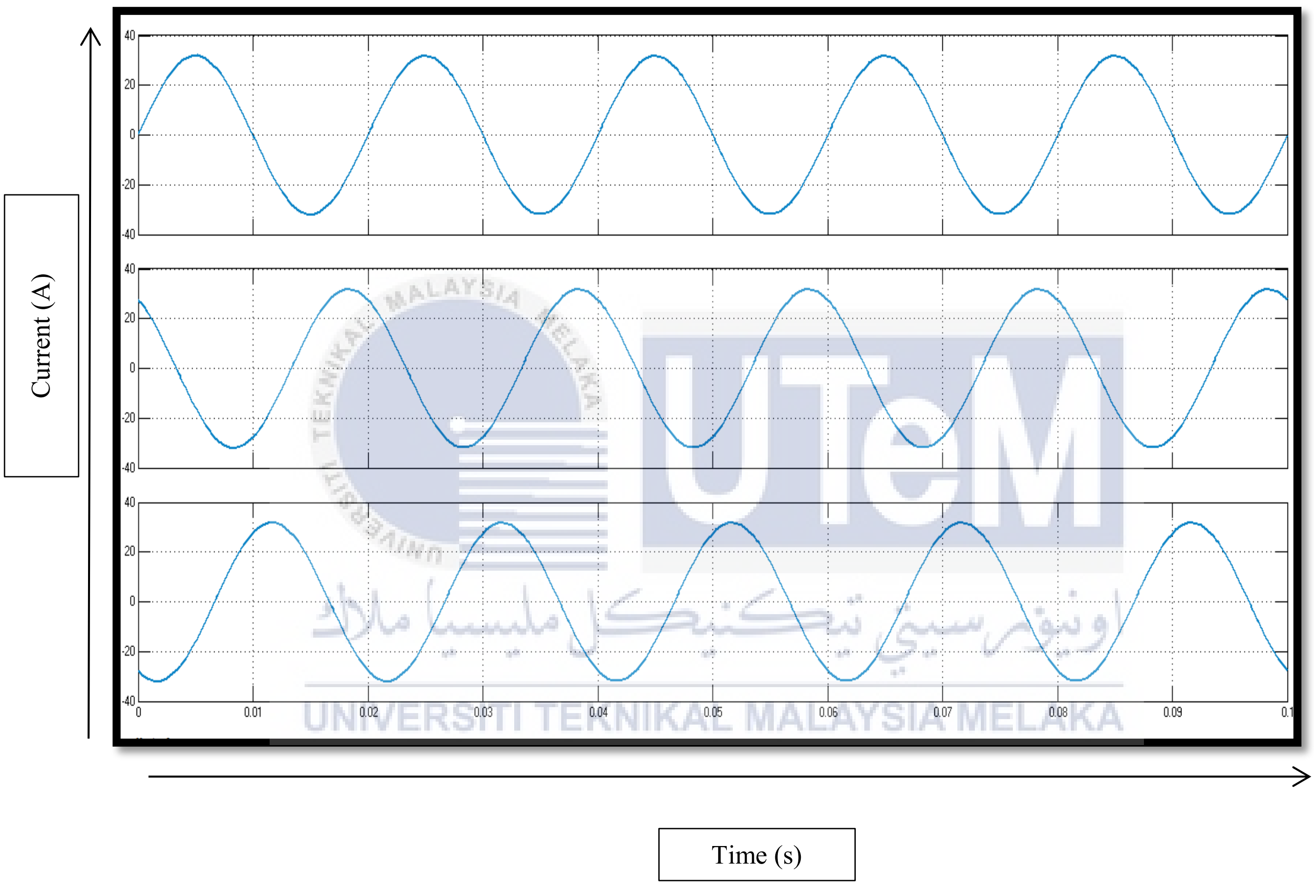


Figure 10.1: Waveform current vs time for helpfulness line current, I_{sf} (Non-linear)

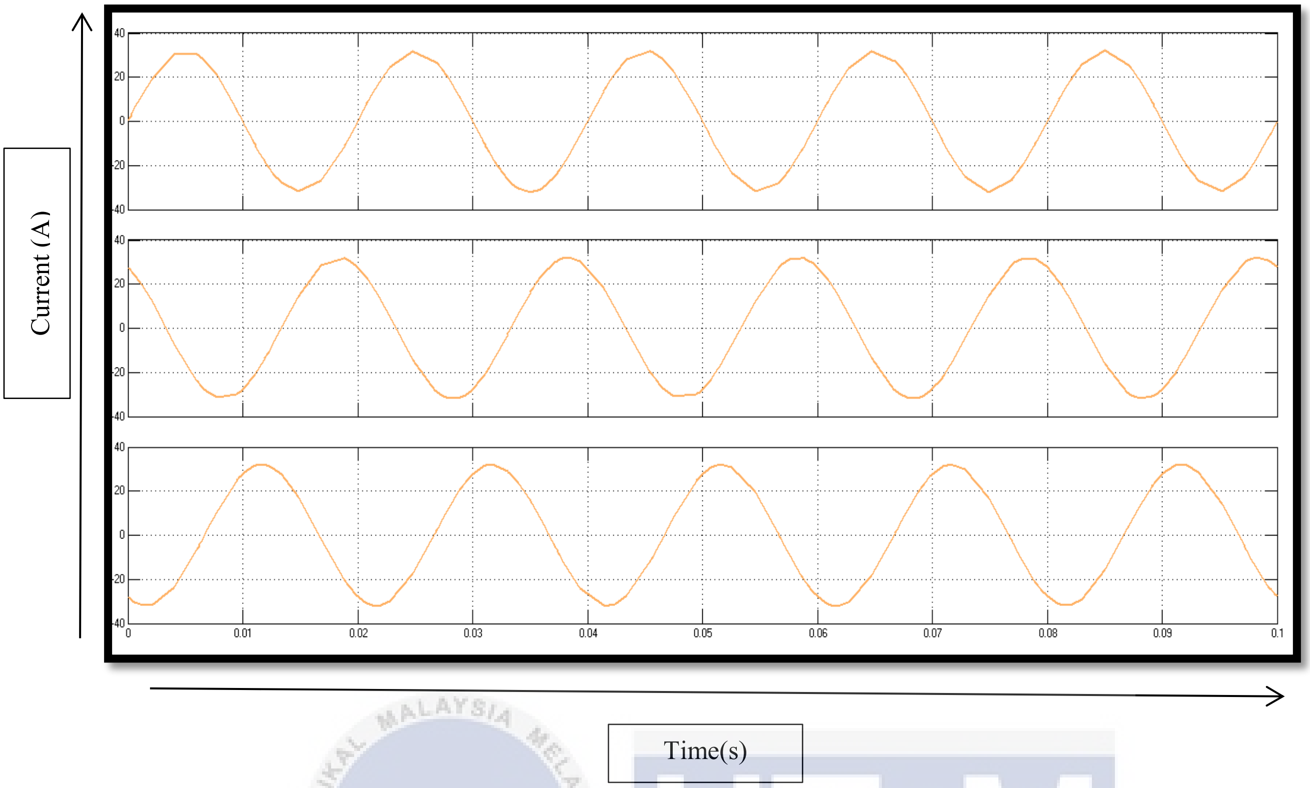


Figure 10.2: Waveform current vs time for helpfulness current line current, I_{Sf} (Linear)

Table 4.2: comparison current obtains between normal current and harmonic current.

Current, A	Linear load	Non-linear load
I source , I_s	Phase a: 50	Phase a: 32
	Phase b: 50	Phase b: 32
	Phase c: 50	Phase c: 32
I load, I_L	Phase a: 50	Phase a: 0.006
	Phase b: 50	Phase b: 0.006
	Phase c: 50	Phase c: 0.006
I helpfulness current, I_{sf}	Phase a: 30	Phase a: 30
	Phase b: 30	Phase b: 30
	Phase c: 30	Phase c: 30

From figure 4.10, it shows the waveform at DC voltage. The reference voltage use for this design and development of active power filter for harmonic reduction in electrical distribution system is 1000V.

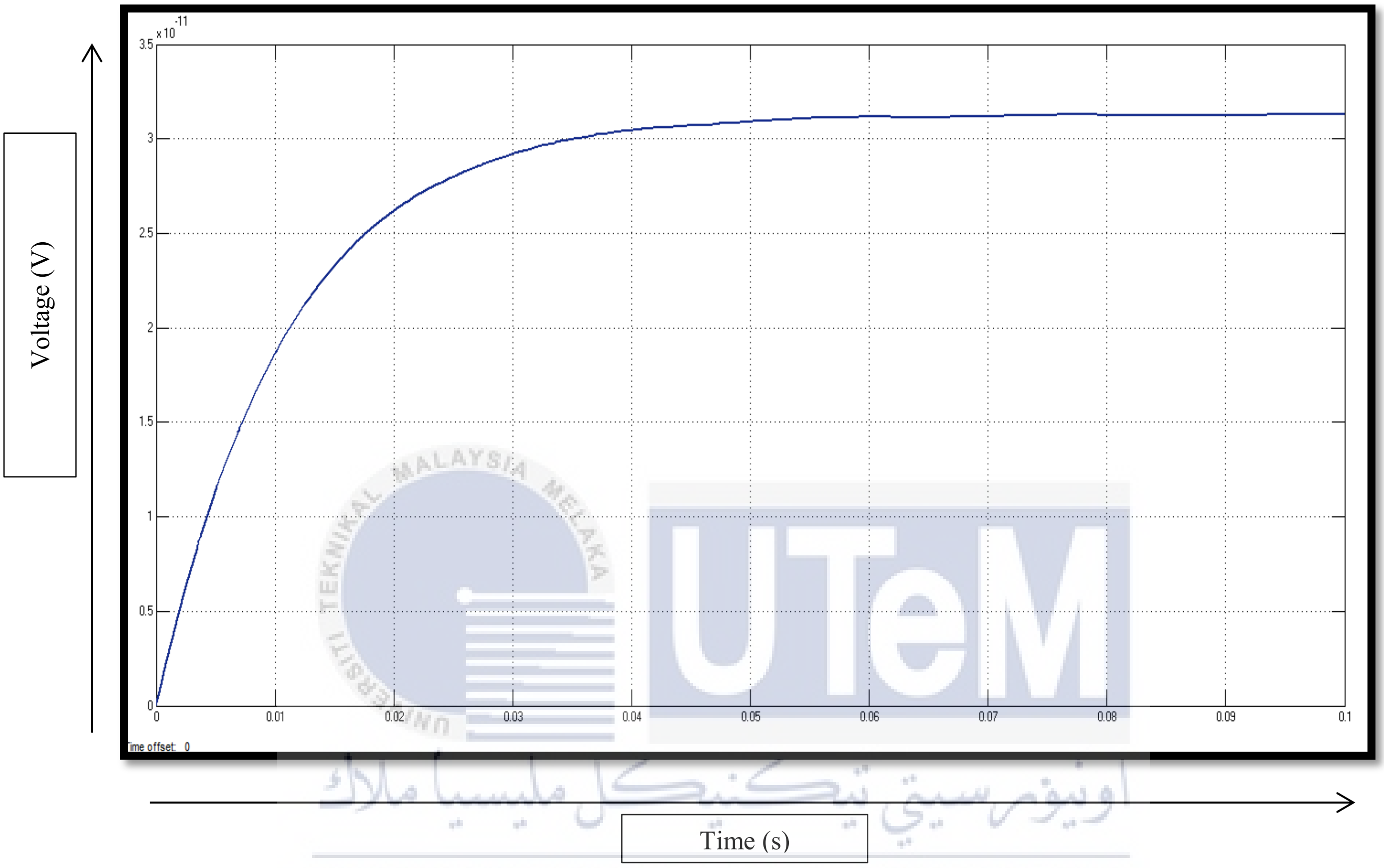


Figure 4.10: Waveform at DC voltage, V_{DC}

From figure 4.11 below shows the waveform for every phase (a, b and c) at compensation current and reference load currents. From the waveform it can see the peak current for every phase a and phase b is 3A whereas for phase c the peak current is 0.006A.

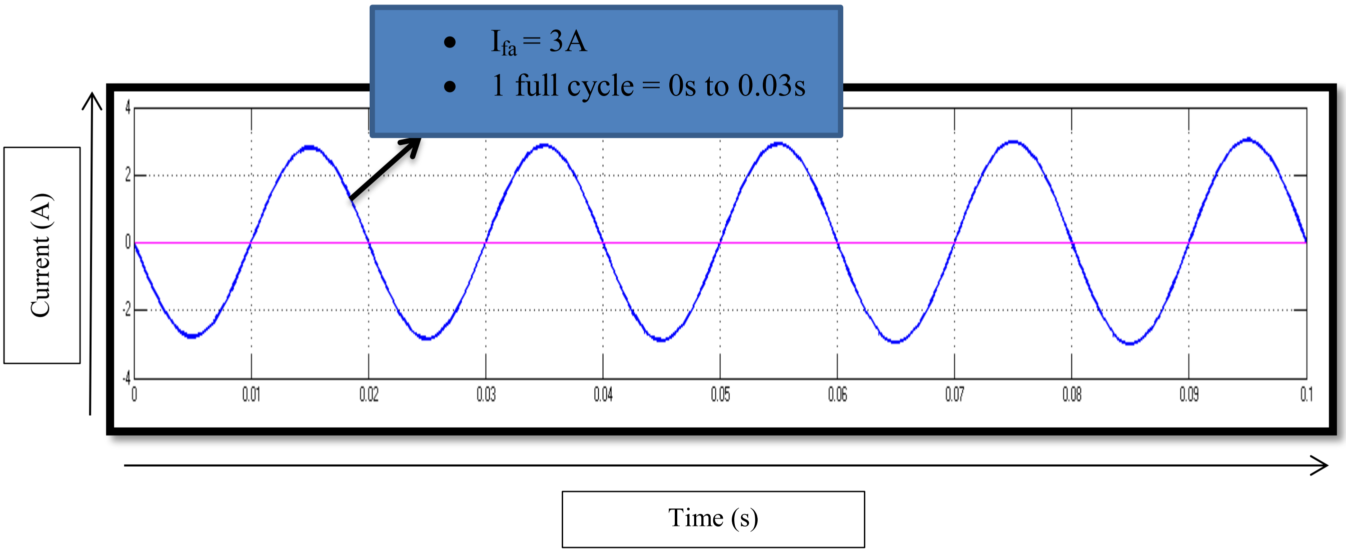


Figure 4.11.1: Waveform current vs time for phase a at compensation current and reference load current

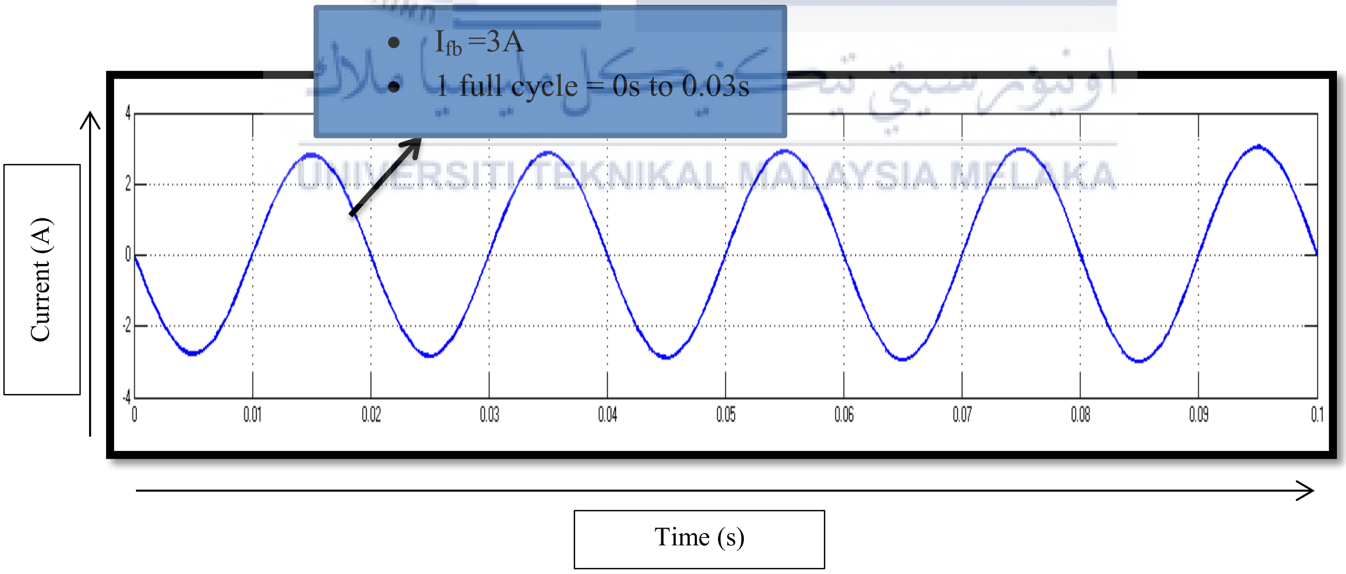


Figure 4.11.2: Waveform current vs time for phase b at compensation current and reference load current

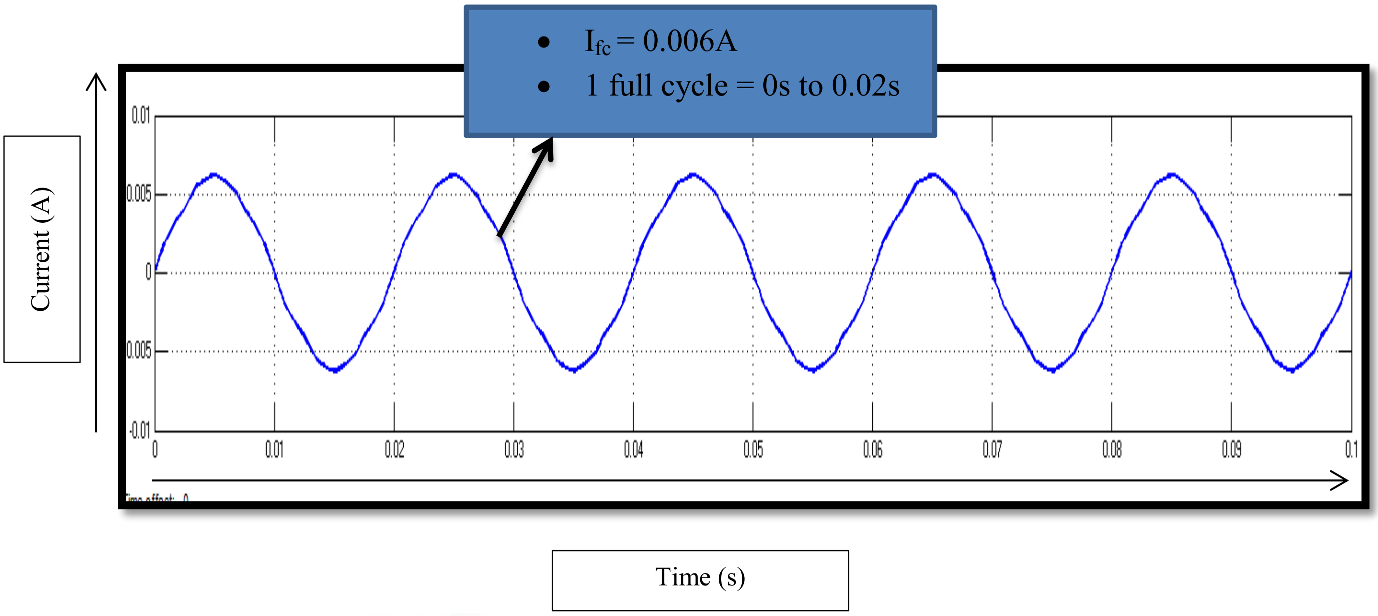


Figure 4.11.3: Waveform current vs time for phase c at compensation current and reference load current

Figure 4.1 presents the electrical scheme of a shunt active filter for a three phase power system which is able to recompense for both current harmonics and power factor. The power stage is predominantly a voltage source inverter with only a single capacitor in the DC side (the active filter does not require any internal power supply) controlled in a way that its performances like a current source.

From the measured values of the phase voltage (V_a , V_b, V_c) and the load currents (I_{La} , I_{Lb}, I_{Lc}) controller analyses the reference currents (I_{fa}, I_{fb} , I_{fc}) used by the inverter to yield the recompense current. The active power filter (APF) is a device that is linked in parallel to and withdraws the reactive and harmonic currents since a nonlinear load. The consequential total current drained from the ac main is sinusoidal. Preferably, the APF needs to produce just enough reactive and harmonic current to recompense the nonlinear loads in the line.

The THD (total harmonic distortion) is also calculated in load current as well as in supply current. The THD is 31.44% before harmonic return in load current and 3.33% in supply current after harmonic current reduction that is within the limit of the harmonic standard of IEEE 519.

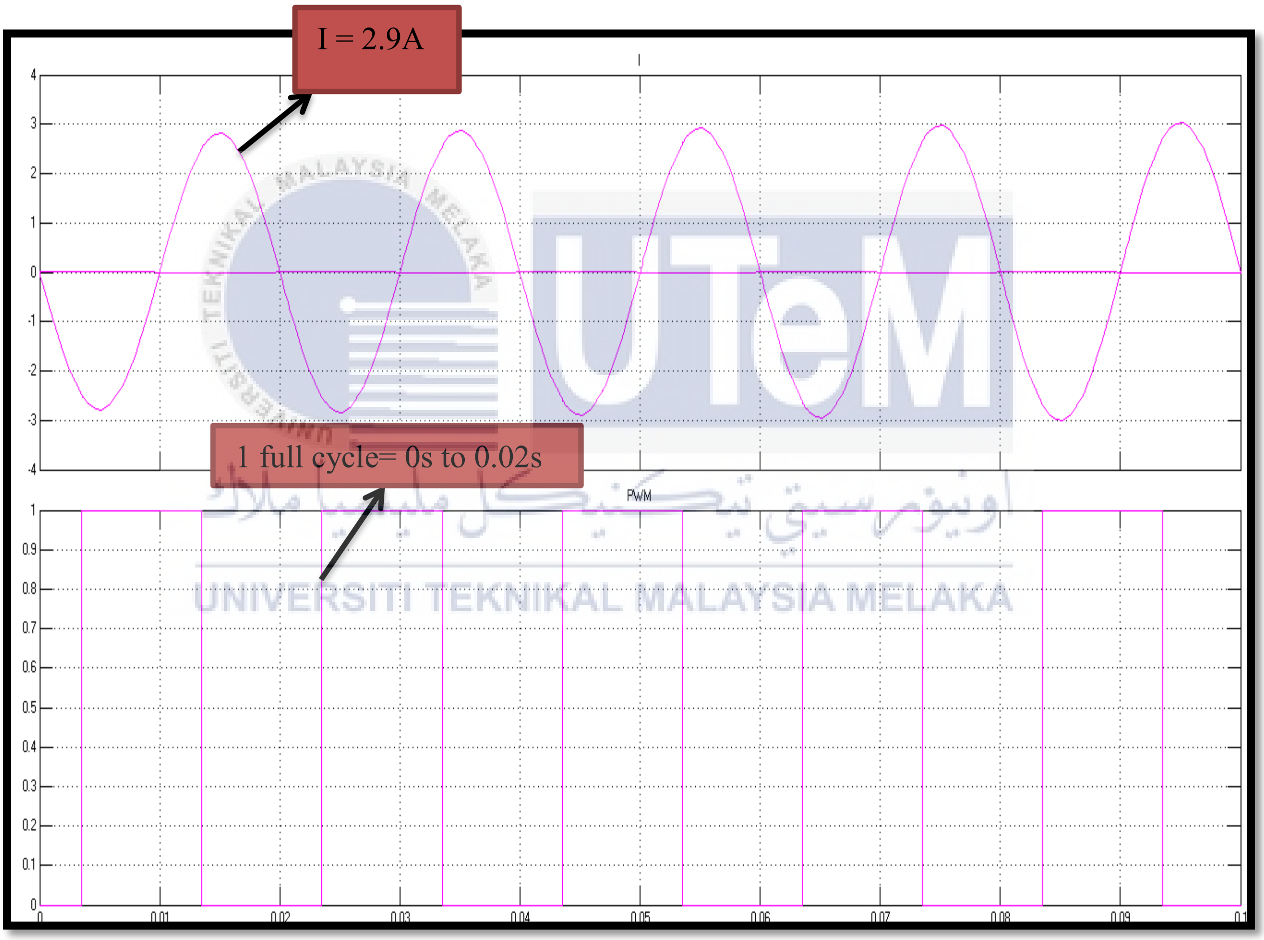


Figure 4.12: Waveform for switching pattern at inverter

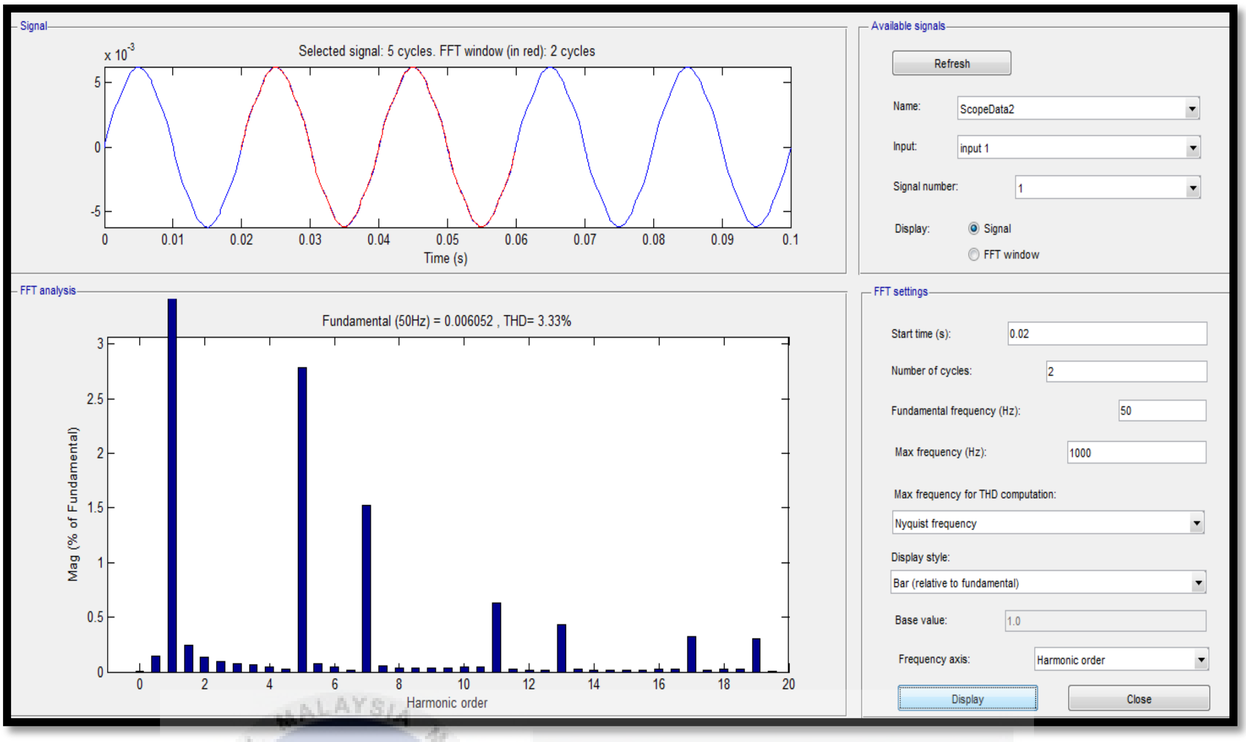


Figure 4.13: Harmonic spectrum after adding APF

Table 4.3: The value of THD before and after adding APF.

	Before	After
THD (%)	31.44	3.33

Based on the table 4.3, it can be seen that the percent of THD became decreases. This shows that by adding APF, it can mitigate the harmonic reduction in electrical system. Thus, the quality and the performance of the system become more effective and stabilize.

CHAPTER 5

CONCLUSION

As a conclusion, the concept of active power filter for harmonic reduction in electrical distribution can be proved by doing the simulation, it shows that without filter the wave ripple will not be in smooth condition and current distortion cannot be solve. Besides that, the effect of harmonic can bring a lot of problems such as, it can produce low power factor resulting the utility bills will increase and it also can cause overheating onto the electrical equipment for distribution system like transformers, cables and induction motor. The performance of active power filter can be studied, model and develop suitable parameters for harmonic reduction in electrical system.

Besides that, the methodology of each objective in this project is created thoroughly. Started from literature review and then proceed to the design and develop the circuit configuration and lastly analyze the performance of an active filter. So, it can be seen that the objective for this project is achieved. The active power filter (APF) obtainable in this research to eliminate the harmonic current components in nonlinear load was actual for harmonic separation and custody the utility supply line current sinusoidal. The rationality of this technique in order to recompense current harmonics remained shown on the origin of simulation consequences by using MATLAB/Simulink. The APF is found operative to meet IEEE 519 standard approval on harmonics points. This defines an adaptive hysteresis-band current control PWM technique where the bandwidth can be set as a purpose of system parameters to enhance the PWM performance.

REFERENCES

[1] Ali Mihring, “Harmonic Study Analysis Guidelines for Industrial Power Systems”.

[2] Cividino L, “Power factor, Harmonic distortion; Cause, effects and Considerations”, IEEE Telecommunications Energy Conference, INTELEC ’92, 14th International, 4-8 Oct. 1992, pg. 505-513.

[3] Awad, H.; Bollen, M. H J, "Power electronics for power quality improvements," Industrial Electronics, 2003. ISIE '03. 2003 IEEE International Symposium on, vol.2, no., pp.1129, 1136 vol. 2, 9-11 June 2003 doi: 10.1109/ISIE.2003.1267983

[4] Singh, Bhim; Al-Haddad, K.; Chandra, A., "A review of active filters for power quality improvement," Industrial Electronics, IEEE Transactions on, vol.46, no.5, pp.960,971, Oct 1999 doi: 10.1109/41.793345

[5] H. Akagi, “Active harmonic filters,” Proc. IEEE, vol. 93, no. 12, pp. 2128– 2141, Dec. 2005.

[6] F. Z. Peng and D. J. Adams, “Harmonics sources and filtering approaches,” in Proc. Industry Applications Conf., Oct. 1999, vol. 1, pp. 448–455.

[7] Sankaran,C. | Electrical Construction and maintenance.

[8] A.Nakagima, J.Nishidai, and T.Shiroishi, “Development of active filter with series resonant circuit”, Conf. Rec. IEEE-PESC, 1168-1173(1998)

[9] M.Rostagi, N.Mohan, and A.A. Edris, “Filtering of harmonic currents and damping of resonance in power systems with a hybrid-active filter”, Conf. Rec. IEEE-PES ICHPS, 242-249 (1994).

[10] S.Bhattacharya, P.T Cheng, and D.M. Divan, “Hybrid solutions for improving passive filter performance in high power application”, IEEE Trans. Ind. Electron. 48(6), 118-1127 (2001).

[11] Salmeron, P.; Litran, S.P, “Improvement of the electric power quality using series active and shunt passive filter,” Power delivery, IEEE Transactions on, vol.22 no. 1, pp. 595, 604, Jan. 2007 doi: 10.1109/TPRWD. 2009.2034902

[12] N.Tokuda, Y.Ogihara, M.Oshima, and T.Miyata,”Active Filter with Series L-C Circuit”, Conf. Rec. IEEE-PESICHPS, 242-249 (1994).

[13] F.Z Peng, “Harmonic Sources and Filtering Approches”, IEEE Ind. Appl. Mag. 7,18-25 (2001).

[14] Issa Batarseh: Power Electronic Circuits. New York: John Wiley, C2004.

[15] M.Depenbrock and C.Niermann, “ A New 18-Pulse Rectifier Circuits with Line-Side Interphase Transformer and Nearly Sinusoidal Line Currents,” Proc. of the International Power Electronic Conference (IPEC), Vol.1, pp.539-546 (1990).

[16] ABS Guidance Notes on Control of Harmoics in Electrical Power Systems, American Bureau of Shipping, 2006.

[17] M.E Habrouk, M.K.Darwish and P.Mehta, "Active power filters: A review", IEEE Proc. Elertronics and Power Applications, Vol. 147, No. 5, September 2000.

[18] D.R. Henderson and J.P. Rose, “Harmonics: The Effects on Power Quality and Transformers,” IEEE Transactions on Industry Applications, vol.30, pp.528–532, 1994.

[19] K.J. Phipps, P.J. Nelson and K.P. Sen, “Power Quality and Harmonic Distortion on Distribution Systems,” IEEE Transactions on Industry Applications, vol.30, pp.476–484, Mar/Apr 1994.

[20] S.J. Subjak and S.J. McQuilkin, “Harmonics-Causes, Effects, Measurements, and Analysis: An Update, ” IEEE Transactions on Industry Applications, vol.26, pp.1034–1042, Nov/Dec 1990.

[21] S. Jain, P. Agarwal, O.H. Gupta and G. Agnihotrin, “Modeling of Frequency Domain Control of Shunt Active Power Filter using MATLAB Simulink and Power System Blockset,” Electrical Machines and Systems (ICEMS).Proceedings of the Eighth International Conference on, pp.1124-1129. 2005.

[22] M. Kesler and E. Özdemir, “Power Qualıty Improvement With UPQC in 3-Phase 4-Wıre Systems,” vol. 25, pp. 681-691, 2010.

APPENDIX

Work Schedule for Semester 1

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Planning and Literature Review														
Study of required component														
Design and set up of APF module														
Planning on APF for harmonic reduction														
Run the circuit configuration														
Data processing														
Preparation of thesis report and presentation														

Work Schedule for Semester 2

* Based on the outcome in semester 1, the APF will be connecting in order to mitigate the harmonic reduction in electrical distribution system.

Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Planning and Literature Review														
Study of required component														
Design and set up of APF module														
Planning on APF for harmonic reduction														
Run the circuit configuration														
Data processing														
Preparation of thesis report and presentation														