CHAPTER 1

INTRODUCTION

1.1 Background of Study

Harmonic frequency has become one of the main problems in electrical power system as it would cause the loads connected to them to overheat due to the increased frequency [1]. As for induction motor, additional losses can occur in the core and windings of the motor which in turn increases the operating temperature of the core and the windings surrounding inside the core.

The source of these harmonics can be from the unstable power supply itself but most of them are due to the electronic load, also known as the non-linear load [1] [2]. There are many techniques being applied in order to resolve these harmonic problems and one of the most commonly used is by using the active power filter. With this technique, the harmonic currents are not just being filtered out but instead, they are being eliminated with the injection of compensation current. In order to determine the compensation current to be injected to the ac line, there are several concepts. The methods of estimation of compensating current is to be understood as the active power filter consists of several parts and each of them have their own role to be played.

1.2 Problem Statement

In electrical motor application, torque is needed for the rotation of the motor which is induced from the current supply. The problem occurs when it comes to starting the motor whereby large initial current is consumed thus causing voltage fluctuation leading to the drawbacks in the performance of other circuits connected to the common power supply. The source of this problem is often due to large capacitors with very low input impedance [3]. Therefore, soft starting is needed to adjust the current input to the motor as to reduce the mechanical stress on the motor and shaft as well as the electrodynamics stresses on the attached power cables and electrical distribution network. By doing that, it would expand the lifespan of the system itself [4].

However, the price for that action is the growth of harmonic currents which increase rather exponentially whenever power factor corrector or harmonics filtering capacitors are connected to the system [3]. Having said that, this project will explore into detail on the best technique in designing active power filter for the elimination of harmonic current.

1.2.1 Problem Identification

Before any modelling and simulation can be made using MATLAB, the understanding on the basic principles of an active filter are needed. Besides having to understand the characteristics of an active filter, learning the method used in determining the reference current are also a necessity for the completion of the project. Only then the designing process of the control unit for the active power filter can be carried out. Aside from the theory of the project, simulating the designed circuits is another thing. Therefore, the author need to master the simulation tools itself in order for the simulation phase to take place.

1.3 Objectives

Several objectives from this study are identified which are:

- Design the Shunt Active Power Filter (SAPF) to eliminate the harmonic current caused by the soft starting in the induction motor application.
- Estimate the reference current of the harmonic current to determine the compensation current that is needed to be injected in the ac line.
- Generate gating signals to control the switching time of the Voltage Source Inverter (VSI). This is to form the signal of the compensation current.
- Simulate the APF in MATLAB/SIMULINK and analyze the waveform of the current and switching frequency of the VSI.

1.4 Scope of Study

The scope of study will involve the study on the SAPF in terms of the type, component and characteristics. It is necessary to identify the type of APF and determine which will be more suitable to be applied for this project. After having done that, a study on the components of the SAPF is needed as there are several important parts which will need to be studied before moving on to the designing part. For SAPF, two main parameters are to be considered which are the estimation of reference current and the generation of gating signals for the VSI. Considerable knowledge and understanding on these two parameters will be the key of success for this project.

Aside from having a firm ground knowledge on those areas, sufficient knowledge and know-how skills on Matlab Simulink SimPower Toolbox is also crucial as the construction and simulation phase of the models will be done using this software. For the project, no prototype will be constructed as it is out of the project scope and the process will require and consume quite an amount of time.

CHAPTER 2

LITERATURE REVIEW

2.1 Induction Motor

Induction motor is a type of alternating current motor whereby it acquires the current supply in the form of electromagnetic induction. An electric motor works by following the principle of power conversion which takes place in the rotor which is the rotating part of the motor [3]. Induction motor is one of the most commonly used AC motor in the industrial application and it is simply because of its simple design and features which has a rugged construction and relatively low manufacturing cost.

2.2 Active Power Filter

Active Power Filter (APF) is a type of analogue electronic filter which is commonly used in the mitigation of harmonic distortion both in voltage and current supply signal [8]. Compared to passive filter, APF actually generates the current components specified to cancel out the harmonic components which is caused by the non-linear loads and this is done by using the power electronic technologies as for the control unit [1].

The information regarding the harmonic currents and other system variables will be handled by a the compensation current or voltage reference signal estimator. The compensation current is responsible in generating the compensation signals (current/voltage) thus providing the control over the gating signal generator [9]. In other words, the compensation reference current will be the one driving the overall system controller.

Aside from being able to suppress the harmonic current supply, APF can also suppress the reactive current and they do not cause any harmful resonances with the power systems itself thus, making them to be independent in the power distribution properties [9]. Even so, APF also have some drawbacks whereby it has a need for fast switching of high currents in its power circuit. This will result in high frequency noise which would cause an Electromagnetic Interference (EMI) in the distribution system [9].

2.3 Shunt Active Power Filter

There are several configurations for APF that can be implemented on the power supply line and each of them has their own pros and cons. For this project, the configuration that will be applied is the SAPF and this is currently the most widely used configuration in the active filtering applications. It consist of controllable voltage or current source depending on its application. The VSI based SAPF is the most common type used it is due to its straight forward installation procedures [9].

SAPF can basically be said as current supply which generates the current necessary to compensate the harmonics developed due to the non-linear loads (i.e. Induction Motor) [9]. The operation involves the injection of compensation current to the ac line which is equal to the distorted current, thus eliminating the original distorted current. This is performed by the VSI switches which will “shape” the compensation current waveform as estimated by the current reference determination unit [9]. The load current (i_L) is measured and then being subtracted from the sinusoidal reference (i_S) which results in the compensation current (i_f) for the system. The relationship between these currents can be expressed using the equation of $i_S = i_L - i_f$ [9].

The advantage of using shunt APF configuration is that not only it can carry the compensation current but also a small amount of active fundamental current supplied to compensate for system losses which also contributes to reactive power compensation [9].

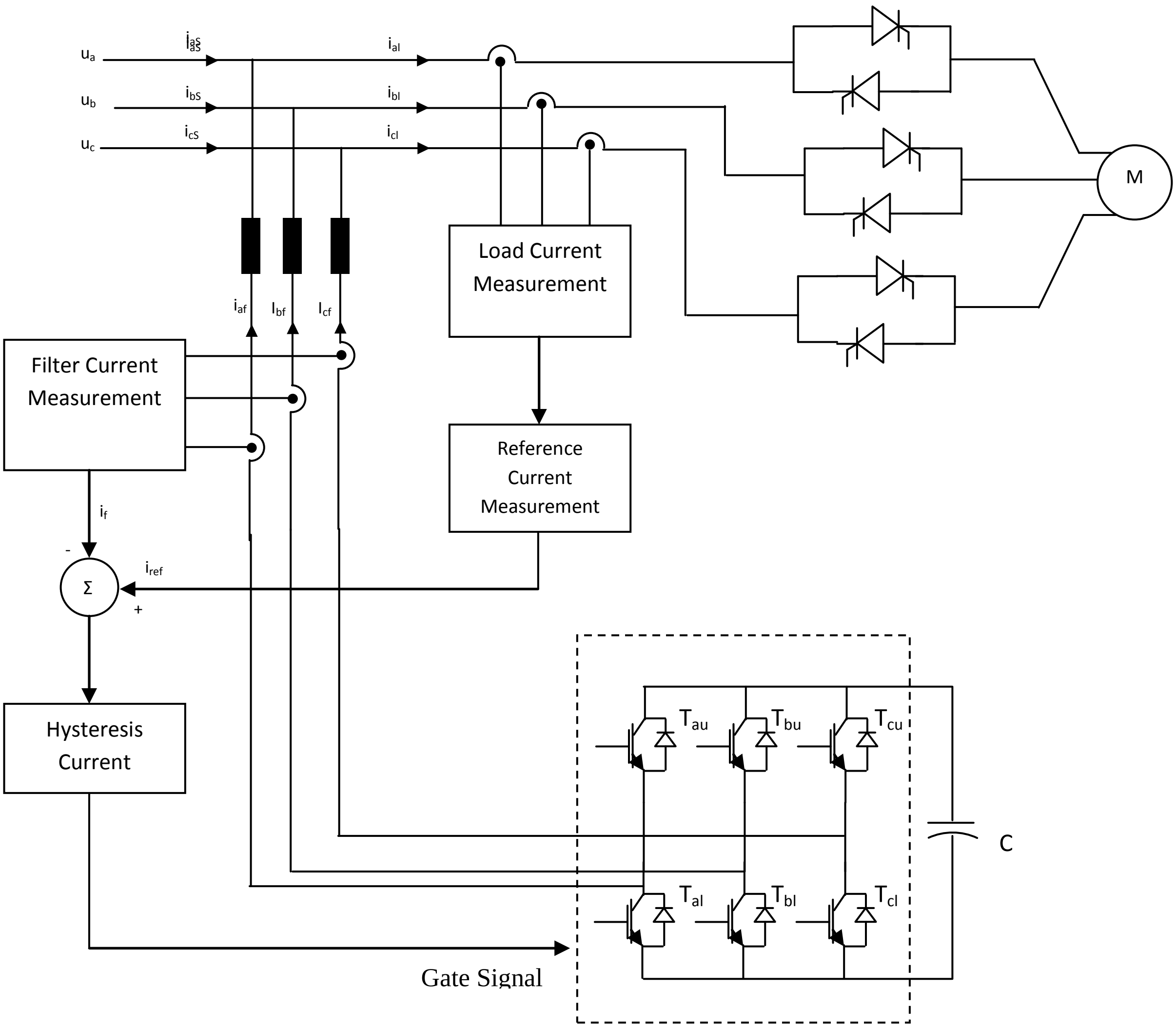


Figure 1: Three Phase Three Legged Shunt Active Power Filter (SAPF) Configuration [1]

Based on **Figure 1**, the currents on the ac lines will be measured and these currents will be directed to the Reference Current Measurement / Estimation Unit. This unit will be the one responsible to calculate the reference current, i_{ref} which will be the one to be generated. Then, this i_{ref} will be compared or subtracted with the generated compensation current from the VSI. Having done that, the resulted current is called the error signal, i_e whereby this will be passed on to the Hysteresis Current Controller Unit. In this part, the i_e will be used in order to generate the gating signals as of to control the switching time of the VSI switches. The VSI is supplied through a capacitor. When a switch is turned on, it will give the value of +Vdc and when it is turned off, it will result in a zero value. The switching between these two voltage levels will eventually "shape" the compensation current for the system which is to be injected through the ac lines.

2.4 Instantaneous Power Theory

In estimating the reference current signal, some calculation methods are required in order to calculate the reference current from the ac lines. Conventional methods used are classified either as time-domain or frequency-domain. The compensation current signals are obtained from the instantaneous real and reactive power components. For this project, the Instantaneous Power Theory is used which does not need phase synchronization. This theory involves the algebraic transformation of the three phase voltages and currents from the a-b-c coordinates to the α-β-0 coordinates (Clark Transformation). Having done that, it is followed by the computation process of p-q theory instantaneous power components. This theory is basically used in order to find the power components in the system.

By knowing these components, identification process can be done to see which are the desired power components and which are not. Having finished with that, the compensation current needed to be injected to the system can be determined in order to eliminate the undesirable power components together with the harmonics [12].

2.5 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a technique which is used to transmit information in terms of series of pulses. The data transmitted is encoded in by the variation of the pulse width in order to control the amount of power being sent to a load. In other words, PWM is a technique used to generate variable width pulses to represent the amplitude or magnitude of an analog signal input. By doing this, PWM can control the amount of power transferred to a certain load by simply controlling the width of the pulses. One of the reasons for using PWM technique is to reduce the total power delivered to a load without resulting in loss, which is normally occurs when a power source is limited by a resistive element.

2.6 Hysteresis Current Controller

For an active power filter to eliminate the harmonic currents in a power system, it needs to calculate the compensation currents first and then inject them back to the system. With that in mind, VSI is used as switches to form the compensation current signal back but to control the switching time of the VSI, a control unit is needed and this calls for a Hysteresis Current Control. This method controls the switching time of the VSI switches asynchronously in order to ramp the current through an inductor up and down so that it can initiate or produce back the reference current signal. This method is indeed the easiest to be implemented compared to others but it does has some drawbacks which is regarding the switching frequency whereby it does not have any limit to that. However, this problem can be solved with the help of some additional circuits [5].

The reference signal, i_{ref} will be given an upper and lower limits and these intervals are called Hysteresis Band (HB). The error signal, i_e will be compared with the HB. If the i_e reaches the upper limit, the inverter will be switched off as to let the current go down and if the i_e is to reach the lower limit, the inverter will be switched on in order to ramp the current up again. The main idea is to force or to restraint the error signal to stay within the specified HB [5]. These processes will be repeated until the reference current is successfully reproduced.

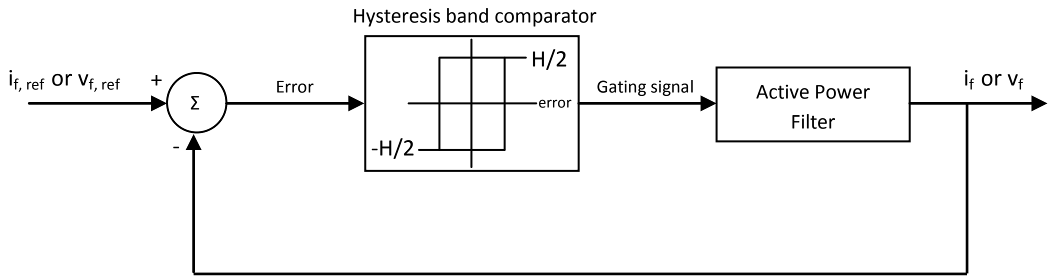


Figure 2: Hysteresis Current Controller Block Diagram [9]

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

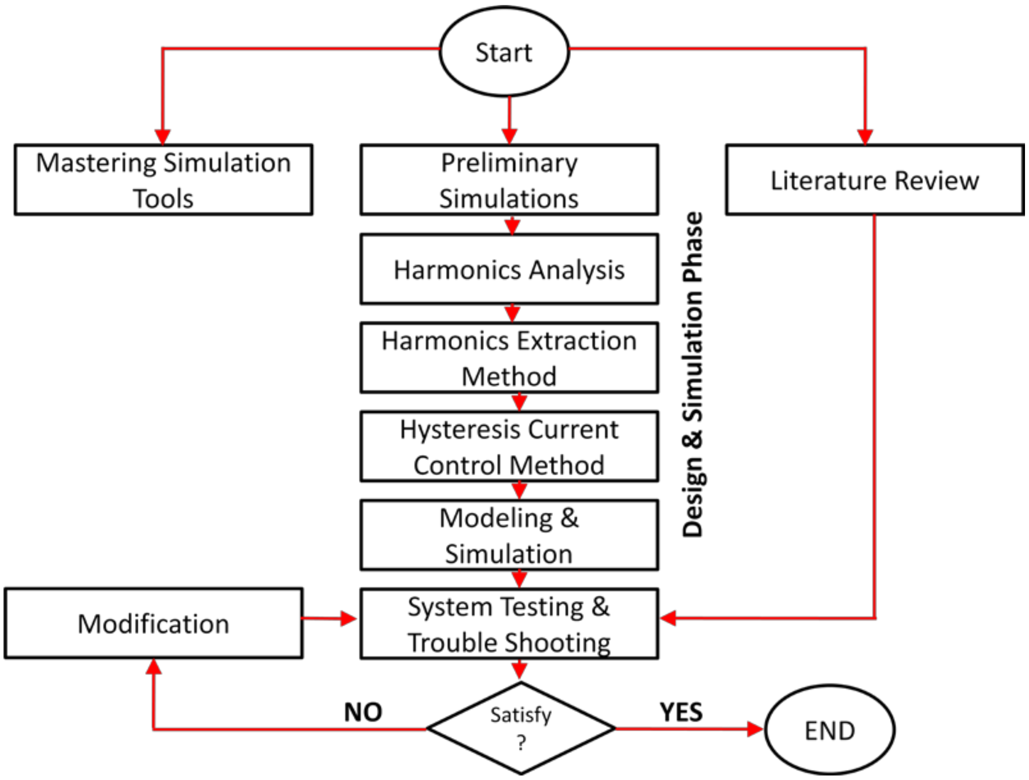


Figure 3: Project Work Flow

The steps involved in the implementation of this project are summarized by Figure 3 and comprises three important phases which are Literature Review, Mastering Simulation Tools and Preliminary Simulation. The project is started by first conducting the literature review and theoretical theory study.

The study covers the type of harmonic sources present in electrical networks and the type of filters available to compensate the harmonics. Regarding the project, the active power filter consist of three major parts which are the Filter, the Reference Current Estimation Method and the Current Control Technique. Focusing on Induction Motor application, SAPF has been chosen as the motor causes major distortion on the current supply signal rather than the voltage supply signal. As for the Reference Current Estimation Method, Instantaneous Power Theory is used to be implemented in the system and finally, Hysteresis Current Control is used to control the current being injected to the system to compensate the harmonics. This will be the main technique to be implemented in this project thus being studied profoundly. Study on another control strategy which in the author's case Pulse Width Modulation (PWM), is also taken into consideration whereby it is important in assisting the analyzing phase and comparing the performance of these two techniques.

The next step is the construction and simulation of the models. Several simulation models using different filters and techniques with different conditions have been tested in order to prove and verify the theoretical study that had been conducted. Model construction and simulation are implemented using Matlab Simulink SimPower Toolbox. Generally, construction and simulation of the models are divided into four levels. The first level will be the construction and simulation of a power system network with a non-linear device as its load without any filter applied. The non-linear load is represented by the use of thyristor converter. The reason for using non-linear device as the load is to test the system first before moving on with Induction Motor load. The second stage is by installing a shunt passive filter to the network. Next is the construction and simulation model for the harmonic compensation using SAPF with the implementation of PWM as its current controller (PWM voltage source inverter). The final step in enhancing the performance of three-phase Induction Motor is by using the same configuration which is implemented using Hysteresis Current Controller technique.

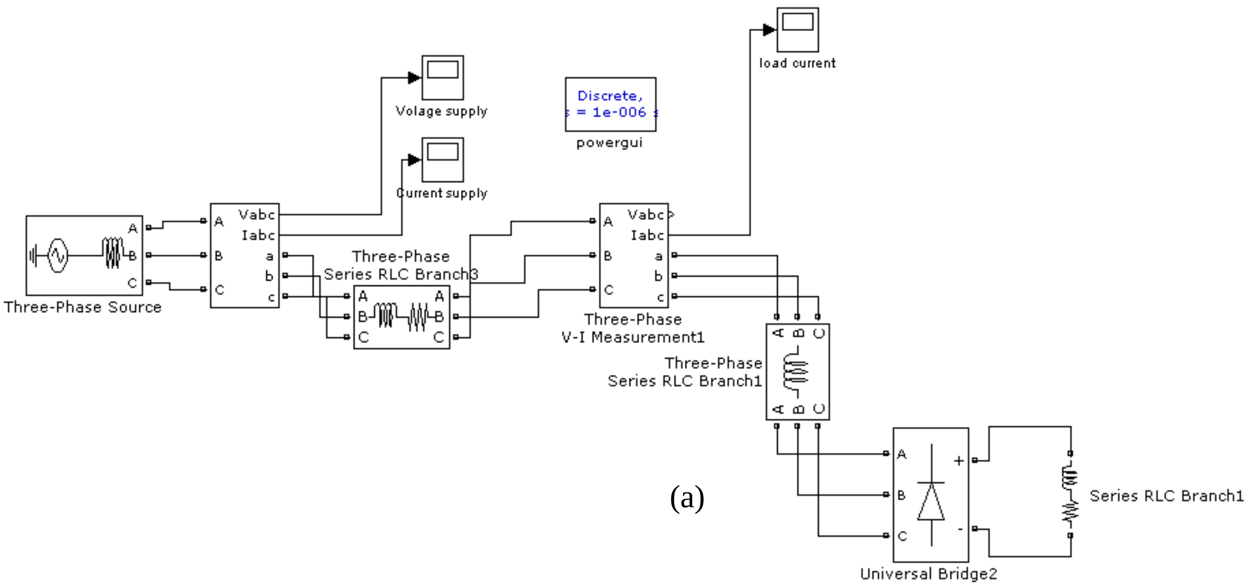
Simulation results of the constructed models are analyzed by observing the signal from the input line current supply and the Total Harmonic Distortion (THD) recorded from the simulation. These signals will be compared between different compensation approaches thus verifying the theoretical study that were conducted earlier.

3.2 Model Construction

The construction of the harmonic compensation model is performed by using Matlab Simulink SimPower Toolbox and generally can be divided into four stages. The **first stage** is to construct a three-phase power distribution with RMS supply voltage of 220 V ac with current supply of 70 A while having a non-linear device as the load. The first stage is basically act as a reference signal to observe the input current supply and the THD recorded which represent the undesired harmonics caused by the non-linear load. Figure 4 shows the constructed model of this power system model.

The **second stage** is where shunt passive filter is installed on the network and the performance will again be compared through the input current supply line and the THD. The shunt passive filter will consist of inductor and capacitor and the network diagram is shown in Figure 5.

At **stage 3**, the system is improved using SAPF as to compensate the harmonics by implementing PWM voltage source inverter as shown in Figure 6. This approach will then be compared with the result of **stage 4** which uses Shunt Active Power Filter implemented with Hysteresis Current Controller as shown in Figure 7. The difference between the two approaches lies with the current control technique whereby this is the part where gating signal is generated and sent to the VSI as to “shape” the compensation current to be injected to the system.



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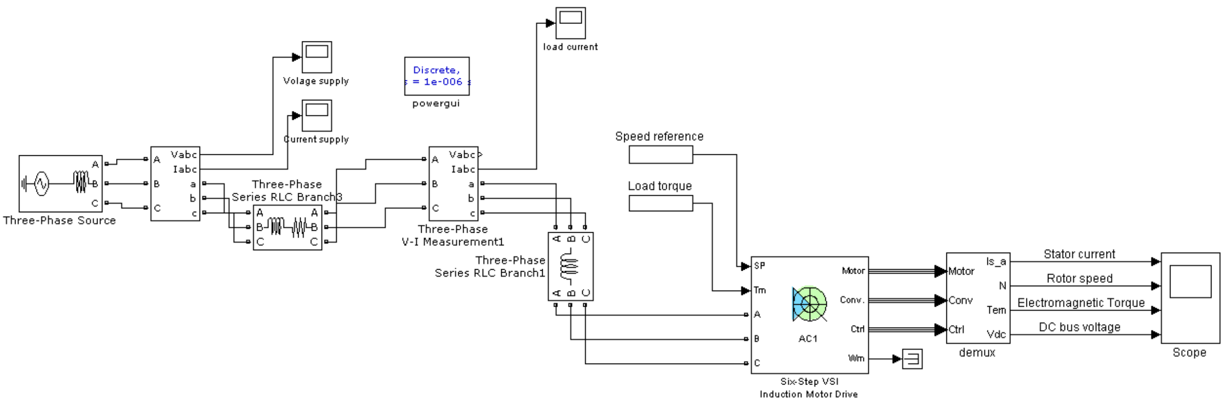
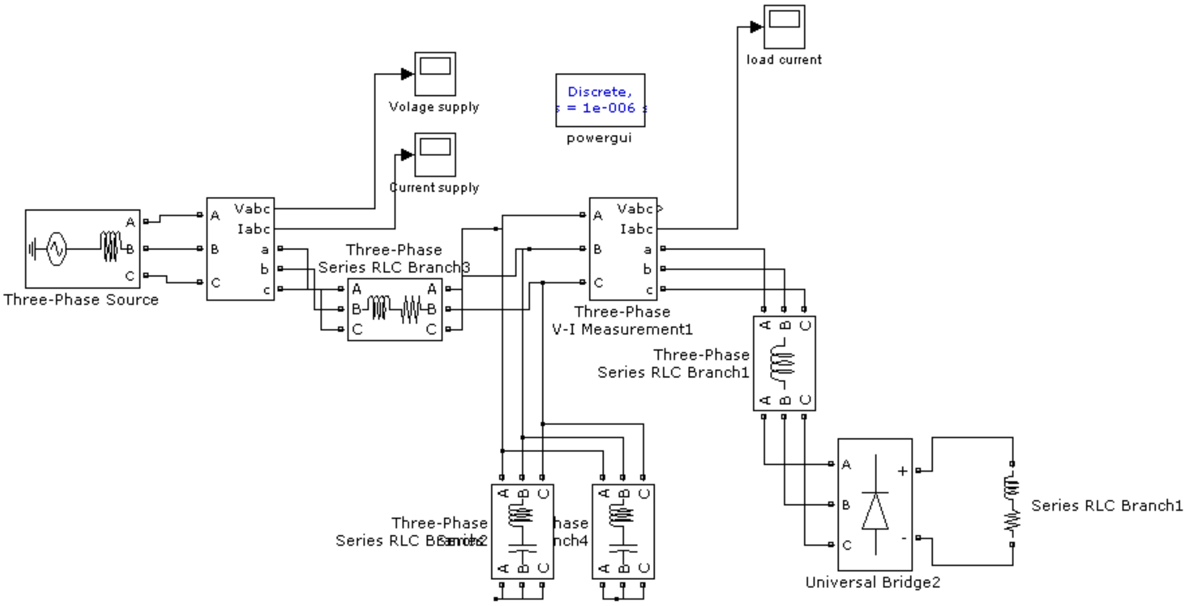


(b)

Figure 4 : Power Distribution System **Stage 1**

(a) Non-Linear Load

(b) Induction Motor Load



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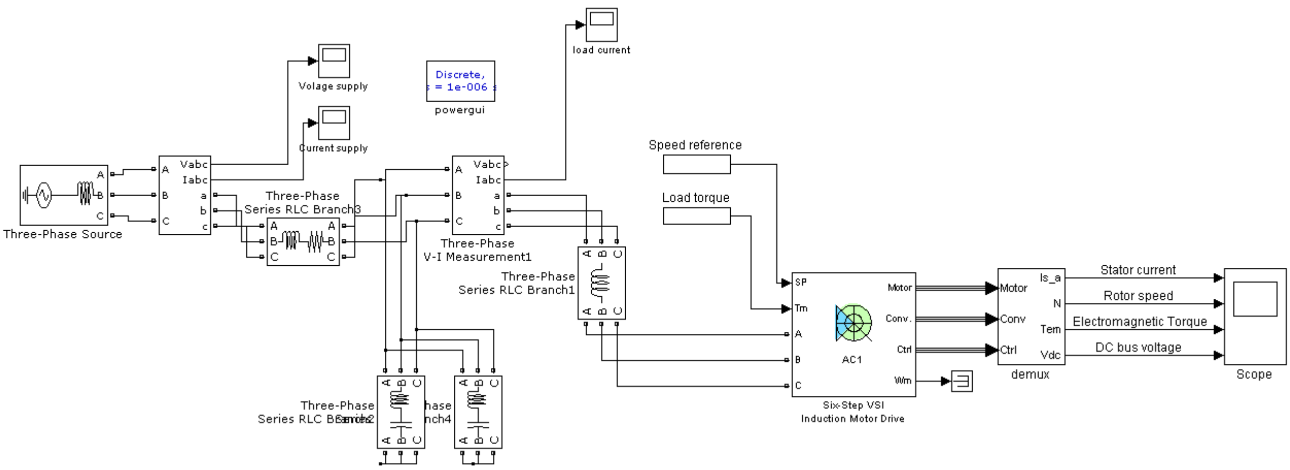

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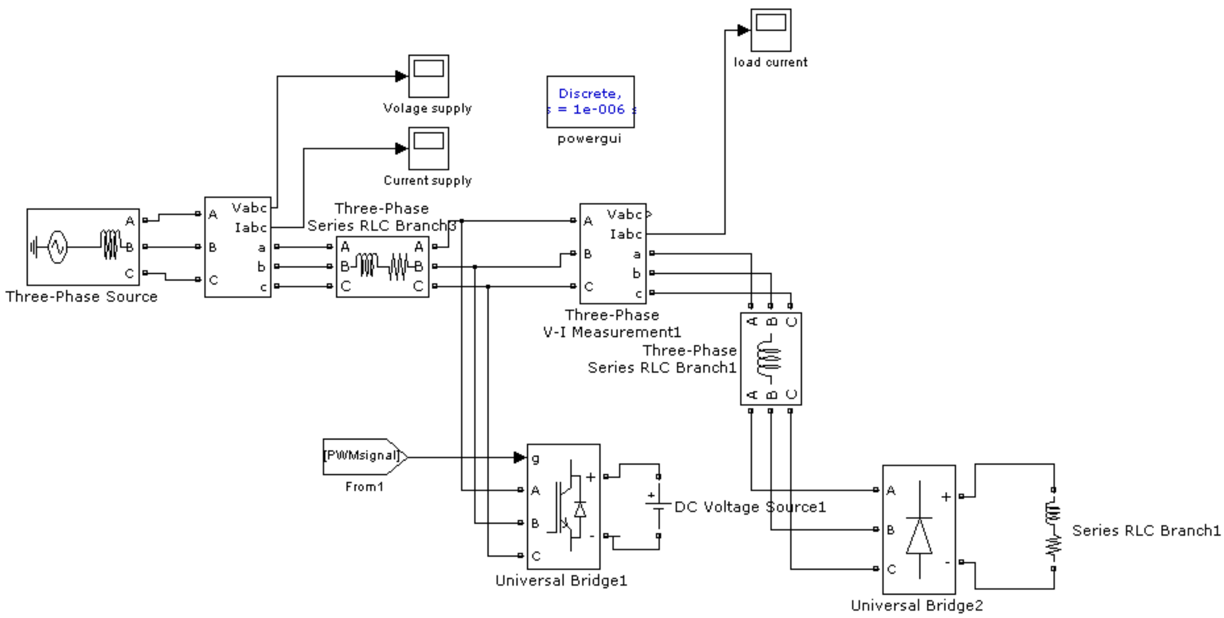
Figure 5 : Power Distribution System **Stage 2**

(a) Non-Linear Load

(b) Induction Motor Load



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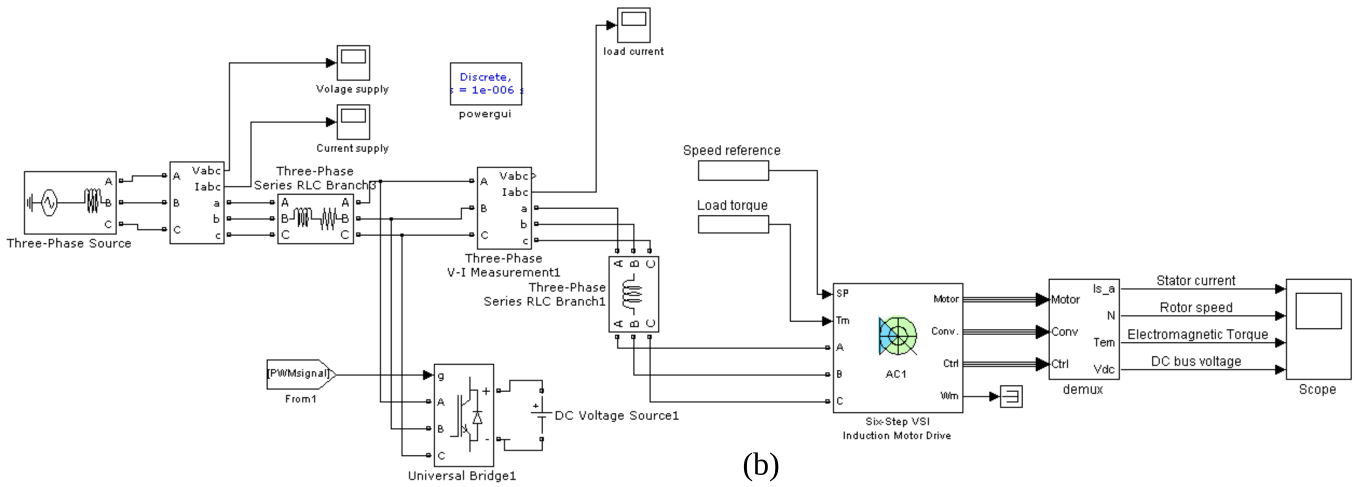

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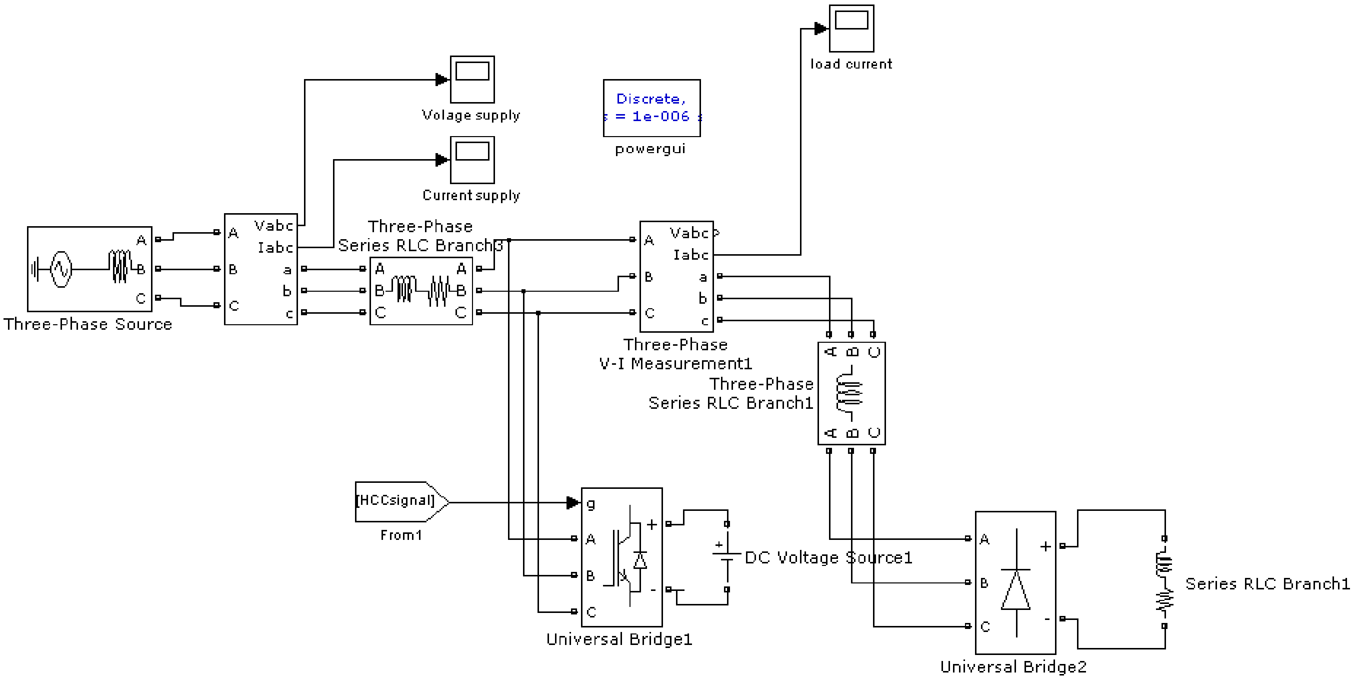
Figure 6 : Power Distribution System **Stage 3**

(a) Non-Linear Load

(b) Induction Motor Load



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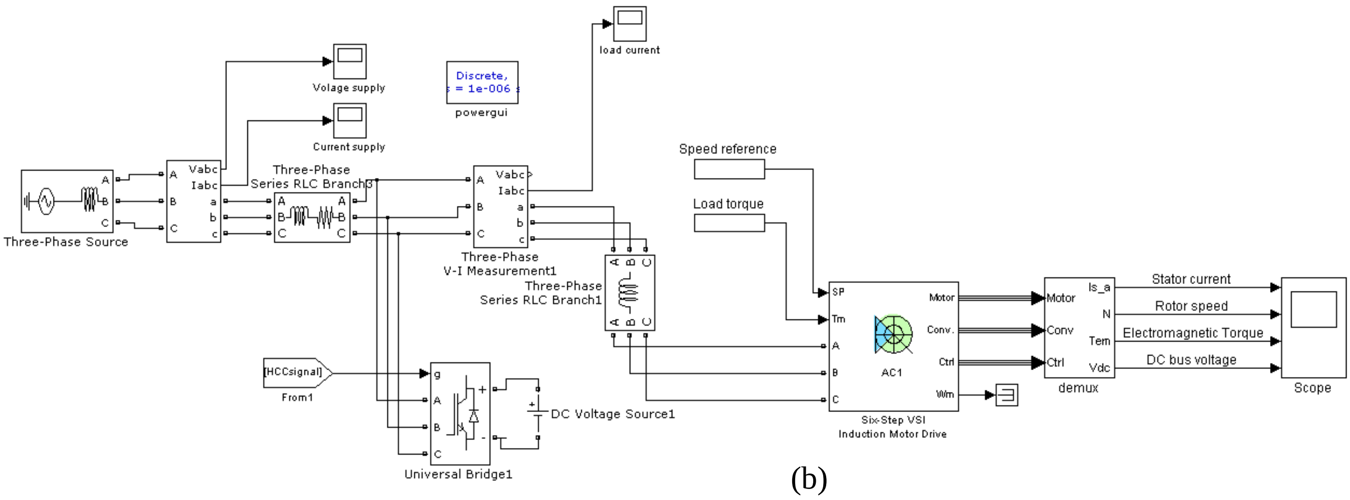

(b)

Figure 7 : Power Distribution System **Stage 4**

(a) Non-Linear Load

(b) Induction Motor Load

3.3 Model Description

3.3.1 Shunt Passive Filter

Shunt Passive filter works by allowing a signal to pass it with certain band of frequency or cut-off frequency. To filter out the harmonics in the system, a low pass filter is used, whereby allowing signal at the fundamental frequency to pass through the system while cutting off the harmonics at higher frequency. In order to study on how passive filter works, an equivalent circuit is simulated as shown in Figure 8.

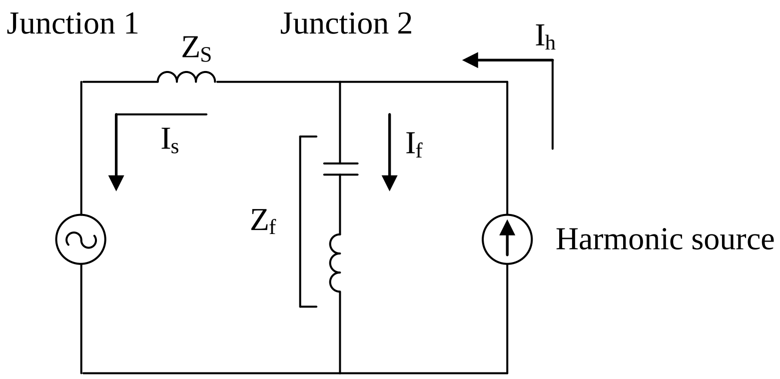

Figure 8: Equivalent Circuit for Shunt Passive Filter

Based on Figure 8, the load is the one producing the harmonic currents therefore can be represented with a current source while the Shunt Passive Filter is represented by RLC series branch at junction 2. As for the source impedance of the system, it is represented by the RLC series branch at junction 1. ***Ih*** is the source of harmonic current, while ***If*** is the harmonic current flowing through the passive filter and ***Is*** on the other hand is the current source of the system. The source impedance is better off high so that most of the harmonic current will go through the filter rather than the source itself.

The harmonic and source currents can be calculated using current divider method :

a) Harmonic Current, If

$$If = \frac{Z_S}{Z_S + Z_f} \times Ih \tag{1}$$

b) Source Current, Is

$$Is = \frac{Zf}{Zs + Zf} \times \ Ih \tag{2}$$

The cut-off frequency is on the other hand can be set or determined by manipulating the value of the parameters which are the inductance and the capacitance used. For setting up the cut-off frequency, f_r for low-pass or in other words single-tuned filter, the inductor impedance, X_L= ωL and the capacitor impedance, X_C= 1/ωC must be equal. This can be shown by the following equations [19]:

$$Z_f = \omega L + \frac{1}{\omega C} \tag{3}$$

$$2\pi f_r L = \frac{1}{2\pi f_r C} \tag{4}$$

$$[2\pi f_r]^2 LC = 1 \tag{5}$$

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{6}$$

Usually the frequency is set for filtering out the undesired signals of the fifth and seventh harmonics as these are the prominent harmonics produced the most. The calculations for the parameter values are shown by the following equations:

a) Fifth Harmonics

Operating frequency, f_o : 60Hz

Cut-off Frequency, f_r : 60×5 = 300Hz

Capacitor, C_f : 34µF (fixed)

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (7)$$

$$L = \frac{1}{[2\pi f_r]^2 \times C} \quad (8)$$

$$L = \frac{1}{[2\pi(300Hz)]^2 \times 34\mu} \quad (9)$$

$$L = 8.3\ mH \quad (10)$$

b) Seventh Harmonics

Operating frequency, f_o : 60Hz

Cut-off Frequency, f_r : 60×7 = 420Hz

Capacitor, C_f : 34µF (fixed)

$$f_r = \frac{1}{2\pi\sqrt{LC}} \quad (11)$$

$$L = \frac{1}{[2\pi f_r]^2 \times C} \quad (12)$$

$$L = \frac{1}{[2\pi(420Hz)]^2 \times 34\mu} \quad (13)$$

$$L = 4.2\ mH \quad (14)$$

3.3.2 Reference Current Estimation

For this part of the project, it is necessary to understand what exactly is harmonic in terms of the characteristics and the effects it brings to the power system as these would be crucial in the determination of the success of the project. The harmonic extraction process can be divided into several sections which are:

3.3.2.1 Clark Transformation

In three-phase system, the voltage and current is in the form of a-b-c sequence. In this part, a transformation on the voltage and current sequence by using Clark Transformation is to be made. By using this technique, the voltage and current sequence will be transformed into zero, alpha and beta (0-α-β) sequence but for this project, the author only needs alpha and beta components. The calculations in computing the α-β sequence are presented as follows:

$$\begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} = \sqrt{\left(\frac{2}{3}\right)} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \tag{15}$$

$$\begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} = \sqrt{\left(\frac{2}{3}\right)} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}^T \begin{bmatrix} X_\alpha \\ X_\beta \end{bmatrix} \tag{16}$$

The reason for neglecting the value for zero component is because the system built is a three-phase system with three wires while the zero sequence power exist only in three-phase system with neutral. Having stated that, any three-phase system with three wire, the zero sequence will only result in a zero value.

3.3.2.2 Instantaneous Real and Reactive Power (p-q) Computation

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (17)$$

After having transformed the three phase voltages and currents, the instantaneous real and reactive powers (p-q) are computed. For each real and reactive powers, there are two components within them which are the mean value and the alternating value [11].

$$p = \bar{p} + \tilde{p} \quad (18)$$

$$q = \bar{q} + \tilde{q} \quad (19)$$

$\bar{p}$: Mean value or DC component of the instantaneous real power. *(The only desired power component to be supplied by the power source).*

$\tilde{p}$: Alternating (AC) value of the instantaneous real power. It is the energy per time unity that is exchanged between the power source and the load through the a-b-c coordinates.

$\bar{q}$: Mean value or DC component of instantaneous imaginary power.

$\tilde{q}$: Alternating (AC) value of instantaneous imaginary power that is exchanged between the system phases which does not imply any transfer or exchange of energy between the power source and the load.

The only desired power component to be supplied by the power source is $\bar{p}$. Knowing that, all of the power components are to be compensated except for $\bar{p}$ as they did not transfer energy to the load [11].

3.3.2.3 Harmonic Extraction

It is noted that both active and reactive power can be decomposed into ac and dc components and only DC component of Real Power ($\bar{p}$) responsible in transferring the energy to the load. Therefore, the power components that the SAPF needs to generate will be:

$$p_F = -\tilde{p}_L \tag{20}$$

In case of harmonic current compensation:

$$q_F = -\tilde{q}_L \tag{21}$$

In case of reactive and harmonic current compensation:

$$q_F = -q_L \tag{22}$$

Accordingly, a high pass filter is used so that $\bar{p}$ can be extracted from the distorted signal, leaving the other power components (harmonic power components) to pass through. These signals will then be used to compute the compensation current needed to be injected to the ac lines.

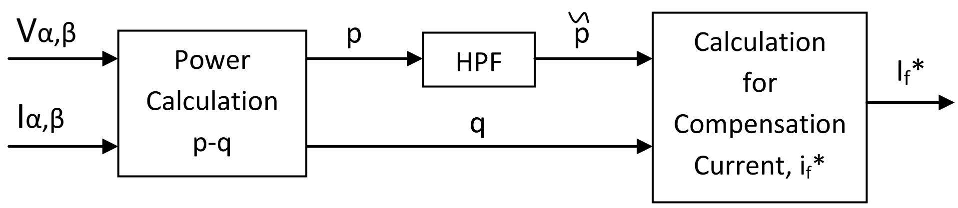

Figure 9 : Compensation Current Determination Block Diagram

3.3.2.4 Compensation Current Generation

The compensation currents are calculated as follows

$$\begin{bmatrix} p_F \\ q_F \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (3.23)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{(V_\alpha{}^2 + V_\beta{}^2)} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} p_F \\ q_F \end{bmatrix} \qquad (3.24)$$

After that, the compensation current components are transformed back to a-b-c sequence as shown in Equation (3.14). The current computed will then be injected to the ac line to compensate the harmonic current in the system.

3.3.3 Pulse Width Modulation (PWM)

Pulse Width Modulation (PWM) is a way to deliver energy through a succession of pulses rather than a continuous variable analog signal. The controller regulates the energy level transferred to a certain load by increasing and decreasing the pulse width signal. In a motor application, which in the author's case Induction Motor, the motor's own inductance itself acts as a filter, storing the energy during the ON state or cycle while releasing it at a rate corresponding to the input or reference signal [15].

A PWM works by comparing two signals which are Command Signal (e.g. Sinusoidal signal) and Chopping signal (e.g. Sawtooth signal) and the interaction between them will trigger the ON and OFF state/cycle of the output signal. The bigger the command signal, the wider the width of the pulses.

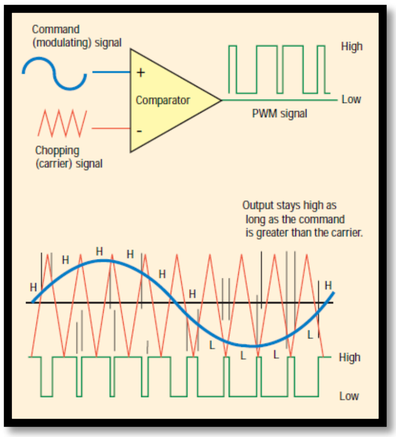

Figure 10 : PWM Waveform [15]

3.3.4 Hysteresis Current Control (HCC)

The concept of hysteresis technique is basically regarding its switching frequency whereby it will be determined by the derivative of the load current and the reference current. Hysteresis Current Control is basically has the same idea with PWM as they both try to generate an analog signal by using a series of pulses with a variable pulse width. Controlling the pulse width, the magnitude of the analog signal can be controlled. The difference is that hysteresis current control creates an upper and lower limit of the reference signal thus creating some sort of a region limiting the analog signal being produced. By doing that, the generated signal will not gone far-off from the original reference signal thus making it a lot more reliable technique.

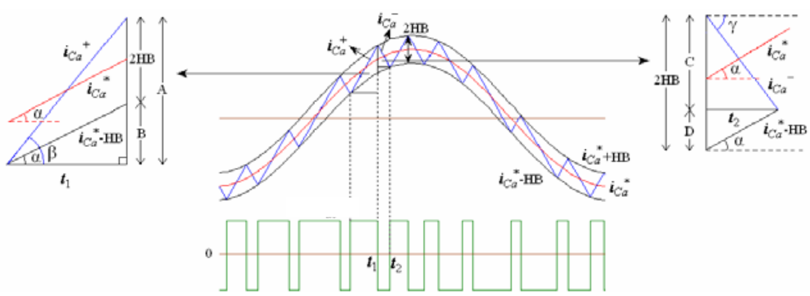

Figure 11 : Hysteresis Current Controller Waveform [10]

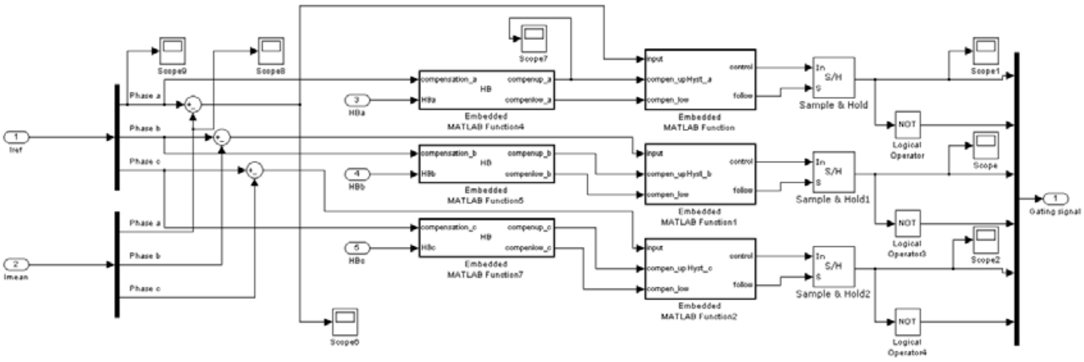

Figure 12: Hysteresis Current Controller Block Diagram

Figure 5 shows the block diagram that has been designed by the author. The input to this model is the reference current signal, Iref produced by the Reference Current Estimation block diagram and the current generated by the VSI, Imean. First, the reference current will be used to generate the upper and lower limit where it will then be compared with the current generated by the inverter. If the reference current reach the upper limit, the gate signal produced will be zero, and the state will hold its state until Imean decreasing hence reaching the lower limit which will then trigger the gate signal to change its state to 1. This cycle will be repeated until the reference signal has been successfully generated by the inverter.

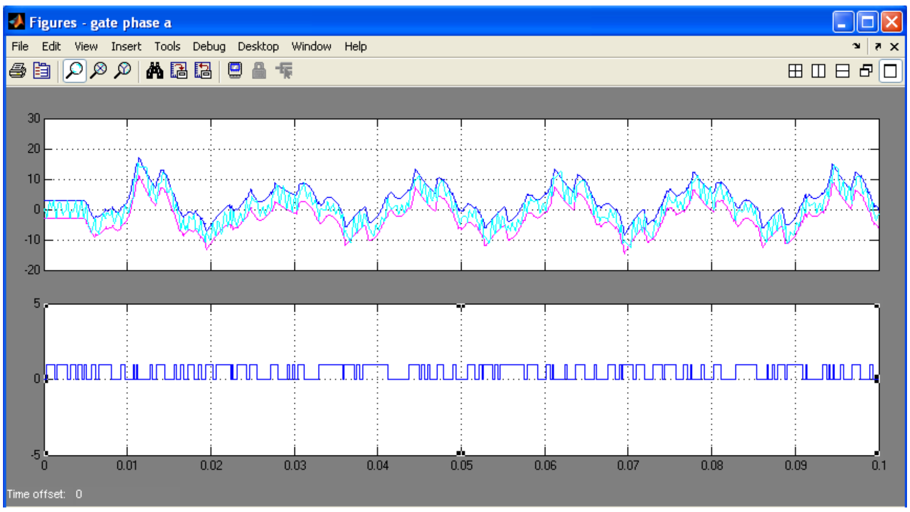

Figure 13 : Hysteresis Current Controller Gate Signal

3.3.5 Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) is the total amount of harmonics contained in the system and it is calculated by comparing the output signal with the input signal in terms of their level of differences in harmonic frequencies [17]. This difference is usually expressed in dB or percentage and defined as the root mean square (RMS) value of the total harmonics of the signal divided by the overall RMS value of its fundamental signal. This relationship is described by the following equations [18]:

$$THD = \frac{A_H}{A_F} \tag{25}$$

Where A_H is the RMS value of the harmonic components,

$$A_H = \sqrt{{A_2}^2 + {A_3}^2 + \cdots + {A_n}^2} \tag{26}$$

and A_F is the fundamental component.

In the simulation of the model, THD is presented in % thus,

$$\%\, THD = \frac{A_H}{A_F} \times 100 \tag{27}$$

3.4 Tools and Equipments Used

This project does not include building or constructing the prototype of the active power filter. The design of active power filter is simulated using Matlab Simulink SimPower Toolbox and analysis of the result will be based on the line supply current. Each of the harmonic compensation approaches are compared in terms of THD from the results recorded thus verifying the theoretical studies conducted.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Results

It has been mentioned in the previous chapter that the simulation and construction of the model comprises four stages which are crucial in making the project a success thus verifying the results gained from the simulation phase and the theoretical studies conducted. In this chapter, the results obtained are presented according to the following sequence:

1. Simulation of power system model without any filter
2. Simulation of power system with shunt passive filter
3. Simulation of power system with SAPF based on PWM
4. Simulation of power system with SAPF based on HCC

The operating frequency of the power system is 60 Hz and the simulation results from the model is analyzed based on the THD percentage at the source current which represent the amount of undesired signal present in the system. The THD percentage is calculated with 60 Hz as its fundamental frequency.

Table 1: System Parameters

Parameters	Quantity
Supply Voltage AC	220 V
Fundamental Frequency	60 Hz
Source Inductance	0.4 mH
Three-Phase Series of RL Branch	R = 1.0 Ω L = 2.2 mH
Three-Phase Series of Inductance Branch	2.2 mH
Inverter DC bus Voltage	200 V
Passive Filter	**5^{th} Harmonic** C = 34.0 µF L = 8.3 mH **7^{th} Harmonic** C = 34.0 µF L = 4.2 mH
Non-Linear Load	R = 15 Ω L = 1 mH
Induction Motor	Power (VA) = 2238 VA Voltage (Vrms) = 220 V Frequency = 60 Hz Pole = 2 pairs **Stator** R = 0.435 Ω L = 0.002 H Mutual inductance = 69.31 mH **Rotor** R = 0.816 Ω L = 0.02 H

4.1.1 Harmonic Compensation Current Simulation Result

Stage 1: Simulation of power system model without any filter

Figure 14 and 15 show the simulation results of power system model without any filter applied with non-linear and induction motor as their load respectively and the signals are taken from the input source current.

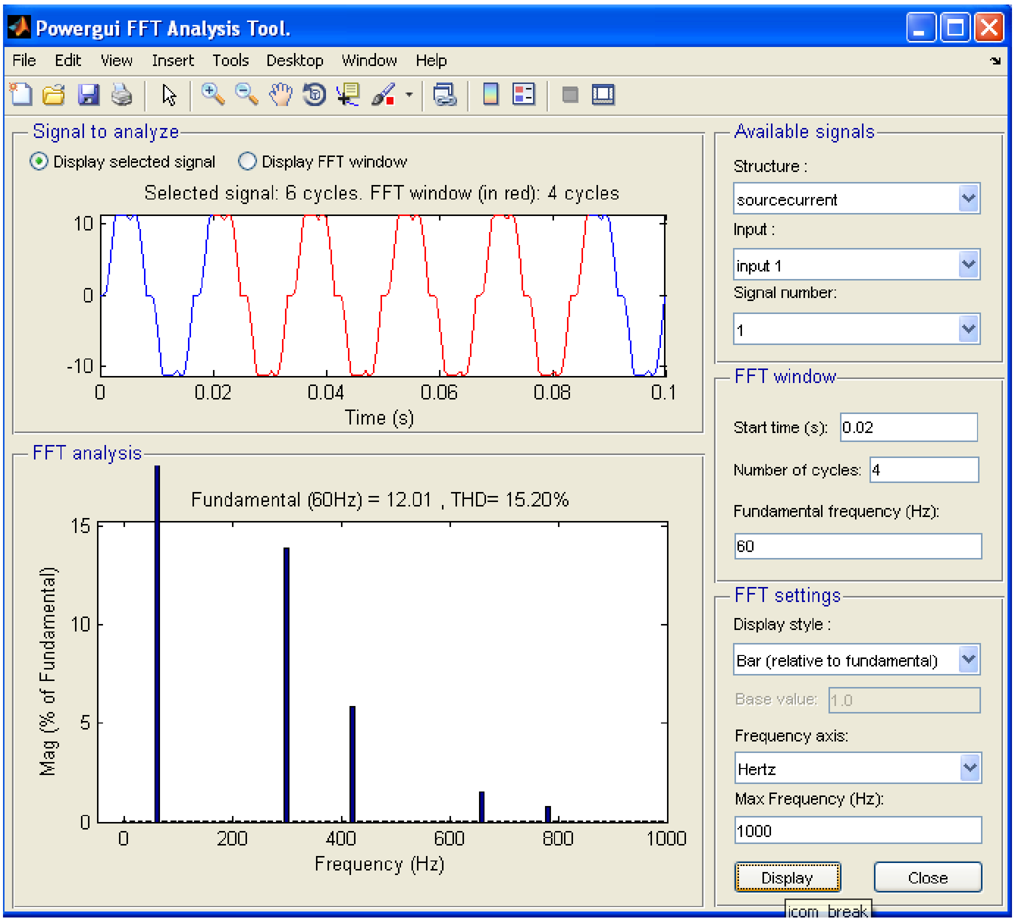

Figure 14: Source current for system without filter with THD = 15.20 % (Non-linear load)

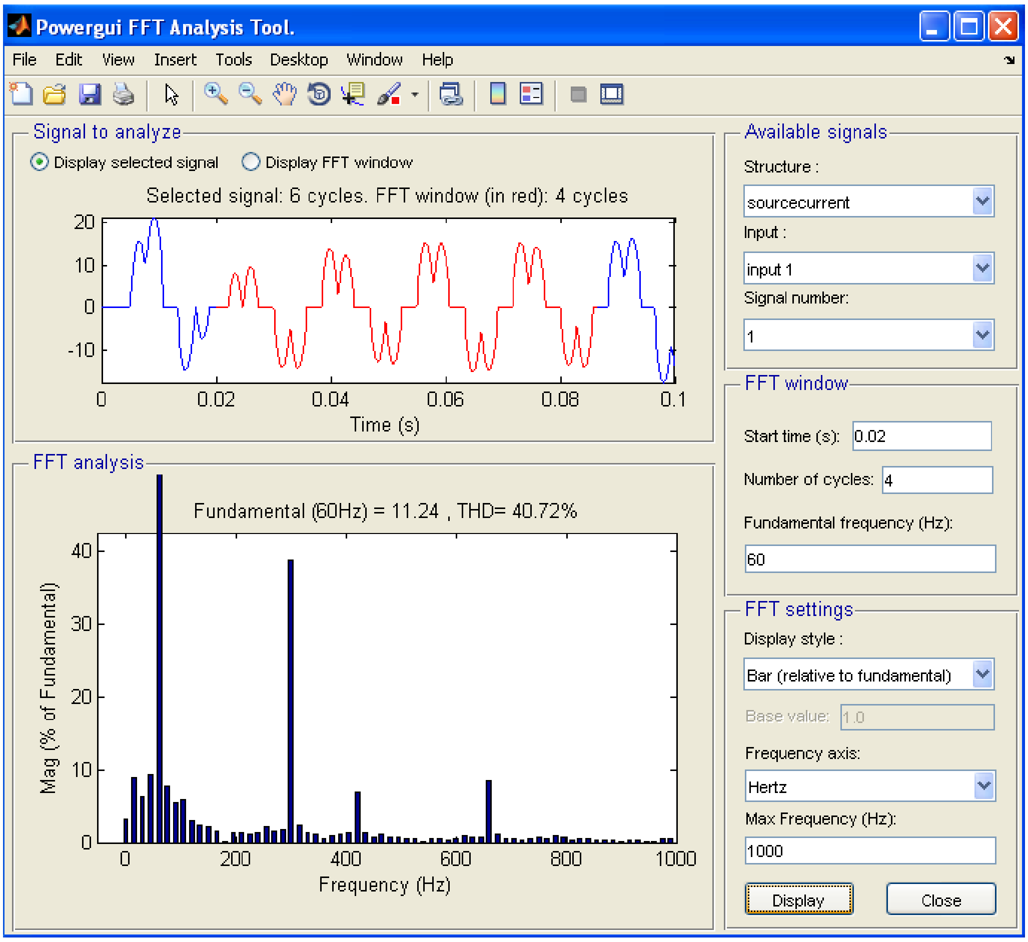

Figure 15: Source current for system without filter and THD = 40.72 % (IM load)

Stage 2: Simulation of power system model with Shunt Passive Filter

Figure 16 and 17 show the simulation results of power system model with Shunt Passive Filter applied with non-linear and induction motor as their load respectively.

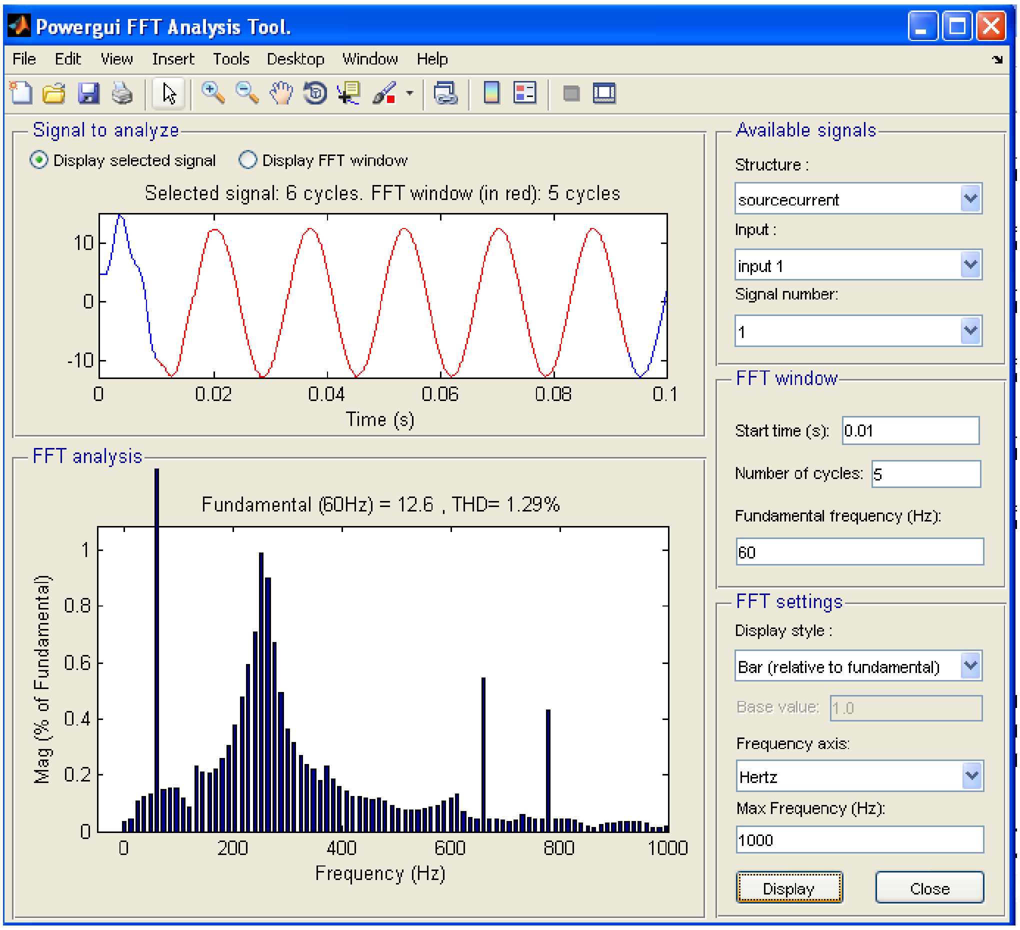

Figure 16: Source current for system with Shunt Passive Filter and THD = 1.29 % (Non-linear load)

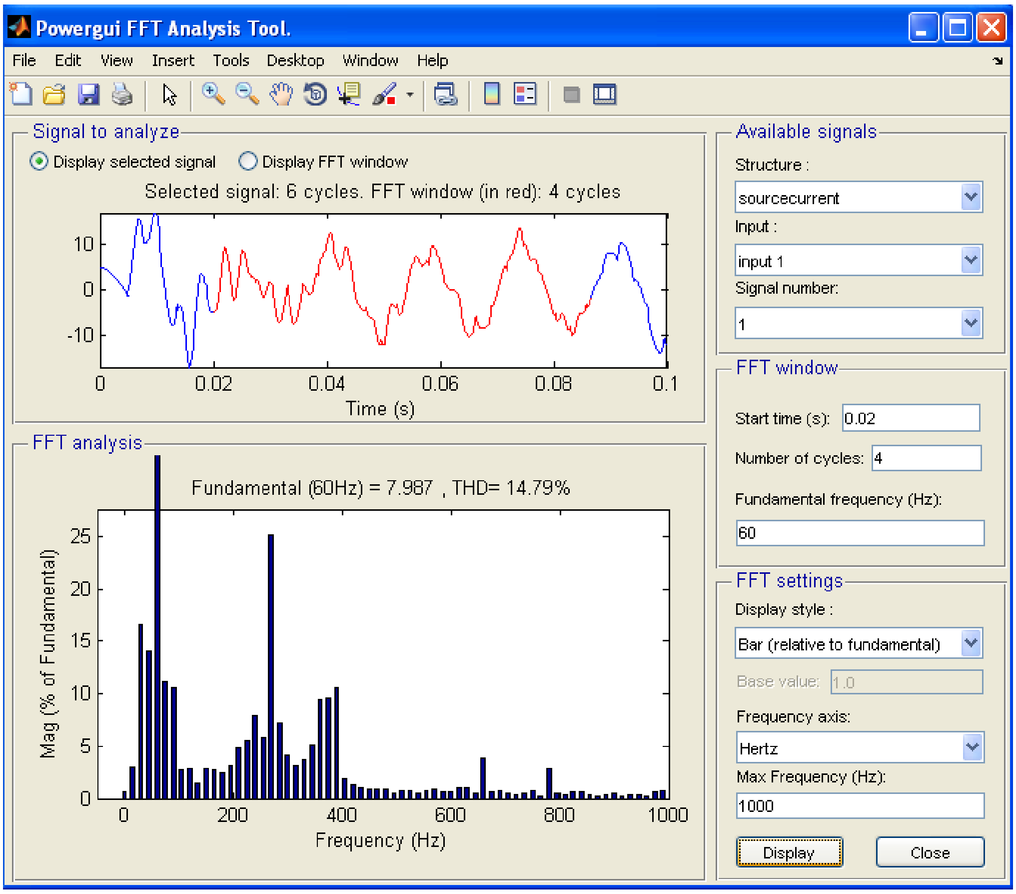

Figure 17: Source current for system with Shunt Passive Filter and THD = 14.79 % (IM load)

Stage 3: Simulation of power system model with SAPF based on PWM

Figure 18 and 19 show the simulation results of power system model with SAPF based on PWM with non-linear and induction motor as their load respectively.

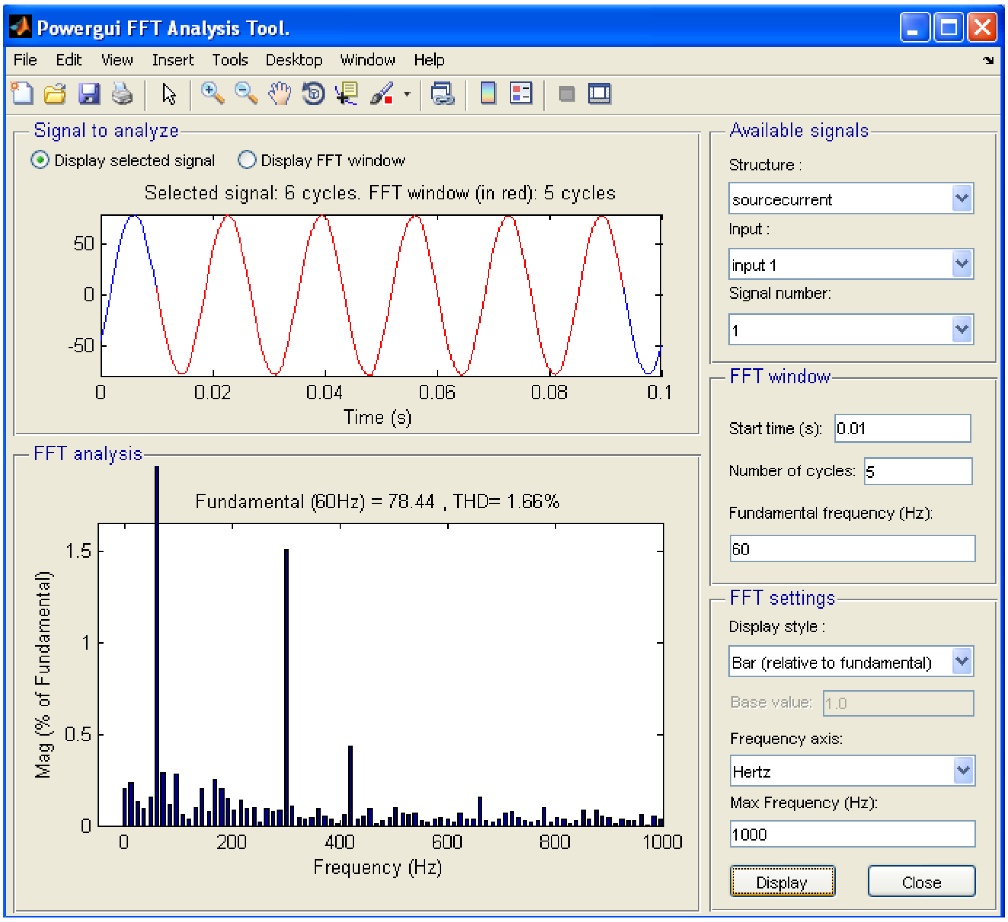

Figure 18: Source current for system with SAPF based on PWM and THD = 1.66 % (Non-linear load)

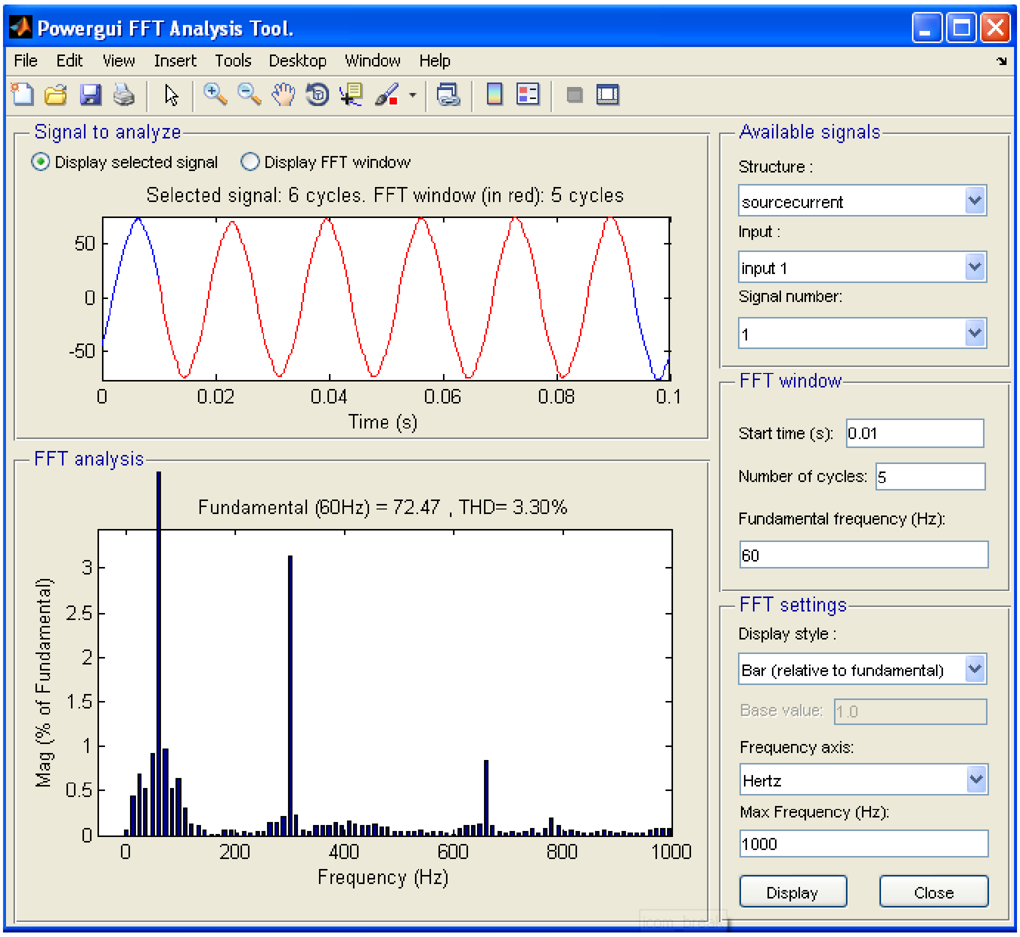

Figure 19: Source current for system with Shunt Active Power Filter based on PWM and THD = 3.30 % (IM load)

Stage 4: Simulation of power system model with SAPF based on HCC

Figure 12 and 13 show the simulation results of power system model with SAPF based on HCC with non-linear and induction motor as their load respectively.

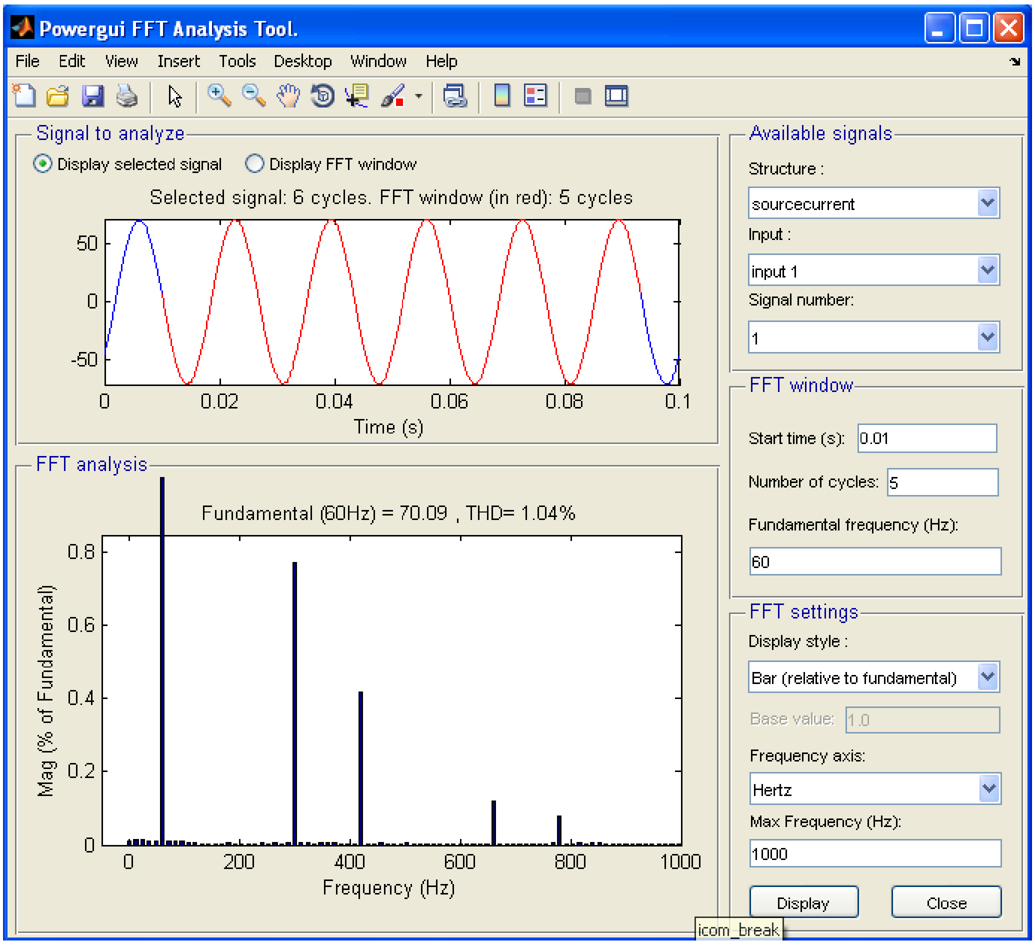

Figure 20: Source current for system with Shunt Active Power Filter based on HCC and THD = 1.04 % (non-linear load)

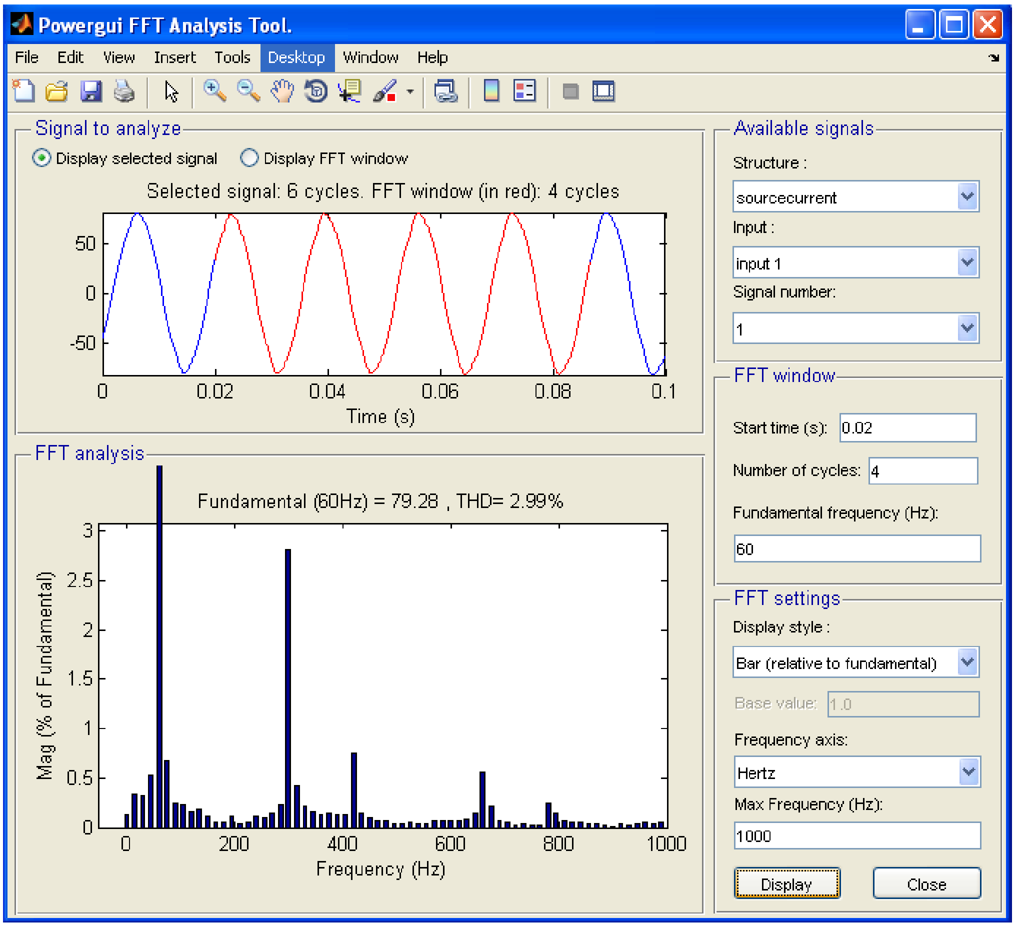

Figure 21: Source current for system with Shunt Active Power Filter based on HCC and THD = 2.99 % (IM load)

4.2 Discussion

In this section, all the simulation results obtained from the model simulation will be further discussed and this is where the operation of the Active Power Filter will be analyzed to conclude and to clarify whether the design has successfully improved the Induction Motor performance thus achieve the project objective.

4.2.1 Total Harmonic Distortion (THD) in the System

To get the value of the Total Harmonic Distortion in Matlab Simulink PowerSim Toolbox, the analyzed signal which is the input current supply need to be saved in the workspace. Having done that, using the PowerGUI Function Block, we can use the Fast Fourier Transform Analysis (FFT) Tool to calculate the THD for the selected signal.

4.2.2 Shunt Active Power Filter Performance Analysis

As mentioned, the first stage of the simulation is to be observed and the results obtained serves as the reference signal for the other stages. The performance of the SAPF will be analyzed based on the results from the second stage through the last stage of the simulation.

Table 2: % THD in the system for all stages through Matlab Simulation

Simulation Model	THD (%) Non-Linear Load	THD (%) Induction Motor Load
Without Filter	15.20	40.72
Shunt Passive Filter	1.29	14.79
Shunt Active Power Filter (PWM)	1.66	3.30
Shunt Active Power Filter (HCC)	**1.04**	**2.99**

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this project, several studies have been conducted which cover the technique in mitigating harmonic current in the power distribution system which focuses on the Induction Motor as its main load. There are four stages in the simulation process and these are conducted using Matlab Simulink PowerSim Toolbox. The first stage is the simulation of the power distribution system without any filter being applied. This is to create a reference signal to measure the performance of the harmonic compensation approaches. The second stage is performed by using Shunt Passive Filter focusing on mitigating the undesired signals at the fifth and seventh harmonics. The third stage on the other applies SAPF to the system that uses PWM as the current controller to generate the gate signal for the VSI. The last stage of the simulation uses the same technique as the previous stage but using Hysteresis Current Control to generate the gate signals. The advantage of the HCC over PWM is its ability in "shaping" the compensation current as it is more reliable and easy to be implemented in a system. By having this characteristic, it helps in improving the generation of compensation current in the system thus resulting in the best performance in the reduction of the harmonics. Referring back to the objective, it is safe to say that the project has successfully achieved its goal as to come up with a design for Active Power Filter which improves the performance of three-phase Induction Motor.

5.2 Recommendations

Using a fixed Hysteresis Band might cause the switching frequency of the VSI switches to be uneven and this might cause difficulties in designing the passive high-pass filter and there is possibilities that it might generate unwanted resonances on the system. Therefore, in order to limit or control the switching frequency, an adaptive hysteresis band can be used. With that in mind, the design for the hysteresis current control might as well includes this specification.

The original target was to design Hysteresis Current Control with adaptive hysteresis band but due to some problem during the implementation phase the author had to use other alternative available and it is by using a fixed hysteresis band. Some modifications in the calculation of the hysteresis band can be done and if it is successful, this could further improve the performance of the Active Power Filter itself. Figure 13 shows the initial proposed design to calculate the Hysteresis Band for the Hysteresis Current Controller.

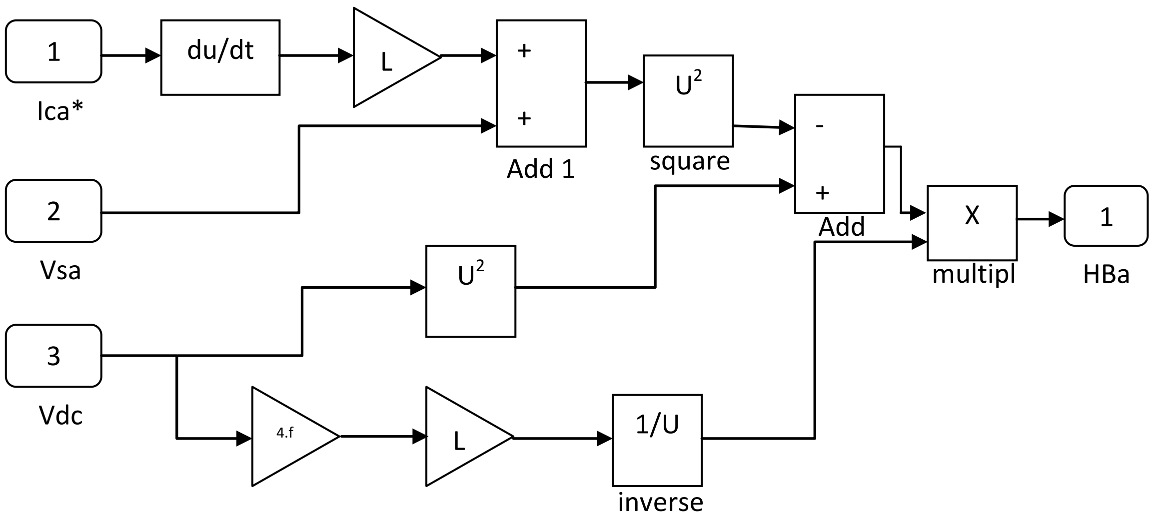

Figure 22 : Hysteresis Band Determination Using Block Set in SIMULINK [14]

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APPENDICES

APPENDIX I

Gantt Chart For FYP I

No.	Task Name / Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Title	■	■						MID SEM BREAK							
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report		●													
4	Project Work					■	■	■								
5	Submission of Progress Report									●						
6	Seminar										●					
7	Further Research on Project Work										■	■	■	■		
8	Submission of Interim Report Final Draft														●	
9	Oral Presentation															●

● **Milestone**

■ **Process**

APPENDIX II

Gantt Chart For FYP II

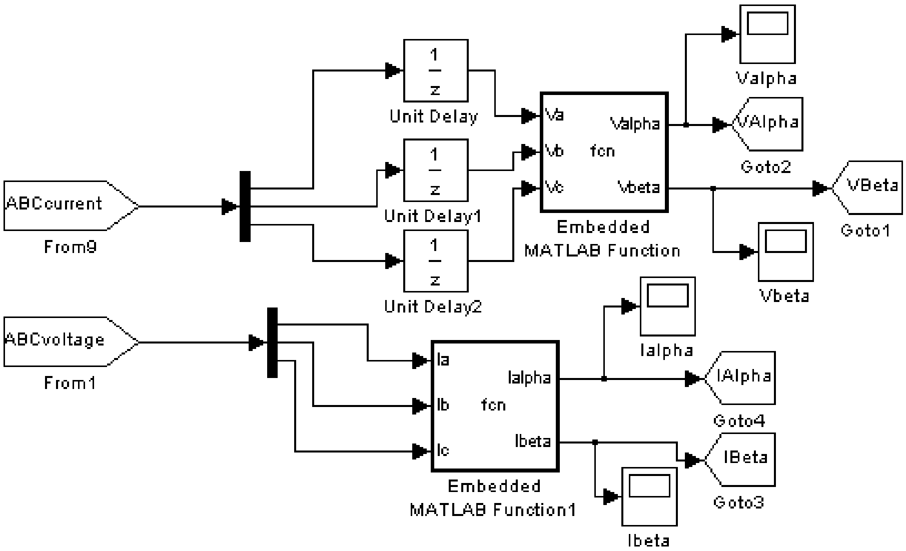
			JUL	AUGUST				SEPTEMBER				OCTOBER				NOV-DEC				
No.	**Task Name**	**Duration (week)**	**1**	**2**	**3**	**4**	**5**	**6**		**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16-18**	**20**
1	Resolve the problems encountered during FYP 1	2							**MID SEM BREAK**										**EXAM WEEK**	
2	Troubleshoot HCC design	1																		
3	Preparation for Progress Report 1	2																		
4	Submission of Progress Report 1																			
5	Work on Hysteresis Band Calculation Block	3																		
6	Work on Induction Motor Load	3																		
7	Preparation for Progress Report 2																			
9	Submission of Progress Report 2																			
10	Complete the entire model	3																		
11	Pre-EDX	1																		
12	Analyze the performance of the design	4																		
13	Preparation for the Final Report	2																		
14	Submission Draft of Final Report																			
15	Submission Final Report (Soft copy) and Technical Report																			
16	Oral Presentation (week 18)																			
17	Submission Final Report (Hard Bound)																			

SAF : Shunt Active Power Filter

HCC: Hysteresis Current Controller

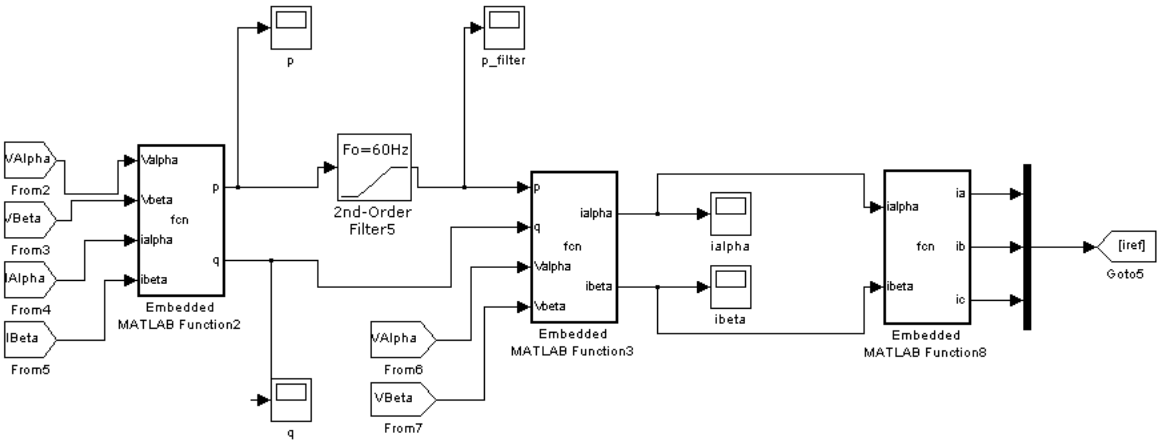
APPENDIX III

Clark Transformation Block Diagram (a-b-c to α-β)



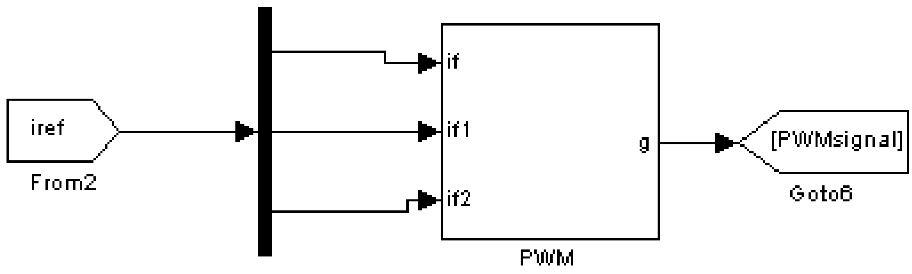
APPENDIX IV

P-Q and Compensation Current Calculation Block Diagram



APPENDIX V

Pulse Width Modulation Block Diagram



APPENDIX VI

Hysteresis Current Controller Block Diagram