SPEED CONTROL OF SINGLE-PHASE INDUCTION MOTOR

By

MOHAMAD KHAIRI TAHAR

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Universiti Teknologi Petronas
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

© Copyright 2009
by
Mohamad Khairi Tahar, 2009

CERTIFICATION OF APPROVAL

SPEED CONTROL OF SINGLE-PHASE INDUCTION MOTOR

by

Mohamad Khairi Tahar

A project dissertation submitted to the
Electrical & Electronics Engineering Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

Approved:

Mr. Mohd Fakhizan Romlie,
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

June 2009

CERTIFICATION OF ORIGINALITY

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

Mohamad Khairi Tahar

ABSTRACT

Main objective of this project is to study the speed control method of single-phase induction motor. Theoretically, there are several ways to control the speed of the motor. The methods are: varying rotor resistance, changing input voltage, changing number of pole and changing electrical frequency. The best way to control the speed of the motor is to control the frequency of the voltage supplied. The Pulse Width Modulation (PWM) technique is used in order to do so. The implementation of this PWM will not affect the performance of the motor and no adjustment on the motor stator is required. The project was done in two phases. In phase one, the characteristics of the motor, technique to control the motor's speed and PWM technique were studied. The second phase covered the development of the simulation model in Matlab/Simulink. The simulations were carried out and the results were analyzed. The simulation was done to test the speed control technique of single-phase induction motor. The motor was able be controlled according to the specific criteria to vary the speed by entering the desired speed value or desired electrical frequency. The acceleration and deceleration ramp function were also tested in the simulation. The characteristic of the 75% and 100% of full load can be observed in this simulation. For conclusion, the speed control method using PWM to control the voltage frequency has been studied, simulated and tested. It is proven that the technique can successfully control the speed of single-phase induction motor.

ACKNOWLEDGEMENT

I would like to praise Allah the Almighty, who gives me strengths to complete my Final Year Project, entitled – Speed Control of Single-phase Induction Motor. My deepest gratitude goes to Mr Mohd Fakhizan Romlie as kindly being my great supervisor for his guiding, sharing and teaching me to undergo this project.

I would like to express the warmest and greatest gratitude, appreciation to all parties who have contributed towards the success of this project. I was indebted to many individuals who contributed to the development of my project. Special thanks to Hafizuddin Razali and Mohd Hakim Mohd Nor for helping me throughout the project.

Next, to all lecturers and staffs of Universiti Teknologi PETRONAS, especially Electrical & Electronics Engineering Department where I was trained with essential skills and knowledge in order to be a well rounded student. Many thanks to Ms. Siti Hawa Tahir for the guidance and effort during the project.

Last but not least, to my beloved parents, Mrs Zainab Ahmad, fellow friends and community of Universiti Teknologi PETRONAS who directly or indirectly involves in completing the project.

Thank You.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

In the fast growing of small and medium enterprise industries in Malaysia, the small electrical machines that used single-phase induction motors as its prime movers have been gaining prominence and their applications are becoming wider. Research and innovation of speed control of single-phase induction motor against various load has improved machines performance. Speed modulation of a single-phase induction motor is usually achieved either by non-electrical means, such as throttling the mechanical output from the motor while it continues to run at full speed, or by switching windings to change the number of motor poles for different operating condition as required [1]. Only a few alternatives have been revealed as to the use of variable frequency converters to achieve continuous variable speed single-phase induction motor operation. One of these approaches uses a single-phase converter to control the phase angle of the voltage applied to the motor auxiliary winding, while the main winding remains connected to the ac supply. These investigations have shown that a standard single-phase induction motor has a quite limited performance, and that while controlling the phase angle of the voltage applied to the auxiliary winding can achieve variable speed operation [2]. The target of this project is to conduct research on speed control of single-phase induction motor by using certain techniques of controlling the speed and then come up with simulation model to control the speed of single-phase induction motor using the technique studied.

1.2 Problem Statement

Attachment of single-phase induction motor to the various loads basically gives some effects. Usually, for this type of motor, there is no speed control since the motor is always run daily. But, for certain application, such as prime mover for mixer, the motor needs to have its own speed control. The adjustment of its speed in improper way will lead to gain some effects in the performance of the motor in the long period of time. There are a few techniques available to control the speed of single-phase induction motor such as controlling rotor resistance, controlling input voltage, varying no of pole and varying electrical frequency. Varying rotor resistance can control the speed of the motor but it will produce rotor ohmic losses as rotor resistance change. Small range speed control of the induction motor can be implemented by decreasing the magnitude of input voltage. However, the efficiency of the motor will decrease simultaneously with decrement in speed and overheating the motor. Changing the number of poles can be used to control the speed of the motor but it may not practical since it may involve huge modification at the stator pole. Varying stator electrical frequency offers the option of changing synchronous speed continuously rather than the modification resulting from pole changing. This project conducted to control the speed of single-phase induction motor without results in the efficiency penalty or effects to the motor.

1.3 Objectives of the Study

Objectives of the study are:

i) To study the speed control technique of single-phase induction motor

ii) To model and simulate the speed control of a single-phase induction motor by using IGBTs and implementing PWM technique for switching of the IGBTs.

1.4 Scope of Study

The project covers the followings;

i) **The principle theory of single-phase induction motor**– the principle theory of single-phase induction motor is studied. This study also covers differences of induction motor compared to synchronous motor and the basic theory of operation and characteristics of single-phase induction motor.

ii) **Speed Control Techniques** – the speed control techniques such as changing the number of poles, voltage control, rotor resistance control and frequency are studied. The best technique to control the speed is determine through understanding and analysis of all techniques

iii) **PWM Technique** – in this scope, the PWM technique is explored to gain knowledge in Pulse Width Modulation techniques and its application in controlling the voltage frequency to control the speed. This scope of study is the continuation from the speed control techniques study.

CHAPTER 2
LITERATURE REVIEW AND THEORY

Single-phase induction motor is an AC machine that requires the alternating supply for operation. Consist of two parts; stator and rotor, this machine has been gained prominence in order to be used as prime movers for small electrical appliances in plants and factories such as mixers, pumps and blowers. This literature review will focusing on basic theory of single-phase induction motor, operation principles and speed control method. The characteristic of the motor also will be covered in this section.

2.1 Induction Motor versus Synchronous Motor

From NEMA MG 1-2003 Motor and Generator Standards state that an induction machine is an asynchronous machine that has a magnetic circuit interlinked with two electric circuits, or sets of circuits, rotating with respect to each other. Power is transferred from one circuit to another by electromagnetic induction. Meanwhile, for a synchronous machine, it is an alternating-current machine in which the average speed of normal operation is exactly proportional to the frequency of the system to which it is connected. [6]

Induction motors are known for its simple and ruggedness and relatively cheap to construct. The induction motors consist of a wound stator and a rotor assembly. They have fixed stator windings that are electrically connected to an AC power source. Current is induced in the rotor circuit by consequence of induced voltage in rotor. The resulting magnetic field of rotor interacts with the stator magnetic field to have induction occur. There is no separate power source required to provide the voltage in order to rotor field to be produced. An induction motor can be started and accelerated to steady state running conditions simply by applying AC power to the fixed stator windings of the motor. There are two types of induction motor; a squirrel-cage motor and a wound rotor motor. A squirrel-cage motor is one where the secondary circuit consists of a number of conducting bars that have their end pieces connected by metal rings or plates at each end. A wound-rotor motor in one where the secondary circuit has a poly phase winding or coils whose terminals are either short circuited or closed through suitable circuits. The rotor assembly of an induction motor is look like a squirrel or hamster cage, thus the name came from. The most common rotor type has cast aluminum conductors (bars) and short-circuiting end rings. The position of the bars in relation to the surface of the rotor, the shape, cross sectional area and material of the bars determine the rotor characteristics. A bar with a large cross sectional area will exhibit a low resistance as well as copper bar also have a low resistance compared to a brass bar of equal proportions. The rotor design will determine the starting characteristics of the motor. The rotor rotates when the moving magnetic field induces current in the shorted conductors.

The stator of an induction motor, which is houses driven windings on its iron core, is located at the outer body of the motor. A single-phase motor typically has two windings. The arrangement of the windings determines the number of poles that a motor has. The poles of stator are like an electromagnet and in multiple numbers of two means 2 poles, 4 poles, 6 poles and etc. The voltage rating of the motor is determined by the number of turns on the stator. The power rating of the motor is determined by the losses. These include copper loss, iron loss and the ability of the motor to dissipate the heat generated by the losses.

For synchronous motor, synchronous machine has been used for a motor. A synchronous motor has been starts by driven of separating starting device. There are several types of synchronous motors. These include direct current excited synchronous motor (field poles are excited by direct current), a permanent magnet synchronous motor (field excitation is provided by permanent magnets) and a reluctance synchronous motor (starts as an induction motor, is normally provided with a squirrel cage winding, but operates at synchronous speed). Synchronous motors have fixed stator windings electrically connected to the AC supply with a separate source of excitation connected to a field winding on the rotating shaft.

A three-phase stator is similar to that of an induction motor. The rotating field has the same number of poles as the stator, and is supplied by an external source of DC. Magnetic flux links the rotor and stator windings causing the motor to operate at synchronous speed. A synchronous motor starts as an induction motor, until the rotor speed is near synchronous speed where it is locked in step with the stator by application of a field excitation. When the synchronous motor is operating at synchronous speed, it is possible to alter the power factor by varying the excitation supplied to the motor field. An important advantage of a synchronous motor is that the motor power factor can be controlled by adjusting the excitation of the rotating DC field. Unlike AC induction motors, which run at a lagging power factor, a synchronous motor can run at unity or even at a leading power factor. This will improve the overall electrical system power factor, voltage drop and also improve the voltage drop at the terminals of the motor.

Synchronous motors can supply reactive power to counteract lagging power factor cause by inductive loads. As the DC field excitation is increased, the power factor (as measured at the motor terminals) becomes more leading. If the excitation is decreased, the power factor of the motor becomes more lagging. Synchronous motors can be classified as brush excitation or brushless excitation. Brush excitation consists of cast-brass brush holders mounted on insulated steel rods and supported from the bearing pedestal. The number of brushes for a particular size and rating depends on the field current. Sufficient brushes are supplied to limit the current density to a low value. The output of a separate DC exciter is applied to the slip rings of the rotor. A brushless excitation system utilizes an integral exciter and rotating rectifier assembly that eliminates the need for brushes and slip rings.

Synchronous motors are started using several reduced voltage methods. The most common is starting across the line with full AC voltage to the windings. As the motor speed increases, the discharge resistor provides the torque required for the motor to reach synchronous speed. Once synchronous speed is reached, the starting resistor is switched out of the field circuit and excitation can be applied to lock the stator and field poles in synchronous. The DC excitation system is used to apply current to the field winding creating a rotating electromagnet field that couples the rotor field to the rotating AC field in the armature winding when the motor is operating at synchronous speed. If the North and South poles of the rotor and stator are aligned, the rotor will lock in step with the stator and the motor will synchronize. If the rotor poles are 180 degrees out of phase with the stator poles, but the motor is accelerating, it is likely that accelerating torque along with magnetic attraction will combine to pull the rotor rapidly into pole alignment with the stator.

Synchronous motor efficiencies are higher than those of induction motors. Their inrush currents are low. They can be designed with torque characteristics to meet the requirements of the driven load and available power supply. A synchronous motor's speed/torque characteristics are ideally suited for direct drive of large horsepower, low rpm loads such as reciprocating compressors. Their precise speed regulation makes them an ideal choice for certain industrial processes. Synchronous motors are used in the pulp, paper processing, water processing treatment, petrochemical and mining industries, to name a few. They are used for chippers, crushers, pumps, and compressor drives to name a few applications.

2.2 Speed Control Techniques

An increase in value of rotor circuit resistance is practical only for a wound rotor induction motor wherein external resistance can be introduced through the slip ring connection. Although the speed of the wound rotor induction motor can be controlled by rotor resistance change, it is not without penalty. The changing in rotor resistance will lead to produce rotor ohmic losses which given by the product of slip and air gap power. Although the increased rotor resistance leads to a decrease in air gap power, the slip increases with the increase in rotor circuit resistance. It must be concluded that a larger potion of air gap power is dissipated as ohmic losses when rotor circuit resistance is increased to control speed and smaller portion is converted to developed power. Consequently, the efficiency of the motor decreases as the speed is reduced by means of rotor circuit resistance control.

For voltage control, small range speed control of the squirrel cage induction motor can be implemented by decrease in the magnitude of input voltage. it has been proven that the induction motor developed torque is proportional to the square on input voltage magnitude at any particular speed. However, the slip will increases as speed decreased just as in the case of rotor resistance control. Hence the efficiency decreases with the decrease in speed and overheating the motor is a potential problem.

Changing the number of poles provides a means to set a different synchronous speed and thus significantly alter the torque speed characteristic of a squirrel cage induction motor. The basic concept of commonly implemented pole changing scheme is one that simply switches the connection pattern of the phase groups of coils from alternating magnetic polarity to a pattern that establishes a single magnetic polarity. Since lines of flux must close on themselves, magnetic poles of opposite polarity appear midway between each coil phase group. The rotor inherently establishes a number of poles equal to the stator. The consequent pole connection has twice the number of magnetic poles; thus its synchronous speed is half of that of the normal alternating polarity connection. Obviously, there is close to a factor of 2 in the motor shaft speed between the two connections. The consequent pole scheme has a single path per phase for both connections. This pole has some increase in leakage reactance over alternating polarity connection. As a result, the maximum torque value will be slightly but not significantly, less for the consequent pole connection. Since the two maximum torque values are close to the same, the scheme is known as a constant torque pole changing connection. Two other consequent pole schemes are possible series to parallel wye connection change (variable torque) and wye to delta connection change.

Variable stator frequency control offers the option of changing synchronous speed continuously rather than the discrete single step resulting from the pole changing. In addition, frequency control allows low speed operation. Further, if properly implemented it does not result in the efficiency penalty that arises with both voltage and rotor circuit resistance methods of speed control.

2.3 Pulse Width Modulation (PWM) Technique

The rotating speed of the rotor is controlled by the number of pole pairs which is can be determined by the number of windings in the stator and the frequency of the supply voltage. Most single-phase induction motors are designed to rotate in one direction. Either by adding extra windings, external relays and switches, or by adding gear mechanisms, the direction of rotation can be changed. There are various techniques to produce a desired frequency available today, the most widely used of which is called PWM (Pulse Width Modulation). Pulse Width Modulation (PWM) is the process of modifying the width of the pulse in a pulse train in direct proportion to a small control signal. PWMs are the main peripherals used to control the motor. There are some important parts of this PWM. They are the triangle or sawtooth wave signal generator, input signal control voltage, and comparator. All these elements are designed and will be implemented to control the switches states of Insulated Gate Bipolar Transistors (IGBT) in the inverter circuit. The insulated-gate bipolar transistor or IGBT is a three-terminal power semiconductor device, noted for high efficiency and fast switching. The IGBT combines the simple gate-drive characteristics of the MOSFETs with the high-current and low–saturation-voltage capability of bipolar transistors by combining an isolated-gate FET for the control input, and a bipolar power transistor as a switch, in a single device [8]

This Pulse Width Modulation technique is commonly used in variable frequency drive. A variable-frequency drive (VFD) is a system for controlling the rotational speed of an alternating current (AC) electric motor by controlling the frequency of the electrical power supplied to the motor [9]. The synchronous speed of an AC motor is determined by the frequency of the AC supply and the number of poles in the stator winding, according to the relation:

$$RPM = \frac{120 \times f}{p}$$

Where

RPM = Revolutions per minute

f = AC power frequency (hertz)

p = Number of poles (an even number)

The constant, 120, is 60 seconds per minute multiplied by 2 poles per pole pair. Sometimes 60 is used as the constant and p is stated as pole pairs rather than poles. By varying the frequency of the voltage applied to the motor, its speed can be changed.

Synchronous motors operate at the synchronous speed determined by the above equation. The speed of an induction motor is slightly less than the synchronous speed. The variable frequency drive consists of two stages; the rectifier or converter and the inverter.

In converter stage, three-phase 50Hz 415V power supply is converted to a fixed or adjustable DC voltage by using full-wave rectifier meanwhile at inverter stage, a current or voltage waveform at desired frequency is being produced by power electronics switches such as power transistor or thyristor.

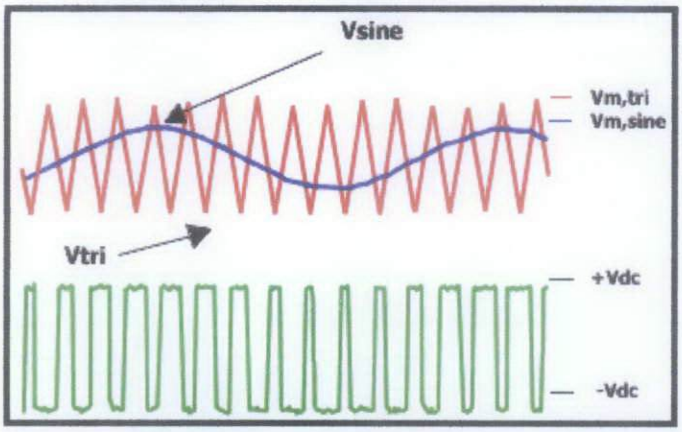

Figure 1 : The sinusoidal pulse width modulation signal

Since the PWM is the process of modifying the width of the pulse in a pulse train which directly proportion to a small control signal, where the greater the control voltage, the wider the resulting pulses, this will produce the inverter's voltage output in PWM voltage output (square waveform). When this square wave voltage output is connected to an induction motor and feeds the stator winding, the currents in stator winding is sine-wave. Control voltage is modulated with carrier signal using comparator, which then produces a square wave.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

The main objective of this project is to control the speed of single-phase induction motor. To control the voltage frequency supplied, the PWM technique is used and implement to the IGBT converter, which act as switching device. In first phase, the PWM is developed based on the basic structure of comparison between two signal; control signal and sawtooth signal. The model then was modified with some adjustment in order to meet certain criteria to be a PWM generator. By using the formula of sine wave, the control signal was constructed and implemented to the model. The model should be tested to produce desired waveform before the model connects to the switching device. To complete the project, the switching device that consist of IGBT inverter need to be constructed. The construction of IGBT inverter was done by considering the factor to develop an inverter. All the simulation then is tested in the Matlab/Simulink by attached to the load (single-phase induction motor). In the next page, the flow charts are the summary of the flow taken in completing this project.

Phase 1: Study, Research and Basic Development of Speed Control Technique flowchart

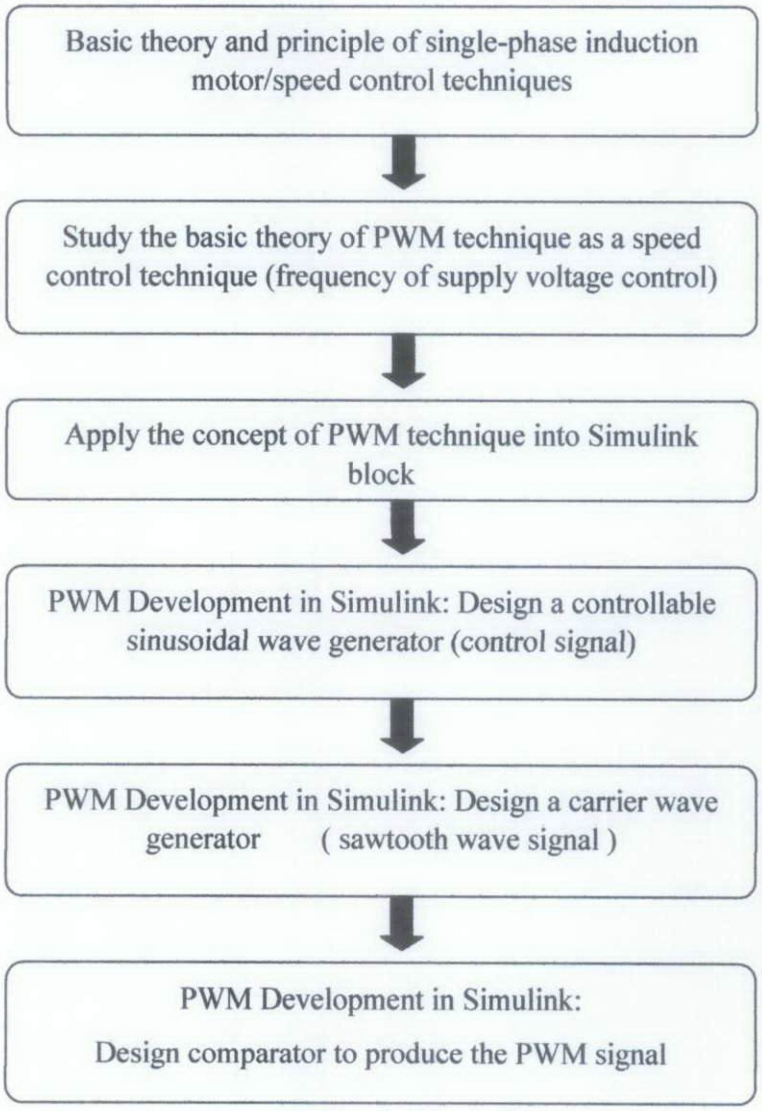

Figure 2 : Flow chart of the project in phase one

Phase 2: Further Development and Simulation on Speed Control Technique and Implementation on Single-phase Induction Motor

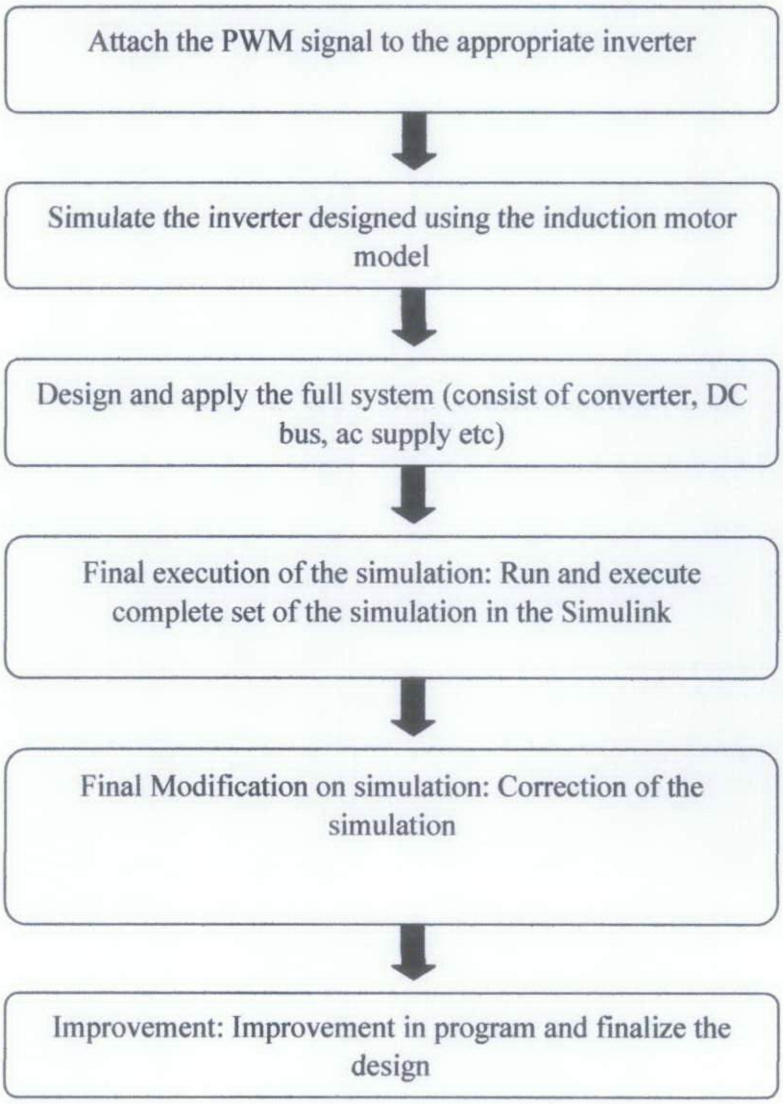

Figure 3 : Flow chart of the project in phase two

3.2 Tools

The tools below are required during the project completion.

1. MATLAB® 7.0 (R14)
2. Simulink® 6.0

3.2.1 Toolbox in Matlab / Simulink

Matlab/Simulink has some toolboxes that related to this project and to conduct the simulation. From the research done, the suitable toolbox will to be used is SimPowerSystems toolbox. By using this toolbox, it can models and simulates electrical power system and drives in Simulink environment. There are also some demos file that can be view and useful in completing this project. There are; *DC/DC and DC/AC PWM Converters (discrete), Three-phase Three-level PWM Converter (discrete), Three-phase SV-PWM Converter (discrete), AC/DC Three-level PWM Converter (discrete), AC Motor Drive - Vector Control (discrete), Three-phase Two-level PWM Converters (discrete),Single-phase Asynchronous Machine in Capacitor Start and Capacitor Start Run Modes Model.*

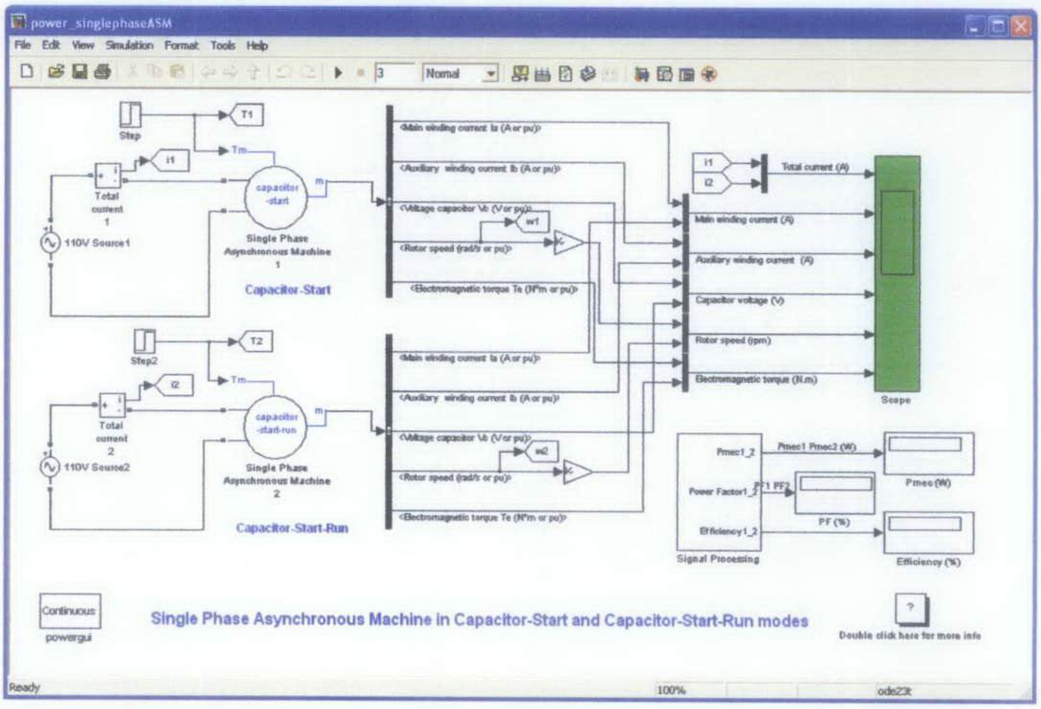

Figure 4 : The schematic of Single-phase Asynchronous Machine demo file

3.3 Project Deliverables

The project is expected to be complete in two phases. The first phase is to study and research on the characteristic and basic operation of single-phase induction motor as well as speed control technique. There is also some basic development of Pulse Width Modulation technique such as designing the PWM generator covers in this phase. The next phase is the further development of the Pulse Width Modulation generator and its implementation on the IGBT switching device before connected to the single-phase induction motor.

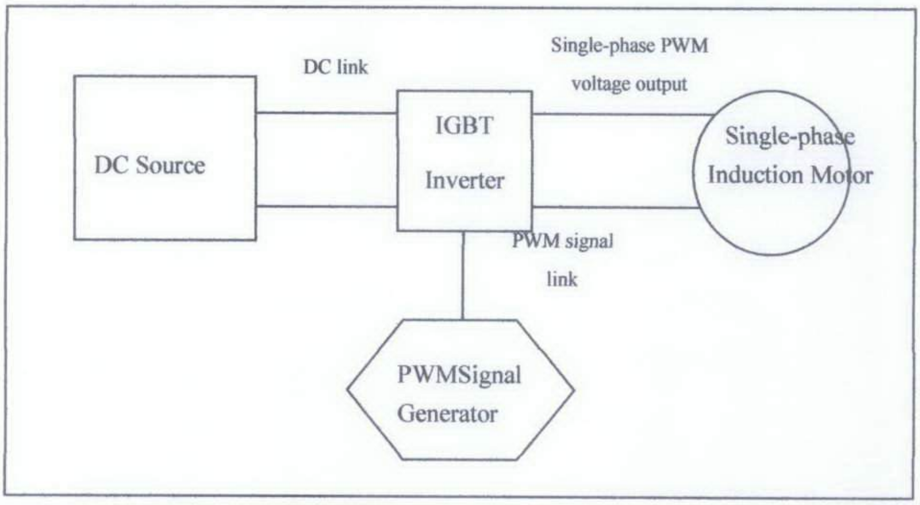

Figure 5 : General block diagram for the system

CHAPTER 4

SYSTEM DESIGN, RESULTS AND DISCUSSION

4.1 Pulse Width Modulation Signal Development

In order to create the PWM signal, there are some elements or parts need to be considered to build the PWM generator. One of the parts is the sawtooth or triangle wave generator. This generator is used to a carrier signal, which will be compared with the control signal to produce the PWM signal. The second part is the control signal. This signal is used to control the output of the PWM generator by controlling its output frequency thus controlling the motor speed. The last part is the comparator. This comparator is used as a comparator to compare the carrier waveform signal with the control signal (according to the intersective method)

The output PWM signal can be obtain by comparing the carrier signal, which is a sawtooth signal to the sinusoidal control signal at certain frequency. Theoretically, the PWM signal would be show the value of one whenever the sinusoidal control signal is greater than the carrier signal. As opposite, the PWM signal would be zero if the sinusoidal control signal less than sawtooth signal.

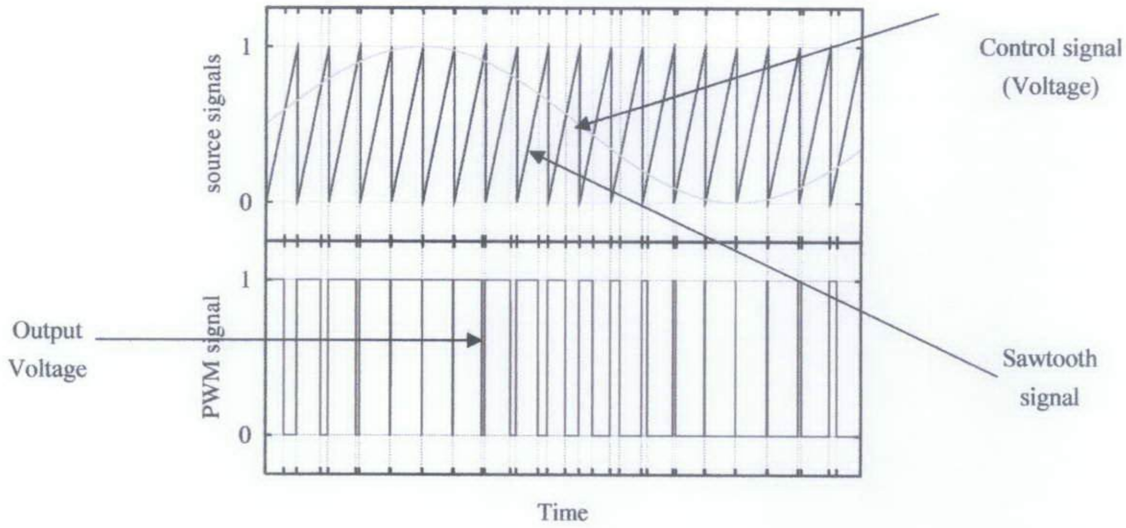

Figure 6 : The digram of theory of PWM signal waveform generation

The process above has been designed into the simulation using blocks such as relational operator block, sawtooth signal block and control signal block.

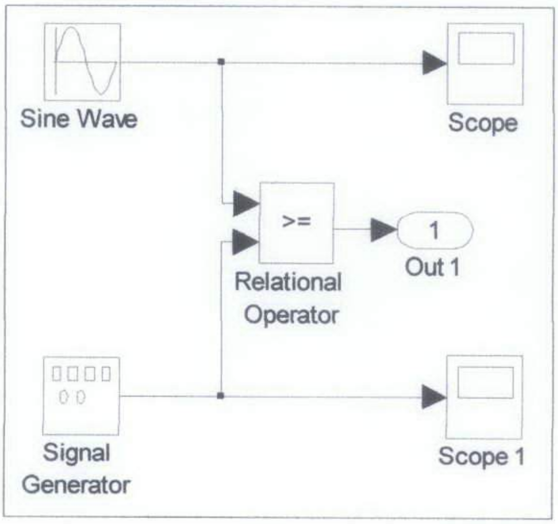

Figure 7 : The basic model of PWM generator in Matlab/Simulink

Experimentally, the process of PWM development starts by develops the simulation block in Simulink. The comparator process has been designed using the signal processing blocksets such as sawtooth signal block and control signal block. On the workspace` of Simulink Editor, the control signal is attach to the upper input of comparator which is consist of Relational Block meanwhile the sinusoidal carrier signal is attach to the bottom input. A stand alone sawtooth generator and a sine wave generator have been used in this base model to supply the signals. In this base model, the operator was set to be ">=" which means the output will be *zero (0)* if the top input is less than the bottom input, otherwise the output will be *one (1)* if the top input is greater than the bottom input.

4.1.1 Simulating using two phase signal

The single-phase induction motor consists of main and auxiliary windings. These windings will be connected to the two signal that coming from inverter. By creating another one PWM signal generators, a two-phase signal is implemented to the model. The phase angel between second generators must be 180°, which is equal to *pi* radian. The values are inserted into the signal generator block parameter at the *Phase (rad)* value. The output waveform for the two-phase PWM signal is shown in figure below.

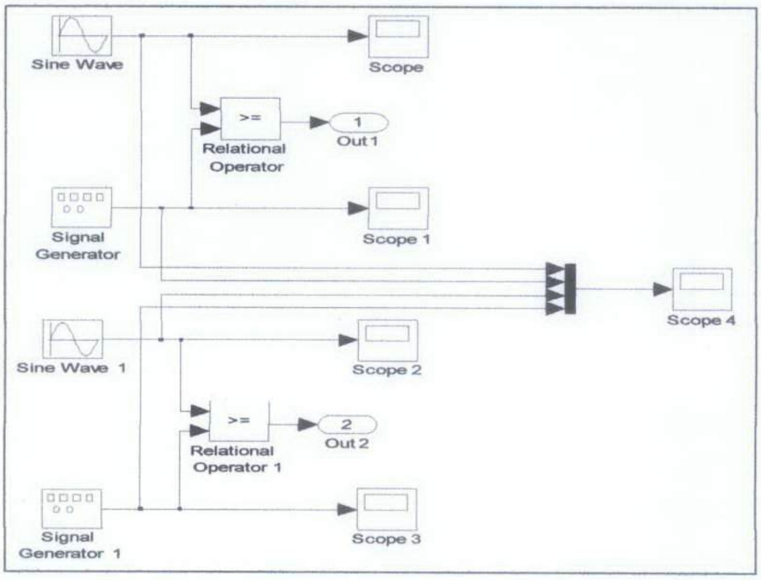

Figure 8 : The double layer of PWM signal build in the Matlab/Simulink

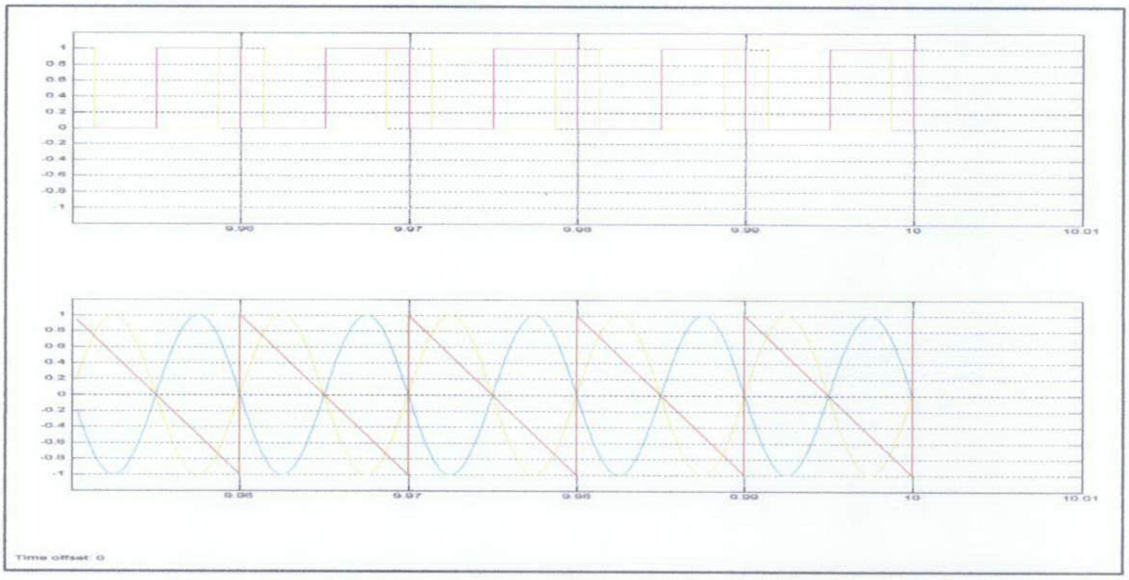

Figure 9 : The two phase signal and its PWM output signal

4.1.2 Design and develop the controllable PWM generator based on the previous model

From the base model discussed and done above, the controllable PWM generator was develop using blocksets by using the three main elements in PWM which are control signal, carrier signal, and comparator, a controllable PWM generator can be designed. A controllable sine wave generator is designed based on sine wave equation. The combination of blocks in Simulink then was used to implement the equation into signal.

$$y = A \sin(\omega t + \theta)$$

where,

ω = the angular frequency = $2\pi f$

f = frequency (Hz)

θ = initial phase shift when $t = 0$

A = peak deviation from center (amplitude)

From equation above, replacing ω to $2\pi f$, yields

$$y = A \sin (2\pi f t + \theta)$$

Converting modified equation into the Simulink form,

$$Output = Amp * Sin (2 * pi * Freq * t + Phase)$$

From equation above,

Output	= desired sine wave (y)
Amp	= amplitude of the sine wave
Sin	= trigonometric function
Freq	= frequency of the generated sine wave
t	= simulation time, and *Phase* is the phase shift for the sine wave.

In the controllable sine wave generator, the value of *t* is represented by the *Clock* block. The block outputs the current simulation time at each simulation step. *Amp* will be represented by the *Constant or Modulation Index* block which will set to 1. *Freq* is represented by the *Signal* input port, and *Phase* is represented by *Phase* block.

Constant or *Modulation* block is the amplitude of the sinusoidal signal. Theoretically it must be greater than zero and lower than or equal to 1. This parameter is used to control the amplitude of the fundamental component of the output voltage of the controlled bridge.

The *Signal* input port will determine the frequency of the generated sine wave. As this sine wave is the control wave that then will control the output, thus this signal will be adjusted by the user according to the desired value. *Phase* block is the phase of the generated sinusoidal signal. Since this is a two-phase PWM generator, the parameter should have two values which are 0° and 180°. Converting those values into radians, they become 0 and *pi* respectively. As the result, the parameter setting for the *Phase* can be written as *[0 pi]*.

Sin block is the sine trigonometric function where it will receive the inputs and converts it into the sine wave. The two inputs with 0° and 180° phase shift respectively then will be converts to two phase sinusoidal wave.

By using the synchronous speed concept, another input was add to the sine wave generator. The idea of this concept is to give user the choices of selecting the desired input. This second input will be use by user to entering the desired speed range below 1500 rpm where by entering this value, it will be converted to frequency with the appearance of *4/120 constant* block.

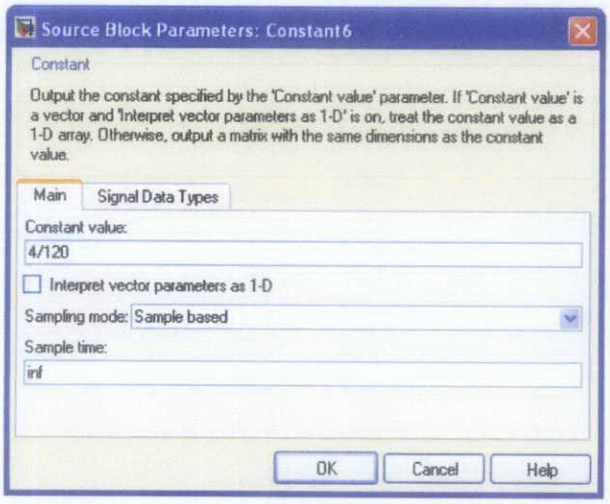

Figure 10 : The parameter set to 4/120 where 4 represent the number of poles whereas 120 is the one of the part for synchronous speed formula.

The frequency signal then will be sum up with the first input (*signal* input block) in the *add2* block. Here, one of the input must be equal to 0 so that the desired value of both input will be achieve in the end of the generator before entering the switching device of IGBT.

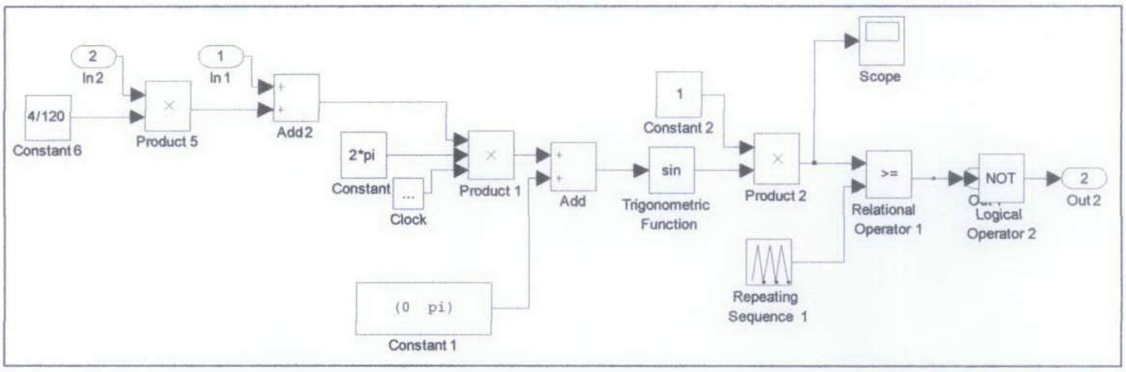

Figure 11 : The blocksets connection of PWM Generator Subsystem

The output of the sine block then will be multiply with the *constant* or *modulation index* block where the ouput wil be entering the relational operator.

4.1.3 Comparison of two signals

For this project, the comparison process between carrier and control signal is done by using the combination of Relational operator and logic blocks. Here, the signal of sine wave was compared to the triangle wave (carrier wave) which coming from the repeating signal block. This triangle wave is extracted from the base model where the sawtooth represent the carrier signal.

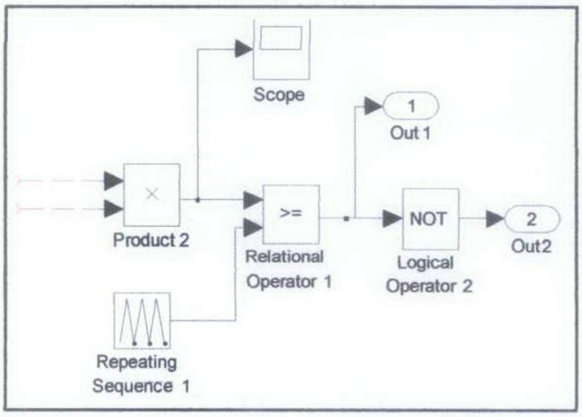

Figure 12 : The comparison blocksets to compare the sine wave (control) and the triangular wave (carrier)

The result of this comparison then will be directly connected to the IGBTs and another inputs of IGBTs will be connected to the conversion signal which coming from the *NOT* logical operational block as complement to the signals at the other input of IGBT.

4.2 PWM to IGBT Inverter

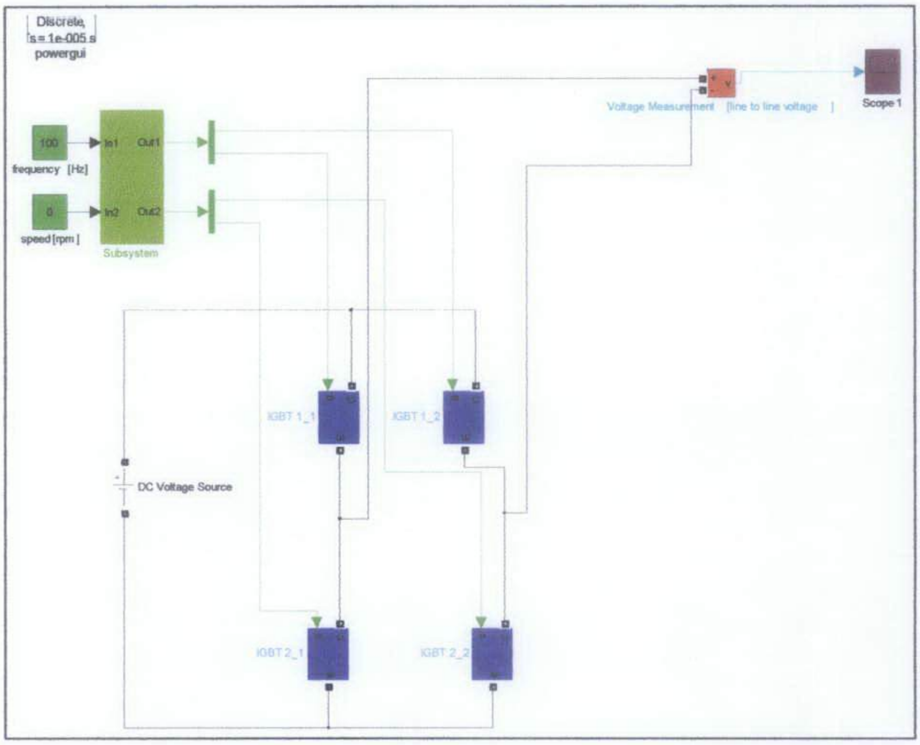

Figure 13 : The connection of PWM generator and IBGT inverter in Matlab/Simulink

The PWM generator is compress into subsystem so that it can reduce and simplified the circuit. The output of the PWM generator directly connected to the 110V powered IGBTs inverter where the switching took place. The line to line voltage of the two voltage produce is recorded as below.

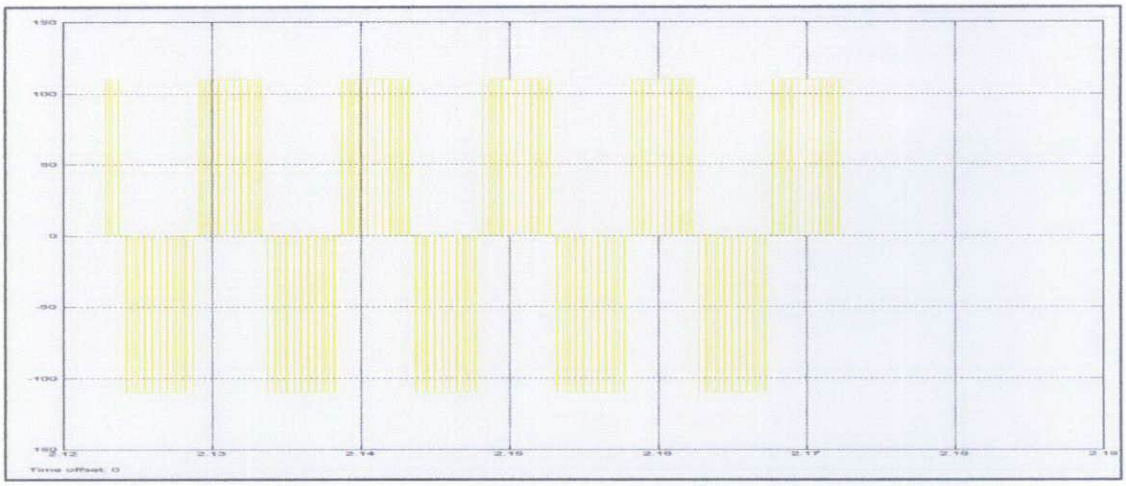

Figure 14 : The voltage/frequency produced from the IBGT inverter

The output produce is the 110 V but in pulse train pattern. This is because of the switching of the IGBT inverter so that the voltage from the DC source will follows the pattern of the switching. From the now on, the frequency of the voltage will directly follows the desired frequency that has been insert at the beginning of the PWM generator.

4.3 PWM technique simulation with Single-phase Induction Motor

To complete the project, the simulation must be done with the single-phase induction motor as the load. The single-phase motor used in this project is capacitor start motor.

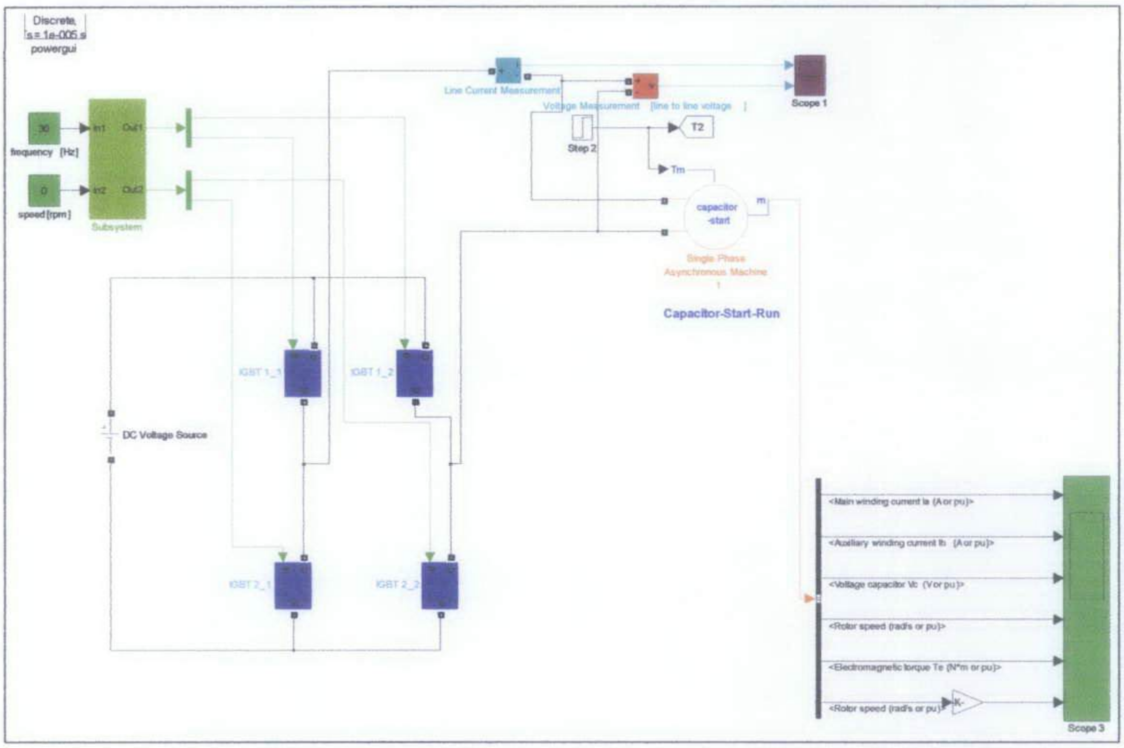

Figure 15 : The overall connection of the system in Matlab/Simulink

The single-phase induction motor consists of various type of its stating device. This project was used the capacitor start motor since this motor has been used in many electrical appliances. At this motor block, some setting adjustment has been done to meet the voltage requirement, which is connected with the output of the inverter.

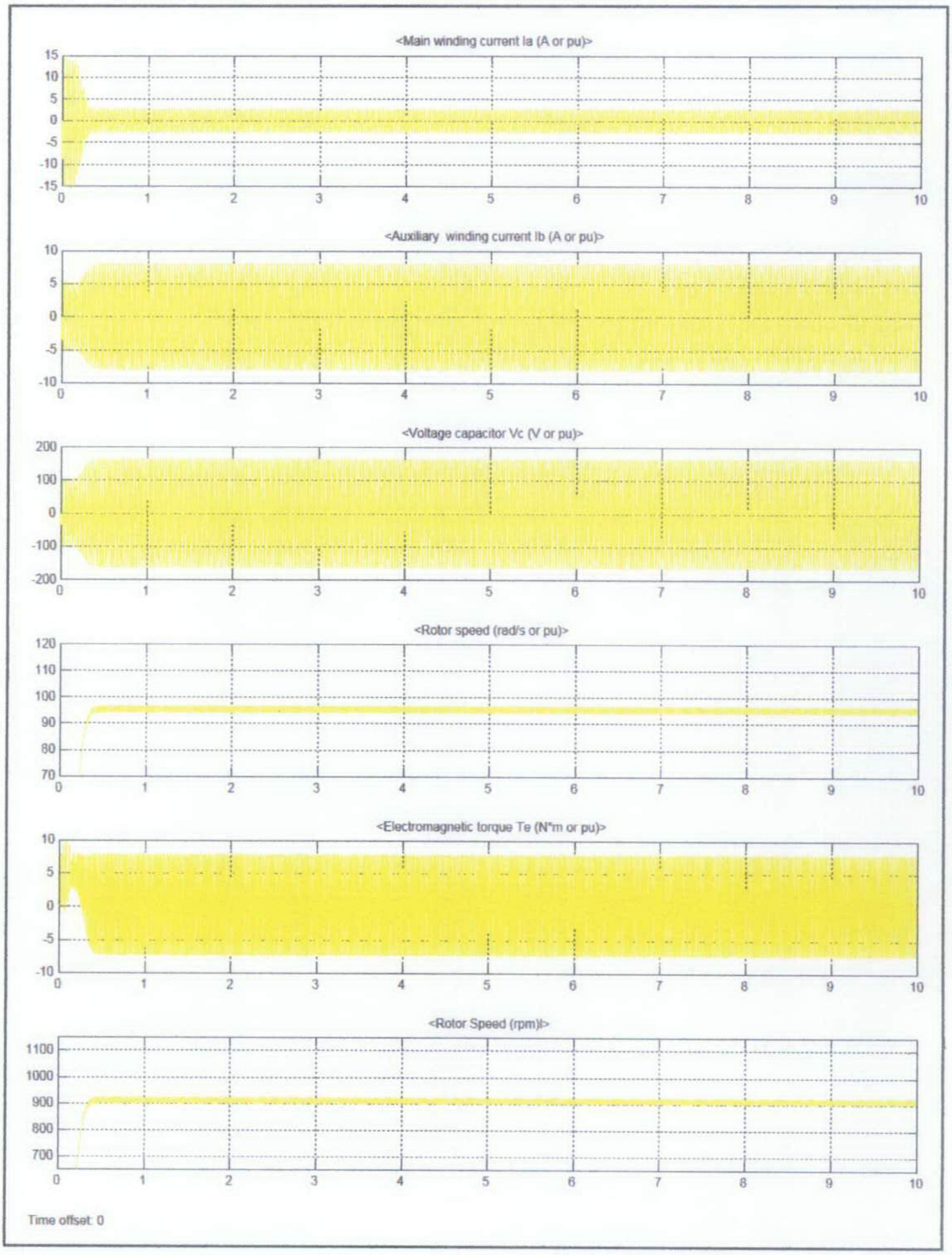

Figure 16 : The motor characteristics when 30 Hz inserted into the PWM generator input

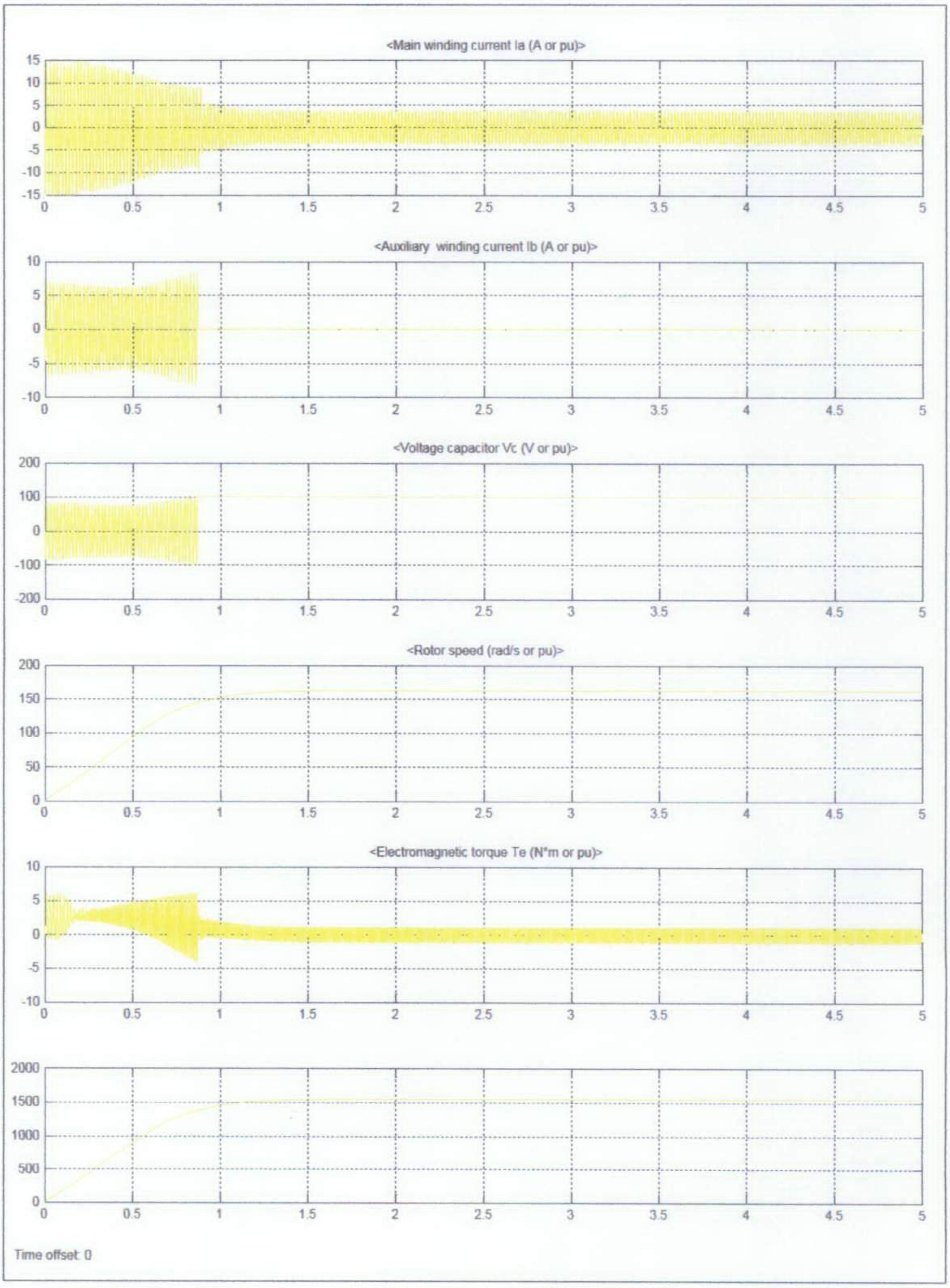

Figure 17 : The motor characteristic when 50 Hz inserted into the PWM generator input

Theoretically, the auxiliary winding of the capacitor start single-phase induction motor will be tripped when the machine is speeded up to 75% of the rated speed. The figure above shows the difference in output values that produce by the machine. The first figure shows the output of 30 Hz or equivalent to 60% of rated speed. The second figure shows the result of the machine when the speed is at 100% load. The auxiliary winding in second figure shows the circuit has been tripped.

4.3.1 Varying the speed in the simulation

Designing the speed control for the motor, there is a must for a few variables in the Simulink blocksets need some adjustment. The variables, which are important in the PWM speed control technique, are the fundamental signal (sine wave) frequency and the carrier (triangle wave) frequency. The signal frequency is the input frequency where the motor receives the power while the carrier frequency is the modulation frequency for the PWM technique. At previous, the input signal frequency for the *PWM Generator* subsystem blockset is a constant value, which means no change has been made until its complete the simulation. In this subsection, the ramp function is introduced to ensure smooth frequency or speed (rpm) changing when the simulation keeps running.

To provide the speed control of the motor by varying the frequency, the value of *Signal frequency* or *signal output of rpm* should be changed at desired value. The value is set at *Signal frequency* block parameter. When the simulation is started, double-clicking the *Signal frequency* block will open up a window where the value of *Constant value* can be set. Changing the value to a different value and applying into the simulation will make the speed of the motor change immediately.

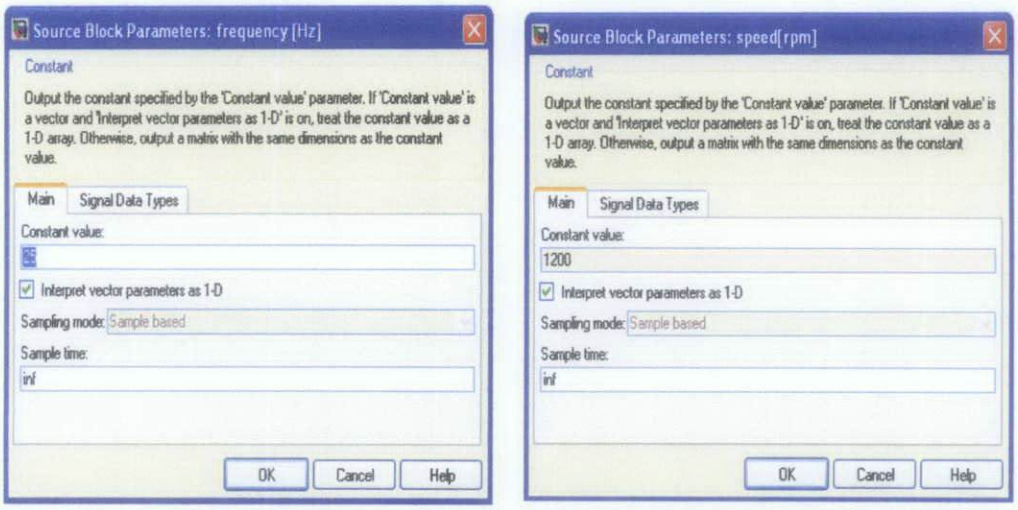

Figure 18 : The pop up window where user needs to insert the desired value

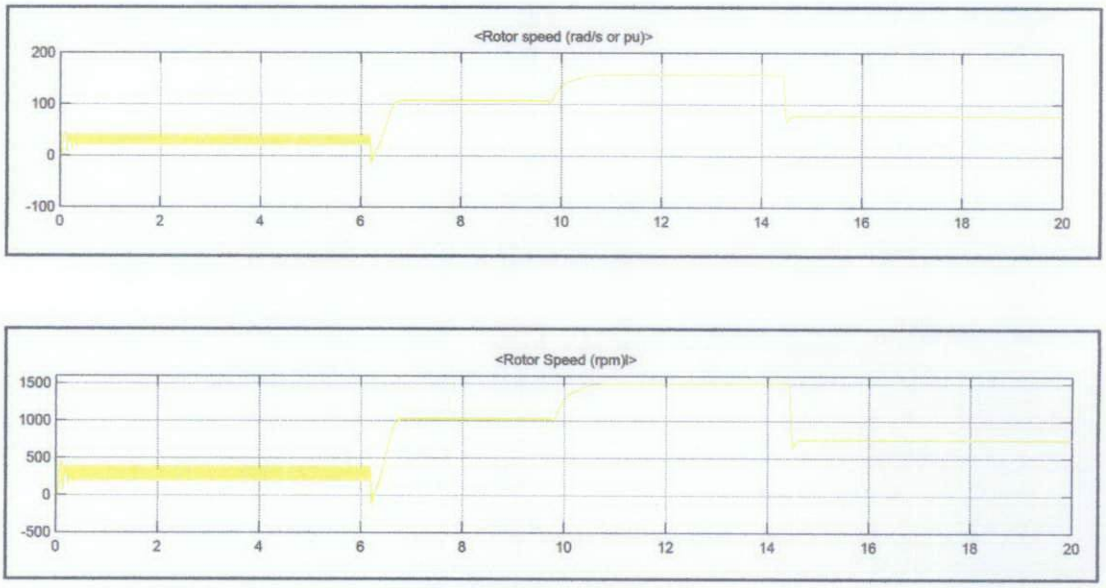

Figure 19 : The motor characteristic when varying the speed

In the simulation of varying the signal frequency, the initial speed is set to be 10 Hz. The speed increases immediately and maintained after 0.1 seconds. When the value is changed to 30 Hz, the large increase will make the speed of the motor increase simultaneously until it reaches the constant speed of 900 rpm. Then, the signal frequency is changed to 50 Hz and the speed increased to 1500 rpm. After a few second from starts, the frequency is changed to 25 Hz and the speed immediately drops to 750 rpm. The resulted waveform shows the unstable increase and decrease rate of every speed increment and decrement. To avoid the unstable condition of speed changing, a ramp system should be introduced in the signal frequency control.

4.3.2 Introduction to ramp function

In order to design the ramp control, a few Simulink blocksets have been added to the PWM generator blockset. The operation of the ramp circuit is to increase the frequency input for the PWM generator block gradually until it reaches the set point.

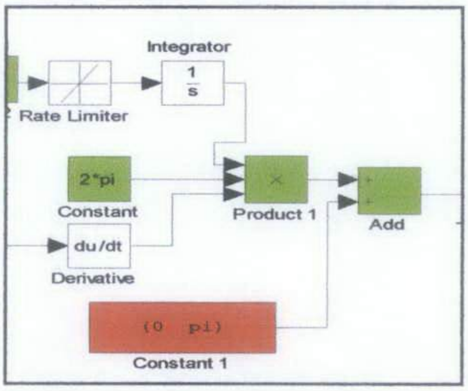

Figure 20 : The blockset added to the PWM generator to build the ramp function

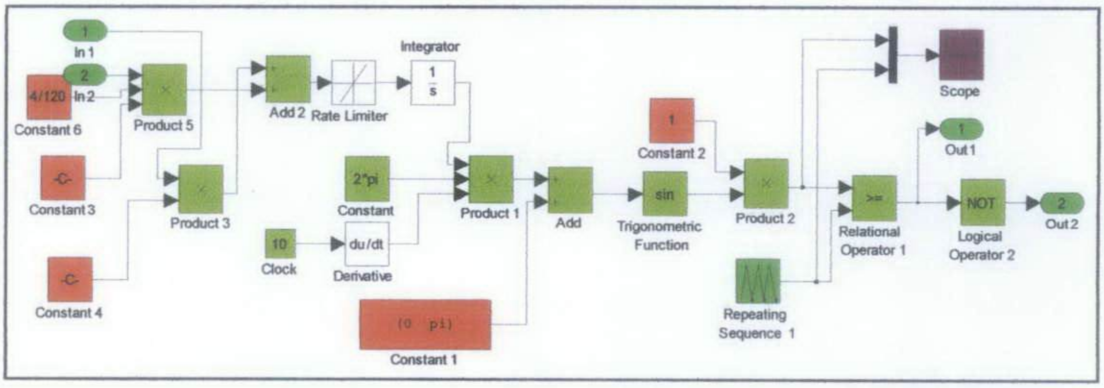

Figure 21 : The ramp function constructed in the PWM generator that consist of several blocksets.

The *Rate limiter* block is used to provide the increment from zero to any set point at the input. The rate of increment can be set in the block parameter. . In this case, the value of *Rising slew rate* is set to be *5* and *Falling slew* rate is set to be *-5*. In simple words, these values are the increment and decrement slope.

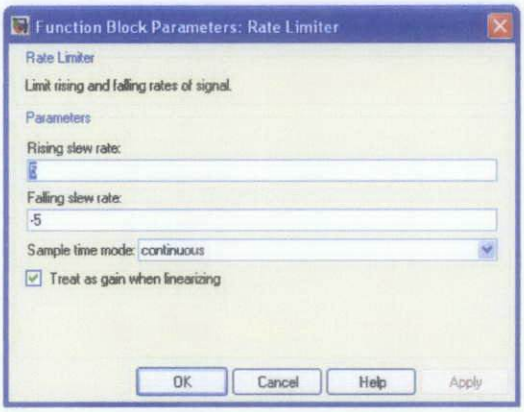

Figure 22 : The parameter set for Rate Limiter

The *Integrator* block outputs the integral of its input at the current time step. The *Derivative* block is connected to the clock to prevent the output from *time* block to increase. The block will make the lower input for the *product* block will remain constant. The used of the *Derivative* block will enable the *Integrator* block to integrate the frequency input value from the *rate limiter* so that the generated sine wave will increase or decrease smoothly in frequency.

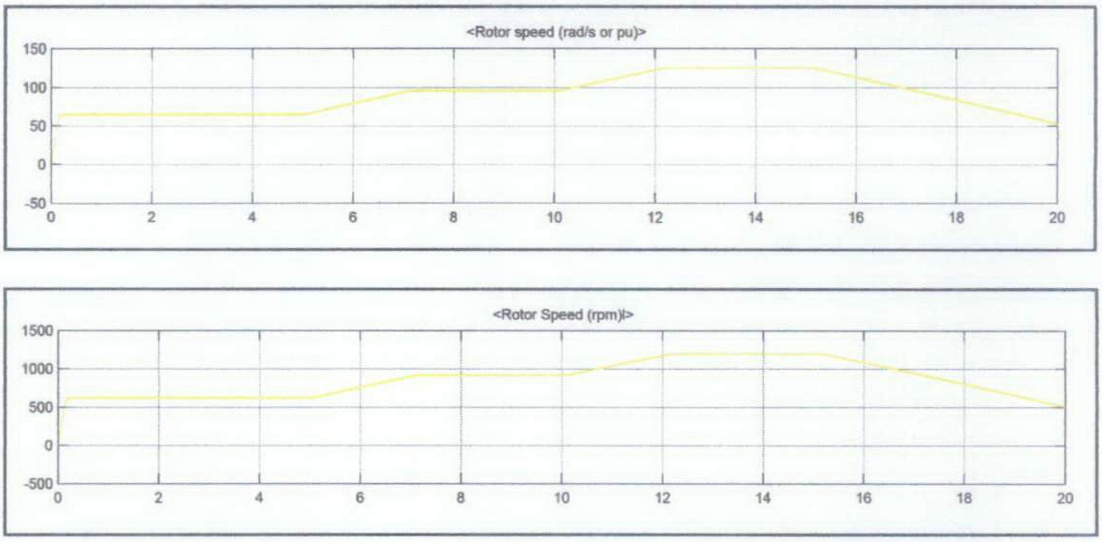

Figure 23 : The motor characteristic when varying the speed with additional ramp function

From the simulation results, at start, the input increase gradually and when it reaches the set point frequency, 10 Hz then the input is maintained and the average speed still increases gradually. When the input reaches the set point (30Hz), the speed is maintained at a constant speed. Then, the input is changed to 50Hz, and the speed of the motor increase gradually with the same slope. For deceleration ramp, the input frequency is immediately set to be a lower value at 25 Hz, yields the motor speed to decrease gradually with the same value of slope. From the results, the speed changes are more effective and reliable by using ramp function for the acceleration and deceleration.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The project is focusing on the designing the speed control method for single-phase induction motor using PWM technique, by implementing theoretical knowledge into simulation model. The PWM signal can be generated by comparing the carrier signal from the triangle wave generator and the sinusoidal control wave from the sine wave generator. The simulation of this project is completed by having the speed control method of single-phase induction motor in such a way where user can varying the speed of the motor and ramp function. During the simulation, the output of the motor is dependence on the value of the desired speed or frequency entered by the user. The ramp function also works successfully with PWM technique. This technique can produce the same results as theoretical results where the characteristic of the motor at 75 % and 100 % obviously similar as its theory. For conclusion, the speed control method using PWM to control the voltage frequency has been studied, simulated and tested. It is proven that the technique can successfully control the speed of single-phase induction motor. As a recommendation, the project has potential to be expanded in advance the simulation into prototype using specific software and hardware such as xPC Target Box software and etc.

REFERENCES

[1] D. G. Holmes, and A. Kotsopoulos, "Variable speed control of single and two phase induction motors using a three phase voltage source inverter," in *IEEE/IAS Annual Meeting Conference Record*, October

1993, pp. 613-620

[2] E.R. Collins Jr, H. B. Püttgen, and I. W. E. Sayle, "Single-phase induction motor adjustable speed drive: Direct phase angle control of the auxiliary winding supply," in *IEEE/IAS Annual Meeting Conference Record*, IEEE, IAS-88, October 1992, pp. 246-252.

[3] E.R. Collins Jr,, "Torque and slip behavior of single-phase induction motors driven from variable speed supplies," in IEEE, IAS-90, pp.246-252.

[4] E.R. Collins Jr, R. E. Ashley, "Operating characteristics of single-phase capacitor motors driven from variable speed supplies," in IEEE, IAS-91,

pp. 52-57.

[6] Induction and Synchronous Motor Fundamentals, PDHengineer.com, 5870 Highway 6 North, Suite 310 Houston, TX 77084

[7] Chapman, Stephen J., "Electric Machinery Fundamentals", *McGraw Hill International Edition, 4th Edition*, 2005

[8] Mohd Fakhizan bin Romlie, Mohammad Fadhil bin Pesol and Khairul Nisak Md Hasan, " PWM Technique to Control Speed of Induction Motor using Matlab/xPC Target Box", Accepted to be presented in 2nd IEEE International Conference on Power and Energy (PECon) 2008, Dec 2008.