Modeling and Simulation of Three Phase Induction Motor For Digital Control

By

SITI ATIQAH BINTI SOHAIMI

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

CERTIFICATION OF APPROVAL

Modeling and Simulation of Three Phase Induction Motor For Digital Control

by

Siti Atiqah binti Sohaimi

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 by:

____

(Assoc. Prof. K.S Rama Rao)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

Dec 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 u nspecified sources or persons.

Siti Atiqah binti Sohaimi

ABSTRACT

This report basically discusses the development of the project which is **Modeling and Simulation of Three Phase Induction Motor for digital control** . The purpose of this project is to get better understanding of the various techniques of variable speed control. This report provides a brief overview of the basic operation principles of two types of variable speed induction motor which are scalar control and vector control. A comparative study to choose the best techniques is reported in this project. The challenge in this project is the author requires better understanding of the design and the characteristics of the model. The author also requires basic knowledge of computer programming to understand and use MATLAB/SIMULINK Tool Box. Lab testing will be done to stimulate the model. This Final Year Project will include the selection of the best techniques to be used to stimulate the three-phase induction motor as well as practical testing and analysis of the data which will be gathered from the simulation.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my gratitude to God, for His grace I was able to accomplish this project. I believe He has blessed me with sufficient strength and wisdom for me to carry out and complete this project.

Thanks a lot to my Final Year Project supervisor, Assoc. Prof. K S Rama RAO, who has always enthusiastically given me valuable input and guidance. I thank you for your patience and many hours of support providing advice, support and knowledge which will always be remembered and appreciated.

I would like to express my gratitude to Mr. Khaleed for helping me to acquire information and work out problems for my case study. To the staffs and technicians of Universiti Teknologi PETRONAS's Electrical and Electronics Engineering Department, I thank you for your tireless effort and assistance in helping me throughout the completion of the project.

I would also like to acknowledge my thanks to my course mates and friends who have always willingly to share ideas and sincere comments .

And lastly, and most importantly, I want to thank my family who have always prayed for my success and given their utmost moral support in my life. I hope I can always be there for them in the way they supported me.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	Alternating Current
AIVT	Alternate Interrupt Vector Table
CPU	Central Processing Unit
DC	Direct Current
DTC	Direct Torque Control
DSP	Digital Signal Processing
DSC	Digital Signal Controller
EEPROM	Electrically Erasable Programmable Read-Only Memory
FOC	Field Oriented Control
IGBT	Insulated-gate Bipolar Transistor
IVT	Interrupt Vector Table
MOSFET	Metal-oxide-Semiconductor field-effect transistor
MCUs	Microcontrollers
PWM	Pulse Width Modulation
PC	Program Counter
ROM	Read Only Memory
SCR	Silicon Controlled Rectifier
SVM	Space Vector Modulation
SFRs	Special Function Registers

VFD	Variable Frequency Drive
VSI	Voltage Source Inverter

CHAPTER 1
INTRODUCTION

1.1 Background of Study

The ideas of developing induction motor were started by Nicola Tesla during the late 1880s where he gets the ideas in 1888. The induction motor is then in recognizable form between 1888 and 1895 and during that period, two and three power sources were developed to produce the rotating magnetic fields within the motor. Then the stator winding was developed and the squirrel cage was introduced. By 1896, three-phase induction motors were fully functional and recognizable.

Increasing demand in power electronics for high performance industrial machinery has contributed to rapid developments in motor control. The improvements in induction motor design were lead to improvements in motor operating efficiency and reducing the material cost of the machines. This field study of induction motor has numerous applications in the areas of manufacturing, mining, and transportation. It is also sometimes difficult to determine which techniques are best suited to particular application in the diversity of digital motor control.

The most common motors used in industrial motion control systems and home main power appliances are AC induction motors [1] because of their simplicity and ease of operation. These motors are operated by motor drives which are known as power electronic devices. AC induction motor drives consists of two main sections, a controller to set the operating frequency to determine the speed and a three phase inverter to generate the required sinusoidal three phase system from a DC voltage supply [1].

The motor speed of AC induction motor is changed by varying the frequency and amplitude of the drive voltage using SCR drives. By firing each SCR, it will produce sinusoidal voltage on the motor phase. The SCR drives can produce six ways to produce motor currents however the disadvantages of these types of circuits are high heat dissipation, and at low frequencies give poor performance. Due to this problem, SCR drives are now replaced with MOSFET or IGBT devices that provide better performance with minimal power losses. By using Pulse Width Modulation signal, variable drive voltages and currents are generated continuously.

1.2 Problem Statement

Induction motor is the most popular of all electric machines because of its robust construction, low manufacturing cost and easy to control. Compared to a DC motor, an induction motor only has one excitation connection rather than two excitation connections. For these reasons, the induction motor is more durable than a DC motor.

Major improvements in modern industrial processes caused the use of induction motor to increase, which attributed to the advances in variable speed motor drives . In order to be in line with modern technologies, high performance control schemes become essential in application. A great deal of work has been under investigation such as research on the application of sensorless control, three phase voltage source inverter, techniques of application of Field Oriented Control (FOC), Direct Torque Control (DTC) and Pulse

Width Modulation (PWM) and a number of high performance control schemes were evaluated.

The designer's problem, in the light of these standards, is to select a suitable technique to use and to control the operation of three-phase induction motor. This project is intended to thoroughly investigate the dynamics and steady state performance of three phase induction motor, using a dsPIC Digital Signal Controller. In addition, the outcomes must produce correct simulation by performing and formulating the required interactive computer software, MATLAB programming. Simulink modeling of the chosen controller will be carried out and this simulation also aids in the selection of controller parameters.

1.3 Objective and Scope of Study

The objectives of this project are:

1. To do literature review on the design specifications and construction of the Induction motor and to choose the suitable techniques for the control of the motor.
2. To study the principles of Field Oriented Control and Space Vector Pulse Width Modulation
3. To study the basic construction/configuration of dsPIC and its application for the speed control of induction motor.

Basic understanding on theoretical aspects of Induction motor is required in order to design an induction motor control using MATLAB. It is essential to understand the operation of the induction motor as the parameters and clarification on the calculation are needed. All parameters of induction motor control scheme have to be understood and calculated.

A good knowledge in using MATLAB programming is really important. This is to ensure that the output results in the form of simulation are produced. All calculations are included and tested in computer aided tool, MATLAB. The major part in this project is to formulate MATLAB programming and produce a correct output results. Also better understanding on how to use the dsPIC is needed by studying the structure and the application of dsPIC.

This project is mainly focused on design study and programming using MATLAB, for which the software is readily available. A lot of self-study, consultation sessions and researches must be done with the aim of getting the job done according to the schedule.

CHAPTER 2
LITERATURE REVIEW

2.1 AC Induction Motor

Most motor applications use an AC induction motor because of its simple rotor construction, simple conceptual ideas for variable speed operation [2], and high level of performance as well as reduced cost and low maintenance cost [3]. There are various types of AC induction motors and different motors are suitable for different applications. To control the torque and speed of an AC induction motor, great understanding of the design and characteristics of the motor are required.

2.1.1 Basic Construction and Operating Principles

The AC induction motor contains two main parts, which are the stator and the rotor. Both stator and rotor have air gap between them. In an induction motor, stator will produce magnetic field to spin the rotor. Inside the motor the electromagnetism created, one produced in the stator and the other produced in the rotor. Interaction between the magnetic fields of stator and rotor produce force in the conductor or torque. As a result, the motor rotates in the direction of the rotating magnetic field and resultant torque [1].

Stator or primary, which is the stationary portion of an induction motor consists of a frame that houses a magnetically active, annular cylindrical structure punched from electrical steel sheet with a three-phase windings set embedded in evenly spaced, internal slots. The stator windings are connected directly to a three-phase ac power source that helps to create magnetic field [1]. For large motors, the individual coils of the electrical windings are form-wound and for smaller motor they are random-wound.

Rotor or secondary of an induction motor is made up of a shaft-mounted, magnetically active, cylindrical structure. It is constructed from electrical steel sheet punching with evenly spaced slots located around the outer periphery to accept the conductors of the rotor winding. There are two types of rotor winding, either *squirrel-cage* or *wound-rotor* [1].

2.1.2 Single-Phase AC Induction motor

It is more often used than all other types of motor because of its low-maintenance type motor and least expensive. This type of motor has only one stator winding as main winding and operates with a single-phase power supply.

For single-phase induction motor, the motor is not self starting as the rotor required a starting mechanism that can provide the starting kick to move the rotor. When motor is connected to single power supply, the main winding carries an alternating current where it will produce an alternating magnetic field. Due to induction, the rotor will be energized and vibrates but not rotates. Here a starting mechanism is needed to make the rotor to rotate [1].

2.1.3 Three-Phase AC Induction motor

This type of motor is mostly used for industrial applications. The three -phase induction motor gives good torque performance at all operating speeds and it is the best type to use for variable speed control. These motors are self -starting because it can generate true rotating magnetic field in the stator windings when fed from a source of three -phase power.

Almost 90% of three-phase induction motors are squirrel cage motor s [1]. Motors of this type are cost less and can start with heavier load. A wound-rotor motor is ideal for very high inertia loads where it is required to generate the pull -out torque at almost zero speed and accelerating to full speed in the minimum time with minimum current draw.

2.2 Three-Phase Motor Operation

When the motor is connected to the three-phase power supply, stator generates a magnetic field. Three electrical phases appears in the motor and each phase energizing an individual field pole. When each phase reaches its maximum current, the magnetic field at that pole reaches a maximum value. As the current decreases, the magnetic field will also decrease. Since each phase reache s its maximum value at different time within a cycle of the current, the field pole whose magnetic field is largest is constantly changing between the other poles. Here the magnetic field is seen by the rotor is rotating.

The speed of the rotation of the magnetic field depends on the frequency of the power supply and the number of poles produced by the stator winding. Standard frequency is 50 Hz supply and the maximum synchronous speed is 3, 000 rpm, for a 2-pole motor.

In three-phase induction motor, the windings on the rotor are not connected to a power supply but are short circuited. When the motor is on and the rotor is stationary, the rotor conductors experience a changing magnetic field. Induction of currents round the stator windings, the rotor will produce torque and starts to turn. The rotor can never rotate at the synchronous speed because there is no relative motion between the magnetic field and the rotor windings and no current could be induced. The induction motor has a high starting torque.

2.3 Three-Phase Voltage Source Inverter

Three-phase voltage source inverter is the most common three-phase inverter topology where it will generate an AC voltage from a DC voltage source. It is commonly used to supply three-phase loads. The most frequently used three-phase inverter circuit consists of three legs where one leg is for each phase. Each of the three converter legs of MOSFETs are switched on by a Pulse Width Modulated (PWM) waveform. Switch mode dc-to-ac inverters are used with ac motors and will produce a sinusoidal ac output voltage whose magnitude and frequency can be controlled [7]. PWM is used to switch the MOSFETs in each of the three converter legs and used like a digital-to-analog converter to produce motor currents of any desired wave shape. Figure below shows six MOSFETs and the inverter circuit six control signals in a sequence. The DC voltage is obtained by rectifying and filtering the line voltage. The energy of DC voltage supply can be obtained from the batteries, or primary energy source. Figure 1 presents the basic components of three phase induction motor control [2] scheme.

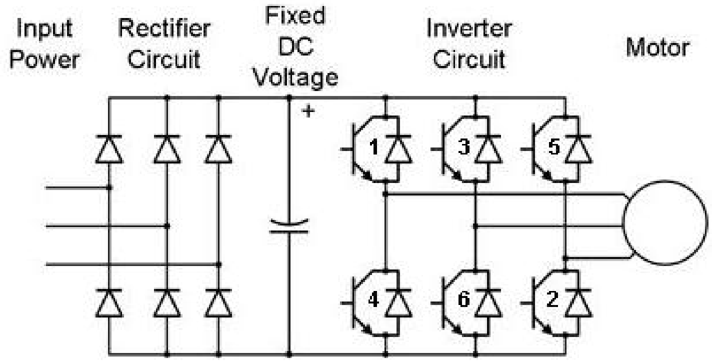

Figure 1 Three-phase variable frequency inverter

2.4 Pulse Width Modulation

The purpose of pulse width modulation (PWM) with three phase inverter is to shape and control the magnitude and frequency of three phase output voltages with constant input voltage [7]. There are two kinds of PWM techniques, one is an on -line generation technique and the other one is an off-line generation technique. The on-line generation technique is divided as two types and there are the carrier-based PWM and space vector (SV)-based PWM. The carrier-based PWM is to run square waves in the power switches and sine wave current in the motor and the points of the intersection is the switching points of the power devices in the inverter. This method is easy to be implemented by analog circuits but it is unlikely to make full use of the inverter's supply voltage as the PWM switching characteristics produce high harmonic distortion in the supply. For off-line generation technique, the switching patterns are to be optimized and eliminate a certain order of harmonics [11].

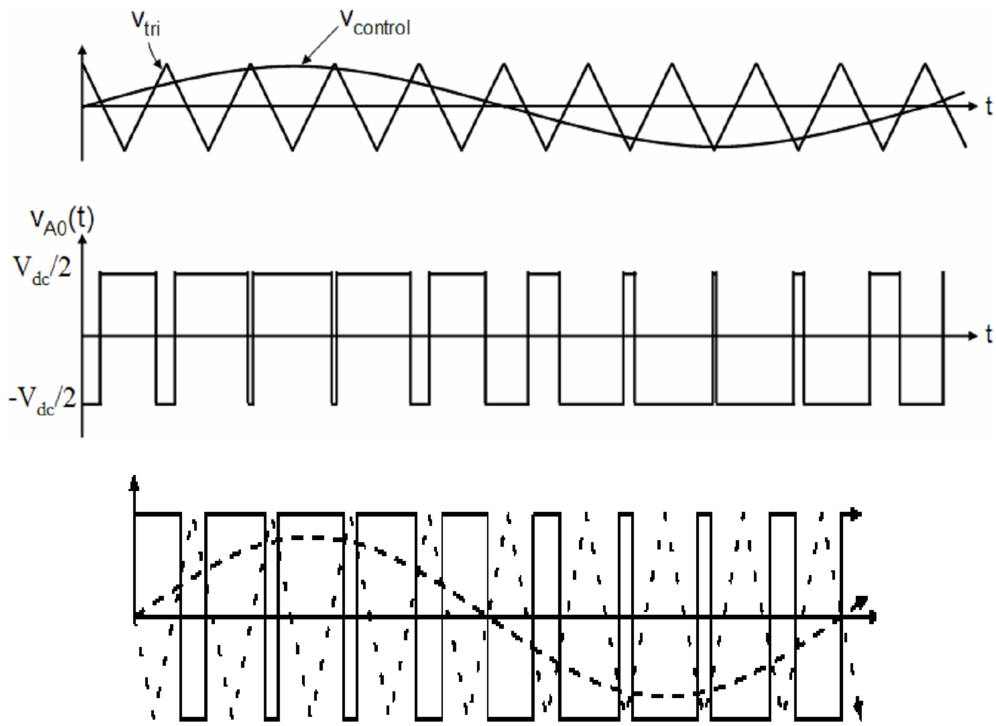

Figure 2 Pulse width modulation

2.5 Space Vector PWM

The Space Vector PWM (SVPWM) is a more sophisticated technique developed for the use of vector control (Field oriented control) which generate a fundamental sine wave that provide higher voltage in the motor and lower total harmonic distortion. With the development of the microprocessor technology, Space Vector Modulation has been a very popular method for three phase converter. The space-vector is simply the digital implementation of PWM modulators where the concept of space-vector is to compute the duty cycle of the power switches and to produce the switching control signals to the three-phase inverter circuit [12].

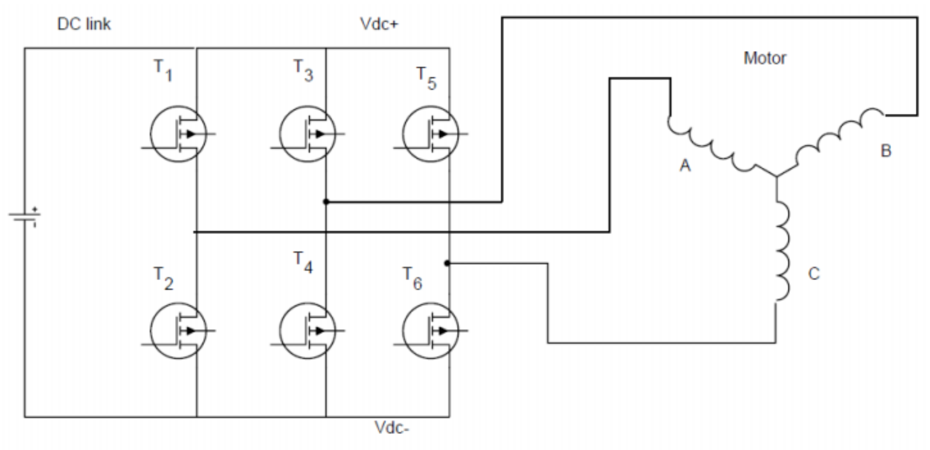

Figure 3 Typical Inverter Bridge Configuration

The control strategy of the SVPWM is the switching sequence of the upper three power switches of a three-phase power inverter. From the Figure 3, the six-power switches in the inverter have eight possible switching states. Six states when a voltage is appli ed to the motor and two states when the motor is shorted through the upper or lower switches resulting in zero volts being applied to the motor. This techn ique has been shown to generate less distortion in the output voltage and or current and to provide more efficient use of supply voltage. The six vectors including the zero voltage vectors can be simply expressed from the Figure 4, Figure 5, and Table 1.

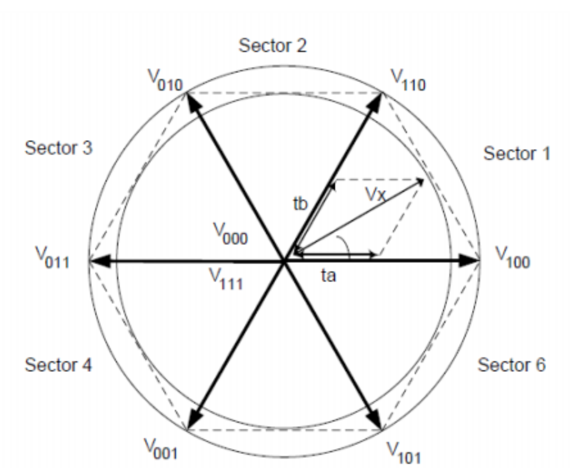

Figure 4 Space Vector Diagram-Line to Neutral Voltage

Table 1   Switching Vectors, Phase Voltage and Output Line to Line Voltage

Voltage vector	On devices	Switching vectors			Line to neutral voltage			Line to line voltage		
		a	b	c	Van	Vbn	Vcn	Vab	Vbc	Vca
V0	T2, T4, T6	0	0	0	0	0	0	0	0	0
V1	T1,T4, T6	1	0	0	2/3	-1/3	-1/3	1	0	-1
V2	T1, T3, T6	1	1	0	1/3	1/3	-2/3	0	1	-1
V3	T3, T2, T6	0	1	0	-1/3	2/3	-1/3	-1	1	0
V4	T2, T3, T5	0	1	1	-2/3	1/3	1/3	-1	0	1
V5	T2, T4, T5	0	0	1	-1/3	-1/3	2/3	0	-1	1
V6	T1, T4, T5	1	0	1	1/3	-2/3	1/3	1	-1	0
V7	T1, T3,T5	1	1	1	0	0	0	0	0	0

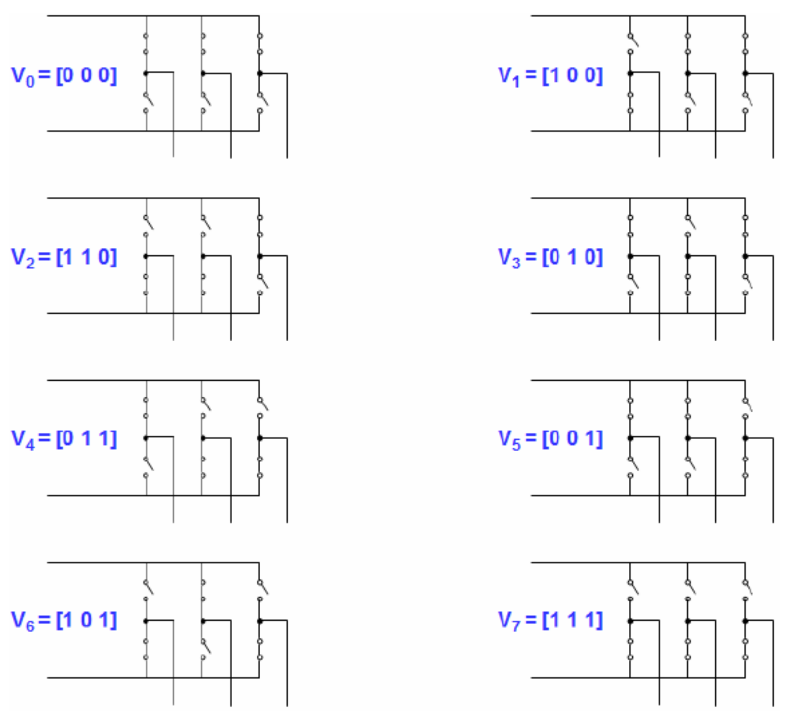

Figure 5   Switching states of the three-phase inverter

SVPWM will average out the adjacent vectors for each sector by using the appropriate PWM signal and provides sinusoidal line to line voltages to the motor. In order to generate the PWM signals that produce the rotating vector, formula must be derived to determine the PWM time intervals for each sector [16].

Below shows the relationship between the switching variable vector [a, b, c]t and the line-to-line voltage vector [V_{ab} V_{bc} V_{ca}]t is given by (2.1) in the following:

$$\begin{bmatrix} Vab \\ Vbc \\ Vca \end{bmatrix} = Vdc \begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ -1 & 0 & 1 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad \text{.......... 2.1}$$

Also, the relationship between the switching variable vector [a, b, c]t and the phase voltage vector [V_a V_b V_c]t can be expressed below:

$$\begin{bmatrix} Vab \\ Vbc \\ Vca \end{bmatrix} = \frac{Vdc}{3} \begin{bmatrix} 2 & -1 & -1 \\ 0 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} a \\ b \\ c \end{bmatrix} \quad \text{.......... 2.2}$$

To determine the PWM time intervals for each sector, construct sector 1 first. Sector 1 is bounded by Vectors 100, 110 and the null vectors 000 and 111. From here, the vector V_x within this sector can be resolved. Below shows the equation of the vector V_x:

$$Vx \bullet \sin\left(\frac{\pi}{3} - \alpha\right) = Va \bullet \sin\frac{\pi}{3} \quad \text{.......... 2.3}$$

$$Vx \bullet \sin\alpha = Vb \bullet \sin\frac{\pi}{3} \quad \text{.......... 2.4}$$

Therefore

$$Va = \frac{2}{\sqrt{3}} \bullet Vx \bullet sin\left(\frac{\pi}{3} - \alpha\right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.5$$

$$Vb = \frac{2}{\sqrt{3}} \bullet Vx \bullet \sin\alpha \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.6$$

V_a and V_b are the components of V_x that are aligned in the direction of V_{100} and V_{110} respectively. By applying V_{100} for a percentage of time t_a and V_{110} for a percentage of time t_b over a period T0, V_x can be approximate using the vector addition.

$$Vx = Va + Vb = V100 \bullet \frac{ta}{T0} + V110 \bullet \frac{tb}{T0} + (V000\ or\ V111) \bullet \frac{t0}{T0} \qquad \ldots\ldots\ldots \; 2.7$$

or

$$Vx \bullet T0 = V100 \bullet ta + V110 \bullet tb + (V000\ or\ V111) \bullet t0 \qquad \ldots\ldots\ldots\ldots\ldots \; 2.8$$

where

$$ta = \frac{Va}{V100} \bullet T0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.9$$

$$tb = \frac{Vb}{V100} \bullet T0 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.10$$

$$t0 = T0 - (1 - ta - tb) \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 2.11$$

Substituting equations 2.5 and 2.6 into 2.9 and 2.10 then

$$ta = m\left[\cos\alpha - \frac{1}{\sqrt{3}}\sin\alpha\right] \qquad \text{......... 2.12}$$

$$tb = \frac{2}{\sqrt{3}} \bullet m\, sin\alpha \qquad \text{......... 2.13}$$

Where *m* is the ratio of $\frac{Vx}{V100{,}110}$, also known as the modulation index for the period T_0 in segment 1.

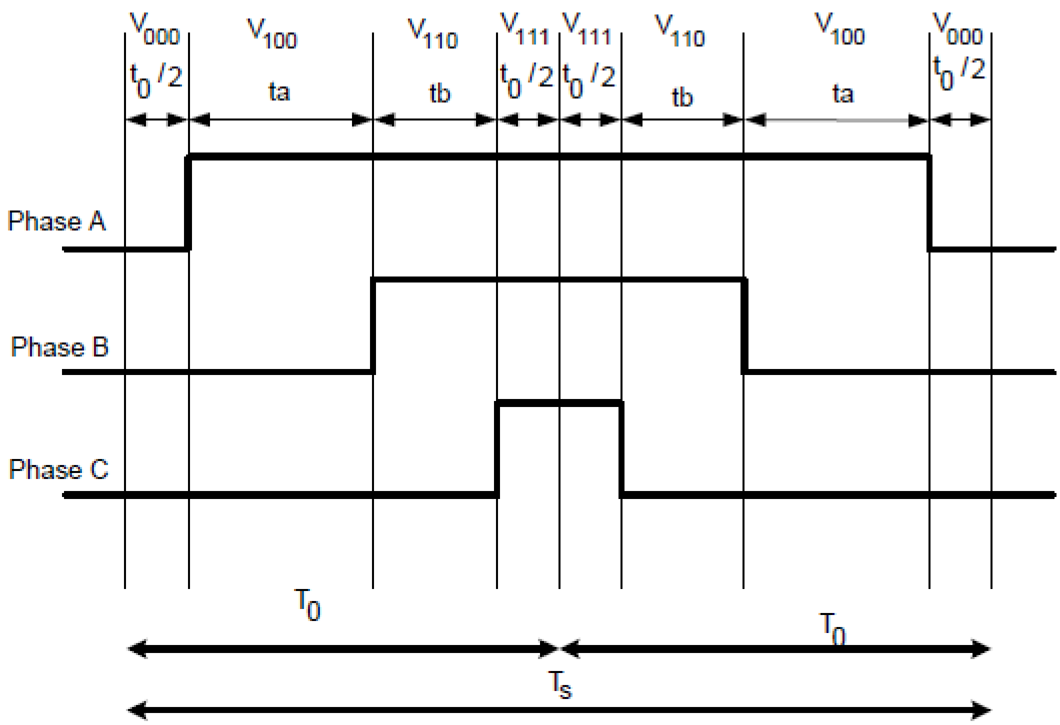

Figure 6 Symmetric SVPWM Pulse Generation

2.6 AC Motor Control Algorithms

An induction motor can run only at its rated speed when it is connected directly to the main supply. Driving and controlling the induction motor are essential and many applications need variable speed for operations. Most of the motors in variable-speed drives are alternating current induction motor. Variable speed drives that drive three-phase motors help to save energy and optimize the system. Suitable control strategies are to applied to the motor to operate at steady torque without speed regulation. Here two types of AC motor controls, scalar control and vector control, are reported.

2.6.1 Scalar Control

For scalar control, voltage and frequency are varied to change the speed of the motor. Scalar control or Volt/Hertz (V/Hz) is a simple technique to control speed of the induction motor. The steady-state model of induction motor is mainly used to derive the technique. The system has no current loop. V/Hz principle requires that the magnitude and frequency of the voltage applied to the stator of a motor maintain a constant ratio.

It is a system that is made up of active or passive devices, a high speed central controlling unit and optional sensing devices and it depends upon the application requirement [1]. The motor speed is proportional to supply frequency. Thus by varying the frequency, the speed of the motor is changed. When the supply frequency is reduced, higher flux will occur due to the higher current produced by the motor and causes the magnetic field reach saturation level. To overcome this problem, the magnitude of the magnetic field in the stator is kept at an approximately constant level throughout the operating range; both supply frequency and voltage are changed in a constant ratio [1]. Thus, constant torque producing capability is maintained. When transient response is critical, switching power converters also allow easy control of transient voltage and current applied to the motor to achieve faster dynamic response.

V/Hz can be programmed by parameters adapting to the motor load. By selecting proper V/f ratio for motor, the current can be under control. Also the motor heat can be reduced and provide overcurrent protection. These features avoid the acceleration together with inertia and load of the motor causing excess of torque and current limitation of the system.

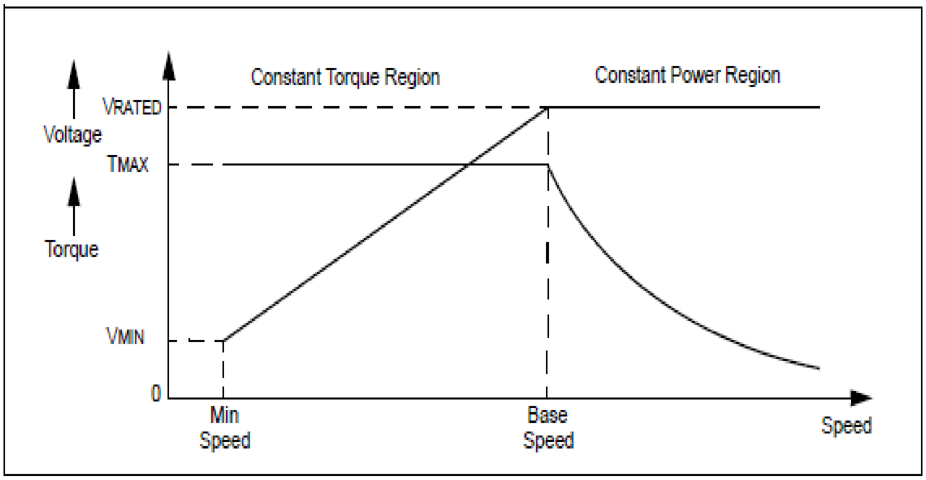

Figure 7 V/f Curve

From the Figure 7, it is observed that the voltage and frequency are varied at a constant ratio up to the base speed. The base speed of the motor is proportional to supply frequency and is inversely proportional to the number of stator poles. At the base speed, the flux and the torque are almost at constant value. When frequency is increased beyond the base speed result, the torque will be reduced due to the field weakening and the curve of the torque will become nonlinear as the friction and windage losses increase significantly [1]. Voltage supply can be increased in order to increase the motor speed but the limitation of this method is when the motor reach its rated voltage, increasing in voltage supply will not affect the motor speed.

2.6.2 The Vector Control

For vector control, matrix and vectors are used to represent the control quantities. The control quantities are the magnitude and the phase of these variables. It uses equations of the system steady state and mathematical model of the induction motor. Because of it complex equations, Field Oriented Control (FOC) is used to solve high order equations and to achieve high performance of the motor system [3].

The basic idea behind the Field Oriented Control is to maintain the relationship between the stator and rotor flux to avoid the oscillations and current spikes during rapid transients and to squeeze out the most performance from the motor [9]. Field Oriented Control consists of controlling the stator currents represented by a vector. This control is based on projections which transform a three-phase time and speed dependent system into a two co-ordinate (*d* and *q* co-ordinates) time invariant system [10].

To control the motor, Field Oriented Control needs two constants as input references. The input references are the torque components (aligned with the *q* co-ordinates) and the flux components (aligned with *d* co-ordinates). The FOC solve the problems by reaching constant reference that is the torque component and flux component of the stator current and also applying direct torque control [10]. The relationship between torque and torque component (i_{Sq}) is linear when the amplitude of the rotor flux is fixed, thus, we can control the motor torque by controlling the motor stator current

$$m \propto \psi_R \, i_{Sq} \quad \text{…………………………………………………………………} \quad 2.14$$

2.6.1.1 Space Vector Definition and Projection

The concept of field oriented control is similar with space vector conc ept where the three-phase voltages, current and fluxes of AC motors are developed in use of vector control. By assumed that i_a, i_b, and i_c are the instantaneous currents in the stator phases, complex stator current vector (i_s) can be defined as:

$$i_s = i_a + \alpha i_b + \alpha^2 i_c \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2.15$$

where $\alpha = e^{j\frac{2}{3}\pi}$ and $\alpha^2 = e^{j\frac{4}{3}\pi}$ is the spatial operations. Figure 8 shows the stator current complex space vector and its component in (a,b,c). Here, the (a,b,c) are the three - phase system axes. The three-phase current space vector needs to be transformed into a two time invariant co-ordinate system [10].

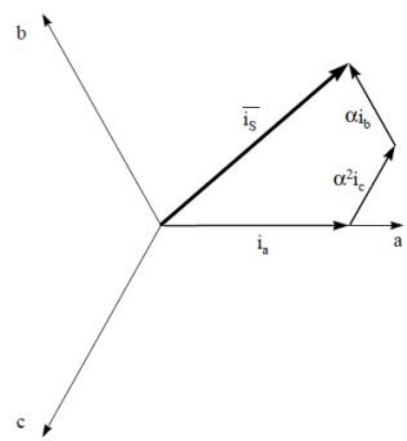

Figure 8 Stator current space vector and its component in (a,b,c)

This transformation can be split into two steps:

- (a,b,c) into (a,b) using the Clarke transformation block which outputs a two co-ordinate time variant system.
- (a,b) into (d,q) using the Park transformation block which outputs a two co-ordinate time invariant system.

2.6.1.2 Clarke Transformation

Clarke Transformation block is used to converts a balanced three phase system into a two-phase system in the stationary α and β reference frame [4].

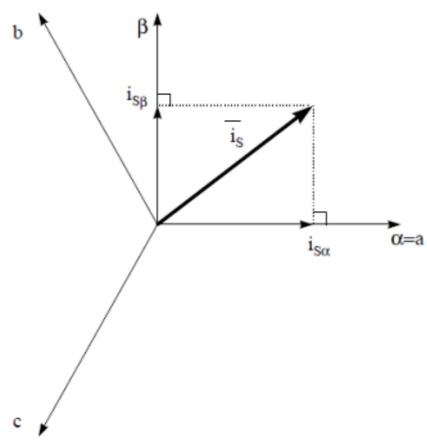

Figure 9 Stator current space vector and its components in (a,b)

From the Figure 9, the projection from three-phase system into the (α,β) two dimension orthogonal system can be represent using this equations [10]:

$$i_{s\alpha} = i_{\alpha} \qquad (2.16)$$

$$i_{s\beta} = \frac{1}{\sqrt{3}} \cdot ia + \frac{2}{\sqrt{3}} \cdot ib \qquad (2.17)$$

2.6.1.3 Parke Transformation

In this block, two-phase orthogonal system (α,β) transformed into d,q rotating reference frame. d-axis is consider as the rotor flux and q-axis as the torque. Figure 10 shows the relationship from the two reference frame [10]:

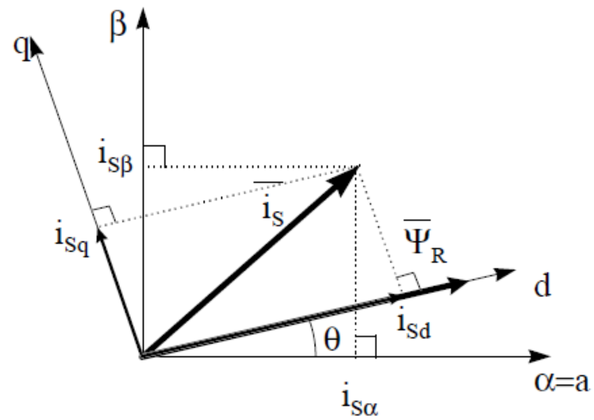

Figure 10 Stator current space vector and its component in (a,b) and in the d,q rotating reference frame

The flux and torque components of the current vecto r are determined by the following equations:

$i_{sd} = i_{s\alpha} \cos\theta + i_{s\beta} \sin\theta$ …………………………………………………………. 2.18

$i_{sq} = -i_{s\alpha} \sin\theta + i_{s\beta} \cos\theta$ ……………………………………………………….. 2.19

where θ is the rotor flux position. D and q components depends on the current vector (α,β) components and on the rotor flux position.

2.6.1.4 Inverse Park Transform

This block is uses to convert the controller's reference voltage back onto the stationary α and β axes so it can be directly synthesized [4]. The voltage transformation equations (2.20 and 2.21) are use to modifies the voltages in d. q rotating reference frame in a two-phase orthogonal system.

$$V_{s\alpha ref} = V_{sdref} \cos\theta - V_{sqref} \sin\theta \quad \text{2.20}$$

$$V_{s\beta ref} = V_{sdref} \sin\theta + V_{sqref} \cos\theta \quad \text{2.21}$$

2.7 dsPIC

dsPIC is a 16-bit microcontroller and it supports instruction used for DSP algorithms which retain the fundamental real time control capabilities of a microcontroller . It is newest and most advanced processor that gives more flexibility and control of a microcontroller with the computation and throughout capabilities of a digital signal processor [5]. To select the right dsPIC to use for any design, better understanding on the architecture and the features of dsPIC are needed.

2.7.1 Digital Signal Controller

A Digital Signal Controller (DSC) is a single- chip, embedded control that incorporates both microcontrollers (MCUs) and digital signal processors (DSPs). It can give efficient digital signal processing and a variety of controller operation in a single chip [13]. Digital Signal Controller is familiar as the microcontroller as it gives fast interrupt responses, offer control-oriented peripherals and watchdog timers [5]. Digital Signal Controller usually using the C programming language and because of its easy-to-design solution, low cost, potential to reduce power consumption in electric motors and power supplies ,and provide high speed, it is widely used in many applications like motor control, power conversion, and sensor processing application.

2.7.2 Architecture of dsPIC

The dsPIC processor has Harvard architecture with separate program and data memory bus that allows different size data (16 bits) and instruction (24 bits) words. This will give faster processing because the dsPIC can pre-fetch the next instruction from program memory and at the same time it executes the current instruction that access data RAM [5].

2.7.2.1 Program Memory and Program Counter

The Program Counter (PC) is 24-bits wide and addresses up to 4M x 24 bits of user program memory space [5]. The program memory space contains the reset location, the interrupt vector tables, the user program memory, the data EEPROM, and the configuration memory. The program block is used to store programs or data tables.

To begin program execution, the processor starts at reset location 0x000000 that programmed with a GOTO construction. After the GOTO instruction at the reset location the interrupt vector tables will generates and then the program memory code will start [5]. All dsPIC processor have their own run time self-program in a finished product [14].

Program looping can be done with the DO and REPEAT instruction, both of which are interruptible at any time. These features make DSP algorithm very efficient and ability to handle real time events.

2.7.2.2 Data Memory

The data space contains 64 Kbytes and it is one linear address space by most instructions. For certain DSP instructions, the memory split into two blocks cal led X and Y data memory to support dual operand reads where data can be fetched from X memory and Y memory at the same for a single cons truction. The data space boundary for X and Y are fixed for any given device and the memory is treated as a single block of X memory when no DSP instruction is done.

The data memory is divided into many parts. The first 2kB of data memory is allocated to the Special Functio n Registers (SFRs). The SFRs are control and status registers for core and peripheral functions in the dsPIC. After SFRs, 8kB of data RAM is implemented. The data RAM is act as data storage and it is split into X and Y memory for DSP instructions. The first 8kB (2kB of SFRs and the first 6kB of RAM) is called “near” and it can be access directly by any instruction that accesses RAM. Other that is not “near” must use indirect addressing as some instruction cannot directly access RAM [5]. The last 32kB of data RAM space is not implemented. To allow tables in program memory to be read, the 32kB of data RAM is mapped into program space for Program Space Visibility [5].

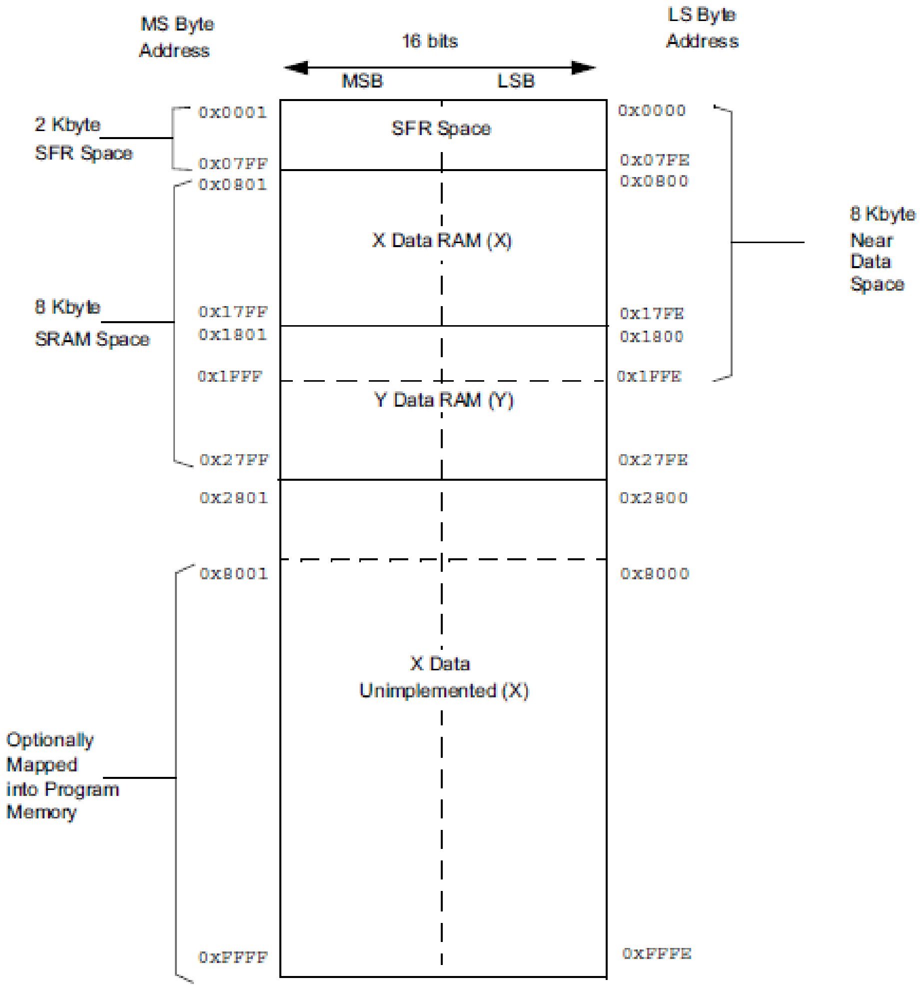

Figure 11 Sample Data Space Memory Map

2.7.2.3 Working Register Array

The dsPIC devices have sixteen 16-bit working registers and each of the working registers act as a data register, data address pointer, or address offset register. The sixteen working register (W0-W15), operates as a software stack pointer for interrupts and calls [5].

2.7.2.4 Data Addressing Modes

Here the CPU supports Inherent, Relative, Literal, Memory Direct, Register Direct, and Register Indirect Addressing modes. Each instruction that addresses data memory can use some of the available addressing modes. The addressing modes are optimized to support the specific features of individual instructions [5].

2.7.2.5 Modulo and Bit Reversed Addressing

The purpose for modulo addressing is to allow circular buffers to be implemented without processor overhead to check the boundaries of the buffer. The pointer for the buffer can be set up automatically wrap around to the beginning of the buffer after it reaches the end, and vice versa. The set up can be done in both X and Y memory, and this reduced the overhead for DSP algorithms [5].

The X memory also supports Modulo Addressing for all instructions, subject to Addressing mode restrictions. Bit-Reversed Addressing is only supported for writes to X memory [15].

2.7.2.6 Program Space Visibility

The upper 32Kbytes of the data space memory may optionally be mapped into any 16K program word boundary, defined by the 8-bit Program Space Visibility Page (PSVPAG) register. This lets any instruction access program space as if it were data space [5]. Moreover, only the lower 16-bits of each instruction word can be accessed using this method.

2.7.2.7 Instruction Set

For instruction set, the author studies the dsPIC30F from MICROCHIP. The dsPIC30F instruction sets consists of two classes of instruction: MCU instruction and DSP instruction. Most instructions are a single program memory word (24-bits) and only three instructions require two program memory locations. Each single-word instruction is a 24-bit word divided into an 8-bit of code which specifies the instruction type, and one or more operands which further specify the operation of the instruction [15].

MCU instruction and DSP instruction are seamlessly integrated into the architecture and execute from a single execution unit. This instruction is design for optimum C compiler efficiency and it includes many addressing modes. In a single cycle, the instruction were execute to change the program flow, the double-word move (MOV.D) that is load and store double word instruction and the program read/write (table) instruction [5].

The capable of dsPIC30F to executing a data memory read, a working register data read, a data memory write and a program memory (instruction) read per instruction cycle allow A + B = C type operations to be executed in a single cycle.

2.7.2.8 DSP Engine

The DSP engine consists of a high speed, 17-bits by 17-bit multiplier, a 40-bit ALU (Arithmetic Logic Unit), two 40-bit saturating accumulators and a 40-bit bi-directional barrel shifter. The barrel shifter is capable of shifting a 40-bit value up to 15-bits right, or up to 16-bits left, in a single cycle [5].

The DSP instructions can be operated with all other instruction. It is designed for optimal instruction and optimal real time performance. For DSP instruction, data memory is split into X and Y memory spaces so that the MAC instruction and other associated instructions are able to fetch two data operands from memory while multiplying two W registers [5].

Data input to the DSP engine is derived directly from one of the W array (registers W4, W5, W6 or W7) via the X and Y data buses for the MAC class of instructions (MAC, MSC, MPY, MPY.N, ED, EDAC, CLR and MOVSAC), from one of the X bus for all other DSP instructions and from one of the X bus for all MCU instructions which use the barrel shifter [15]. The derivation create a multiply and subtract (MSC) or multiply and negate (MPY.N) operation.

Data output from the DSP engine is written to one of the target accumulator, that defined by the DSP instruction being executed, the X bus for MAC, MSC, CLR and MOVSAC accumulator writes, where the EA is derived from W13 only. (MPY, MPY.N, ED and EDAC do not offer an accumulator write option), and the X bus for all MCU instructions which use the barrel shifter [15].

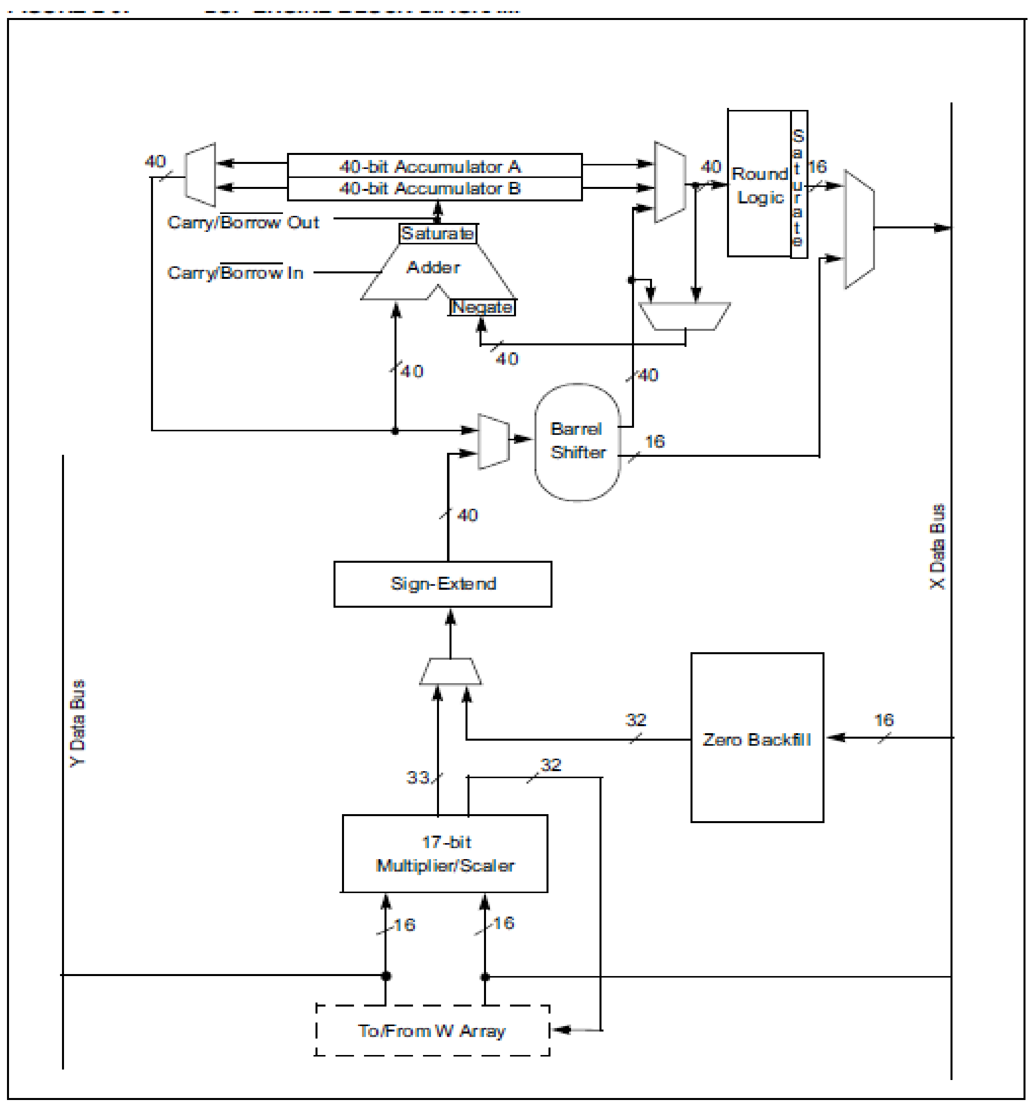

Figure 12 DSP Engine Block Diagram

2.7.2.9 Interrupts

The dsPIC30F has a vector interrupt scheme and each interrupt s ource has its own vector and can be assigned as one of seven priority levels. The interrupt entry and return latencies are fixed and it provides deterministic timing for real time application.

The Central Processing Unit (CPU) will read the Interrupt Vector Table (IVT) and transferring the address to the program counter. The address contains in the interrupt vector where the interrupt vector is to transferred from the program data bus into the program counter, via a 24-bit wide multiplexer on the input of the program counter. The Interrupt Vector Table (IVT) and Alternate Interrupt Vector Table (AIVT) are placed near the beginning of program memory (0x000004) [15]. Figure 13 shows the IVT AND AIVT.

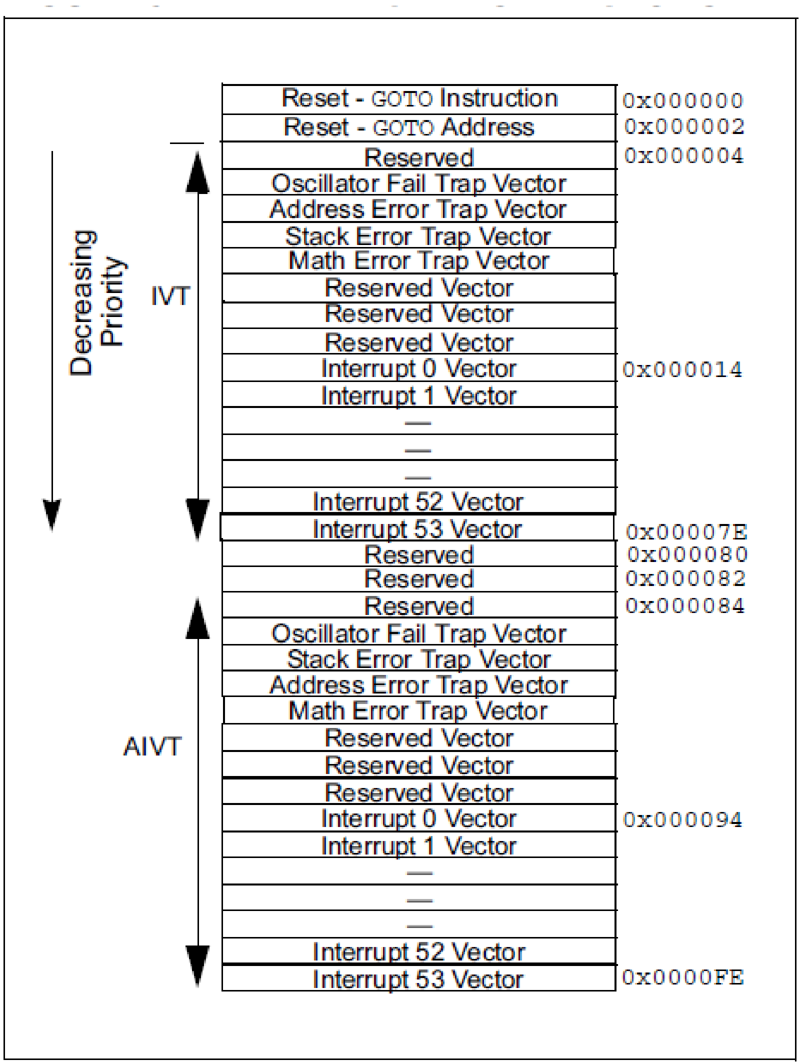

Figure 13 Exception Vectors

2.7.2.10 System and Power Management

The dsPIC consists many system and power management features like oscillator modes, clock switching and oscillator failure detection. For power saving modes the dsPIC is able to selectively shut down and wake up parts of the processor and peripherals and also with other safety features, it gives low voltage detection, brown -out reset, watchdog timer reset and several error traps.

2.7.2.11 Peripherals

The dsPIC are available with wide range of peripheral to suits a diverse assortment of applications. Table 2 shows the main peripherals and the function of each peripheral [15].

Table 2 Main peripherals and the function of each peripheral

FEATURES	FUNCTION
I / O Ports	• A connection pin to the outside world which can be configured as input or output. I/O is needed in most cases to allow the microcontroller to communicate, control or read information.
Timers	• A 16-bit timer which can serve as the time counter for the real -time clock, or operate as a free running interval timer/counter. • May increment on the instruction clock or by an external source. • Applying a pre-scalar may slow increment. • When timer1 overflows from 65535 to 0, an interrupt can be generated. • In capture mode, the timer1 count may be saved in another register when a pin changes. An interrupt may also be generated. • In compare mode, a pin can be changed when the count reaches a preset value, and an interrupt may also be generated. • This timer is used as part of the PWM.
Input Capture	• The feature is useful in applications requiring Frequency (Period) and Pulse measurement • The key operational features of the Input Capture module are:

	o Simple Capture Event mode o Timer2 and Timer3 mode selection o Interrupt on input capture event
Output Compare / PWM	• The features is useful in applications requiring operational modes such as: o Generation of Variable Width Output Pulses o Power Factor Correction • The key operational features of the Output Compare module include: o Timer2 and Timer3 Selection mode o Simple Output Compare Match mode o Dual Output Compare Match mode o Simple PWM mode o Output Compare during Sleep and Idle modes o Interrupt on Output Compare/PWM Event
Motor Control PWM	• This module generating multiple, synchronized Pulse Width Modulated (PWM) outputs. • Power and motion control applications are supported by the PWM module: o Three Phase AC Induction Motor o Switched Reluctance (SR) Motor o Brushless DC (BLDC) Motor o Uninterruptible Power Supply (UPS) • The PWM module has the following features: o 8 PWM I/O pins with 4 duty cycle generators o Up to 16-bit resolution o 'On-the-Fly' PWM frequency changes o Edge and Center Aligned Output modes o Single Pulse Generation mode o Interrupt support for asymmetrical updates in Center Aligned mode o Output override control for Electrically o Commutative Motor (ECM) operation o 'Special Event' comparator for scheduling other o peripheral events o FAULT pins to optionally drive each of the PWM output pins to a defined state • This module contains 4 duty cycle generators, numbered 1 through 4. • The module has 8 PWM output pins, numbered PWM1H/PWM1L through PWM4H/PWM4L. • The eight I/O pins are grouped into high/low numbered pairs, denoted

	by the suffix H or L, respectively. • For complementary loads, the low PWM pins are always the complement of the corresponding high I/O pin. • There are two versions of the PWM module depending on the particular dsPIC30F device selected: an 8-output PWM module and a 6-output PWM module.
Quadrature Encoder Interface (QEI)	• The QEI module provides the interface to incremental encoders for obtaining motor positioning data. Incremental encoders are very useful in motor control applications. • Features: o Phase A, Phase B and Index Pulse input o 16-bit up/down position counter o Count direction status o Position Measurement (x2 and x4) mode o Programmable digital noise filters on inputs o Alternate 16-bit Timer/Counter mode o Interrupt on position counter rollover/underflow
10-bit or 12-bit ADC	• The10-bit high-speed analog-to-digital converter (A/D) allows conversion of an analog input signal to a 10-bit digital number. • The A/D module has up to 16 analog inputs which are multiplexed into four samples and hold amplifiers. The output of the sample and hold is the input into the converter, which generates the result. • The A/D converter has a unique feature of being able to operate while the device is in Sleep mode. • The A/D module has six 16-bit registers: o A/D Control Register1 (ADCON1) o A/D Control Register2 (ADCON2) o A/D Control Register3 (ADCON3) o A/D Input Select Register (ADCHS) o A/D Port Configuration Register (ADPCFG) o A/D Input Scan Selection Register (ADCSSL) • The ADCON1, ADCON2 and ADCON3 registers control the operation of the A/D module. The ADCHS register selects the input channels to be converted. The ADPCFG register configures the port pins as analog inputs or as digital I/O. The ADCSSL register selects inputs for scanning.
Universal Asynchronous	• The key features of the UART module are: o Full-duplex, 8 or 9-bit data communication o Even, Odd or No Parity options (for 8-bit data)

Receiver Transmitter (UART)	o One or two Stop bits o Fully integrated Baud Rate Generator with 16 -bit prescaler o Baud rates range from 38 bps to 1.875 Mbps at a o 30 MHz instruction rate o 4-word deep transmit data buffer o 4-word deep receive data buffer Parity, Framing and Buffer Overrun error detection o Support for Interrupt only on Address Detect o (9th bit = 1) o Separate Transmit and Receive Interrupts o Loopback mode for diagnostic support • The UART module is enabled by setting the UARTEN bit in the UxMODE register (where x = 1 or 2). Once enabled, the UxTX and UxRX pins are configured as an output and an in put respectively, overriding the TRIS and LATCH register bit settings for the corresponding I/O port pins. The UxTX pin is at logic ‘1’ when no transmission is taking place.
The Serial Peripheral Interface (SPI)	• It is useful for communicating with other p eripheral devices such as EEPROMs, shift registers, display drivers and A/D converters, or other microcontrollers. It is compatible with Motorola's SPI and SIOP interfaces.
The Inter-Integrated Circuit (I^2C)	• Provides complete hardware support for both Slave and Multi-Master modes of the I2C serial communication standard, with a 16 -bit interface. • This module offers the following key features: o I2C interface supporting both Master and Slave operation. o I2C Slave mode supports 7 and 10 -bit address. o I2C Master mode supports 7 and 10-bit address. o I2C port allows bi-directional transfers between master and slaves. o Serial clock synchronization for I2C port can be used as a handshake mechanism to suspend and resume serial transfer (SCLREL control). o I2C supports Multi-Master operation; detects • I2C module can operate either as a slave or a master on an I2C bus.
Data Converter (CODEC) Interface	• A system having a serial interface for a codec containing multiple converters employs a local memory and a DMA (direct memory access) unit for transferring data to and from the codec. To distinguish data associated with each converter, a separate DMA channel is assigned to each converter. Data is transmitted

	in frames having fields associated with different DMA channels to avoid confusion regarding the source or destination of data.
Controller Area Network (CAN)	• It is a serial interface, useful for communicating with other CAN modules or microcontroller devices. This interface/ protocol were designed to allow communications within noisy environments. • The module features are as follows: o Implementation of the CAN protocol CAN 1.2, CAN 2.0A and CAN 2.0B o Standard and extended data frames o 0-8 bytes data length o Programmable bit rate up to 1 Mbit/sec o Support for remote frames o Double buffered receiver with two prioritized received message storage buffers (each buffer may contain up to 8 bytes of data) o 6 full (standard/extended identifier) acceptance filters, 2 associated with the high priority receive buffer, and 4 associated with the low priority receive buffer o 2 full acceptance filter masks, one each associated with the high and low priority receives buffers o Three transmit buffers with application specified prioritization and abort capability (each buffer may contain up to 8 bytes of data) o Programmable wake-up functionality with integrated low pass filter o Programmable Loopback mode supports self-test operation o Signaling via interrupt capabilities for all CAN receiver and transmitter error states o Programmable clock source o Programmable link to Input Capture #2 (IC2) module for time-stamping and network synchronization o Low power Sleep and Idle mode • The CAN bus module consists of a protocol engine, and message buffering/control. • The CAN protocol engine handles all functions for receiving and transmitting messages on the CAN bus. Messages are transmitted by first loading the appropriate data registers. • Status and errors can be checked by reading the appropriate registers. Any message detected on the CAN bus is checked for errors and then matched against filters to see if it should be received and stored in one of the receive registers.

2.7.3 Application

2.7.3.1 Motor Control

The dsPIC can control Brushless DC, AC Induction and Switch Reluctance motors. The ideal dsPIC for motor control is that the dsPIC needs more than a basic 8-bit microcontroller. The dsPIC can handle noise reduction and energy efficiency and the applications require sensorless control, torque management, variable speed, position, and servo control [5].

CHAPTER 3

METHODOLOGY

3.1 Procedure Identification

3.1.1 Project Flow

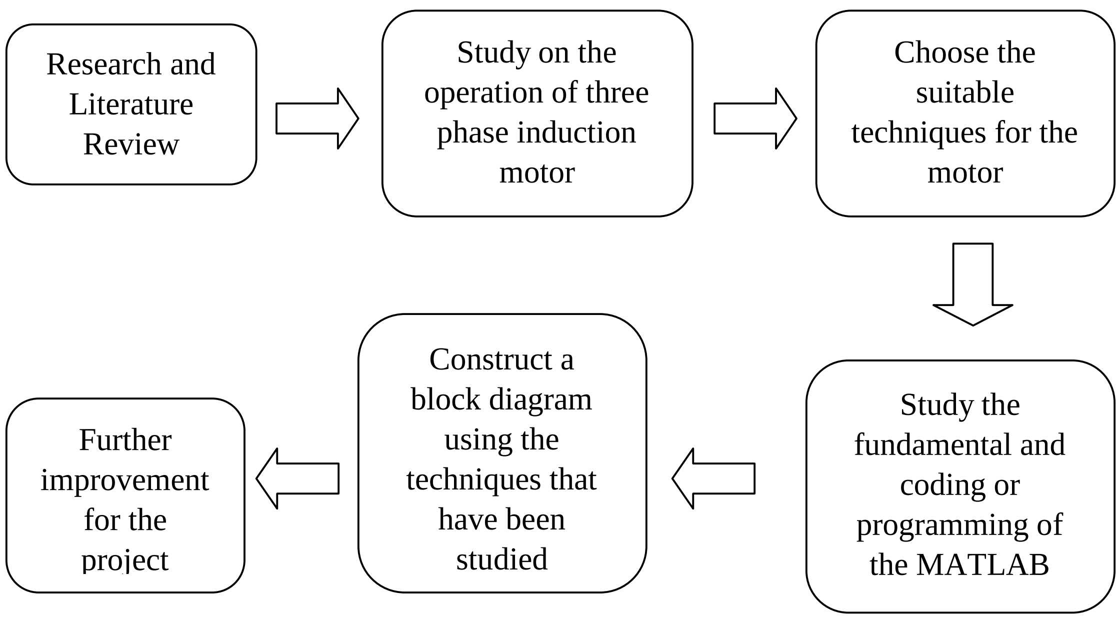

Figure 14 Project Flow Chart

- **Phase 1:** Research and literature review

  Theories and concepts relevant to the project's field of study are looked into and analyzed.

- **Phase 2:** Study on the operation of three phase induction motor

  The properties and operating mechanism of a three-phase induction motor is explored.

- **Phase 3:** Choose the suitable techniques for the motor

  Several techniques are compared to find which control technique is more suitable to develop for the motor control

- **Phase 4:** Study the fundamentals of coding and programming of MATLAB

  The basics and relevant commands of MATLAB is learnt and mastered.

- **Phase 5:** Construct block diagrams using MATLAB

  To studied the operation using the techniques that have been studied

- **Phase 6:** Further improvement for the project

  Amendments and re-attempts are made in order to improve the results from the project execution.

3.2 Data Gathering and Analysis

3.2.1 Control Techniques

Most of the motors in variable-speed drives are AC induction motors. There are various types of speed control techniques implemented to the induction motors. Speed control techniques can be classified in three categories:

- Scalar control – Volts per Hertz Control
- Vector control – Field Oriented Control
- Direct Torque Control (DTC)

3.2.1.1 Volts per Hertz Control Theory

For scalar control, the technique is to vary the voltage and frequency to vary the speed of the motor. One of the techniques is the constant Volts per Hertz (V/f). It is the most common control that is used in adjustable speed drives of induction motor. The basic function of V/f is to act as variable frequency generator in order to vary the speed of the motor drives [2]. If the input frequency of the motor is changed, the synchronous speed of the motor also changes. The changes of the frequency affect the torque profile curve where the curve depends on the voltage and frequency that are applied to the stator. The torque developed by the induction motor is directly proportional to the ratio of the voltage and frequency. By keeping the ratio constant, the torque developed can be kept constant throughout the speed range and the air gap flux at its rated value.

$$Stator\ Voltage(V) \propto [Stator\ Flux\,(\emptyset)] \times [Angular\ Velocity\,(\omega)] \quad \text{...............} (4.1)$$

$$V \propto \emptyset \times 2\pi f \quad \text{..........................} (4.2)$$

$$\emptyset \propto V/f \quad \text{..........................} (4.3)$$

3.2.1.2 Field Oriented Control

The purpose of FOC is to manage the interrelationship of the fluxes and to squeeze out the most performance from the motor. For FOC there are several blocks that will be used to control the performance of the induction motor. Here Clar ke-Park transformation is used where three-phase current vectors are converted to a two -dimensional stationary rotating reference frame (d-q). The d component represents the flux produced by the stator current and the q component represents the torque. Fig ure 12 shows the basic scheme of torque control with FOC [15].

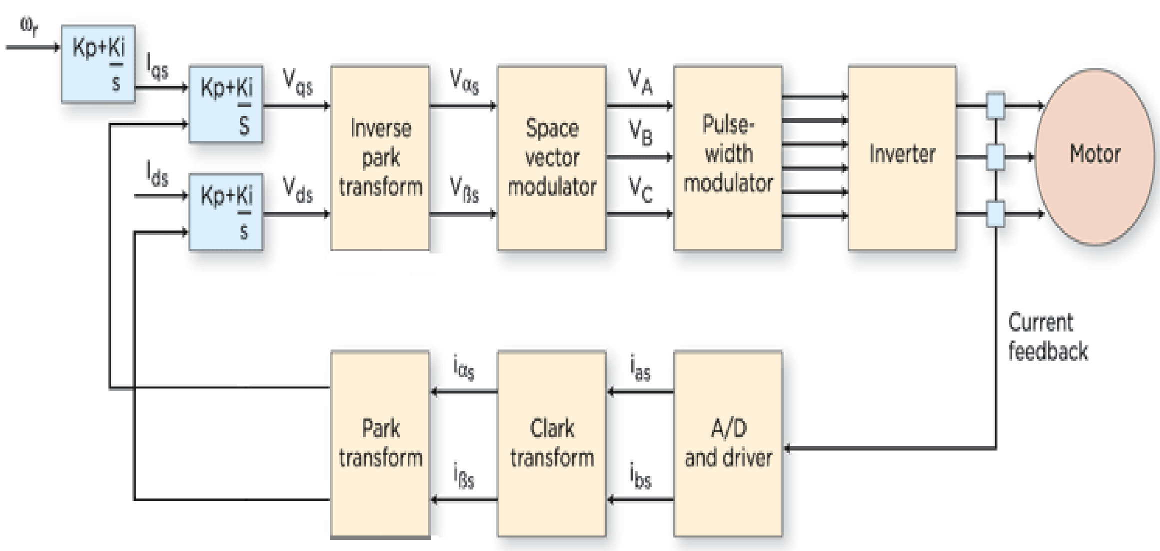

Figure 15 Field Oriented Control Scheme

To implement the basic principle of FOC it is important to control the stator currents that produce the stator flux. The Clarke and Park transforms are used to perform a two-step transformation on the stator currents. The first steps is to transform a three -phase to a two phase where the Clarke transform is used to convert the three -axis coordinates into two-axis orthogonal coordinates (i_a and i_b). From the Clarke transform, i_a and i_b are designated to $i_{s\alpha}$ and $i_{s\beta}$. These two components are fed to Park transform where Park transform will convert the fixed coordinates into two -axis rotating coordinates (i_{sd} and i_{sq}).

The i_{sd} and i_{sq} components are compared to the flux reference (i_{sdref}) and torque reference (i_{sqref}). At this point, the control structure can be used to control either synchronous or induction machines by changing the value of flux reference and obtaining rotor flux position. For induction motor, the value of flux reference should not be set at zero because the motor need a rotor flux creation in order to operate [10]. A speed regulator block also known as PI regulator produce a torque command to run the motor at a given speed set point. This speed regulator acts on the set point and the measu red speed to produce the torque command. If the motor works below the set speed, the PI regulator commands a larger torque to increase the speed and vice -versa. Here the torque command is i_{sqref}.

The ouput of the current regulators (V_{sdref} and V_{sqref}) will feed to the inverse Park transform. This block is used to convert the controller's reference voltage back onto the stationary α and β axes ($V_{s\alpha ref}$ and $V_{s\beta ref}$) so that the output can be directly fed to SVPWM. The SVPWM block calculates the switching duty ratios for the PWM unit to generate voltage vector and will give pulses to three -phase inverter to run the motor [10].

3.2.1.3 Direct Torque Control

The DTC switches on the inverter according to the load needs. It can calculate torque without the complex equation of algorithms or mechanical speed sensors. The main model in DTC is its adaptive motor model. The model is base d on mathematical expression of basic motor theory [1]. It calculates actual flux and torque of the motor by getting the motor parameters like stator resistance, mutual inductance and saturation coefficiency. The model can get the information without rotating the motor but by rotating the motor helps in the tuning of the model [1].

3.3 Tools and Equipment

3.3.1 Tools

Tools required for this project is MATLAB /SIMULINK. MATLAB is required to execute the simulations for the analysis performed in the design of three -phase induction motor. MATLAB software is used throughout the whole code development process like writing, compiling, debugging, and programming

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Result and Discussion

4.1.1 Results

4.1.1.1 Field Oriented Control

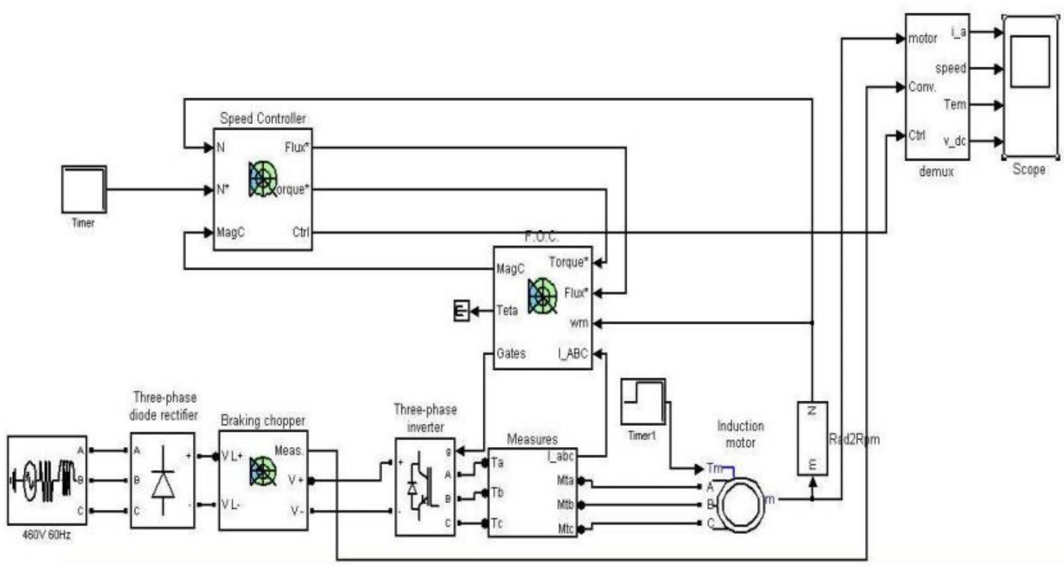

Figure 16 Three Phase Induction Motor with Field Oriented Control

The model blocks or configuration blocks were taken from MATLAB demo. The operating of this block diagram starts with 460 V ac supply with frequency 60 Hz into three phase diode bridge rectifier. AC supply need to be converted first to DC voltage supply being supplied to the inverter, by using the three-phase diode bridge rectifier. DC voltage is used to generate a variable voltage and variable frequency power supply and a breaking chopper is used to absorb the energy produced by motor deceleration. Three-phase inverter will convert back the dc voltage to ac voltage. The frequency is not changed at in ac voltage controller so that the output voltage has the same frequency as the supply voltage.

During simulation, the motor will send the motor speed to speed controller to compare the value of it speed with speed reference. Author has set constant value of the speed references, with time where when t = 0 s the speed will be 500 rpm and at t = 1 s the speed will be 0 rpm. Figure 8 shows the result of rotor speed. Field Oriented Control (FOC) will receive the values of flux and motor torque. FOC block diagram is used to control both frequency and magnitude of the output voltages and it will supply gate pulses into three phase inverter. FOC is also able to control the magnitude of output current of source inverter. The result in Figure 17 shows the motor stator current, rotor speed, electromagnetic torque and DC bus voltage respectively.

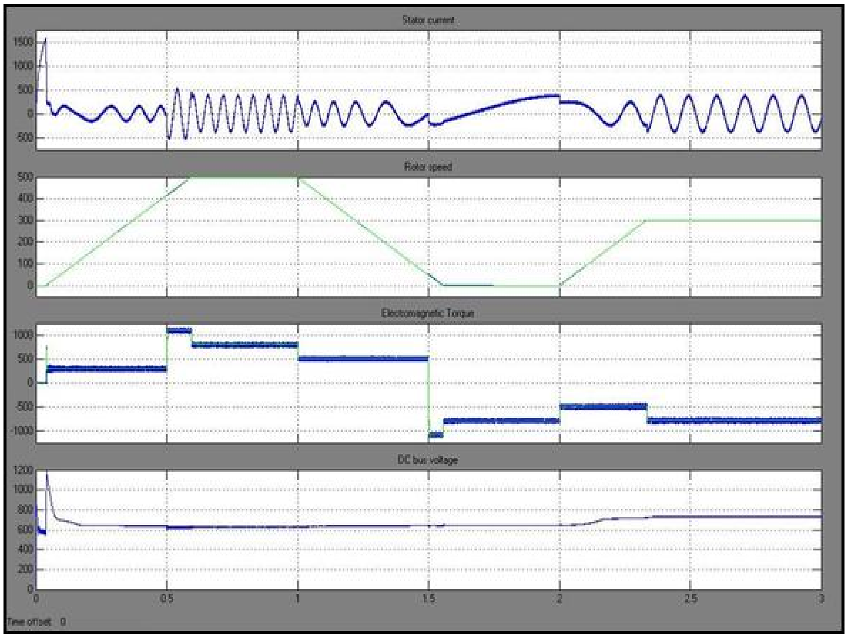

Figure 17 Result of Three Phase Induction Motor with Field Oriented Control

4.1.1.2 Space Vector Modulation Generator

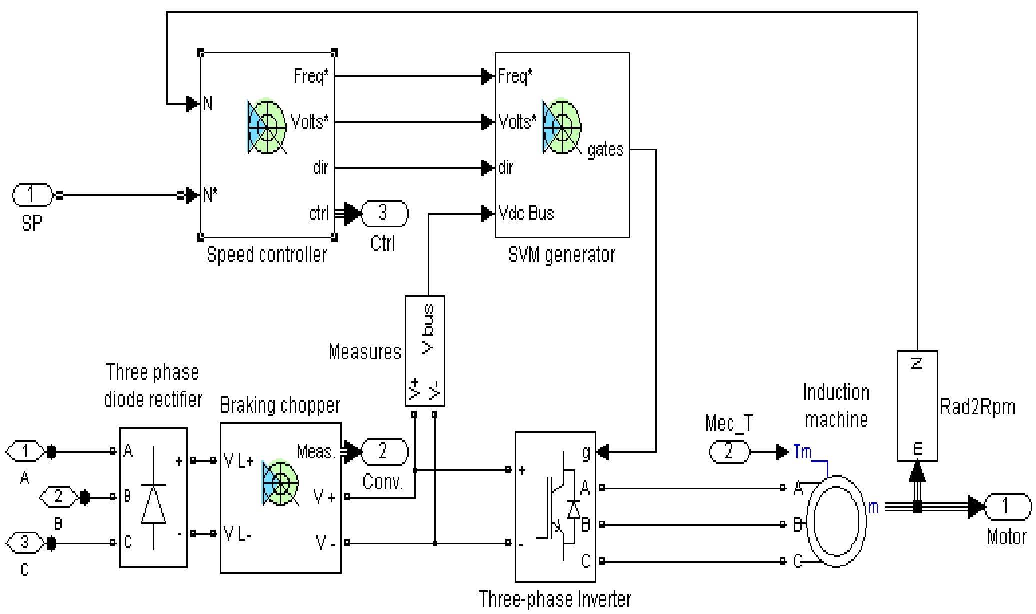

Figure 18 Space Vector PWM VSI Induction Motor Drive

Figure 18 is the block diagram of space vector PWM VSI induction motor drive. This circuit is constructed from existing blocks in the Simulink library or the MATLAB demo. The motor drive starts with 220 V ac power supply and input frequency 60 Hz. The ac supply is converted into dc by three-phase diode rectifier. The DC voltage is used to generate a variable voltage and variable frequency power supply, and the breaking chopper is used to absorb the energy produced by motor deceleration.

The block diagram starts with the speed regulator (PI regulator). Where the speed regulator at block SP produces a slip compensation and feed to the rotor speed in order to derive the commanded stator voltage frequency. In this block diagram, V/f is also applied to the motor. During simulation, the speed of the block diagram is set at 1000 rpm at time t = 0 s, the speed follows precisely the acceleration ramp. Then at tim e t = 1 s, the speed set point is changed to 1500 rpm and the electromagnetic torque reaches again a high value so that the speed ramps precisely at 1800 rpm/s up to 1500 rpm under full load and at time t = 1.5 s, the mechanical load passed from 11 N.m to -11 N.m, which causes the electromagnetic torque to stabilize at approximately at -11 N.m shortly after. Figure 19 shows the result of the motor stator current, the rotor speed, the electromagnetic torque and the DC bus voltage on the scope. The speed set point and the torque set point are also shown.

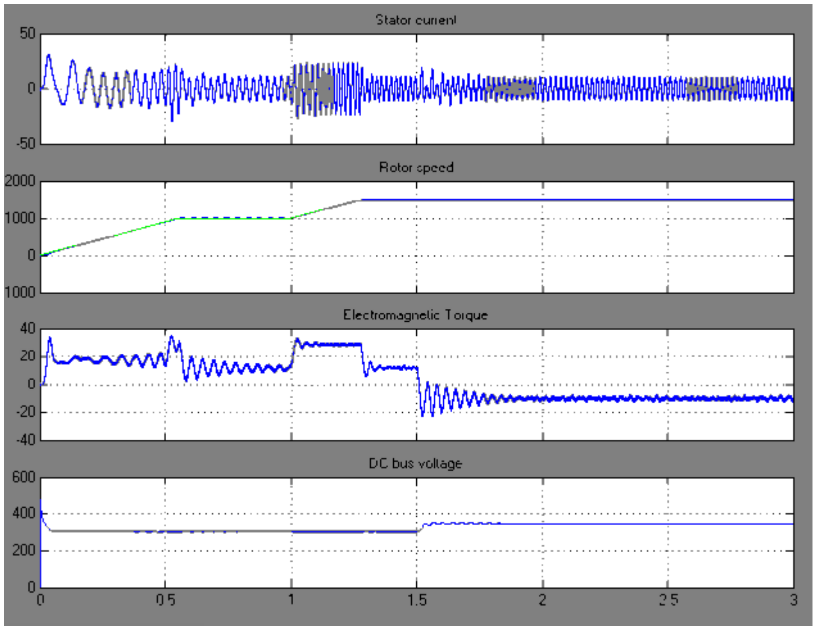

Figure 19 Result of Space Vector PWM VSI Induction Motor Drive

4.1.2 Discussion

Vector control principles are based on the control of both the magnitude and the phase of each phase current and voltage. Here vector contro l is represented to control the capability performance of motor drive and achieving higher power conversion efficiency. Most of the motor operations are in variable speed drives. This is because variable speed drives help to save energy and optimize system . There are various induction motor control techniques in practice today and the popular control techniques are the V/f and FOC.

The principle of Field Oriented Control is to control the stator currents represented by a vector. The control is based on pr ojections where three-phase current vectors are converted to a two-dimensional stationary rotating reference frame (d -q). To control the motor drive, FOC need two constant s as input references which are the torque component (aligned with the q co-ordinate) and the flux component (aligned with d co-ordinate). The strategy of this control is to manage the interrelationship of the fluxes where FOC allows torque and flux to be decoupled and controlled independently. This makes the control is accurate in every working operation (steady state and transient) and is independent of the limited bandwidth of the mathematical model.

For Space Vector Modulation (SVM), the technique is similar to the concept of FOC. Transformation from three-phase to two-phase is required. The purpose of SVM is to generate the respective output signals based on the given input. A technique which exploits space vectors to synthesize the command or reference voltage within a sampling period by selecting the two adjacent voltage vectors and zero voltage vectors. The switching frequency of the VSI utilizing SVM is constant, depending on the sampling period .

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The project has been completed in parallel with the objectives and time line established in the project. All the studies of the performance, the characteristics and the techniques of the induction motor were conducted and understood.

For variable speed techniques, it is proven that field oriented control is the best technique to drive the induction motor. The principle of FOC is easy to understand and develop using MATLAB.

Rapid development of DSP helps to save energy, less cost and maintain the good performance of induction motor. DSP helps to reduce the complexity of the operation of induction motor where now only writing a code is needed to run the motor. The hardware-software interaction between the motor and dsPIC controller is more challenging.

5.2 Recommendations

5.2.1 MATLAB

Study of dynamic performance and tuning the controller design are taking so much time in doing research and better understanding of the performance. Better understanding in using MATLAB is essential because it helps the author to able to understand more, using the equations with MATLAB coding. Getting the code and assemble the coding could possibly be challenge to the author. A comparison between Simulink result and actual measured result is needed to give effectiveness of modeling for future motor control algorithms.

5.2.2 dsPIC Controller

DsPIC controller is the newest advanced processor. It gives better performance and low power losses during the operation of the motors. The dsPIC is supported widely by a wide variety of development tools centered in the industry. Great knowledge in using MATLAB coding is highly recommended as dsPIC required C language.

REFERENCES

[1] AN887, "AC Induction Motor Fundamentals" (DS00887) , downloaded from http://ww1.microchip.com/downloads/en/AppNotes/00887 a.pdf

[2] AN984, "An Introduction to AC Induction Motor Control Using the dsPIC30F MCU" (DS00984), downloaded from http://ww1.microchip.com/downloads/en/AppNotes/00984a.pdf

[3] TI Document BPRA043 – "Digital Processing Solution for AC Induction Motor", downloaded from: http://www.ti.com

[4] Michael Filippich "Digital Control of a Three Phase Induction Motor" degree thesis, October 2002

[5] Microchip, "Getting Started with the dsPIC Digital Signal Controller", downloaded from: http://www.microchip.com/stellent/idcplg?Idcservice=SS_GET_PAGE&node ID=2126

[6] AN889, "VF Control of Three Phase Induction Motors Using PIC16F7X7 Microcontroller", (DS00889A) downloaded from: http://ww1.microchip.com/downloads/en/AppNotes/00889a.pdf

[7] Ned Mohan, Tore M. Undeland, William P. Robbins, Third Edition, " Power Electronics: Converters, Applications, and Design ", John Wiley & Sons Inc

[8] AN843, "Speed Control of 3-Phase Induction Motor Using PIC18 Microcontrollers" (DS00843), downloaded from http://ww1.microchip.com/downloads/en/AppNotes/00843.pdf

[9] Industrial Control DesignLine – "Field Oriented Control Reduces Motor Size, Cost and Power Consumption in Industrial Applications", down loaded from: http://www.industrialcontroldesignline.com

[10] TI Document BPRA073 – "Field Oriented Control of 3-Phase AC-Motors", downloaded from: http://www.ti.com

[11] Bingsen Wang, Jimmie J. Cathey, Third Edition, "DSP-controlled Space-Vector PWM, Current Source Converter for STATCOM Application", Electric Power Systems Research, 5 March 2003

[12] A. Maamoun, A. M. Soliman, A. M. Kheireldin, "Space-Vector PWM Inverter Feeding a Small Induction Motor, Electric Power Systems Research", Electronics Research Institute El-Tahrir Street, Dokki, Cairo EGYPT

[13] Freescale Semiconductor Digital Signal Controller Operation, "Digital signal controller applications", downloaded from: http://www.dsp-fpga.com//pdfs/Freescale.Oct05.pdf?__utma=1.2068465804.1259676670.1259676670.1259676670.1&__utmb=1.4.10.1259676670&__utmc=1&__utmx=-&__utmz=1.1259676670.1.1.utmcsr=google|utmccn=(organic)|utmcmd=organic|utmctr=%20digital%20signal%20controller&__utmv=1.DSP&__utmk=232712223

[14] Microchip, “dsPIC® Digital Signal Controllers; The Best of Both Worlds”, downloaded from: http://ww1.microchip.com/downloads/en/DeviceDoc/DS-70095K.pdf

[15] Microchip, “dsPIC30F Data Sheet Motor Control and Power Conversion Family High Performance Digital Signal Controllers” (DS70082G), Microchip Technology Inc, 2004

[16] Ing. Pavel GAJDŮŠEK, “PROGRAMABLE LABORATORY INVERTOR AND SPACE VECTOR PWM”, Dept. of Electrical Power Engineering, FEEC, VUT

APPENDICES

Appendix A: Gantt Chart