INSULATED-GATE BIPOLAR TRANSISTOR (IGBT) INVERTER WITH VECTOR MODULATION

NORHAZILINA BINTI BAHARI

MAY 2007

"I/We hereby declare that I have read this project report and in my/opinion this project report is sufficient in term of scope and quality for the award of Degree of Electrical Engineering (Power Electronic and Drive)"

Signature : ....

Name of Supervisor : PM. DR ZULKIFLIE BIN IBRAHIM

Date : ......07/05/2007.......................

INSULATED-GATE BIPOLAR TRANSISTOR (IGBT) INVERTER WITH SPACE VECTOR MODULATION

NORHAZILINA BINTI BAHARI

This Project Report Is Submitted In Partial Fulfillment of the
Degree of Bachelor in Electrical Engineering (Power Electronic and Drive)

Faculty of Electrical Engineering
Universiti Teknikal Malaysia Melaka

May 2007

"I hereby declare that this project report is the result of my own work and all sources of reference have been clearly acknowledged."

Signature :.................................

Name : NORHAZILINA BINTI BAHARI

Date : 7/05/07

To my beloved father, mother and family and friends.

ACKNOWLEDGEMENTS

First of all, I want to thank Allah S.W.T. the almighty God because of HIS blessings that I can complete this project and make this project successful. Without His blessing I'm not be here right now and would not be able to complete my project.

I would like to take this opportunity to express my deepest gratitude to my supervisor, Prof Madya Dr Zulkiflie Bin Ibrahim for PSM II and not forget Mr.Auzani Bin Jidin supervisor PSM I for his engagement, support, and encouraging attitude, coursed and editorial advice in preparation during this project. I also express my thanks to my panels PM.Md Noah Bin Jamal and Mr.Azzidin Bin Mohammad Razali for their feedback on comment during my presentation.

Not forgetting my dedication to my members of academic and technical staff that continuously support and guiding me directly or indirectly to complete this project in time. Their sharing of experiences helped me to overcome all the obstacles encountered in this project.

Last but not least, to my parents, family and friends for their support, prays and helps all the way during this project been implemented. I am really appreciated and grateful of what they have done. It was their kindness that given me opportunity to successfully undergo my degree's project.

Thank you all.

ABSTRACT

Space vector modulation (SVM) is one of the best choice techniques of modulation to drive 3-phase load such as 3-phase induction motor. In this project, the pulse width modulation strategy with vector modulation is analyzed in detail. The power circuit of a three-phase inverter consists of six-Insulated Gate Bipolar Transistor is used for turn on and off at fast repetition rates and this switching device are selected based on good performances and characteristic. The inverter demanded two inputs which are desired frequency and voltage. The modulation strategy uses switching time calculator to calculate the timing of voltage vector applied to the three-phase balanced-load. Another modulation technique investigated in the research is Sinusoidal Pulse Width Modulation (Sine PWM). The comparative studies of various modulation techniques were based on modeling and simulation approach using Simulink MATLAB Toolbox.

ABSTRAK

Pemodulatan Ruang Vektor adalah salah satu teknik pemodulatan yang terbaik bagi memicu beban tiga-fasa contohnya motor aruhan tiga-fasa. Di dalam project ini, strategi pemodulatan lebar denyut dengan pemodulatan vektor akan di analisis dengan lebih terperinci. Litar kuasa bagi penyonsang tiga-fasa mengandungi enam transistor dwikutub get tertebat yang digunakan untuk kitar hidup dan kitar mati pada kadar pengulangan yang pantas dan pemilihan peranti pensuisan ini adalah berdasarkan ciri-ciri dan perlaksanaan yang bagus. Penyonsang memerlukan dua masukan iaitu nilai frekuensi dan voltan yang di ingini. Strategi pemodulatan menggunakan kalkulator masa pensuisan untuk menghitung masa bagi mengaplikasikan vector voltan kepada beban terimbang tiga-fasa. Teknik lain yang akan digunakan bagi penyelidikan ini adalah Pemodulatan Lebar Denyut Gelombang Sinus. Perbandingan bagi kedua-dua strategi ini dari segi rekabentuk dan simulasi akan dilaksanakan dengan menggunakan program Simulink MATLAB.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

θ	Space Vector angle
AC	Alternating Current
DC	Direct Current
ia,ib,ic	Three- Phase Current
ICs	Integrated Circuit
ids	p-axis Stator Current
IGBT	Insulate Gate Bipolar Transistor
iqs	q-axis Stator Current
PWM	Pulse Width Modulation
SPWM	Sinusoidal Pulse Width Modulation
Te	Develop Torque
THD	Total Harmonic Distortion
Van,Vbn,Vcn	Three-Phase Line to Neutral Voltage
Vds	d-axis Stator Voltage
Vqs	q-axis Stator Voltage
VSI	Voltage Source Inverter

CHAPTER 1

INTRODUCTION

The purpose of this chapter is to review the background of Pulse Width Modulation (PWM) algorithm which is involved in this case study. This chapter also describes the objectives, scope of project and research methodology.

1.1 Background

Due to the growing of fast processor, many researches today show great interest to develop new technique or to improve PWM control algorithm to obtain better performances particularly in AC drives applications.

The conventional PWM method known as sinusoidal pulse-width modulation (SPWM) is commonly used in voltage source inverter (VSI) application. This technique applies simple control strategy by comparing the three-phase modulated signals (known as reference signal) with carrier signal [1].

Traditionally this technique is widely used in variable speed drive of induction machine especially for scalar control where the stator voltage and frequency can be controlled with minimum online computational requirement. Another advantage is easy to implement even with simple analogue ICs circuits. However, this algorithm has certain drawbacks which affect the overall system efficiency and performance as follows:

1) The sine PWM algorithm is unable to fully utilize the available DC bus supply voltage to the VSI,
2) This technique gives more total harmonic distortion (THD),
3) This algorithm does not smooth the progress of future development of vector control implementation of ac drive.

These drawbacks lead to development of other sophisticated advanced switching algorithms, like Space Vector Modulation (SVM) and the SVM utilized space vector theory and there is consensus in many facts that this technique is the best alternative for the modulation of three-phase switching power converters [2],[3]. This algorithm gives 15% more voltage output compare to the Sinusoidal PWM algorithm, thereby increasing the DC bus utilization. Furthermore, it minimizes the total harmonic distortion (THD) as well as loss due to minimize number of commutations in the inverter.

1.2 Scope and Outline

Modern technique for controlling switching power converters is an interesting and challenging research topic. As mentioned above, the improved signal performances and stability of power electronic system has always been a main concern. The scope of this project is to model, simulate and analyze the pulse width modulation strategy with vector modulation. The modulation strategy switching time calculation technique to calculate and estimate the timing voltage vector applied to the three-phase balanced load. The simulation results of SVM are compared with Sinusoidal PWM for improved signal performance of PWM waveform.

The main objectives of the research in this project are to investigate, conduct analysis, develop and design a vector controlled Induction Motor drive based on VSI. The overall performance of the motor drive is evaluated based on the simulation results obtained from Sinusoidal PWM vector controlled Induction Motor drive.

1.3 Project Methodology

The flow charts in Figure 1.1 shows the steps of progress to achieve the project objectives.

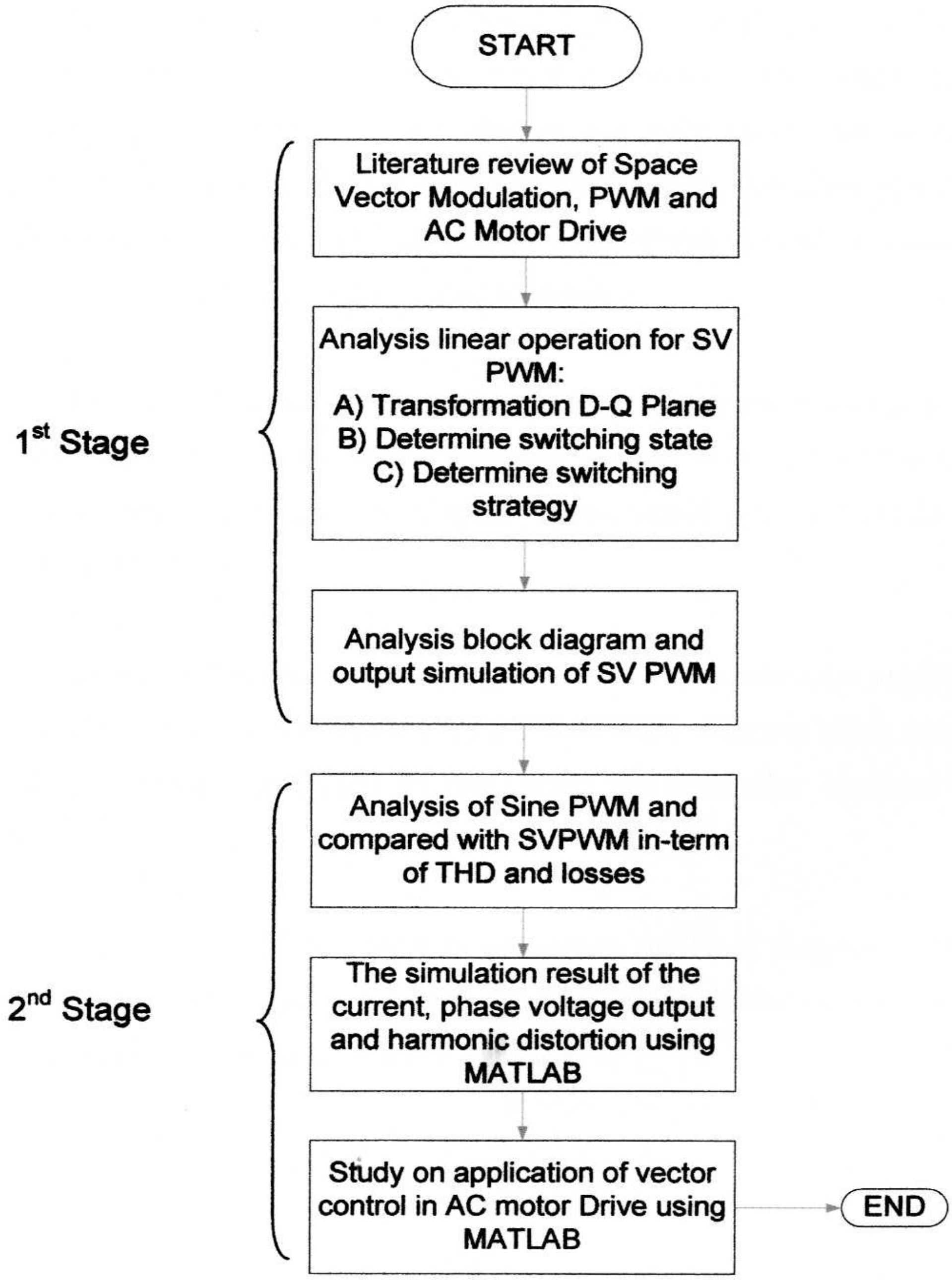

Figure 1.1 Flow Chart of Project

1.4 Project Organization

The rest of the project's chapters are organized are as follows:

Chapter 2 reviews the basic theory of Space Vector modulation along with the model of SV PWM and mathematical equations involved. This chapter also explains the manipulation of space vector in three-phase wye connection also and the vector modulation strategy. In this chapter, the space vector control method is implemented using three-phase Simulink Toolbox and the switching signals are fed to the voltage source inverter. Functionally of the circuits including Insulated-Gate Bipolar Transistor (IGBT's) is described in details.

Chapter 3 discusses the performances criteria in terms of current waveforms and harmonic losses in the power converter and the load. These criteria provide means of comparing the qualities of space vector controlling method for the different operating conditions.

Chapter 4 describes the designing of space vector modulation model perform the simulation and result of phase voltages, line-to-line voltages, phase currents and hexagonal voltages and 2-plane of load current that have been captured by using MATLAB.

Chapter 5 briefly described the simulation and block diagram of Sinusoidal PWM fed VSI with 3-phase R-L load. The simulation results for both modulation techniques are evaluate, analyzed and compared.

Chapter 6 describes the applications of vector control in AC motor drive. This chapter also interpreted simulation of vector control in AC motor drive and investigation results in-terms of torque and speed control and harmonic distortion on 3-phase currents.

Chapter 7 gives the conclusions and suggestions of the future works to the project.

CHAPTER 2

SPACE VECTOR MODULATION (SVM) THEORY

Chapter 2 reviews the basic of Space Vector theory along with the model of SV PWM and equations involved. This chapter also explains the manipulation of space vector in three-phase wye connection. Besides, it also explains on the vector modulation switching state and the strategy of space vector switching time.

2.1 Definition of Space Vector

The three-phase line-to-neutral sine waves required for driving 3-phase load can be represented as 120^0 phase-shifted vectors (v_{an}, v_{bn} and v_{cn}) in space as shown in Figure 2.1.

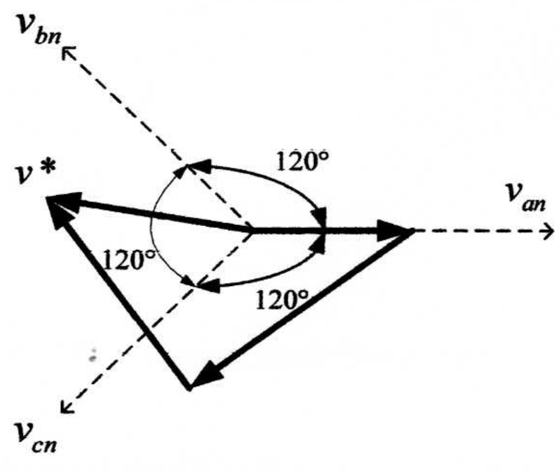

Figure 2.1 Three-Phase Voltage Vectors and the Resultant Space Reference Vector

For a balanced load, 3-phase connected system, these vectors sum to zero. At any time instant the three-phase load voltages can be expressed by a single space reference vector, $\boldsymbol{v}^*$ as shown in Figure 2.1. In space vector modulation strategy, the motor frequency and the motor voltage can be controlled by controlling the amplitude and the frequency of $\boldsymbol{v}^*$. This PWM control strategy of the inverter can be applied to the various modulation technique of ac motor drive such as scalar control, Field Oriented Control (FOC) and Direct Torque Control (DTC) [2, 3, 4, 5].

2.2.1 Manipulation of Space Vectors

In this section the manipulation of space vector is discussed. To understand the basic principle of space vector manipulation concept, the three-phase stator currents of a induction motor are used as a example shown in Figure 2.2.

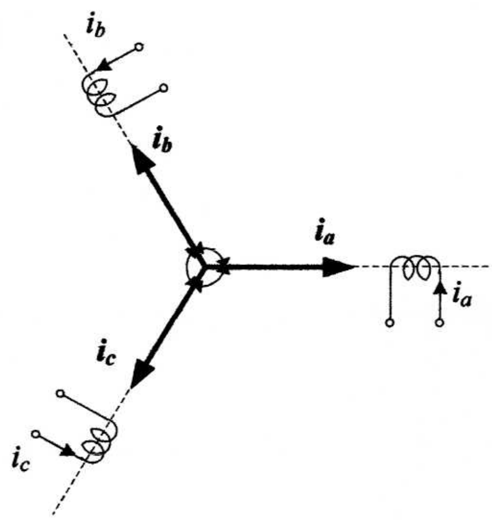

Figure 2.2 The Vector of Three-Phase Stator Currents

The induction motor is assumed to be configured as wye connection and i_a, i_b and i_c are the phase stator currents. Each coil of the stator windings produces a sinusoidally distributed mmf. These phase stator currents vector can be added vectorially and gives equation 2.1,

$$i_s = \frac{2}{3}\left(i_a + i_b + i_c\right) \tag{2.1}$$

where, i_s is an instantaneous quantity and it is not a phasor quantity. i_s can be written as a complex number,

$$i_s = i_s e^{j\theta} \tag{2.2}$$

and in steady state i_s is expressed as

$$i_s = i_s e^{j\omega t} \tag{2.3}$$

By applying Euler theorem the three-phase stator phase currents are expressed as

$$\begin{aligned} i_a &= i_a e^{j0^0} = i_a \\ i_b &= i_b e^{j120^0} = a i_b \\ i_c &= i_c e^{j240^0} = a^2 i_c \end{aligned} \tag{2.4}$$

By substituting equation (2.4) into equation (2.1), the following equation is obtained

$$i_s = \frac{2}{3}\left(i_a + a i_b + a^2 i_c\right) \tag{2.5}$$

To determine the resultant vector or space reference vector of the three-phase voltages and currents, it is important to transform the three-phase vectors to *d-q* axis. This process is popularly known as *Park Transformation* [7]. Basic principles of the rotating (D-Q) transformation and space vector modulation are discussed in details in Appendix A. Transient and steady-state operation of AC motor drove performance is investigated based on dynamic and steady-state motor model.

The rectangular coordinate in Figure 2.3(a) shows how the complex vectors can be transformed into real and imaginary components.

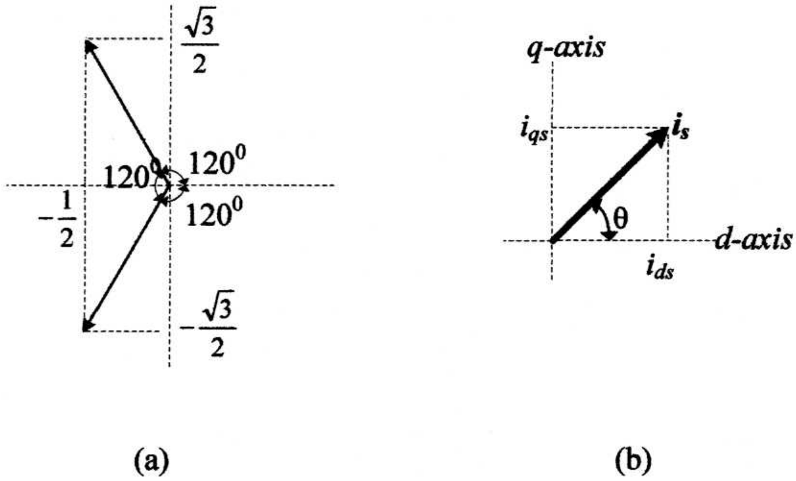

Figure 2.3 (a) The Complex Vectors in Rectangular Coordinates
(b) Space Reference Vector in Two-Axis Coordinates

From equation (2.4), by applying the Euler Theorem, the real and imaginary components can be presented

$$a = e^{j120^0} = -\frac{1}{2} + j\frac{\sqrt{3}}{2} \quad \text{and}$$

$$a^2 = e^{240^0} = -\frac{1}{2} - j\frac{\sqrt{3}}{2} \tag{2.6}$$

Separate into real and imaginary terms and hence the expressions for the two axis currents in terms of the three-phase currents can be determined as

$$i_s = \left(\frac{2}{3}i_a - \frac{1}{3}i_b - \frac{1}{3}i_c\right) + j\frac{1}{\sqrt{3}}\left(i_b - i_c\right) = i_{ds} + ji_{qs} \tag{2.7}$$

Therefore, the space reference vector can be derived using Phytogoras Theorem as depicted in Figure 2.3(b)[6].