DEVELOPMENT OF SPACE VECTOR MODULATOR FOR 3-PHASE VOLTAGE SOURCE INVERTER (VSI)

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Bachelor of Power Electronics and Drive

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SUPERVISOR DECLARATION

"I hereby declare that I have read through this report entitle "**Development of Space Vector Modulator for 3-Phase Voltage Source Inverter (VSI)"** and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Power Electronic and Drives)"

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Date	: 19 June 2013

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A report submitted in partial fulfillment of the requirements for the degree Of Power Electronic and Drives

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

JUNE 2013

DECLARATION

I declare that this report entitle **"Development of Space Vector Modulator for 3-Phase Voltage Source Inverter (VSI)"** is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	:...
Name	: MOHD HANAFI BIN MD RASUL
Date	: 19 June 2013

DEDICATION

Specially dedicated to my beloved family especially my mother Pn. Zabidah bt. Mohamad and my father En. Md Rasul bin Yasin.

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Thanks to Allah S.W.T for give me an enthusiasm and strength for completing this PSM smoothly.

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ABSTRACT

This thesis presents the development of Space Vector Pulse Width Modulation for 3-phase Voltage Source Inverter in electrical drive applications. The rapid developments of power electronic device and microprocessor have led to improvement the modulation technique to increase the power output and efficiency of the inverters. In many industrial applications the conventional modulation technique such as Sinusoidal Pulse Width Modulation (SPWM) suffers a problem with limited output voltage capability. In this project it proves that the Space Vector Modulation (SVM) technique is the best solution to increase the inverter's output voltage capability and suitable for digital implementation. Moreover, it showed that the Space Vector modulation technique can provide less harmonic distortion of the output current, and increase the efficiency due to optimal switching strategy. The theory of SVM was validated by simulation using Matlab/Simulink and the implementation is achieved by using optimized IQ-Math block in Embedded IDE in Matlab 2011a. It can be shown, the sampling time period can be minimized to 50μs, and the switching frequency can be increased up to 2 kHz. The feasibility and effectiveness of SVM implementation using ezDSP F28335 to provide less switching losses, less harmonic distortion and better dc bus utilization were verified through simulation and experimental results.

ABSTRAK

Tesis ini membentangkan pembangunan Permodulatan Ruang Vektor (SVM) untuk sistem 3 fasa penyongsang sumber voltan (VSI) digunakan dalam aplikasi pemacu elektik. Peningkatan dalam bidang alat elektronik kuasa dan mikropemprosesan telah membawa kepada perkembangan teknik permodulatan untuk meningkatkan kuasa keluaran dan kecekapan penyongsang sumber voltan (VSI). Dalam banyak aplikasi perindustrian teknik permodulatan konvensional seperti Permodulatan Denyut Lebar Sinus (SPWM) mengalami masalah dengan keupayaan voltan keluaran yang terhad. Dalam projek ini ia membuktikan bahawa Permodulatan Ruang Vektor (SVM) adalah penyelesaian terbaik untuk meningkatkan keupayaan voltan keluaran penyongsang sumber voltan (VSI) dan sesuai untuk perlaksanaan digital. Tambahan lagi, ia menunjukkan bahawa Permodulatan Ruang Vector (SVM) boleh memberikan pengurangan gangguan harmonik pada keluaran arus dan meningkatkan kecekapan kerana strategi penukaran yang optimum. Teori Permodulatan Ruang Vektor (SVM) telah disahkan melalui simulasi menggunakan Matlab/Simulink dan pelaksanaan dicapai dengan menggunakan modul yang telah dioptimiskan blok IQ-Math dalam Embedded IDE dalam Matlab 2011a. Ini boleh ditunjukkan tempoh masa persampelan boleh diminimumkan kepada 50µs dan frekuensi pensuisan boleh ditingkatkan sehingga 2 kHz. Keberkesanan dan kebolehan bagi melaksanakan SVM menggunakan ezDSP F28335 memberikan pengurangan kehilangan pensuisan, kurang herotan harmonic arus dan bagus kegunaan dc bus disahkan melalui simulasi dan keputusan ujikaji.

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LIST OF ABBREVIATION

PWM	-	Pulse Width Modulation
SVM	-	Space Vector Modulation
SVPWM	-	Space Vector Pulse Width Modulation
EZdsp	-	Digital Signal Processor from Texas Instrument
IGBT	-	Insulated Gate Bipolar Transistor
FPGA	-	Field Programmable Gate Array
MOSFET	-	Metal-oxide Semiconductor Field Effect Transistor
2D	-	Two Dimension
DSP	-	Digital Signal Processor
I/O	-	Input and Output
Hz	-	Frequency unit in Hertz
THD	-	Total Harmonic Distortion
SPWM	-	Sinusoidal Pulse Width Modulation
DC	-	Direct Current
AC	-	Alternating Current
VHDL	-	Very High Description Language
VSI	-	Voltage Source Inverter
V_{dc}		Voltage DC Source
°		Degree
Aβ		Alfa and beta refer to stationary frame
V_{an}		Voltage phase A to neutral
I_a		Current phase A
μs		Micro Second
Ω		Unit for resistance (OHM)
H		Unit for inductance (Henry)

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CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter will discuss the background of the project, project statement, objectives and scope of the project.

1.2 Project Background

In general, inverter is the one of the power electronic device that converts DC voltage into AC voltage. Many type of application that required the use of inverter in other to regarding AC waveform such as uninterruptable power supply (UPS), variable-frequency ac drives, high power ac traction and high voltage direct current (HVDC) power transmission. Basically inverters have a two type of topology which is voltage source inverter (VSI) and current source inverter (CSI). For voltage source inverter the controlled ac output is a voltage waveform where it popular for variable frequency ac drives in industrial application and current source inverter (CSI) independently controlled ac output is a current waveform for high quality voltage waveform application.

At high frequency application three-phase inverter is use in other to provide three-phase voltage source where the amplitude, phase and frequency can be controlled. To realize the VSI, modulation technique is required in other to control the switching power transistor. There have several types of modulation technique that widely use for three-phase VSI which is Sinusoidal PWM and Hysteresis (Bang-bang) PWM .These modulation technique have several aims which is less Total Harmonic Distortion (THD), less switching losses, and thus commutation losses, wider linear modulation range and achieving the chance of controlling the frequency and magnitude of the output voltage.

Among of this modulation technique there have a best advance pulse width modulation (PWM) method which is space-vector pulse width modulation (SVPWM). SVM provides better dc bus utilization, reduce switching losses, less total harmonic distortion and easy to implement [1-4]. SVM is very suitable for digital implementation compare to sinusoidal pulse width modulation (SPWM), because it provide higher dc bus utilization that will result a better total harmonic distortion (THD) [4]. In recent years SVM is widely use in power electronic application for variable-frequency ac drives due to its better performance characteristic.

1.3 Problem Statement.

The conventional Sinusoidal Pulse Width Modulation (SPWM) technique used to drive 3-phase inverter has some major drawbacks which is it requires 3 references signals as input of modulator to generate gate pulses for driving power switches in 3-phase inverter. The need of 3 references signals results in inflexibility control for advanced electrical drive which is complicated to implement in digital processors. Besides that SPWM cannot fully utilize the available DC link voltage to produce higher output voltages. Note that, the higher output voltage is required to improve power output and dynamic performance.

1.4 Objective

The two main objective of this project as listed below:

i. To develop a simulation model of 3-phase voltage source inverter based on space vector modulation technique.
ii. To prove the performance of SVPWM that can produce higher output voltage, less harmonic distortion and a constant switching frequency.
iii. To verify the SVM algorithm and its improvement via experimental results.

1.5 Project Scope.

The scopes of the project are firstly to study the SPWM and SVM theory for driving 3-phase voltage source inverter, next to model the simulation of SVM using MATLAB/Simulink, third to analyze the performance of inverter based on SVM technique, in terms of switching frequency, output voltage, total harmonic distortions and efficiency and lastly to implement prototype inverter based on SVM using Ezdsp F28335 and FPGA.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will discuss about the review of journal or technical paper that related to the project. This chapter also covers the space vector modulation theory and mathematical modeling algorithm of the space vector briefly explained. Subsequently, the basic principles of space vector modulation are specified.

2.2 Introduction to Space Vector Modulation.

In recent years, advance in power electronic in voltage source inverter (VSI) for electrical drive application has led increase and gained popularity since it can offer higher efficiency and improvement output power [1,4,5]. Besides that faster growth in technology impact on manufacturing of power solid state switch device that provide excellent characteristics and performances. Mostly there are two solid states switches that popular use in practical inverter application such as metal-oxide-semiconductor field effect transistors (MOSFET) and insulated gate bipolar transistors (IGBT). This two solid state switches have excellent characteristic to operate at high switching frequency for low, medium and high power application with lower conduction losses [6].

The performance characteristic of the inverter depends on the modulation technique that employed into three-phase voltage source inverter (VSI) [5]. In last few decades most of inverter drives employed the traditional sinusoidal PWM for industrial application because it’s well established theory and implementation [6]. However, this technique is not flexible to be adapted for advanced variable voltage and frequency drive and limited output voltage capability [6- 7].

Recently, many of technical papers reported that space vector modulation (SVM) technique provide great advantages which is it increase the output voltage capability of the sinusoidal PWM scheme without distorting the line-to-line output voltage waveform [6]. Besides that SVM technique offers superior performance over another technique in term of lower THD, switching losses, torque ripple, better dc link utilization and simply implemented in digital system [5]. Besides that, voltage utilization by using SVPWM is $2/\sqrt{3}$ times of SPWM.

In general space vector theory employs the rotating space vector form of a balance three phase voltage as reference signal [5]. There are eight possible combination of on and off state of three phase power transistor available in an inverter output are used to approximate the reference vector and waveform for all three phase can be achieve simultaneously [1,6]. Basically, the principle of SVM technique based on the application of averaged switching states per sampling period (T_s) with respect to the given reference voltage ($\boldsymbol{v}^*$). For convinience, the switching of inverter states per sampling period for a given reference voltage, e.g. $\boldsymbol{v}^*=(\boldsymbol{v_z}.t_z+\boldsymbol{v_1}.t_1+\boldsymbol{v_2}.t_2)/T_s$,where $\boldsymbol{v_z}=\boldsymbol{v_0}$ or $\boldsymbol{v_7}$ can be illustrated as shown in Figure 1.

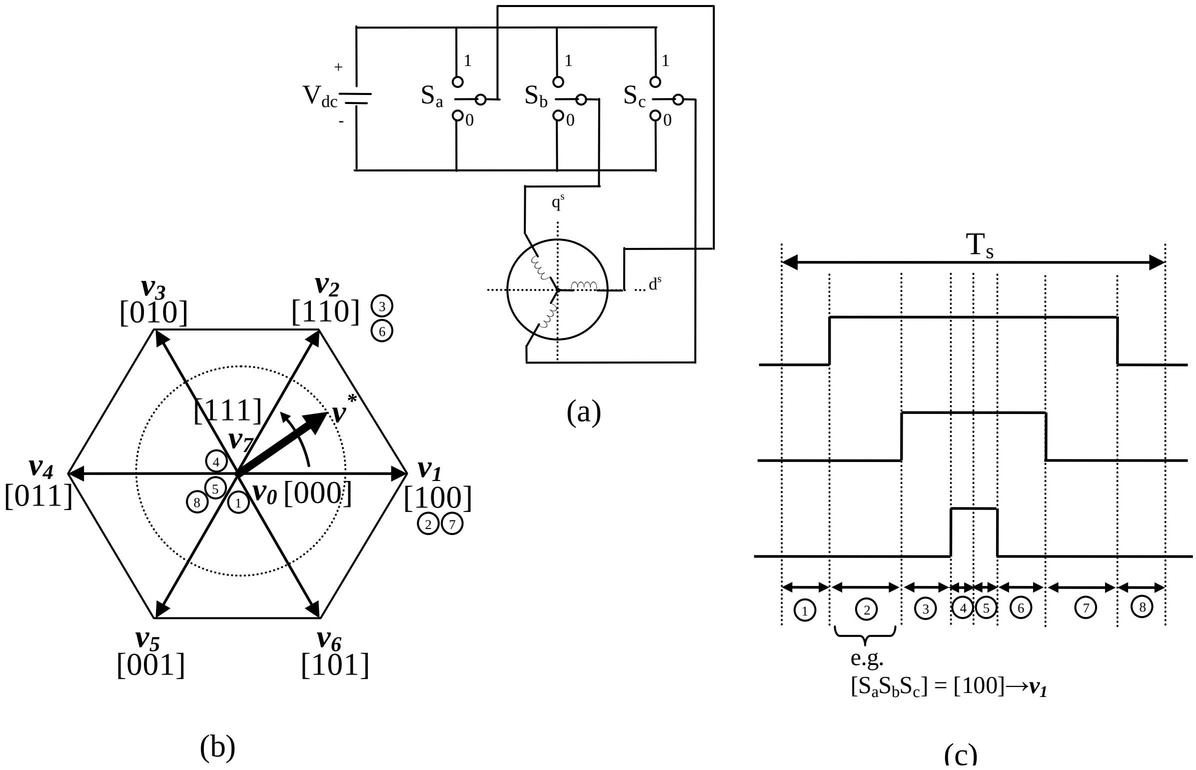

Figure 2.1: Principle of SVM. (a) simplified circuit of 3-phase VSI (b) eight possible switching configuration in VSI (c) timing diagram of switching states generation for one-sampling cycle.

A symmetrical space vector modulation algorithm will be use in this project because it shows advantage of lower THD without increasing the switching losses [2]. This project is to develop a prototype space vector modulator for three phase voltage source inverter (VSI) by using low-cost Digital Signal Processor (DSP) controller board i.e. eZdsp F28335. In other to prevent short circuit between upper and lower gate of the transistor, blanking time is develop by using field programmable gate array (FPGA).

2.3 Principle of SVPWM

The Space Vector Pulse Width Modulation (SVPWM) refers to a special switching sequence of the upper three power device of three-phase voltage source inverter (VSI). This special switching scheme for the power devices results in 3 pseudo-sinusoidal currents in the stator phases. It has been shown that SVPWM generates less harmonic distortion in the output voltages or currents in the windings of the motor load and provides more efficient use of DC supply voltage in comparison to direct sinusoidal modulation technique [1]. Basically SVPWM treats the three-phase sinusoidal voltage as a constant amplitude vector rotating at constant frequency, ω conveniently analyzed in terms of complex space vectors (or phasor) is given in the equation (2.1). This amplitude vector is represent in the (α, β) frame where it denotes the real and imaginary axis by using Clarke transform equation. For the three phases power inverter configurations shown in Figure 2 there are eight possible combinations of on and off states of the upper power transistor that the result is approximates the reference voltage, V_{ref}.

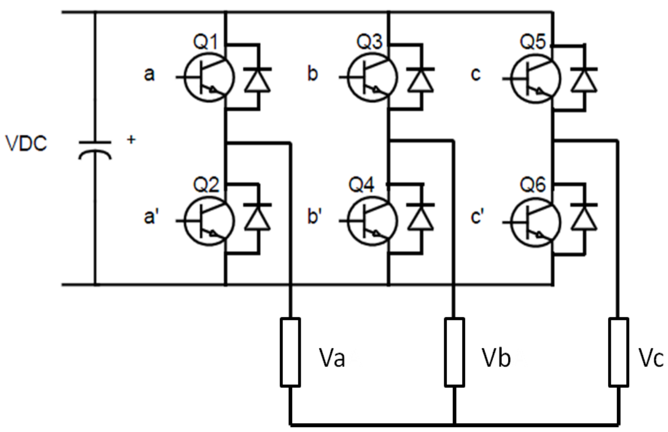

Figure 2.2: Power Bridge for the three-phase VSI

From Figure 2.1 there are six power transistor that shape the output voltage which is upper transistor is (Q1, Q3, Q5) and lower transistor (Q4, Q6, Q2). When the upper switch is turn on i.e. when a, b and c are 1, the corresponding lower transistor is turn off, i.e. a', b' and c' is 0[1]. This employs eight possible combinations of on and off switching patterns for the three upper transistors (Q1, Q3, and Q5) that resulting instantaneous output line-to-line and phase voltages, for a dc bus voltageV_{DC}, by using the equation (2.2) and (2.3) are shown in Table 2.1

Table 2.1: Switching on/off patterns and resulting instantaneous voltages of a 3-phase Power Inverter.

a	b	c	V_{AN}	V_{BN}	V_{CN}	V_{AB}	V_{BC}	V_{CA}
0	0	0	0	0	0	0	0	0
1	0	0	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}/3$	V_{DC}	0	$-V_{DC}$
0	1	0	$-V_{DC}/3$	$2V_{DC}/3$	$-V_{DC}/3$	$-V_{DC}$	V_{DC}	0
1	1	0	$V_{DC}/3$	$V_{DC}/3$	$-2V_{DC}/3$	0	V_{DC}	$-V_{DC}$
0	0	1	$-V_{DC}/3$	$-V_{DC}/3$	$2V_{DC}/3$	0	$-V_{DC}$	V_{DC}
1	0	1	$V_{DC}/3$	$-2V_{DC}/3$	$V_{DC}/3$	V_{DC}	$-V_{DC}$	0
0	1	1	$-2V_{DC}/3$	$V_{DC}/3$	$V_{DC}/3$	$-V_{DC}$	0	V_{DC}
1	1	1	0	0	0	0	0	0

Reference voltage vector, U_{out} in complex form:

$$U_{out} = \frac{2}{3}[V_a + aV_b + a^2V_c] \tag{2.1}$$

Where :

$$a = e^{j\frac{2}{3}}$$

$$V_a = V_m \sin(\omega t)$$

$$V_b = V_m \sin(\omega t - 120°)$$

$$V_c = V_m \sin(\omega t + 120°)$$