

**IMPLEMENTATION OF SPACE VECTOR MODULATION FOR THREE
PHASE INVERTER UTILIZING FIELD-PROGRAMMING GATE ARRAY**

HALIMAHANI BINTI ROSLI

**BACHELOR OF ELECTRICAL ENGINEERING
(GENERAL)
UNIVERSITY TECHNICAL MALAYSIA MELAKA**

“ I hereby declare that I have read through this report entitle “*Implementation Of Space Vector Modulation For Three Phase Inverter Utilizing Field-Programming Gate Array*” and found that it complies the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering”

Signature :

Supervisor's Name : DR. Auzani Bin Jidin

Date :

**IMPLEMENTATION OF SPACE VECTOR MODULATION FOR THREE
PHASE INVERTER UTILIZING FIELD-PROGRAMMING GATE ARRAY**

HALIMAHANI BINTI ROSLI

**A report submitted in partial fulfilment of the requirements for the degree of Bachelor of
Electrical Engineering**

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2018

I declare that this report entitle “*Implementation Of Space Vector Modulation For Three Phase Inverter Utilizing Field-Programming Gate Array*” 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 : HALIMAHANI BINTI ROSLI

Date :

Special dedication to my parent Murdiati binti Darwis and Rosli bin Saat which give me a lot of love and support to complete my final year project 1. As well as my sibling, Hamidahsyahri, Yahamzah and Yabahalif which give me strength and happiness.

ACKNOWLEDGEMENT

Gratitude to Allah SWT, with His willing that give me this strength and motivation to complete my final year project at University Technical Malaysia Melaka. I would like to take this opportunity to express my gratitude to my supervisor, Dr. Auzani bin Jidin for his constant guidance, advised and encouragement throughout the completion of this report.

I also would like to extend my appreciation and thanks to my friends who have helped share their knowledge and time with me in the completion of this project. As well as my panel supervisor, Dr. Kasrul for his time and effort to evaluate my report.

In addition, to my family for their moral support through the entire progress of this report. Last but not least, I would like to thank each and every one who has helped me directly or indirectly in completing and preparing for this report until realization.

ABSTRACT

Industries that used ac drives are growing rapidly to become more advanced because of high performances drive technology. In industry different there are different type of motor and variable speed. As for that, the three-phase inverters will give a variable voltage and variable frequency supply to the machines. As for that, using Space Vector Modulation (SVM) with Field-Programmable Gate Array (FPGA) can increase the performance of the three-phase inverter. The problem occurs within the SPWM technique and the existing SVM works. The SPWM techniques are difficult to control three-phase quantities such as amplitudes, frequencies and phase angle of three-phase voltage and depending to the torque and flux demands in vector control. This method also has a constrain for output voltage such as it cannot fully utilize the DC link voltage. Next, the problem with the existing SVM works because it totally implement the complex calculation of SVM algorithm and vector control in DSP which can increase the computational burden and hence reduce AC drive performance as the sampling time increase. The main objectives to be achieved in this task is to design and implement a space vector modulator utilizing Field-Programmable Gate Array (FPGA) which produce appropriate switching states, according to the inputs of d- and q- axis of space vector for measuring the output voltage and Fast Fourier Transform (FFT) Analysis. This modulator is suitable to be employed for any type of AC motor controls. Second objective is to verify the effectiveness of the design of SVM modulator through simulation and experiment. The scope of the project is to study various PWM and SVM techniques, especially for AC motor drives. Next, to develop simulation models of SVM using MATLAB or SIMULINK. Besides, implement SVM modulator using FPGA. As well as, performing the simulation and the experiment results to verify the effectiveness of SVM. The simulating and experimental designing the Space Vector Pulse Width Modulation (SVPWM) technique for three phase Voltage Source Inverter (VSI) using MATLAB/Simulink software for simulation as well as to develop the experimental result using FPGA. SVM can operated in high voltage and high frequency. The results that produce by SVM is high quality because it can managed to read in nanosecond.

ABSTRAK

Industri yang menggunakan pemacu ac berkembang pesat untuk menjadi lebih maju kerana prestasi yang tinggi memacu teknologi. Oleh itu, inverter tiga fasa akan memberikan pemboleh ubah voltan dan pemboleh ubah frekuensi kepada mesin. Untuk itu, menggunakan Modulasi Vektor Ruang (SVM) dengan Field-Programmable Gate Array (FPGA) boleh meningkatkan prestasi inverter tiga fasa. Masalah yang berlaku dalam teknik SPWM dan kerja-kerja SVM sedia ada. Teknik SPWM sukar untuk mengawal kuantiti tiga fasa seperti amplitud, frekuensi dan sudut fasa voltan tiga fasa dan bergantung kepada tork dan permintaan fluks dalam kawalan vektor. Kaedah ini juga mempunyai kekangan untuk voltan keluaran seperti tidak dapat menggunakan sepenuhnya voltan pautan DC. Seterusnya, masalah dengan SVM yang sedia ada berfungsi kerana ia benar-benar melaksanakan pengiraan kompleks algoritma dan kawalan vektor SVM di DSP yang boleh meningkatkan beban pengiraan dan dengan itu mengurangkan prestasi pemacu AC apabila peningkatan masa pensampelan. Objektif utama yang akan dicapai dalam tugas ini adalah untuk mereka bentuk dan melaksanakan modulator vektor ruang yang menggunakan litar Field-Programmable Gate Array (FPGA) yang menghasilkan litar bersesuaian sesuai dengan input d dan q - paksi vektor ruang untuk mengukur voltan keluaran dan Analisis Fast Fourier Transform (FFT). Modulator ini sesuai digunakan untuk sebarang jenis kawalan motor AC. Objektif kedua adalah untuk mengesahkan keberkesanan reka bentuk modulator SVM melalui simulasi dan eksperimen. Skop projek ini adalah untuk mengkaji pelbagai teknik PWM dan SVM, terutamanya untuk pemacu motor AC. Seterusnya, untuk membangunkan model simulasi SVM menggunakan MATLAB atau SIMULINK. Selain itu, melaksanakan modulator SVM menggunakan litar FPGA. Serta, melaksanakan simulasi dan hasil percubaan untuk mengesahkan keberkesanan SVM. Simulasi dan eksperimen merancang teknik Modulasi Lebar Pulse Vector Space (SVPWM) untuk tiga fasa Voltage Source Inverter (VSI) menggunakan perisian MATLAB / Simulink untuk simulasi serta untuk membangunkan hasil eksperimen menggunakan FPGA. SVM boleh dikendalikan dalam voltan tinggi dan frekuensi tinggi. Hasil yang dihasilkan oleh SVM adalah berkualiti tinggi kerana ia dapat dibaca dalam nanosecond.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	ACKNOWLEDGEMENT	v
	ABSTRACT	vi
	TABLE OF CONTENTS	viii
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF ABBREVIATIONS	viii
	LIST OF APPENDICES	viii
1	INTRODUCTION	1
	1.1 Research Background	1
	1.2 Motivation	1
	1.3 Problem Statement	2
	1.4 Objectives	2
	1.5 Scopes of project	2
	1.6 Report Outline	3
2	LITERATURE REVIEW	4
	2.1 Introduction	4
	2.2 Inverter	4
	2.3 Pulse Width Modulation (PWM)	6
	2.4 Digital Signal processor and Field-Programmable Gate Array	9
	2.5 Review of previous related work	9

3	METHODOLOGY	10
3.1	Introduction	10
3.2	Three-phase inverter	10
3.3	Space phase defination	12
3.4	Mapping of voltage vector	15
3.5	Space vector modulation technique	16
	3.5.1 Calculation of on-duration	17
	3.5.2 Sequences of selection for voltage vectors	21
3.6	Flow chart	23
3.7	Simulation Model of Space Vector Modulation	24
3.8	Detail of the hardware setup	26
	3.8.1 Inverter hardware	28
	3.8.2 Field-Programmable Gate Array	29
3.9	Software	29
	3.9.1 Quartus II (Altera)	30
	3.9.2 MATLAB	33
	3.9.3 Microsoft Excel	34
4	RESULT AND DISCUSSION	35
4.1	Introduction	35
4.2	Result analysis between SPWM and SVM	35
4.3	Result of Switching states	38
4.4	Performance Analysis of AC output voltage at different switching frequency using SVPWM	41
	4.4.1 Triangular carrier frequency, f_{tri} for 1000Hz	42
	4.4.2 Triangular carrier frequency, f_{tri} for 2550Hz	48

5	CONCLUSION AND RECOMMENDATIONS	54
	5.1 Introduction	54
	5.2 Conclusions	54
	5.3 Recommendations	55
	REFERENCES	56
	APPENDICES	57

LIST OF TABLES

TABLE	TITLE	PAGE
3.1	Switching vectors according to voltage vectors	15
3.2	Hardware component description	28
4.1	Comparison result between simulation and hardware based on the formula	41
4.2	Result simulation and hardware of FFT Analysis for 1000Hz	42
4.3	Result simulation and hardware of FFT Analysis for 2550Hz	48

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Adjustable Speed Drives (ASD)	5
2.2	Uninterruptible Power Supply (UPS)	5
2.3	Illustration of High Voltage Direct Current (HVDC)	5
2.4	PWM control circuit	6
2.5	Basic diagram SVM	8
3.1	Topology circuit for three-phase VSI	11
3.2	Simplified circuit of three-phase VSI	11
3.3	Space phasor diagram based on d- and q-axis	13
3.4	Simulation for space phasor	14
3.5	Result transformation of three phase to two phase quantities	14
3.6	Mapping of voltage vectors	16
3.7	General representation for every sector	19
3.8 (a)	Case 1 is \bar{v} closed to \bar{v}_a ,	20
3.8 (b)	Case 2 is \bar{v} at the middle \bar{v}_a and \bar{v}_b	20
3.8 (c)	Case 3 is \bar{v} closed to \bar{v}_b	20
3.9	\bar{v} is located within sector I	21
3.10 (a)	Switching status for sector I	22
3.10 (b)	Switching status for sector II	22

3.10 (c)	Switching status for sector III	22
3.10 (d)	Switching status for sector IV	22
3.10 (e)	Switching status for sector V	22
3.10 (f)	Switching status for sector VI	22
3.11	Flow chart	23
3.12	Complete simulation model for space vector modulation	24
3.13	Simulation model of duty ratio calculation at subsystem 3	25
3.14	Simulation model of switching states at subsystem 4	25
3.15	Simulation model of inverter circuit for two level inverter	26
3.16	Experimental setup	27
3.17	Hardware setup	27
3.18	Inverter with the gate driver	28
3.19	The Altera FPGA Cyclone IV DEO-Nano Controller Board	29
3.20	Software Altera Quartus II	30
3.21	The successful completion of VHDL coding	32
3.22	Assigning the pin at the pin planner	32
3.23	Status of successful upload of the program	33
3.24	Software Matlab	34
3.25	The binary data	34
4.1	The output voltage for SPWM	36
4.2	FTT Analysis for SPWM	36
4.3	The v_d waveform for SVM	37
4.4	FTT Analysis for SVM	37

4.5 (a)	Switching status for d-axis voltage, vd	38
4.5 (b)	Switching status for q-axis voltage, vq	38
4.5 (c)	Switching status for combination of vd and vq	38
4.6	Voltage triangle, V_{tri} waveform	39
4.7	The position references voltage vector, v^*	39
4.8	General representation for sector IV	40
4.9	Switching status waveform for S_a , S_b and S_c respectively	40
4.10(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.2 with frequency of 1kHz	43
4.11(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.4 with frequency of 1kHz	44
4.12(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.6 with frequency of 1kHz	45
4.13(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.8 with frequency of 1kHz	46
4.14(a)(b)(c)	The comparison of simulation and experimental results for amplitude 1.0 with frequency of 1kHz	47
4.15(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.2 with frequency of 2.55kHz	49
4.16(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.4 with frequency of 2.55kHz	50
4.17(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.6 with frequency of 2.55kHz	51

4.18(a)(b)(c)	The comparison of simulation and experimental results for amplitude 0.8 with frequency of 2.55kHz	52
4.19(a)(b)(c)	The comparison of simulation and experimental results for amplitude 1.0 with frequency of 2.55kHz	53
5.1	Proposed for future works	55

LIST OF ABBREVIATIONS

PWM	-	Pulse width modulation
SPWM	-	Sinusoidal pulse width modulation
SVPWM	-	Space vector pulse width modulation
SVM	-	Space vector modulation
AC	-	Alternating current
DC	-	Direct current
DTC	-	Direct torque control
FPGA	-	Field-programmable gate array
VHDL	-	VHSIC hardware description language
VHSIC	-	Very high speed integrated circuit
FFT	-	Fast fourier transform
VSI	-	Voltage source inverter
CSI	-	Current source inverter
ASD	-	Adjustable speed drives
VSD	-	Variable speed drives
UPS	-	Uninterruptible power supplies
HVDC	-	High voltage direct current
BJT	-	Bipolar junction transistor
MOSFET	-	Metal oxide semiconductor field effect transistor

IGBT	-	Insulated gate bipolar transistor
GTO	-	Gate turn off
DSP	-	Digital signal processor
MIPS	-	Measurement in millions of instruction per second
HDL	-	Hardware description language
IC	-	Integrated circuit
RAM	-	Random Access Memory
HDMI	-	High Definition Multimedia Interface
USB	-	Universal Serial Bus
PC	-	Personal Computer
LED	-	Light Emitting Diode
SOPC	-	System-on-a-programmable-chip
MATLAB	-	MATrix LABoratory
RMS	-	Root mean square
TNB	-	Tenaga Nasional Berhad

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	Gantt Chart and Milestone	57
B	List for MATLAB FUNCTION Sources Code	58
C	List for VHDL Sources Code	62
D	FPGA DATA SHEET	68

CHAPTER 1

INTRODUCTION

1.1 Research Background

A conventional Sinusoidal Pulse Width Modulation (SPWM) technique is not practical to be adapted in Alternating Current (AC) motor drives due to inflexibility control of three-phase quantities and lower output voltages. Space Vector Modulator Width Modulation (SVPWM) or known as Space Vector Modulator (SVM) technique was intensively used for obtaining high performances of AC motor drives such as produce a constant switching frequency in Direct Torque Control (DTC), fast dynamic torque control with over modulation strategy adopted in SVM and improved torque control capability for a wide-speed range. SVM is one of the approached to improve the SPWM technic for a better performance.

1.2 Motivation

The development of high performance drive technology is a center in the industry because technologies become more advanced from time to time. Industries that used AC drives, mostly are necessary to be conducted at different speed because in industries used different types of drives and machines. As for that, to get a variable speed, this machine is fed from inverters with variable voltage and variable frequency supply. So, using SVM with Field-Programmable Gate Array (FPGA) can increase the performance of the three-phase inverter. This is because FPGA used very high speed integrated circuit VHSIC Hardware Description Language (VHDL), where it is capable to perform Pulse Width Modulation (PWM) control algorithm especially SVM at high speed calculation.

1.3 Problem Statement

The problem is divided into two which is the SPWM technique and the existing SVM works. The SPWM techniques are inflexible control because difficult to control three-phase quantities such as amplitudes, frequencies and phase angle of three-phase voltage. It is according to the torque and flux demands in vector control of induction motor. This technique also has a limit for output voltage such as it cannot fully utilize the DC link voltage. Next, the problem with the existing SVM works because it totally implement the complex calculation of SVM algorithm and vector control in DSP which can increase the computational burden and hence reduce AC drive performance as the sampling time increase.

1.4 Objectives

In that respect are various objectives to be achieved in this task which include:

- i. To design and implement a space vector modulator utilizing FPGA which produce appropriate switching states, according to the inputs of d- and q- axis of space vector for measuring the output voltage and Fast Fourier Transform (FFT) Analysis. This modulator is suitable to be employed for any type of AC motor controls.
- ii. To verify the effectiveness of the design of the SVM modulator through simulation and experiment

1.5 Scopes of Project

The scope of the project is to study various PWM and SVM techniques, especially for AC motor drives. The scope of work is more to the investigate the performance of SVM for two levels with three-phase inverter. Next, to develop simulation models of SVM using MATLAB or SIMULINK. Besides, implement SVM modulator using FPGA. As well as, performing and comparing the results of simulation and experiment to validate the effectiveness of SVM.

1.6 Report Outline

Chapter 1 Introduction

This chapter will brief explains the main idea of this project is discussed in the overview. The idea is then elaborated in research background, objectives and scopes of work.

Chapter 2 Literature Review

The review of basic inverter and principle PWM method that will used in this project. Besides, this chapter summed up the research information in related previous work and journals.

Chapter 3 Methodology

The overall of this chapter is discussed the principle of SVPWM switching technique for three-phase Voltage Source Inverter (VSI). The flow of the project is explained and illustrated in flow chart. Besides, in this chapter also will this discuss the simulation of the MATLAB/Simulink. In this chapter, the hardware setup will concisely explain.

Chapter 4 Result and Discussion

The software and hardware is used for simulation and experimental is described. This chapter will discuss the comparison result between SPWM and SVM. Besides, this chapter discusses about the switching result and the SVM result from the simulation and hardware, which is the output voltage and FFT Analysis.

Chapter 5 Conclusion and recommendation

This chapter will summarize the idea about this report and there will be recommended for the future works.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses about the study from the journal or technical paper that related to the three-phase inverter which contain Voltage Source Inverter (VSI) and Current Source Inverter (CSI). This review also includes the Pulse Width Modulation (PWM) such as Sinusoidal Pulse Width Modulation (SPWM), SPWM with third harmonic injection and Space Vector Modulation (SVM). This review will briefly explained about the two levels of three-phase inverter to justify the main topic in this report. Besides, this review also discusses about the connection of Field-Programmable Gate Arrays (FPGA).

2.2 Inverter

An inverter is used to convert Direct Current (DC) to Alternating Current (AC) at desired output voltage and frequency. The application that will be used inverter is grid-connected system, Uninterruptible Power Supplies (UPS), High Voltage Direct Current (HVDC) power transmission and adjustable speed motor drive. An inverter function to supply an induction motor and need a switching device capable of being turned off and on through the gate. The output voltage can be controlled with the help of drives and the switches.

Three phase inverter is a large application in the industry. Adjustable Speed Drives (ASD) or known as Variable Speed Drives (VSD) where the motor's supplied voltage and frequency of power is changing by hold at the speed of an AC induction

motor. Using this approach the energy can save because the speed of motor can vary according to the situation. Figure 2.1 shows the example application of ASD.



Figure 2.1 : Adjustable Speed Drives (ASD)

Next, three phase inverter can act as an Uninterruptible Power Supply (UPS) or known as a backup power supply. When the main power from the supplier is discontinuous, it is function to provide and supply the energy from the battery stored while protecting the hardware. Figure 2.2 shows the example application of UPS.



Figure 2.2 : Uninterruptible Power Supply (UPS)

High Voltage Direct Current (HVDC) gives permission between unsynchronized AC transmission systems for power transmission. This system can stabilize a network against disturbances due to rapid changes in power using the force flow over an HVDC link. Besides, it also can go through independently of the phase angle between source and load. Figure 2.3 shows the illustration application of UPS.

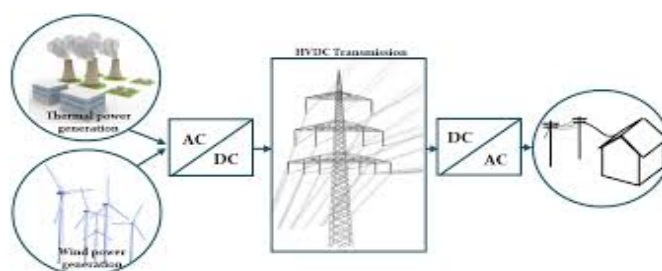


Figure 2.3 : Illustration of High Voltage Direct Current (HVDC)