THE FIELD ORIENTED CONTROL OF A PERMANENT MAGNET SYNCHROUNOUS MOTOR (PMSM) BY USING FUZZY LOGIC

SAMAT BIN IDERUS

A project report submitted in partial fulfillment of the
requirement for the award of the
Degree of Master of Electrical Engineering

Faculty of Electrical and Electronic Engineering
University Tun Hussein Onn Malaysia

JANUARY 2014

ABSTRACT

This project presents the comprehensive performance analysis on the principle of operation, design considerations and control algorithms of the field oriented control (FOC) for a permanent magnet synchronous motor (PMSM) drive system of Fuzzy Logic Controller (FLC) and proportional-integral PI for speed control in closed loop operation. To perform speed control of typical PMSM drives, PI controllers and FOC method are classically used. PI Controller controller suffers from the drawback that for its proper performance, the limits of the controller gains and the rate at which they would change have to be appropriately chosen. Fuzzy based gain scheduling of PI controller has been proposed in which uses in order to overcome the PI speed controller problem. The simulation results show that the proposed FLC speed controller produce significant improvement control performance compare to the PI controller. FLC speed controller produced a better performance than PI speed controller where the overshoot is totally removed and the settling time faster than PI speed controller in achieving desired output speed. The fuzzy algorithm is based on human intuition and experience and can be regarded as a set of heuristic decision rules. It is possible to obtain very good performance in the presence of varying load conditions changes of mechanical parameters and inaccuracy in the process modelling. Research and application of fuzzy logic are developing very rapidly, with promising impacts on electric drives and power electronics in future.

Keywords: FOC, PMSM, FLC, PI and for Speed Control.

ABSTRAK

Projek ini membentangkan analisis prestasi yang komprehensif tentang prinsip operasi , pertimbangan reka bentuk dan algoritma *field oriented control* (FOC) untuk motor segerak magnet kekal (MSMK) sistem kawalan Logik Fuzzy dan pengawal PI adalah penting untuk mengawal kelajuan beroperasi gelung tertutup. Untuk melaksanakan kawalan kelajuan pemacu PMSM, kebiasaannya pengawal PI dan kaedah FOC adalah klasik digunakan. Pengawal PI mengalami kelemahan dari segi prestasi. Logik Fuzzy beroperasi berasaskan pengawal PI telah dicadangkan di mana menggunakan untuk mengatasi masalah pengawal kelajuan PI. Keputusan simulasi menunjukkan bahawa kelajuan pengawal FLC yang dicadangkan menghasilkan prestasi kawalan peningkatan yang ketara berbanding dengan pengawal PI. Pengawal kelajuan Logik Fuzzy menghasilkan prestasi kawalan kelajuan yang lebih baik daripada PI kelajuan pengawal di mana terlajak sama sekali dikeluarkan dan masa pengenapan lebih cepat daripada kelajuan pengawal PI dalam mencapai kelajuan output yang dikehendaki. Pengawal logik adalah berdasarkan kepada gerak hati dan pengalaman manusia dan boleh dianggap sebagai satu set peraturan keputusan heuristik. Ia adalah mungkin untuk mendapatkan prestasi yang sangat baik di hadapan pelbagai keadaan beban perubahan parameter mekanikal dan ketidaktepatan dalam pemodelan proses. Penyelidikan dan aplikasi logik kabur membangun dengan pesat, dengan kesan cerah pada pemacu elektrik dan elektronik kuasa pada masa akan datang.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

A	- Ampere
AC	- Alternating Current
DC	- Direct Current
DTC	- Direct Torque Control
FLC	- Fuzzy Logic Controller
FOC	- Field Oriented Control
Hz	-Hertz
IPMSM	- Interior Permanent Magnet Synchronous Motor
Nm	- Newton meter
PI	- Proportional Integral
PMSM	- Permanent Magnet Synchronous Motor
rad/s	- Radian per second
SM	- Synchronous Motor
SVPWM	- Space Vector Pulse Modulation
V	- Volts
VC	- Vector Control

CHAPTER 1

INTRODUCTION

1.1 Overview

In this chapter, the introduction of the project will be clarified in detail in which consists of the project background towards the focusing of the project study, problem statement, project objective, research scopes and project outline.

1.2 Background of study

In recent years, the permanent-magnet synchronous motor (PMSM) has emerged as an alternative to induction motor due to the increasing energy saving demand. PMSM are widely used in high-performance applications such as industrial robots and machine tools because of its compact size, high-power density, high air-gap flux density, high-torque/inertia ratio, high torque capability, high efficiency and free maintenance [1-6,10-12,17-20].

The Advancements in magnetic materials, semiconductor power devices and control theories have made the PMSM drives play a vitally important role in motion-control applications. The rotor of PMSM is connected to the load that cause low pulsation torque quality. Overlapping control during phase transition may also trim down the torque pulsation [2-5]. For this PMSM required the power inverter to operate at higher switching frequency. So that it attains overlap control and noise reduction but result is high switching losses and lessening in the overall drive efficiency [6,7].

In order to achieve the desired performances of PMSMs as the behavior of DC motors, direct control of stator currents is needed. Nevertheless, it is quite unattainable due to the strong coupling and nonlinear natures of the AC motors. Hence, to realize the decoupling of relevant variables, a particular algorithm must be introduced. Fortunately, this problem has been resolved by the vector control technology, often referred to as Field-Oriented-Control (FOC) [3,10,11-15,18&23].

The principle of FOC was first proposed by F. Blaschke of Siemens in the early 1970s for controlling induction motors. This method had been developed into a complete theory system within several years of efforts [8,9]. FOC of PMSM motor drive gives improved performance in terms of faster dynamic response and more efficient operation. The FOC or vector control method gives the performance characteristics similar to that of a dc machine which are considered desirable in certain applications[10,11].Vector controlled PMSM drive provides better dynamic response and lesser torque ripples, and necessitates only a constant switching frequency.

Proportional plus integral (PI) controllers are usually preferred, but due to its fixed proportional gain and integral time constant, the performance of the PI controllers are affected by parameter variations, load disturbances and speed variations [1,2&12]. The complexity of PI controller tuning and high response time is overcome by Fuzzy controller [1,2,4&12].

1.3 Problem statement

Vector controlled PMSM drive provides better dynamic response and lesser torque ripples, and necessitates only a constant switching frequency. With the advent of the vector control methods, permanent magnet synchronous motor can be operated like separately excited dc motor high performance application.

The complexity of conventional Proportional plus integral (PI) controller has low speed control performance such as high overshoot and less response time can be overcome by Fuzzy logic controller [1,2,4,12,19,20 & 22]. Which has less response time and high accuracy without any mathematical calculation [1,2,4,12,19,20&22].This project presents a simulation of speed control system on fuzzy logic approach for an indirect vector controlled permanent magnet synchronous drive by applying space vector modulation.

1.4 Objectives

The main objective of the project is to describe a comprehensive analysis on the principle of operation, design considerations and control algorithms of a PMSM drives speed control system, in order to improved speed control performance of PMSM such as low overshoot, fast response time, low torque and current ripple.

The performances of the proposed FLC based system are investigated and compared to those obtained from the conventional PI controller based drive using commercially available software MATLAB/SIMULINK at different dynamic operating conditions such as sudden change in command speed with no load and load condition.

1.5 Scopes of project

The area covered by an activity or topic are quit wide. The scopes of the project are limited as follows:

(i). To model a Permanent Magnet Synchronous motor (PMSM) by using mathematical modeling in MATLAB Simulink software.

(ii). To develop fuzzy logic controller based on field oriented control of vector control in order to control PMSM speed. The fuzzy logic controller are executes the rule based taking inputs and give output by defuzzification.

(iii). To test the performance of Fuzzy Logic controller comparing to PI controller by using simulation. The design analysis of speed control of a PMSM realized in MATLAB Simulink software.

1.6 Dissertation outlines

The project dissertation is basically to document the concept, implementation and outcome of the project which relevant to the project progress. This dissertation is organized into five main chapters which are introduction, literature reviews, and methodology, result analysis and conclusion.

(i). Chapter 1 discussed the background and general idea of the proposed project. Besides that, the objectives and scopes of the project are explained in detail in this chapter.

(ii). Chapter 2 discovered the reviews of the literature which includes the principles of Field Oriented control technique implemented in controlling PMSM drive.

Some basis Space Vector Pulse Width Modulation (SVPWM) theory and the brief reviews of the fuzzy logic also mentioned in this chapter.

(iii). Chapter 3 shows the methodology/steps of each design stage. The details of the topology are discussed in this chapter with the operations of the system.

(iv). Chapter 4 presents the various results are shown and discussed from the simulation results and analysed the compensation performance of the proposed Fuzzy Logic Controller (FLC) in comparing with traditional Proportional Integral (PI) controller of speed control system on PMSM drive system. The simulation results of the systems performance have been observed.

(v). Chapter 5 states the conclusions or outcome simulation results of the systems performance have been observed of this project and the recommendation for the further work in order to improve this project are discussed in this chapter.

CHAPTER 2

LITERATURE REVIEWS

2.1 Overview

In this chapter consist of the several definitions and theoretical background of AC motor control, permanent magnet synchronous motor (PMSM) and fuzzy logic approach. This chapter also discussed the previous works or regarding this project are discussed which will be used to analyze the simulation and experimental data.

2.2 AC motor control schemes

High performance drives refers to the drive system ability to offer precise control to a rapid dynamic response and a good steady state response. Several techniques involved to control AC machines speed, flux and torque. The basic controlling parameters are the voltage and the frequency of the applied voltages/currents, and thus are not suitable for obtaining controlled operation of machines [13].

The power electronic converter has been introduced to control interface between grid supply and the electric motors. In most cases AC-DC-AC converters are used for AC machines drives and extremely complex. These AC-DC-AC converters most commonly called as inverter and are used to feed the motors for adjustable speed applications. Other alternatives are direct AC-AC converters, such as cyclo-converter and matrix converter. However these converters experienced from some drawbacks, including the limited output frequency for cyclo-converter and matrix converter will experience 86% of input voltage magnitudes [13]. Figure 2.1 illustrated the AC motor control schemes can be divided into two main controls.

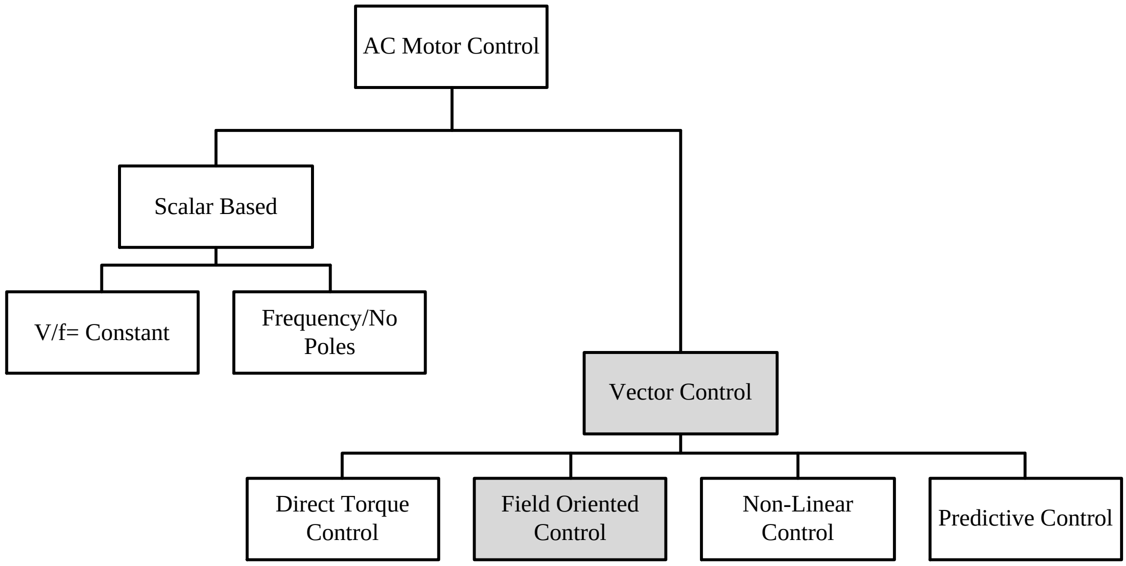

Figure 2.1: AC motor control schemes [13].

Scalar controls are easy to implement and offer steady-state response, but the dynamics are slow. Vector control with closed loop feed back control has introduced in order to obtain high precision, good dynamics and steady-state response. Direct torque control (DTC) is control schemes for low and medium speed applications. In However, in high speed case, it becomes very hard to realize DTC. It is caused mainly by necessity of high sampling rate, which is hard to obtain in high velocity range [13]. . Drawbacks of scalar control and DTC, moves the scope on the field oriented control (FOC) solution [13].

2.3 Principle of vector control

The invention of vector control (VC) in the beginning of 1970's and demonstrated in induction motor can be controlled by separately excited DC motor, which increase the efficiency of AC drives [6]. In VC the instantaneous position of voltage, current, and flux space vectors are controlled, ideally giving correct orientation both in steady state and during transients. Vector control is applicable to both Asynchronous and synchronous motor drive. The Figure.2.2 shows the block diagram of conventional vector control of PMSM [6].

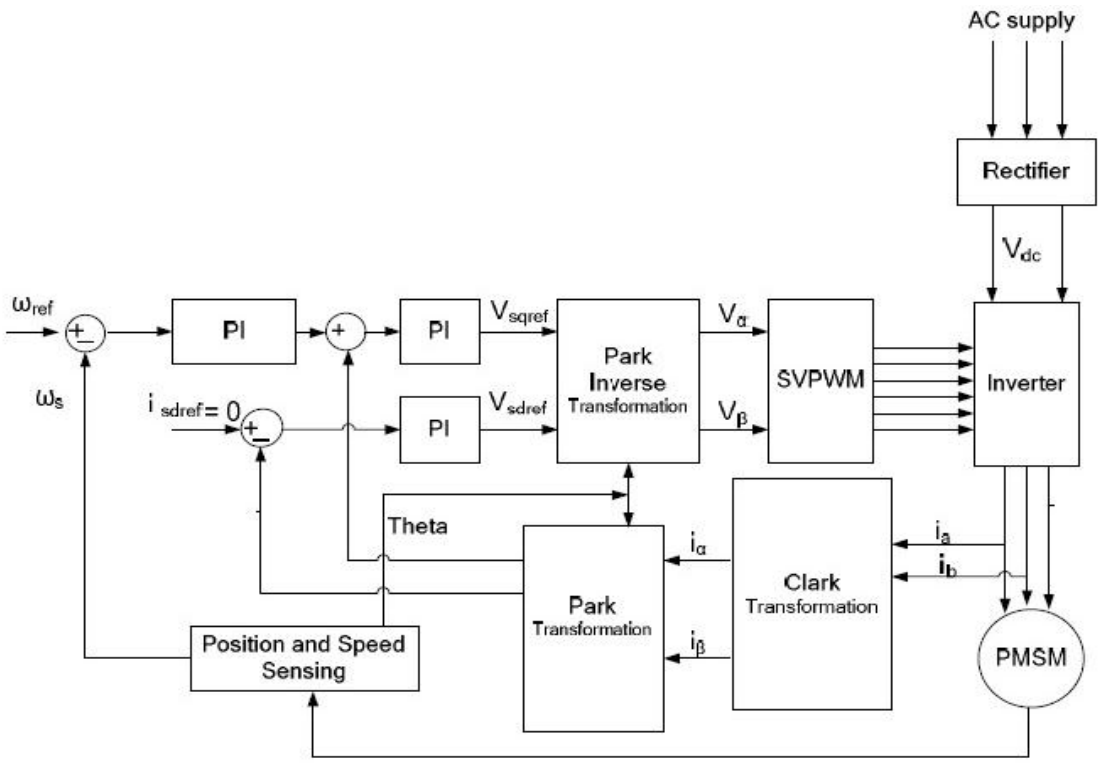

Figure 2.2: Conventional vector control of PMSM [6].

The synchronous inductance L_s and the corresponding armature flux Ψ_a very small that is, Ψs= Ψm= Ψf. The produced torque expression can be presented as equation 2.1

$$T_e = \frac{3p}{2}\,[\Psi_a i_{qs}] \tag{2.1}$$

This indicates that the torque is proportional to i_q power factor angle φ equals the torque angle δ as presented in equation 2.2

$$\cos\varphi = \Psi_s / \cos\delta = \Psi_f \qquad (2.2)$$

The stator command current $i_{qs}$is derived from the speed control loop.

2.4 Field Oriented Control

The Field Orientated Control (FOC) consists of controlling the stator currents represented by a vector [10,11,15]. 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. These projections lead to a structure similar to that of a DC machine control.

Field orientated controlled machines need two constants as input references: the torque component (aligned with the *q* co-ordinate) and the flux component (aligned with *d* co-ordinate). As FOC is simply based on projections the control structure handles instantaneous electrical quantities. This makes the control accurate in every working operation (steady state and transient) and independent of the limited bandwidth mathematical model. The FOC thus solves the classic scheme problems, in the following ways :

(i). The ease of reaching constant reference

(ii). The ease of applying direct torque control.

2.4.1 Space vector definition and projection

The three-phase voltages, currents and fluxes of AC-motors can be analyzed in terms of complex space vectors [15]. With regard to the currents, the space vector can be defined as follows. Assuming that i_a, i_b, and i_c,are the instantaneous currents in the stator phases, then the complex stator current vector is defined by [11,15,16]:

$$i_s = i_a + i_b + i_c \tag{2.3}$$

where $\alpha = e^{j\frac{2}{3}\pi}$and $\alpha^2 = e^{j\frac{4}{3}\pi}$are present the spatial operators. The following diagram shows the stator current complex space vector:

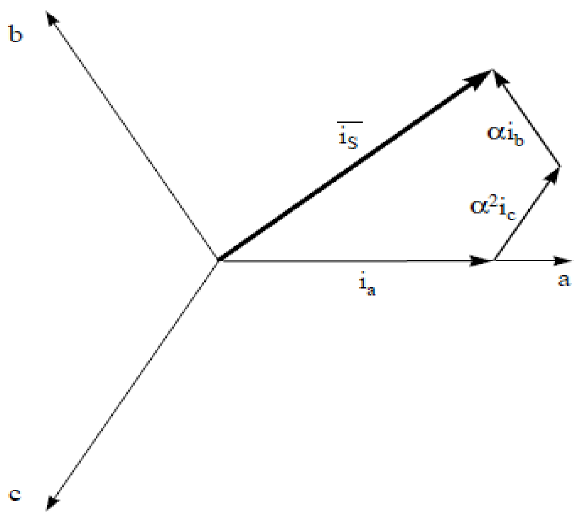

Figure 2.3: Stator current space vector and its component in (a,b,c) [15]

where (a,b,c) are the three phase system axes. This current space vector depicts the three phase sinusoidal system. It still needs to be transformed into a two time invariant co-ordinate system. This transformation can be split into two steps:

(i). (a,b,c) → (α, β) (the Clarke transformation) which outputs a two co-ordinate time variant system.

(ii). (α, β) → (d,q) (the Park transformation) which outputs a two co-ordinate time invariant system

2.4.2 The Clarke transformation

The space vector can be reported in another reference frame with only two orthogonal axis called (α, β). Assuming that the axis a and the axis α are in the same direction as the following vector diagram [11,15]:

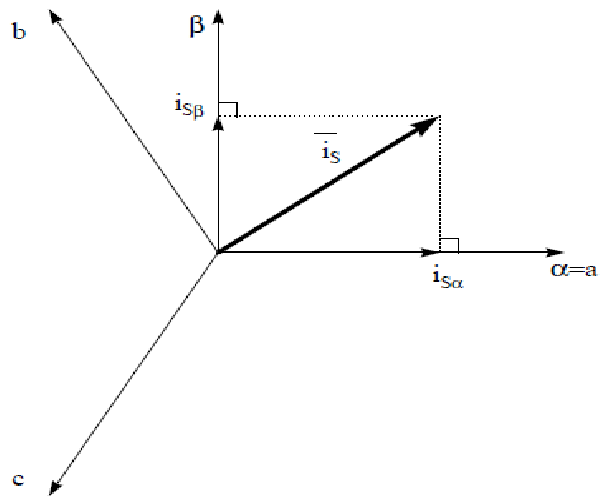

Figure 2.4: Stator current space vector and its components in (a,b) [15].

The projection that modifies the three phase system into the (a,b) two dimension orthogonal system is presented below.

$$i_{S\alpha} = i_a$$
$$i_{S\beta} = \frac{1}{\sqrt{3}} i_a + \frac{2}{\sqrt{3}} i_b \tag{2.4}$$

2.4.3 The Park transformation

This projection modifies a two phase orthogonal system (α, β) in the d,q rotating reference frame. Consider the d axis aligned with the rotor flux, the next diagram shows, for the current vector, the relationship from the two reference frame [11,15]:

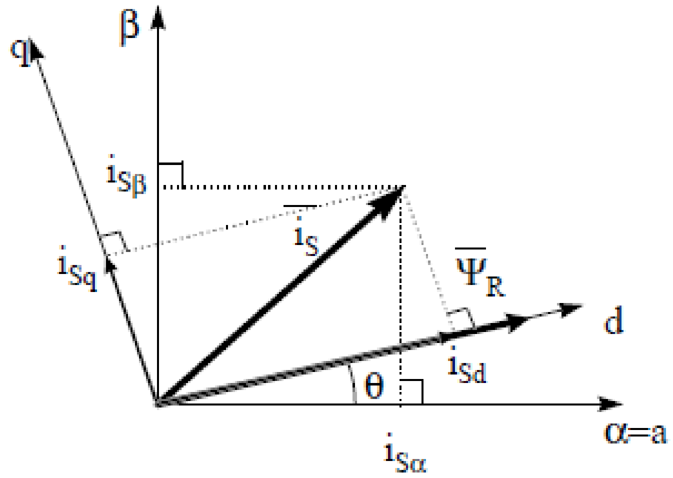

Figure 2.5: Stator current space vector and its component in (a,b) and in the d,q rotating reference frame [15].

Where θ is the rotor flux position. The flux and torque components of the current vector are determined by the following equations:

$$i_{Sd} = i_{S\alpha} \cos\theta + i_{S\beta} \sin\theta$$
$$i_{Sq} = -i_{S\alpha} \sin\theta + i_{S\beta} \cos\theta \qquad (2.5)$$

These components depend on the current vector (a,b) components and on the rotor flux position.

2.5 Space vector pulse width modulation

The space vector pulse width modulation (SVPWM) technique of the most popular technique due to a higher DC bus voltage and offered easy digital realization [8,14,16]. the concept of SVPWM relies on the representation of the output voltage the inverter output as space vector or space phasors. Space vector representation of the output voltages of the inverter is realized of the implementation of SVPWM [2,8,16].

Space vector simultaneously represents three phases quantities as one rotating vector, hence each of phase is not considered separately. The three phases are assumed as only one quantity. In recent years, the space vector theory demonstrated some improvement for both the output crest voltage and the harmonic copper loss [8,16]. The maximum output voltage based on the space vector theory is $2/\sqrt{3}$ = 1.55 times as large as the conventional sinusoidal modulation [8,14,16]. It enables to feed the motor with a higher voltage than the easier sub-oscillation modulation method. This modulator allows to have a higher torque at high speeds, and a higher efficiency [6,8,16]. The space vector is defined as

$$f_s = \frac{2}{3}\left[f_a + e^{j2\frac{2}{3}}f_b + e^{j4\frac{\pi}{3}}f_c\right] \tag{2.6}$$

Where f_a, f_b and f_c are three phase quantities of voltages, current and fluxes. In the inverter PWM, the voltage space vectors considered.

Since the inverter can attain either +5V_{dc} or -5V_{dc} or 0V_{dc}, i.e only two states, the total possible output are 2^3 = 8(000, 001, 010, 011, 100, 101, 110, 111). Here 0 indicates switch is 'OFF' and 1 indicates switch is 'ON'. Thus there are six active switching states an two zero switching states. The operation of the lower switch are complimentary. By using equation 2.5 and Table 2.1 shows the possible space vector are computed [8,16].

Table 2.1: Phase to neutral space vector for three phase voltage source inverter [8]

Switching states	Space vector number	Phase to neutral Voltage Space Vector
000	7	0
001	5	$\frac{2}{3}V_{dc}e^{j\frac{4\pi}{3}}$
010	3	$\frac{2}{3}V_{dc}e^{j\frac{2\pi}{3}}$
011	4	$\frac{2}{3}V_{dc}e^{j\pi}$
100	1	$\frac{2}{3}V_{dc}e^{j0}$
101	6	$\frac{2}{3}V_{dc}e^{j\frac{5\pi}{3}}$
110	2	$\frac{2}{3}V_{dc}e^{j\frac{\pi}{3}}$
111	8	0

The space vector is graphically in Figure 2.6 below. The hexagon consists of six distinct sector spanning over 360 degrees with each sector of 60 degrees [8,16].

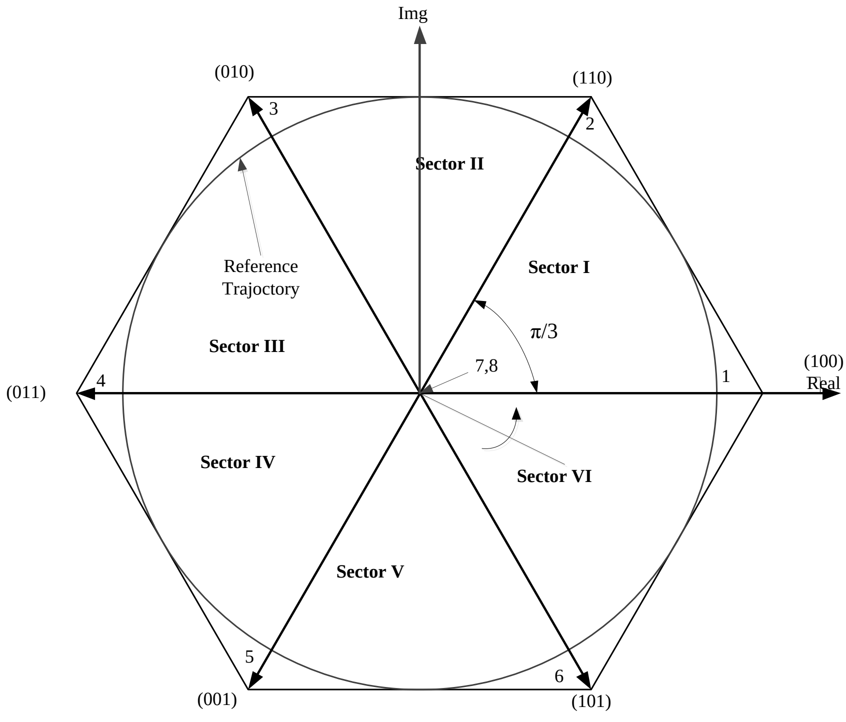

Figure 2.6: Voltage space vector locations corresponding to different switching states.

Space vector 1, 2…6 called the active states and 7, 8 called zero states vectors. Are redundant vector but they are used to minimize the switching frequency. The references voltage follows a circular trajectory in a linear modulation range and the output is sinusoidal. The reference trajectory will change over the modulation and the trajectory will be hexagon boundary when the inverter is operating in the six-step mode [16].

In implementing the SVPWM, the references voltage is synthesized by using the nearest two neighboring active vector and zero vectors. The choice of the active vector upon the sector vector is located. Hence, it is important to locate the position of the reference voltage. Then the references vector located will be used for SVPWM implementation to be identified. After identifying the vector to be used next task is to find time of application of each vector called the 'dwell time'. The output voltage frequency of the inverter is the same as the speed reference voltage and the output voltage magnitude is the same as the magnitude of the reference voltage[16].

2.6 Permanent magnet synchronous motor

Among all of the existing motors on the market are three 'classical' motors: the Direct Current with commutators (wound field) and two Alternative Current motors the synchronous and the asynchronous motors. These motors, when properly controlled, produce constant instantaneous torque (very little torque ripple) and operate from pure DC or AC sinewave supplies [22]. Figure 2.7 shows the classification of electric motors.

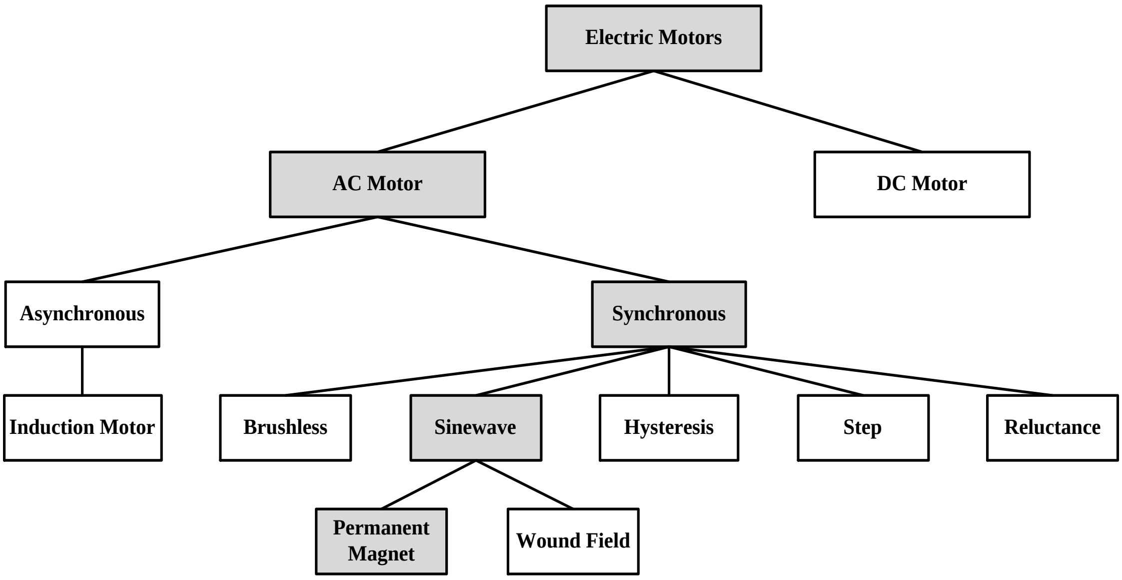

Figure 2.7: Classification of electric motors [22].

A PMSM is a motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets. These motors have significant advantages, attracting the interest of researchers and industry for use in many applications such as spinning mills, robotics, electric vehicles, cement mills and etc [1-6].

The synchronous motor (SM) has two primary parts. The non-moving is called the stator and the moving, usually inside the stator, is called the rotor. SM can be built in different structures [21]. To enable a motor to rotate two fluxes are needed, one from the stator and the other one from the rotor. For this process several motor configurations are possible. From the stator side three-phase motors are the most common as illustrated in Figure 2.8. There are mainly two ways to generate a rotor flux. One uses rotor windings fed from the stator and the other is made of permanent magnets and generates a constant flux by itself [21,22].

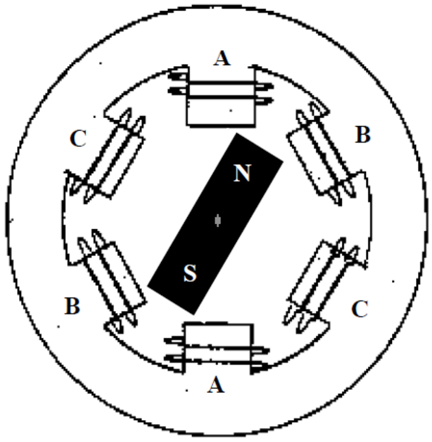

Figure 2.8: A three-phase synchronous motor with a one permanent magnet pair pole rotor

Motors have been constructed with two to fifty or more magnet poles. A greater number of poles usually create a greater torque for the same level of current. This is true up to a certain point where due to the space needed between magnets, the torque no longer increases. Advanced magnet materials such as Samarium Cobalt (SmCo) magnets and Neodymium Iron Boride (NdFeB) magnets permit a considerable reduction in motor dimensions while maintaining a very high power density. In the case of embedded systems where the space occupied is important, a PMSM is usually preferred to an AC synchronous motor with brushes [21-24].

The SM with rotor windings maintains maximum efficiency by regulating the rotor currents and then the flux. For high-speed systems where high efficiency is required, AC synchronous motors with rotor windings may be a good compromise.

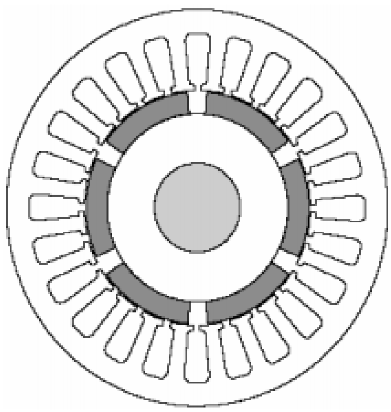

Figure 2.9: Surface permanent magnet motor [21]

2.6.1 Advantages of PMSM

The application of PMSM technology and its advantages over the conventionally used induction principle. The main points which can be considered while summarizing this advantage are as [24]:

(i). PMSM provides higher power density for their size compared to induction machine. This is because with an induction machine, part of the stator current is required to "induce" rotor current in order to produce rotor flux. These additional currents generate heat within the motor where as, the rotor flux is already established in a PMSM by the permanent magnets on the rotor.

(ii). With the low power density it aids compactness. This results in development of a PMSM with low rotor inertia, which is capable of providing faster response.

(iii). It is operating at a higher power factor compared to induction motor (IM) due to the absence of magnetizing current.

(iv). The design of controller required for the design of speed control of the fan operated by PMSM is simple. The PMSM also provides a key feature of operating at high efficiency with low speeds, thus giving all round efficient operation for the cooling tower at high and low speeds.

2.7 Fuzzy logic controller

Fuzzy Logic Controller (FLC) is a technique to embody human-like thinking into a control system. FLC can be designed to emulate human deductive thinking, that is, the process people use to infer conclusions from what they know. FLC has been primarily applied to the control of processes through fuzzy linguistic descriptions [1-4,12,17-20].

The FLC initially converts the crisp error and change in error variables into fuzzy variables and then are mapped into linguistic labels [17,18-20]. FLC is utilized to design controllers for plants with complex dynamics and high nonlinearity model. In a motor control system, the function of FLC is to convert linguistic control rules into control strategy based on heuristic information or expert knowledge[1,2,17-20]].

It has been reported that fuzzy controllers are more robust to plant parameter changes than classical PI or PID controllers and have better noise rejection capabilities. The proposed scheme exploits the simplicity of the Mamdani type fuzzy systems that are used in the design of the controller [1,2,4,12,19&20]. The Figure 2.11 illustrated the block diagram of FLC structure.

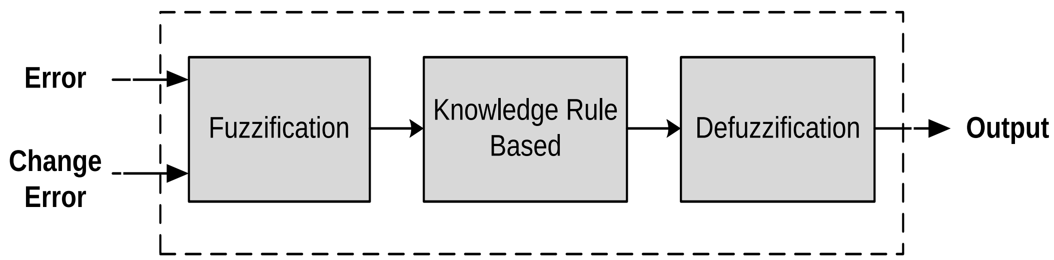

Figure 2.10: The basic structure of fuzzy logic controller [17]

The structure of FLC is shown in Figure 2.11. There are four main parts for fuzzy logic approach. The first part is 'fuzzification unit' to convert the input variable to the linguistic variable or fuzzy variable [17]. The second part is 'knowledge base' to keep the necessary data for setting the control method by the expert engineer. The 'decision making logic' or the inference engine is the third part to imitate the human decision using rule bases and data bases from the second part. The final part is 'defuzzification unit' to convert the fuzzy variable to easy understanding variable [1,2,19,20].

2.8 Previous works

From the review has been made since 1995 until 2011 for PMSM Drive System, there were several of controller, method or technique has been proposed in order to optimize the efficiency. PMSM have been widely used in motion control applications [1–9&12] but among these, the IPMSM have been of a particular attention due to their distinct features of low-torque ripples and high power density [1011 13&14].

Table 2.2: Survey on previous works

References	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
PMSM	/	/	/	/	/	/	/	/		/	/					/	/
controller	/	/	/	/	/		/		/		/	/	/	/	/	/	/

From the Table 2.2 above, most of the researchers focus on the controller in order to improve the efficiency. The numbering in the Figure represent of references number. But some of them used Interior Permanent Magnet Synchronous Motor (IPMSM) as their electric rotating load. This is because with permanent magnets buried inside the rotor, features such as smooth rotor surface and reduced air-gap will result in a robust mechanical construction and thus permitting higher speed with quiet operation and better dynamic performance [14]. It's different with [2], which is used no position sensor to controlled the magnitude of the voltages in order to maintain a constant stator flux linkage in the PMSM.

For paper [5,7&12], all are deals with analysis and hardware implementation, and methodologies in VC and described of FOC technique. FOC or VC is mostly used as it provides superior torque to inertia ratio, high controllability and greater power density as in [1,5,7-9,12&16]. This topics will discussed about recent previous works and the comparison regarding to the PMSM Drive speed control based on FLC.

In 2011, B.Adhavan et al was performed the simulation of speed control system on fuzzy logic approach for an indirect vector controlled permanent magnet synchronous drive by applying space vector modulation. The method of formulation of control algorithms allows implementing heuristic strategies. From this research found that the initial starting torque of the machine is reduced so the initial stator current drawn by the motor is also reduced [19].

Chalermpon Pewmaikam et al. (2012) performing their research on a torque control system with an adaptive fuzzy logic compensator for torque control and the torque estimator of the machine for torque measurement. This method can improve the efficiency of the torque control system. Additionally, this method leads to the process that can apply to decrease the calibration time of the automatic screw machines.

In year 2011 also Siti Noormiza Mat Isa et al developed the control strategy focuses on fuzzy rule base which are contribute to some level of output in obtaining the desired performance. Two FLCs with reduced rule base (9- rules and 7-rules) are designed and the performance results are compared and evaluated with the standard FLC (49-rules). The simplification of rule base is determined by eliminating some of rule bases that are infrequently fired by the PMSM drive. The simplified FLCs produce almost equivalent performance to 'Standard FLC' in some cases and better performance than 'Standard FLC' in some other cases. Therefore, it feasible to reduce the rule base from 49-rules to 9-rules or 7-rules in implementation of vector controlled PMSM drives.The test results on the performance of the DSP based fuzzy pre compensated PI speed controller for vector controlled PMSM drive have confirmed the validity of the algorithm developed to analyse the behaviour of the PMSM drive system. The assembly language programming for the implementation on DSP has resulted in the use of reduced hardware [2].

Amit Vilas Sant and K. R. Rajagopal in 2009 founded that The former method based on switching often causes chattering effects, and later method demands larger execution time because of inclusion of separate switching algorithms. This paper reports the vector control of PMSM with hybrid fuzzy-PI speed controller with switching functions calculated based on the weights for both the controller outputs using the output of (a) only the fuzzy controller, (b) only the PI controller and (c) a combination of the outputs of both the controllers. These switching functions are very simple and effective and do not demand any extra computations to arrive at the hybrid fuzzy-PI controller outputs. The hybrid fuzzy-PI speed controllers with the three switching functions calculated based on the weights for both the controller outputs using the output of only the fuzzy controller, only the PI controller and the combination of the outputs of both the controllers, are performing better than the PI alone and fuzzy alone speed controllers [1].

In 2003, Bhim Singh with his friends was discovered that the deals with the analysis and hardware implementation of a Fuzzy Pre compensated Proportional-Integral (FPPI) speed controller for Vector Controlled (VC) Permanent Magnet Synchronous Motor (PMSM) drive using a digital signal processor. The power circuit of the PMSM drive consists of insulated gate bipolar transistor (IGBT) based Voltage Source Inverter (VSI) and the gate driver circuit. The hardware of control circuit has current sensors and interfacing circuits. The simulation model of the drive system is developed in MATLAB environment with Simulink, PSB and FLC toolboxes to analyze the performance of PMSM drive system. Simulated results are validated with test results of the PMSM drive for starting, speed reversal and load perturbation. The test results on the performance of the DSP based fuzzy pre compensated PI speed controller for vector controlled PMSM drive have confirmed the validity of the algorithm developed to analyse the behaviour of the PMSM drive system. The assembly language programming for the implementation on DSP has resulted in the use of reduced hardware [3].

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter described the method that used for this project. In order to complete this project, the development a method and step to make sure this project successful without any problems and to avoid confusing and unprepared. Lots of information is required in relation to full fill this project. This project development is divided into two main phases.

The phase A consisting extensive literature reviews were done on related knowledge to assist in any ways that it may. Such reviews are based on international publications, websites, and engineering books represented the development of PMSM system based on MATLAB Simulink and establish the field oriented control simulation.

The second part which at phase B reflected to development of intelligent control system that used Fuzzy Logic Controller and SVPWM module. Lastly come out with data and result analysis or outcome of this project. The development of this project can be summarized in term of flow chart diagram such as shown in **APPENDIX A.**

3.2 System Architecture

Figure 3.1 shows the block diagram proposed system. In tradional PI controller it suffers from overshoots of response, when some unknown nonlinear are present in the system [6,17,19&20]. The fuzzy logic controller overcomes this disadvantage [1,2,12&19]. The fuzzy logic executes the rule base taking the input and gives the output by defuzzification, input are speed error and change in speed error the output will be the torque limit which equivalent with Iqs.

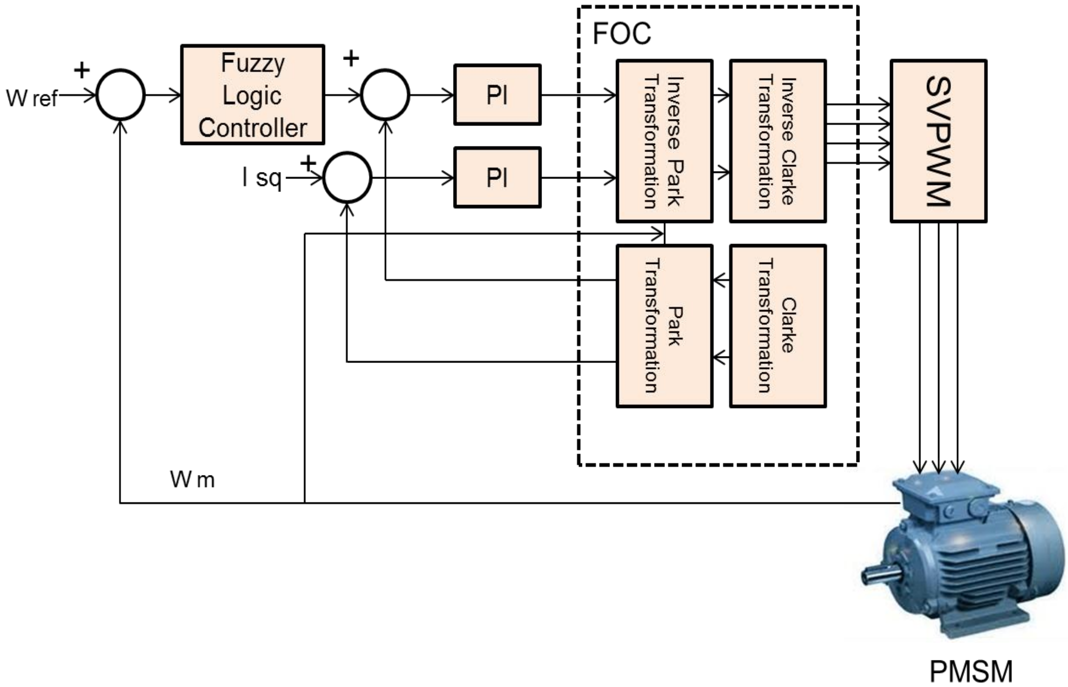

Figure 3.1: Block diagram of proposed system [6].

The outputs of the current controller are passed through the inverse Park transform and a new stator voltage vector is impressed to the motor using the space vector pulse width modulation (SVPWM) technique [7,14]. In order to control the mechanical speed of the motor, In order to control the mechanical speed of the motor, an outer loop is driving the reference current *isq* [1,2&3]. The PI regulator compares the speed set point with the measured mechanical speed of the rotor and produces the stator current quadrature axis reference, *isq*. That is the speed controller outputs a reference torque, which is proportional to the quadrature-axis stator current component *isq*. The mechanical speed reference is denoted ωref [1,2&3].

REFERENCES

1. Amit Vilas Sant and K. R. Rajagopal PM Synchronous Motor Speed Control Using Hybrid Fuzzy-PI With Novel Switching functions IEEE transactions on magnetic, vol. 45, no. 10, October 2009 pp 4672-4675
2. Siti Noormiza Mat Isa, Zulkifilie Ibrahim, Fazlli Patkar Comparative Study of Fuzzy Logic Speed Controller in vector Controlled PMSM Drive: Minimum Number of Fuzzy Rule-Base 2009 Conference on Innovative Technologies in Intelligent Systems and Industrial Applications (CITISIA 2009) Monash University, Sunway campus, Malaysia, 25th & 26th July 2009.
3. Bhim Singh, Senior Member, IEEE, B.P. Singh, Senior Member, IEEE and Sanjeet Dwivedi, DSP based implementation of Hybrid Speed Controller for Vector Controlled Permanent Magnet Synchronous Motor Drive. Emerging electric power system vol.8,no 2,pp1-22 2007.
4. M. Nasir Uddin, Senior Member, IEEE, M. A. Abido, Member, IEEE, and M. A. Rahman, Fellow, IEEE Real-Time Performance Evaluation of a Genetic-Algorithm-Based Fuzzy Logic IEEE transactions on industry applications, VOL. 41, NO. 1, January/February 2005 Controller for IPM Motor Drives.
5. M. A. Rahman, M. Vilathgamuwa, M. N. Uddin, and K. J. Tseng, ‘‘Nonlinear control of interior permanent magnet synchronous motor,’’ IEEE Trans. Ind. Appl., vol. 30, no. 2, pp. 408---416, Mar./Apr. 2003.
6. Bimal K. Bose, "Modern Power Electronics and AC drives," Pearson Education Asia, Low Price Edition (LPE) 2003.
7. Shiyoung Lee, B. M. Song and T. H. Won, “Evaluation of a Software Configurable Digital Controller for the Permanent Magnet Synchronous Motor using Field-Oriented Control”, in 42nd Southeastern Symposium on System Theory, p. 302-306, 2010.

8. P. Vas, Vector Control of Ac Machines., New York: Oxford University Press, USA, 1990.
9. W. Leonhard, Control of Electrical Drives. 3rd ed, Berlin: Springer- Verlag, 2001.
10. J. Qian and M.A. Rahman, "Analysis of Field Oriented Control for Permanent Magnet Hysteresis Synchronous Motors", IEEE Trans. on Industrial Applications, Vol. IA-29, NO. 6, NOV. 1993, p 1156.
11. M.T. Wishart, R.G. Harley and G. Diana, "The Application of the Field Oriented Control to the Brushless dc Machine", Proceedings of the European Power Electronics Conferences(FIRENZE), 1991, p 629.
12. Z. Ibrahim and E. Levi, "Fuzzy logic versus PI speed control in high-performance AC drives: A comparison," Electric Power Components and Systems, vol. 31, p. 403, 2003.
13. Holtz, J. (2006) Sensorless control of induction machines. Proc. IEEE, 90(8), 1359-1394.
14. K. Jalili, S. Bernet, M. Malinowski, B. J. Cardoso Filho, Design and Characteristics of a Rotor Flux Controlled High Speed Induction Motor Drive Applying Two-Level and Three-Level NPC Voltage Source Converters, IEEE, 2005, p. 1820-1826.
15. R. Di Gabriele, F. Parasiliti, M. Tursini, “Digital Field Oriented Control for induction motors: implementation and experimental results”, Universities Power Engineering Conference (UPEC’97)
16. Van der Broeck, H.W., Skuenly, H., and Stanke,G. (1988) Analysis and realization of pulse width modulator based on voltage space vectors. IEEE Trans. Ind. Elec.24(1), pp 142-150.
17. L. Xu, C. Wang, Implementation and Experimental Investigation of Sensorless Control Schemes for PMSM in Super-High Variable Speed Operation, IEEE, 1998, p. 483-489
18. Bon-Ho Bae, Seung-Ki Sul, Jeong-Hyeck Kwon, Ji-Seob Byeon, Implementation of Sensorless Vector Control for Super-High-Speed PMSM of Turbo-Compressor, IEEE Transactions on Industry Applications, May/June 2003, p. 811-818.

19. B.Adhavan,. Kuppuswamy, G.Jayabaskaran and Dr.V.Jagannathan, Field Oriented Control Of Permanent Magnet Synchronous Motor (PMSM) Using Fuzzy Logic Controller, IEEE pp 587-592, 2011.

20. Pewmaikam C., Srisertpol J., and Khajorntraidet C. Adaptive Fuzzy Logic Compensator for Permanent Magnet Synchronous Motor Torque Control System, International Journal of Modeling and Optimization, Vol. 2, No. 2, April 2012.

21. M. Aydin, "Axial Flux Mounted Permanent Magnet Disk Motors For Smooth Torque Traction Drive Application," in *Electrical and Computer Engineering*, vol. PhD: University of Wisconsin 2004, pp. 453.

22. R. Krishnan, Electric Motor Drives Modeling, Analysis, and Control Pearson Education, 2001.

23. Digital Signal Processing Solutions for Motor Control' by Stefan Beierke, m, Texas Instruments.

24. Brushless Permanent-Magnet and Reluctance Motor Drives' from T.J.E. Miller, Oxford Science publications 1993.

25. J. Holtz, "Pulse width modulation – A Survey", IEEE Transactions on Industrial Electronics, Vol. 30, No.5, Dec 1992, pp. 410-420.

26. H. W. V. D. Brocker, H. C. Skudenly and G. Stanke, "Analysis and realization of a pulse width modulator based on the voltage space vectors,"