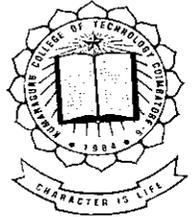Γ -1420

VECTOR CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

By

M.SAVITHA
Reg. No. 71203415015

of

KUMARAGURU COLLEGE OF TECHNOLOGY
COIMBATORE – 641 006

A PROJECT REPORT

Submitted to the
FACULTY OF ELECTRICAL & ELECTRONICS ENGINEERING

In partial fulfillment of the requirements
for the award of the degree

of

MASTER OF ENGINEERING

in

POWER ELECTRONICS AND DRIVES

June 2005

ABSTRACT

Permanent magnet synchronous motor is a highly efficient motor and it is an important drive in servo, positioning and robotic applications. It gets increasing importance in the field of low cost drives as pumps, fans etc .Several control techniques like vector control have been evolved for achieving high performance .This project discusses about the vector control of PMSM. The objective of the vector control is to control the electromagnetic torque in a way equivalent to that of a separately excited dc machine. Field-oriented control enables control over both the excitation flux-linkage and the torque-producing current in a decoupled way.

However, the PMSM is non-linear and exhibits coupled dynamics. As a result, PI controllers are inadequate in applications where good transient performance under all motor operating conditions is desired. This has prompted the application of modern control techniques for PMSM control such as intelligent systems.

This project discusses an intelligent controller, consisting of fuzzy logic and neural network control algorithm for increasing correction of tracking and reducing load torque disturbances. The software of system is developed in MATLAB and simulation results are presented. The actual speed of motor tracks the reference speed accurately. The performance of the motor using neuro with fuzzy technique and PI controller are compared.

The model equations are based on the direct and quadrature access (d-q) components The PI structure of the nonlinear plant consists of an outer speed control loop with an inner current control loop. The plant consists of a PMSM, a position and speed sensor and a 3-phase full bridge inverter. The controller accepts the speed and current feedback signals and generates PWM signals to drive the motor based on the control algorithm.

iii

BONAFIDE CERTIFICATE

Certified that this project report titled **"Vector Control of Permanent Magnet Synchronous Motor"** is the bonafide work of **Ms. M.SAVITHA,** who carried out the research under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other thesis or dissertation on the basis of which a degree or award was conferred on an earlier occasion on this or any other candidate.

PROJECT GUIDE

HEAD OF THE DEPARTMENT

The candidate with university no : 712034150 was examined by us in the project viva-voce examination held on: 23.6.05
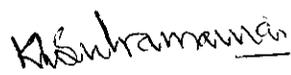
INTERNAL EXAMINER

EXTERNAL EXAMINER

AKNOWLEDGEMENT

As I ponder in circumspect, there comes in number of persons who have contributed to my success in this work. Here, I want to thank the few among them.

I am also thankful to Principal, **Dr.K.K.Padmanabhan B.Sc (Engg), M.Tech, Ph.D, FIE, FIMech.E, FI Prod.E, FIV, MISTE, MIIE.,** Kumaraguru College of Technology, for providing the facilities necessary to complete this project work.

I extend my heartful thanks to our Head of the Department, **Mr.K.Regupathy Subramaniam B.E(Hons), M.Sc, MIEEE, IES.,,** Department of Electrical and Electronics Engineering, Kumaraguru College of Technology, for his constant support and encouragement throughout the project.

My sincere thanks to my Guide **Mr. K.T.Vardharajan M.E ,FIE,** Professor , Department of Electrical and Electronics Engineering, for having extended his kind help throughout this project.He has always been kind enough and motivated the author through his inspiring guidance and suggestions. I, sincerely, owe my deepest sense of gratitude to him.

Last, but not the least, I thank my Parents and Friends with felicitation who gave their moral encouragement and doughtiness to accomplish the project.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF NOMENCLATURE

1. Is — Stator current

2. Ia,Ib,Ic — a,b,c pahse currents,A

3. V_q, V_d — q,d axis stator voltage,V

4. i_q,i_d — q,d axis stator current,A

5. L_q L_d — q,d axis stator inductance,H

6. λ_q λ_d — q,d axis stator flux linkage,Wb turn

7. R — stator Resistance Ω

8. ω_s — inverter frequency Hz

9. ωr — rotor speed rad/sec

10. p — derivative

11. L_{md} — d-axis mutual inductance,H

12. I_{fd} — Equivalent d-axis magnetizing current ,A

13. P — number of pole pairs

14. λ_{af} — mutual flux linkage between rotor and stator due to PM,Wb turn

15. Te — Electric torque Nm

16. T_L — Load torque,Nm

17. B — Damping constant ,Nm/rad/s.

18. J — Moment of inertia kgm^2

19. ωe — Electrical speed,rad/sec

20. Φ_m — Magnetic flux of permanent magnet,Wb

CHAPTER 1

INTRODUCTION

Traditionally, DC motors have been the popular choice for servo applications. This is due to their excellent dynamic performance and ease of control. Conventional linear control techniques like PI (proportional plus integral) or PID (proportional plus integral derivative) have been successfully used for this class of motors. However, these motors pose several difficulties, most of which are due to the presence of the mechanical brush and commutator arrangement. In recent years, much research work has been directed towards the use of AC motors for high performance servo and position control applications. The delay of the entry of AC motors in servo control applications was mainly due to their poor dynamic performance compared to the DC motors. Techniques like variable frequency control have been used but were inadequate for high performance servo applications.

The theory of vector control had brought out the similarities between the DC and AC motors but then the practical implementation of vector control techniques was too complex. However, rapid advancements in micro-controller and power electronic devices made vector control feasible. The application of vector control to PMSM is done in this project. A hybrid control scheme has been developed, consisting of fuzzy logic and neural network control algorithm for increasing correction of tracking. The software of system is developed in MATLAB (Version 6.5) and simulation results are presented. The actual speed of motor track the reference speed accurately. Neuro Fuzzy based field oriented control of PMSM is used to deal with nonlinearities and uncertainties. Since real time implementation of Neuro fuzzy based control required specialized IC's the concept had been simulated using MATLAB. The hardware implementation has been done using PIC microcontroller.

1. OUTLINE OF THE PROJECT:

SIMULATION:

In this project, neuro-fuzzy algorithms are used for the PI speed controllers. The Proposed Neuro-Fuzzy controller consists of a neural network controller and a Fuzzy logic controller.
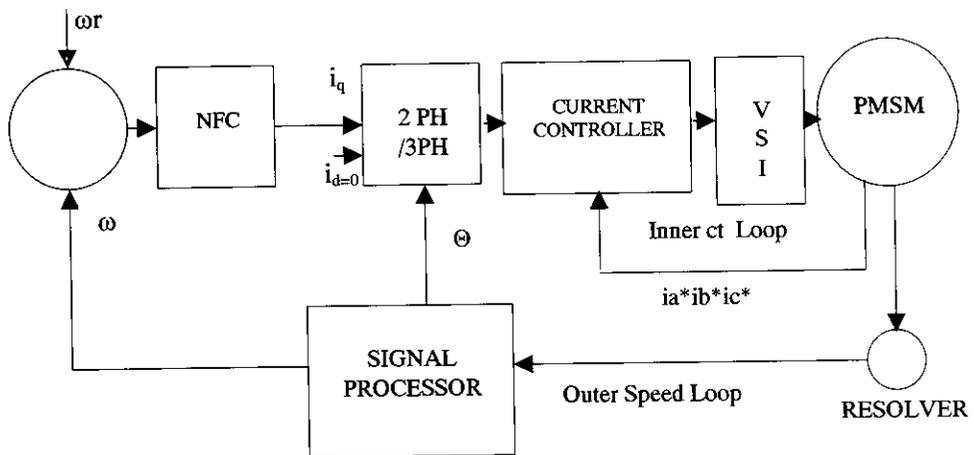
Figure 1.1 NFC based FOC of PMSM

The output of the neural network controller is given to the Fuzzy logic controller. The neural network is formed by three layers. In choosing the optimum output from the three networks a fuzzy logic controller was introduced. Neuro-fuzzy control has two inputs to be error and error derivative and has two outputs to be direct and quadrature components of the desired current .The two inputs are given to three network layers. Each layer consists of one hidden layer and one input layer and one output layer. All networks have same number of layers except each layer differs in the transfer function. Chapter 4 gives a general view about artificial neural networks and Fuzzy logic. Chapter 5 deals with the actual work done in the project in the simulation part using Simulink (MATLAB).

HARDWARE IMPLEMENTATION:

The vector control is implemented using the PIC microntroller. The figure1.2 shows the block diagram of the Vector control of PMSM .The block diagram consist of three sensors. Proximity sensor to obtain the speed of the PMSM. Slot sensor to obtain the rotor position and three current sensors to obtain the three phase currents. The analog values are given to the microcontroller unit. The Microcontroller unit converts analog values to digital values.
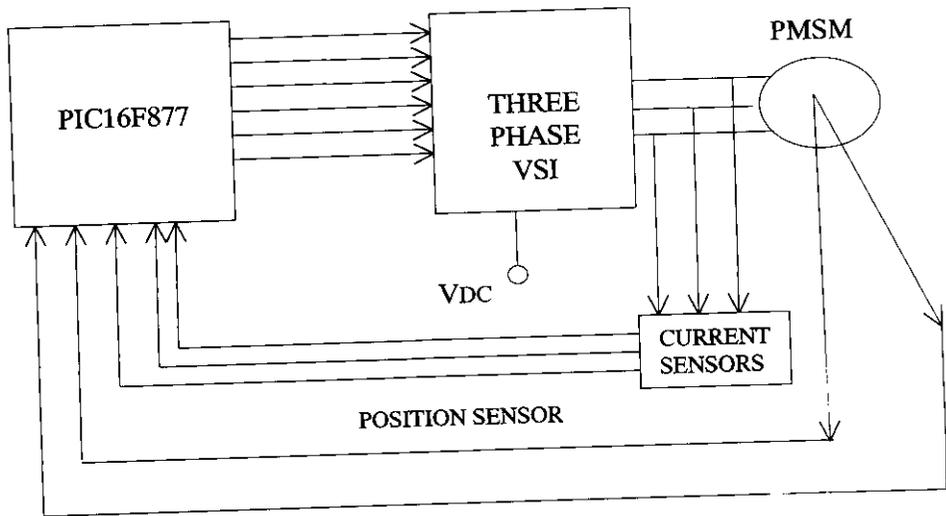
Figure 1.2 Block diagram of vector control of PMSM

The actual speed is compared with the reference speed and the error is generated which is given to the PI controller .The ouput from the PI controller is iq and id is set to zero. Then this transformed into three phase currents and this is compared with the actual stator currents and the required pulses are generated using the PWM module. This concept of vector control is implemented by software written in HI-TECH PICC. Six pulses are generated and given to the driver stage. The driver stage consist of optocoupler to amplify the signal and given to the three phase inverter. The output from the three phases is given to the PMSM.

CHAPTER 2

PERMANENT MAGNET SYNCRONOUS MOTOR

The PM Synchronous motor is a rotating electric machine where the stator is a classic three phase stator like that of an induction motor and the rotor is made of permanent magnets. The use of a permanent magnet to generate a substantial air gap magnetic flux makes the highly efficient PM motors. Compared to dc motors and induction motors, the PMSM has many advantages, especially high efficiency, high torque per volume and low moment of inertia. Also permanent magnet excited synchronous motor has no excitation losses. It is free of wear out and therefore needs no maintenance.

The Permanent Magnet Synchronous Motor is an important drive in servo, positioning and robotic applications. It gets increasing importance in the field of low cost drives as pumps, fans etc. Two configurations of permanent magnet brushless motor are usually considered:

1. The trapezoidal type (Brushless DC motor)
2. The sinusoidal type. (Permanent Magnet Synchronous Motor)

Depending on how the stator is wounded, the back-electromagnetic force will have a different shape (the BEMF is induced in the stator by the motion of the rotor). To obtain the maximum performance from each type of PMSM, an appropriate control strategy has to be implemented. The trapezoidal BEMF motor called DC brushless motor (BLDC) uses a "two phases on" strategy, whereas the sinusoidal BEMF motor offers its best performances when driven by sinusoidal currents (three phases on strategy).

The characteristic features of the brushless D.C. motor of square wave type are

1) Rectangular distribution of magnetic flux in the air gap

2) Rectangular current waveforms

3) Concentrated stator windings

The sinusoidal motor differs in all three aspects

1) Sinusoidal or quasi –sinusoidal distribution of magnetic flux in the air gap

2) Sinusoidal or quasi –sinusoidal current waveforms

3) Quasi –sinusoidal distribution of stator conductors, i.e., short pitched and distorted or concentric stator windings.

The quasi sinusoidal magnetic flux distribution around the air gap is achieved by tapering the magnet thickness at the pole edges and by using a shorter magnet pole arc, typically 120 degrees.

2.1 CONSTRUCTION OF PERMANENT MAGNET SYNCHRONOUS MOTOR

The permanent magnet 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.
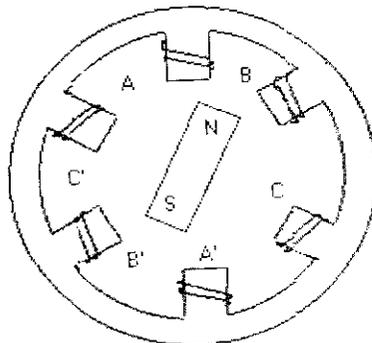

Figure 2.1 Three Phase Synchronous Motor with one Permanent Magnet rotor pole

The stator is laminated and has frequently slots like a classical AC stator. However, the stator may be skewed for reducing torque due slotting. Small PMSMs can be fitted with an air-gap winding system, hence no slots are used and the full winding space is filled with copper. This yields an extreme low stator inductance and hence high current per time. Different rotor constructions are possible. The magnets are either mounted on the surface of the rotor or buried in the interior of the rotor. The motor are classified as surface mounted PM motor and buried or interior PM motor.

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. There are mainly two ways to generate a rotor flux. One uses rotor windings to generate the rotor flux. A motor fitted out with rotor windings require brushes. The contacts are, in this case, made of rings and do not have any commutator segment; the lifetime of both the brushes and the motor may be similar. The drawback of this structure is it needs maintenance. Replacing common rotor field windings and pole structure with permanent magnets put the motor into the category of brushless motors. The rotor (equivalent to a bar magnet) is attracted by the energized stator phase, generating a rotation. By using the appropriate sequence to supply the stator phases, a rotating field on the stator is created and maintained. This action of the rotor - chasing after the electromagnet poles on the stator - is the fundamental action used in synchronous permanent magnet motors. The lead between the rotor and the rotating field must be controlled to produce torque. This synchronization implies knowledge of the rotor position.

It is possible to build brushless permanent magnet synchronous motors (PMSM) with any even number of magnetic poles. Motors have been constructed with 2 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. The use of magnets enables an efficient use of the radial space and replaces the rotor windings, therefore suppressing the rotor copper losses. Advanced magnet materials such as Sm_2Co_{17} or

NdFeB permit a considerable reduction in motor dimensions while maintaining a very high power density.

A point is reached where the supply voltage is maximum and the rotor field has to be weakened to obtain speed above base speed. The high-speed region is also called the field-weakening region, while a PMSM motor needs an angle shift to demagnetize the stator windings.

2.1 PMSM DRIVE SYSTEM

For a PMSM the rotor position information is fed back to the controller which generates the stator voltages according to the rotor position. So the rotor is always in synchronism with the rotating magnetic field. Such an arrangement is called the self controlled synchronous motor. Figure 2.2. shows the block diagram of PMSM in self control mode.The PM Synchronous motor drive system has the following components

1. Brushless motor
2. Position sensor
3. Switching Converter
4. Controller
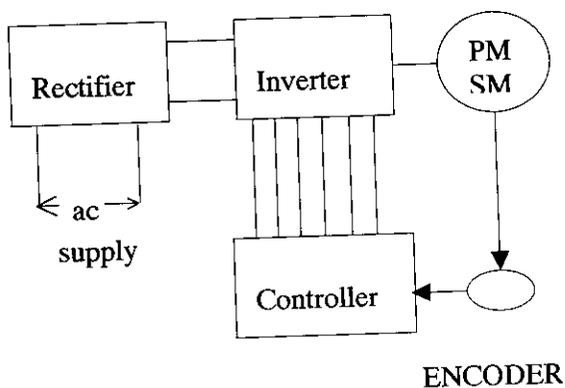
Figure 2.2 Block Diagram of PMSM
in Self Control Mode

BRUSHLESS MOTOR

The PM Synchronous motor is a rotating electric machine where the stator is a classic three phase stator, like that of an induction motor and the rotor has surface-mounted permanent magnets. In this respect, the PM Synchronous motor is equivalent to an induction motor where the air gap magnetic field is produced by a permanent magnet. The use of a permanent magnet to generate a substantial air gap magnetic flux makes it possible to design highly efficient PM motors. Brush maintenance is also not required.

The PM Synchronous motor is driven by sine wave voltage coupled with the given rotor position. The generated stator flux together with the rotor flux, which is generated by a rotor magnet, defines the torque. The sinusoidal output voltage have to be applied to the 3-phase winding system in a way that angle between the stator flux and the rotor flux is kept close to 90° to get the maximum generated torque. To meet this criteria, the motor requires electronic control for proper operation. With the rotor position feedback it can be held in synchronism with the inverter at all times ,and the rotor cage is not needed to run the machine up to the commanded speed.

For a common 3-phase PM Synchronous motor, a standard 3-phase power stage is used. The power stage utilizes six power transistors with independent switching. The sine wave output is generated using a PWM technique.

POSITION SENSOR:

The rotor position sensor is an integral part of the brushless dc motor system. The different types of sensors that can be used are

1. Electro optical sensors

2.Hall effect sensors

3.Resolvers

4.Digital encoders

The Hall Effect sensor can detect the magnitude and direction of a magnetic field. The three phase half wave motor requires three of these sensors symmetrically mounted on the stator to detect the magnetic field due to the main rotor magnet or due to separate shaft mounted mantes .The output signals from the sensors are processed to provide the logic signals required for the base drives circuits.

The electro optical sensor consists of a light –emitting diode (LED) of phototransistor, which act as a light transmitter and detector, respectively. A slotted wheel is mounted on the motor shaft with a number of stator mounted sensors around its periphery. Shaft relation produces a shutter action so the sensor outputs are switched high or low. Again, these output signals are processed to provide the logic signals required for electronic commutation.

Simple Hall or electro –optical sensors are appropriate for the trapezoidal type of brushless motor with its abrupt phase to phase current switching .In sinusoidal type of motor ,however, the phase current is a sinusoidal function of rotor position and an absolute encoder or resolver or other high resolution sensor is necessary to obtain position information with the required resolution .In absolute optical encoder ,an accurately patterned disk rotates between a light source ,giving a unique digital output signal for every shaft position .Standard encoders are available with up to 16-bit resolution and with natural binary, gray code or binary coded decima l output formats. However, each bit in the digital word represents an independent track on the encoder disk, resulting in a complex and costly sensor.

In permanent magnet synchronous motor, absolute rotor position information is required to at least 9-10 bit resolution. Sinusoidal reference current waveforms are generated with is precise positron information, and actual phase currents track the reference currents in a current controlled PWM inverter.

The provision of a high resolution sensor adds significantly to the cost of the sinusoidal system .On the other hand; BLDC motor has a rugged and inexpensive sensor and simple control logic.

SWITCHING CONVERTER

The power board can be designed to the required power range . The converter topology support either sinusoidal currents (Three phases ON operation) or direct currents (Two phases ON operation). Figure 2.3 shows the converter which is used here.
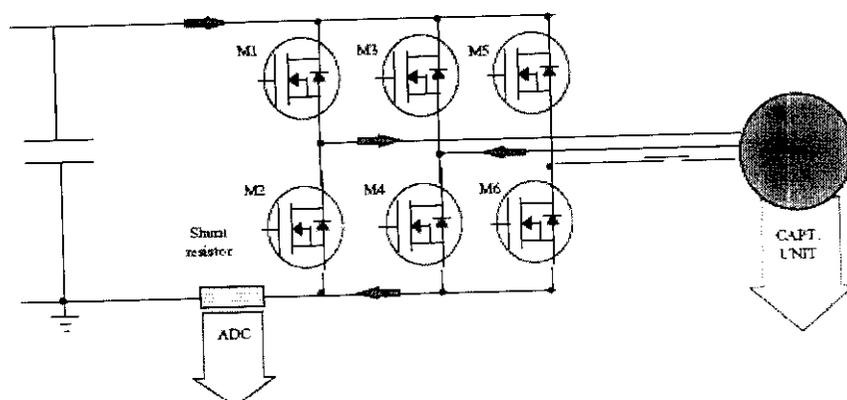
Figure2.3Switching Converter

The power switches uses the power MOSFET, of type IRF830. The PWM output signals coming from microcontroller unit are directly connected to the pre-driver without any additional buffer. The pre-driver output signals go through a resistor and then directly to the power switches. The relative ground of the upper half bridge is implemented with bootstrap capacitors. This hardware configuration allows hard chopping as well as soft chopping operation. All the elements for protection of the power device securities are provided. The current sensing is ensured by a low cost shunt resistor, its voltage drop is directly interfaced with the microcontroller unit. Finally, the power board supports the voltage supply for position sensors such as Hall Effect sensors and incremental encoders.

CONTROLLERS

Then different control strategies (and control hardware) are implemented. In this document, a control for the sinusoidal PMS motor is described. The different types of controllers are

1. Hysterisis current controller
2. PWM current source inverter
3. PWM based voltage source inverter
4. Space vector PWM controller

2..3 SPEED TORQUE CHARACTERISTICS
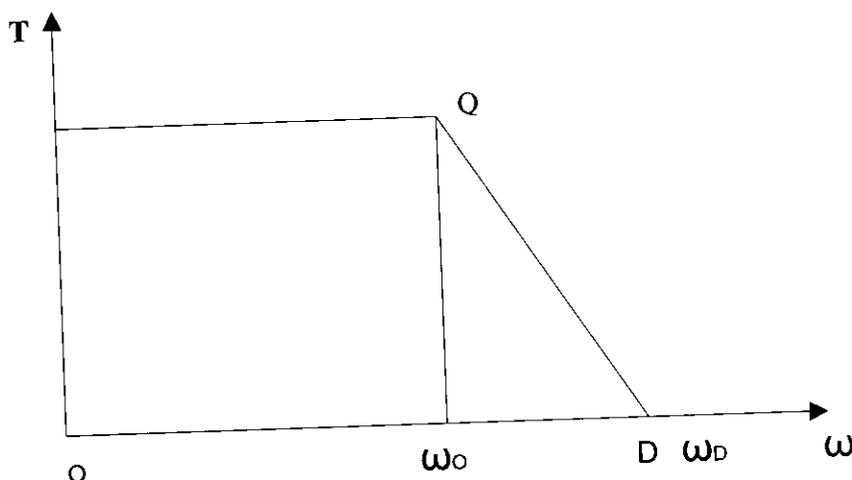
Figure 2.4.Speed Torque characteristics

The speed torque characteristic of PMSM is shown in Figure.2.4. Along OQ maximum torque can be developed with maximum current I oriented along q-axis. Q is the corner point, the maximum speed a which full torque is developed. Along QD the torque decreases until at point D it is zero , with maximum current I still flowing but oriented in the d-axis in the negative (demagnetizing) direction.

2.4 COMPARISON, ADVANTAGES AND APPLICATIONS OF PMSM

ADVANTAGES OF PMSM

The most obvious advantage of brushless configuration is the removal the brushes. Brush maintenance is no longer required and many problems associated with the brushes are eliminated.Brushses tend to produce RFI (Radio Frequency Interference) and the sparking associated with them is a potential source of ignition in inflammable atmospheres .The advantages of PMSM are

High reliability (no brush wear), even at very high achievable speeds

High efficiency

Low EMI

Sensorless speed control possible

Smooth rotation - without torque ripple

Appropriate for position control.

The torque does not drop in the low-speed region.

In the same frame with same cooling the PMSM motor will have better efficiency and power factor and therefore greater output power. Since the efficiency of brushless motors is higher than for an inverter-driven three-phase induction motor, the electricity consumption is greatly reduced. This contributes to energy savings for the factory.

Though PMSM has many advantages it does not come out without disadvantages. The two main disadvantages are

(i)The need for shaft position sensing

(ii) Increased complexity in electronic controller.

Thus it is important to weigh the advantage and disadvantages of brushless d.c motor relative to induction motor.

COMPARISON OF PMSM OVER INDUCTION MOTOR

FEATURES	PMSM	INDUCTION MOTOR
Speed Torque characteristics	Enables to operate at all speeds with rated load.	Non-linear-Lower torque at lower speed
Efficiency	High compared to induction motor.	Moderate
Output power per frame size	High-because small size PM's can be achieved for a given o/p power	Low because both stator and rotor has windings output power to size is low.
Rotor inertia	Low-because it has PM on rotor. This improves dynamic response.	Poor dynamic characteristics.
Starting current	No special starting circuit is required.	7 times the rated current. So starters are required.
Cost	Cost to build is high because of PM.A complex and expensive controller is required.	Low. No controller is required for fixed speed. But controller is required for variable speed.

TABLE: 1

APPLICATIONS OF PMSM

1. Appliances (washers, blowers, compressors)

2.HVAC (heating, ventilation and air conditioning)

3.Industrial servo drives (Motion control, Power supply inverters, Robotics)

4.Automotive control (Power steerings, Anti-lock brakes, Suspension controls)

CHAPTER 3

VECTOR CONTROL OF PERMANENT MAGNET SYNCHRONOUS MOTOR

A vector control is referring to the magnitude and to the phase of the control variables. Matrix and vectors are used to represent the control quantities. This method takes into consideration real mathematical equations that describe the motor itself. The space phasor theory is a method to handle the equations.

The vector control philosophy started to be developed around 1970 .Several types of vector control are possible: rotor-oriented, rotor-flux-oriented, stator-flux-oriented and magnetizing-flux-oriented . The final objective of the vector control philosophy is to control the electromagnetic torque in a way equivalent to that of a separately excited dc machine: Field-oriented control enables control over both the excitation flux-linkage and the torque-producing current in a decoupled way. However, only the rotor-flux-oriented control yields complete decoupling. Choosing a different flux orientation may outweigh the lack of complete decoupling for some special applications. Here, only the rotor-flux-oriented type of control, also termed "Field-Oriented Control" (FOC), is considered. FOC can be implemented as indirect (feed-forward) or direct (feedback) depending on the method used for rotor flux identification.

The direct FOC determines the orientation of the air-gap flux by use of a hall-effect sensor, search coil or other measurement techniques. However, using sensors is expensive because special modifications of the motor are required for placing the flux sensors. Furthermore, it is not possible to directly sense the rotor flux. Calculating the rotor flux from a directly sensed signal may result in inaccuracies at low speed due to the dominance of stator resistance voltage drop in the stator voltage equation and

inaccuracies due to variations on flux level and temperature. Indirect FOC does not have inherent low-speed problems and is therefore preferred in most applications. The difference between rotor and flux speed depends on the slip frequency being almost proportional to the generated electromagnetic torque. In the case of PMSM, the rotor flux linkage is inevitably fixed to the rotor position. The goal of FOC is to maintain the amplitude of the rotor flux linkage Φr at a fixed value, except for field-weakening operation or flux optimization, and only modify a torque-producing current component in order to control the torque of the ac machine. This control strategy is based on projections. Electromagnetic torque is produced by the interaction of stator flux linkages and stator currents (or rotor flux and rotor current), and can be expressed as a complex product of the flux and current space phasors. In order to gain a complete decoupling of torque and flux, the current phasor *is* is transformed into two components of a rotating reference frame: A flux producing component *id*, aligned with the d-axis representing the direction of the rotor flux phasor, and a torque-producing component *iq*, aligned with the q-axis perpendicular to the rotor flux. In this way, a linear relation between torque and torque producing current is achieved.

Thus, the electromagnetic torque generated by the motor can be controlled by controlling the q-axis current. This is equivalent to the torque control of a separately excited dc machine. As shown later, the rotor flux can be controlled directly by controlling the d-axis current. FOC provides fast dynamic response due to the independent torque and flux control of the ac machine making the control accurate in every operation point (steady state and transient).

3.1 ELECTRICAL EQUATIONS OF PMSM

In electric motors, two measures of position and speed are usually defined: mechanical and electrical .The mechanical position is related to the rotation of the rotor shaft .When the rotor shaft ha accomplished 360 mechanical degrees; the rotor is back in the same position where it is started. The electrical position of the rotor is related to the rotation of the rotor magnetic field. The electrical position of the rotor is

related tot the number of magnetic pole pairs on it. The electrical position of the rotor is linked to the mechanical position of the rotor by the relationship

$$\theta e = \theta mxP \tag{3.1}$$

The speed is related to the position by $\omega = d\Theta/dt$ (3.2)

The phase voltage is given by

$$Va = V \cos(\omega_e * t)$$
$$Vb = V \cos(\omega_e * t - 2\Pi/3) \tag{3.3}$$
$$Vc = V \cos(\omega_e * t + 2\Pi/3)$$

To create the rotating stator flux, the commonly applied phase voltages present a phase shift of 120 electrical degrees from one to another that tales into account the mechanical degrees angle between coils. A one phase electrical equation is given by

$$v = Z * i = Ri + d(Li + \Phi_m(\theta))/dt \tag{3.4}$$

From the electrical power delivered to the motor, part of it is transformed in joule losses, another part is going to the energy stored in the magnetic felid and the last part is transformed to mechanical energy (torque production).The torque production is expressed as

$$Te = P * \Phi_m * (Ia * k_a(\theta) + Ib * k_b(\theta) + Ic * k_c(\theta)) \tag{3.5}$$

Where
$$Ia = I_s \sin((\omega_e * t)$$
$$Ib = I_s \sin(\omega_e * t - 2\Pi/3) \tag{3.6}$$
$$Ic = I_s \sin(\omega_e * t + 2\Pi/3)$$

The goal of the Field Oriented Control is to perform real-time control of torque and to control the rotor mechanical speed and to regulate phase currents in order to avoid current spikes during transient phases. To perform these controls, the

electrical equations are projected from a 3 phase non rotating frame into a two co-ordinate rotating frame. These mathematical projections (Clarke & Park) greatly simplify the expression of the electrical equations and remove their time and position dependencies.

3.2 THE CLARKE AND PARKS TRANSFORMATION

The idea of the Clarke transformation is that the rotating stator current vector that is the sum of the 3 phase currents can also be generated by a bi-phased system placed on the fixed axis α and β.
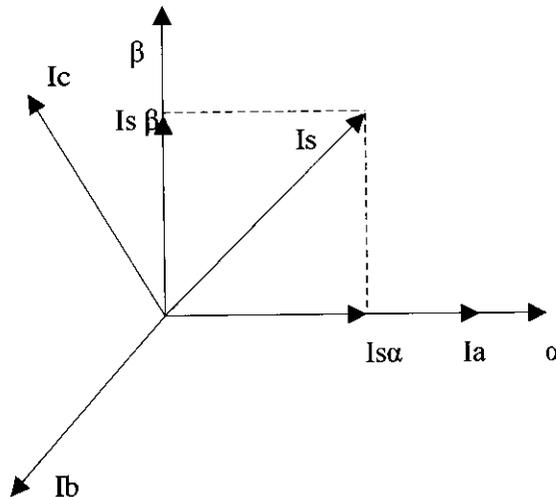
Figure 3.1 Phasor diagram for Clark's Transformation

$$Is\alpha=Ia$$
$$Is\beta=1/\Gamma3.Ic+2/\ \Gamma3.Ib \qquad\qquad (3.7)$$
$$Ia+Ib+Ic=0$$

In this new frame the expression of the torque is still dependent on the position of the rotor flux, preventing any easy solution of the electrical differential equation. To remove the dependency the electrical equations are projected in a 2 phase (d,q)systems that rotates at the electrical speed of the rotor .
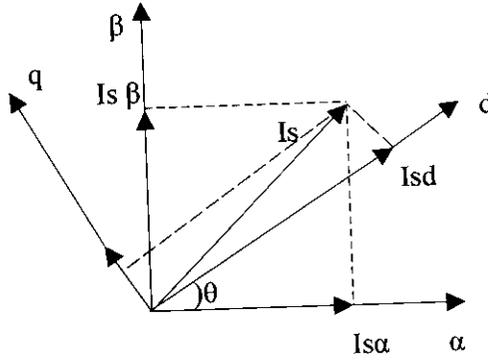
Figure 3.2 Phasor diagram for Park's Transformation

$$Isd= Is\alpha.\cos(\theta)+ Is\beta.\sin(\theta)$$
$$Isq= -Is\alpha.\sin(\theta)+ Is\beta.\cos(\theta) \qquad (3.8)$$

In this new system

$$Is=\Gamma(isd^2+isq^2) \qquad (3.9)$$
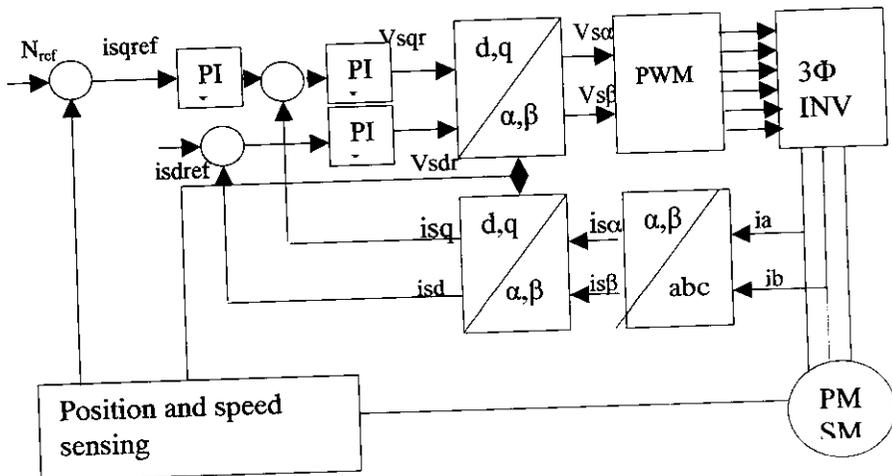
Figure 3.3 FOC of PMSM

In order to optimize the torque production for a given Is value ,the appropriate strategy is to set Isdref to 0. The action of current regulator is then shift to q-axis vector.ia and ib are measured with a current sensor. The Clarke transform is applied to them to determine the stator current projection in a two co-ordinate non-rotating frame. The Park co-ordinate transformation is then applied in order to obtain this projection in the (d,q) rotating frame. The (d,q) projections of the stator phase currents are then compared to their reference values Isqref and Isdref (set to 0) and corrected by mean of PI current controllers. The outputs of the current controllers are passed through the inverse Park transform and a new stator voltage vector is impressed to the motor using the pulse width modulation technique. In order to control the mechanical speed of the motor (speed FOC), an outer loop is driving the reference current Isqref.

However this approach needs more calculations than a standard control scheme. It can be solved by the use of a calculation unit included processor and has the following advantages:

Full motor torque capability at low speed

Better dynamic behavior

Higher efficiency for each operation point in a wide speed range

Decoupled control of torque and flux

Short term overload capability.

CHAPTER 4

INTELLIGENT CONTROL

Many methodologies have shown up in the field of intelligent control as Neural network, Fuzzy logic and genetic control providing a practical solution for nonlinear control problems. Artificial neural network have some desirable characteristics and capabilities similar to the brain system, such as parallel processing, learning, nonlinear mapping and genralisation.Fuzzy sets and technologies have also been implemented as new tool in many field. Therefore hybrid systems will form a key technology in the future.

An artificial neural network consists of many processing elements (neurons) joined together by connecting the output of each neuron to the inputs of other neurons through a set of connection weights.NN are usually trained by means of back propagation which tends to minimize error function. The main draw back of back propagation is that it is slow and in gradient descent method it may become trapped in local minima.

Fuzzy logic provides a means to convert the linguistic knowledge of human experts into a control strategy. Complete ill-defined processes, which cannot be analyzed, can be effectively handled by fuzzy control. However Fuzzy controllers lack a general systematic procedure for automatic rule learning and tuning.

Neural network and Fuzzy systems can essentially be applied to solve the same problems. As they have different advantages and drawbacks, it is quite reasonable to consider the possibility of integrating two paradigms into the same system. Various ways are available for implementing Fuzzy controllers by NN's and various fuzzifications of NN's are available.

4.1 MODEL OF NEURAL NETWORK

Artificial neural network is a highly simplified model of the biological neural network.. An ANN consists of interconnected processing units. The general model of a processing unit consists of a summing part followed by an output part. The summing part receives N inputs values ,weights each value and computes a weighted sum .The weighted sum is the activation value .The output part produces a signal from the activation value. The sign of the weight for each input determines whether the input is excitory (positive weight) or inhibitory (negative weight). Either way, the output of the summing function is then sent into a transfer function. This function then turns this number into a real output via some algorithm. It is this algorithm that takes the input and turns it into a zero or a one, a minus one or a one, or some other number.
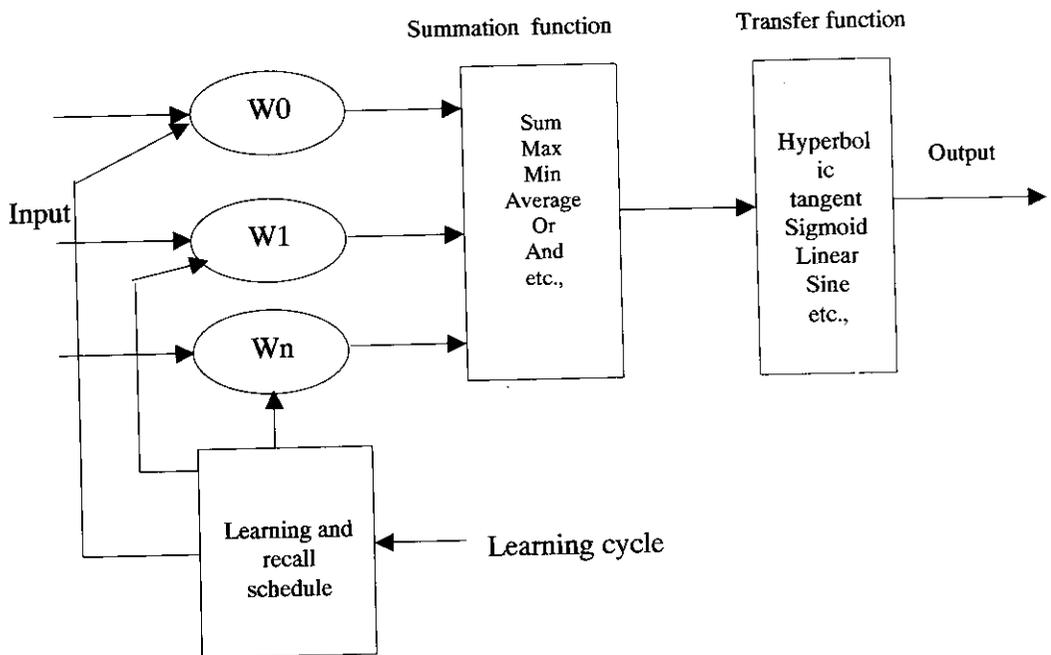
Figure 4.1 Model of a processing Element

The transfer functions that are commonly supported are sigmoid, sine, hyperbolic tangent, etc.The inputs could be discrete or continuous data values, and likewise the outputs also could be deterministic or stochastic or fuzzy.

There are three models of artificial neuron or proceesing unit.They are

1.McCulloch-Pitts model

2.Perceptron

3.Adaline

4.2 COMPONENTS OF AN ARTIFICIAL NEURON

There are seven major components which make up an artificial neuron. These components are valid whether the neuron is used for input, output, or is in one of the hidden layers.

Weighting Factors:

Weights are adaptive coefficients within the network that determine the intensity of the input signal as registered by the artificial neuron. They are a measure of an input's connection strength. These strengths can be modified in response to various training sets and according to a network's specific topology or through its learning rules.

Summation Function:

The first step in a processing element's operation is to compute the weighted sum of all of the inputs. Mathematically, the inputs and the corresponding weights are vectors which can be represented as (i1, i2 . . . i*n*) and (w1, w2 . . . w*n*). The total input signal is the dot, or inner, product of these two vectors. This simplistic summation function is found as input 1 = i1 * w1, input2 = i2 * w2, etc., are added as input1 + input2 + . . . + inputn. The result is a single number, not a multi-element vector.

The summation function can be more complex than just the simple input and weight sum of products. The input and weighting coefficients can be combined in

many different ways before passing on to the transfer function. In addition to a simple product summing, the summation function can select the minimum, maximum, majority, product, or several normalizing algorithms. The specific algorithm for combining neural inputs is determined by the chosen network architecture and paradigm

Transfer Function:

The result of the summation function, almost always the weighted sum, is transformed to a working output through an algorithmic process known as the transfer function. In the transfer function the summation total can be compared with some threshold to determine the neural output. If the sum is greater than the threshold value, the processing element generates a signal. If the sum of the input and weight products is less than the threshold, no signal (or some inhibitory signal) is generated. Both types of response are significant.

The threshold, or transfer function, is generally non-linear. Linear (straight-line) functions are limited because the output is simply proportional to the input. Linear functions are not very useful. Another type of transfer function, the threshold or ramping function, could mirror the input within a given range and still act as a hard limiter outside that range. It is a linear function that has been clipped to minimum and maximum values, making it non-linear. Yet another option would be a sigmoid or S-shaped curve. That curve approaches a minimum and maximum value at the asymptotes. It is common for this curve to be called a sigmoid when it ranges between 0 and 1, and a hyperbolic tangent when it ranges between -1 and 1.

Scaling and Limiting:

After the processing element's transfer function, the result can pass through additional processes which scale and limit. This scaling simply multiplies a scale factor times the transfer value, and then adds an offset. Limiting is the mechanism which insures that the scaled result does not exceed an upper or lower bound. This

limiting is in addition to the hard limits that the original transfer function may have performed.

Output Function

Each processing element is allowed one output signal which it may output to hundreds of other neurons. Normally, the output is directly equivalent to the transfer function's result. Some network topologies, however, modify the transfer result to incorporate competition among neighboring processing elements. Neurons are allowed to compete with each other, inhibiting processing elements unless they have great strength.

Error Function and Back-Propagated Value:

In most learning networks the difference between the current output and the desired output is calculated. This raw error is then transformed by the error function to match particular network architecture. The most basic architectures use this error directly, but some square the error while retaining its sign, some cube the error, and other paradigms modify the raw error to fit their specific purposes. The artificial neuron's error is then typically propagated into the learning function of another processing element. This error term is sometimes called the current error.

The current error is typically propagated backwards to a previous layer. Normally, this back-propagated value, after being scaled by the learning function, is multiplied against each of the incoming connection weights to modify them before the next learning cycle.

Learning Function:

The purpose of the learning function is to modify the variable connection weights on the inputs of each processing element according to some neural based algorithm. This process of changing the weights of the input connections to achieve some desired result can also be called the adaption function, as well as the learning mode.

4.3 TRAINING AN ARTIFICIAL NEURAL NETWORK.

Once a network has been structured for a particular application, that network is ready to be trained. To start this process the initial weights are chosen randomly. Then, the training, or learning, begins. There are two approaches to training - supervised and unsupervised. Supervised training involves a mechanism of providing the network with the desired output either by manually "grading" the network's performance or by providing the desired outputs with the inputs. Unsupervised training is where the network has to make sense of the inputs without outside help.

In supervised training, both the inputs and the outputs are provided. The network then processes the inputs and compares its resulting outputs against the desired outputs. Errors are then propagated back through the system, causing the system to adjust the weights which control the network. This process occurs over and over as the weights are continually tweaked. The set of data which enables the training is called the "training set." During the training of a network the same set of data is processed many times as the connection weights are ever refined

Many learning laws are in common use. Most of these laws are some sort of variation of the best known and oldest learning law, Hebb's Rule. Research into different learning functions continues as new ideas routinely show up in trade publications. Some researchers have the modeling of biological learning as their main objective. Others are experimenting with adaptations of their perceptions of how nature handles learning. Either way, man's understanding of how neural processing actually works is very limited. Learning is certainly more complex than the simplifications represented by the learning laws currently developed. A few of the major laws are

Hebb's Rule

Hopfield Law

The Delta Rule

Gradient Descent Rule

Kohonen's Learning Law

Every neural network possesses knowledge which is contained in the values of theconnections weights. Modifying the knowledge stored in the network as a function of experience implies a learning rule for changing the values of the weights. Information is stored in the weight matrix W of a neural network. Learning is the determination of the weights. Following the way learning is performed, we can distinguish two major categories of neural networks:

Fixed networks in which the weights cannot be changed, ie $dW/dt=0$. In such networks, the weights are fixed a priori according to the problem to solve.Adaptive networks which are able to change their weights, ie dW/dt not$= 0$.

The rate at which ANNs learn depends upon several controllable factors. In selecting the approach there are many trade-offs to consider. Obviously, a slower rate means a lot more time is spent in accomplishing the off-line learning to produce an adequately trained system. Usually this term is positive and between zero and one. If the learning rate is greater than one, it is easy for the learning algorithm to overshoot in correcting the weights, and the network will oscillate. Small values of the learning rate will not correct the current error as quickly, but if small steps are taken in correcting errors, there is a good chance of arriving at the best minimum convergence.

4.4 FUZZY LOGIC

Fuzzy logic is a super-set of Boolean logic which has been extended to allow for partial truths. This means that it can handle things which are neither completely true nor completely false. Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems.

Some of the terms that are used in fuzzy sets are Degrees of membership which is defined as how much of a member the fuzzy subset F of a set S is. A 0

represents complete non-membership, and a 1 represents complete membership. Any numbers in between represent how much of a member F is of S.Membership function is the mapping of the values of a set S onto the range [0,1].

Fuzzy logic is implemented in three phases (see Figure 4.2):

1. Fuzzification (crisp input to fuzzy set mapping).

2. Inference (fuzzy rule generation).

3. Defuzzification (fuzzy to crisp output transformation).
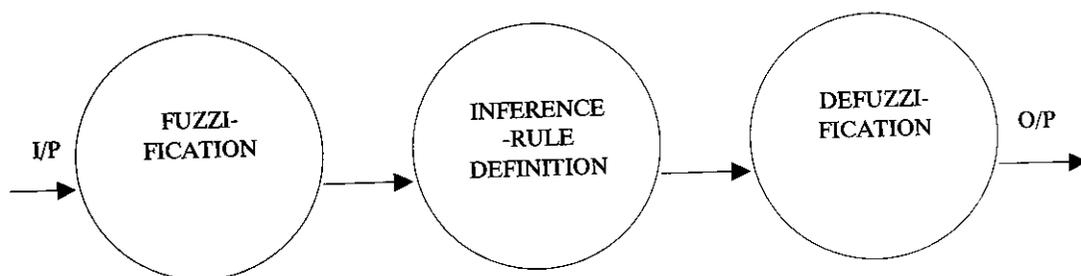
Figure 4.2 Fuzzy logic phases

a) Fuzzification

Establishes the fact base of the fuzzy system. First, it identifies the input and output of the system. Fuzzification then defines appropriate IF THEN rules and uses raw data to derive a membership function. At this point, one is ready to apply fuzzy logic to the system. In the first fuzzy logic phase—fuzzification—actual measured input values are mapped into fuzzy membership functions. The Fuzzification can be a Logical decision,Normalisation or Knowledge Based.

b)Inference

The next step is to define the fuzzy rules. The fuzzy rules are mearly a series of if-then statements as mentioned above. These statements are usually derived by an expert to achieve optimum results. As inputs are received by the system, inference

evaluates all IF THEN rules and determines their truth values. If a given input does not precisely correspond to an IF THEN rule, then partial matching of the input data is used to interpolate an answer.

The logical products for each rule must be combined or inferred (max-min'd, max-dot'd, averaged, root-sum-squared, etc.) before being passed on to the defuzzification process for crisp output generation. Several inference methods exist.

c) Defuzzification

Combines all fuzzy conclusions obtained by inference into a single conclusion. Different fuzzy rules might have different conclusions, so it is necessary to consider all rules. There are a number of composition methods available, but they lie beyond the scope of this introduction. The different defuzzifications methods are

1) Maximum of maximum
2) Sum of Maximum
3) Centre of gravity
4) Smallest of maximum
5) Mean of maximum.

Tuning and system enchancement

Tuning the system can be done by changing the rule antecedents or conclusions,changing the centers of the input and/or output membership functions, or adding additional degrees to the input and/or output functions such as "low", "medium", and "high" levels of "error", "error-dot", and output response. These new levels would generate additional rules and membership functions which would overlap with adjacent functions forming longer "mountain ranges" of functions and responses. The techniques for doing this systematically are a subject unto itself.

4.5 FUZZY LOGIC TOOLBOX

This package has two general methods which may be used for fuzzy inference:

1. The Mamdani form of fuzzy rules where the right-hand side of each rule is a fuzzy set.The rules are evaluated using one of many variants of Mamdani inference .

2. The Sugeno form of fuzzy rules where the right-hand side is either a constant (zero-order) or a more general function of the inputs.The results are combined using a weighted average.

The FIS Editor displays a menu bar that allows you to open related GUI tools, open and save systems, and so on.The two FIS editor are   New Mamdani FIS and New Sugeno FIS. Five pop-up menus are provided to change the functionality of the five basic steps in the fuzzy implication process:

- And method: Choose min, prod, or Custom, for a custom operation.

- Or method: Choose max, probor (probabilistic or), or Custom, for a custom operation.

- Implication method: Choose min, prod, or Custom, for a custom operation. This selection is not available for Sugeno-style fuzzy inference.

- Aggregation method: Choose max, sum, probor, or Custom, for a custom operation. This selection is not available for Sugeno-style fuzzy inference.

- Defuzzification method: For Mamdani-style inference, choose centroid, bisector, mom (middle of maximum), som (smallest of maximum), lom (largest of maximum), or Custom, for a custom operation. For Sugeno-style inference, choose between wtaver (weighted average) or wtsum (weighted sum).

The Fuzzy Logic Toolbox includes 11 built-in membership function types. These 11 functions are, in turn, built from several basic functions

The simplest membership functions are formed using straight lines. Of these, the simplest is the triangular membership function, and it has the function name trimf.It's nothing more than a collection of three points forming a triangle. The trapezoidal membership function, trapmf, has a flat top and really is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity. Two membership functions are built on the Gaussian distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves. The two functions are gaussmf and gauss2mf.

The generalized bell membership function is specified by three parameters and has the function name gbellmf. The bell membership function has one more parameter than the Gaussian membership function, so it can approach a non-fuzzy set if the free parameter is tuned. Because of their smoothness and concise notation, Gaussian and bell membership functions are popular methods for specifying fuzzy sets. Both of these curves have the advantage of being smooth and nonzero at all points.

The sigmoidal membership function, which is either open left or right. Asymmetric and closed (i.e. not open to the left or right) membership functions can be synthesized using two sigmoidal functions, so in addition to the basic sigmf, we also have the difference between two sigmoidal functions, dsigmf, and the product of two sigmoidal functions psigmf.

CHAPTER 5

NEURO-FUZZY BASED FOC OF PMSM

The vector control principle consists of controlling the angle and amplitude components of the stator field. For ease of motor equation representation, the components of the stator current are represented in a rotating reference frame d ,q aligned with the rotor axis, i.e., with the magnet flux. The motor torque for a permanent magnet machine depends only on the quadrature (q) current component (torque component). In this case, the most convenient control strategy is to set to zero the direct (d) current component to minimize the torque vs. current ratio and then increase the motor (and Converter)efficiency. The control of current components requires the knowledge of the instantaneous rotor position.

The dynamic model of the PMSM is required to derive the field oriented control algorithm .The rotor frame is chosen as reference because the position of the rotor magnets determines ,independently stator voltage and current, the instantaneous induced emf and subsequently the stator currents and torque of the motor.

5.1 MODELLING OF PMSM

The machine model with respect to rotor reference frame is described as follows based on the assumptions that the air gap is uniform and motor is excited by sinusoidal supply. Also the induced emf is sinusoidal. Eddy currents and hysteresis losses are negligible. There are no field current dynamics .Saturation is neglected. With these assumptions, the stator d, q equations of the PMSM in the rotor reference frame are given by the equations (5.1) and (5.2)

$$V_q = Ri_q + p\lambda_q + \omega_s\lambda_d \qquad (5.1)$$

$$V_d = Ri_d + p\lambda_d - \omega_s\lambda_q \qquad (5.2)$$

Where

$$\lambda_q = L_q\, i_q \qquad (5.3)$$

$$\lambda_d = L_d\, i_d + L_{md}\, I_{fd} \qquad (5.4)$$

$$\lambda_{af} = L_{md}\, I_{fd} \qquad (5.5)$$

$$\omega_s = P\,\omega_r \qquad (5.6)$$

The electric torque is expressed as

$$T_e = 3P[L_{md}\, I_{fd}\, i_q + (L_d - L_q)\, i_q i_d/2 \qquad (5.7)$$

and the equation for motor dynamics is

$$T_e = T_L + B\,\omega_r + Jp\,\omega_r \qquad (5.8)$$

Depending upon the type of controller and switching technique used the modeling may differ. If i_d is forced to zero,then

$$\lambda_d = \lambda_{af} \qquad (5.9)$$

$$T_e = 3P\,\lambda_{af}\, i_q /2 \qquad (5.10)$$

$$T_e = Kt\, i_q \qquad (5.11)$$

$$Kt = 3P\,\lambda_{af} /2 \qquad (5.12)$$

Equation (5.11) is similar to that of a separately excited dc motor, and this is the transformation of PMSM to an equivalent separately excited dc motor. Since the generated motor torque is linearly proportional to the q-axis current, the maximum torque per ampere can be achieved.

SYSTEM CONFIGURATION

The machine, speed and position feedback, speed and current controllers, and inverter constitute the PMSM drive system as shown in Figure 5.1. The error between the reference and actual speeds is operated upon by the speed controller to generate the torque reference. In the constant air gap flux mode of operation where id*=0, the torque reference is divided by the motor torque constant to give the reference quadrature axis current. This goes through the inverse Park transform to generate the a,b,c, stator reference currents. The hysteresis or PWM current controller attempts to force the actual motor currents to equal the commanded values at all times.

Rotor position feedback is needed to generate these currents. Current feedback is required for the hysteresis or PWM current controllers to chives this. Current control is implemented by the appropriate firing of power devices T1-T6 as discussed previously. Both position and speed feedback can be obtained from the resolver/signal processor combination.

Figure 5.1 System configuration of a field oriented

synchronous motor drive

The configuration of a field oriented PM synchronous motor drive is shoωn in Figure5.1,which consist of current controlled PWM voltage source inverter(VSI),a field oriented mechanism, including co-ordinate translator, Speed control loop and current control loop.

The actual speed is compared with the reference speed. The error signal is given to a PI speed controller. The output of the speed controller is iqs*and ids* is zero. The rotor position is received from the signal processor. Using the two phase to three phase transformation the reference currents ia*,ib*,ic* are calculated from iqs* and ids*.Then this is compared with the actual value of phase currents in the current controller and base drive amplifier circuit. Then the thyristors are triggered. The simplified control system block diagram with PI controller is shown in Figure.5.2.

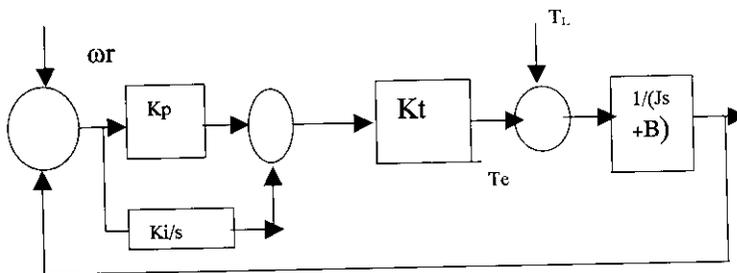Figure 5.2 Simplified control system block diagram
with PI controller

$$wr^* \over wr = H(s) \tag{5.13}$$

$$H(s) = \frac{(sKt.Kpb+KiKtb)}{(s2+sKtKpb+KiKtb)} \tag{5.14}$$

$$Hs(s) = \frac{1}{(Js+B)=b/(s+a)} \tag{5.15}$$

Let U=Kt/b (5.16)

Hence

Kp=2xKs/U (5.17)

Ki=(Ks)2xTs/U (5.18)

Ks=1/4Ts (5.19)

where Ts is sampling time of speed controller

The PMSM used in this system is a three phase four pole 330V,10A,1500 rpm type.The coordinate translation of the current from two phase to three phase is given by inverse of park's transformation

$$
\begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} = \begin{bmatrix} \cos\Theta & \sin\Theta & 1 \\ \cos(\Theta-120) & \sin(\Theta-120) & 1 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} iq \\ id \\ io \end{bmatrix} \quad (5.20)
$$

The speed loop controller is implemented PI controller. The drive model is consist of the following datas (on a scaling of 50 rad/s/V). Kt=.6732Nm/A, J=0.066Nmsrad/V.

5.2 NEURO-FUZZY CONTROLLER

The Proposed Neuro-Fuzzy controller consist of a neural network controller and a Fuzzy logic controller. The output of the neural network controller is given to the Fuzzy logic controller. The neural network is formed by three layers. The signal propagation and basic function in each layer is different. Each layer had its limitation. So in choosing the optimum output from the three networks a fuzzy logic controller was introduced. The structure is shown in Figure.5.3.There are two inputs, both these inputs are given to three network layers. Each layer consists of one hidden layer and one input layer and one output layer. The descriptions is given in Table.1.All network has same number of layers except the transfer function.

DESCRIPTION OF NEURAL NETWORK

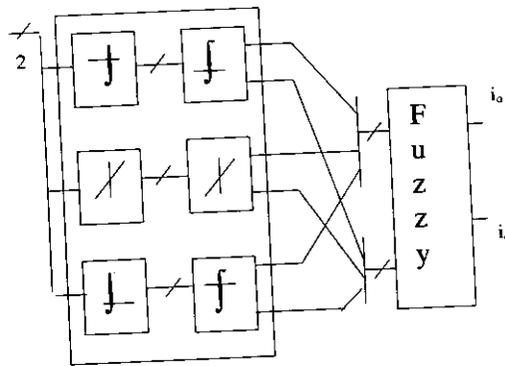The inputs to the neural network layer are error signal and the derivative of the error signal .

Figure 5.3 .Neural Network and Fuzzv controller

Number of input neurons	2
Number of output neurons	2
Number of hidden layers	1
Number of hidden neurons	6

Table.2

Network1:   The inputs x1 correspond to e of the speed and x2 corresponds to derivative of the error. The transfer function of the hidden layer is log sigmoid .Logsigmoid responds to complex integrals . The log sigmoid function is given by

$$y_i^1 = 1 / (1 + \exp(-z_i)) \qquad (5.21)$$

$$z = x1p_i + x2q_i \quad i = 1, 2 \dots 6 \qquad (5.22)$$

The output of the hidden layer is given to output neurons whose transfer function is tansigmoid. The tansigmoid algorithm is given by

$$y_j^2 = 2/(1+\exp(-2* z_j))-1 \qquad (5.23)$$

$$z_j = \sum y_i^1 r_j \quad j=1,2 \; i=1,2....6 \qquad (5.24)$$
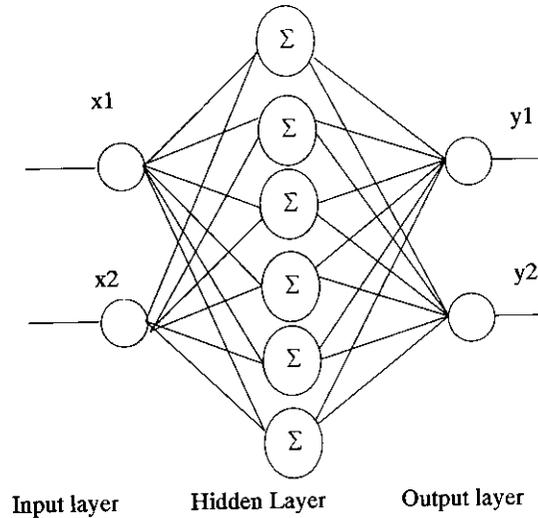

Input layer   Hidden Layer   Output layer

Figure 5.4..Schematic diagram of Neural Network controller

Network 2: Network 2 is formed by pure linear transfer functions which to propotional controllers. The pure linear function is given by f(x)=x.

	Hidden Layer	Output Layer
NETWORK1	Log sigmoid	Tan sigmoid
Layer 2	Pure Linear	Pure Linear
Layer 3	Tan sigmoid	Log sigmoid

Table.2

Network3 : Network 3 is formed by reverse of first layer that is hidden layer transfer function is tansigmoid which responds to integral controller and output layer transfer function is log sigmoidal.The networks are similar to the network1 except the transfer function.

FUZZY CONTROLLER DESCRIPTION

A Sugeno fuzzy inference system is extremely well suited to the task of smoothly interpolating the linear gains similarly, a Sugeno system is suited for modeling nonlinear systems. There are totally 6 outputs, i.e 2 output from each neural network, the outputs corresponds to id and iq which is the intermediate values. There are 3 iq's and 3 id's.The best among these three values of the two parameters are chosen by means of fuzzy logic rules. The input membership function is a guassian distribution function. The Gaussian membership function is used since the response is nonlinear. The intervals indices are calculated and also the degree of the membership functions. The equation is given by equation (5.25).

$$f(x)= 1/(1+obs\{[(x-c)/a]\}^{2b} \qquad (5.25)$$

where c is mean, b is the shape function and a is standard deviation.

From the current values calculate the degree of membership function. Take the maximum of two values. From each MF one value is obtained. Thus three id's are obtained. Form the rules based on which curve either low or high the value lies. For example in id1 (network1) 0.8 is maximum value it lies in L. Thus valid rules are framed. Totally 8 rules are framed for id and also for iq the rules are framed.

The rules are based on the condition true. The rule base is developed by self tuning. For each of the output from the neural network the rules are applied and from the fuzzy rule table four valid rules are identified. Using the logic operator .A crisp value is calculated by defuzzification.Weight average method from the rule obtained and the point is marked on the output membership function.

5.3 SIMULATION RESULTS

The field oriented speed control of PMSM using neural and Fuzzy approach are simulated using the MATLAB (simulink) .First a PI controller was designed and its outputs were obtained. Then the proposed neural network with fuzzy logic controller was simulated and trained with PI as the reference model.

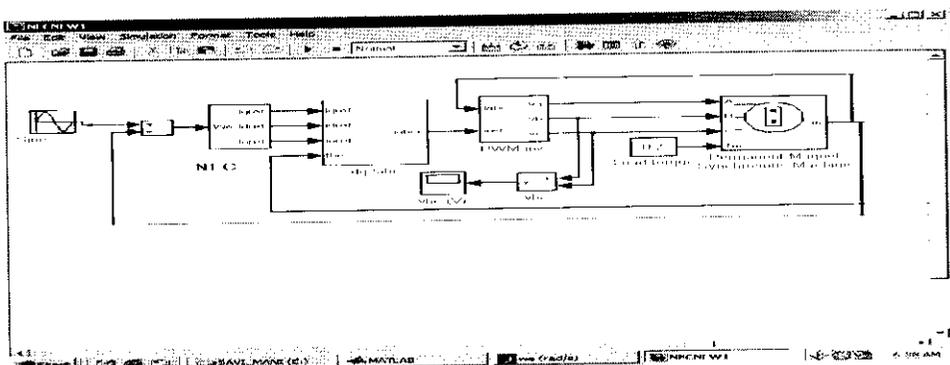The figure shows the block set of vector control of PMSM and also neuro fuzzy block sets are shown.

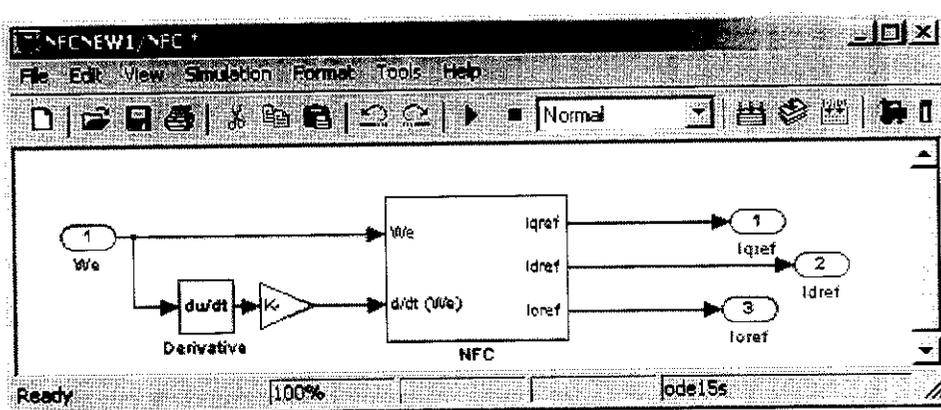Figure 5.5.The Field oriented control of PMSM using Simulink

Figure 5.6 .Neuro-fuzzy blocks
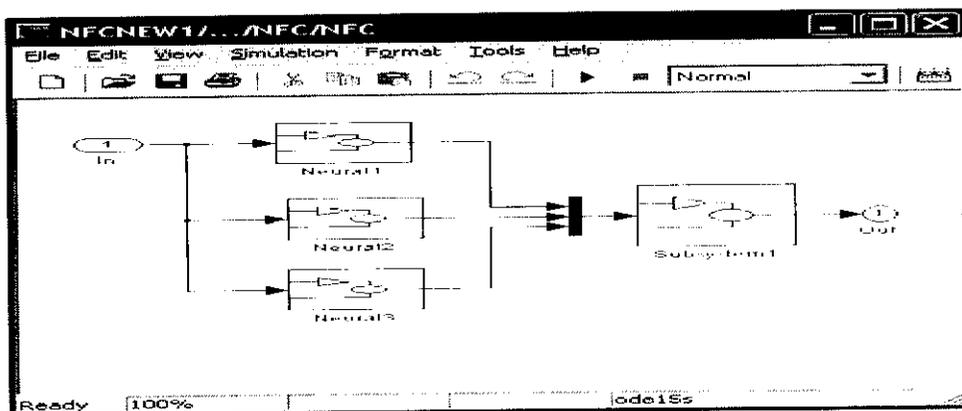
The carrier frequency is 100Khz.The sampling time for the PI speed controller is 1 microsecond. The simulation results are shown . Figure 5.7 and Figure5 .8 shows the output current(three phase currents) and voltage.The x-axis is the representation of time.
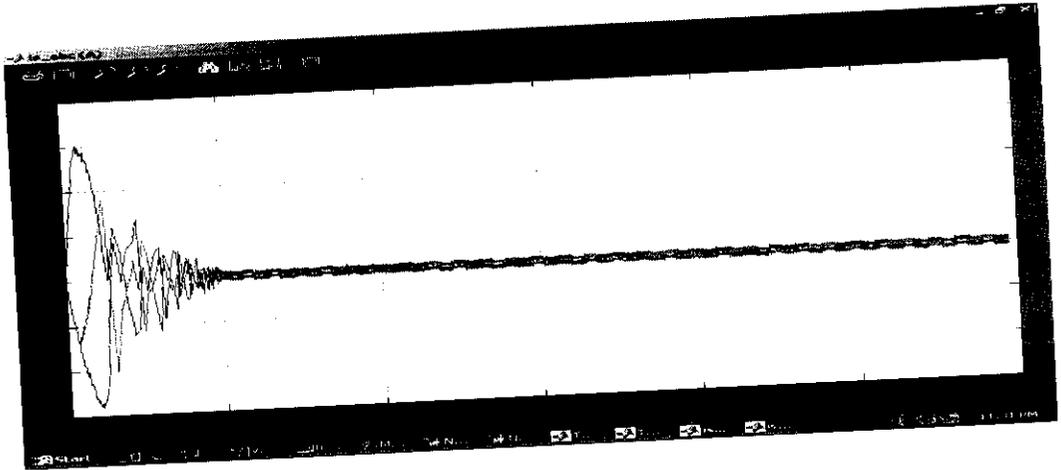
Figure 5.7 .Stator currents using NFC control
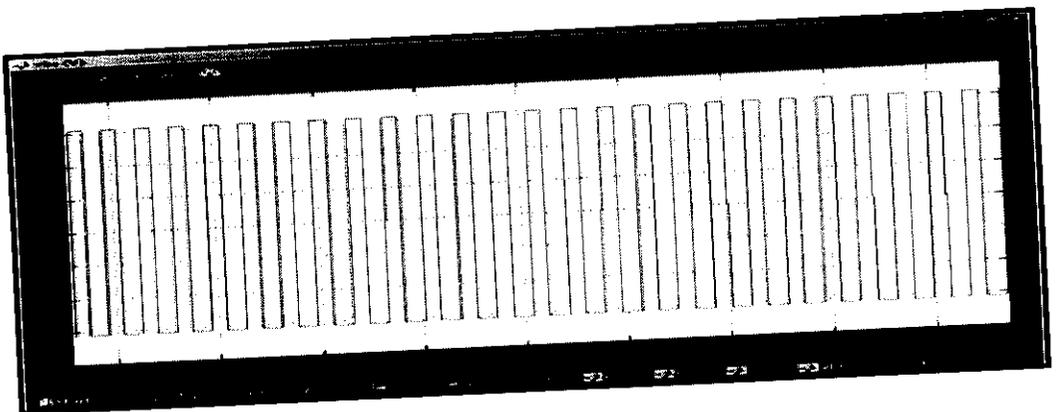
Figure 5.8 .PWM based output voltage

It is seen that the PI controller output is dominating over the Neuro-fuzzy controller. From the result it can be seen that the settling frequency is higher i.e the time of settlement is faster. Peak overshoot is reduced. Figure 5.12 and Figure5.13 shows the speed at 500 rpm for constant reference input and for sinusoidal reference input.

The results shows the three phase stator currents for Load torque of 5 Nm and 3 Nm Fig.11.shows the change in three phase currents for a change in the load torque from 5 to 3 Nm.
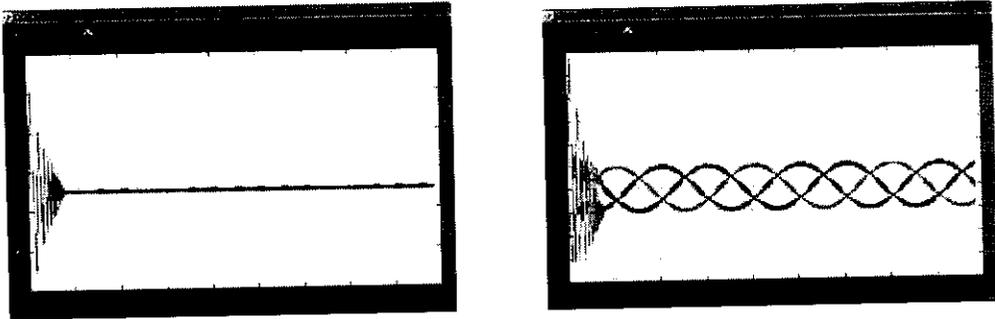
Figure 5.9 3Φ Stator current for a load torque of 3Nm.
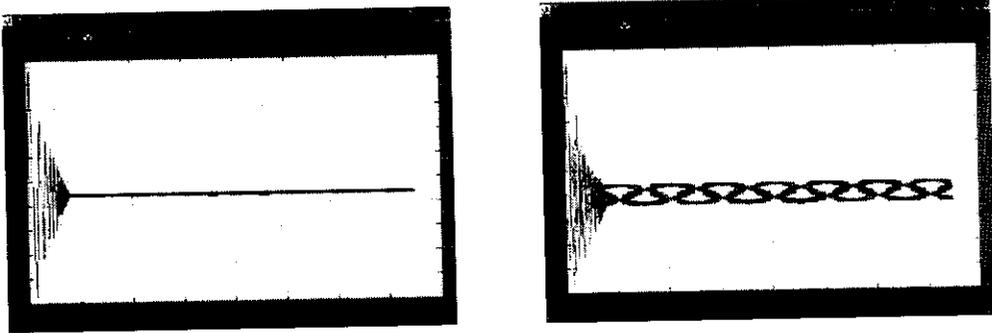
Figure 5.10 3Φ Stator current for a load torque of 5 Nm.
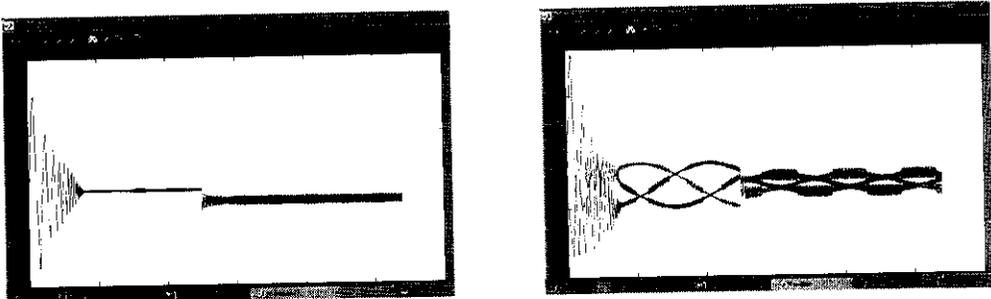
Figure 5.11 3Φ Stator current for a load torque change from 5Nm to 3 Nm.
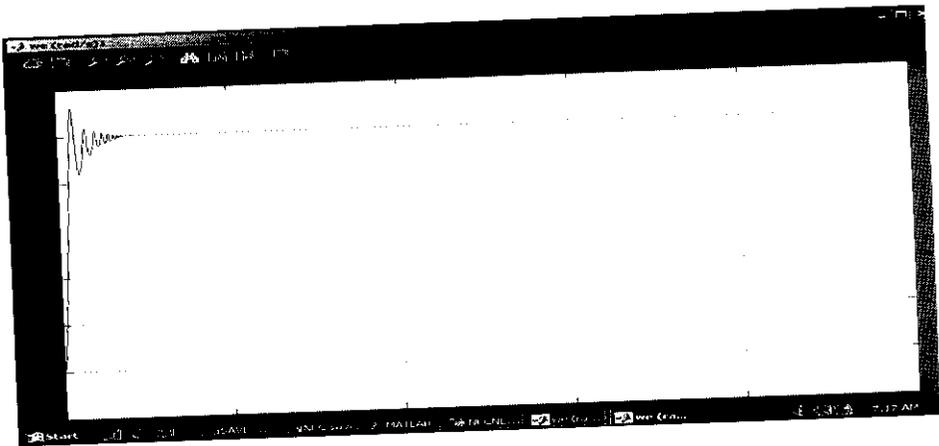
Figure 5.12 .Output response for the constant input reference speed
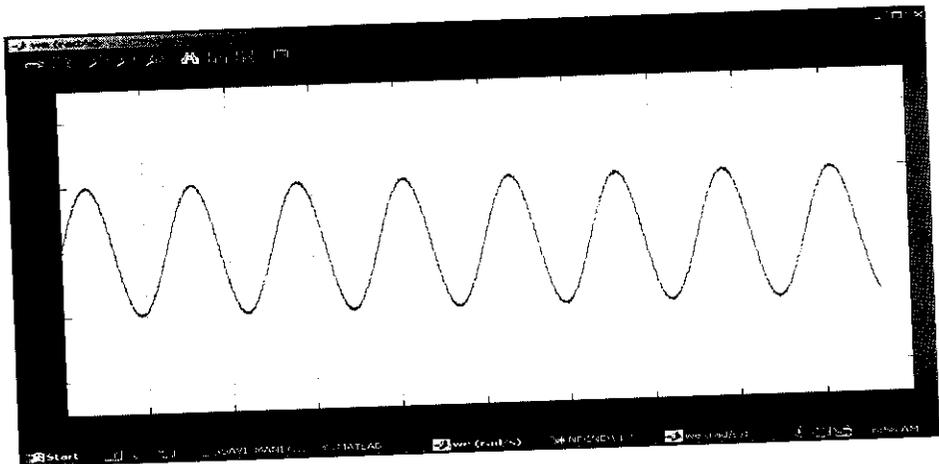
Figure 5.13.Output response for the sinusoidal input reference speed

The comparable result showed that improvement of speed tracking performance which has been done in Matlab using simulink.Also the variation of the stato currents for the increase in torque is also shown.

CHAPTER 5

HARDWARE IMPLEMENTATION

The vector control is implemented using the PIC microntroller. .PIC is 8 bit microntroller having many peripheral devices and inbuilt memory sufficient to implement vector control.

6.1 HARDWARE COMPONENTS

The block diagram consists of three sensors. Proximity sensor to obtain the speed of the PMSM. Slot sensor to obtain the rotor position and three current sensors to obtain the three phase currents. The analog values are given to the microcontroller unit. The Microcontroller unit converts into digital values. With these datas the required pulses are generated using the PWM module. The concept of vector control is implemented by software written in HI-TECH PICC. Six pulses are generated and given to the driver stage. The driver stage consist of optocoupler to amplify the signal and given to the three phase inverter. The hardware requirements are as follows

1. Microcontroller unit(PIC16F877)
2. Power supply unit
     a) For microcontroller   b) For inverter
3. Sensors
     a) Speed sensor
   b) Current sensor
     c) Position sensor
5. LCD module

The control unit is P16F877.PIC is an 8 bit microcontroller. The vector control logic is implemented as software written in HITECH PICC language. The codings are written in MP LAB IDE.The program is debugged using the software debugger. The

circuit diagram with the interfacing unit is shown in Figure 6.1. The architecture of PIC microcontroller is discussed. There are two power supply unit one for the PIC .The other supply unit required is 230 volts ac supply. This is converted into DC supply using bridge converter.LCD module is used for display of speed. The other interfacing unit is USART which is used for communication with PC.The various parameters can be made to be displayed in the PC.The hardware is designed to drive a 3 phase Permanent synchronous motor whose motor ratings are as follows

Motor 1:

      Voltage rating: 230V

      Current   : 500mA

      Frequency   : 50 Hz

      Application   : Large clocks

Motor 2:

      Max voltage: 24 AC

      Current   : 10A

      Frequency   : 150-400Hz

      Application: Electric bikes

      Manufactures : S.K.Dynamics

                      Roorkhee

                      Uttranchal

The Hardware designed for the motor 2 did not work and the MOSFETS were damaged twice. Thus the hardware were redesigned for the motor1 and the complete model was made to function.Also the position sensor for the vector control requires high cost resolver.So a position sensor of less resolution was designed .
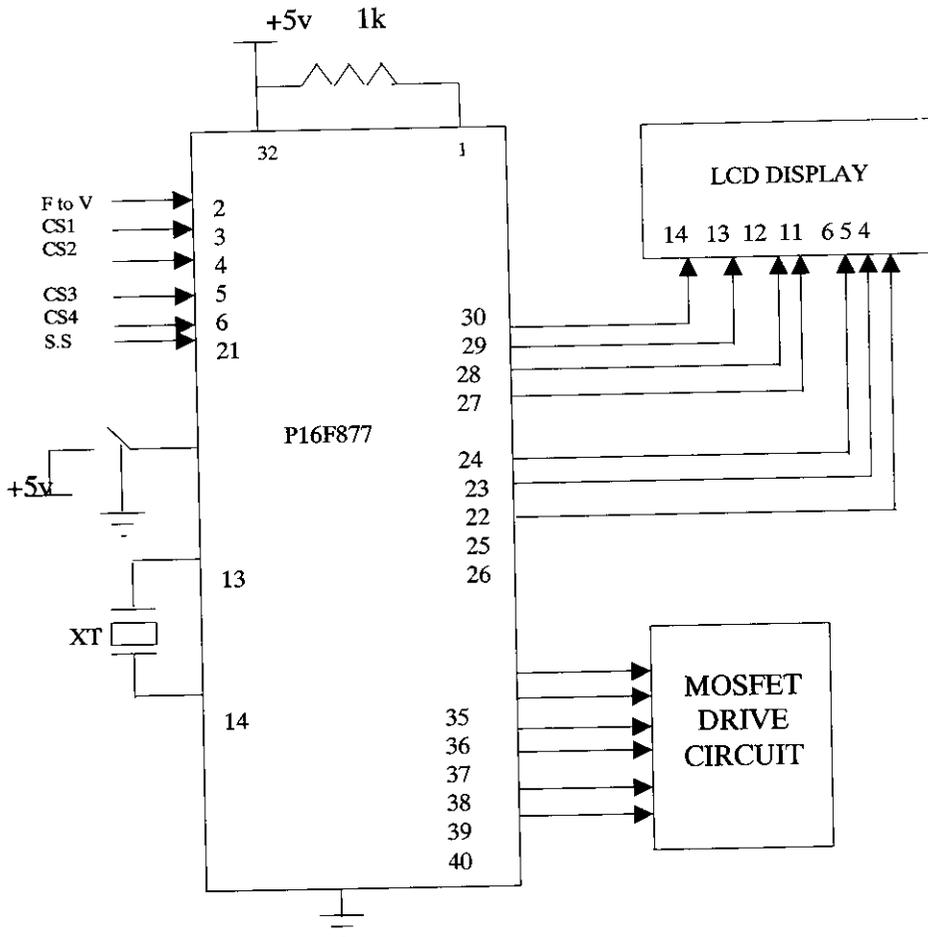
Figure 6.1.Circuit Diagram of Control of PMSM using Microcontroller

6.1.1 MICROCONTROLLER (16F877)

PRODUCT OVERVIEW

The PIC series of microcontrollers are the product on microchip technology. The special features of the microcontrollers are

- Long Word Instructions
- Single Cycle Instructions

- Reduced Instruction Set
- Register File Architecture

ARCHITECTURE:

PIC 16 series devices contain 8 bit a ALU and working register and special function registers. The ALU perform arithmetic and logic functions between working register and any register file data in a memory. Depending on the instruction executed, the ALU may affect carry, Digit carry and zero bit in the STATUS register.

CPU

The CPU is responsible for using the information in the program memory to control the operation of the device. It is responsible for fetching the correct instruction and execution of those instructions.

MEMORY ORGANISATION

The program memory is 8 K.Each address is of 14 bit length capable of holding a instruction. The program counter is of 13 bit wide for addressing 8k memory. The interrupt vector address is 0x04 and reset vector address is 0x00.The program memory are divided into four pages. Each page being 2K size.PCL and PC LATH are the two registers for program counter.

Data memory contains special function register and general purpose register. The data memory is divided into four banks. Bits 5 and 6 in the status register are used to select the banks.

PERIPHERALS

PIC has many input and output ports like PORTA, PORTB....PORTG.Other peripheral devices include CCP-Compare Capture and Pulse Width modulation ADC, Comparator, Timers (Timer0, Timer1, Timer2), USART, I2C, SPI.

6.1.2 POWER SUPPLY UNIT

The unit consists of transformer, rectifier, filter and regulator. A.C. voltage typically 230V rms is connected to a transformer which steps that AC voltage down to the level to the desired AC voltage. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a DC voltage. This resulting DC voltage usually has some ripple or AC voltage variations. A regulator circuit can use this DC input to provide DC voltage that not only has much less ripple voltage but also remains the same DC value even the DC voltage varies some what, or the load connected to the output DC voltages changes. A transformer is a static (or stationary) piece of which electric power in one circuit is transformed into electric power of the same frequency in another circuit. It can raise or lower the voltage in a circuit but with a corresponding decrease or increase in current.
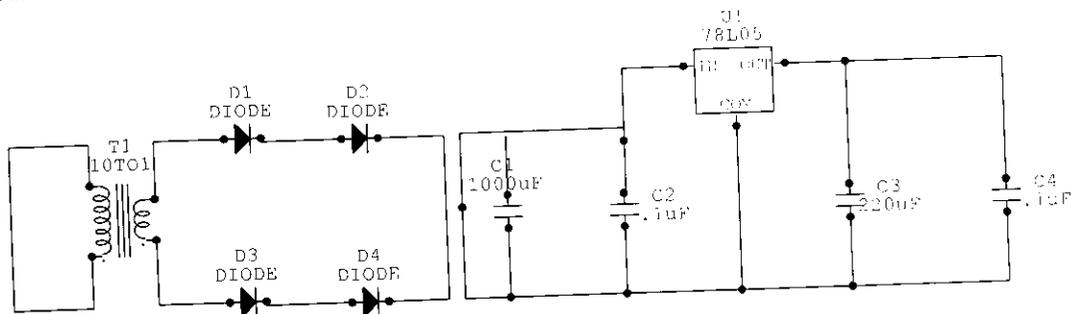
Figure 6.2.Regulated power supply unit

The DC level obtained from a sinusoidal input can be improved 100% using a process called full-wave rectification. The filter circuit used here is the capacitor filter circuit where a capacitor is connected at the rectifier output, and a DC is obtained across it. The filtered waveform is essentially a DC voltage with negligible ripples, which is ultimately fed to the load. The voltage regulator (LM 7805) maintains the output voltage constant irrespective of the change in supply variations, load variation and temperature changes. Regulator IC units contain the circuitry for reference source, comparator amplifier, control device, and overload protection all in a single IC.

6.1.3 Proximity Sensors

Inductive proximity sensors are non contact proximity devices that set up a radio frequency field with an oscillator and a coil. The presence of an object alters this field and the sensor is able to detect this alteration. An inductive proximity sensor comprises an LC oscillating circuit, a signal evaluator, and a switching amplifier. The coil of this oscillating circuit generates a high-frequency electromagnetic alternating field. This field is emitted at the sensing face of the sensor. If a metallic object (switching trigger) nears the sensing face, eddy currents are generated. The resultant losses draw energy from the oscillating circuit and reduce the oscillations. The signal evaluator behind the LC oscillating circuit converts this information into a clear signal. The measurement of proximity, position and displacement of objects is essential in many different applications: valve position, level detection, process control, machine control, security,etc.

The body style of inductive proximity sensors can be barrel, limit switch, rectangular, slot, or ring. A barrel body style is cylindrical in shape, typically threaded. A limit switch body style is similar in appearance to a contact limit switch. The sensor is separated from the switching mechanism and provides a limit of travel detection signal. A rectangular or block body style is a one piece rectangular or block shaped sensor. A slot style body is designed to detect the presence of a vane or tab as it passes through a sensing slot, or "U" channel. A ring shaped body style is a "doughnut" shaped sensor, where the object passes through center of ring. Electrical connections for proximity sensors, inductive can be fixed cable, connector(s), and terminals. A fixed cable is an integral part of sensor and often includes "bare" stripped leads. A sensor with connectors has an integral connector for attaching into an existing system. A sensor with terminals has the ability to screw or clamp down.

Load configurations are also important parameters to consider. Inductive proximity sensors may switch an AC load or a DC load. DC load configurations can be NPN or PNP. NPN is a transistor output that switches the common or negative voltage to the load; load connected between sensor output and positive voltage supply.

PNP is a transistor output that switches the positive voltage to the load; load connected between sensor output and voltage supply common or negative. Wire configurations are 2-wire, 3-wire NPN, 3-wire PNP, 4-wire NPN, and 4-wire PNP. Switch types can be normally open (NO) or normally closed (NC). Switch specifications include whether or not the switch is normally open or normally closed. Switch repeatability and maximum switching frequency are important parameters to consider. Other important parameters to consider when specifying inductive proximity sensors include power requirements, housing materials, dimensions, special features, and environmental operating conditions.
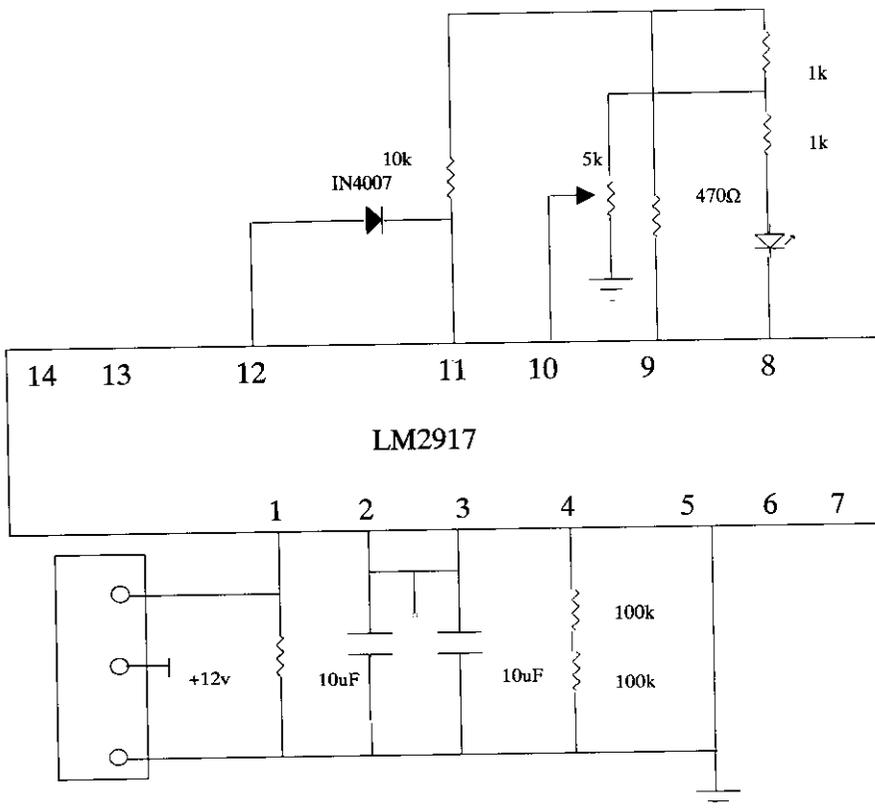
Figure 6.3.Frequency to voltage converter circuit

6.1.4 Shunt-Current Sensor

A circuit like this in Figure 6.4 can effect an amplification and noise reduction of the current signal from the dc link shunt. It is important that the operational amplifier have a high slew rate (e.g. 15V/μs) because the switching periods are in some cases very short. The Shunt must have good power dissipation (P=R*I2) and high resistance to became a good signal from it. There are three types of current feedback sensing.
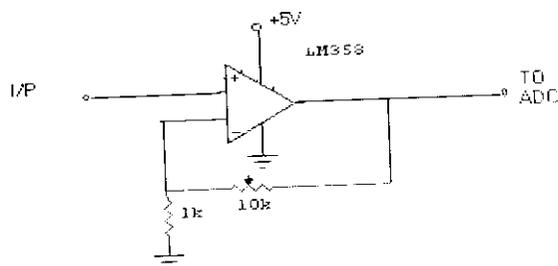
Figure 6.4.Current Amplifier circuit
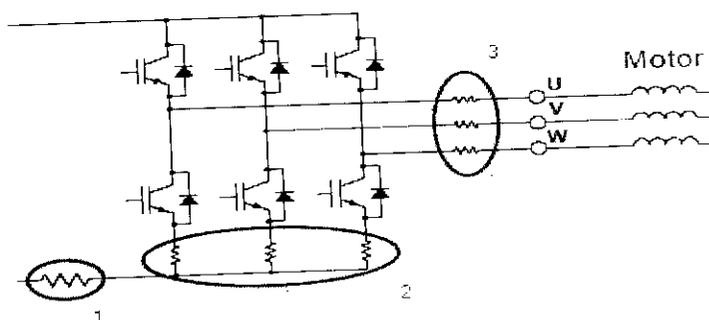
Figure 6.5Current Sensing circuit

The current sensed from position 1 is complex, only the information of the amplitude is obtained. It is difficult to construct but it is lowest cost. The current sensed at position 2 is medium complex and easy to reconstruct. Sensor at position 3 is reliable, simple and easy to construct.

6.1.5 POSITION SENSOR

There are different types of position sensors which has been already described in chapter3.Since vector control need either resolver or optical encoder for measurement of exact position, they are very costly. It cost around 45,000Rs.So a position sensor was designed which has but lower resolution. The disk in it has 72 teeths.This disk is made to rotate in a slot sensor. This sensor has a light emitter and a light receiver. The disk is shown in figure6.6. Normally the light is emitted and receiver is normally high .This is given to comparator amplifier. Thus there would be high output. Whenever the disk slot crosses transmitter the receiver stops conducting and hence output becomes low. Thus pulses are generated. This is used to measure the position .For every slot rotation the angle of movement is 5 degrees. Since 360/72=5.Thus from this the position can be calculated.
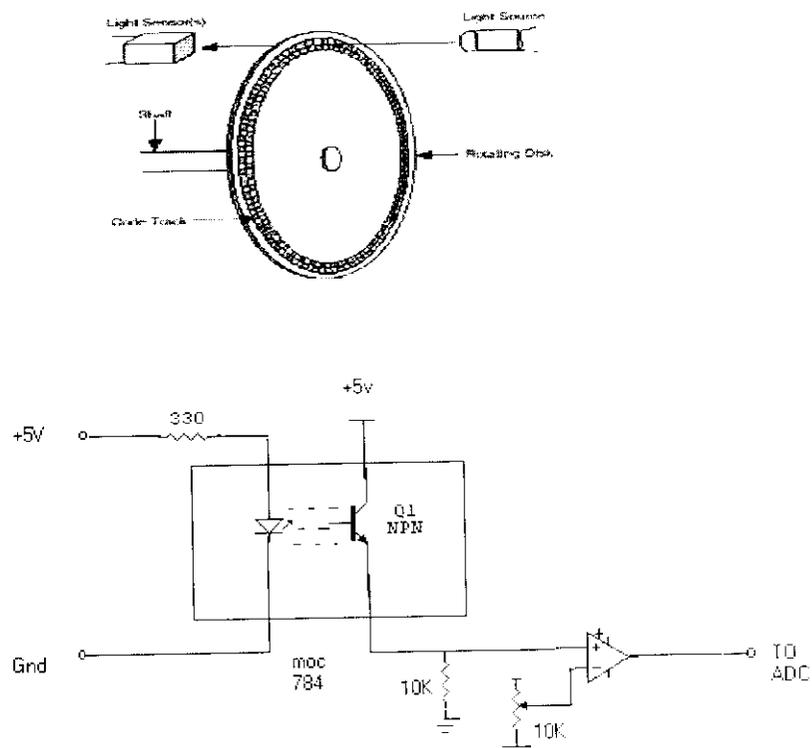
Figure 6.6 .Circuit diagram of position sensor

6.1.6 MOSFET AND MOSFET DRIVER:

Mosfets are used in the three phase inverter circuits.IRF830 is the type of Mosfet used. The Mosfet driver is optocoupler.The Mosfet and its driver circuit is shown in figure6.7
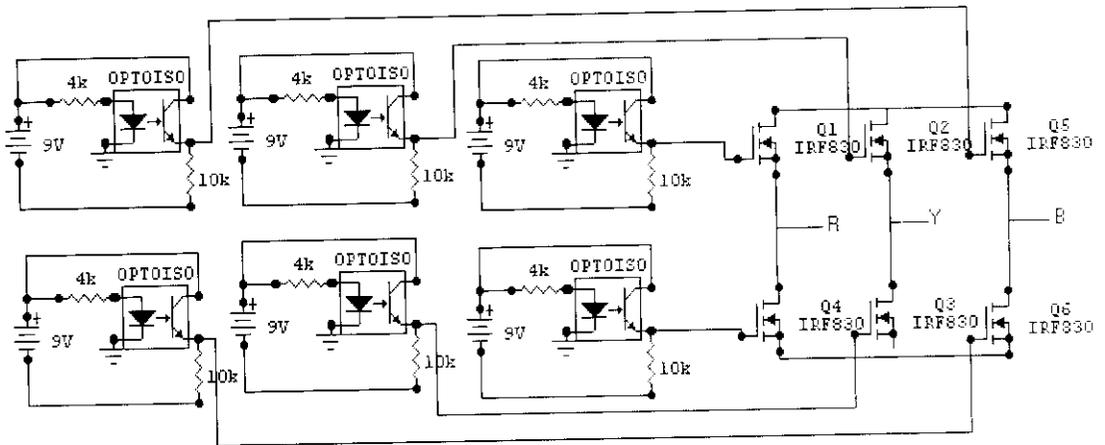
Figure 6.7 Mosfet Driver circuit

Choice of Power device

For low voltage (12- 150V) bus, FETs are the choice

For intermediate bus voltage (170 – 340V)

Power < 250 W, FETs are overall lower cost

Power > 250 W, IGBTs are better choice

For 400V bus (PFC)

Power < 200 W, MOSFETs are overall lower cost

Power > 200 W, IGBTs are better choice

For >400V bus, for >400V bus, IGBTs clear choice are the clear choice

MOSFETs come in four different types. They may be enhancement or depletion mode, and they may be n-channel or p-channel. There are also logic-level MOSFETs and normal MOSFETs. It is a majority carrier Device and has the following features

- Turns on as fast as gate can be fully enhanced

- Turns off as fast as gate voltage can get below threshold.

The source terminal is normally the negative one, and the drain is the positive one (the names refer to the source and drain of electrons). The diode is called the "intrinsic diode", because it is built into the silicon structure of the MOSFET. It is a consequence of the way power MOSFETs are created in the layers of silicon, and can be very useful. In most MOSFET architectures, it is rated at the same current as the MOSFET itself.

OPTO COUPLER

The proper isolation between input and output becomes very important in several of the digital and analog applications. The traditional methods isolation involves the use of such devices as capacitor, relays, transformers and optocouplers of these the Optocoupler provide an ideal combination of speed, OC response, high common mode nose for both analog and digital applications in industrial, medical and military products. Examples are logic isolations, line receivers, sensing circuits, power supply feed back, high voltage current monitoring, telephone, lines patient monitoring equipments, adaptive control, audio and video amplifiers, triggering of thyristors, and so on.
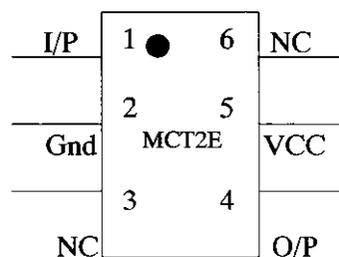
Figure 6.8 Pin diagram of Optocoupler

Optocoupler consists of an LED emitter and a photo sensor of transistor or diode type. The one that utilizes a phototransistor is limited in its improves the speed

upto a hundred times that of a phototransistor coupler by reducing the base-collector capacitance. Al high speed Optocoupler employs this as principle of operation. The driver stage uses optocouplers. Each Mosfet is driven by an optocoupler.The source to the optocoupler is a battery source.

6.1.7 LIQUID CRYSTAL DISPLAY

LCD's are electronically switched display panels that make use of changes in the reflective properties of liquid crystals in series with an electric field. There are single line double line and multi line LCD's.The data lines can be 8 bit or 4 bits. The LCD in it contains character generator RAM, CG ROM, DD RAM and address counter.

The built-in controller IC has the following features:

➢ 80 x 8 bit display RAM (80 Characters max)

➢ 9,920-bit character generator ROM for a total of 240 character fonts. 208 character fonts (5 x 8 dots) 32 character fonts (5 x 10 dots)

➢ 64 x 8 bit character generator RAM 8 character generator RAM 8 character fonts (5 x 8 dots) 4 characters fonts (5 x 10 dots)

➢ Programmable duty cycles

  1/8 – for one line of 5 x 8 dots with cursor

  1/11 – for one line of 5 x 10 dots with cursor

  1/16 – for one line of 5 x 8 dots with cursor

➢ Wide range of instruction functions display clear, cursor home, display on/off, cursor on/off, display character blink, cursor shift, display shift.

INTERFACING THE MICROPROCESSOR /CONTROLLER:

The module, interfaced to the system, can be treated as RAM input/output, expanded or parallel I/O. Since there is no conventional chip select signal, developing a strobe signal for the enable signal (E) and applying appropriate signals to the register select (RS) and read/write (R/W) signals are important.

6.2. SOFTWARE MODULE

The software program is written in HITECH PICC.The different software modules are explained and the peripherals used are given for implementing the vector control. The software core modules are

1. Conversion of analog to digital signal.

    1. Speed

    2. Three phase currents

    3. Position

2. Speed regulation module.

3 .Generation of cos Θ from math function

4. Coordinate transformation

5. Generation of PWM

6. LCD interface for setting the speed

Thus the peripherals that are to be used in PIC16F877 are

1. Five channels of ADC modules

2. Ports.

    1. Four port pins for LCD display.

    2. Six port pins for PWM pulse generation.

    3. One port pin for Switch to set the reference speed.

The flow chart for the vector control is shown .The reference speed is obtained from the input port and the actual speed is obtained and digitally converted. Also other parameters such as three phase currents and position input are also converted.

Then these values are placed in general purpose registers. The speed is compared with the reference speed and the error is stored in the ERR register.Then the PI regulator logic is programmed .The output of the PI regulator will be digital value of iq and id is set to zero.These values are then used and the two phase currents are transformed into three phase currents using the parks transformation. Then with these

values the actual values of the current stored are compared and the difference in error value is used to produce the pulse width modulation. If there is change in the value of the current there will be change in the frequency of the pulse width.

6.2.1FLOW CHART
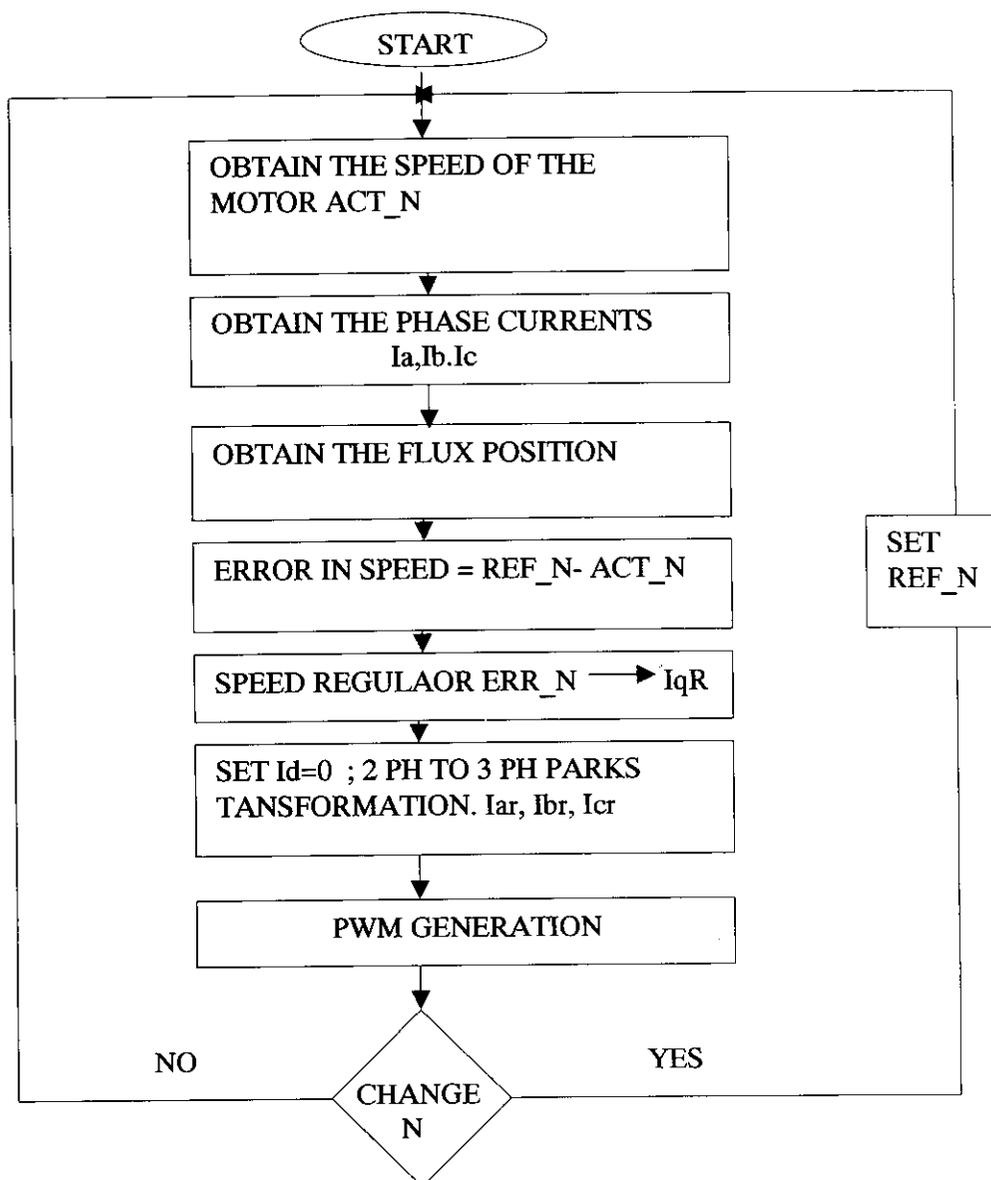
Figure 6.9 FLOW CHART FOR VECTOR CONTROL OF PMSM

The actual program written for the motor speed control consists of generation of PWM signals using timers based on the given input frequency. The hardware to control involves Microcontroller unit, inverter driver circuit and the voltage source inverter. The motor is operated at three different speeds by varying the frequency .The reasons for not implementing the actual vector control program as discussed earlier was due to the non availability of the motor with proper specification and also the cost of the position sensor was expensive.

The algorithm for driving the PMSM is as follows

1. Initialize the header files of PIC 877.

2. Initialize the ports, timer and interrupt controller.

3. The switch is checked for the input frequency.

4. Corresponding digital value is placed in the timer1 module.

5. The pulse is transmitted and the width of the pulse is based on the timer1 value.

6. As the timer is overflowed an ISR is invoked to provide a dead time.

7. This dead time is provided inorder to avoid the short circuit.

8. The Width of the pulse is varied inorder to change the speed of the motor according to the input frequency.

9. The switches are turned on in the sequence of M1 to M6.

The program was written in the MPLAB-IDE and debugged using the simulator. The hex code of the program is the downloaded to the IC through PROPIC software and programmer. Then the hardware designed was tested and the motor was driven for three different speeds.

CHAPTER 7

CONCLUSION

Variable speed or adjustable torque control of electrical motor drives are crucial components in almost all modern industrial manufacturing processes. For low performance applications, open loop voltage/frequency control strategies are employed. Considering high-performance motion control, recently Field oriented control or vector control has been developed.

This project discussed Field Oriented speed Control of a Permanent Magnet Synchronous Motor. The Field Oriented Control provides the smooth motion at slow speeds as well as efficient operation. PMSM control incorporated neuro-fuzzy controller for increasing correction of tracking .The results has showed an improvement in speed tracking performance, which has been done with NFC.

The necessary hardware requirements were designed and the control technique has been written and implemented using PIC. A better performance of the motor was been not able to achieve due to non availability of exact motor specification which is needed to design PI speed regulator and also cost of resolver were expensive. The motor was made to run at no load at low voltage at three different speeds. So the motor was driven from a three phase inverter for different speeds.

Experimental verification of the high performance vector control along with intelligent control could be achieved by using Digital signal processors or special IC's which form the basis of future work.

APPENDIX

PROGRAM

```
#include <pic.h>
#include <f87x.h>
#include <stdio.h>
#include <lcd_d.h>


unsigned int delay, an0, an1;
unsigned char T1_load_H, T1_load_L, freq, dead_time, i, input;
bit disp, transmit;
void Hardware_Setup( void );
main()
{
        Hardware_Setup();
        RB7 = 1;
        RB6 = 0;
        RB5 = 1;
        RB4 = 0;
        freq = 45;
        disp = 1;
        while(1)
        {
                if ( RD0 )
                {
                        switch ( freq )
                        {
                                case 45:
                                {
```

```c
                                freq = 50;
                                break;
                }
                case 50:
                {
                                freq = 55;
                                break;
                }
                case 55:
                {
                                freq = 45;
                                break;
                }
                default:
                {
                                freq = 45;
                                break;
                }
        }
        disp = 1;
        for( delay = 0; delay <= 65000; delay++ );
        for( delay = 0; delay <= 65000; delay++ );
        for( delay = 0; delay <= 65000; delay++ );
}
switch ( freq )
{
        case 0:
        {
                TMR1ON = 0;
                break;
        }
        case 45:
```

```c
        {
                TMR1ON = 1;
                T1_load_H = 0x27;
                T1_load_L = 0x01;
                break;
        }
        case 50:
        {
                TMR1ON = 1;
                T1_load_H = 0x3C;
                T1_load_L = 0xAF;
                break;
        }
        case 55:
        {
                TMR1ON = 1;
                T1_load_H = 0x4E;
                T1_load_L = 0x75;
                break;
        }
        default:
        {
                TMR1ON = 1;
                freq = 45;
                break;
        }
}
if( disp )
{
        sprintf(LCD_TABL,"Frequency = %02u  ", freq);
        display();
        disp = 0;
```

```
            }
            if( transmit )
            {
                    an0 = adc_read_10bit( 0 );
                    an1 = adc_read_10bit( 1 );
                    sprintf( LCD_TABL, ":1%04u2%04u$", an0, an1 );
                    for( i = 0; i <= 11; i++ )
                    {
                            putbyte( LCD_TABL[i] );
                    }
                    transmit = 0;

            }
        }
}
interrupt isr( )
{
 GIE = 0;
        if( TMR1IF )
        {
                RB0 = !RB0;


                RB4 = !RB4;
                RB6 = !RB6;
                for( dead_time = 0; dead_time <= 30; dead_time++ );
                RB5 = !RB5;
                RB7 = !RB7;
                for( dead_time = 0; dead_time <= 30; dead_time++ );
                TMR1H = T1_load_H;
                TMR1L = T1_load_L;
                TMR1IF = 0;
        }
        if( RCIF )
```

```c
{
    input = getbyte();
    disp = 1;
    switch( input )
    {
        case 'A':
        {
            freq = 45;
            break;
        }
        case 'B':
        {
            freq = 50;
            break;
        }
        case 'C':
        {
            freq = 55;
            break;
        }
        case 'D':
        {
            freq = 0;
            break;
        }
        case 'R':
        {
            transmit = 1;
            break;
        }
    }
    RCIF = 0;
```

```c
        }
  GIE = 1;

}
void Hardware_Setup( void )
{                       /* PORT DECLARATION */
        TRISC = 0x80;
        TRISB = 0x00;
        TRISA = 0xFF;
        ADCON1 = 0x80;
        lcd_init();
        USART_INIT9600_20MHZ();
                        /* Timer 1 Setup */
        TMR1IF = 0;
        TMR1IE = 1;
        T1CON = 0x05;
        TMR1H = 0x27;
        TMR1L = 0x01;
        RB0 = 0;
        GIE = 1;
        PEIE = 1;

}
```
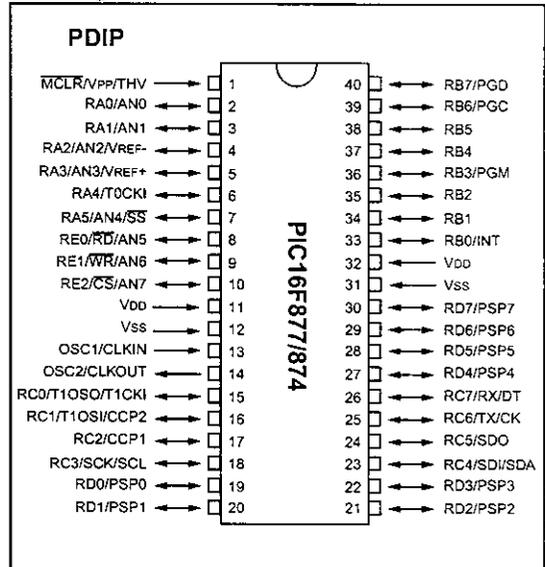
MICROCHIP

PIC16F87X

28/40-pin 8-Bit CMOS EEPROM/Flash Microcontrollers

Microcontroller Core Features:

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input
  DC - 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory,
  Up to 368 x 8 bytes of Data Memory (RAM)
  Up to 256 x 8 bytes of EEPROM data memory
- ★ **Pinout compatible to the PIC16C73/74/76/77**
- Interrupt capability (up to 14 internal/external interrupt sources)
- Eight level deep hardware stack
- Direct, indirect, and relative addressing modes
- Power-on Reset (POR)
- Power-up Timer (PWRT) and
  Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS EPROM/
  EEPROM technology
- Fully static design
- In-Circuit Serial Programming™ via two pins
- ★ Only single 5V source needed for programming
- ★ In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.5V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
  - < 2 mA typical @ 5V, 4 MHz
  - 20 µA typical @ 3V, 32 kHz
  - < 1 µA typical standby current

Pin Diagram

PDIP

```
MCLR/VPP/THV  →  [ 1        40 ]  ↔  RB7/PGD
      RA0/AN0  ↔  [ 2        39 ]  ↔  RB6/PGC
      RA1/AN1  ↔  [ 3        38 ]  ↔  RB5
   RA2/AN2/VREF-  ↔  [ 4        37 ]  ↔  RB4
   RA3/AN3/VREF+  ↔  [ 5        36 ]  ↔  RB3/PGM
     RA4/T0CKI  ↔  [ 6        35 ]  ↔  RB2
     RA5/AN4/SS  ↔  [ 7        34 ]  ↔  RB1
    RE0/RD/AN5  ↔  [ 8        33 ]  ↔  RB0/INT
    RE1/WR/AN6  ↔  [ 9        32 ]  ←  VDD
    RE2/CS/AN7  ↔  [ 10       31 ]  ←  VSS
          VDD  →  [ 11       30 ]  ↔  RD7/PSP7
          VSS  →  [ 12       29 ]  ↔  RD6/PSP6
    OSC1/CLKIN  →  [ 13       28 ]  ↔  RD5/PSP5
   OSC2/CLKOUT  ←  [ 14       27 ]  ↔  RD4/PSP4
 RC0/T1OSO/T1CKI  ↔  [ 15       26 ]  ↔  RC7/RX/DT
  RC1/T1OSI/CCP2  ↔  [ 16       25 ]  ↔  RC6/TX/CK
      RC2/CCP1  ↔  [ 17       24 ]  ↔  RC5/SDO
     RC3/SCK/SCL  ↔  [ 18       23 ]  ↔  RC4/SDI/SDA
      RD0/PSP0  ↔  [ 19       22 ]  ↔  RD3/PSP3
      RD1/PSP1  ↔  [ 20       21 ]  ↔  RD2/PSP2
```
(PIC16F877/874)

Peripheral Features:

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler,
  can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules
- Capture is 16-bit, max. resolution is 12.5 ns,
  Compare is 16-bit, max. resolution is 200 ns,
  PWM max. resolution is 10-bit
- ★ 10-bit multi-channel Analog-to-Digital converter
- ★ Synchronous Serial Port (SSP) with SPI™ (Master Mode) and I²C™ (Master/Slave)
- ★ Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9-bit address detection
- Parallel Slave Port (PSP) 8-bits wide, with external RD, WR and CS controls (40/44-pin only)
- Brown-out detection circuitry for
  Brown-out Reset (BOR)

This is an advanced copy of the data sheet and therefore the contents and specifications are subject to change based on device characterization.

BANNARI AMMAN INSTITUTE OF TECHNOLOGY

Stay Ahead

BANNARI AMMAN INSTITUTE OF TECHNOLOGY

Sathyamangalam - 638 401　　Erode Dt.　　Tamil Nadu

FIRST NATIONAL CONFERENCE ON

"CUTTING EDGE TECHNOLOGIES IN POWER CONVERSION AND INDUSTRIAL DRIVES"

PCID-2005

Organised by : Department of Electrical & Electronics Engineering

(Accredited by NBA,AICTE New Delhi)

Sponsored by : Council of Scientific and Industrial Research(CSIR), New Delhi

THIS CERTIFIES THAT

Prof./Dr./Mr./Ms.　　__M. SAVITHA__

has participated in the NATIONAL CONFERENCE on "POWER CONVERSION AND INDUSTRIAL DRIVES",

PCID-2005 held during 25 - 26 March 2005 and has presented a paper titled __Neuro-Fuzzy based Field__
__Oriented Speed Control of Permanent magnet synchronous Motor.__

in the session __SD-2__ *of the conference.*

Dr. A. Nirmal Kumar
Convenor PCID-2005

Session Chair
PCID-2005

Dr.G.Gurusamy
Dean EEE

Dr. A. Shanmugam
Principal

REFERENCES

[1]. Ahmed Rubaai and Raj Kotaru(1999) "Neural Net based Robust Controller Design for brushless DC Motor Drives",IEEE Transaction on systems ,Man and Cybernetics-PartC:Application and reviews ,Vol .29 ,No.3,pp.460-474.

[2]. Beatrice Lazzerini ,Leonardo M.Reyneri and Marcello Chiaberge(1999),"A Neuro-Fuzzy Approach to Hybrid Intelligent Control"IEEE Transaction on Industry Applications,,Vol..35,N0.2 ,pp413-424.

[3]. El-Sharkawi M.A,.El –Samahy A.A and Sayed M.L. l (1994)"High Performance of DC Brushless Motors using Neural Network",IEEE transaction on Energy Conversion ,Vol.9,No.2,pp317-322

[4]. Faa-Jeng Lin ,Rong-Jong Wai and Hong –Pong Chen (1998)"A PM synchronous Servo Motor Drive with On-Line Trained Fuzzy Neural Network Controller"IEEE Transaction on Energy Conversion ,Vol.13 No.4,pp319-325.

[5]. Miller T.J.E (1993)'Brushless Permanent-Magnet and Reluctance Motor Drives' from, Oxford Science publications

[6]. Muhammad H.Rashid (2000)'Power Electronics ,Circuits ,devices and Aplications' ,Prentice Hall,New Delhi

[7]. Pragesan Pillay and Ramu Krishnan(1989), "Modeling ,Simulation and Analysis of Permanent Magnet Sychronous Motor Drive", IEEE transaction on Industry Application,Vol .25,No.2 ,pp265-273.

[8]. Singh MD and Khanchandani KB (1998) Power Electronics,Tata McGraw Hill ,New Delhi

[9]. Teck-Seng,Mohammed A.Jabbar andAzizur Rahman.M (1990)"Permanent-Magnet Motors for Brushless Operation ",IEEE transaction on Industry Applications,Vol.26,pp124-129.

[10]. Yegnanarayana.B (2001), "Artificial Neural Networks "Prentice Hall ,New Delhi

[11]. www.ti.com