"MODELLING AND SIMUALTION OF PERMANENT MAGNET SYNCHRONOUS MOTOR DRIVE SYSTEM WITH PROPORTIONAL INTEGRAL CONTROLLER"

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ABSTRACT: *This paper presents analytical results, numerical simulations, and experiments that improving the control design for permanent magnet synchronous motor . Field oriented control is used for the operation of the drive. The simulation includes all realistic components of the system. This enables the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions. The losses in different parts are calculated, facilitating the design of the inverter. A closed loop control system with a Proportional Integral (PI) controller in the speed loop has been designed to operate in constant torque and flux weakening regions. Implementation has been done in Simulink. Pulse Width Modulation (PWM) control schemes associated with current controllers has been made in terms of harmonic spectrum and total harmonic distortion. Experimental tests have been presented to demonstrate the effectiveness of the proposed commissioning methodology.*

Keyword: AC drives, inverters, low switching frequency, pulse width modulated (PWM) systems, space vector modulation MOSFET, IGBT.

1. INTRODUCTION

Permanent magnet (PM) synchronous motors are widely used in low and mid power Applications such as computer peripheral equipments, robotics, adjustable speed drives and Electric vehicles.

The growth in the market of PM motor drives has demanded the need of simulation tools capable of handling motor drive simulations. Simulations have develop new system including motor drives, with less cost and save valuable time. Simulation tools have the capabilities of performing dynamic simulations of motor drives in a visual environment so as to facilitate the development of new systems.

In this paper, the simulation of a field oriented controlled PM motor drive system is developed using Simulink. The simulation circuit will include all realistic components of the drive system. This enables the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions. The losses in different parts can be calculated facilitating the design of the inverter.

A closed loop control system with a PI controller in the speed loop has been designed to operate in constant torque and flux weakening regions. Implementation has been done in Simulink. study of Pulse Width Modulation (PWM) control scheme associated with current controllers has been made in terms of harmonic spectrum and total harmonic distortion.

1.1 Motivation

Modeling and simulation is usually used to reduced the cost as compared to building system prototypes . Having selected a components, the simulation process can start to calculate steady state and dynamic performance and losses that would have been obtained if the drive were actually constructed. This practice reduces time, cost of building prototypes and ensures that requirements are achieved.

In this work, the simulation of a PM motor drive system is developed using Simulink. The simulation circuit includes all realistic components of the drive system. This enables the calculation of currents and voltages in different parts of the inverter and motor under transient and steady conditions. The losses in different parts are calculated. A study associated with Pulse Width Modulation (PWM) control technique in current controllers has been made. A speed controller has also been designed for closed loop operation of the drive.

2. DESCRIPTION OF THE DRIVE SYSTEM

In this description of the different components such as permanent magnet motors, position sensors, inverters and current controllers of the drive system. A review of permanent magnet materials and classification of permanent magnet motors is also given.

2.1 Permanent Magnet Synchronous Motor Drive System

The motor drive consists of four main components, the PM motor, inverter, and control unit and the position sensor. The components are connected as shown in figure 2.1.

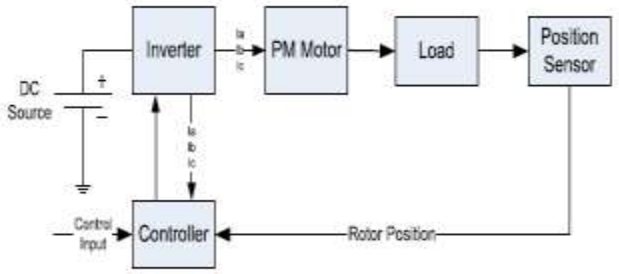


Figure 2.1 Drive System Schematic

2.2 Permanent Magnet Synchronous Motor

A permanent magnet synchronous motor (PMSM) is a motor that uses permanent magnets insist of electromagnets. These motors have significant advantages in various fields attracting the interest of researchers and industry for use in many applications.

2.2.1 Permanent Magnet Materials

The properties of the permanent magnet material will affect directly the performance of the motor and proper knowledge is required for the selection of the materials and for understanding PM motors.

The earliest manufactured magnet materials were hardened steel. Magnets made from steel were easily magnetized. However, they could hold very low energy and it was easy to demagnetize. In recent years other magnet materials such as Aluminum Nickel and Cobalt alloys (ALNICO), Strontium Ferrite or Barium Ferrite (Ferrite), Samarium Cobalt (First generation rare earth magnet) (SmCo) and Neodymium Iron-Boron (Second generation rare earth magnet) (NdFeB) have been developed and used for making permanent magnets.

The rare earth magnets are categorized into two classes: Samarium Cobalt (SmCo) magnets and Neodymium Iron Boride (NdFeB) magnets. SmCo magnets have higher flux density levels but they are very expensive. NdFeB magnets are the most common rare earth magnets used in motors these days. A flux density versus magnetizing field for these magnets is illustrated

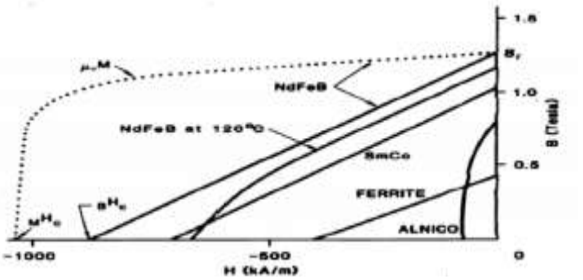


Figure 2.2 Flux Density versus Magnetizing Field of Permanent Magnetic Materials

2.3 Position Sensor

Operation of permanent magnet synchronous motors requires position sensors in the rotor shaft when operated without damper winding. The need of knowing the rotor position requires the development of devices for position measurement. There are four main devices for the measurement of position, the potentiometer, linear variable differential transformer, optical encoder and resolvers. The ones most commonly used for motors are encoders and revolvers.

Depending on the application and performance desired by the motor a position sensor with the required accuracy can be selected

2.4 Current Controlled Inverter

The motor is fed form a voltage source inverter with current control. The control is performed by regulating the flow of current through the stator of the motor. Current controllers are used to generate gate signals for the inverter. Proper selection of the inverter devices and selection of the control technique will increase guarantee the efficiency of the drive.

2.4.1 Inverter

Voltage Source Inverters convert a DC voltage to AC voltage of variable frequency and magnitude. They are very commonly used in adjustable speed drives and are characterized by a well defined switched voltage wave form in the terminals. Figure 2.3 shows a voltage source inverter. The AC voltage frequency can be variable or constant depending on the application.

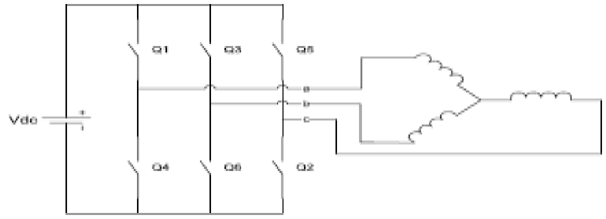


Figure 2.3 Voltage Source Inverter Connected to a Motor

Three phase inverters consist of six power switches connected as shown in figure 2.3 to a DC voltage source. The inverter switches must be carefully selected based on the requirements of operation, ratings and the application. There are several devices available today and these are thyristors, bipolar junction transistors (BJTs), MOS field effect transistors (MOSFETs), insulated gate bipolar transistors (IGBTs) and gate turn off thyristors (GTOs). The devices list with their respective power switching capabilities are shown in table 2.1 MOSFETs and IGBTs are preferred by industry because of the MOS gating permits high power gain and control advantages. While MOSFET is considered a universal power device for low power and low voltage applications, IGBT has wide acceptance for motor drives and other application in the low and medium power range. The power devices when used in motor drives applications require an inductive motor current path provided by antiparallel diodes when the switch is turned off. Inverters with antiparallel diodes are shown in figure 2.4.

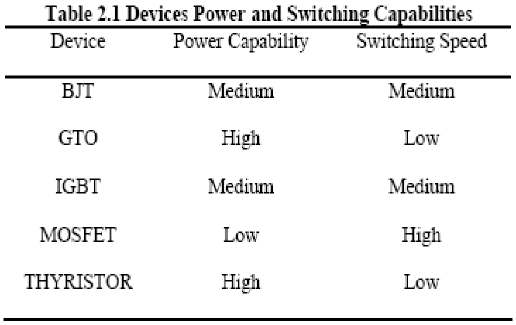


Table 2.1 Devices Power and Switching Capabilities

Device	Power Capability	Switching Speed
BJT	Medium	Medium
GTO	High	Low
IGBT	Medium	Medium
MOSFET	Low	High
THYRISTOR	High	Low

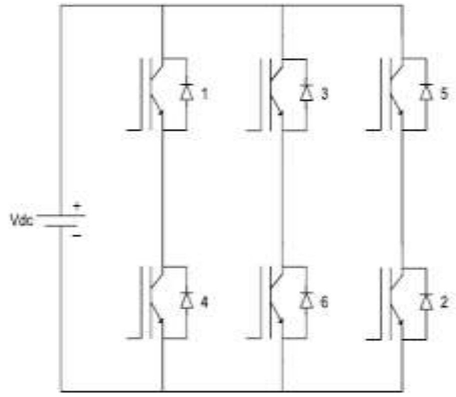


Figure 2.4 Inverter with IGBTs and Antiparallel Diodes

2.4.2 Current Control

The power converter in a high-performance motor drive used in motion control essentially functions as a power amplifier, reproducing the low power level control signals generated in the field orientation controller at power levels appropriate for the driven machine. High-performance drives utilize control strategies which develop command signals for the AC machine currents. The basic reason for the selection of current as the controlled variable is the same as for the DC machine; the stator dynamics (effects of stator resistance, stator inductance, and induced EMF) are eliminated. Thus, to the extent that the current regulator functions as an ideal current supply, the order of the system under control is reduced and the complexity of the controller can be significantly simplified.

Current regulators for AC drives are complex because an AC current regulator must control both the amplitude and phase of the stator current. The AC drive current regulator forms the inner loop of the overall motion controller. As such, it must have the widest bandwidth in the system and must, by necessity, have zero or nearly zero steady-state error. Both current source inverters (CSI) and voltage source inverters (VSI) can be operated in controlled current modes. The current source inverter is a "natural" current supply and can readily be adapted to controlled current operation. The voltage source inverter requires more complexity in the current regulator but offers much higher bandwidth and elimination of current harmonics as compared to the CSI and is almost exclusively used for motion control applications.

2.4.3 PWM Current Controller

PWM current controllers are widely used. The switching frequency is usually kept constant throughout. They are based in the principle of comparing a triangular carrier wave of desire switching frequency and is compared with error of the controlled signal. The error signal comes from the sum of the reference signal generated in the controller and the negative of the actual motor current. The comparison will result in a voltage control signal that goes to the gates of the voltage source inverter to generate the desire output. Its control will respond according to the error. If the error command is greater than the triangle waveform, the inverter leg is held switched to the positive polarity (upper switch on). When the error command is less than the triangle waveform, the inverter leg is switched to the negative polarity (lower switch on). This will generate a PWM signal like in figure 2.5. The inverter leg is forced to switch at the frequency of the triangle wave and produces an output voltage proportional to the current error command. The nature of the controlled output current consists of a reproduction of the reference current with high-frequency PWM ripple superimposed.

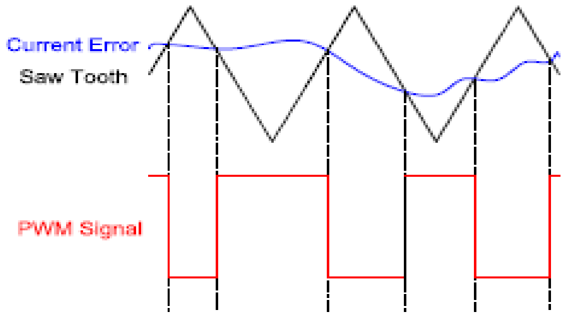


Fig. 2.5 PWM current controller

MODELING OF PM DRIVE SYSTEM

In the modeling of a permanent magnet synchronous motor Field oriented control of the motor in constant torque and flux-weakening regions are discussed. Closed loop control of the motor is developed using a PI controller in the speed loop. Design of the speed controller is discussed.

3.1 Detailed Modeling of PMSM

Detailed modeling of PM motor drive system is required for accurate simulation of the system. The d-q model has been developed on rotor reference frame as shown in figure 3.1. At any time t, the rotating rotor d-axis makes and angle θr with the fixed stator phase axis and rotating stator mmf makes an angle α with the rotor d-axis. Stator mmf rotates at the same speed as that of the rotor.

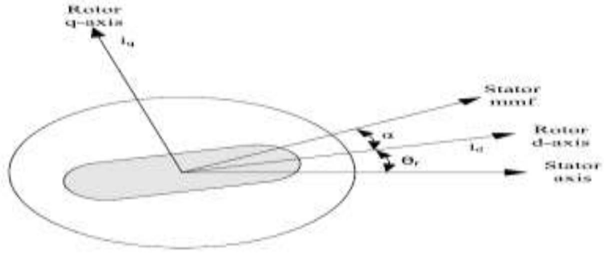


Figure 3.1 Motor Axis

The model of PMSM without damper winding has been developed on rotor reference frame using the following assumptions:

1) Saturation is neglected.
2) The induced EMF is sinusoidal.
3) Eddy currents and hysteresis losses are negligible.
4) There are no field current dynamics.

NOMENCLATURE

J	Motor and load inertia.
B	Friction coefficient.
T_{load}	Load torque.
Φ	Back-emf constant.
$R_d = R_q = R_a$	Resistance of the d and q windings.
$L_d = L_q = L$	Inductance of the d and q windings (a non-salient machine is assumed).
i_d, i_q	Currents in d-q frame.
V_d, V_q	Voltages in d-q frame.
V_d^*, V_q^*	Reference voltages in the d-q coordinates.
V_α, V_β	Voltages in the stationary α-β frame.
V_α^*, V_β^*	Reference voltages in the stationary reference frame.
V_1, V_2, V_3	Three-phase PWM output line voltages.
θ	Rotor angle (in "electrical degrees").
ω	Rotor (electrical) speed, corresponding to the time derivative of θ.
T	Time required for one (electrical) revolution, corresponding to angle θ; when the system is close to a steady state, $T = (2\pi/\omega)$ is approximately constant.
ω_0	Frequency of the basic switching PWM cycles
T_0	Period of the basic switching PWM cycles ($T_0 = 2\pi/\omega_0$).
N	Ratio between the (electrical) revolution period and the PWM cycle period. $N = \omega_0/\omega = T/T_0$.

Voltage equations are given by:

$$V_q = R_s i_q + \omega_r \lambda_d + \rho \lambda_q \qquad 3.1$$

$$V_d = R_s i_d - \omega_r \lambda_q + \rho \lambda_d \qquad 3.2$$

Flux Linkages are given by:

$$\lambda_q = L_q i_q \qquad 3.3$$

$$\lambda_d = L_d i_d + \lambda_f \qquad 3.4$$

Substituting equations 3.3 and 3.4 into 3.1 and 3.2

$$V_q = R_s i_q + \omega_r \left(L_d i_d + \lambda_f\right) + \rho L_q i_q \qquad 3.5$$

$$V_d = R_s i_d - \omega_r L_q i_q + \rho \left(L_d i_d + \lambda_f\right) \qquad 3.6$$

Arranging equations 3.5 and 3.6 in matrix form

$$\begin{pmatrix} V_q \\ V_d \end{pmatrix} = \begin{pmatrix} R_s + \rho L_q & \omega_r L_d \\ -\omega_r L_q & R_s + \rho L_d \end{pmatrix} \begin{pmatrix} i_q \\ i_d \end{pmatrix} + \begin{pmatrix} \omega_r \lambda_f \\ \rho \lambda_f \end{pmatrix} \qquad 3.7$$

The developed torque motor is being given by

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left(\lambda_d i_q - \lambda_q i_d\right) \qquad 3.8$$

The mechanical Torque equation is

$$T_e = T_L + B\omega_m + J\frac{d\omega_m}{dt} \qquad 3.9$$

Solving for the rotor mechanical speed form equation 3.9

$$\omega_m = \int\left(\frac{T_e - T_L - B\omega_m}{J}\right)dt \qquad 3.10$$

and

$$\omega_m = \omega_r\left(\frac{2}{P}\right) \qquad 3.11$$

In the above equations ωr is the rotor electrical speed where as ωm is the rotor mechanical speed.

3.1.1 Parks Transformation and Dynamic d q Modeling

The dynamic d - q modeling is used for the study of motor during transient as well as in steady state. It is done by converting the three phase voltages variable to dqo variables by using Parks transformation.

Converting the phase voltages variables vabc to vdqo variables in rotor reference frame the following equations are obtained:

$$\begin{bmatrix} V_q \\ V_d \\ V_o \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta_r & \cos(\theta_r - 120) & \cos(\theta_r + 120) \\ \sin\theta_r & \sin(\theta_r - 120) & \sin(\theta_r + 120) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad 3.12$$

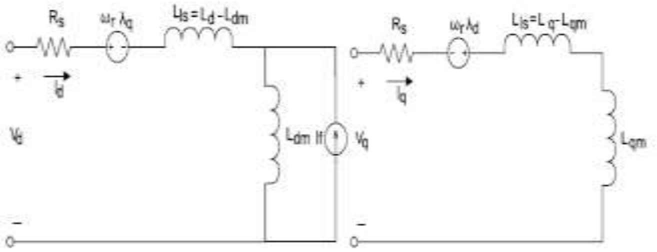
Convert V_{dqo} to V_{abc}

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \sin\theta_r & 1 \\ \cos(\theta_r - 120) & \sin\theta_r - 120 & 1 \\ \cos(\theta_r + 120) & \sin(\theta_r + 120) & 1 \end{bmatrix}\begin{bmatrix} V_q \\ V_d \\ V_o \end{bmatrix} \qquad 3.13$$

3.1.2 Equivalent Circuit of Permanent Magnet Synchronous Motor

Equivalent circuits of the PMSM are shown above in fig., 3.1.2. and used for study and simulation of motors. From the d-q modeling of the motor using the stator voltage equations the equivalent circuit of the motor can be derived. Assuming rotor d -axis flux from the permanent magnets is represented by a constant current source as described in the following equation

f= Ldmif



3.2 PM Motor Control

Control of PM motors is performed using field oriented control for the operation of synchronous motor as a dc motor. The stator windings of the motor are fed by an inverter that generates a variable frequency variable voltage. Instead of controlling the inverter frequency independently, the frequency and phase of the output wave are controlled using a position sensor as shown in figure 3.3.

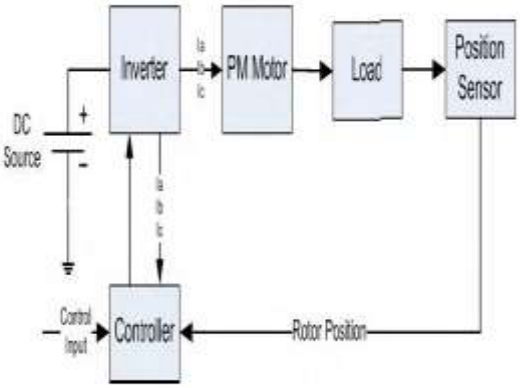


Fig 3.3 Self Control Synchronous Motor

Field oriented control was invented and used from 1970s and it demonstrates that an induction motor or synchronous motor could be controlled like a separately excited dc motor by the orientation of the stator mmf or current vector in relation to the rotor flux to achieve a desired operation. In order for the motor to behave like DC motor, the control needs knowledge of the position of the instantaneous rotor flux or rotor position of permanent magnet motor. This needs a resolver or an absolute optical encoder. By knowing the position, the three phase currents can be calculated. Calculation using the current matrix depends on the control desired. Some control options are constant torque and flux weakening. These options are based in the physical limitation of the motor and the inverter. The limit is established by the rated speed of the motor, at which speed the constant torque operation finishes and the flux weakening starts as shown in figure 3.4.

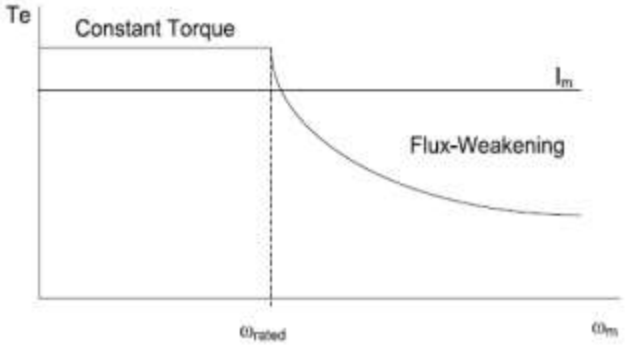


Fig 3.4 Steady State Torque versus Speed

3.2.1 Field Oriented Control of PMSM

The PMSM control is nearly equivalent to that of the dc motor by a decoupling control known as field oriented control and also called as vector control. The vector control separates the torque component of current and flux channels in the motor through its stator excitation. The vector control of the permanent magnet synchronous motor(PMSM) is derived from its dynamic model.

Considering the currents as inputs, then the three currents can be written as,

$$i_a = I_m \sin(\omega_r t + \alpha) \qquad 3.14$$

$$i_b = I_m \sin(\omega_r t + \alpha - \frac{2\pi}{3}) \qquad 3.15$$

$$i_c = I_m \sin(\omega_r t + \alpha + \frac{2\pi}{3}) \qquad 3.16$$

Writing equations 3.14 to 3.16 in the matrix form:

$$\begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} = \begin{pmatrix} \cos(\omega_r t + \alpha) \\ \cos(\omega_r t + \alpha - \frac{2\pi}{3}) \\ \cos(\omega_r t + \alpha + \frac{2\pi}{3}) \end{pmatrix} \begin{pmatrix} I_m \end{pmatrix} \qquad 3.17$$

Where α is the angle between the rotor field and stator current and phasor, ω_r is the electrical rotor speed.

Previously , the currents obtained are the stator currents that must be transformed to the rotor reference frame with the rotor speed ω_r, using Park's transformation. The q and d axis currents are constants in the rotor reference frames since α is a constant for a given load torque. As these constants, they are similar to the armature and field currents in the separately excited dc machine. The q axis current is distinctly equivalent to the armature current of the dc machine; the d axis current is field current, but not in its entirety. It is only a partial field current; the other part is contributed by the equivalent current source representing the permanent magnet field. For this reason the q axis current is called the torque producing component of the stator current and the d axis current is called the flux producing component of the stator current.

Substituting equation 3.17 and 3.12 is obtain id and iq in terms of Im as follows:

$$\begin{pmatrix} i_q \\ i_d \end{pmatrix} = I_m \begin{pmatrix} \sin\alpha \\ \cos\alpha \end{pmatrix} \qquad 3.18$$

Using equations 3.1, 3.2, 3.8 and 3.18 the electromagnetic torque equation is obtained as given below.

$$T_e = \frac{3}{2} \cdot \frac{P}{2} \left[\frac{1}{2} (L_d - L_q) I_m^2 \sin 2\alpha + \lambda_f I_m \sin\alpha \right] \qquad 3.19$$

3.2.1.1 Constant torque operation

Constant torque control strategy is derived from field oriented control, where the maximum possible torque is desired at all times like the dc motor. This is performed by making the torque producing current iq equal to the supply current Im. That results in selecting the angle to be 90 º degrees according to equation 3.18. By making the id current equal to zero the torque equation can be rewritten as:

$$T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right) \lambda_f \cdot i_q \qquad 3.20$$

Assuming that:

$$k_t = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right) \lambda_f \qquad 3.21$$

The torque is give by

$$T_e = k_t \cdot i_q \qquad 3.22$$

Like the dc motor, the torque is dependent of the motor current.

3.2.1.2 Flux-weakening

Flux weakening is the process of reducing the flux in the d axis direction of the motor which results in an increased speed range.

The motor drive is operated with rated flux linkages up to a speed where the ratio between the induced emf and stator frequency (V/f) is maintained constant. After the base frequency, the V/f ratio is reduced due to the limit of the inverter dc voltage source which is fixed. The weakening of the field flux is required for operation above the base frequency.

This reduces the V/f ratio. This operation results in a reduction of the torque proportional to a change in the frequency and the motor operates in the constant power region [22].

The rotor flux of PMSM is generated by permanent magnet which cannot be directly reduced as induction motor. The principle of flux-weakening control of PMSM is to increase negative direct axis current and use armature reaction to reduce air gap flux, which equivalently reduces flux and achieves the purpose of flux-weakening control [28].

This method changes torque by altering the angle between the stator MMF and the rotor d axis. In the flux weakening region where ωr > ωrated angle α is controlled by proper control of id and iq for the same value of stator current. Since iq is reduced the output torque is also reduced. The angle α can be obtained as:

$$\alpha = Tan^{-1}\left(\frac{i_q}{i_d}\right) \qquad 3.23$$

The current Im is related to id and iq by:

$$I_m = \sqrt{i_d^2 + i_q^2} \qquad 3.24$$

Flux-weakening control realization

The realization process of equivalent flux-weakening control is as follows,

1) Measuring rotor position and speed ωr from a sensor which is set in motor rotation axis.

2) The motor at the flux weakening region with a speed loop, Te* is obtained from the PI controller.

3) Calculate Iq* using equation 3.20

$$(i_q = \frac{T_e^*}{\left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\lambda_f})$$

4) Calculate Id* using equation:

$$i_d^* = \frac{\lambda_d - \lambda_f}{L_d}$$

5) Calculate α using equation 3.23.

6) Using α and rotor position the controller will generate the reference currents as per

Equation 3.17.

7) Then the current controller makes uses of the reference signals to control the inverter for

The desired output currents.

8) The load torque is adjust to the maximum available torque for the reference speed

$$T_L = T_{e(rated)} \frac{\omega_{rated}}{\omega_r}.$$

3.3 Speed Control of PM Motor

Many applications, such as robotics and factory automation, require precise control of speed and position. Speed Control Systems allow one to easily set and adjust the speed of a motor. The control system consists of a speed feedback system, a motor, an inverter, a controller and a speed setting device. A properly designed feedback controller makes the system insensible to disturbance and changes of the parameters.

The purpose of a motor speed controller is to take a signal representing the demanded speed, and to drive a motor at that speed. Closed Loop speed control systems have fast response, but become expensive due to the need of feed back components such as speed sensors.

3.3.1 Implementation of the Speed Control Loop

For a PM motor drive system with a full speed range the system will consist of a motor, an inverter, a controller (constant torque and flux weakening operation, generation of reference currents and PI controller) as shown in figure 3.5.

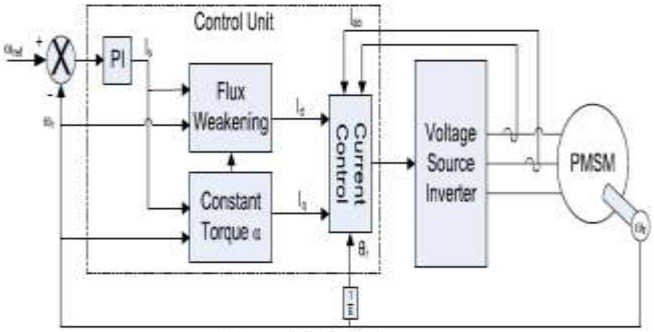


Figure 3.5 Block Diagram

The operation of the controller must be according to the speed range. For operation up to rated speed it will operate in constant torque region and for speeds above rated speed it will operate in flux-weakening region. In this region the d-axis flux and the developed torque are reduced.

Speed controller calculates the difference between the reference speed and the actual speed producing an error, which is fed to the PI controller. PI controllers are used widely for motion control systems. They consist of a proportional gain that produces an output proportional to the input error and an integration to make the steady state error zero for a step change in the input. Block diagram of the PI controller is shown in figure 3.6.

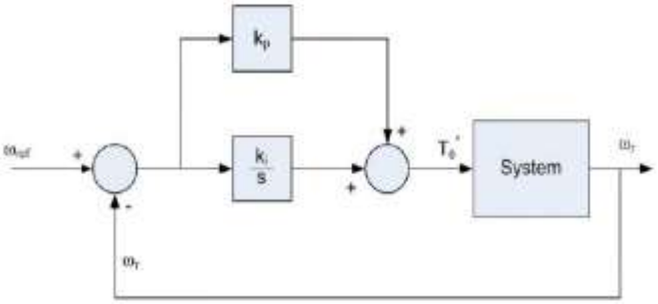


Figure 3.6 PI Controller

Speed control of motors mainly consist of two loops the inner loop for current and the outer loop for speed. The order of the loops is due to their response, how fast they can be changed. This requires a current loop at least 10 times faster than the speed loop.

Since the PMSM is operated using field oriented control, it can be modeled like a dc motor. The design begins with the innermost current loop by drawing the block diagram. But in PMSM drive system the motor has current controllers which make the current loop. The current control is performed by the comparison of the reference currents with the actual motor currents.

The design of the speed loop assumes that the current loop is at least 10 times faster than speed loop, all owing to reduce the system block diagram by considering the current loop to be of unity gain as shown in figure 3.8.

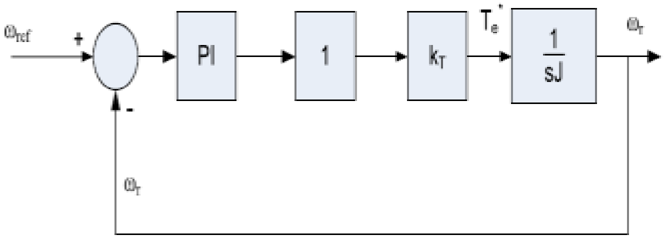


Figure 3.8 Block Diagram of Speed Loop

The open loop transfer function of the motor is given by:

$$GH_{(s)} = \left(\frac{k_i k_T \alpha}{J}\right)\left(\frac{1+s\,{k_p}/{k_i}}{s^2}\right) \qquad 3.25$$

kT = PM flux = λf

The crossover frequency has been selected an order smaller than the current loop. To

Satisfy dynamic response without oscillations the phase margin (φ*PM*) should be greater than

45º, preferably close to 60º. Knowing the motor parameters and phase margin, the ki and kp

Gains can be obtained for the motor controller using equations 3.26 and 3.27.

Phase Margin =φOL +180°

$$\left|\frac{k_i k_T \alpha}{J\cdot s^2}\left(1+s\,{k_p}/{k_i}\right)\right|_{s=j\omega} = 1 \qquad 3.26$$

$$\text{Angle}\left[\frac{k_i k_T \alpha}{J\cdot s^2}\left(1+s\,{k_p}/{k_i}\right)\right] = 180^\circ + \phi_{PM} \qquad 3.27$$

The gains for the speed controller was obtained using the motor parameters and by selecting a crossover frequency. The selected values are:

fc (crossover frequency)= 100Hz J = 0.000179

kT = λf = 0.272

Using equation 3.26 and 3.27 and motor parameters the values of ki and kp are obtained as 129.9014 and 0.3581 respectively.

4. DRIVE SYSTEM SIMULATION IN SIMULINK

This chapter describes different tools available for electrical and electronic systems

Simulation and then justification is given for selecting Simulink for the PMSM system. Block by block an explanation is given for Simulink simulation of the drive system.

4.1 Simulation Tools

Study of electric motor drives needs the proper selection of a simulation tool. Their complex models need computing tools capable of performing dynamic simulations. Today with the growth in computational power there is a wide selection of software titles available for electrical simulations such as ACSL, ESL, EASY5, and PSCSP are for general systems and SPICE2, EMTP, and ATOSEC5 for simulating electrical and electronic circuits. IESE and SABER are examples of general-purpose electrical network simulation programs that have provisions for handling user-defined modules. SIMULINK is a toolbox extension of the MATLAB program. It is a program for simulating dynamic systems

Simulink has the advantages of being capable of complex dynamic system simulations, graphical environment with visual real time programming and broad selection of tool boxes. The simulation environment of Simulink has a high flexibility and expandability which allows the possibility of development of a set of functions for a detailed analysis of the electrical drive .Its graphical interface allows selection of functional blocks, their placement on a worksheet, selection of their functional parameters interactively, and description of signal flow by connecting their data lines using a mouse device. System blocks are constructed of lower level blocks grouped into a single maskable block. Simulink simulates analogue systems and discrete digital systems.

4.2 Simulation of PMSM Drive

The PM Synchnronous Motor drive is composed of four main parts: The electrical motor, the Three-phase Inverter, the VECT controller and the Speed Controller.

The electrical motor is a 288 Vdc, 100 kW PMSM .This motor has 8 pole and magnets are buried (salient rotor's type).

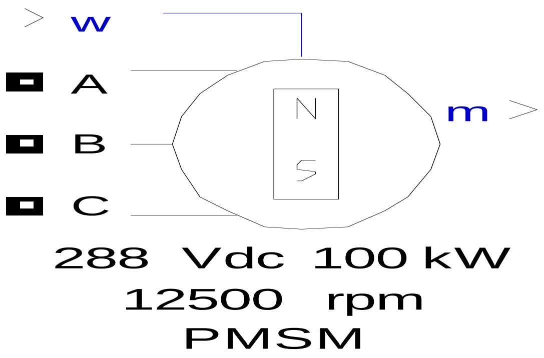


Figure 4.1 Electrical Motor

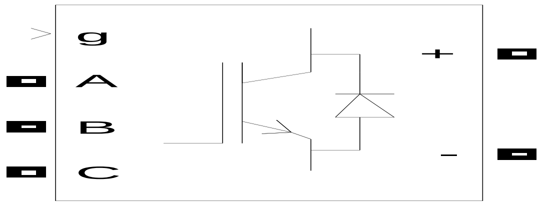


Figure 4.2 Three-phase Inverter

The VECT controller block computes the three reference motor line currents corresponding to the flux and torque references and then generates a corresponding PWM using three-phase current regulator. When the nominal flux is required, an optimal control is used in order to minimize the line current amplitude for required torque. When a flux weakening is needed, the amplitude and the phase of the current are changed to extend the torque-speed operating range.

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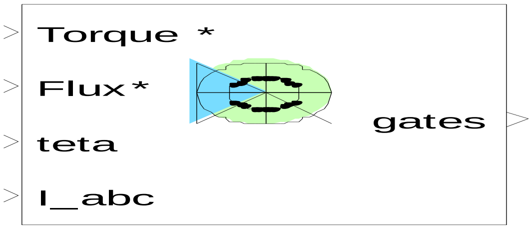


Figure 4.3 VECT Controller

The speed controller is used in torque regulation mode. The normalized flux value is computed with the speed of the machine in order to perform a flux weakening control.

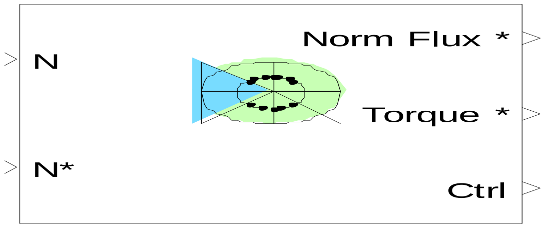


Figure 4.4 Speed Controller

Using all above blocks the PMSM drive system block is formed as shown in fig 4.5 below .

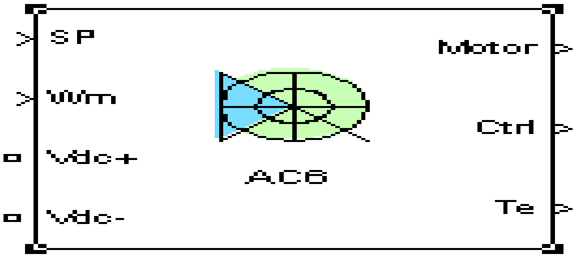


Figure 4.5 PM Synchronous Motor Drive

The block parameters of PMSM drive is shown in following fig 4.6

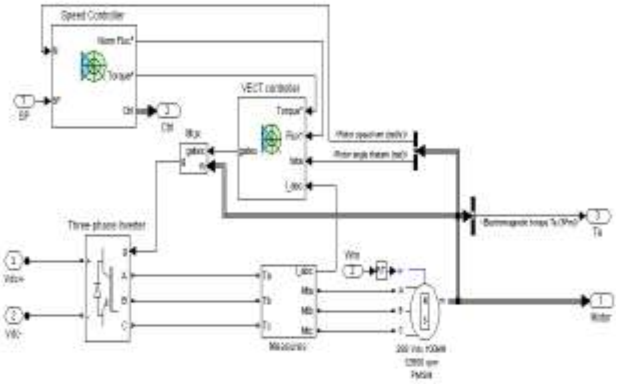


Fig.4.6 PM Synchronous motor drive parameters

The mechanical system is connected externally. The transfer function of mechanical system us as follows.

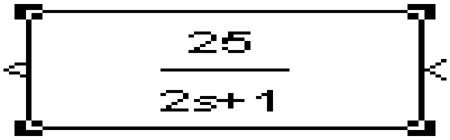


Fig. 4.7 Mechanical System

The Torque limitation block is used to prevent the limitation due to the torque-speed characteristic of this motor for a 288 Vdc source. When the internal machine's voltage reaches the inverter voltage (because the desired torque is too high for the motor's speed), the inverter becomes in saturation mode (the desired current cannot flow anymore into motor). After this point, there will be a loss of current tracking which will decrease the motor current. This block is used to reduce the reference torque as a function of the motor's speed and the torque-speed characteristic in order to never operate in inverter saturation mode.

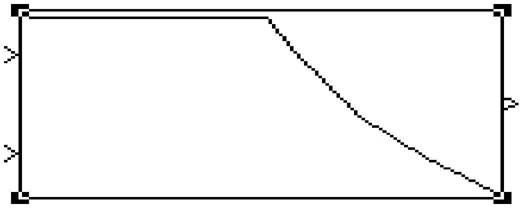


Fig.4.8 Torque limitation

Using all the drive system blocks the complete system block has been developed as Shown in figure 4.8

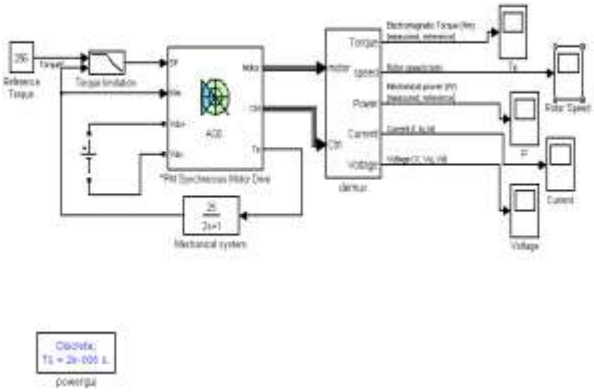


Figure .4.9 Permanent Magnet Synchronous Motor Drive System in Simlunk

4.3 Simulation results

The simulation results of Permanent Magnet Synchrous Motor Drive are as follows:

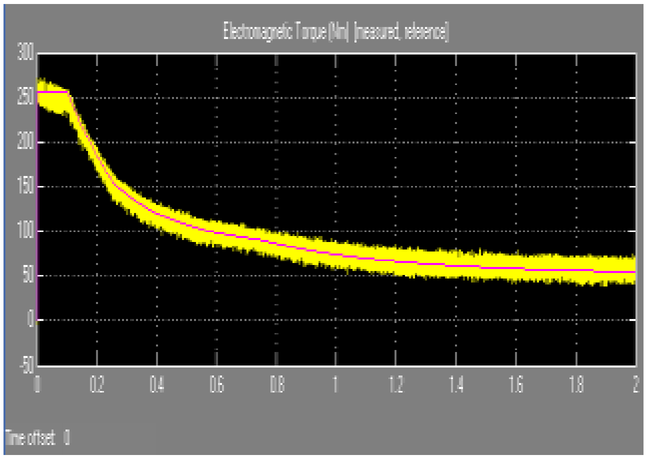


Figure 4.10 Electromagnetic Torque

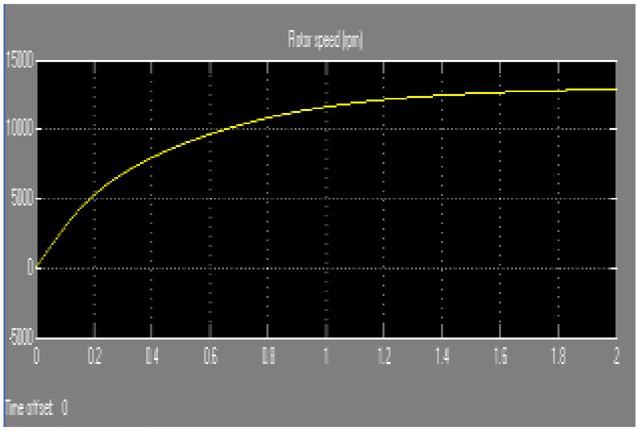
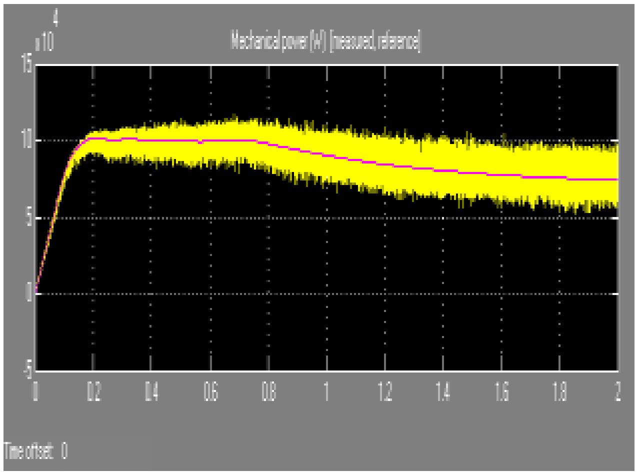


Figure 4.11 Rotor Speed



Fiure 4.12 Mechanical Power (W)

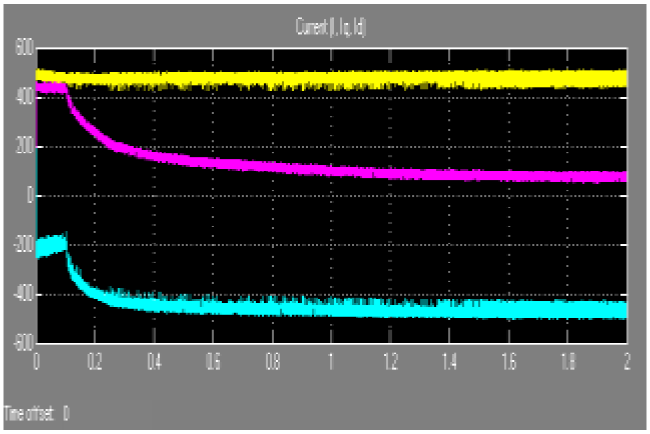


Figure 4.13 Current (I, Iq, Id)

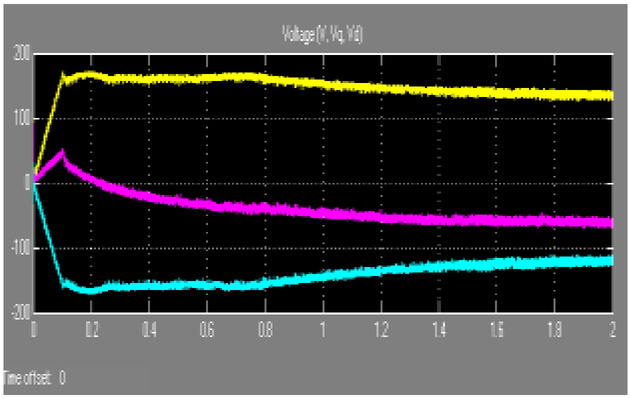


Figure 4.14 Voltage (V, Vq, Vd)

5. FUTURE WORK

Advance techniques may be implements for control design such as Modelling And Simualtion Of Permanent Magnet Synchronous Motor Drive System by using fuzzy logic which increase the flexibility of control system and reduce the distortion occur in the system at the time of operation,

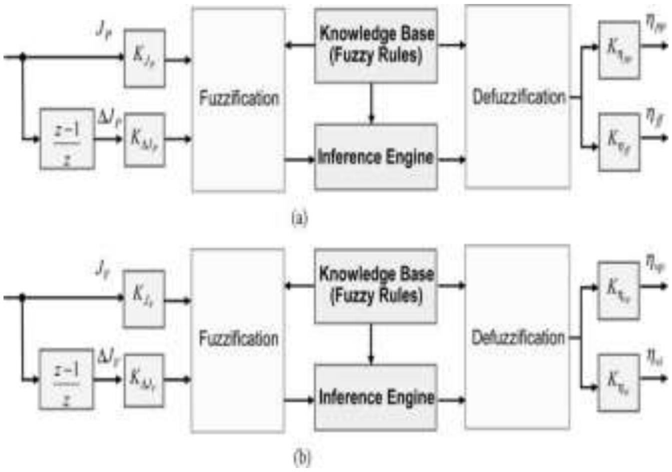


Figure 5.1 Block diagram of the fuzzy step-size tuners: (a) position control loop and (b) velocity control loop.

6. CONCLUSIONS

A detailed Simulink model for a PMSM drive system has being developed. Simulink has been developed from several simulation tools because its flexibility in working with analog and digital devices are impressive. Mathematical models can be easily incorporated in the simulation and the presence of numerous tool boxes and support guides simplifies the simulation of large system compared to spice. Simulink is capable of show in real time results with reduced simulation time and debugging. And with fuzzy logic controlling accuracy can increases.

7. REFERENCES

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