Vector Control Drive of Permanent Magnet Synchronous Motor Using Resolver Sensor

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ABSTRACT: Now - a - days, Permanent Magnet Synchronous Motor (PMSM) is designed not only to be more powerful but also with lower mass and lower moment of inertia. Due to its high power density and smaller size, PMSM has in recent years evolved as the preferred solution for speed and position control drives on machine tools and robots. One of the efficient control strategies of PMSM is Vector- Control (or Field oriented control).The rotor position is necessary to achieve the vector control drive system of Permanent Magnet Synchronous Motor. In this project, the resolver sensor detecting the rotor position of PMSM is focused. The outstanding features of this sensor are its robust structure and noise insensitivity. The resolver algorithm is proposed and implemented in the vector control drive system of PMSM. The proposed scheme has to be verified by simulation and using MATLAB/SIMULINK.

Keywords: PMSM, MATLAB, SIMULINK.

I. INTRODUCTION:

The electrical machine that converts electrical energy into mechanical energy and vice versa is the workhorse in the drive system. Drive system are widely used in applications such as pumps, fans, paper, robotics, textile mills, elevators and electric vehicles etc…More than 85% of drive systems use Induction motors at present but Permanent Magnet Synchronous Motors (PMSM) can replace them as they are more efficient which in turn reduces the replacement cost. Hence they have more market now a days and it can be used for low and mid power applications such as computer peripherals and adjustable speed drives effectively. In this work, the simulation of a field oriented controlled PM motor drive system is developed using SIMULINK.

1.2 LITERATURE REVIEW:

The topic, overview of electrical drives has been extracted from [3]. The classification of Permanent Magnet Synchronous Motor (PMSM), their merits and demerits, magnetic characteristics of magnets used for PMSM and their comparison with Induction Motors has been taken from [4].The content, control strategies and theory about position sensors has been extracted from [2]. The theory and equations related to 'Implementation of Vector Control' has been derived from [1]. The topic, 'Introduction to MATLAB-SIMULINK' has been extracted from [5].

2. OVERVIEW OF ELECTRICAL DRIVES

Motion control is required in large number of industrial and domestic applications like transportation systems, rolling mills, paper machines, textile mills, fans, pumps, robots, washing machines etc. System employed for motion control are called drives and may employ any of the prime movers such as, diesel or petrol engines, gas or steam turbines, steam engines, hydraulic motors and electric motors for supplying mechanical energy for motion control. Drives employing electric motors are known as Electrical Drives.

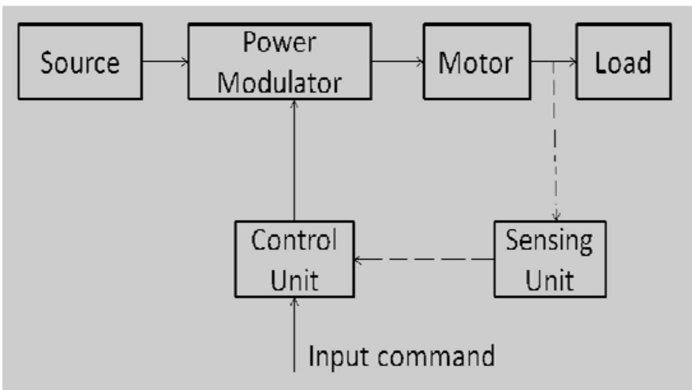


Fig 2.1: Block diagram of an electrical drive

Block diagram of an electrical drive is shown in Fig 2.1. Load is usually machinery designed to accomplish a given task, e.g. fans, pumps, robots, washing machines, machine tools, trains and drills. Usually load requirements can be specified in terms of speed and torque demands. A motor having speed-torque characteristics and capabilities compatible to the load requirements is chosen. 1) 1)Modulates flow of power from the source to the motor in such a manner that motor is imparted speed-torque characteristics required by the load.

2)During transient operations, such as starting, braking and speed reversal, it restricts source and motor currents with in permissible values; excessive current drawn from source may overload it or may cause a voltage dip.
3)Converts electrical energy of the source in the form suitable to the motor, e.g. if the source is D.C and an Induction motor is to be employed, then the power modulator is required to converts D.C into variable frequency A.C.
4)Select the mode of operation of the motor, i.e. motoring or braking.

2.2 PERMANENT MAGNET SYNCHRONOUS MACHINE DRIVES

In order to overcome the problems associated with Synchronous motors, Permanent Magnet Synchronous Machine (PMSM) is introduced. In PMSM the excitation coil is replaced with a Permanent Magnet.

The stator current of an Induction Motor (IM) contains magnetizing as well as torque-producing components. The use of the permanent magnet in the rotor of the PMSM makes it unnecessary to supply magnetizing current through the stator for constant air gap flux; the stator current need only be torque-producing. Hence for the same output, the PMSM will operate at a higher power factor (because of the absence of magnetizing current) and will be more efficient than the IM. The conventional wound-rotor synchronous machine (SM), on the other hand, must have dc excitation on the motor, which is often supplied by brushes and slip rings. This implies rotor losses and regular brush maintenance, which implies downtime.

2.3 Permanent Magnet Synchronous Motor (PMSM)

Its three phase stator winding has sinusoidal winding distribution. Therefore the generated voltages are also sinusoidal. The key reason for the development of the PMSM was to remove the foregoing disadvantages of the SM by replacing its field coil, dc power supply, and slip rings with a permanent magnet. The PMSM, therefore, has a sinusoidal induced EMF and requires sinusoidal currents to produce constant torque just like the SM.

2.4 Classification of Permanent Magnet Synchronous machines on the basis of the direction of the field flux

- Radial field: flux direction is along the radius of the machine.
- Axial field machines: the flux direction is parallel to the rotor shaft.

The radial field machines are common; axial field machines are coming into prominence in a small number of applications because of their higher power density and acceleration. But these are very desirable features in high performance applications. Here radial field permanent magnet synchronous machines are discussed.

2.8.3 Radial field permanent magnet synchronous machines:

There are basically three types of permanent magnet synchronous machines.

- Surface mounted permanent magnet synchronous machines
- Inset permanent magnet synchronous machines
- Interior permanent magnet synchronous machines

Regardless of manner of mounting the permanent magnets, the basic principle of operation is same. An important consequence of method of mounting the rotor magnets is the difference between the direct and quadrature axes inductance values. It is explained as follows.

The rotor magnetic axis is called the direct axis and the principal path of flux flow is through the magnets. The permeability of high flux density permanent magnets is almost that of air. This results in magnetic thickness becoming an extension of air gap by that amount. The stator inductance when direct axis or magnets are aligned with the stator winding is known as direct axis inductance. By rotating the magnets from aligned position by 90^0, the stator flux sees inter polar area of rotor, containing only the iron path, and inductance measured in this position is referred to as quadrature axis inductance. The direct axis reluctance is greater than quadrature axis reluctance, because the effective air gap of direct axis is multiple times that of air gap seen by the quadrature axis.

Therefore $L_d > L_q$

L_d is the inductance along the magnetic axis.

L_q is the inductance along the axis in quadrature with the magnetic axis.

Now a brief discussion is given about various types of permanent magnet synchronous machines.

2.5 Surface mounted permanent magnet synchronous machines

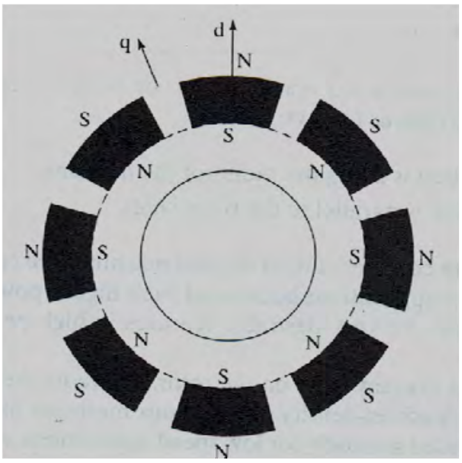


Fig 2.2 Surface mounted PMSM

Machines with this arrangement are known as surface mount Surface mounted permanent magnet synchronous machines. Surface mounted permanent magnet synchronous machines with radial field versions are used for low speed applications. Following are some of the characteristics of Surface mounted permanent magnet synchronous machines.

3. CONTROL STRATEGIES:

3.1. SCALAR CONTROL

Scalar control, as the name indicates, is due to magnitude variation of the control variables only, and disregards the coupling effects of the machine. For example, the voltage of a machine can be controlled to the flux, and frequency or slip can be controlled to control the torque. However, flux and torque are also functions of frequency and voltage, respectively. Scalar control is in contrast to vector or field oriented control, where both the magnitude and phase alignment of vector variables are controlled. Scalar-controlled drives give somewhat inferior performance has diminished recently because of the superior performance of vector-controlled drives, which is demanded in many applications.

3.1.1. VOLTS PER HETZ CONTROL

Although it has been superseded open loop volts/hertz control or scalar control as it is known, is still widely used in applications that don't require precise speed control such as fans for heating ventilation and air condition (HVDC). It is the simplest scalar control method of a synchronous machine, but it is achieved at the cost of inferior performance, unlike high-performance vector control, which will be described later. In topology and performance, the scheme is somewhat similar to the volts/hertz controlled I.M drive. This method of speed control is particularly popular in multiple synchronous reluctance or permanent magnet machine drives as shown in figure3.1, where close speed tracking is essential among a number of machines for applications such as fibre spinning mills. Here, all the machines are connected in parallel to the same inverter so that they move in synchronism corresponding to the command frequency ω_e^* at the input. The phase voltage command V_s^* is generated through a function generator (FG), where the voltage is essentially maintained proportional to the frequency so that the stator flux remains constant. Similar to the induction motor drive, a boost voltage is added to near zero frequency to compensate the stator resistance drop. Maintaining a constant and rated stator flux permits nearly maximum available torque/ampere of stator current of fast transient response. The front end of the voltage fed PWM inverter is supplied from the utility line through a diode rectifier and LC filter. The machine is normally built with a damper or cage winding to prevent oscillatory or under damping behaviour during the transient response.

3.1.2. BLOCK DIAGRAM FOR VOLTS PER Hz CONTROL

The closed loop speed control with volts per hertz control described in the previous is implemented using the below the block diagram.

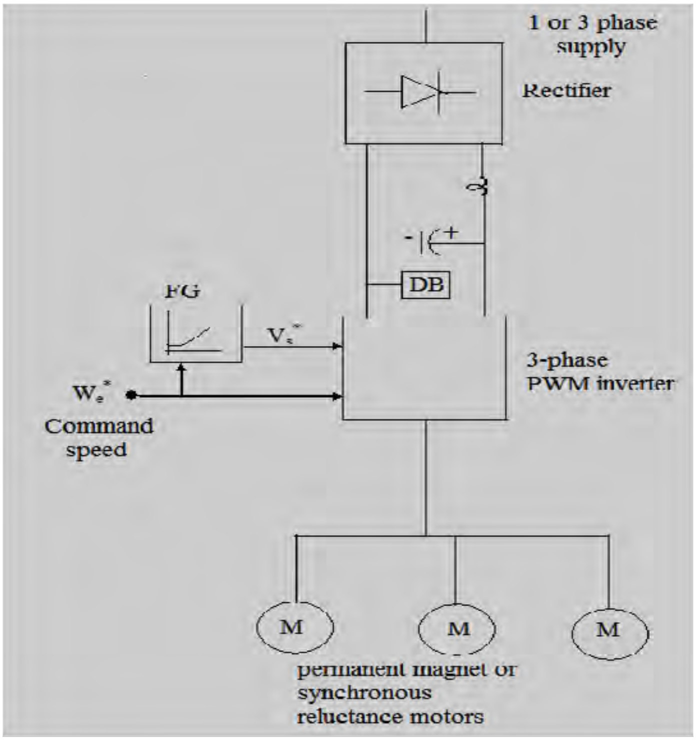


Fig 3.1 open loop volts/HZ speed control of multiple PM synchronous motors

3.2. VECTOR CONTROL

So far, we have discussed scalar control techniques of voltage-fed and current-fed inverter drives. Scalar control is somewhat simple to implement, but the inherent the coupling effect (i.e., both torque and flux are functions of voltage or current and frequency) gives sluggish response and system is easily prone to instability because of a high-order (fifth-order) system effect. To make it more clear, if, for example, the torque increased by incrementing the slip (i.e., the frequency), the flux tends to decrease. Note that the flux variation is always sluggish. The flux decrease is then compensated by the sluggish flux control loop feeding in additional voltage. This temporary dipping the flux reduces the torque sensitivity with slip and lengthens the response time. This expansion is also valid for current-fed drives.

The forgetting problems can be solved by vector or field-oriented control. The invention of the vector control in the beginning of 1970s, and the demonstration that an induction motor can be controlled like separately exited dc motor, brought a renaissance in the high-performance control of AC drives. Because of de machine-like performance, vector control is also known as decoupling, orthogonal, or Trans vector control. Vector control is applicable to both synchronous and induction motor drives. Undoubtedly, vector control and the corresponding feedback signal processing, particularly for modern sensor less vector control, are complex and the use of powerful micro computer or DSP is mandatory. It appears that eventually, vector control will oust scalar control, and will be accepted as the industry-standard control for AC drives.

3.3 Principles of Vector Control

The fundamentals of vector control implementation can be explained with the help of fig 3.4, where the machine model is represented in a synchronously rotating frame of reference. The inverter is omitted from the fig., assuming that it has unity current gain, i.e., it generates currents i_a ,i_b and i_c as dictated by the corresponding common currents i_a^*,i_b^* and i_c^* from the controller. A machine model with internal conversion is shown on the right. The machine terminal phase currents i_a ,i_b and i_c are converted to i_{ds}^s and i_{qs}^s components by 3phase/2phase transformation. These are then converted to synchronously rotating frame by the unit vector component $\cos\theta_e$ and $\sin\theta_e$ before applying them to the d^e- q^e machine as shown. The controller makes two stages of inverse transformation, as shown, so that the control currents i_{ds}^* and i_{qs}^* corresponds to the machine currents i_{ds} and i_{qs}, respectively. In addition, the unit vector assures correct alignment of i_{ds} current with the flux vector and i_{qs} perpendicular to it, as shown. Note that the transformation and the inverse transformation including the inverter ideally do not incorporate any dynamics, and therefore, the response to i_{ds} and i_{qs} is instantaneous (neglecting computational and sampling delays).

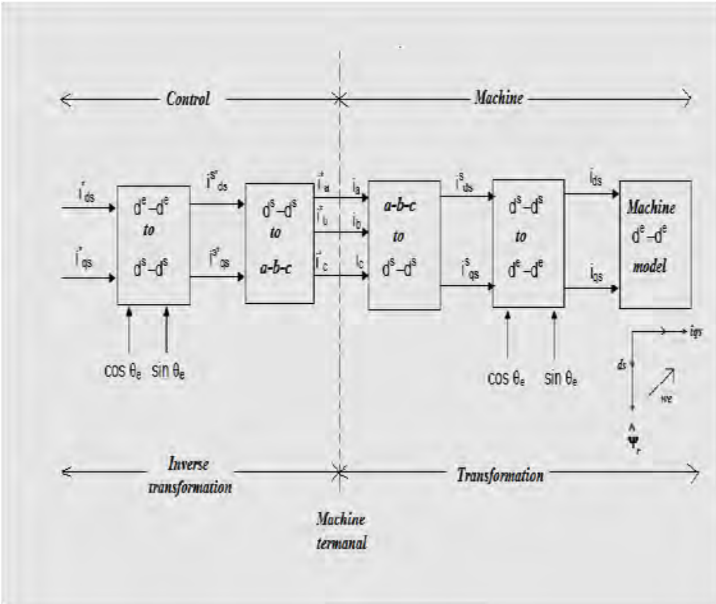


Fig. 3.3 Vector control implementation principal with d^e-d^e model

3.4 POSITION SENSORS:

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

3.4.1 Optical Encoders

The most popular type of encoder is the optical encoder which consists of a rotating disk, a light source, and a photo detector (light sensor). The disk, is mounted on the rotating shaft, has coded patterns of opaque and transparent sectors. As the disk rotates, these patterns interrupt the light emitted onto the photo detector, generating a digital pulse or output signal.

Optical encoders offer the advantages of digital interface. There are two types of optical encoders, incremental encoder and absolute encoder.

3.4.2 Position Resolver

Position revolver as shown in figure, also called rotary transformers, works on the transformer principle. The primary winding is placed on the rotor and depending upon the rotor shaft angle the induced voltage at the two secondary windings of the transformer shifted by 90° would be different. The position can be calculated using the two voltages. The resolver is basically a rotary transformer with one rotating reference winding (Vref) and two stator windings. The reference winding is fixed on the rotor, and therefore, it rotates jointly with the shaft passing the output windings, as is depicted in figure 3.5. Two stator windings are placed in quadrature (shifted by 90°) with one another and generate the sine and cosine voltages (Vsin , Vcos) respectively. Both windings will be further referred to as output windings. In consequence of the excitement applied on the reference winding Vref and along with the angular movement of the motor shaft θ the respective voltages are generated by resolver output windings Vsin , Vcos.

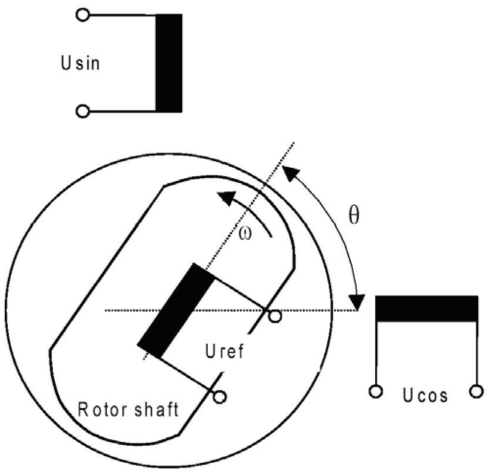


Fig.3.4.3 Resolver

The frequency of the generated voltages is identical to the reference voltage and their amplitudes vary according to the sine and cosine of the shaft angle θ. Considering that one of the output windings is aligned with the reference winding, then it is generated full voltage on that output winding and zero voltage on the other output winding and vice versa. The rotor angle θ can be extracted from these voltages.

The shaft angle can be determined by an Inverse Tangent function of the quotient of the sampled resolver output voltages Vsin , Vcos . This determination can be expressed, in terms of resolver output voltages, as follows:

$$\theta = a\,Tan\,(U\,Sin / U\,Cos)$$

4. IMPLEMENTATION OF VECTOR CONTROL:

To explain the principle of vector control, an assumption is made possible that the position of the rotor flux linkages phasor (λ_r) is known. λ_r is at θ_f from a stationary reference where θ_f is referred to as field angle hereafter, and the three stator currents can be transformed into q and d axes currents in the synchronous reference frames by using the transformation.

$$\begin{bmatrix} i_{qs}^e \\ i_{ds}^e \end{bmatrix} = \begin{bmatrix} \sin\theta_f & \sin\left(\theta_f - 120^0\right) & \sin\left(\theta_f + 120^0\right) \\ \cos\theta_f & \cos\left(\theta_f - 120^0\right) & \sin\left(\theta_f + 120^0\right) \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} \quad \text{…..... (4.1)}$$

From which the stator current phasor, i_s is derived as

$$i_s = \sqrt{(i_{qs}^e)^2 + (i_{ds}^e)^2} \quad \text{……. (4.2)}$$

And the stator phase angle is given by,

$$\theta_s = \tan^{-1}\left(\frac{i_{qs}^e}{i_{ds}^e}\right) \quad \text{……. (4.3)}$$

Where i_{qs}^e and i_{ds}^e are the 'q' and 'd' axes currents in synchronous reference frames that are obtained by projecting the stator current phasor on the 'q' and 'd' axes respectively. That the current phasor magnitude remains the same regardless of the reference frame chosen to view it is evident from Fig (4.1), the current phasor i_s is produces the rotor flux λ_r and torque T_e. The component of current producing the rotor flux phasor has to be in phase with λ_r. Therefore, resolving the stator current phasor along λ_r reveals that the component i_f is the field-producing component as shown in Fig (4.1). The perpendicular component i_T is hence the torque-producing component. By writing rotor flux linkages and torque in terms of these components as

$$\lambda_r \propto i_f \quad \text{…….(4.4)}$$

$$T_e \propto \lambda_r\, i_T \propto i_f\, i_T \quad \text{……. (4.5)}$$

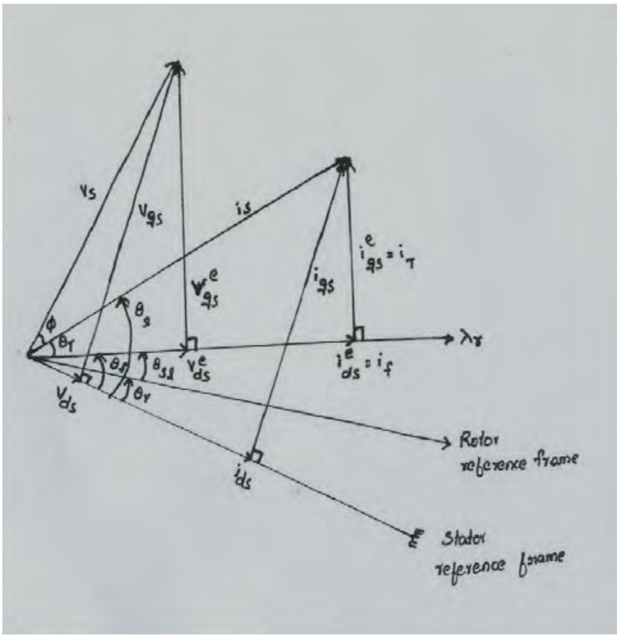


Fig.4.1 The phasor diagram of the vector Controller

It can be seen that i_f and i_T have only dc components in steady state, because the relative speed with respect to that of the rotor field is zero. The rotor flux linkage phasor has a speed equal to the sum of the rotor and slip speeds, which is equal to the synchronous speed. Orientation of λ_r amounts to considering the synchronous reference frames, and hence the flux and torque producing components of currents are dc quantities. Because they are dc quantities, they are ideal for use as control variables the bandwidth of the computational control circuits will have no effect as the processing of these dc control signals. Crucial to the implementation of vector control, then is the acquiring of the instantaneous rotor flux phasor position θ_f. This field can be written as,

$$\theta_f = \theta_r + \theta_{sl} \qquad \text{…..(4.6)}$$

Where θ_r is the rotor position and θ_{sl} is the slip angle. In terms of speed and time, the field angle is written as,

$$\theta_f = \int (\omega_r + \omega_{sl}) dt = \int \omega_s \, dt \qquad \text{….. (4.7)}$$

4.1 Algorithm summarizing the vector control:

- Obtain the field angle.
- Calculate the flux producing component of current, i_f *, for a required rotor flux linkages (λ_r). By controlling only this field current, the motor flux linkages are controlled. It is very similar to the separately excited dc machine, in that the field current controls the field flux; the armature current has no impact on it.
- From λ_r* and required T_e*, calculate the torque-producing component of stator current i_T*. Controlling the torque-producing component current then the rotor flux linkages phasor is constant gives an independent control of electromagnetic torque. It is very similar to the case of the armature currents controlling the electromagnetic torque in a separately excited dc machine with the field current maintained constant. Above two statements enable a complete decoupling of flux from torque-producing channels in the induction machine.
- Calculate the stator-current phasor magnitude, i_s* from the vector sum of i_T* and i_f *.
- Calculate torque angle from the flux and torque-producing components of the stator-current commands, $\theta_T = \tan^{-1}\left(\frac{i_f^*}{i_T^*}\right)$.
- Add θ_T and θ_f to obtain the stator current phasor angle θ_s.
- By using the stator-current phasor angle and its magnitude, θ_s and i_s*, the required stator current commands are found by going through the 'qdo' transformation to 'abc' variable:

$$i_{as}^* = i_s^* \sin \theta_s$$

$$i_{bs}^* = i_s^* \sin(\theta_s - 2\pi/3)$$
$$i_{cs}^* = i_s^* \sin(\theta_s + 2\pi/3)$$

- Synthesize these currents by using an inverter, when they are supplied to the stator of the induction motor, the commanded rotor flux linkages and torque is produced.

4.2 Theory and operation of PMSM:

4.2.1 Dynamic model of PMSM:

The mathematical model of a non- salient PMSM in the synchronously rotating reference frame aligned with the rotor flux linkage can be expressed as follows.

$$V_d = r_s i_d - \omega_r \lambda_q + p\lambda_d \ldots\ldots (1)$$
$$V_q = r_s i_q - \omega_r \lambda_d + p\lambda_q \ldots\ldots (2)$$
$$\lambda_d = L_s i_d + \lambda_m \ldots\ldots (3)$$
$$\lambda_q = L_s i_q \ldots\ldots (4)$$
$$T_e = (3/2)(P/2)(\lambda_d i_q - \lambda_q i_d) \ldots\ldots (5)$$

Where

V_d and Vq = the stator voltages in dq-axis;

id and iq = the stator currents in dq-axis;

λ_d and λ_q= the stator flux linkages in dq-axis;

λ_m= the permanent-magnet flux linkage;

Te= the electromagnetic torque;

ω_r = the angular velocity of rotor;

r_s=the stator resistance;

L_s=the stator self inductance;

P = the number of poles;

P=d/dt

Substituting equations (3) and (4) into the stator voltage equations (1) and (2), the stator current dynamic equations in the state-space form can be derived as follows.

$$di_d/dt = -\gamma i_d + \omega_r i_q + \beta V_d \ldots\ldots (6)$$
$$di_q/dt = -\gamma i_q + \omega_r i_d + \beta \omega_r \lambda_m + pV_q \ldots\ldots (7)$$

Where

$\beta = 1/L_s$ and $\gamma = r_s/L_s$

When the id current is controlled to be zero, the stator flux linkages and torque equations (3) and (5) become.

$$\lambda_d = \lambda_m \ldots\ldots (8)$$
$$\text{Torque, } T_e = (3/2)(P/2)(\lambda_m i_q) \ldots\ldots (9)$$

As a result, the electromagnetic torque is controlled merely by the current iq, similarly to the DC motor operation.

4.3 The Resolver sensor

Resolver is a type of sensor that uses in servo system. The schematic of resolver is shown in Fig.3.5. Three signals (i.e., excitation, sine and cosine signals) are obtained from the resolver. The sinusoidal excitation signal (U0) is applied to the rotor winding. The resolver outputs (stator windings) consist of two sinusoidal signals whose amplitudes are modulated according to the sine and cosine (U1 and U2) of the rotor position (θ).

The relevant equations of rotor winding (*U*0) and stator windings (*U*1 and *U*2) are summarized as follows.

$$U_0(t) = U_0^* \,.\, \text{Sin}(\ _{ref}\, t) \ldots\ldots (10)$$
$$U_1(\theta, t) = U_0^* \,.\, k.\, \text{Sin}\theta\ \text{Sin}(\ _{ref}\, t) \ldots\ldots (11)$$
$$U_2(\theta, t) = U_0^* \,.\, k.\, \text{Cos}\theta\ \text{Sin}(\ _{ref}\, t) \ldots\ldots (12)$$

Where k = turn ratio of the resolver

U_0^* = is the peak value

$_{ref}$ = frequency (rad/sec) of the excitation signal

θ =rotor position (rad.)

4.4 Calculation of rotor speed and position from Resolver Signals

Fig. 3 shows the block diagram of resolver algorithm, including the demodulation and Speed/position calculation. The algorithm attempts to minimize the error between the actual rotor angle θ the computed angle θ_1, using a feedback loop. The error calculation is formulated basing on the following trigonometric identity.

$$err = (U_0^*. \text{Sin} (_{ref}\ t). \text{Cos}\theta_1) (U_0^*. k. \text{Sin} (_{ref}\ t). \text{Sin}\theta) - (U_0^*. \text{Sin} (_{ref}\ t) \text{Sin}\ \theta_1)$$

$$(U_0^*. k. \text{Sin} (_{ref}\ t). \text{Cos}\theta) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (13)$$

$err= U_0^*(t)(U_0^*. k \text{ Sin} (_{ref}\ t)) [\text{Sin}\ \theta. \text{Cos}\ \theta_1\text{- Cos}\theta. \text{Sin}\ \theta_1]$…… (14)

$err= A [\text{Sin} (\theta\text{-}\theta_1)]$…………………………………………………(15)

Where $A= U_0^*(t) (U_0^*. k \text{ Sin} (_{ref}\ t))$…………........................... (16)

This error is controlled to zero by PI controller. The integrator is used to increase the resolution of computed angle. Once this control loop is accomplished (i.e., err = 0), then the computed angle θ_1, which is limited within 0-2π rad, is equal the actual rotor angle θ .

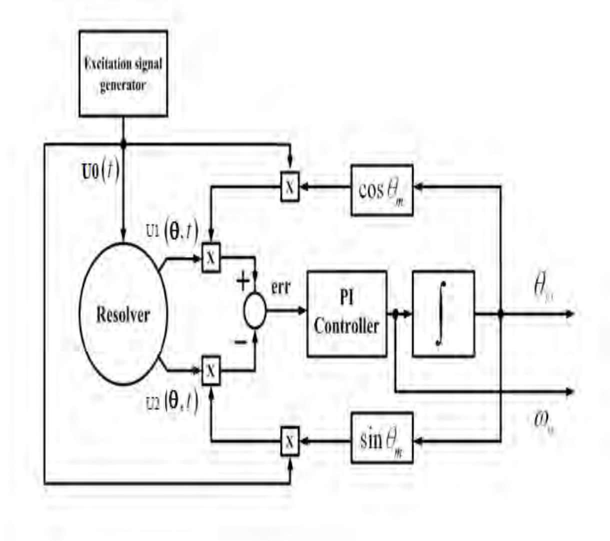


Fig. 4.2 Block Diagram of Resolver algorithm

From the signals obtained from the resolver sensor, a vector controlled Permanent Magnet Synchronous Motor drive is designed using MATLAB/ SIMULINK.

5. SIMULATIONS RESULTS:

5.1 SIMULINK MODEL:

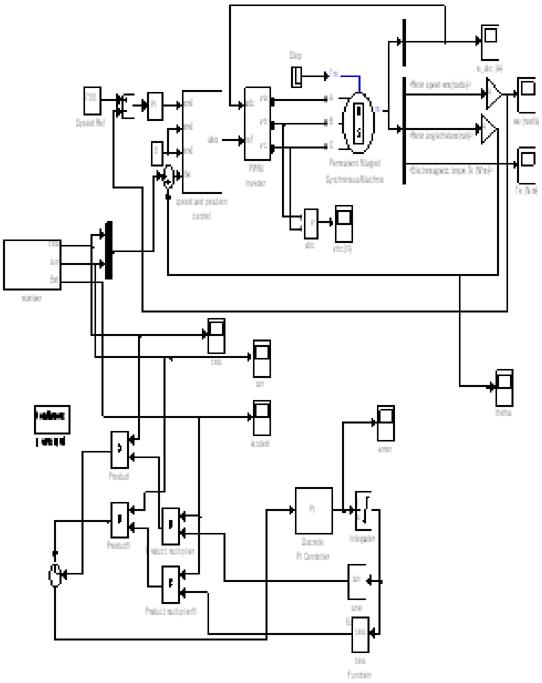
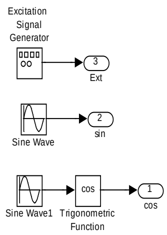


Fig 6.1 Simulink model of PMSM vector controlled drive

6.2 SUB BLOCKS:

The sub blocks used in the Fig. 6.1 are given below.

6.2.1 Resolver sub block:



6.2.2 Speed and Position control Sub Block:

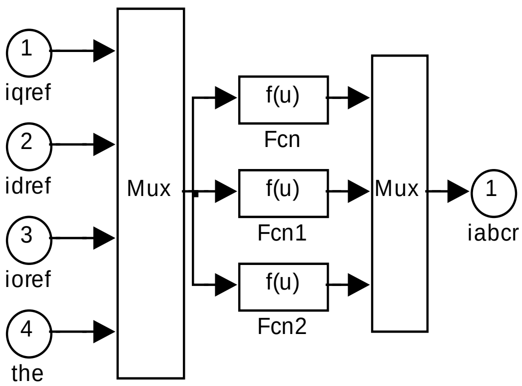


Fig 6.3 speed and position control Sub Block

6.2.3 PWM Inverter Sub Block:

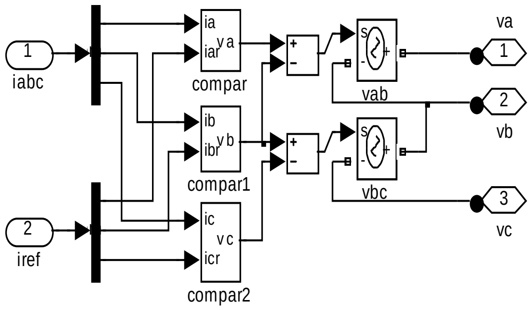


Fig 6.4 PWM Inverter Sub Block

6.2.3.1 Comparator Sub Block:

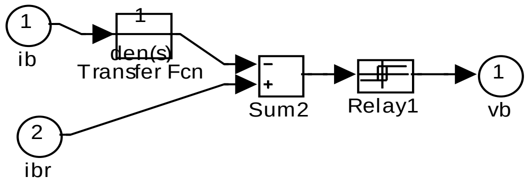


Fig. 6.5 Comparator Sub Block

6.3 RESULTS:

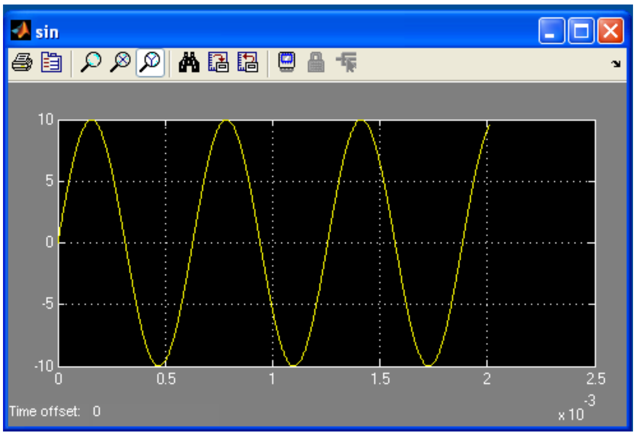


Fig 6.6 Sine Signal from Resolver

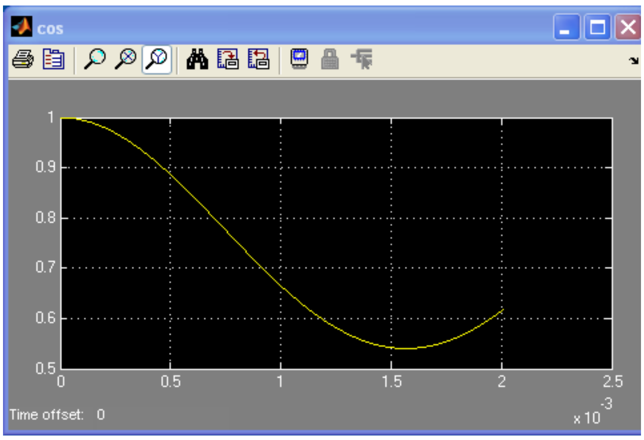


Fig 6.7 Cosine Signal from Resolver

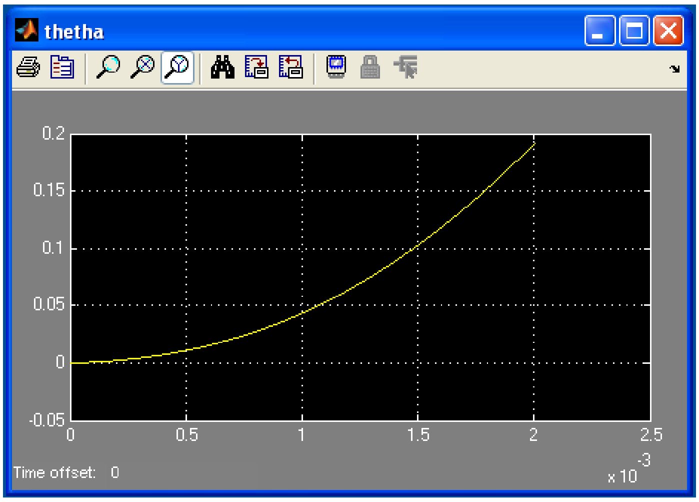


Fig 6.8 Position of Rotor of PMSM

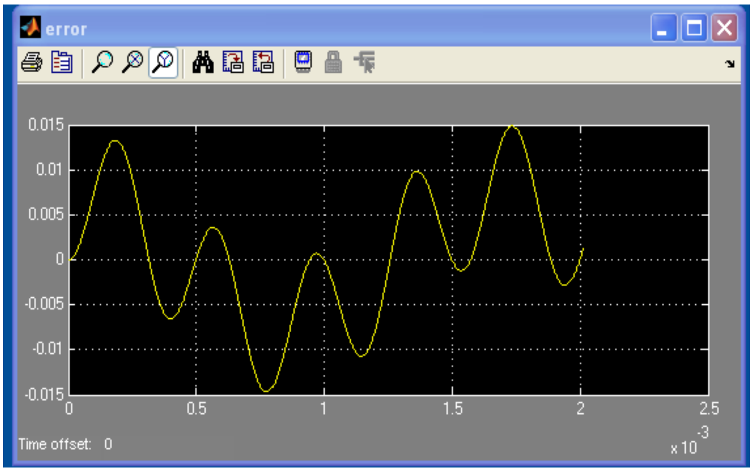


Fig 6.9 Error in rotor position

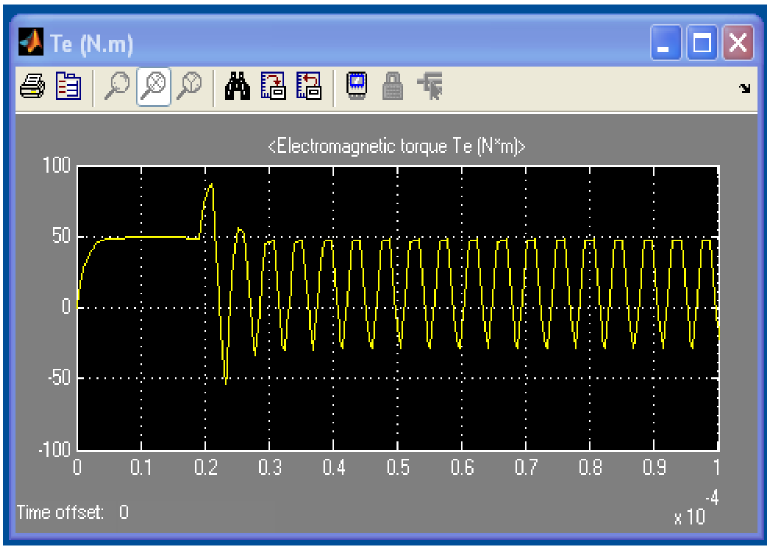


Fig 6.10 Electromagnetic Torque of motor

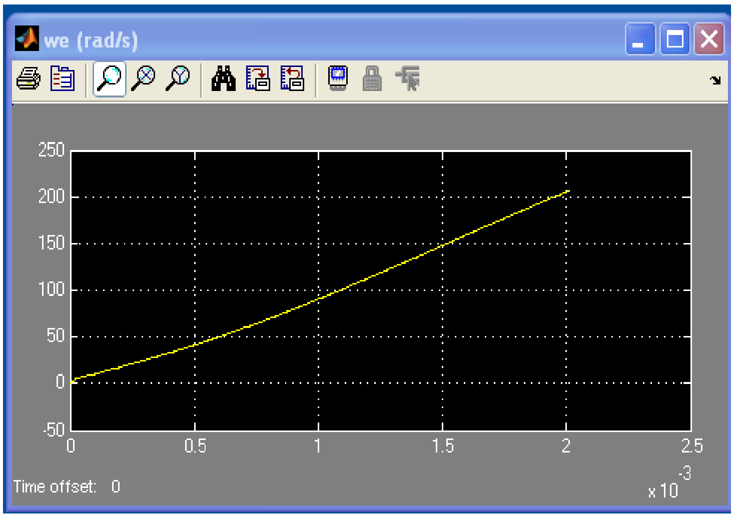


Fig 6.11 Angular speed of rotor

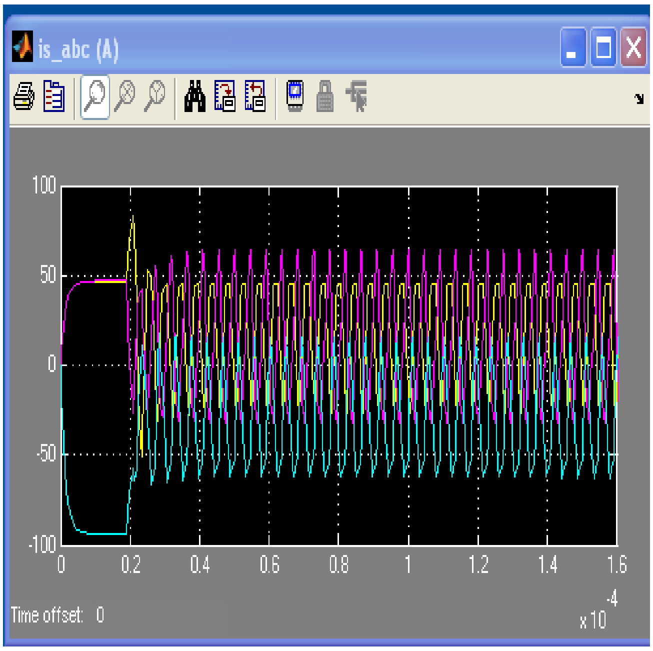


Fig 6.12 Stator current

Parameters considered are:

The motor parameters and PI gains used in the system are summarized below:

d-axis current loop: Kp = 0.5, Ki = 0.1

q-axis current loop: Kp = 0.5, Ki = 0.05

Speed loop: Kp =40, Ki = 0.2

Resolver algorithm : Kp = 0.00015,Ki = 0.0008

Parameters of PMSM:

Stator resistance 2.2*Ω*

Stator inductance 0.0029 mH

Number of poles 4

Base voltage 179.629 V

Base current 10 A

Base flux linkage 1 volt.sec/rad

Base electric frequency 200 Hz

Base Speed 6000 rpm

***7.* CONCLUSIONS:** In this paper a brief overview of electrical drives has been presented with their respective advantages and disadvantages. It also gives a detailed report on the constructional features, classification and magnetic characteristics of Permanent Magnet Synchronous Motors (PMSM), its advantages over Induction Motors and Synchronous motors.

In this thesis, the proposed resolver algorithm has been verified in the current controlled drive system of PMSM. The simulation results are presented. According to these results, the resolver algorithm can force the angle error to zero. Thus, the computed angle can eventually match with the actual rotor angle. Then, the correct rotor speed computation is guaranteed. In the future works, this algorithm will be extensively tested in the speed controlled drive system of PMSM.

8. FURTHER SCOPE OF WORK:

The implementation of additional control techniques like unity power factor control, constant mutual air gap flux linkages control, optimum torque per ampere control and sensorless control can be taken up for detail simulation and performance calculation of PMSM drive systems. Detailed modelling and simulation of other types of synchronous motor drives can also be taken up for transient and steady state analysis.

8.1 SENSORLESS CONTROL:

In vector control or Field Oriented Control (FOC) we have used sensors to obtain the position of the rotor but in sensorless control, as the name indicates it does not have sensors. It is the extension of FOC algorithm that allows synchronous motors to operate without the need for mechanical speed sensors (like Resolver). These sensors are notoriously prone to breakages. So removing them not only reduces the cost and the size of the motor but improves the drive's long term accuracy and reliability. This is particularly important if the motor is being used in the harsh, inaccessible environment such as an oil well.

Instead of physically measuring certain values, control engineers can calculate them from a system's state variables. This is known as the state space modelling approach, and is a powerful method for analysing and controlling complex non-linear systems with multiple inputs and outputs. In high performance sensorless motor drives, the two main control techniques used are open loop estimators and closed loop observers. In earlier literature the terms observer and estimator are often used interchangeable however most recent papers defined estimators as devices that use a model to predict the speed using the phase currents and voltages as state variables. Observers also use a model to estimate values. However these estimates are improved by an error feedback compensator that measures the difference between the estimated and actual values. The predicted value of speed is then used by the FOC to adjust the PWM waveform in exactly the same way as an actual measured value

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