Design and Simulation of PMSM Drive for EPS Applications using MATLAB

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Abstract – In this paper The practical design considerations of a low torque ripple Permanent Magnet Synchronous Motor (PMSM) drive for Electric Power Steering (EPS) application using Matlab is presented. The Design detail of various controller elements on torque ripple performance is discussed. The Hardware & software results show that the Microcontroller scheme used in the design can reduced torque ripples and applicable for Automotive Industry.

***Keywords*- PM synchronous motor, torque control, SMPS, Invertors, Microcontroller, ULN 2803, and Crystal Oscillator.**

1. Introduction

Permanent magnet synchronous motors (PMSM) 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 PMSM motor drives has demanded the need of simulation tool capable of handling motor drive simulations. Simulations have helped the process of developing new systems including motor drives, by reducing cost and 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. Due to factors such as high power density and efficiency, maintenance, and extremely wide operating speed range, permanent magnet synchronous motors (PMSM) are the subject of development for automotive applications. For effective drives of PMSM, the power converter and controller are also effectively developed and integrated as the PMSM drive system. A steering system is a significant subsystem for a vehicle operation. Since considerable steering effort is required with the increase of vehicle weight increasing and parking convenience for maneuvers, a power steering system was introduced to assist the drivers in turning the steering wheel in such driving conditions. Most power steering systems are hydraulic, which use a pump to supply hydraulic pressure and is driven by an engine all the time. The EPS system has a compact structure compared with conventional one, and it is an on-demand system that operates only when the steering wheel is turned. In other words, substituting an EPS for a hydraulic one Improves both space and engine efficiency and is more environmentally friendly. Besides, the EPS has more flexibility by the advantage of electronic control of the motor. It is easy to adjust the steering system characteristic just by modifying the program of the EPS controller. This is also the reason why there are many features developed for the EPS system. Electric Power Steering (EPS) is a relatively new technology in the Automotive Industry. Compared to traditional Hydraulic Power Steering, EPS reduces fuel consumption, simplifies assembly process and provides some intelligent steering features. A Permanent Magnet Synchronous Motor (PMSM) drive system is the core of an EPS system. Consumer requirements that the steering system have a smooth feel means that the motor and controller must yield a low torque ripple. High torque ripple causes rough steering feel and also may excite mechanical resonance resulting in acoustic noise. Depending on specific system, a peak to- peak torque ripple of less than 2% to 5% is typically required [1-3]

In this paper Section 1 describes Introduction. Section 2 describes design considerations. Section 3 describes experimental results. Section 4 describes conclusion.

2. PMSM Drive Design Considerations

The following aspects of the system design are described in this section: PMSM drive architecture, SMPS, Invertor, Microcontrollor, ULN 2803, Crystal Oscillator and software functional blocks.

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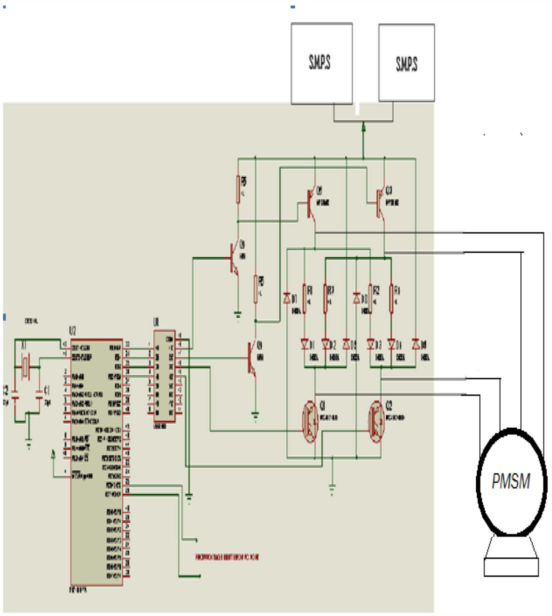

Fig.1 Block Diagram of PMSM Drive

A) SMPS (Switching mode power supply)

The main function of the SMPS is to convert AC power supply into DC power supply. In this we use two SMPS unit. Both this SMPS is of 20Amp & 12V rating which is then connected in series to obtained 24V supply.

B) Convertor section

In this section the output dc obtained from the SMPS is not a pure dc it contained some ac ripples in it so the capacitor is connected in across the diode bridge rectifier which filtered out the ac contained in the dc and gives almost pure dc voltage.

C) Microcontroller IC

In this the microchip 16F 877A 8K flash Ic is used . the voltage required for the operation of IC is 5V which is obtained from voltage regulator IC. The microcontroller IC is used for the operation of PMSM drive using MATLAB. It is 40 pin IC & the output from the ic is goes to IC ULN 2803.

D) ULN 2803

For fast operation instead of using MOSFET we use ULN IC 2803.The output from the microcontroller IC coming from pin 33,34,35,36 is goes to ULN IC input 1,2,3,4 and its is goes to convertor section. The output from the pin -8,-7,-5,-6 of ULN IC is connected to the TRANSISTOR Q5,Q4,Q2,Q1 of convertor section.

E) Crystal oscillator

The crystal oscillator is connected in between the pin of microcontroller IC 0 & 1.in this circuit the two capacitor of the equal rating of 33pf is used. It is used to generate the high frequency..

In this drive the feedback loop in an electrical drive may be provided to satisfy the requirement of the speed response and accuracy also in the protection of motor form variable load. In the closed loop control scheme, torque and actual motor torque follows the reference torque and speed feedback loop by putting the actual pressure on driver and adjust the speed depend on load condition and also it limit the speed.

This scheme widely used in the electrical drive if employed and current control within the speed of the motor. The motor torque below set speed is process to speed control. The maximum allowable current when choose to desired speed and current for which the motor torque is equal to the load torque

2.1 .Mathematical Model of PMSM

PMSM is an important group of the electric machines, in which the rotor magnetization is produced by permanent magnets attached to the rotor. Many mathematical models have been proposed for different Automotive applications, such as converts the *abc*-model in to the two axis *dq*-model. Due to the simplicity of the two axis *dq*-model, it becomes the most widely used model in PMSM controller design. The two axis *dq*-model offers significant convenience for control system design by transforming stationary symmetrical AC variables to DC ones in a rotating reference frame. Based on the *dq* reference frame theory, the mathematical model of the PMSM can be expressed as the following equations: The two axes PMSM stator windings can be considered to have equal turn per phase. The rotor flux can be assumed to be concentrated along the d axis while there is zero flux along the q axis, an assumption similarly made in the derivation of indirect vector controlled induction motor drives. Also, rotor flux is assumed to be constant at a given operating point. There is no need to include the rotor voltage equation as in the induction motor since there is no external source connected to the rotor magnet and variation in the rotor flux with respect to time is negligible. The stator equations of the induction machine in the rotor reference frames using flux linkages are taken to derive the model of the PMSM. The rotor reference frame is chosen because the position of the rotor magnets determine independently of the stator voltages and currents, the instantaneous induced emfs and subsequently the stator currents and torque of the machine. In Induction motor, the rotor fluxes are dependent variables, they are influenced by the stator voltage and currents and that is why any frame of reference is suitable for the dynamic modeling of the induction machine.

(a) PMSM equations & its motion Model

The stator flux linkage vector and rotor flux linkage of PMSM can be drawn in the rotor flux (dq), stator flux (xy), and stationary (DQ) frames as shown in figure 2.1 &2.2

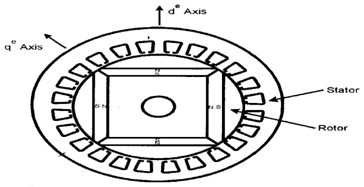

Fig.2.1 Cross Section of Interior Permanent Magnet Sinusoidal Machine (IPM)

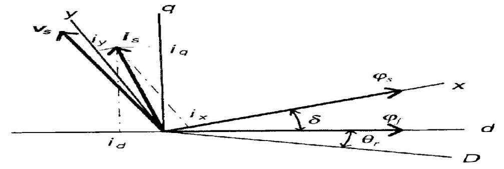

Fig.2.2 The Stator & Rotor Flux Linkages in different reference frames

The characteristics of the salient pole machine differ from those of a nonsalient pole machine because of the nonuniform air gap reluctances in the d^e and q^e axes. The resulting asymmetry in the direct and quadrature axes magnetizing reactance's causes the corresponding synchronous reactance's to be unsymmetrical (i.e., $X_{ds} \neq X_{qs}$). Figure 2.5 shows phasor diagrams of a salient pole machine for the motoring and generating modes, and also includes flux linkage. Again, for simplicity, the stator resistance has been dropped. The excitation or speed emf V_f is shown aligned with the q_e axes, whereas ψ_f is aligned with the d^e axes. The phase voltage V_s and phase current I_s are resolved into corresponding d^e and q^e components, and a voltage phasor diagram is drawn with the corresponding reactive drops. In the phasor diagram, the armature reaction flux ψ_a aids the field flux to result in the stator flux ψ_s as shown. The motoring mode phasor diagram, which is drawn for lagging power factor, $\psi_s > \psi_f$, whereas in the generating mode, $\psi_s < \psi_f$, because it is operating at leading power factor. Note that d^e-q^e axes phasor diagrams can also be drawn for a nonsalient pole machine where $X_{ds} = X_{qs}$.

From the phasor diagram, fig. 2.5 we can write

$I_s \cos\phi = I_{qs} \cos\delta - I_{ds} \sin\delta$ - ----------- (1)

The figure can also be a vector diagram if all the rms phasors are multiplied by the factor √2, as mentioned before.

The power input to the machine is

$P_i = 3V_sI_s \cos\phi$ ------------- (2)

Substituting equation (12) in (13), the input power P_i can be given as

$P_i = 3V_s(I_{qs}\cos\delta - I_{ds} \sin\delta)$ - -------------(3)

Again, from the phasor diagram we can write

$I_{ds} = V_s \cos \delta - V_f / X_{ds}$ - -------------(4)

$I_{ds} = V_s \sin\delta / X_{qs}$ - -------------(5)

Substituting equations (4) – (5) in (3) yields

$$P_i = 3\frac{V_sV_f}{X_{ds}}\sin\delta + 3V_s^2\frac{(X_{ds} - X_{qs})}{2X_{ds}X_{qs}}\sin 2\delta$$

---------------(6)

or

$$T_e = 3\left(\frac{p}{2}\right)\frac{1}{\omega_e}\left(\frac{V_sV_f}{X_{ds}}\sin\delta + V_s^2\frac{(X_{ds} - X_{qs})}{2X_{ds}X_{qs}}\sin 2\delta\right)$$

------------(7)

$$T_e = 3\left(\frac{p}{2}\right)\left(\frac{\psi_s\psi_f}{L_{ds}}\sin\delta + \psi_s^2\frac{(L_{ds} - L_{qs})}{2L_{ds}L_{qs}}\sin 2\delta\right)$$

-------------(8)

The torque developed in an IPM machine has two components: (1) the component due to field flux, and (2) the reluctance torque components. The general torque expression of a salient pole machine can be given by

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)\left(\frac{\psi_s\psi_f}{L_{ds}}\sin\delta + \psi_s^2\frac{(L_{ds} - L_{qs})}{2L_{ds}L_{qs}}\sin 2\delta\right)$$

-----------------(9)

or

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)(\psi_{ds}i_{qs} - \psi_{qs}i_{ds})$$

--------------(10)

where P = number of poles, $\psi_{ds} = \psi_f + L_{ds}i_{ds}$, $\psi_{qs} = L_{qs}i_{qs}$, and $\psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2}$. Note that equation (8) is same as equation (9), except the rms phasor have been replaced by corresponding peak values ($\psi_f = \sqrt{2}\psi_f$ and $\psi_s = \sqrt{2}\psi_s$). Substituting ψ_{ds} and ψ_{qs} equations in Equation , we get

$$T_e = \frac{3}{2}\left(\frac{P}{2}\right)\left[\psi_f i_{qs} + (L_{ds} - L_{qs})i_{ds}i_{qs}\right]$$

- -------------(11)

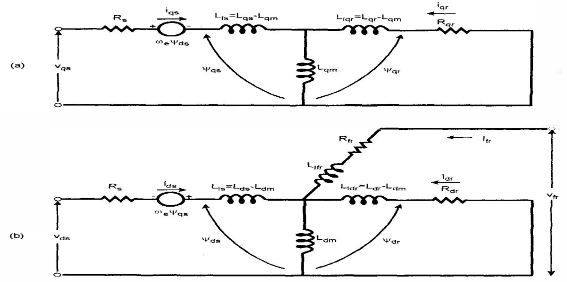

Fig 2.3 d^e-q^e equivalent circuit of synchronous machine q^e – axis circuit, (b) d^e axis circuit.

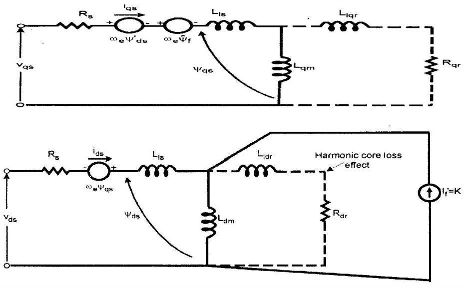

Fig .2.4 Synchronously rotating frame (d^e-q^e) equivalent circuit of IPM machine.

The steady-state analysis of a sinusoidal PM machine with an equivalent circuit and phasor diagram remains the same as a wound field machine except that the equivalent field current I_f should be considered constant, that is, the flux linkage $\psi_f = L_mI_f$ = constant. The synchronously rotating frame transient equivalent circuits, shown in figure 2.3, also hold true here, except the machine may not have any damper winding. Figure shows the equivalent circuit where the finite core loss is represented by the dotted damper windings. Ignoring the core loss, the circuit equations can be written as

$$v_{qs} = R_s i_{qs} + \omega_e \psi_{ds} + \omega_e \psi_f + \frac{d}{dt}\psi_{qs} \quad \text{----------------(12)}$$

$$v_{ds} = R_s i_{qs} - \omega_e \psi_{ds} + \omega_e \psi_{qs} + \frac{d}{dt}\psi_{ds} \quad \text{---------- (13)}$$

Where,

$\psi_f = L_{dm} I_f$ ----------------(14)

$\psi_{ds} = i_{ds} (L_{ls} + L_{dm}) = i_{ds} L_{ds}$ ----------------(15)

$\psi_{ds} = \psi_f + \psi_{ds}$ --------------(16)

$\psi_{qs} = i_{qs} (L_{ls} + L_{qm}) = i_{qs} L_{qs}$ -----------------(17)

and the torque equation is

$$T_e = \frac{3}{2}\left(\frac{p}{2}\right)(\psi_{ds} i_{qs} - \psi_{qs} i_{ds}) \quad \text{------------------(18)}$$

Substituting equations (14)- (17) in (12), (13) and (18) and simplifying we can write

$$\frac{di_{qs}}{dt} = \frac{\omega_b}{X_{qs}}\left[v_{qs} - R_s i_{qs} - \frac{\omega_e}{\omega_b} X_{ds} i_{ds} - \frac{\omega_e}{\omega_b} V_f \right] \quad \text{----------(19)}$$

$$\frac{di_{ds}}{dt} = \frac{\omega_b}{X_{ds}}\left[v_{ds} - R_s i_{ds} - \frac{\omega_e}{\omega_b} X_{qs} i_{qs} \right] \quad \text{-----------(20)}$$

$$T_e = \frac{3P}{4\omega_b}\left[(F'_{ds} + V_f) i_{qs} - F_{qs} i_{ds} \right] \quad \text{-----------(21)}$$

Where $V_f = \omega_b \psi_f$, $X_{qs} = \omega_b L_{qs}$, $X_{ds} = \omega_b L_{ds}$, $F'_{ds} = \omega_b \psi_{ds}'$, $F_{qs} = \omega_b \psi_{qs}$, and ω_b = base frequency. These equations, which are valid for IPM as well as SPM (except $L_{dm} = L_{qm}$), can be used for computer simulation study.

Again for steady-state operation of the machine, the time derivative components of Equation (12) and (13) are zero.

Phasor Diagram:

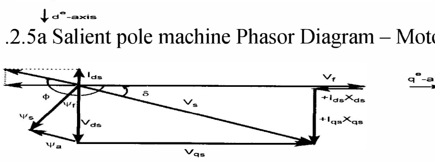

Fig .2.5a Salient pole machine Phasor Diagram – Motoring mode

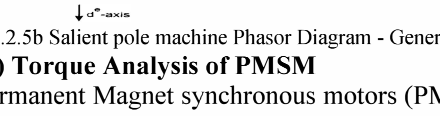

Fig.2.5b Salient pole machine Phasor Diagram - Generating Mode

(b) Torque Analysis of PMSM

Permanent Magnet synchronous motors (PMSM's) are used in low & medium power applications that require good torque response and high performance operation. The torque in PMSM's is usually controlled by controlling the armature current based on the fact that the electromagnetic torque is proportional to the armature current. For high performance the current control is normally executed in the rotor dq reference frame that rotates with the synchronous speed. In this frame, the armature inductances and magnet flux linkage are constant if the back electromotive force (EMF) and variation of inductances are sinusoidal. In addition to the influence of the harmonic terms in inductances and back EMF, saturation in flux, and temperature effect on the magnet, the torque response under current control is limited by the time constant of the armature windings.

The stator flux reference frame Motor Equation:

The stator flux linkage vector φ_s and rotor (magnet) flux linkage vector φ_f can be drawn in the rotor flux (dq), stator flux (xy) and stationary (dq) reference frames, as in fig. 2.2.

The angle between the stator and rotor flux linkages δ is the load angle when the stator resistance is neglected. In the steady state, δ is constant corresponding to a load torque, and both stator and rotor flux rotate at the synchronous speed. In transient operation, δ varies and the stator and rotor flux rotate at different speeds. Since the electrical time constant is normally much smaller than the mechanical time constant, the rotating speed of stator flux, with respect to the rotor flux, can be easily changed. It is shown in this section that the increase of torque can be controlling the change of δ or the rotating speed of the stator flux.

The well-known stator flux linkage, voltage, and electromagnetic torque equations in the dq reference frame are as follows:

$\varphi d = L_d{}^{i}{}_{d} + \varphi_f$

$\varphi d = L_q{}^{i}{}_{q}$ -------------(22)

$v_d = R_s{}^{i}{}_{d} + p\varphi d - \omega_r \varphi q$

$v_d = R_s{}^{i}{}_{q} + p\varphi q - \omega_r \varphi d$ -------------(23)

$T = 3/2\ p\ (\varphi_d{}^{i}{}_{q} - \varphi_q{}^{i}{}_{d})$ ---------------(24)

Where φ_f, L_d, and L_q are the armature (or stator) back EMF constant and inductances, respectively, when the back EMF and the variation of the stator inductances are sinusoidal. Otherwise, these are the fundamental quantities of these variables. With the transformation in (25) and (26), (22)-(24) can be transformed to the xy reference frame:

$$\begin{bmatrix} F_x \\ F_y \end{bmatrix} = \begin{bmatrix} \cos\delta & \sin\delta \\ -\sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} F_d \\ F_q \end{bmatrix}. \quad \text{------------(25)}$$

The inverse transformation is

$$\begin{bmatrix} F_d \\ F_q \end{bmatrix} = \begin{bmatrix} \cos\delta & -\sin\delta \\ \sin\delta & \cos\delta \end{bmatrix} \begin{bmatrix} F_x \\ F_y \end{bmatrix}. \quad \text{------------(26)}$$

Where F represents the voltage, current, and flux linkage.

A) The torque Equation in xy Reference Frame

From fig. 2.2, it can be found that

$$\sin\delta = \frac{\varphi_q}{|\varphi_s|}$$

$$\cos\delta = \frac{\varphi_d}{|\varphi_s|}$$ ----------------(27)

Where |φ$_s$| represents the amplitude of the stator flux linkage. Substituting (26) and (27) for current into (23) gives

$$T=\frac{3}{2}p\left[\varphi_d(i_x\sin\delta+i_y\cos\delta)-\varphi_d(i_x\cos\delta-i_y\sin\delta)\right]$$

$$=\frac{3}{2}p\left[i_x\frac{\varphi_d\varphi_q}{|\varphi_s|}+i_y\frac{\varphi_d^2}{|\varphi_s|}-i_x\frac{\varphi_d\varphi_q}{|\varphi_s|}+i_y\frac{\varphi_d^2}{|\varphi_s|}\right]=\frac{3}{2}p|\varphi_s|i_y$$ --------(28)

Equation (28) means that the torque is directly proportional to the y-axis component of the stator current if the amplitude of the stator flux linkage is constant.

B) The flux linkage Equation in the xy reference frame Equation can be rewritten into matrix from as follows:

$$\begin{bmatrix}\varphi_d\\ \varphi_q\end{bmatrix}=\begin{bmatrix}L_d & 0\\ 0 & L_q\end{bmatrix}\begin{bmatrix}i_d\\ i_q\end{bmatrix}+\begin{bmatrix}\varphi_f\\ 0\end{bmatrix}$$ -------------(29)

Substituting (26) into (29) gives

$$\begin{bmatrix}\cos\delta & -\sin\delta\\ \sin\delta & \cos\delta\end{bmatrix}\begin{bmatrix}\varphi_x\\ \varphi\end{bmatrix}=\begin{bmatrix}L_d & 0\\ 0 & L_q\end{bmatrix}\begin{bmatrix}\cos\delta & -\sin\delta\\ \sin\delta & \cos\delta\end{bmatrix}\begin{bmatrix}i_x\\ i_y\end{bmatrix}+\begin{bmatrix}\varphi_f\\ 0\end{bmatrix}$$ ---------(30)

Premultiplying (30) with

$$\begin{bmatrix}\cos\delta & -\sin\delta\\ \sin\delta & \cos\delta\end{bmatrix}^{-1}=\begin{bmatrix}\cos\delta & \sin\delta\\ -\sin\delta & \cos\delta\end{bmatrix}$$ -------------- (31)

gives (32),

$$\begin{bmatrix}\varphi_x\\ \varphi_y\end{bmatrix}=\begin{bmatrix}L_d\cos\delta & L_q\sin\delta\\ -L_d\sin\delta & L_q\cos\delta\end{bmatrix}\begin{bmatrix}\cos\delta & -\sin\delta\\ \sin\delta & \cos\delta\end{bmatrix}\begin{bmatrix}i_x\\ i_y\end{bmatrix}+\varphi_f\begin{bmatrix}\cos\delta\\ -\sin\delta\end{bmatrix}$$

$$=\begin{bmatrix}L_d\cos^2\delta+L_q\sin^2\delta & -L_d\sin\delta\cos\delta+L_q\sin\delta\cos\delta\\ -L_d\sin\delta\cos\delta+L_q\sin\delta\cos\delta & L_d\sin^2\delta+L_q\cos^2\delta\end{bmatrix}\begin{bmatrix}i_x\\ i_y\end{bmatrix}+\varphi_f\begin{bmatrix}\cos\delta\\ -\sin\delta\end{bmatrix}$$ ---(32)

PMSM'a with Uniform Airgap: for this type of PMSM, L$_d$ = L$_q$ = L$_s$ can be simplified as in (12)

$$\begin{bmatrix}\varphi_x\\ \varphi\end{bmatrix}=\begin{bmatrix}L_s & 0\\ 0 & L_s\end{bmatrix}\begin{bmatrix}i_x\\ i_y\end{bmatrix}+\varphi_f\begin{bmatrix}\cos\delta\\ -\sin\delta\end{bmatrix}$$ ---------(33)

or

$\varphi_x = L_s{}^{1}{}_{x} + \varphi_f\cos\delta$
$\varphi_y = L_s{}^{1}{}_{s} - \varphi_f\sin\delta$ -----------(34)

φ$_y$ is zero since the x- axis is fixed at the stator flux linkage.

Then, i$_y$ can be solved from the second equation of (34)

$i_y = 1/L_s \times \varphi_f\sin\delta$ ---------------(35)

Substituting (35) into torque (28) gives

$$T=\frac{3}{2}\frac{1}{L_s}p|\varphi_s|\varphi_f|\sin\delta=\frac{3}{2}\frac{1}{L_s}p|\varphi_s|\varphi_f|\sin\delta t$$ -----------------(36)

Where δ is the angular velocity of the stator flux linkage relative to magnet flux linkage.

Equation (36) implies that the torque increases with the increase in δ if the amplitude of the stator flux linkage is kept constant and δ is controlled within the range of -π/2 -π/2.

The maximum torque occurs when δ is π/2.

δ is considered to be a step change corresponding to a change of voltage vector. Then, the derivative of (36) becomes

$$\left.\frac{dT}{dt}\right|_{t=0}=\frac{3}{2}p\frac{|\varphi_s|\varphi_f}{L_s}\delta\cos\delta$$ ----------------(37)

The right-hand side of (37) is always positive if δis positive if δ is within the range of -π/2-π2. This equation implies that the increase of torque is proportional to the increase of the angle δ, which is the angle between the stator and magnet flux linkage. In other words, the stator flux linkage should be controlled in such a way that the amplitude is kept constant and the rotating speed is controlled as fast as possible to obtain the maximum change in actual torque.

PMSMs with pole saliency: for a PMSM with pole saliency, that is, L$_d$ ≠L$_q$, the torque equation in terms of stator flux linkage and angle δ can be obtained by solving i$_x$ from (33), with φ$_y$ = 0:

$$i_x=\frac{2\varphi_f\sin\delta-[(L_d+L_q)+(L_d-L_q)\cos2\delta}{(L_q-L_d)\sin2\delta}i_y$$ --------------(38)

Substituting (38) into the first equation in (32), one obtains

$$i_y=\frac{1}{2L_dL_q}[2\varphi_fL_q\sin\delta-|\varphi_s|(L_q-L_d)\sin2\delta$$ --------------(39)

Then, the torque equation is as follows:

$$T=\frac{3p|\varphi_s|}{4L_dL_q}[2\varphi_fL_q\sin\delta-|\varphi_s|(L_q-L_d)\sin2\delta]$$ -------------(40)

Equation (40) consists of two terms. The first is the excitation torque, which is produced by the permanent magnet flux, and the second term is the reluctance torque. For each stator flux linkage, there exists the maximum in this equation. It will not be discussed how to control the amplitude of stator flux linkage and load angle to get maximum torque. However, it is necessary to discuss the relationship between the amplitude of stator flux linkage and the derivative of the torque. Fig. 2.6 shows the torque -δ characteristics when the amplitude of stator flux linkage is at φ$_f$:

Therefore, for a PMSM with pole saliency, the amplitude of the stator flux linkage should be changer, with the change of actual torque even for constant torque operation.

The derivative of torque in (41) is as shown in (42), with constant stator flux and dδ/dt:

$$\frac{dT}{dt}=\frac{3p|\varphi_s|}{4L_dL_q}[2\varphi_f L_q\delta\cos\delta-2|\varphi_s|(L_q-L_d)\delta\cos 2\delta] \qquad \text{--------(41)}$$

At t = 0:

$$\left.\frac{dT}{dt}\right|_{t=0}=\frac{3p|\varphi_s|}{2L_dL_q}[\varphi_f L_q\delta-|\varphi_s|(L_q-L_d)\delta] \qquad \text{-------(42)}$$

The condition for dT/dt for positive dδ/dt is

$$|\varphi_s|<\frac{L_q}{L_q-L_d}\varphi_f \qquad \text{---------(43)}$$

The Primary voltage vector v_s is defined by the following equation

$$v_s=\frac{2}{3}(v_a+v_b e^{i(2/3)\pi}+v_c e^{(4/3)\pi} \qquad \text{--------(44)}$$

The amplitude of the stator flux linkage should be chosen according to (44) if fast dynamic response is desired. Otherwise, the should be varied with the change of actual torque if the linearity is more important. It should also be kept in mind that for the same torque, a higher stator current is needed when the amplitude of the stator flux linkage is lower.

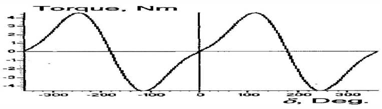

Fig.2.6 Torque with respective δ: $|\varphi_s| = \varphi_f$

2.2 Testing of PMSM drive by using MATLAB

Following procedure was carried out for the testing of variable frequency mode of operation of the motor. Before connecting the motor to the drive, the drive operation was worked on dummy load.

Various test points are taken out from the control card on the drive which helps in troubleshooting during fault condition. The various test points are tabulated by the pressing gradually following key of computer key board.

- To start the motor
- To increase speed of motor
- To decrease the speed of motor

Also here we use the terminal box for up and down the speed. The set up was again switched on and the drive was started. The set speed pot was slowly moved to its maximum position so that maximum voltage was applied to the motor. Now the frequency knob was changed and moved at various positions. This changes frequency of input supply voltage to motor and hence changes the synchronous speed of the motor. Thus the motor runs at variable speed depending on the frequency.

3. Experimental Results

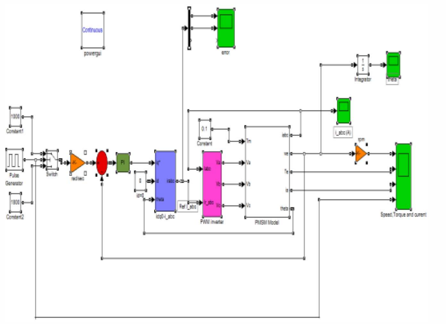

Fig.3.1 PMSM Simulation Block Diagram

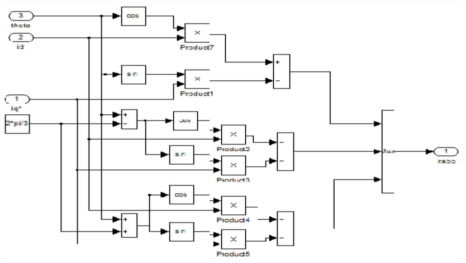

Fig 3.2 .Mathematical Model Of d-axis & q-axis Currents (id & iq).

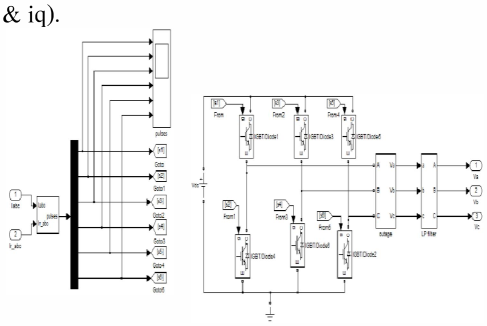

Fig. 3.3 Block Diagram Of Three Phase PWM inverter

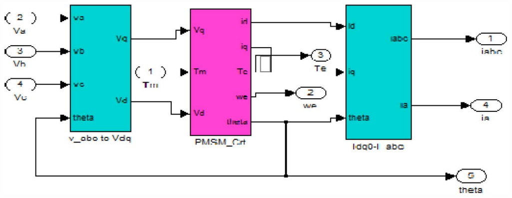

Fig. 3.4 Permanent Magnet Synchronous Motor model

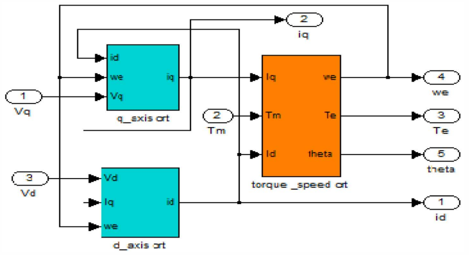

Fig 3.5. PMSM Characteristics Block diagram

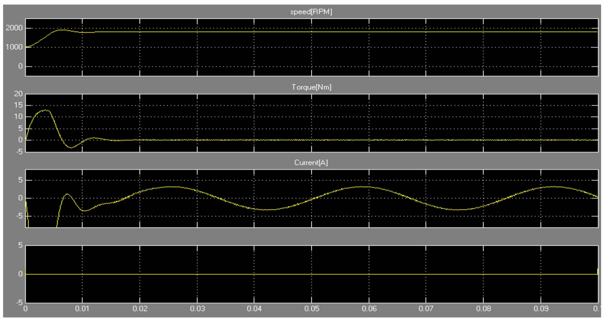

Fig.3.6. Speed, Torque, Current Characteristics of PMSM drive without auto scale in the range of 1000 to 1800 rpm

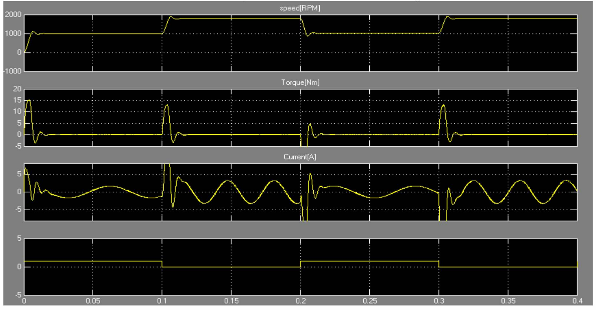

Fig.3.7 Speed, Torque, Current Characteristics of PMSM drive in the range of 1000 to 1800 rpm

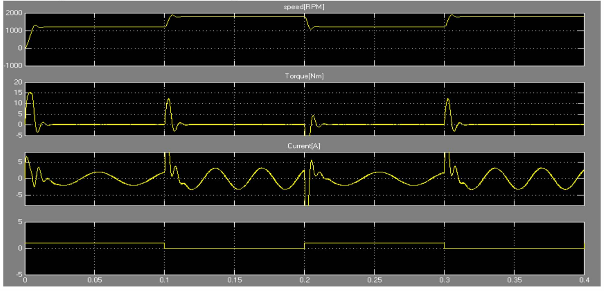

Fig.3.8 Speed, Torque, Current Characteristics of PMSM drive in the range of 1200 to 1800 rpm

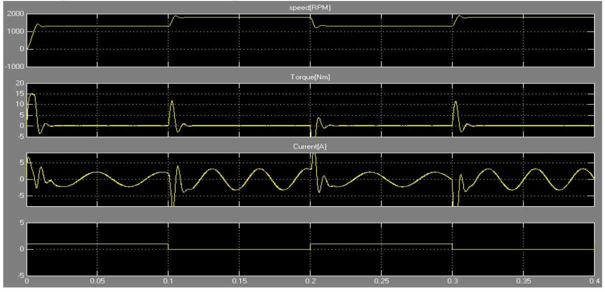

Fig.3.9 Speed, Torque, Current Characteristics of PMSM drive in the range of 1400 to 1800 rpm

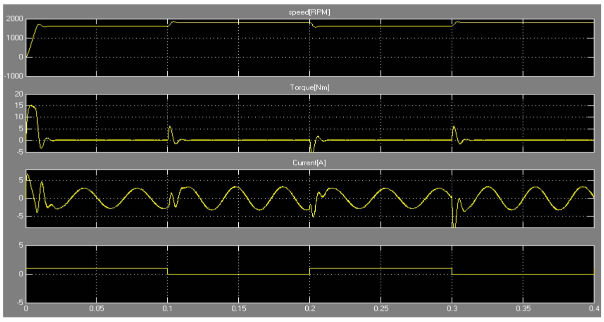

Fig.3.10 Speed, Torque, Current Characteristics of PMSM drive in the range of 1600 to 1800 rpm

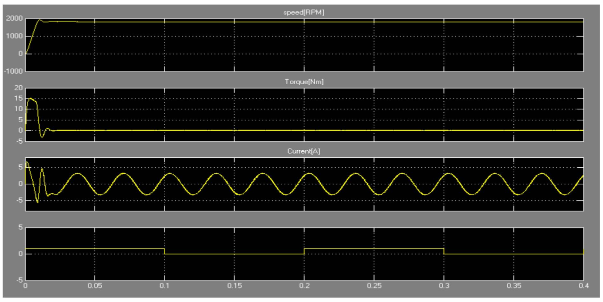

Fig.3.11 Speed, Torque, Current Characteristics of PMSM drive in the range of 1800 to 2000 rpm

4. Conclusion

Design and Simulation of PMSM Drive for EPS Applications using MATLAB has been presented in this paper. With the microcontroller IC (16F 877A 8K) and SMPS, Invertors, ULN 2803, Crystal Oscillator and software functional blocks. Good torque ripple performance can be achieved .accuracy has the highest impact factor on torque ripple performance. Fast and robust dynamic response and flux weakening operation are demonstrated. The experimental results prove that the PMSM drive presented in this paper is very suitable for EPS controllers.

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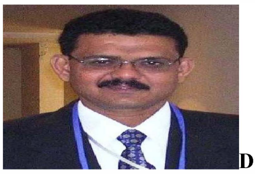

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