Speed Control techniques of Permanent Magnet Synchronous Motor (PMSM) Drive Using Vector Control

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ABSTRACT:

Permanent Magnet Synchronous Motor (PMSMs) are used in many applications that require rapid torque re-sponse and high performance operation.In this paper the mathematical modeling of PMSM drive is done, which was used in the speed control of PMSM drive. Speed con-trol of PMSM drive is done by using Vector PI, vector PD and vector PID. The corresponding responses are also shown.

Introduction:

Permanent magnet synchronous motors are widely used in high performance drives such as industrial robots and machine tools. In recent years, the magnetic and thermal capabilities of the Permanent Magnet Synchronous Mo-tors have been considerably increased by employing the high-coercive permanent magnet material. The speed control of synchronous motor depends upon two fac-tors viz number of poles, P and supply frequency, f. as in case of shipping propulsion, the speed of the motor can be changed by changing the speed of the alternator – the speed of the motor changes exactly in the same propor-tion as that of the alternator supplying power to it. It is to be noted here that the voltage and frequency are directly proportional to the speed at which alternator is driven.

The effective way of producing the variable speed Per-manent Magnet Synchronous Motor drive is to supply the motor with variable voltage and variable frequency or constant V⁄f supply variable frequency is required be-cause the rotor speed is directly proportional to the stator supply frequency. A variable voltage is required because the motor impedance is reduced at lower frequencies and consequently the current has to be limited by means of reducing the supply voltage. Unlike a DC motors, Perma-nent magnet synchronous motors (PMSM) are very popu-lar in a wide range of applications.

The PMSM does not have a Commutator, which makes it more reliable than a DC motor. The PMSM also has ad-vantages when compared to an AC induction motor. The PMSM generates the rotor magnetic flux with rotor mag-nets, achieving higher efficiency. Therefore, the PMSM is used in applications that require high reliability and ef-ficiency.

PMSM Drive Equations:

In a motor with more than one pair of magnetic poles the electric angle differ the mechanical. Their relationship is

$$\theta_r = \frac{p}{2}\theta_m$$

The voltage V, over each stator winding is the sum of the resistive voltage drop and the voltage induced from the time varying flux linkages, $d\psi/dt$.

$$V_a = r_a i_a + \frac{d}{dt}\psi_a$$

$$V_b = r_b i_b + \frac{d}{dt}\psi_b$$

$$V_c = r_c i_c + \frac{d}{dt}\psi_c$$

The stator windings are wound with the same number of turns so the resistance is equal in all three windings,

$$r_a = r_b = r_c = r_s$$

$$V_{abc} = r_s i_{abc} + \frac{d}{dt}\psi_{abc}$$

$$= \begin{bmatrix} r_s & 0 & 0 \\ 0 & r_s & 0 \\ 0 & 0 & r_s \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \frac{d}{dt}\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix}$$

Inductance Matrix L_s

$$L_s = \begin{bmatrix} L_{aa} & L_{ab} & L_{ac} \\ L_{ba} & L_{bb} & L_{bc} \\ L_{ca} & L_{cb} & L_{cc} \end{bmatrix}$$

The diagonal elements in the inductance matrix L_s are self inductances and the off diagonal elements are mutual in-ductances. The matrix is symmetric because the flux cou-pling between two windings is equal in both directions. A current in stator windings gives rise to a leakage flux and a magnetizing flux. The magnetizing flux is confined to the air-gap and give rise to the rotating MMF wave. Leakage flux is assumed to only affect its own winding. In a magnetically linear circuit flowing in the winding with all currents set to zero.Let the self inductance be $L_{aa} = L_{ls} + L_m$ where L^{ls} is the leakage inductances and L_m the magnetizing inductances. The magnetizing inductance is generally not constant; reluctance may depends on rotor position.

$$L_{aa} = L_{ls} + L - L_\Delta \cos(2\theta_r)$$

$$L_{bb} = L_{ls} + L - L_\Delta \cos(2\theta_r + 2\pi/3)$$

$$L_{cc} = L_{ls} + L - L_\Delta \cos(2\theta_r - 2\pi/3)$$

The mutual inductances are given by

$$L_{ab} = -\frac{L}{2} - L_\Delta \cos\left(2\theta_r - \frac{2\pi}{3}\right)$$

$$L_{ac} = -\frac{L}{2} - L_\Delta \cos\left(2\theta_r + \frac{2\pi}{3}\right)$$

$$L_{bc} = -\frac{L}{2} - L_\Delta \cos(2\theta_r)$$

The above derivations lead to the following inductance matrix

$$L_{aa}(\theta_r) = \begin{bmatrix} L_{ls} + L - L_\Delta \cos(2\theta_r) & -\frac{L}{2} - L_\Delta \cos(2\theta_r - 2\pi/3) & -\frac{L}{2} - L_\Delta \cos(2\theta_r + 2\pi/3) \\ -\frac{L}{2} - L_\Delta \cos(2\theta_r - 2\pi/3) & L_{ls} + L - L_\Delta \cos(2\theta_r + 2\pi/3) & -\frac{L}{2} - L_\Delta \cos(2\theta_r) \\ -\frac{L}{2} - L_\Delta \cos(2\theta_r + 2\pi/3) & -\frac{L}{2} - L_\Delta \cos(2\theta_r) & L_{ls} + L - L_\Delta \cos(2\theta_r + 2\pi/3) \end{bmatrix}$$

The flux linkage from the permanent magnet is

$$\psi_m = |\psi_m| \begin{bmatrix} \sin(\theta_r) \\ \sin\left(\theta_r - \frac{2\pi}{3}\right) \\ \sin\left(\theta_r + \frac{2\pi}{3}\right) \end{bmatrix}$$

Both the inductance matrix and the permanent magnetic flux linkage depend on rotor position. Therefore, the me-chanical equations of the rotor must be included in the model to have a complete description of the motor Using Newton's law

$$J\frac{d}{dt}\omega_m = T_e - T_l - B\omega_m$$

$$\text{Where} \quad \omega_m = \frac{d}{dt}\theta_m$$

Torque is change in energy per change in angle, thus us-ing co energy

$$W_e = \frac{1}{2} i^T{}_{abc} L_s i_{abc} + i^T{}_{abc} \psi_m + W_{PM}$$

The torque produced by the machine is

$$T_e = \frac{d}{dt} W_e$$

$$\therefore\ A^{-1} = \frac{1}{|\mathrm{A}|}\, adj\ A$$

$$= \frac{1}{\frac{-3\sqrt{3}}{2}} \begin{bmatrix} -\sqrt{3}\cos\theta & -\sqrt{3}\cos\left(\theta - \frac{2\pi}{3}\right) & -\sqrt{3}\cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sqrt{3}\sin\theta & -\sqrt{3}\sin\left(\theta - \frac{2\pi}{3}\right) & -\sqrt{3}\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{-\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix}$$

Therefore inverse of K is given as

$$K_s^{-1} = 2/3 \begin{bmatrix} \cos(\theta) & \cos(\theta_r - 2\pi/3) & \cos(\theta_r + 2\pi/3) \\ \sin(\theta) & \sin(\theta_r - 2\pi/3) & \sin(\theta_r + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

In K_s there is a factor of 2⁄3 in front of the matrix. This factor can be understood by discussion about mmf wave. For a balanced set, of say voltages the resultant voltage vector has amplitude 3⁄2 times that of the individual amplitude. The factor 2⁄3 makes the amplitude of quantities expressed in the qdo reference frame correspond to that of each individual phase in the stator abc frame. The last row in K_s is the zero sequence. Another feature that may be noted with the above definition of the park transform, it is not power invariant. This is because $|K_s| \neq 1$.

$$K_s^{-T} * K_s^{-1} =$$

$$\frac{2}{3}\begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} * \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}$$

$$\frac{2}{3}\begin{bmatrix} \cos\theta^2 + \sin\theta^2 + \frac{1}{2} & \cos\theta\cos\left(\theta - \frac{2\pi}{3}\right) + \sin\theta\sin\left(\theta - \frac{2\pi}{3}\right) + \frac{1}{2} & \cos\theta\cos\left(\theta + \frac{2\pi}{3}\right) + \sin\theta\sin\left(\theta + \frac{2\pi}{3}\right) + \frac{1}{2} \\ \cos\left(\theta - \frac{2\pi}{3}\right)\cos\theta + \sin\theta\sin\left(\theta - \frac{2\pi}{3}\right) + \frac{1}{2} & \cos\left(\theta - \frac{2\pi}{3}\right)^2 + \sin\left(\theta - \frac{2\pi}{3}\right)^2 + \frac{1}{2} & \cos\left(\theta - \frac{2\pi}{3}\right)\cos\left(\theta + \frac{2\pi}{3}\right) + \sin\left(\theta - \frac{2\pi}{3}\right)\sin\left(\theta + \frac{2\pi}{3}\right) + \frac{1}{2} \\ \cos\theta\cos\left(\theta + \frac{2\pi}{3}\right) + \sin\theta\sin\left(\theta + \frac{2\pi}{3}\right) + \frac{1}{2} & \cos\left(\theta + \frac{2\pi}{3}\right)\cos\left(\theta - \frac{2\pi}{3}\right) + \sin\left(\theta + \frac{2\pi}{3}\right)\sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right)^2 + \sin\left(\theta + \frac{2\pi}{3}\right)^2 + \frac{1}{2} \end{bmatrix}$$

$$= \frac{2}{3}\begin{bmatrix} \frac{3}{2} & 0 & 0 \\ 0 & \frac{3}{2} & 0 \\ 0 & 0 & \frac{3}{2} \end{bmatrix}$$

Let the power equation in the qdo reference frame is

$$P_{\mathrm{qdo}} = (v_{\mathrm{qdo}},\quad i_{\mathrm{qdo}}) = W_1 v_q i_q + W_2 v_d i_d + W_3 v_o i_o$$

The input power in the ABC – frame is

$$P_{abc} = v_{abc}{}^T i_{abc} = v_{abc} i_{abc}{}^T$$

Transform the abc variables to the qdo frame and use the fact power must be equal in both references frames

$$P_{abc} = v_{abc}{}^T i_{abc}$$

$$= \left(K_s{}^{-1} v_{qdo}\right)^T K_s{}^{-1} i_{qdo}$$

$$= v_{qdo}{}^T K_s{}^{-T} K_s{}^{-1} i_{qdo}$$

$$= v_{qdo}{}^T \begin{bmatrix} 3/2 & 0 & 0 \\ 0 & 3/2 & 0 \\ 0 & 0 & 3/2 \end{bmatrix} i_{qdo}$$

$$= 3/2\left(v_q i_q + v_d i_d + 2\, v_o i_o\right)$$

$$= P_{qdo}$$

$$P_{qdo} = 3/2\left(v_q i_q + v_d i_d + 2\, v_o i_o\right)$$

We are now going to transform v $_{abc}$, first to an arbitrary qdo reference frame and then let this transformation be attached to the rotor. Express v_{abc} in qdo variables

$$v_{abc} = r_s K_s{}^{-1} i_{qdo} + \frac{d}{dt} K_s{}^{-1} \psi_{qdo}$$

$$v_{qdo} = K_s r_s K_s{}^{-1} i_{qdo} + \frac{d}{dt} K_s{}^{-1} \psi_{qdo}$$

The resistance does not change when transformed since

$$K_s r_s K_s{}^{-1} = r_s K_s K_s{}^{-1} = 1 * r_s = r_s$$

The second term is

$$K_s \frac{d}{dt}\left(K_s{}^{-1}\psi_{qdo}\right) = K_s\left(\frac{d}{dt}K_s(\theta_T)\right)\psi_{qdo} + K_s{}^{-1}\frac{d}{dt}\psi_{qdo}$$

$$(\theta_T, \theta_r)$$

$$K_s(\theta_T)\frac{d}{dt}K_s(\theta_T) = \omega_T \begin{bmatrix} 0 & 1 & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$K_s \frac{d}{dt}\left(K_s{}^{-1}\psi_{qdo}\right) = \omega_T \begin{bmatrix} \psi_d \\ -\psi_q \\ 0 \end{bmatrix} + \frac{d}{dt}\psi_{qdo}$$

Voltage equation in the arbitrary frame

$$v_{qdo} = r_s i_{qdo} + \omega_T \begin{bmatrix} \psi_d \\ -\psi_q \\ 0 \end{bmatrix} + \frac{d}{dt}\psi_{qdo}$$

Now let us express flux in component form

First expand Ψ_{abc}

$$\psi_{abc} = L_s K_s{}^{-1} i_{qdo} + \psi_m$$

$$\psi_{qdo} = K_s L_s K_s{}^{-1} i_{qdo} + K_s \omega_m$$

$$K_s(\theta_T)\omega_m(\theta_r) = \omega_m \begin{bmatrix} -\sin(\theta_T - \theta_r) \\ \cos(\theta_T - \theta_r) \\ 0 \end{bmatrix}$$

For a three phase machine the space mmf wave has amplitude 3⁄2 times that of each individual phase which gives

$$L_{mq} = 3/2\,(L - L_\Delta)(3.39)$$

$$L_{md} = 3/2\,(L + L_\Delta)(3.40)$$

Flux in qdo coordinates may therefore be expressed as If the reference frame rotates in synchronism with the rotor and both angles have the same initial conditions then, and total flux in the rotor reference becomes

$$= \begin{bmatrix} L_q & 0 & 0 \\ 0 & L_d & 0 \\ 0 & 0 & L_{ls} \end{bmatrix} \begin{bmatrix} i_q{}^r \\ i_d{}^r \\ i_o{}^r \end{bmatrix} + \begin{bmatrix} 0 \\ \psi_m \\ 0 \end{bmatrix}$$

Stator voltage expressed in the rotor qdo frame then is

$$v_{qdo}{}^r = r_s i_{qdo}{}^r + \omega_m \begin{bmatrix} \psi_d \\ -\psi_q \\ 0 \end{bmatrix} + \frac{d}{dt}\psi_{qdo}{}^r$$

$$v_q{}^r = (r_s + \rho L_q) i_q{}^r + \omega_r L_d i_q{}^r + \omega_r L_m$$

$$v_d{}^r = (r_s + \rho L_d) i_d{}^r - \omega_r L_q i_q{}^r$$

$$v_o{}^r = (r_s + \rho L_{ls}) i_o{}^r$$

Where $\rho = d/dt$

$$\therefore T_e = \frac{dW_e}{d\theta_m}$$

$$= \frac{P}{2}\left(\frac{dW_e}{d\theta_r}\right)$$

$$= \frac{P}{2}\left(\frac{1}{2} i_{abc}{}^{T} \frac{d}{d\theta_r} L_s i_{abc} + i_{abc}{}^{T} \frac{d}{d\theta_r} \psi_m\right)$$

By substituting various variables, we have

$$T_e = \frac{P}{2}\left(\frac{9}{4} L_\Delta i_{qdo}{}^{T}\right)\begin{bmatrix} -\sin(2\theta_T - 2\theta_r) & -\cos(2\theta_T - 2\theta_r) & 0 \\ \cos(2\theta_T - 2\theta_r) & \sin(2\theta_T - 2\theta_r) & 0 \\ 0 & 0 & 0 \end{bmatrix} i_{qdo} + \frac{3}{2}\psi_m i_{qdo}{}^{T} \omega_m \begin{bmatrix} \cos(\theta_T - \theta_r) \\ \sin(\theta_T - \theta_r) \\ 0 \end{bmatrix}$$

$$\therefore T_e = \frac{3}{2}\frac{P}{2}\left(\psi_d i_q - \psi_q i_d\right)$$

$$T_e = \frac{3}{2}\frac{P}{2}\left((L_d - L_q) i_q{}^{r} i_d{}^{r} + \psi_m i_q{}^{r}\right)$$

In the above equation the first term is due to reluctance variations and disappears in a salient free machine. The second term is due to the permanent flux. These equations describe the electro mechanical behavior of the machine in the qdo reference frame. From above equations it can be rewritten as follows

$$\psi_d = \frac{1}{s}\left(v_d + w_r \psi_q - i_d r_s\right)$$

$$\psi_q = \frac{1}{s}\left(v_q + w_r \psi_d - (i_d r_s)\right)$$

Simulink models of the PMSM Direct axis flux ψ_d

From equation direct axis flux can be modeled in MATLAB/SIMULINK model. Summation of two parameters and subtraction of one parameters, whole thing has to be integrated. Simulation model for direct axis flux is shown in Fig.1

$$\psi_d = \frac{1}{s}\left(v_d + w_r \psi_q - i_d r_s\right)$$

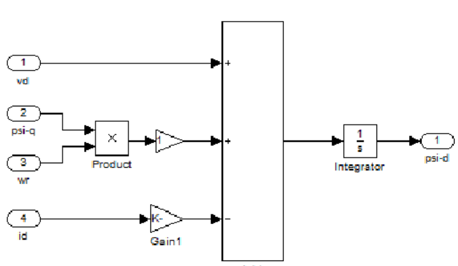

Fig.1 Model for Direct Axis Flux of PMSM

Quadrature axis flux ψ_q

From equation the quadrature axis flux can be simulated in MATLAB/SIMULINK model. Four inputs are given to additional block, addition of two parameters and subtraction of one parameter, the whole has to integrated. Simulation model is shown in Fig.2

$$\psi_q = \frac{1}{s}\left(v_q + w_r \psi_d - (i_d r_s)\right)$$

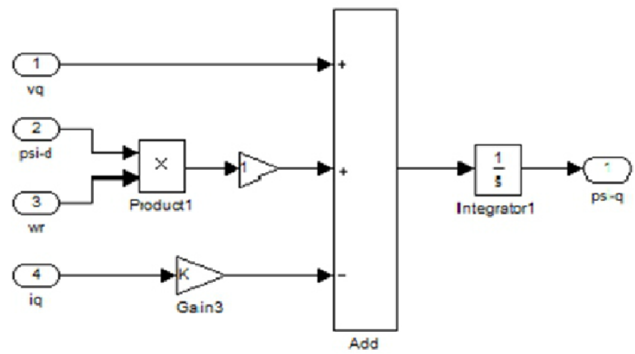

Fig.2 Model for Quadrature Axis Flux of PMSM

Electro Magnetic Torque T_e:

Electro Magnetic torque as given in equation it includes direct axis flux, quadrature axis flux, direct axis current, quadrature axis current and number of poles. Electro Magnetic torque is developed in MATLAB/SIMULINK model. Product of direct axis flux and quadrature axis cur-rent has to be subtracted with product of quadrature axis flux and direct axis current. Simulation model is shown in Fig.3

$$T_e = \frac{3}{2}\frac{P}{2}\left(\psi_d i_q - \psi_q i_d\right)$$

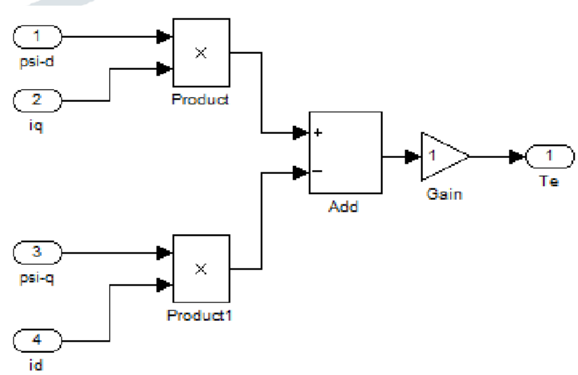

Fig.3 Model for Electro Magnetic Torque of PMSM

Speed can be written as

$$\omega_r = \frac{1}{s}\left(\frac{1}{jp}(T_e - T_l)\right)$$

According to above formula, the simulation model for speed is shown in Fig.4.

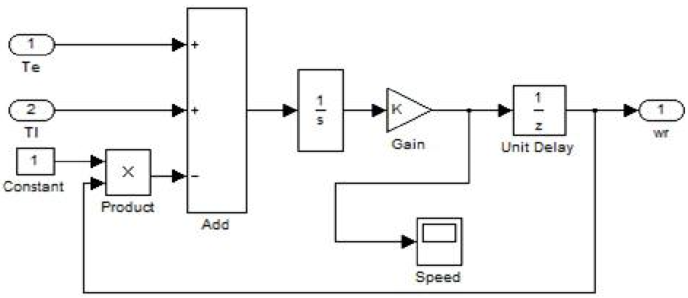

Fig.4 Model for reference Speed of PMSM

Motor parameter used in the simulation:

PMSM drive control strategy is shown in Fig.5. The out-put of PMSM is generated by using tachometer. In order to generate the speed output filter is used in the feedback path, the filter output is applied to the comparator. The other input to the comparator is reference speed. The speed output from the comparator is taken as error signal. Motor parameters used in MATLAB/Simulink are given below.

Stator resistance	1.4 ohm
q-axis self inductance	0.009 H
d-axis self inductance	0 . 0056 H
Mutual flux linkage due to rotor magnets	0 . 1546 wb-turn
Moment of inertia	0.006 kg-m2
Friction coefficient	0.0 1 N-m/(rad/sec)
Number of poles	6
Constant frequency	2 KHz
Maximum control voltage	10 V
DC link voltage	285 V
Gain of the current transducer	0.8 V/A
Gain of the speed filter	0.05 V

Vector Control of PMSM drive:

Vector control of PMSM drive contains qdr2abc block, inverter and PMSM drive design. In qdr2abc block con-version from qd reference frame to abc phases has done, in general there are three frames they are field frame, sta-tionary frame and synchronous reference frame. The field frame outputs obtained as θ, i_q and i_q. These three pa-rameters are inputs to the stationary frame which is repre-sented as qdr2qds. Vector control of PMSM drive with PI controller is shown in Fig.5

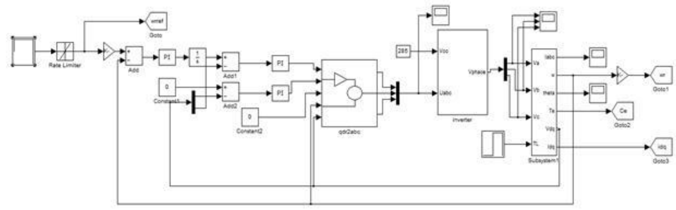

Fig.5 Vector control of PMSM Drive with PI controller

Before running this simulation, initialization program has to be run, which calls the all motor specifications of PMSM drive to work space of MATLAB.The dynamic performance of an ac machine is somewhat complex be-cause the three-phase rotor windings move with respect to three phase rotor winding. Assume that the d_s-q_s axes are oriented at θ angle. The voltages vds_s and vqs_s can be resolved into as-bs-cs components and can be represented in the matrix form as

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta - 120^0) & \sin(\theta - 120^0) & 1 \\ \cos(\theta + 120^0) & \sin(\theta + 120^0) & 1 \end{bmatrix} \begin{bmatrix} v_{qs}{}^s \\ v_{ds}{}^s \\ v_{0s}{}^s \end{bmatrix}$$

Synchronously rotating d_e-q_e axes, which rotate at syn-chronous speed ω_e with respect to the d_s-q_s axes and the angle $\theta_e = \omega_e t$. The two-phase d_s-q_s windings are trans-formed into the hypothetical windings mounted on the d_e-q_e axes. The voltages on the d_s-q_s axes can be converted (or resolved) into the d_e-q_e frame as follows

$$v_{qs} = v_{qs}{}^s \cos\theta_e - v_{ds}{}^s \sin\theta_e$$

$$v_{ds} = v_{qs}{}^s \sin\theta_e + v_{ds}{}^s \cos\theta_e$$

For convenience, the superscript e has been dropped from now on from the synchronously rotating frame parame-ters. Again, resolving the rotating frame parameters into a stationary frame, the relations are

$$v_{qs}{}^{s} = v_{qs}\cos\theta_e + v_{ds}\sin\theta_e$$

$$v_{ds}{}^{s} = -v_{qs}\sin\theta_e + v_{ds}\cos\theta_e$$

The overall output from qdr2abc is given to inverter. The output pulses of the inverter are fed to the PMSM drive. With individual blocks of direct axis Flux, Quadrature axis Flux, Electro Magnetic Torque and speed. In timer the speed reference is taken as 1200 represented in radians, from zero to positive limit. The speed response is shown in Fig.6.

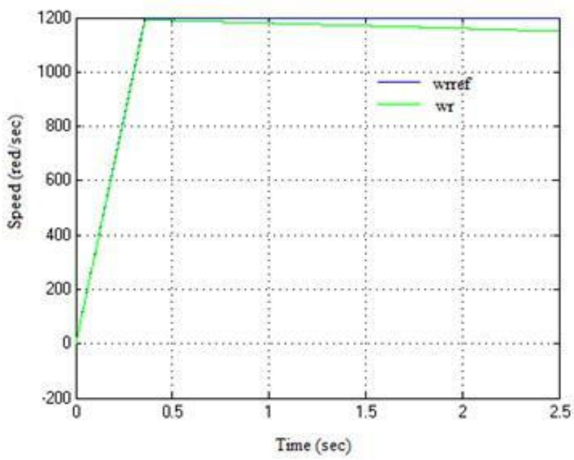

Fig.6 Speed response of PMSM drive using Vector control PI.

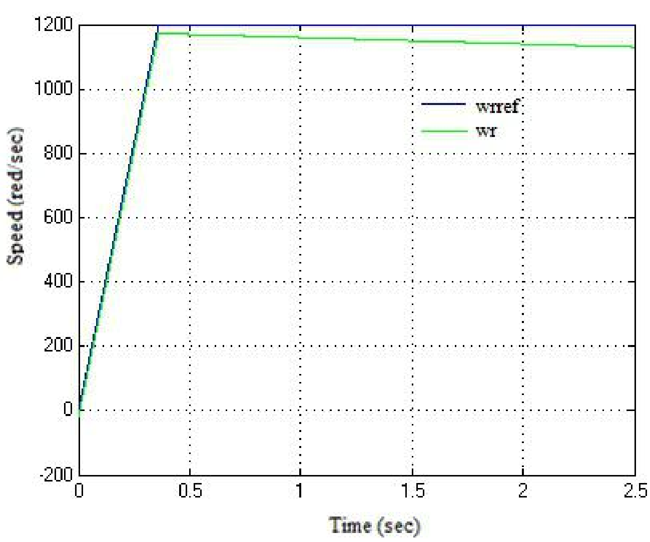

Fig.7 Speed response of PMSM drive using Vector control PD.

PI controller is replaced with PID controller with K_p value is 3.56, K_i values is 1.36 and K_d value is 0.005 then the speed response is shown in Fig.8. By using vector PI and vector PD controllers the speed response is somewhat deviated from the reference speed. Whereas with vector PID controller the speed response is exactly equal to the reference speed, by comparing, it is observed that better speed control is obtained with vector PID controller.

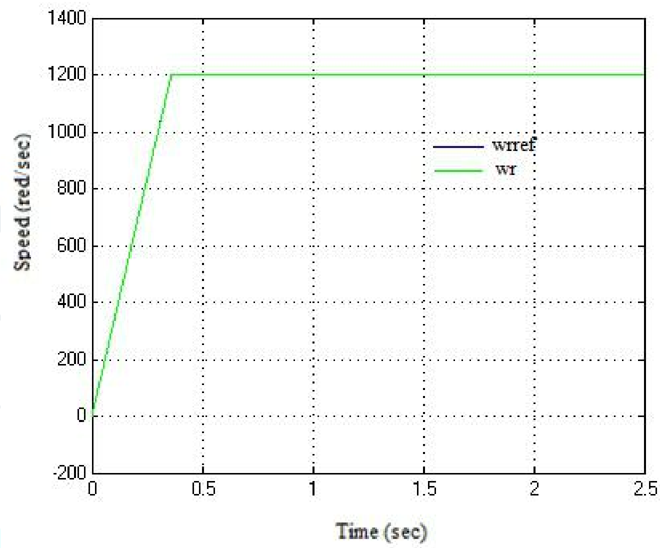

Fig.8 Speed response of PMSM drive using Vector control PID

Speed error signal is given by the difference between reference speed and obtained speed. Due to some disturbance in the load the speed of the PMSM drive may change. Speed error graph is shown in Fig.9 the desirable condition is that the difference between reference speed and the obtained speed is zero. In this case there are only five or six cases where the difference is not zero.

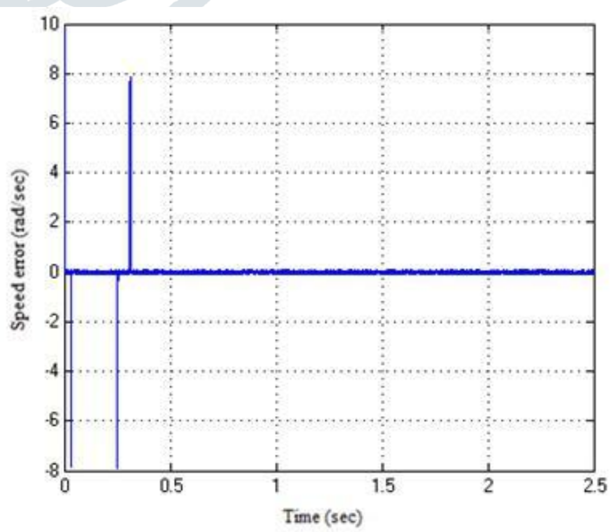

Fig.9 Speed error variations

After converting qdr2abc the output from the conversion block is fed to inverter block. Two outputs from the qdr2abc block and one reference dc voltage. Inverter again consists of some sub-blocks; finally it converts dc to ac, which is in pulsated form.

The pulse from the inverter is given to PMSM drive Model, Again in the modeling it contains abc2qdo block and qdr2abc In abc2qdo block first conversion have been done for abc2qdo after that qds2qdr. Where as in qdr2abc block conversion have been done for qdr2qds then qds2abc.

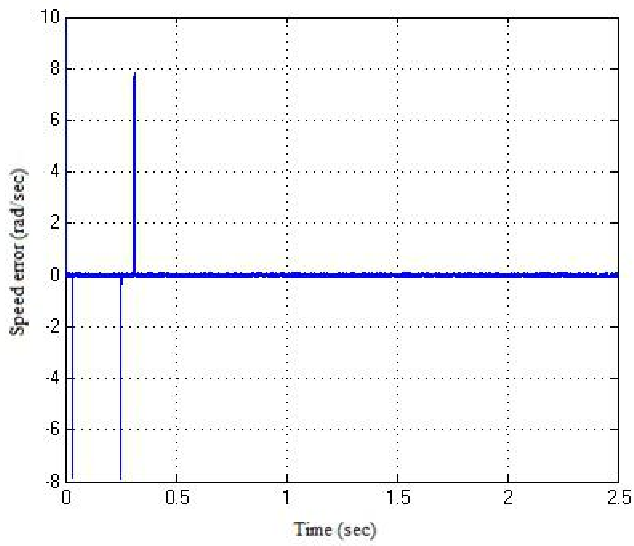

Fig.10 Speed error variations

Stator current components of PMSM drive are shown in Fig.11. After converting qdr2abc the output from the con-version block is fed to inverter block. Two outputs from the qdr2abc block and one reference dc voltage. Inverter again consists of some sub-blocks; finally it converts dc to ac, which is in pulsated form. The pulse from the inverter is given to PMSM drive Mode,

Again in the modeling it contains abc2qdo block and qdr2abc block. In abc2qdo block first conversion have been done for abc2qdo after that qds2qdr. Where as in qdr2abc block conversion have been done for qdr2qds then qds2abc.graph for Electro Magnetic torque is shown in Fig.12

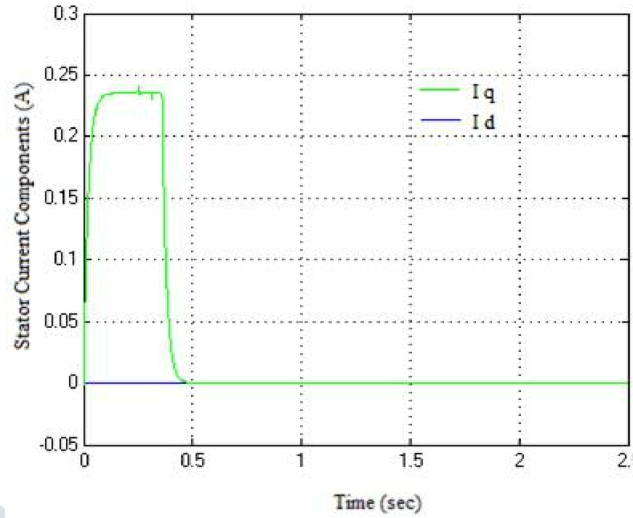

Fig.11 Stator Current Components

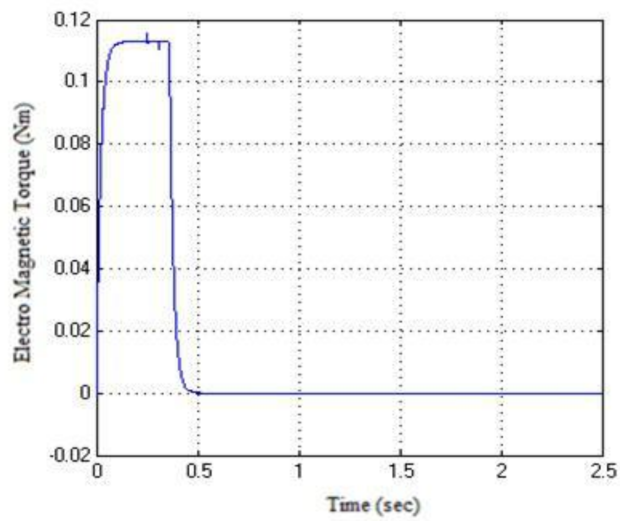

Fig.12 Electromagnetic torque of PMSM drive

In this paper a vector control based speed control for PMSM drive is presented. Speed of the PMSM drive can be smoothly controlled by using vector PID controller.

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