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Robust Speed Control of PMSM Drive System

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Abstract: Among AC drives permanent magnet synchronous motor drives, have been widely used in the field of high performance due to its advantageous features. For electric drives good dynamic response is mandatory for the sudden variations in machine parameters .This work presents a simple and robust speed control scheme of Permanent Magnet Synchronous Motor (PMSM). It is to achieve accurate control performance in the presence of load torque and plant parameter variation.Vector control scheme is used to simplify the PMSM drive. .Kalman Observer is used for estimating the speed of the motor. Space vector pulse width modulation (SVPWM) technique is employed to obtain the required output voltage in the line side of the inverter. Simulation results clearly show that the proposed control scheme can track the speed reference signal successfully under parameter uncertainties and load torque disturbance.

Keywords: Vector Control, SVPWM, Kalman Observer

I. INTRODUCTION

Among AC drives permanent magnet synchronous motor(PMSM) drives has been widely used in many industrial application due to it advantageous features such as high efficiency, high speed performance, high power factor and high torque to inertia ratio. Among the synchronous motor types the permanent magnet synchronous motor (PMSM) is one possible design of three phase synchronous machines. The stator of a PMSM has conventional three phase windings. In the rotor, PM materials have the same function of the field winding in a conventional synchronous machine. Their development was possible by the introduction of new magnetic materials, like the rare earth materials. The use of a PM to generate substantial air gap magnetic flux makes it possible to design highly efficient PM motors. For electric drives good dynamic response is mandatory for the sudden variations in machine parameters .This requirement of the machine can be overcome by using vector control technique.

The objective of the vector control of PMSM is to allow the motor to be controlled just like a separately excited DC motor. So, the direct 'd' axis is aligned with permanent magnet flux linkage phase and the direct current ' i_d is forced to be zero. Essentially, it requires the coordinate transformations that converts three phase stationary line current into two phase rotating currents, like in DC machines. The outer loop of the vector control is the speed loop which greatly affects the performance of the system. Traditional vector control uses a PI controller in the speed loop because of its simplicity, stability and robustness. A voltage source inverter is commonly used to supply a three-phase synchronous motor with variable frequency and variable voltage for variable speed applications. A suitable pulse width modulation (PWM) technique is employed to obtain the required output voltage in the line side of the inverter. The vector controller must know the rotor position continuously with a fine precision. It is known that the control performance of vector controller highly depends on the accuracy of position information. In a typical variable speed application, a high-precision sensor such as an encoder or resolver is used. But due to mechanical vibrations ,low quality sensors the measured position may contain error which will affect the performance. A Kalman observer is also proposed in order to overcome this situation

II. MATHEMATICAL MODELLING OF PMSM.

The mathematical model of PMSM can be expressed by equations in the rotor reference frame using following assumptions:

1) Saturation is neglected
2) The induced EMF is sinusoidal
3) Eddy current and Hysteresis losses are negligible.

$$\frac{di_q}{d_t} = \frac{v_q}{L_q} - \frac{Ri_q}{L_q} - \frac{L_d w_e i_d}{L_q} - \frac{w_e \emptyset_f}{L_q} \quad (1)$$

$$\frac{di_d}{d_t} = \frac{v_d}{L_d} - \frac{Ri_d}{L_d} + \frac{L_q i_q w_e}{L_q} \quad (2)$$

The electromagnetic torque is given by

$$T_e = \frac{3}{2} P[\phi_f i_q] \quad (3)$$

The mechanical equation is given by

$$\frac{dw_m}{dt} = \frac{1}{J}[T_e - Bw_m - T_m] \quad (4)$$

$$\frac{d\theta}{dt} = w_m \quad (5)$$

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Where i_q and i_d are the direct and quadrature axis current, v_q and v_d are the direct and quadrature axis voltage,R is the stator resistance, L_q=L_d direct and quadrature axis inductance, B is the friction factor,J is the rotary inertia, θ rotor position, T_e electromagnetic torque, T_m is the load torque, w_m mechanical angle speed and w_e is the electrical angle speed.

III.VECTOR CONTROL PMSM DRIVE

Figure 1 shows the vector control PMSM drive system. The current loop and speed loop are both composed of PI regulator. The PMSM drive system mainly includes PMSM body module, three-phase voltage ,inverter module, coordinate transformation module ,SVPWM production module. and an Observer. Figure 1 shows the block Diagram of PMSM Drive. The measured stator currents from the inverter are transformed to the d-q revolving reference frame through Clarke and park transformations. The measured speed is compared with the reference speed and the difference is computed by the PI regulator. The output of the PI regulator will be the torque current component i_{qref} which controls the torque. Herei_{dref} =0(proving maximum torque range). The reference currents are compared with i_q and i_d and given to the PI regulators. It outputs voltages corresponding to the d q reference frame which is v_d and v_q.Using inverse park transformations the voltages in d q reference frame is transformed to the α-β reference frame resulting v_α and v_β. These voltages are applied across the space vector pulse width modulation module in order to control inverter so as to achieve close loop control.

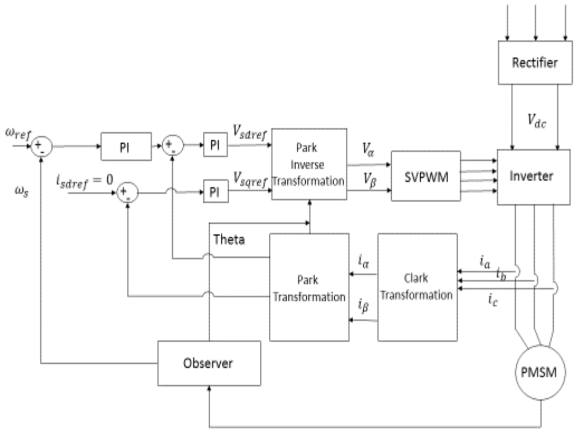

Fig 1 Block Diagram of PMSM Drive System

A. Coordinate transformation module.

Coordinate transformation module's function is to transform motor's stator three phase current into the corresponding current in synchronized revolving dq coordinate. The coordinate transformation used in vector control: Clark transformation and Park transformation and Park inverse transformation,. Its transformation matrix is as follows:

Clarke transformation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & \frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

Park transformation

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (2)$$

Inverse park transformation

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (3)$$

B. Space vector pulse width modulation module.

The main aim of any modulation scheme is to obtain variable output having a maximum fundamental component with minimum harmonic. Space vector pulse width modulation is an advanced, computational intensive PWM method and possibly the best technique for variable frequency drive operation. This PWM method is frequently used in vector controlled and direct torque controlled drives. In vector controlled drive this technique is used for reference voltage generation when current control is exercised in rotating reference frame. SVPWM is accomplished by rotating a reference vector around the state diagram, which is composed of six basic non-zero vectors forming a hexagon.[3]-[4].Figure 2 shows space vector of 3 phase bridge inverter.

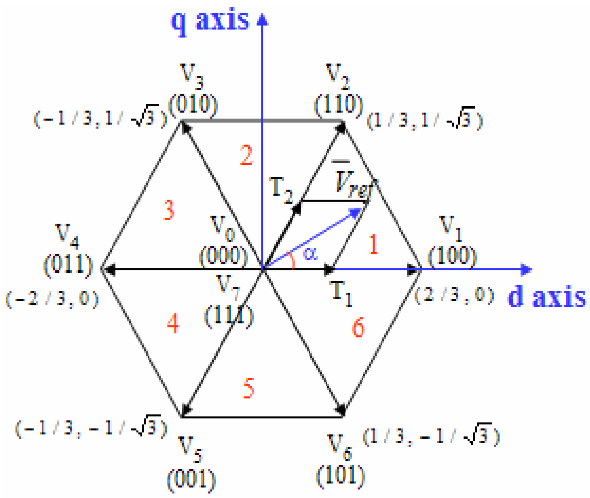

Fig 2 Space vector of phase bridge inverter

Six non-zero vectors $(V_1 - V_6)$ shape the axes of a hexagonal as depicted in Figure-2, and supplies power to the load. The angle between any adjacent two non-zero vectors is 60 degrees. Meanwhile, two zero vectors (V_0 and V_7) and are at the origin and apply zero voltage to the load. The objective of SVPWM technique is to approximate the reference voltage vector V_{ref} using the eight switching patterns.

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Three sinusoidal and balanced voltages are given by the relations:

$$V_a(t) = V_{ref}\cos wt \quad (1)$$
$$V_b(t) = V_{ref}\cos(wt - \frac{2\pi}{3}) \quad (2)$$
$$V_c(t) = V_{ref}\cos(wt + \frac{2\pi}{3}) \quad (3)$$

For any three-phase system with three wires and equal load impedances, we have

$$V_a(t) + V_b(t) + V_c(t) = 0 \quad (4)$$

The space vector with magnitude V_{ref} rotates in a circular direction at an angular velocity of w where the direction of rotation depends on the phase sequence of the voltages. If it has a positive phase sequence, then it rotates in the counter clockwise direction.

Otherwise, it rotates in the clockwise direction with a negative phase sequence. The three-phase voltages could be described with only two components, α and β, in a two-dimensional plane. The magnitude of each active vector is $\frac{2V_{dc}}{3}$.

$$V_{ref} = \frac{2}{3}[V_a + aV_b + a^2V_c] \quad (5)$$

where a=$e^{\frac{j2\pi}{3}}$. The magnitude of the reference vector is:

$$|V_{ref}| = \sqrt{V_\alpha{}^2 + V_\beta{}^2} \quad (6)$$

The phase angle is evaluated from

$$\theta = \tan^{-1}\left(\frac{V_\beta}{V_\alpha}\right) \quad (7)$$

These are the basics equations for constructing a SVPWM.

C Kalman Observer

The function of the Kalman observer is to predict the rotor position in order to control the quadrature current in turn controls the torque of the motor

Kalman observer[5] has two distinct phases, prediction and correction. The prediction phase uses the state estimate from the previous time step to produce an estimate of the state at the current time step. This predicted state estimate is also known as the a priori state estimate because, although it is an estimate of the state at the current time step, it does not include observation information from the current time step. In the correction phase, the current a priori prediction is combined with current observation information to refine the state estimate. This improved estimate is termed the a posteriori state estimate. The block diagram of Kalman observer is shown in Figure 3.

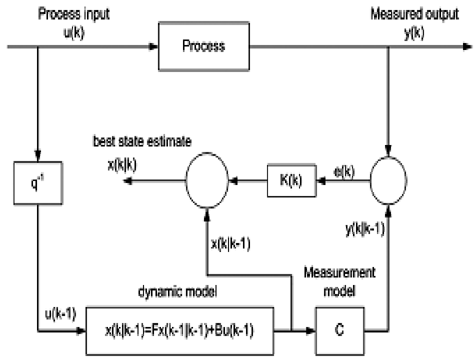

Fig 3 Block diagram of Kalman Observer

Consider a linear time invariant discrete system given by the following equation

$$X_{k+1} = FX_k + Bu_k \quad (1)$$
$$Z_{k+1} = HX_{k+1} + V_{k+1} \quad (2)$$

where F is the state transition matrix, B is the control input matrix, W_k is the process noise with zero mean multivariate normal distribution having covariance Q_k, H is the observation matrix, V_{k+1} is the observation noise which is zero mean Gaussian white noise having covariance R_k, u_k is the control input.
Prediction (time update) equations

$$x(k|k-1) = Fx(k-k|k-1) + Bu(k) \quad (3)$$
$$p(k|k-1) = Fx(k-1|k-1)F^T + Q(k) \quad (4)$$

Correction (measurement update) equations

$$x(k|k) = x(k|k-1) + Kerr(k) \quad (5)$$
$$p(k|k) = (I-K(k)H)p(k|k-1) \quad (6)$$

where K(k) is the kalman gain which is equal to

$$K(k) = p(k|k-1)H^T Hp(k|k-1)H^T + R(k)^{-1} \quad (7)$$

IV. SIMULATION RESULTS

Table 1
Simulation parameters

System parameters	Value	Unit
Rs	4.7	Ω
Ld	0.0140013	H
Lq	0.0140013	H
J	0.0031	$\frac{kgm}{s^{\wedge 2}}$
Phi	0.3846985	wb
P	4	Polepair
B	0.0001	Nmrad/s
N(rated)	5000*pi/3	rad/sec
Prated	400	W
Trated	1.271	Nm

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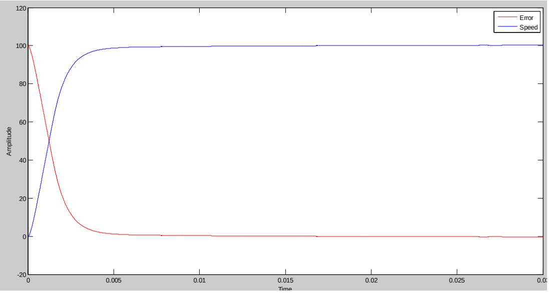

Fig. 4. Response of PMSM Drive system when a reference speed of 100rsd/s is given

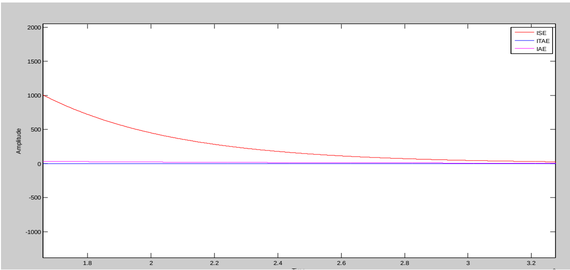

Fig 5 Error chart

V. CONCLUSION

A simple and robust speed control scheme of Permanent Magnet Synchronous Motor (PMSM)drive is designed. Simulation results clearly show that the proposed control scheme can track the speed reference signal successfully under parameter uncertainties and load torque disturbance.

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