Matlab-based Permanent Magnet Synchronous Motor Vector Control Simulation

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***Abstract*—Proposed permanent magnet synchronous motor based on MATLAB (PMSM) vector control system model of simulation. And take the model for simulation experiment in Matlab / Simulink environment. The simulation result indicated that the controlling system had a better dynamic response and regulator character. And validate its control algorithm for a theoretical basis that design and debugging permanent magnet synchronous motor control system.**

Keywords-PMSM；The vector controls；Matlab/Simulink

I. FOREWORD

Compared with other forms of motor, permanent magnet synchronous motor (PMSM) has better dynamic performance, smaller size and higher efficiency. In recent years, with the rapid development of electric power electronics technical, rare earth permanent magnetic materials and the increasingly sophisticated research in permanent magnet motor. PMSM is widely used in national defense, agriculture and daily life.[1]

PMSM is a multivariable, nonlinear and high coupling system. The output torque and stator current present a complicated function relation. Magnetic field can be decoupled to get a good control performance: It was no slip frequency current, less affected by the rotor parameters, easier to implement vector control. Therefore, the model of PMSM vector control has become a widespread concern.

This paper analyzes the mathematical model of permanent magnet synchronous motor based on the use of powerful simulation with Matlab modeling capabilities. In the Matlab / Simulink to create a simulation model of PMSM control system can be provide effective means and tools for analysis and design of the servo control system.

II. PMSM MATHEMATICAL MODEL

A. Basic Model

The permanent magnet synchronous motor mainly from stator and rotor two part constitute. Three-phase stator windings produce a rotating magnetic field through the three-phase AC. Rotor is usually equipped with high-performance permanent magnet in surface or inside of ferromagnetic materials. Such as neodymium iron boron or rare earth magnetic materials to obtain a strong magnetic field, etc. And the rotor magnetic field to distribute for the sine or look like a sine wave form. The interaction between the stator and rotor magnetic field generated torque when the stator three-phase inverter with access to electricity generated in the motor rotating magnetic field. Then the torque push synchronization of the rotor to the stator magnetic field rotation speed to achieve the purpose of frequency control. In order to facilitate analysis, the motor to make the following assumptions: the stator winding three-phase symmetrical, uniform air gap, ignoring the end effect; neglected magnetic saturation and iron loss ,magnetic circuit is linear; converter provides an ideal three-phase power, ignoring higher harmonics ; ignore the rotor shaft friction.

Motor voltage balance equation is given by:

$$\begin{bmatrix} Ua \\ Ub \\ Uc \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} d\psi_a/dt \\ d\psi_b/dt \\ d\psi_c/dt \end{bmatrix} \tag{1.1}$$

Motor flux balance equation is given by:

$$\begin{bmatrix} \psi_a \\ \psi_b \\ \psi_c \end{bmatrix} = \begin{bmatrix} \cos 0^o & \cos 120^o & \cos 240^o \\ \cos 240^o & \cos 0^o & \cos 120^o \\ \cos 120^o & \cos 240^o & \cos 0^o \end{bmatrix} \begin{bmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} \psi_{fr} \cos\theta \\ \psi_{fr} \cos(\theta - 120^o) \\ \psi_{fr} \cos(\theta - 240^o) \end{bmatrix} \tag{1.2}$$

Torque expression is given by:

$$T_e = \lambda \begin{bmatrix} i_a & i_b & i_c \end{bmatrix} \frac{d}{d\theta} \begin{bmatrix} \psi_{fr} \cos\theta \\ \psi_{fr} \cos(\theta - 120^o) \\ \psi_{fr} \cos(\theta - 240^o) \end{bmatrix} \tag{1.3}$$

Equation of motion for the motor is given by:

$$J \frac{dw}{dt} = T_e - T_l \tag{1.4}$$

Type of Ua, Ub, Uc for the three-phase stator winding voltage. ia, ib, ic for the three-phase stator winding current. ψa, ψb, ψc for the three-phase stator winding flux. R, L, ψfr are the stator windings of each phase of resistance, inductance, the equivalent rotor field flux. TL is load torque. λ, J, ω are the motor pole number, rotor inertia, the rotor electrical angular velocity.

The AC permanent magnet synchronous motor is a multi-variable coupled and nonlinear time-varying system in last type. Direct use of traditional linear control theory can not achieve effective control of it. Therefore, it must be possible to transform and simplify the use of classical control theory regulator design.

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B. Coordinate transformation and field-oriented control

Figure 1 shows the coordinate system of permanent magnet synchronous motor stator and rotor. In order to effectively apply the field oriented control theory, firstly let the three phase system into a two-phase orthogonal system, then pinwheel two-phase orthogonal system for angle θ in order to control direct axis and quadrature axis.

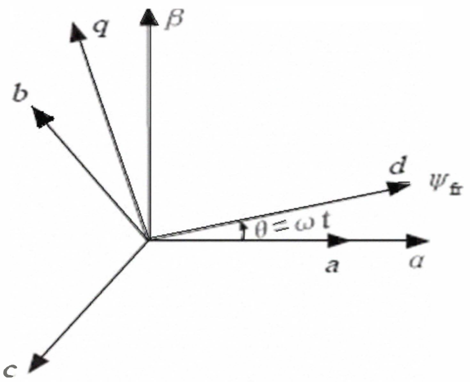

Figure 1. Coordinate system of permanent magnet synchronous motor

Voltage transformation is similar to current transformation and current transformation is a example in the text. Stator current to the current two-phase orthogonal transformation between the following:

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos 0^o & \sin 0^o & 1/\sqrt{2} \\ \cos 120^o & \sin 120^o & 1/\sqrt{2} \\ \cos 240^o & \sin 240^o & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} \quad (1.5)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_o \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos 0^o & \cos 120^o & \cos 240^o \\ \sin 0^o & \sin 120^o & \sin 240^o \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1.6)$$

Since the stator three-phase current $i_a + i_b + i_c = 0$, Therefore, zero sequence current component $i_0 = (i_a + i_b + i_c)/\sqrt{3} = 0$ can be neglected. The stator current of orthogonal coordinate system transformation for rotor two-phase of orthogonal coordinate system is given by:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_d \\ i_q \end{bmatrix} \quad (1.7)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (1.8)$$

The formula (1.5) to (1.8) into formula (1.1) to (1.3) finishing available:

$$I'_{dq} = \begin{bmatrix} -R_s/L_s & \lambda\omega \\ -\lambda\omega & -R_s/L_s \end{bmatrix} I_{dq} + \frac{1}{L_s} U_{dq} - \frac{2\lambda\omega}{3L} \begin{bmatrix} 0 \\ \psi_{fs} \end{bmatrix} \quad (1.9)$$

$$T_e = \lambda \times \psi_{fs} \times i_q \quad (1.10)$$

The last two formula: current vector $I_{dq} = [i_d \quad i_q]^T$, Voltage vector $U_{dq} = [u_d \quad u_q]^T$, $R_s = R$, $L_s = 3L/2$, $\psi_{fs} = \sqrt{3/2}\psi_{fs}$. By the formula (1.9) and (1.10) can known, the current is a linear time-invariant systems. When ω constant through the coordinate transformation, particularly ψfs is constant and iq proportional to the electromagnetic torque. By controlling the torque current component iq to complete the linear motor electromagnetic torque control to obtain high performance.

III. PMSM VECTOR CONTROL THEORY

Vector control is actually control of phase and amplitude for a motor stator voltage or current vector at the same time. The motor torque will depend on the stator current space vector is = id + jiq. When the permanent magnet flux and the direct excitation, cross-axis inductance is confirmed. In other words, control id and iq that can control the motor torque. Current id as excitation current, on the id of the control, in practical application there are three kinds of general circumstances, this paper use id = 0 of the control strategy.

Permanent magnet rotor according to the location of the different permanent magnet synchronous motor can be divided into: the surface and inside buried. The tile-shaped magnet was generally and in the outer surface of the rotor iron core in the surface permanent magnet synchronous motor (SPM SM). This important feature of the motor is that straight axis and cross axis for the main inductance is equal (L d = L q). And within the interior permanent magnet synchronous motor (IPMSM) of the permanent magnets in the rotor inside the stator magnet in vitro surface and inner circle core made of ferromagnetic material between the pole shoe can protect the permanent magnets. This important feature of permanent magnet motor is direct, cross-axis of the main inductance is not equal to (L d ≠ L q). For surface-type PMSM, as L d = L q, this style incorporated into the electromagnetic torque equation. Torque equation can be obtained equation (2.10) that only related to the electromagnetic torque and the q axis current iq. So let id = 0, through control the iq, you can achieve maximum torque control in the surface type PM SM vector control.

Figure 2shows a vector control strategy block diagram with the use of id = 0.

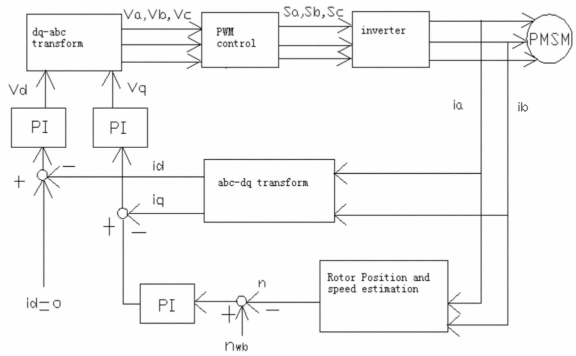

Figure 2. PMSM vector control system block diagram

IV. DIRECT POSITION DETECTION of PMSM SIMULINK BASED SIMULATION MODEL

Figure 3 is a model for sensorless vector control, which is called this simulation platform. Permanent magnet motor and inverter models used directly in the Simulink side Simpowersystems own model of parts library. Speed and position information from the measurement module Machines Measurement Demux direct feedback. Use id = O control method to control the speed and dq-axis current with PI control.

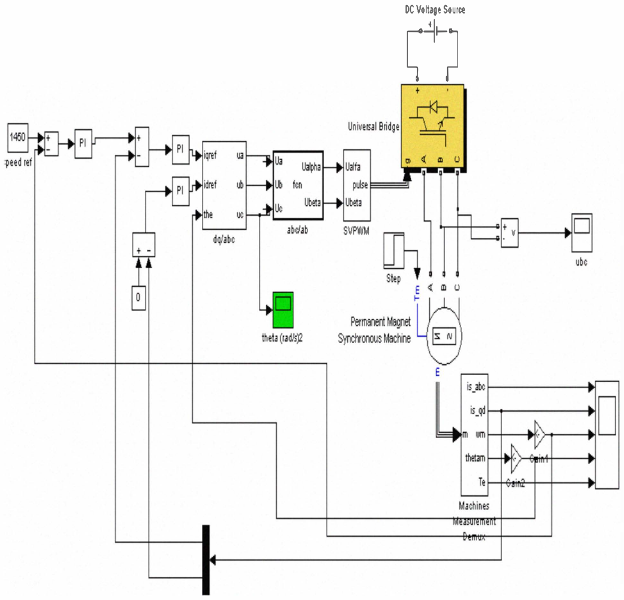

Figure 3. Simulation Model of permanent magnet synchronous motor

V. SIMULATION RESULTS

According to the proposed vector control of PMSM simulation model, run in Matlab, using the motor parameters are as follows: electrical power P = 2kw, DC voltage Udc = 550V, stator windings resistance Rs = 2.875Ω, d-phase winding inductance Ld = 8.5 e-3H, d-axis winding inductance Ld = 805e-3H, the rotor magnetic flux Ψ f = 0.175 Wb, moment of inertia J = 0.8 e-3 kg • m ^ 2, the pole number p = 4, magnetic flux density B = 0. Set the total simulation time t = 0.2 s, for the sudden increase in torque test.

No load start, t = 0.1s when the additional load Tm = 5N.m, speed is 2000 r / min. Waveforms as follows:

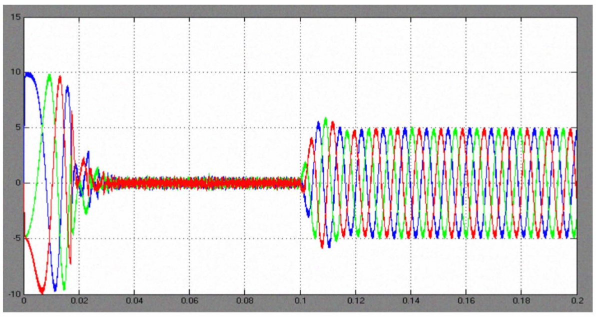

Figure 4. Current response curve

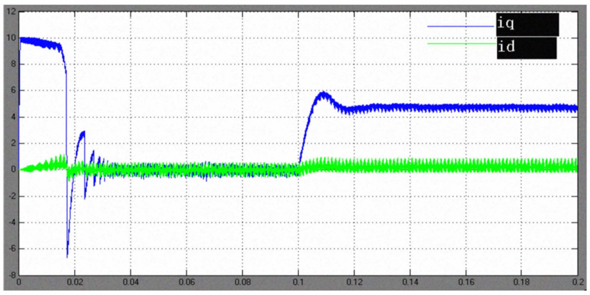

Figure 5. dq axis current waveform

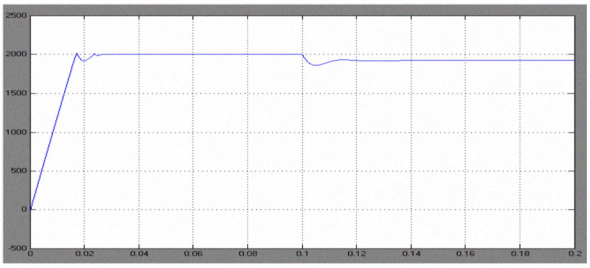

Figure 6. Speed response curves

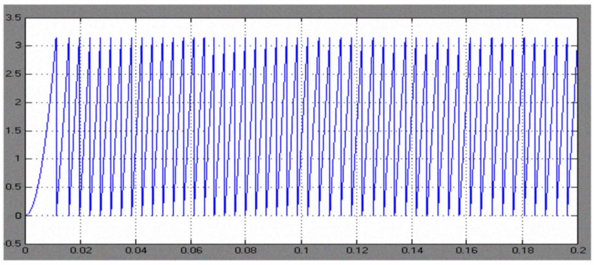

Figure 7. Rotor position waveform

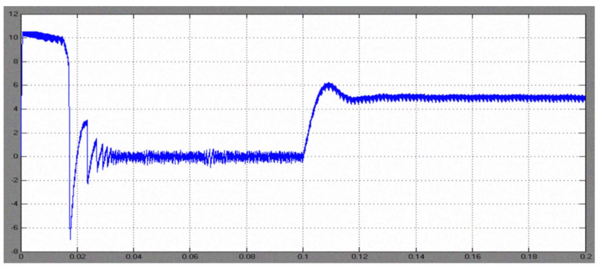

Figure 8. Electromagnetic torque waveform

Sudden increase in torque when the speed becomes 2000 r / min (Fig. 4 to Fig. 8). Then you can see the current, torque response time is very short and very small fluctuations in speed. We can see steady speed when in stable operation with load and stator phase current maintain to a good sinusoidal. This implies that the system has a good anti-interference ability.

VI. CONCLUSION

In this paper, Simulink-based simulation of PMSM vector control system modeling. Simulation results show that the system can run smoothly, has good static and dynamic characteristics. Experiment and validate id = 0 is a good control algorithm. It provides an effective means and tools for analysis and design of PMSM control system provides. And provides a guideline of designing and debugging for practical PMSM system.

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