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SIMULATION OF PERMANENT MAGNET SYNCHRONOUS MOTOR FIELD ORIENTED VECTOR CONTROL SYSTEM

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Abstract
This template illustrates the control system of permanent magnet synchronous motor(PMSM) which uses field oriented vector control(field oriented vector control). PMSM is a complex, strong coupling and nonlinear system. And field oriented vector control could provide good performance as well as the PI controller setted with well parameter matching. Whereas limited by the number of voltage vector, the other control method of PMSM, direct torque control, could not satisfy accurate control when the machine running with a low speed. So modulation of the whole system is built here to realize closed-loop field oriented vector control control by keeping id ☐ 0 , and the machine model and the transformation among different coordinate system are discussed. The system is verified effective and feasible.

Keywords: PMSM, Simulation, Field oriented vector control

INTRODUCTION

PMSM is a complex, strong coupling and nonlinear system. Because of no exciting current, PMSM has relatively high efficiency and power factor, its stator current and resistance loss reduces, and the rotor parameter is measurable. PMSM is used throughout industrial automation instrument field.In this paper, the mathematical modeling of PMSM will be analyze, and field oriented vector control is applied with space vector pulse width modulation.

The Field Oriented Vector Control System

PMSM control system is a double colesed loop control, usually there are two methods , one is direct torque control, and the other is field oriented vector control. The difference between them is that DTC uses torque as the object to control the stator flux linkage and electromagnetic torque directly, while Field oriented vector control selects current and flux linkage to implement indirect control. The weak point of DTC is the voltage vector number is limited that may not provide good performance during low-speed operation. Therefore Field oriented vector control is explained here for its simplicity.The whole system is shown in Fig. 1.

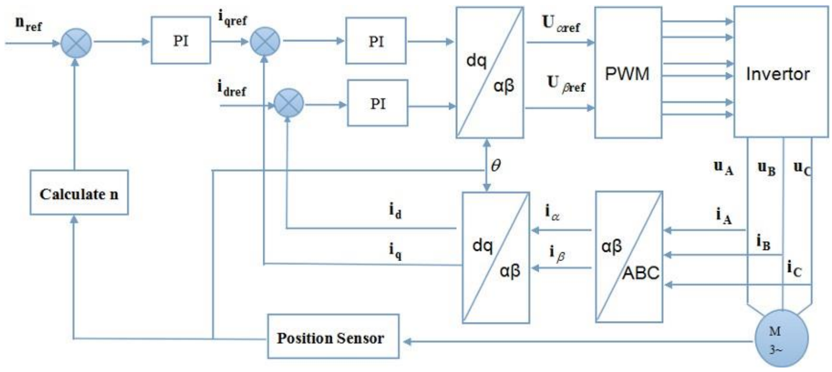

Fig.1 Field oriented vector control Control System[1]

The core concept of Field oriented vector control is coordinate conversion. According to the principle of remain the magnetic potential and power unchanged, converse the ABC coordinate system to the □□ coordinate system, then converse it to the dq coordinate system, during this process the stator current vector is reduced to direct components id, represents excitation current, which could control flux, and iq represents torque current which applies torque control. By setting id=0, and comparing with the two reduced values, ud and uq is acquired after electric current loop. Then these vectors are sent to the input of the SVPWM model to generate switching pulse.

Mathematical Model of the System

Field oriented vector control could make the PMSM speed control as well as the continuous current motor, and it is build on the theory of coordinate system conversion.Supposed the three-phase stator winding are space symmetry, the interval angle is 120°, ignored the current loss and hysteresis loss[2].Then set the north direction of permanent magnet field axis as d-axis and its vertical direction as q-axis, a 2r -coordinate-system is established, which rotate at a speed of □ . While a 2s-coordinate-system is built, which is static because it is associated with the stator, its direction is relatively fixed compared with the positon of the three-phase winding. The□ -axis is the direction of A-phase winding magnetic potential, and □ -axis leads □ -axis 90°. Where □ is electrical angle shift, both coordinate systems are shown in Fig. 2.

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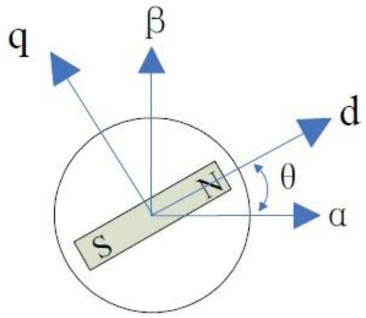

Fig.2 2s and 2r Coordinate System

According to the principle of Field oriented vector control, the motor outputs three-phase current, which belongs to the 3s-coordinate-system, that is ABC-coordinate-system. The three-phase stator winding coupling is closely related with the rotor positon, thus the inductance matrix is quite complex . Conversion is needed here to transform the equivalent output current vector into 2r coordinat system and 2s coordinate system[3]. Supposed each phase of the three-phase symmetric stator winding has N3 turns, the two-phase stator winding and two-phase rotor winding both have N2 turns, take the current for example, the equation of transformational relation is

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{pmatrix} i_A \\ i_B \\ i_C \end{pmatrix} \tag{1}$$

And the equation transform 2s-coordinate-system into 2r -coordinate-system is

$$\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} \tag{2}$$

Therefore the motor mathmatical is simplified as followed. Where □ is the rotor speed in rad/s, R1 is the winding resistance, p is the differential operator ,□ represents the flux linkage, np number of pole-pairs.The stator voltage is illustrated by

$$\begin{cases} u_d = R_1 i_d + p\varphi_d - \omega\varphi_q \\ u_q = R_1 i_q + p\varphi_q + \omega\varphi_d \end{cases} \tag{3}$$

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The stator flux equations are $\begin{cases} \varphi_d = \varphi_f + L_d i_d \\ \varphi_q = L_q i_q \end{cases}$ (4)

The electromagnetic torque is

$$T_e = 1.5 n_p (\varphi_d i_q - \varphi_q i_d) = 1.5 n_p [\varphi_d i_q - (L_q - L_d) i_d i_q] \quad (5)$$

Field oriented vector control is applied, so set the current vector value in d-axis id=0 the formula above is simplified into

$$T_e = 1.5 n_p \varphi_d i_q \quad (6)$$

Obviously the electromagnetic torque is proportional to the current iq, so it is only need to control the current to realize the torque control, which at the same time assure the maximum output torque.

The equation of motion balance is

$$T_e - T_1 = \frac{J}{n_p} \frac{d_\omega}{dt} \quad (7)$$

Where T_1 is the counter torque and J is the moment of inertia which is the whole mechanical load system savings to the shaft [4]

According to the analysis described in the second part, the PMSM control system is strong coupling, hign order and nonlinear[5]. Thus closed-loop control with PI controller is appreciated to add to the system. Set the PMSM single phase voltage at 220V, rated power 1.1kW, and the stator winding resistance R_1 is 2.875Ω, inductance $\mathbf{L_d}$ is 8.5mH $\mathbf{L_q}$ is 8.5mH, the flux linkage in the stator winding □ **f** is 0.175Wb, the moment of inertia is 0.0008**kg□m²** , number of pole pairs is 4, friction factor is zero.

After compared the setted speed 800 rad/s with the output speed, a PI controller is applied to transform speed value into current of q-axis, then applied PI controller again to acquire voltage value in 2s-coordinate-system. Then S-function is programmed to produce SVPWM pulse. Finally all the output vectors are send back to the current- closed loop and speed-closed loop to realize accurate control.

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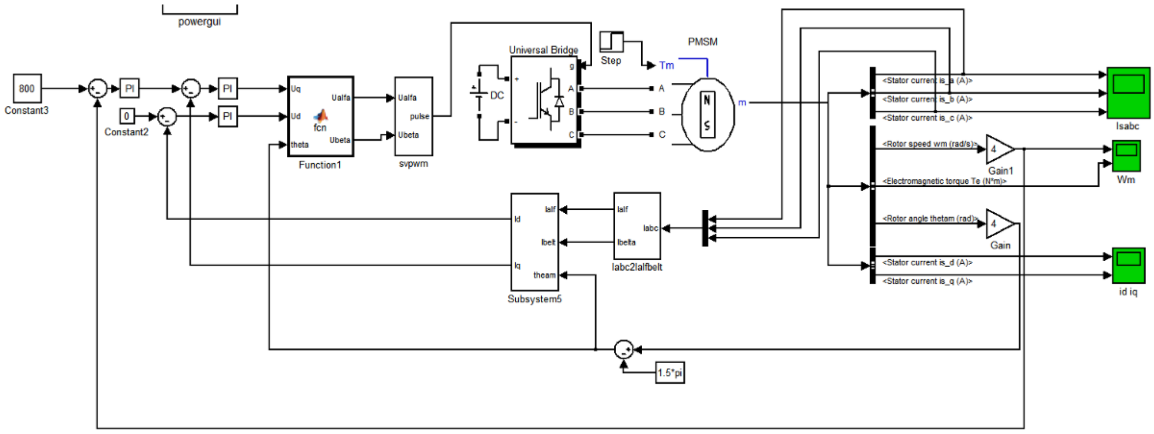

Fig.3 Control System Simulation in Simulink

The motor speed is preset at 800 rad/s, Fig.4 shows the outputs speed and torque. It can be seen that the torque rises until reach its maximum value, in this process the motor speed increase rapidly. When the speed up ends, PMSM operates at steady state, and there is a balance between the motor electromagnetic torque and load torque. The simulation proves the accuracy of the field oriented vector control control method and provides theory basis for actual design of the control system.

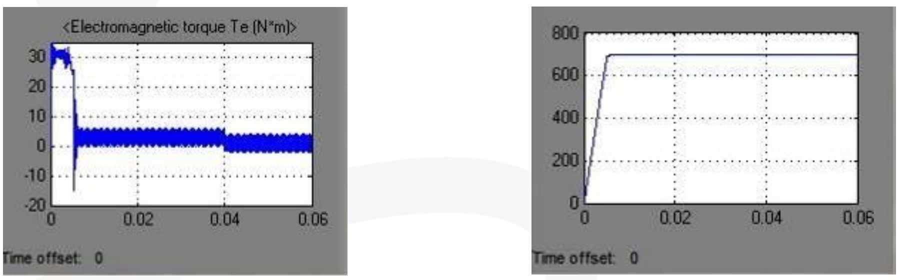

Fig.4 Output Torque and Speed

Summary

Above all, simulation is verified with given machine parameter and further work will be done which follows the DSP implementation, the sensor-less position estimation, advanced algorithm, system applicability and so on to achieve an accurate rapidly response PMSM control system[6].

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