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MATLAB SIMULATION RESEARCH ON PERMANENT MAGNET SYNCHRONOUS MOTOR VECTOR CONTROL

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Abstract:-
According to the mathematical model of PMSM (permanent magnet synchronous motor) and vector control method, PMSM FOC (vector control) simulation model is built on the basis of MATLAB/Simulink environment. The system adopts the rotor field oriented vector control method of id □0 to realize PMSM decoupling control. The speed regulator and current regulator uses the conventional PI control algorithm, and the inverter adopts SVPWM modulation strategies. The simulation results proved the feasibility of the control method, which provides a good theoretical basis for the parameters of PMSM control system hardware settings. At the same time, building simulation model PMSM FOC SPWM modulation strategy on the basis of FOC SPVWM simulation, making FFT (spectrum analysis) comparison between which and the SVPWM modulation's single phase current. The result that the output harmonic of SVPWM modulation is far less than SPWM modulation proves the advantages of SVPWM modulation strategies.

Keywords: *PMSM, vector control, SVPWM, MATLAB/Simulink.*

1. INTRODUCTION

Permanent Magnet Synchronous Motor (PMSM), as a new type motor, the operation reliability of which is relatively high without the electrical brush as well as the commutator. The studies on PSMS have significant social and economic benefits, with the rapid development of it as well as the high efficiency, low loss, small volume and some other excellent properties, which have important implications for energy saving and environment protection.

The control mode of the traditional U/F (constant voltage frequency ratio)is not suitable for the driving system, which has higher requirement on speed, with low speed, little torque and low static stability of speed [4]. In this context, the actual speed of alternating current dynamo cannot be controlled accurately [3]. In some occasions with higher requirements, the square wave (brushless direct current motor) and the SPWM (silent pulse width modulation) modulation strategy are impossible to meet the demand of high precision and low noise, because of the influence of the torque ripple, such as the radar servo control system, robot, numerically-controlled machine tool and etc. The vector control has become the important direction of modern AC variable speed [5][6].

Based on the rotor field oriented vector control, this text has presented theoretical analysis and study and established the simulation model of PMSM system with the help of MATLAB/Simulink thus to make study on control simulation. The result indicates that this control mode is consistent with the theoretical analysis and has a good dynamic performance.

2. Pmsm mathematical model

The mathematical model of Permanent Magnet Synchronous Motor (PMSM), as a strong coupling linear system, is used to analyze the performance of motor and realize theoretical basis of torque and rotational speed control[7][8]. It can transform the motor form three-phase static coordinate system into two-phase rotating coordinate system in order to realize decoupling of torque and flux linkage.

The mathematical model of d-q coordinate system as follows:

The voltage model of d-q coordinate system:

$$u_d = ri_d + L_d \frac{di_d}{dt} - w_e L_d i_q \quad (1)$$

$$u_q = ri_q + L_q \frac{di_q}{dt} + w_e (L_d i_d + \psi_f) \quad (2)$$

The stator winding of the electromagnetic torque expression is:

$$T_e = \frac{3}{2} N_p (L_d - L_q) i_d i_q + \frac{3}{2} N_p i_q \psi_f \quad (3)$$

The motor motion equation is:

$$T_e - T_L = \frac{3}{2} N_p (i_q \psi_d - i_d \psi_q) - T_L = J \frac{dw_m}{dt} \quad (4)$$

in this equation: u_d 、 u_q respectively are direct-axis voltage, quadrature-axis voltage; i_d 、 i_q respectively are direct-axis current, quadrature-axis current; L 、 L respectively are direct-axis inductance, quadrature-axis inductance; ψ_f is the flux linkage given by rotor; T_e is motor output electromagnetic torque; T_L is load torque; N_p is motor pole logarithmic; w_e 、 w_m respectively are electrical angular velocity and angular velocity of rotation.

Can be obtained by mathematical expressions: using the control mode of id=0, the PMSM is equivalent to a separately excited dc machine from the motor pot. At the same time, the three-phase stator current only includes the part of torque current and the stator flux linkage vector is orthogonal in the permanent magnet flux linkage space vector. In this way, motor's output torque is just connected with i_q , and in direct proportion to i_q ($T_e = 1.5 N_p i_q \psi_f$).

3. PMSM control strategy

3.1 FOC control thoughts

PMSM is a nonlinear, multivariable and strong coupled system. It is very difficult to control it directly and accurately. Thus realizing the torque and flux of decoupling and simplifying the magnetic chain relationship is necessary. The following figure 2 draws a physical model of the secondary dc motor[9][10].

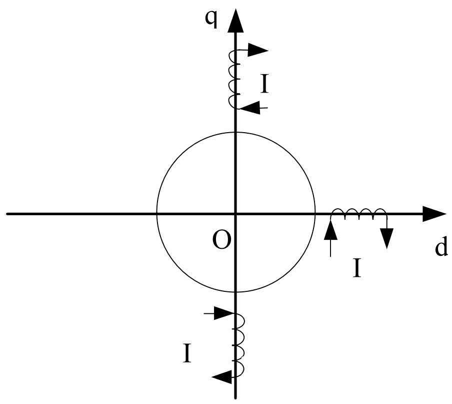


Figure 1: physical model of the secondary dc motor

As shown in the figure 1, the field winding f and the compensation winding c are both on the stator, and only the armature winding a is on the rotor. The f axis is called direct axis or d axis, and the direction of the main flux along the d axis; the axis of a and c will become quadrature axis or q axis. The armature reaction can be counteracted by compensation winding, so the main flux of dc motor is mainly and only determined by field current of field winding. The current which controls the armature winding can also control torque, and there is no interference between field and torque. That's why the control is so simple.

Therefore, the analysis and control will be simplified greatly [10] according to the principle that different coordinate system will generate the same magnetomotive force. The PMSM physical model and the dc electromotor model are regarded as an equivalent through the Clark transform and Park transform. The total magnetic flux rotor of PMSM is the equivalent dc motor excitation flux through control. At this moment, i_d can be equivalent to field current of dc motor, and i_q is equivalent to the armature winding current. Because the rotor permanent magnet can produce excitation, the flux will be realized constant if i_t can be controlled as zero. Torque can be controlled by controlling the size of i_q . That's the best advantage of the control mode of $i_d = 0$.

3.2 FOC system construction

The basic thought in vector control technology of PMSM is set up on the equation of transformation of coordinates and the electromagnetic torque of the machine. The control on torque and rotate speed can be realized by adjusting the quadrature axis current in the thought, with the transformation of PMSM from three-phase stationary coordinate system to d-q coordinate system. Its system structure frame is shown as figure

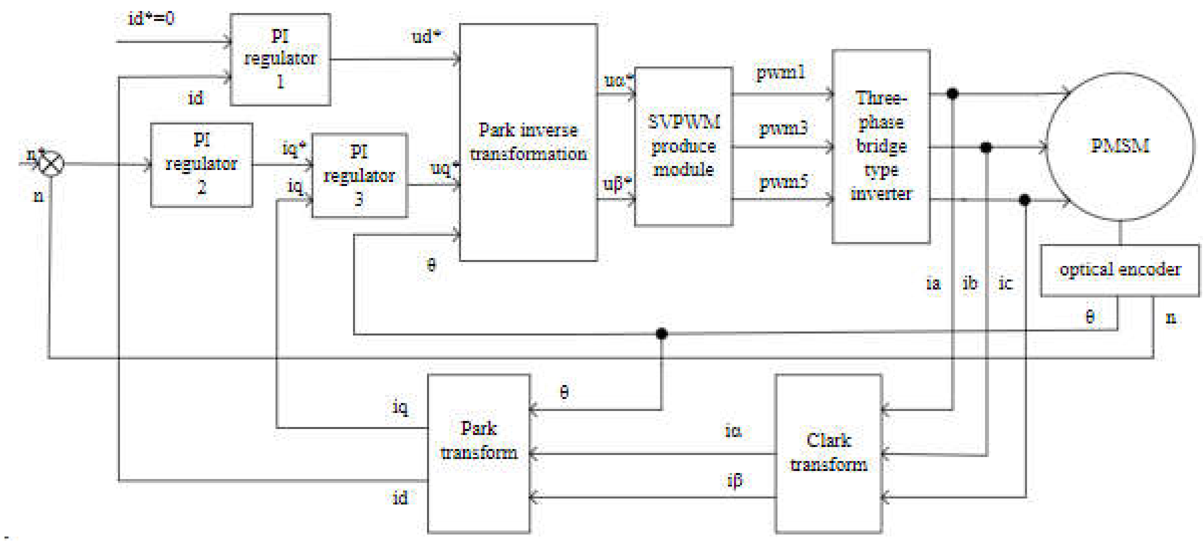


Figure 2: PMSM FOC system structure frame

As is shown as figure 2 above, id*, the current signal of d axis, is set 0, and i_{q^*} , the current signal of q axis, is set by the given rotate speed and actual rotate speed through a speed regulator. The actual current i_a 、 i_b 、 i_c which collected by electric current transducer will become the equivalent current i_d 、 i_q of rotating coordinate system (d-q coordinate system) through Clark and Park transformation. The fixed quantity and feedback quantity output the given voltage signal u_{d^*} and u_{q^*} ， u_{d^*} and u_{q^*} of d-q axis through current regulator. And through reversing the Park transformation, it can get given quantity u and $u$of two-phase static coordinate system $(\alpha-\beta$ coordinate system), then load into SVPWM thus to generate model, and finally output PWM wave which can be used to control the voltage source pressure transducer and fundamental current amplitude and adjustable frequency ac voltage.

4. The realization of PMSM FOC system's MATLAB/Simulink

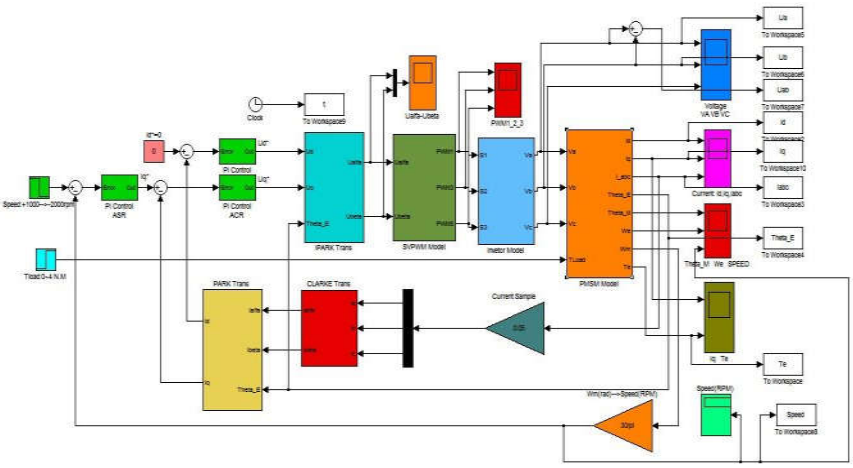


Figure 3: PMSM FOC MATLAB/Simulink simulation structure chart

As shown in figure 3, it is a simulation structure chart of permanent magnet synchronous motor vector control simulation structure chart which based on MATLABS/Simulink. It can be divided into a rotation speed link, two current links, SVPWM generator module, voltage type inverter module and motor style module. Besides, the rotation speed link and current link both adopt the traditional PI control algorithm.

The resultant vector and voltage sector decided simulation chart uses inverse Park transformation and inverse Clark transformation to change the voltage of rotary coordinate system to three-phrase stationary frame. In this way, the section of composite voltage vector can be confirmed and lots of operations of anti-trigonometric function can be avoided. As a result much time can be saved. The action time of adjacent voltage vector computational simulation chart: to get composite voltage vector in fixed section, the size and direction of composite voltage vector must be ascertained by calculating the action time of adjacent voltage vector. In order to reduce torque ripple, more voltage vector must be compouned, which leads to magnetic linkage that keep very close to round. Then the period of PWM and sampling time can be highly reduced. But limited by the switching frequency of power tube, the rate of PMW is 20KHz. The motor module, which is built according to mathematics model of permanent magnet synchronous motor. D-axis inductance and electromagnetic torque given both are 8.5mh. Stator resistance given is 2.873 Ω, and the given rotor flux control is 0.175Wb.

5. Simulation results

The simulation time was set as 0.4s. In order to validate the given rev of motor, direction and the impact of given load torque to stator three phase, the simulation speed must be set from 1000rpm to -2000rpm, with 1000rpm before 0.25s, and -2000rpm after 0.25s; at the same time, the given load torque is set from 1nm to 4nm, with 1nm before 0.4s and 4nm after 0.4s; meanwhile, the initial position is set to 0 in the PMSM.

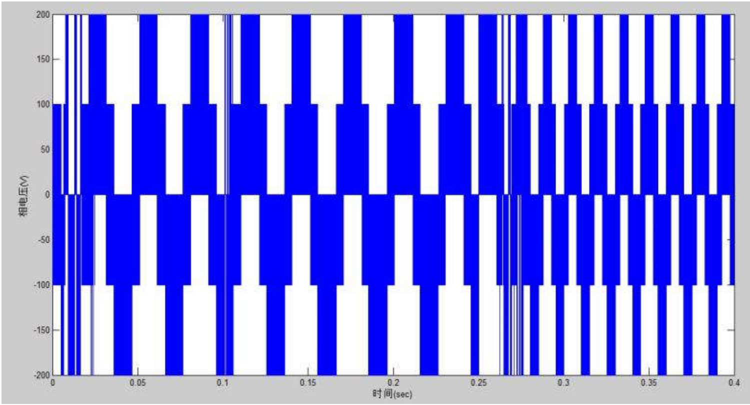


Figure 4: simulating waveform of a single-phase voltage

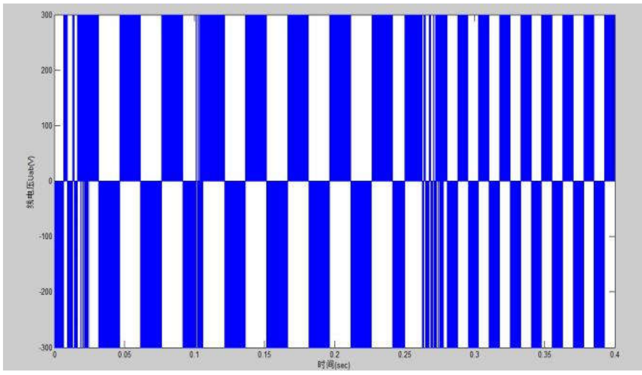


Figure 5: simulating waveform of line voltage

Figure 4 shows the single-phase voltage simulation waveforms of the PMSM. If the three-phase bridge inverter is given 300V DC voltage Udc, then the above voltage will change into 100V, 200V, 100V, 100V, - 200V, 100V, namely 1/3Udc, 2/3Udc, 1/3Udc, -1/3Udc, -2/3Udc, -1/3Udc. Also, when the speed is 0.25s and the change is given, the frequency changes significantly. We can conclude that simulation results are in accord with theory.

Figure 5 is the line voltage simulation waveform of PMSM. Given that the three-phase bridge inverter DC voltage Udc is 300V,and the above output line voltage is 300V, then SVPWM modulation output voltage utilization rate is 100%. It proves one of the advantages of the SVPWM modulation.

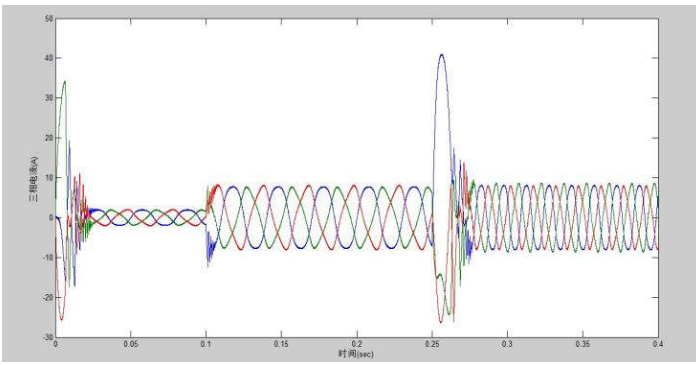


Figure 6：stator three-phase current waveform

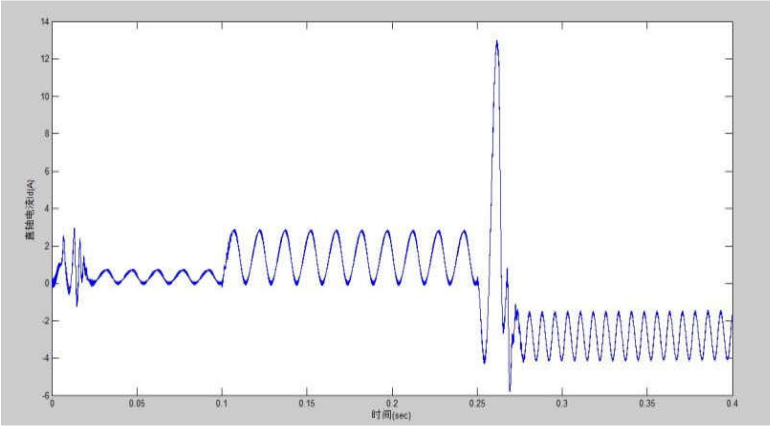


Figure 7：direct-axis current simulation simulation waveform

Figure 6 is the stator three-phase current simulation waveform of the PMSM. As is shown in the picture, at 0.1s when the given load torque changes from 1n.m to 4n.m, the stator three-phase current amplitude increases to 4 times of the original with the frequency remaining invariant; at 0.25s when the given speed changes from 1000rpm to -2000rpm, the stator three-phase current frequency increases to 2 times of the original with the amplitude unchanged and phase sequence changed. This verifies that the electromagnetic torque of the motor output is only proportional to the three-phase stator current amplitude and irrelevant to frequency; the speed is proportional to frequency and irrelevant to current amplitude; direction is related to phase sequence.

Figure 7 is the direct-axis current simulation waveform of the PMSM. The figure shows that given that the current is zero and the air-gap flux is fixed, the actual ID value is influenced by the given load torque, speed and direction.

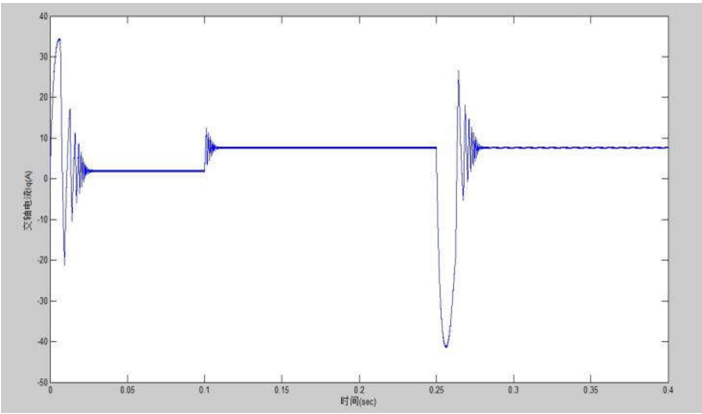


Figure 8：q-axis current simulation waveform

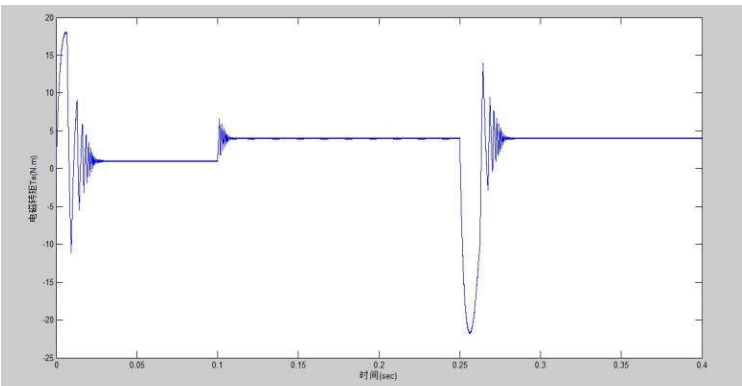


Figure 9：output electromagnetic torque simulation waveform

Figure 8 is the q-axis current simulation waveform of the PMSM. As is shown in the figure, at 0.1s when the given load torque changes from 1n.m to 4n.m, the q-axis current value increases to four times of the original; at 0.25s when the given speed varies from 1000rpm to -2000rpm, it quickly comes back to the initial value after a series of pulsating, thus verifying that the q-axis current value is only affected by a given load torque and irrelevant to speed and direction.

Figure 9 is the output electromagnetic torque simulation waveform of the PMSM. The figure shows that the waveform is consistent with that of the above-mentioned q-axis current (torque current). Therefore, it verifies that while the air-gap flux maintains constant, electromagnetic torque is proportional to the q-axis current, that is, the electromagnetic torque of the motor output can be changed by changing the q-axis current value.

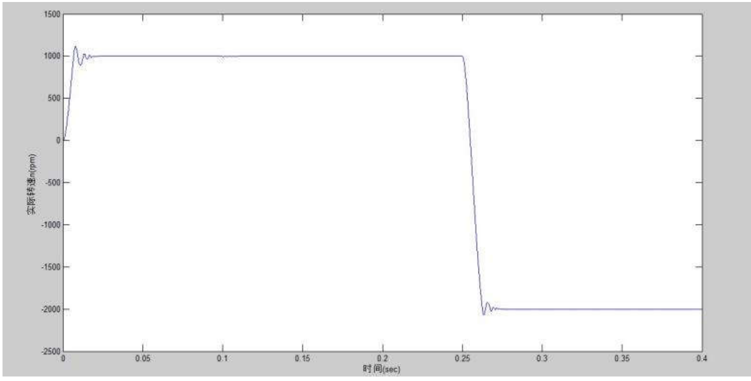
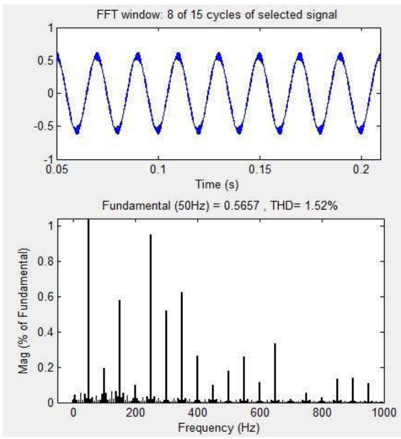


Figure 10: the motor speed simulation waveform

The figure 10 is the actual speed simulation waveform of permanent magnet synchronous motor, it shows that the actual speed follows the given speed strictly and response quickly, and the stabilization error can be controlled between -1rmp to 1rmp. To some extent, it proves the advantages of vector control.

At the same time, in order to prove the advantages of SVPWM's modulation strategy, on the basis of FOC SVPWM Delta-Sigma and then build the open loop control model of PMSM FOC SPWM, apply the model to the three stator current polarity. From the two models of stator current A, carry out the analysis of FFT, which fundamental frequency is 50 HZ and the period is eight weeks. The frequency spectrum analysis of the them are as follow:



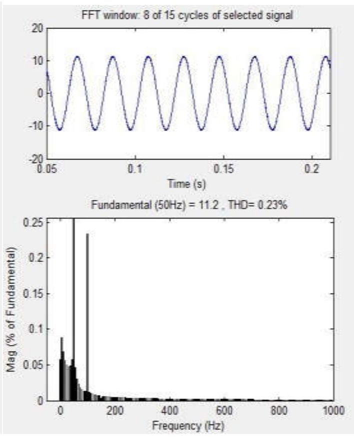


Figure 11all-digital fuzzy stator current based on SVPWM waveform and FFTanalysis

Figure 12all-digital fuzzy stator current based on SVPWM waveform and FFTanalysis

The image shows that the model's total harmonic distortion is 1.52%, which is established by SPWM. With established under the control of PMSM by SVPWM, the other model's total harmonic distortion is 0.23%, which is smaller than the former one. So we should choose the SVPWM modulation strategy.

6. Conclusions

This paper introduces the origin of permanent magnet synchronous motor's vector control ideas as well as the construction of control system. Then making comparison between the modulation simulation model of PMSM FOC SVPWM made by MATLAB/Simulink and SPWM open loop control. The result proves the methods of vector control's feasibility and the advantages of modulation strategy.

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