Open Science Journal of Electrical and Electronic Engineering
2016; 3(1): 7-11
http://www.openscienceonline.com/journal/j3e

Research on Direct Torque Control of Permanent Magnet Synchronous Motor Based on Svpwm

Liu Yong

School of Mathematics and Statistics, Yancheng Teachers University, Yancheng, China

Email address

jzeyong@163.com

To cite this article

Liu Yong. Research on Direct Torque Control of Permanent Magnet Synchronous Motor Based on Svpwm. *Open Science Journal of Electrical and Electronic Engineering.* Vol. 3, No. 1, 2016, pp. 7-11.

Received: November 2, 2016; **Accepted**: December 19, 2016; **Published**: January 12, 2017

Abstract

The paper expounds the mathematical model of permanent magnet synchronous motor, which introduces the general principle of the direct torque control and the space vector pulse width modulation. In the matlab/simulink environment, the mathematical model of permanent magnet synchronous motor sets up a simulation model of the direct torque control which based on the theory of svpwm. Each step and process of the simulation model are introduced in detail and finally the simulation result is obtained. The simulation result shows that the direct torque control system which based on the theory of svpwm has a constant switch frequency, can reduce the torque ripple greatly, and improves the current waveforms and flux linkage waveforms. So it makes the system have a better dynamic and static performance and also verify the feasibility and effectiveness of the plan.

Keywords

Permanent Magnet Synchronous Motor, Direct Torque Control, SVPWM

1. Introduction

With the rapid development of power electronic technology, motor speed regulation theory and microelectronic technique, and permanent magnetic material is constantly updated, the variable frequency adjusting technology of permanent magnet synchronous motor enters a rapid developing stage. Permanent magnet synchronous motor has received extensive attention with its simple structure, high torque to inertia ratio, small loss, high power density, high efficiency, high power and good maintenance. Meanwhile, PMSM has been widely used in industry robot, machining center, electronic traction, numerical control machine, aeronautical and space technologies and so on.

Traditional direct torque control method uses hysteresis control. The band width is limited by the switching frequency of the inverter, requiring only one working basic voltage vector in a control cycle, causing a big ripple of flux linkage and torque. But based on SVPWM control plan, it can synthesizing any required voltage vectors. So it can obviously reduce the ripple of flux linkage and torque, so as to improve the dynamic and static performance of the system [1]. This paper briefly introduces a direct torque control system of permanent magnet synchronous motor based on SVPWM, carrying out simulation studies on MATLAB/simulink.

2. Mathematical Model of Permanent Magnet Synchronous Motor

For purposes of analysis, make the following assumptions before building mathematical model of motor:

1 ignore the effects of iron core saturation, eddy current and hysteresis;

2 permanent magnet rotor without damper winding;

3 three phase stator winding is completely symmetrical, and each phase winding axis is spatially different with 120°stator, the armature resistance and inductance of each winding are equal;

4 the induction electromotive force and the air gap magnetic field are distributed according to the sine distribution, disregarding effect of magnetic field on high order harmonic

There are A、B、C three-phase windings on the stator, excitation winding f and direct axis damping winding D on rotor axis, quadrature-axis damper winding Q on the quadrature-axis.

Based on the following assumption, the mathematical model under quiescent coordinate of PMSM rotor flux three phase a, b, c:

The stator voltage equation is:

$$\begin{cases} u_a = R_s i_a + p\psi_a \\ u_b = R_s i_b + p\psi_b \\ u_{ca} = R_s i_c + p\psi_c \end{cases} \tag{1}$$

Inside, u_a, u_b, u_c are the instantaneous value of terminal voltage of stator winding; i_a, i_b, i_c are the instantaneous value of phase current of stator winding; ψ_a, ψ_b, ψ_c are the instantaneous value of flux linkage; p is the differential operator, $p = \frac{d}{dt}$; R_s is the phase resistance of stator armature.

The electromagnetism torque equation:

$$T_e = -n_p \psi_f \left[i_a \sin\theta + i_b \sin(\theta - \frac{4\pi}{3}) \right] \tag{2}$$

Inside, T_e is the electromagnetic torque of permanent magnet synchronous motor;

The stator flux linkage equation:

$$\begin{cases} \psi_a = L_{aa} i_a + M_{ab} i_b + M_{abc} i_c + \cos\theta \psi_f \\ \psi_b = M_{ba} i_a + L_{bb} i_b + M_{bc} i_c + \cos\left(\theta - \frac{2\pi}{3}\right)\psi_f \\ \psi_c = M_{ca} i_a + M_{cb} i_b + L_{cc} i_c + \cos\left(\theta - \frac{4\pi}{3}\right)\psi_f \end{cases} \tag{3}$$

Inside, L_{xx} is the self-inductance coefficient of stator winding; M_{xy} is the mutual inductance coefficient of stator winding; xy stand for one phase of abc; ψ_f is the rotor flux; θ is the electrical angle of rotor axis and a-axis.

Based on the above assumptions, the mathematical model of the PMSM rotor magnetic field in a two phase $\alpha\beta$ stationary coordinate system is described:

The stator voltage equation is:

$$\begin{cases} u_\alpha = R_s i_\alpha + L_\alpha p i_\alpha + L_{\alpha\beta} p i_\beta - \omega\psi_f \sin\theta \\ u_\beta = R_s i_\beta + L_\beta p i_\beta + L_{\alpha\beta} p i_\alpha + \omega\psi_f \sin\theta \end{cases} \tag{4}$$

Stator flux linkage equation:

$$\begin{cases} \psi_\alpha = \int \left(u_\alpha - R_s i_\alpha\right) dt \\ \psi_\beta = \int \left(u_\beta - R_s i_\beta\right) dt \end{cases} \tag{5}$$

Electromagnetic torque equation:

$$T_e = \frac{3}{2} n_p \left(\psi_\alpha i_\beta - \psi_\beta i_\alpha\right) \tag{6}$$

u_α, u_β are axis components of the $\alpha\beta$ stator voltage vector; R_s is stator armature resistance; θ is electrical angle of rotor axis and a axis angle; i_α, i_β are axis components of the $\alpha\beta$ stator current; p is differential operator; ψ_f is Rotor flux; L_{xx} is the self inductance of stator winding; T_e is electromagnetic torque of permanent magnet synchronous motor; n_p is polar logarithm; ψ_α, ψ_β are $\alpha\beta$ axis stator flux linkage.

3. SVM-DTC Control Strategy

The traditional DTC control method is to select the appropriate voltage vector by means of the query vector switch table, so as to realize the direct control of flux and torque. The traditional direct torque control scheme is established in the two phase stationary coordinates. First, terminal voltage and current measurement of the motor; and the coordinate transformation, is three-phase static coordinate system to the two-phase stationary coordinate system; use type (5) to calculate the stator flux, by type (6) to calculate the electromagnetic torque and flux, determine the sector; given the flux and torque respectively. The calculated and compared the flux and torque control; error in hysteresis comparator two and sector value through the error value, can choose the appropriate voltage space vector, so as to realize the direct control of the flux and torque of the motor.

Compared with direct torque control system, SVM-DTC system uses PI regulator to replace the traditional method of torque hysteresis comparator and flux hysteresis comparator. Besides, SVPWM module replaces the way to inquiries switch table. In the SVM-DTC control strategy, with any control period, the motor will issue a number of voltage vectors according to the error of torque and flux linkage, so it can eliminate the steady state error of torque and flux linkage, reduce torque ripple, enable output waveform more smooth, and obtain better dynamic performance and static performance [2-3].

Working principle of space vector pulse width modulation is through two adjoining basic voltage space vectors' working time, 8 basic voltage space vectors can be synthesized in any number of different voltage space vectors. So in this way, in each cycle it can choose reasonable voltage space vectors to compensate the error between observed value and participation value of motor torque and stator flux linkage [4]. In order to be able to compensate the error range ΔT_e between torque observation T_e and torque reference value T_{ref} exported by speed controller, use PI controller to count out the needed phase angle $\Delta\theta$ to add of stator flux linkage. The reference vector of flux linkage ψ_{ref}, the observations of flux linkage ψ_s and the phase angle of observations θ_{ψ_s} enter flux linkage compensation module, calculating the components $\Delta\psi_{S\alpha}$, $\Delta\psi_{S\beta}$ of compensating value of flux linkage. Then $\Delta\psi_{S\alpha}$, $\Delta\psi_{S\beta}$ get the components of stator voltage $U_{\alpha ref}$ and $U_{\beta ref}$ in the voltage space vector calculation module.

The stator flux vector of permanent magnet synchronous

Inside, ψ_s is the observation of stator flux vector. ψ_{ref} is the reference of stator flux vector. ψ_f is the flux vector of rotor permanent magnet. θ is the angle of the observation of stator flux vector. $\Delta\theta$ is the added angle of stator flux vector phase angle.

Flux compensation value equation:

$$\begin{cases} \psi_{S\alpha} = \left|\psi_{ref}\right| \cos\theta + L_s i_\alpha \\ \psi_{S\beta} = \left|\psi_{ref}\right| \sin\theta + L_s i_\beta \end{cases} \tag{7}$$

Reference voltage space vector equation:

$$\begin{cases} U_{\alpha ref} = \dfrac{\Delta\psi_{S\alpha}}{T_s} + R_s i_\alpha \\ U_{\beta ref} = \dfrac{\Delta\psi_{S\beta}}{T_s} + R_s i_\beta \end{cases} \tag{8}$$

Stator flux vector equation:

$$\begin{cases} \Delta\psi_{S\alpha} = \left|\psi_{ref}\right| \sin(\theta+\Delta\theta) - \left|\psi_s\right| \sin\theta \\ \Delta\psi_{S\beta} = \left|\psi_{ref}\right| \sin(\theta+\Delta\theta) - \left|\psi_s\right| \sin\theta \end{cases} \tag{9}$$

In the three-phase inverter circuit, assume the on-state of power switch is 1, the off-state is 0. We will get 8 switch status(000～111) of power switch. The corresponding inverter will output 6 motion voltage rectors U_1 U_2 U_3 U_4 U_5 U_6 and 2 zero-voltage vectors. Every vector size is $\frac{2}{3}U_{dc}$. The included angle between two adjacent voltage vectors is 60°. The radius of inscribed circle of hexagons composed by vector vertices is $1/\sqrt{3}U_{dc}$ [6].

4. Simuation Experiment Controlled by SVPWM

In the Simulink simulation environment of MATLAB, on the basis of control theory of SVPWM, build simulation model of permanent magnet synchronous motor system based on SVM-DTC, as shown in Figure 1. In the simulation experiment, set the parameter of PMSM as follows: the given motor rated speed is 100 r/min, the sampling period T_s is 1e-005s, the simulation time of MATLAB is 0.2s, the DC bus voltage Udc is 310V, the added step load is 1N·m at 0.05s, the pole number P is 2, the stator resistance R_s is 20.51Ω, the given stator flux linkage value $\left|\psi_{ref}\right|$ is 0.8wb,the q-axis inductance L_q is 0.168H, the d-axis inductance L_d is 0.168H,the torque to inertia J is 0.0008 $kg \cdot m^2$.

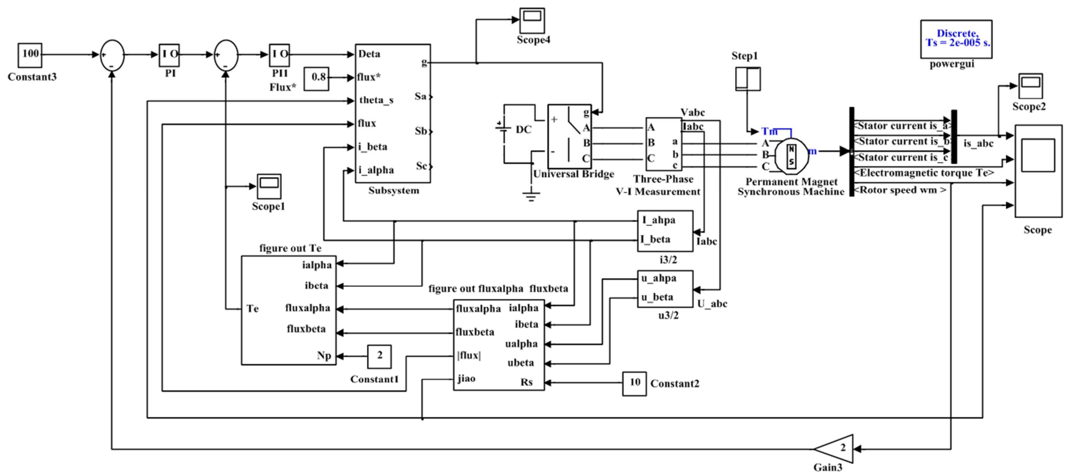

Fig. 1. SVM-DTC simulation module of permanent magnet synchronous motor.

5. The Simulation Results of DTC and SVM-DTC Control Strategy

The results of simulation are shown from Figure 2 to Figure 5. Figure 2 is the trace plot of stator flux under the two control systems. Observing Figure 2(a) and Figure 2(b), both flux linkage locus are approximated by round under the two systems. However, in comparison, the flux trace waveform under SVM-DTC system is more smooth, and the flux fluctuation is obviously small. It shows the stability of the whole system is greatly promoted by using SVM-DTC system.

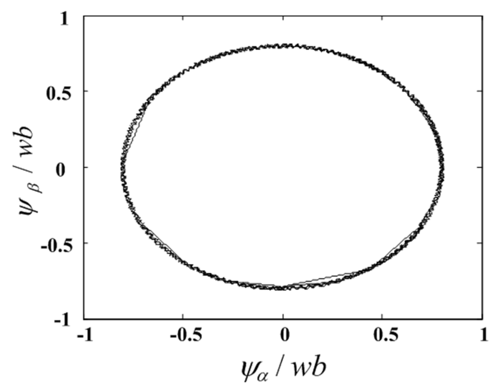

Fig. 2(a). DTC flux linkage locus.

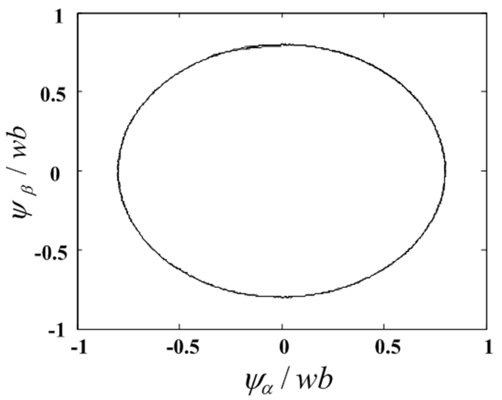

Fig. 2(b). *SVM-DTC flux linkage locus.*

Figure 3 is the phase current waveform of stator. Comparing Figure 3(a) to Figure 3(b), we will find that the starting current is big and the time coming to steady-state is long by using traditional DTC system. However, by using SVM-DTC system, we will get smooth starting phase current of motor stator, small overshoot, short time to reach stable state, and waveform which is more like sine wave. What's more, in the SVM-DTC system, the stator current has better sine quality, and the current fluctuation is less than 0.1A.

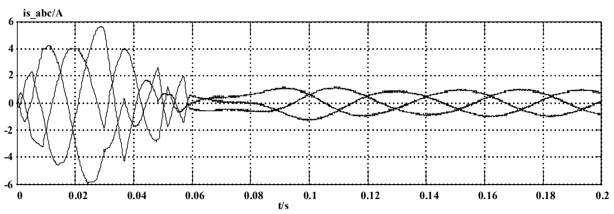

Fig. 3(a). *DTC stator three-phase current.*

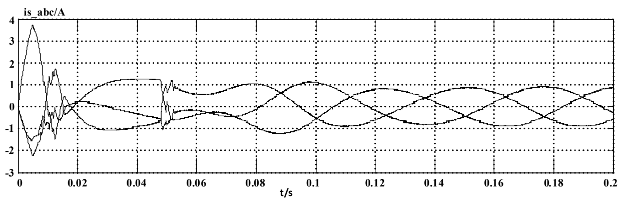

Fig. 3(b). *SVM-DTC stator three-phase current.*

Figure 4(a) and Figure 4(b) are the electromagnetic torque waveform under steady state. In these two systems, the torque of motor is 0 N·m at first, and add step load torque 1N·m at 0.05s. Comparing Figure 4(a) to Figure 4(b), we find that, when the motor starts, the torque waveform of traditional DTC system fluctuates apparently, and the torque waveform response time is long. However, in the SVM-DTC control system, torque responses quickly the change of the load torque. It means that the rapid dynamic response of the system, small overshoot, and no static errors at stable state. It shows that the motor system under SVM-DTC control system is well compensated, and the motor can output more smooth and accurate torque.

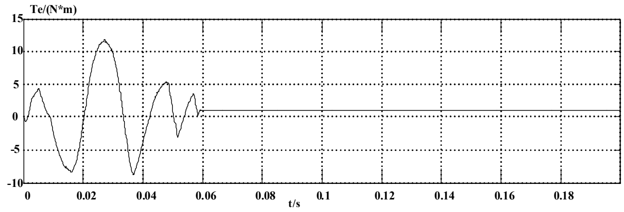

Fig. 4(a). *DTC torque waveform.*

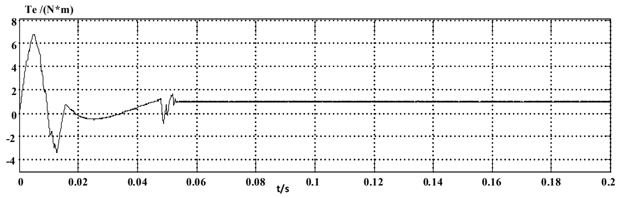

Fig. 4(b). *SVM-DTC torque waveform.*

Figure 5 is the motor speed waveform with given speed of 100 rad/s. Comparing Figure 5(a) to Figure 5(b), we find that the speed response time of the system using SVM-DTC control system is shorter. When the load changes suddenly from 0 to 1 N*m at 0.05s, the rotational speed has an overshoot, but it will settle down quickly. However, the speed response time using traditional DTC control system is long. When load torque changes, the speed fluctuates apparently.

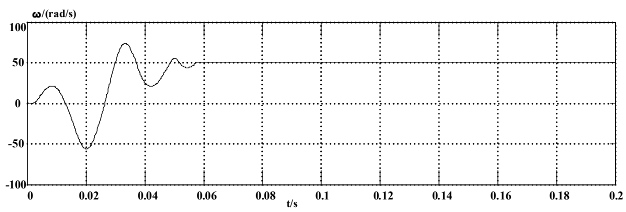

Fig. 5(a). *DTC speed waveform.*

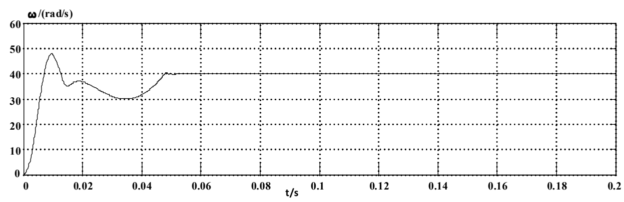

Fig. 5(b). *SVM-DTC speed waveform.*

6. Conclusions

From the simulation experiment result of this paper we know, in the traditional DTC control strategy, current, torque and the flux linkage ripple are big, and the static and dynamic performance are not particularly stable. But with SVM technology, space voltage vector modulation technology uses voltage vector to completely compensate the error of stator flux linkage, and uses PI regulator to replace the traditional hysteresis, achieving steady state of flux without static error control. It reduces the flux ripple and torque ripple of the motor, getting more smooth flux linkage locus, faster tracking speed of electromagnetic torque, the advantage of fast response speed in traditional DTC control system.

References

[1] Feng tao, Lu hua. Direct torque control and simulation of permanent magnet synchronous motor [J]. EMCA, 2013, 40(6):27-28.

[2] Lin C K, Liu T H, Fu L C, et al. Model-free predictive current control for interior permanent-magnet synchronous motor drives based on current difference detection technique[J]. IEEE Transactions on Industrial Electronics, 2014, 61(2): 667-681.

[3] Yang xiuqin, Zou Kaifeng, Zang xiaojie. Direct torque control of permanent magnet synchronous motor based on SVPWM [J]. Explosion-proof Electric Machine, 2013, 48(6): 27-29.

[4] NIU Li, YANG Ming, WANG Geng, et al. Research on the Robust Current Control Algorithm of Permanent Magnet Synchronous Motor Based on Deadbeat Control Principle[J]. Proceedings of the CSEE, 2013, 33(15): 78-85.

[5] Siami M, Khaburi D A, Abbaszadeh A, et al. Robustness Improvement of Predictive Current Control Using Prediction Error Correction for Permanent-Magnet Synchronous Machines [J]. IEEE Transactions on Industrial Electronics, 2016, 63(6): 3458-3466.

[6] Qiu henan, Wang xudong, Li zhiwei, Na risha. Feedback linearization direct torque control of permanent magnet synchronous motor based on the five-stage SVPWM [J]. Journal of Harbin University and Technology, 2015, 20(6): 66-69.

[7] Lin C K, Lai Y S, Yu H C, et al. Simplified model-free predictive current control for interior permanent magnet synchronous motors [J]. Electronics Letters, 2016, 52(1): 49-50.

[8] LIU Xu-dong, LI Ke, SUN Jing, et al. Generalized predictive control based on extended state observer for permanent magnet synchronous motor system [J]. Control Theory & Applications, 2015, 32(12): 1613-1619.

[9] Mao Chengxiong, He Jinping, Wang Dan, et al. Multivariable feedback linearization scheme for new excitation system based on full controlled devices [J]. Proceedings of the CSEE, 2013, 33(0): 1-8.

[10] MEI Cong-Li, YIN Kai-ting, HUANG Wen-tao, et al. Data-driven adaptive decoupling control of induction motors using multi-model inversion [J]. Control and Decision, 2016, 31(6): 1037-1041.

[11] Weiping Guo, Diantong Liu. Sliding mode supervised fuzzy control for a class of underactuated nonlinear systems [J]. Journal of Information & Computational Science, 2013, 10(2): 493-500.

[12] PAN Yue-dou, CHEN Hu. Research on high gain technique based on-line fluxes estimation for IMs [J]. Control and Decision, 2014, 29(8): 1495-1500.