The Discrete Space Vector Modulation Strategy for the Permanent Magnet Synchronous Machine with Large Inertia

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Abstract—In order to reduce the torque ripple and improve the dynamic performance, a direct torque control strategy with special discrete space vector modulation (DSVM) for the permanent magnet synchronous motor (PMSM) control system with large inertia is proposed in this paper. With this discrete space vector modulation strategy, more voltage vectors will be generated that the electromagnetic torque variation will be controlled and the undesired torque will be restrained. An improvement of the drive performance can be obtained using the DVSM. Numerical simulations have been carried out to validate the proposed method.

Keywords-permanent magnet synchronous motor; large inertia; direct torque control; discrete space vector modulation

1   Introduction

The permanent magnet synchronous motor (PMSM) is widely used in the industry including the flywheel energy storage system, wind turbine system and electric propulsion system, due to its small volume, low weight, and high efficiency especially in the system with large inertia.

The direct torque control method which was proposed by Professor M. DePenbrok and I. Takahashi for induction machines in the middle of 1980's is applied to control the PMSM with large inertia. And this method has become more and more popular nowadays because of its simple structure and strong robustness indicated in [1]. Compared with other control methods, the direct torque control system can eliminate the PI regulators, ABC-dq coordinate transformation, current regulators and the PWM signal generator. It satisfies the features of the precise and quick torque control and the reduction of the complexity in the whole system in [2-4].

The predictive control and the back stepping control to eliminate the torque ripple are mentioned in [5-6]. The prediction of the flux and torque is the expected values, so the torque and flux will be satisfied with the given values in the next time. The direct torque control with the space vector modulation is presented in [7-9]. The algorithms are too complex to be practical for the high-speed machine. Hysteresis comparators can be replaced by the sliding mode control in [10-13] to eliminate the hysteresis comparator shortcomings.

In this paper, the PMSM with large inertia is controlled by the direct torque method with the discrete space vector modulation (DSVM). The DSVM is not to change the structure of the direct torque control but to maintain the control method simple without adding the power circuit and the inverter switching frequency. The simulation results verify that PMSM with large inertia has good dynamic performance and the torque ripple of the system is restrained effectively.

2   System Model

A mathematical model representing the real system with sufficient accuracy is necessary. Based on the models, the behavior of variables of interest can be predicted.

The electromagnetic torque can be expressed:

$$T_e = \frac{3}{2} p \left[\frac{\psi_f |\boldsymbol{\psi}_s|}{L_d} \sin \delta_{sm} + \frac{L_d - L_q}{2 L_d L_q} |\boldsymbol{\psi}_s|^2 \sin 2\delta_{sm} \right] \quad (1)$$

Because of this paper uses the surface mount permanent magnet synchronous motor as the motor/generator, $L_d = L_q = L_s$ and L_s is the stator inductance. Equation (1) is rewritten as:

$$T_e = \frac{3}{2} p \frac{\psi_f |\boldsymbol{\psi}_s|}{L_s} \sin \delta_{sm} \quad (2)$$

The stator flux linkage of the PMSM can be calculated by (3):

$$\psi_s = \int (u_s - i_s R_s) dt \quad (3)$$

Neglecting the stator's resistance, equation (4) can be changed into:

$$\psi_s = \int u_s dt \quad (4)$$

Making the system discrete, equation (5) was written to:

$$\psi_{s(k+1)} = \psi_{s(k)} + u_s \Delta t \qquad (5)$$

In equation (10), k is any simple time, k=1, 2, ……

3 Control Strategy

In this paper the number of voltage vectors is increased using a standard VSI topology and introduced a simplified space vector modulation technique-DVSM. The DVSM generates new voltage vectors and the magnitude are 1/3 and 2/3 original's respectively; new vectors are synthesized by the two boundary vectors as shown in Fig. 1.
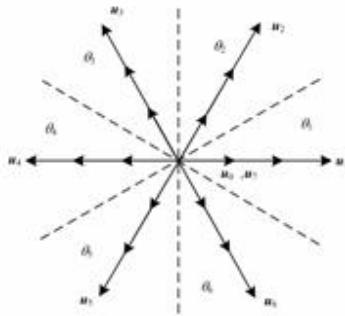

Fig. 1. Distribution of the discrete vectors and sectors

The block diagram of the direct torque control with the DSVM is shown in Fig. 2.
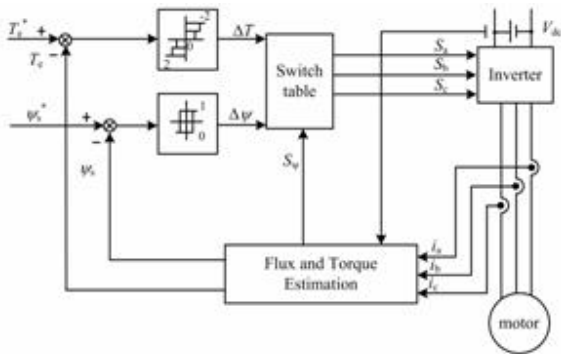

Fig. 2. The direct torque control based on DVSM

The direct torque control with the DSVM consists of the flux and torque hysteresis comparators, the flux and torque estimators, switching tables and the inverter. S_ψ is the sector of the stator flux, the whole control system is not changed.

4 Simulation Results

In order to show the effectiveness of the proposed method, a numerical simulation has been carried out on the PMSM. The following table shows the parameters of the PMSM.

Table 1. Parameter of The PMSM with The Large Inertia

Parameter	Values
Rated voltage U_N(V)	380
Rated power P_N(kW)	1.5
Rated speed n_N(r/min)	1000
Rotational inertia J(kg·m^2)	0.5
Permanent magnet flux linkage ψ_f(V·s)	0.24
Stator resistance R_s(Ω)	0.975
Stator inductance L_s(mH)	8.5

Fig. 3 (a) is the waveform of the motor velocity, the torque with the DTC and (b) is the DTC with DVSM. It can be seen from the waveform that direct torque control of the PMSM with large inertia meets its required control performance. The phase B current has a little serious distortion and owns a good sinusoidal waveform as shown in the Fig. 4 (a).
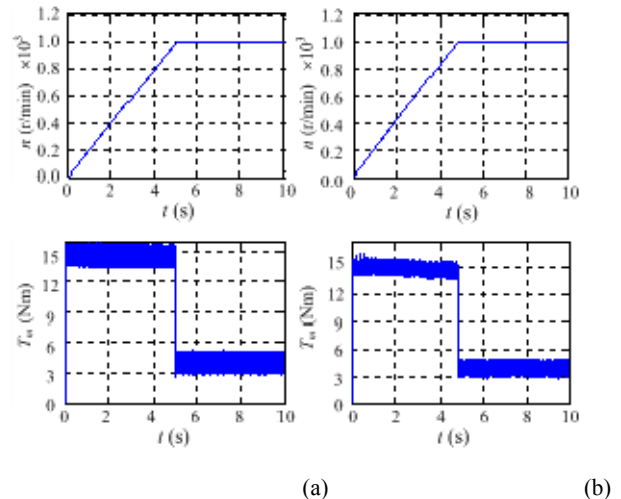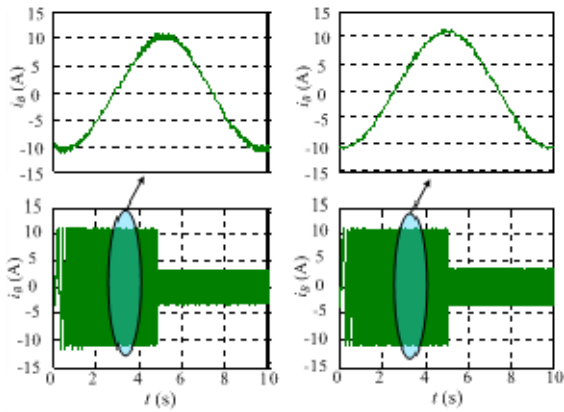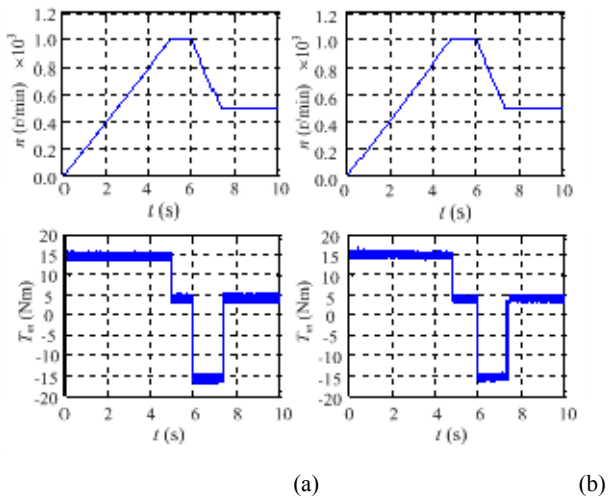

(a)   (b)

Fig. 3. Waveform of the speed and the torque from 0 r/min to 1000 r/min. (a) Traditional DTC. (b) DTC with DVSM

Fig. 3 (b) shows the waveform of the system based on the direct torque control and DVSM. The discrete space voltage vector modulation method does not affect the overall system performance. The system still

spends about 4.8s to reach its steady state and the phase B current maintains a better sine wave than the traditional DTC method as shown in the Fig. 4 (b). And the electromagnetic torque ripple has been suppressed.

(a)

(b)

Fig.4. Waveform of phase B current and the zoom picture from 0 r/min to 1000 r/min. (a) Traditional DTC. (b) DTC with DVSM


(a)   (b)

Fig.5. Waveform of the speed and the torque from 0 r/min to 1000 r/min and to 500 r/min. (a) Traditional DTC. (b) DTC with DVSM

It can be seen from Fig. 5 (a), the system with the traditional direct torque control has good dynamic response, and the short transient process which meets the fast performance of the PMSM with large inertia. The electromagnetic torque waveform is good, but its large torque ripple also affects the motor stator current as show in the Fig. 5 (a) and other operating results.

But the Fig. 5 (b) shows the PMSM with large inertia based on the discrete voltage vector modulation and

direct torque control is still operated in the same conditions. From the Fig. 5 (b), it can be seen that the original system's dynamic response is not affected by discrete voltage vector modulation; and the phase B current does not have the serious distortion, and the current has less harmonics compared with the traditional DTC method from the Fig. 6 (b).

(a)

(b)
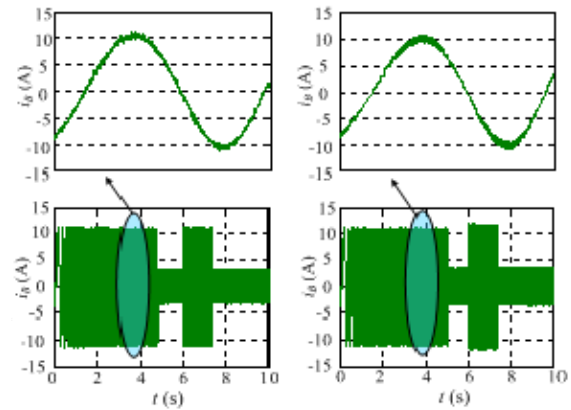
Fig. 6. Waveform of phase B current and the zoom picture from 0 r/min to 1000 r/min and to 500 r/min. (a) Traditional DTC. (b) DTC with DVSM

Conclusion

In this paper, direct torque control method is used to control the PMSM with large inertia. Compared with other control methods, the system with direct torque control has better dynamic characteristics. The torque ripple which causes by direct torque control itself is restrained by using the discrete space vector modulation, and the discrete space vector modulation does not affect the direct toque control method. Matlab simulation results verify the effectiveness of this method.

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